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Volume 2

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Any queries about these proceedings (or corrections of significant errors) should be directed to one of the editors listed below by 31 March 2009.

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An Easy Guide to Navigating the Proceedings for SB08

The full Proceedings of SB08 have been made available as three multiple "PDF" documents.

• **Volume 1** includes conference welcome speeches, conference sponsors, special reports and SB07 papers, special forums and regional papers.

• **Volume 2** is approximately 168MB. Downloading of this file can take some time, however, once downloaded and saved to your hard drive, it is laid out in a manner that allows fast and simple navigation.
This file contains the full abstracts for both oral and poster presentations that form the scientific program of the conference. Abstracts can be searched by author or oral theme.

• **Volume 3** contains the power point presentations of plenary sessions and photo gallery.

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- BACK – takes you back one page
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- AUTHOR INDEX – direct link to the alphabetical "Index by Author "
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"Index by Author"

This section lists all 1500 word abstracts for oral and poster presentations from SB08 by author, alphabetically. Click on the box next to the author to be taken to the author's abstracts the reference number of which is listed next to the box. Note: some authors have several abstracts listed.

"Index by Theme Orals"

This section lists all 1500 word abstracts by presenters within each theme (as listed in the right hand column). Again, click on the box in the left hand column to be taken to that abstract.

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Sunday 21 September

3.00 to 6.00	**Registration**
6.00 to 7.30	**Welcome Drinks**

Monday 22 September

8.30 to 10.00	**Plenary 1A:** **Sustainable Future and the Built Environment: Towards a Connected, Viable and Liveable Planet** **Speakers: • The Hon. Peter Garrett** AM MP – Minister for the Environment, Heritage and the Arts (Australia) • **The Hon. Gavin Jennings** MLC - Minister for the Environment and Climate Change (Victoria, Australia) • **Bill Rees** – Professor, University of British Columbia School of Community and Regional Planning									
10.00 to 10.20	Tea/coffee Break									
10.20 to 11.20	**Plenary 1B:** **Understanding the Global SB Landscape** **Speakers: •Dr Greg Foliente** - Leader, High Performance Built Environment, CSIRO Sustainable Ecosystems (Australia) •**Nils Larsson** – Executive Director, International Initiative for a Sustainable Built Environment (iiSBE) •**Thomas Luetzkendorf** – Professorial Chair, Sustainable Management of Housing and Real Estate, University of Karlsruhe (Germany)									
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Monday, 22 September 2008

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NIST BusiBEES METRICS AND TOOLS FOR GREEN BUILDINGS abs#003

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A Life Cycle Inventory for Australian forest products abs#004

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12:10pm Harvey Bryan
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12:10pm Phillip Paevere
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Tuesday, 23 September 2008

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Smart Vernacular Planning: sustainable regional design based on local potentials and optimal deployment of the energy chain abs#125

2:20pm Malcolm Lewis
Case Studies of applications of a quantitative modeling system for optimization of community-scale sustainable design decisions abs#126

2:40pm Yoshiyuki Shimoda
Evaluation on sustainability of urban energy system by energy flow analysis. abs#127

3:00pm Stephen Yim
Micro-climate studies for high density and high rise sustainable public housing developments in hong kong abs#128

Energy Efficiency - Building Services - 2

2:00 PM - 3:30 PM Room 5

Chair: Andrew Pettifer

2:00pm Atsushi Yokoyama
Evaluation of Natural Ventilation System by Simultaneous Multipoint Airflow Measurement abs#129

2:20pm Takashi Yanai
The Evaluation of Thermal Performance in the Sustainable Office Building with Environmental Adjustable System abs#130

2:40pm Husam Haron
Sustainable Residential Low Density Urban Development – Integrating Sustainable Consciousness with Commercial Viability abs#131

3:00pm Simon Dunstall
Controlling chp microturbines as a virtual power plant abs#132

Material Efficiency, Recycling & Durability - 5

2:00 PM - 3:30 PM Room 6

Chair: David Ness

2:00pm Olivia Guerra Santin
Analysis of material and energy efficiency of mexican, peruvian and dutch dwellings using the three-step-strategy abs#133

2:20pm Tomas Vrana
Frost formation and condensation in stone-wool insulants – the course of moisture resistance factor abs#134

2:40pm Arjen Sevenster
European Life Cycle studies' updateD information about PVC and PVC products abs#135

3:00pm Stephen Hennessy
Maintaining Green Buildings - Beyond the Design Process abs#136

International Case Studies & Technologies - 1

2:00 PM - 3:30 PM Room 7

Chair: Selwyn Tucker

2:00pm Ryota Kuzuki
Improving Sustainability of Building Blocks by Extended Use of Decentralized Combined Heat and Power Systems abs#567

2:20pm Manuel Pinheiro
LiderA an assessment system to support environmental management –The factorial approach abs#434

2:40pm Vanessa Gomes da Silva
Sustainability in office building design - assessment methodology: the case of florianópolis, sc, brazil abs#090

3:00pm Vanessa Silva
Integrated design process and the conventional practice: reflections on the environmental performance of one case study in brazil abs#085

Enhanced Sustainability Assessment Methods - Buildings & Components - 4

4:00 PM - 5:30 PM Room 1

Chair: Richard Hyde

4:00pm Soo Jin Lee
Cost efficiency analysis of design elements for an energy efficient apartment complex abs#141

4:20pm Yat-Hang, Felix Wong
Benchmarking of the health performance of residential buildings for a combined life cycle assessment , Life Cycle Costing and Health Impact Assessment tool for public housing in Hong Kong abs#142

4:40pm Wim Zeiler
Methodical system approach for user oriented infrastructural energy flows in the built environment; Flexergy abs#143

5:00pm John Connaughton
Embodied carbon assessment: a new carbon-rating scheme for buildings abs#144

Sustainability Assessment Case Studies - Buildings & Components - 6

4:00 PM - 5:30 PM Room 2

Chair: David Hood

4:00pm Sung-Ho Tae
The LCCO2 Reduction Effect and Economical Evaluation of the Reinforced Concrete Structure Using High-Strength Concrete abs#145

4:20pm Usha Iyer-Raniga
Excelling the uptake of leed india - integrating lessons learnt from the development of green star abs#146

4:40pm Stefan Preuss
'Towards Zero' – Methodology and strategies towards zero net emissions office buildings in Australia abs#147

5:00pm Eric Peterson
The effect of roof colour on the outdoor to indoor temperature difference in passively cooled non-air-conditioned buildings abs#148

Water Efficiency - 1

4:00 PM - 5:30 PM Room 3

Chair: Matthew Inman

4:00pm Sheridan Blunt
Cities as a catchment: a strategy for adaptation abs#149

4:20pm Dominique Hes
Opportunities for semi-decentralised water reuse and power production abs#150

4:40pm Alex Fearnside
Carbon sensitive water schemes: implementation for urban water schemes abs#151

5:00pm Sam Trowsdale
Water balance of a green building abs#152

Adaptation to Changing Environments - 1

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Chair: Tom Roper

4:00pm Shunji Fujii
Seismic retrofit method of tall-narrow buildings which can be applied from outside of buildings abs#154

4:20pm Irene Cheng
The redevelopment of kwai chung estate, hong kong. abs#155

4:40pm Rob Geraedts
A second chance for old buildings abs#156

5:00pm Tony Genco
Downsview Park: A Sustainable Community in the Making abs#153

Energy Efficiency - Building Services - 3

4:00 PM - 5:30 PM Room 5

Chair: Mark Lister

4:00pm Tomonari Yashiro
'Information embedded building ' for sustainable living abs#158

4:20pm Vanessa da Silva
Energy efficiency in Brazilian buildings: state-of-the art, policy instruments and main recent achievements abs#157

4:40pm Yukiko yoshida
Development of environmental information system to reduce energy consumption in buildings using BAC-net abs#159

5:00pm Andreas Jonsson
Simulations of energy influence using different control mechanisms for electrochromic windows abs#160

Cultural Identity & Construction Traditions - 2

4:00 PM - 5:30 PM Room 6

Chair: Rodney Milford

4:00pm Simon McPherson
An Eastern philosophical approach to sustainable urban development ● abs#161

4:20pm Bob Giddings
Public squares as a means of integrating economy, environment and society in British city centres ● abs#162

4:40pm Luís Bragança
Building Refurnishing: one step towards sustainable built environment ● abs#163

5:00pm A Santos
Building deconstruction in Portugal: a case study ● abs#164

New Products, Technologies & Systems - Building Services & Equipment - 1

4:00 PM - 5:30 PM Room 7

Chair: Thomas Mueller

4:00pm Kenneth Ip
Application of ground heat-exchanger to reduce energy demand of a low-rise office building in the Southeast of UK ● abs#165

4:20pm Mark Luther
A new paradigm for sustainable residential buildings ● abs#166

4:40pm Joshua Wall
Autonomous controllers for intelligent HVAC management ● abs#167

5:00pm Hideo Isozaki
Green engineering for High Rise Office building -Integration of architectural design and HVAC design- ● abs#168

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Chair: Dominique Hes

11:00am Eivind Selvig
Holistic life-cycle ghg emissions associated with buildings ● abs#169

11:20am Patxi Hernandez
Life cycle energy performance: Exploring the limits of passive "low energy" buildings ● abs#170

11:40am Holger Wallbaum
Sustainability indicators for the built environment – The challenges ahead ● abs#171

12:00pm Torben Rasmussen
Buildings designed with an energy-efficient building envelope ● abs#172

Sustainability Assessment Case Studies - Subdivisions & Regions - 2

11:00 AM - 12:30 PM Room 2

Chair: Susan Roaf

11:00am Luciana Aparecida Jesus
Methodology to assess the cost-effectiveness of sustainable measures in buildings. ● abs#173

11:20am Sabrina Krank
The Neglected Dimension: Socio-cultural Indicators in the Assessment of Sustainable Development in Megacities ● abs#174

11:40am Kirsty Chessher
Envirodevelopment - inspiring and delivering sustainable developments ● abs#175

12:00pm Sylviane Nibel
Modelling a sustainable urban management system ● abs#176

Water Efficiency - 2

11:00 AM - 12:30 PM Room 3

Chair: Peter Holt

11:00am Jaroslaw Chudzicki
Structural model of water and energy consumption efficiency in residential buildings ● abs#177

11:20am Eric Peterson
Rainwater harvesting system design based on rain guage time series ● abs#178

11:40am Maggie Lawton
Making New Zealand Policy, Water Conservation FrieNDly ● abs#179

Economics - 1

11:00 AM - 12:30 PM Room 4

Chair: Eckhart Hertzsch

11:00am Thomas Luetzkendorf
Creating products for sustainable property investment - a blueprint for green property investment funds from germany abs#181

11:20am David Lorenz
Next generation decision support instruments for the property industry - understanding the financial implications of sustainable building abs#182

11:40am Verney Ryan
Energy 'from serial renovator to sensible retrofitter' abs#183

12:00pm Joanne Chong
Costs and benefits of a green village: demonstrating Lochiel Park's value abs#184

Energy Efficiency - Building Services - 4

11:00 AM - 12:30 PM Room 5

Chair: Xiaoming Wang

11:00am Hiroshi Sako
A series of design method and measurement results of office buildings utilizing natural ventilation in central Tokyo abs#185

11:20am Keisuke Hama
"Factor4 dwelling" in the NEXT21, experimental housing of Osaka Gas abs#186

11:40am Paulien de Bruijn
Predicted Improvement of Energy Efficiency following Terrace House Renovation abs#187

12:00pm Po-Cheng Chou
Development and Testing on the Hybrid Lighting System Coupled Daylight with Artificial Lights abs#188

Energy Efficiency - Monitoring / Benchmarking / Demand Management - 1

11:00 AM - 12:30 PM Room 6

Chair: Bob Leicester

11:00am Roman Smutny
Passive houses in Austria - sustainability monitoring of the students' hostel Molkereistrasse abs#189

11:20am Tim Farrell
"Bottom up" model to estimate energy use in australia's residential sector abs#190

11:40am Yee Chow
How 'zero' is a 'zero carbon' home?- a comprehensive assessment of a 'zero carbon' home abs#191

12:00pm Kevin Grosskopf
Rate absorption approach for business sector adoption of energy conservation measures (ECMs) abs#192

Market Transformation - 1

11:00 AM - 12:30 PM Room 7

Chair: Geoff Lawler

11:00am Chris Wood
Govt3: Helping the New Zealand government GET sustainable Building abs#193

11:20am Bram Entrop
Decision making processes and the adoption of energy saving techniques in residential and commercial real estate abs#194

11:40am Sirimas Hengrasmee
The philosophy of "Sufficiency Economy" and sustainable suburban community development in Thailand abs#195

12:00pm Woytek Kujawski
How the results of EQuilibrium initiative could affect the future of Canadian housing abs#196

Enhanced Sustainability Assessment Methods - Buildings & Components - 6

2:00 PM - 3:30 PM Room 1

Chair: Toshiharu Ikaga

2:00pm Vanessa Gomes da Silva
Sustainability indicators for buildings: state of the art and challenges for development in Brazil abs#197

2:20pm Aoífe Houlihan
Certification In The Hotel Sector; Does It Actually Reduce Global CO 2 Emissions? abs#198

2:40pm Hiroaki TAKAI
Three studies on the promotion of Assessment Tools and Market Transformation: The case of CASBEE abs#199

3:00pm Hong Hua
construction and Eco-efficiency evaluation of liveable communities In CHINESE TOWNS abs#200

Enhanced Sustainability Assessment Methods - Subdivisions & Regions - 1

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Chair: Peter Newton
2:00pm Soon Kam Lim
Defining sustainability for Australian road infrastructure projects abs#201
2:20pm Thomas MACOUN
Amount of body energy versus external energy - the decisive ratio for sustainable structures abs#202
2:40pm Sylviane Nibel
Sustainable industrial and business parks : Decision making method FOR DIAGNOSIS and PROJECT SPECIFICATION BRIEF abs#203
3:00pm Kay Saville-Smith
Neighbourhoods, Local Authorities and Community Development: Opportunities for Improved Sustainability abs#204

Advanced Design & Project Delivery Principles - 3

2:00 PM - 3:30 PM Room 3
Chair: Peter Scuderi
2:00pm Lois Easton
Beacon now homes® and now home® renovations: transforming new zealand's housing stock abs#205
2:20pm Guenter Loehnert
Energy Efficiency in Commercial Buildings abs#206
2:40pm Byron Stigge
International sustainable design – applying global thinking and local knowledge abs#207
3:00pm Matt Grace
Urban Potential of Sustainable Office Refurbishment Measures abs#208

Economics - 2

2:00 PM - 3:30 PM Room 4
Chair: Brian Ashe
2:00pm Kok Ng
Clinical outcomes and subjective valuations for remodelled green health care facilities abs#209
2:20pm John Munroe
In Search of Net Zero – Calgary International Airport Expansion abs#210
2:40pm Kim Haugbølle
Energy savings: the client as change agent abs#211
3:00pm Bee Hua Goh
Client-led sustainable construction: decision support for whole-life cost implications abs#212

Energy Efficiency - Building Services - 5

2:00 PM - 3:30 PM Room 5
Chair: Adam Leggett
2:00pm Nancy Banks
Energy benefit and comparison of Dedicated Outside Air Systems abs#213
2:20pm Alex Summerfield
Changes in Energy Consumption Since 1990: results from a longitudinal study of low energy dwellings in the UK abs#214
2:40pm Eric Peterson
ENVIRONMENTALLY SUSTAINABLE DESIGN ATLAS OF AUSTRALIA abs#215
3:00pm Cheng Cheng
A Sustainable Approach of Energy Conservation in Improving the Envelope of Existing Buildings in Taiwan abs#216

Energy Efficiency - Monitoring / Benchmarking / Demand Management - 2

2:00 PM - 3:30 PM Room 6
Chair: Brian Sinclair
2:00pm Herbert Guettinger
Eawag Forum Chriesbach - A step towards the 2000-watt society abs#217
2:20pm Dennis Johansson
Energy and moisture related user behaviour measurements in residential buildings – Study approach abs#218
2:40pm Antonia Moropoulou
IR thermography for the performance assessment of abipv installation on a public building in greece abs#219
3:00pm Robert Wimmer
Wireless House, Self - sufficient and sustainable building solutions abs#220

Market Transformation - 2

2:00 PM - 3:30 PM Room 7

Chair: Manuel Pinheiro

2:00pm Mark Allen
'Mirvac's Waverley Park, working towards a sustainable future' abs#221

2:20pm Maria McGibbon
Green Buildings Initiate, Promote and Enhance Environmental Stewardship and Sustainability Among Occupants abs#222

2:40pm Fan Yang
Study on Resident Behavior DURING Construction of Energy-saving and Pollution-reduction Community in China abs#223

3:00pm Michael Edén
Land property distributions as a means for enhancing sustainable building. The Lundby competition in Gothenburg, Sweden, as an example. abs#224

Enhanced Sustainability Assessment Methods - Buildings & Components - 7

4:00 PM - 5:30 PM Room 1

Chair: Tomanari Yashiro

4:00pm Selwyn Tucker
Life cycle assessment of forest and wood products in Australia abs#225

4:20pm Marcelo Izquierdo Millán
Heat losses in housing during the night stopped period of the heating system. abs#226

4:40pm Getachew Assefa
Development of a damage-based system for weighting environmental impacts from buildings abs#227

5:00pm Jan Desmyter
Performance indicators for health, comfort and safety of the indoor environment abs#228

Enhanced Sustainability Assessment Methods - Subdivisions & Regions - 2

4:00 PM - 5:30 PM Room 2

Chair: Andy van den Dobbelsteen

4:00pm Nosizo Sebake
Developing the sustainable building assessment tool for stadia abs#229

4:20pm Yohei Yamaguchi
Understanding of socio-technical system built environment and transition of building stock and supporting infrastructure to sustainability abs#230

4:40pm Ted Wilson
The Burbs Are Alright abs#231

5:00pm Drew Heard
Building sustainability or sustainable buildings? abs#232

Advanced Design & Project Delivery Principles - 4

4:00 PM - 5:30 PM Room 3

Chair: Stephen Lau

4:00pm Ken Chueng
Designing for sustainability of building – Hong Kong context abs#233

4:20pm Philippa Howard
Exploring principles of regenerative tourism in a community driven EcoTourism development in the Torres Strait Islands abs#234

4:40pm Xiaoming Wang
Technology Development and Livability Demonstration of Green community Construction in Different Areas of China abs#235

5:00pm Joshua Sperling
E-Business adoption: Case study on Melbourne City Council CH2 building abs#236

Economics - 3

4:00 PM - 5:30 PM Room 4

Chair: Bram Entrop

4:00pm Georgia Myers
Sustainable Property Investment– The Future of the New Zealand Market abs#237

4:20pm Ying Hua
Barriers for green building practice in China abs#238

4:40pm Kuei-Feng Chang
How can sustainable building affect to real estate marketing in Taiwan ? abs#239

5:00pm Andrea Moro
Economic incentives and building rating systems abs#240

Energy Efficiency - Building Services - 6

4:00 PM - 5:30 PM Room 5
Chair: Paul Bannister
4:00pm Adrian Michaels
A Holistic Approach to the Reduction of Greenhouse Gas Emissions in a Commercial Office Building using Trigeneration abs#241
4:20pm Andrew Miller
Thermal Storage – an evaluation of the thermal performance of the Brighton Earthship abs#242
4:40pm Bo-Kyoung Koo
Energy performance evaluation in the case of applying external insulation and finish system to the wall- slab joints in apartment building envelope abs#243
5:00pm Xiaoming Wang
Studies on solar energy for residential use in Australia with consideration of climate change scenarios abs#244

Energy Efficiency - Monitoring / Benchmarking / Demand Management - 3

4:00 PM - 5:30 PM Room 6
Chair: Stephen Berry
4:00pm Masato Yamazaki
Potential of energy conservation and practical countermeasures of buildings for the future by a case study of Japanese city abs#245
4:20pm Sue Salmon
The Warren Centre's "Low energy high rise" project abs#246
4:40pm Mario Castagna
Energy performance of buildings in social housing in the autonomous province of South Tyrol, Italy abs#247
5:00pm Craig Roussac
Changing the culture of commercial buildings in Australia: The role of green leases abs#248

Market Transformation - 3

4:00 PM - 5:30 PM Room 7
Chair: Kim Haugbølle
4:00pm Kang-Li Wu
A study of the demand and marketing strategies for promoting ecological communities in taiwan under the trend of global climate changes abs#249
4:20pm luke middleton
Mildura River House - performance of a "luxury" sustainable home abs#250
4:40pm Paula Femenias
Supporting development towards more sustainable building: perspectives on demonstration projects as strategies for change abs#251
5:00pm Jón Kristinsson
The Greenest Building in the Netherlands - no external fuel, electricity, water or sewage abs#252

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Enhanced Sustainability Assessment Methods - Buildings & Components - 8

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Chair: Tarja Häkkinen
8:45am Toshio Fukushima
Evaluation of ecobalance performance of building composite materials by LCA Multi Eco-indicators abs#253
9:05am Kyuin Lee
A study on the characteristics of residential complexes certified with korean green building certification criteria abs#254
9:25am Andras Zold
Does the building system predefine the cumulated life cycle energy demand? abs#255
9:45am Kerryn Wilmot
Bridging the gap between finance and sustainability in construction abs#256
10:05am Masaaki Sato
Incorporation of LCCO2 Assessment to CASBEE abs#257

Sustainability Assessment Case Studies - Subdivisions & Regions - 3

8:45 AM - 10:40 AM Room 2

Chair: Michael Ambrose

8:45am Vincent Cheng
Planning the Eco-city in China – Challenges and opportunities abs#258

9:05am Takehiro Arishiro
Evaluation of global warming mitigation measures in the residential and non-residential sectors of a suburban city in Japan. abs#259

9:25am Lluís Grau i Molist
Sustainable district in Barcelona abs#260

9:45am Andrew Low
Eleven Studios in 11 Cities - 11 Scenarios for a Sustainable Future. abs#261

10:05am Roger Bayley
Vancouver's Olympic Village: Designing a Sustainable Community at Southeast False Creek abs#262

Education - 1

8:45 AM - 10:40 AM Room 3

Chair: Faridah Shafii

8:45am Carolyn Hayles
Do Construction Management graduate skills meet the needs of a greener building industry? abs#263

9:05am Peter Graham
Sustainability and the struggle for hegemony in Australian architectural education abs#264

9:25am Nori Yokoo
Study on the transition and progress of building environmental performance and human perception in architectural community in Japan abs#265

9:45am Wim Zeiler
Workshops in Dutch sustainable building design practice abs#266

10:05am Paul Leech
"Budging bau' (building as usual)the gaia ecotecture approach" abs#267

New Products, Technologies & Systems - Construction Products - 4

8:45 AM - 10:40 AM Room 4

Chair: Kwok Yum

8:45am Petr Stepanek
Optimized design of concrete structures from the environmenmtal point of view abs#268

9:05am Christine Kunze
Unfired industrial loam brick buildings with passive house standard. abs#270

9:25am Kenneth Ip
Thermal behaviour of a wall-lining containing phase change materials abs#271

Energy Efficiency - Building Services - 7

8:45 AM - 10:40 AM Room 5

Chair: Hans Erhorn

8:45am Hans Erhorn
Ecobuildings: Towards an energy-efficient European building stock beyond national requirements abs#273

9:05am Kahori Genjo
Energy conservation behavior and energy saving potential of single households in Japan abs#274

9:25am Daniel Hallett
A global review of outside air in buildings abs#275

9:45am Shuichi Numanaka
Proposal of methodology and optimization tool to achieve safety and energy saving for highly energy consuming building, such as laboratory abs#276

10:05am Yu-Min Kim
Contribution to Heating load reduction in double skin envelope abs#277

New Products, Technologies & Systems - Building Services & Equipment - 2

8:45 AM - 10:40 AM Room 6

Chair: Dong Chen

8:45am Wim Zeiler
Active house, an alternative sustainable building envelope concept abs#278

9:05am Jin-Hee Kim
An experimental study of air-type pvt collector with performance improvements abs#279

9:25am Guomin Zhang
Integrated technologies for sustainable refurbishment of office buildings abs#280

9:45am Shin-ichi Matsumoto
Development of bioclimatic maps of Japan for application of passive heating and cooling design techniques abs#281

10:05am Klaas Visser
The energy and water saving, and other benefits, when using transcritical carbon dioxide refrigeration for building cooling and heating. abs#282

Policy Making / Regulation / Standardisation - 4

8:45 AM - 10:40 AM Room 7

Chair: Lam Pham

8:45am Shoichi Ando
Sustainable building policy evaluation criteria and the application to Japanese policies abs#283

9:05am Jacques LAIR
Standardisation in the field of sustainability of the built environment abs#284

9:25am Jan Peter Amundal
Major challenges in obtaining sustainable buildings in Norway abs#285

9:45am Sean McArdle
New trends in sustainable education design abs#286

10:05am Connie Lai
Redevelopment of public rental housing estates in Hong Kong abs#287

DEVELOPING AN OPERATIONAL AND MATERIAL CO_2 CALCULATION PROTOCOL FOR BUILDINGS

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Keywords: CO_2 calculations, Life-Cycle Assessment (LCA), energy, materials, sustainable buildings, green buildings

Summary

The building sector is being called upon to help fight climate change by achieving ambitious reduction targets for greenhouse gas emissions while at the same time incorporating other "green" considerations. To resolve this dilemma, the Green Building Initiative (GBI) has embarked on converting Green Globes™ into an official national green building rating standard. At the heart of this proposed standard are an operational energy and materials sections that will use CO_2 as the basis for their respective calculations. This paper will review how both operational energy and materials CO_2 calculation protocol operate in this proposed standard. The authors of this paper are on the standards committee and were particularly active in developing the energy and materials sections. It will be argued that such a CO_2 calculation protocol will become an important new tool for promoting sustainable technologies and one that needs to be understood by the sustainable building community.

1. Introduction

With the launch of several recent carbon reduction initiatives, the U.S. is finally beginning to tackle the reduction of carbon emissions. These initiatives range from Kyoto Now, a movement to get corporations to address their carbon emissions similar to the Architecture 2030 initiative, which is asking the building community to design carbon-neutral buildings by 2030. Cities are also anxious to demonstrate their commitment to carbon reduction, as evidenced by the recent adoption of a resolution very similar to the Architecture 2030 goals by U.S. Council of Mayors. In addition, the U.S. Congress also has begun to discuss how best to introduce carbon emission reduction into national environmental policy. For example, carbon reduction strategies such as a carbon tax or a cap and trade type of system currently are being actively discussed in Washington, D.C.

Unfortunately, what these business people, designers, city administrators and politicians are quickly realizing is that there is a lack of proven tools to help them determine if they are on track to achieving such goals. To resolve this dilemma, the Green Building Initiative (GBI) has embarked on developing a national green building rating standard. At the heart of this proposed standard are operational energy and materials sections that will use CO_2 as the basis for their respective calculations. This standard has undergone one public review and is targeted for completion later this year. Significant changes could result from the public review process, thus this paper represents the thinking of the standard committee as of Spring 2008.

2. Green Globes™

Green Globes is a web-based environmental rating system which has been operating in Canada for a number of years. There it has been widely used by several federal agencies and is the basis for the Building Owners and Managers Association of Canada's "Go Green Plus" program for assessment of existing buildings. In 2004, the Green Building Initiative (GBI) acquired the rights to distribute Green Globes in the U.S. (www.thegbi.org). Since then it has been operating in the U.S. and a wide range of buildings have been certified. In the process of bringing this system to the U.S., GBI made a commitment to continually improve the system to ensure that it reflects changing opinions and ongoing advances in the field. In 2005, GBI applied for and became the first green building organization to be accredited as a standard developer by the American

National Standards Institute (ANSI), and began the process of establishing Green Globes as an official ANSI standard. The GBI ANSI technical committee and sub-committees feature a range of nearly 100 building science experts including representatives from federal agencies, states, municipalities, universities, leading AEC firms and building owners. Unlike other U.S. attempts at developing a green building standard, such as the ASHRAE 189 Standard, the proposed Green Globes Standard will be an environmental rating system which will allow a building to achieve several levels of environmental performance.

3. The Green Globes Operational Approach

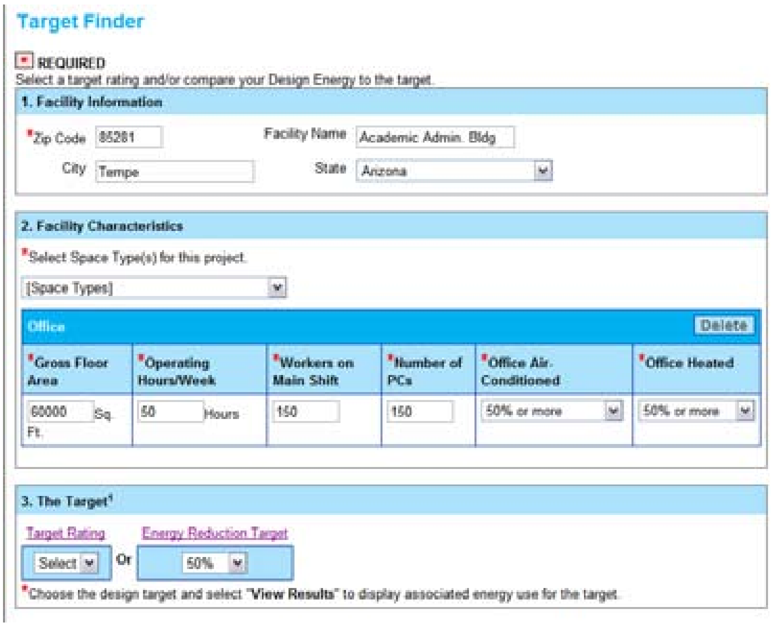
The energy or operational approach proposed by the GBI/ANSI committee is based on what has transpired in Europe in regards to CO_2 calculations procedures for buildings. Documents produced by the European Union provides a framework for all 27 EU countries to put into place CO_2 based calculation procedures for buildings by 2007 (EU 2003). The best application of this framework document is the United Kingdom's L2A Standard which became a requirement for all new U.K. buildings (ODPM 2006). The L2A Standard requires a new building to model its energy performance based on a set of prescriptive criteria, and then multiply the fuel mix of the building by the CO_2 emissions factor in order to determine a building's CO_2 target. This process is repeated for the proposed building and if the proposed building's CO_2 level is below the target, the building passes.

The proposed GBI/ANSI energy approach has some similarities to the ASHRAE Standard 90.1 (ASHRAE 2007), though it differs in several fundamental ways. For example, the Green Globes standard does not have any mandatory provisions except that minimum points have to be met in this category and that all buildings must meet local energy code, which would be most likely either ASHRAE Standard 90.1 or the International Energy Conservation Code. Points within the proposed standard are achieved only by going beyond code, which can be accomplished by either using the prescriptive or performance approach. The prescriptive approach gives points for meeting incrementally higher levels of component efficiencies, while the performance approach gives points as a function of how much better the proposed building performs vs. an industry agreed upon benchmark, which for the energy section is determined by the U.S. Department of Energy's Commercial Building Energy Consumption Survey (CBECS) database (DOE 2006). This is the most comprehensive source for building energy benchmarking currently available in the U.S. The CBECS database is also used by the U.S. Environmental Protection Agency's Energy Star Target Finder tool, which has been incorporated into Green Globes.

Unlike approaches such as ASHRAE Standard 90.1, which require designers to model a benchmark building as well as the building being proposed, the Green Globes standard is a much easier modeling exercise. Since CBECS is being used to determine the benchmark, only the building simulation for the proposed building needs to be completed. In order to determine a building's benchmark the EPA Energy Star Target Finder is used (www.energystar.gov/target_finder), which is a web based calculator that uses the CBECS database. This tool has the ability to normalize CBECS data to location, space type, occupancy density, internal load and hours of use (see Figure 1.). Target Finder generates an Energy Use Intensity (EUI) value and typical fuel mixes for a proposed 60,000 square foot Academic Administration building (see Figure 2.), which is then multiplied by the CO_2 equivalent (CO_2e) emission factor in order to determine the CO_2 target. Table 1 presents the CO_2e emission factors that are being proposed; a majority of these factors were generated by the National Renewable Energy Laboratory (NREL 2007). CO_2e has been used rather than CO_2, because CO_2e takes several other greenhouse trapping gases into consideration, particularly methane (CH_4) and nitrous oxide (N_2O). CO_2e also has a time horizon due to the atmospheric reactivity or stability of these contributing gases over time. The International Panel on Climate Change (IPCC 2001) 100-year time horizon figures have been used as the basis for establishing the CO_2e for both the operational energy and material calculations, that equivalence per unit mass is as follows:

$$CO_2 \text{ equivalent} = CO_2 + (CH_4 \times 23) + (N_2O \times 296) \quad (1)$$

The proposed building is then simulated; the resulting EUI and fuel mix is multiplied by the CO_2e emission factors in order to determine the proposed building's CO_2e level. This value is then divided into the CO_2e benchmark that was generated by Energy Star Target Finder to get percentage savings. The proposed Green Globes Standard currently awards 150 points to buildings that achieve a 50% CO_2e emission reduction from the average CBECS's building for that location. In addition, for every 1% CO_2e emission reduction beyond 50%, 2 points will be assigned to a maximum of 100 points (the Green Globes system has a total of 1000 points). Thus a CO_2e neutral building would score the maximum points allowable, 250 points which is one-quarter of all available points. As presently structured the GBI/ANSI energy approach dovetails very nicely with the Architecture 2030, only the time dimension (CO_2 neutral by 2030) would have to be included.


Target Finder

* REQUIRED
Select a target rating and/or compare your Design Energy to the target.

1. Facility Information
*Zip Code 85281 Facility Name Academic Admin. Bldg
City Tempe State Arizona

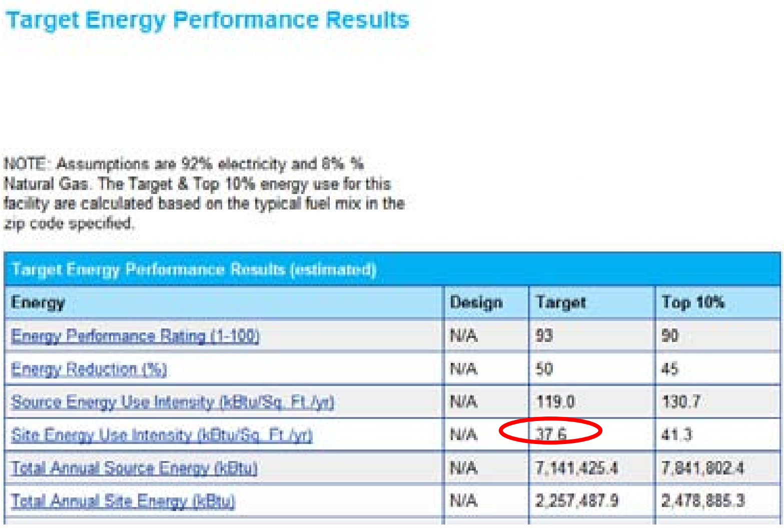
2. Facility Characteristics
*Select Space Type(s) for this project.
[Space Types]

Office Delete

*Gross Floor Area	*Operating Hours/Week	*Workers on Main Shift	*Number of PCs	*Office Air-Conditioned	*Office Heated
60000 Sq. Ft.	50 Hours	150	150	50% or more	50% or more

3. The Target[1]
Target Rating Or Energy Reduction Target
Select 50%
*Choose the design target and select "View Results" to display associated energy use for the target.

Figure 1. Target Finder's Input Screen for Example Building


Target Energy Performance Results

NOTE: Assumptions are 92% electricity and 8% % Natural Gas. The Target & Top 10% energy use for this facility are calculated based on the typical fuel mix in the zip code specified.

Target Energy Performance Results (estimated)

Energy	Design	Target	Top 10%
Energy Performance Rating (1-100)	N/A	93	90
Energy Reduction (%)	N/A	50	45
Source Energy Use Intensity (kBtu/Sq. Ft./yr)	N/A	119.0	130.7
Site Energy Use Intensity (kBtu/Sq. Ft./yr)	N/A	37.6	41.3
Total Annual Source Energy (kBtu)	N/A	7,141,425.4	7,841,802.4
Total Annual Site Energy (kBtu)	N/A	2,257,487.9	2,478,885.3

Figure 2. Target Finder's Output Screen for Example Building

Table 1. CO_2e Emission Factors

Fuel	kg-CO_2e/kWh(lb-CO_2e/kWh)
Natural gas	0.232 (0.510)
LPG	0.274 (0.602)
Fuel oil (residual)	0.311 (0.686)
Fuel oil (distillate)	0.299 (0.660)
Coal (bituminous)	0.373 (0.822)
Coal (lignite)	0.585 (1.289)
Gasoline	0.326 (0.719)
Biomass	0.026 (0.057)
Grid delivered electric	0.758 (1.670)
Grid displaced electric	-0.833 (-1.835)
Off-site renewable electric	-0.758 (-1.670)
Waste heat	0.019 (0.042)

3.1 The Operational CO_2e Benchmarking Calculation

From the Target Finder exercise we determine that the building's baseline EUI to be 37.6 kBtu/sf/yr. Target Finder also assumes fuel mix to be 92% for electricity and 8% for natural gas. Thus, the operational CO_2e benchmark that the proposed building will need to improve on is 17.39 lb/sf/yr.

Example of the benchmarking calculation:

For Electricity

$$\frac{0.92 \times 37.6 \text{ kBtu/sf/yr}}{3.412 \text{ kBtu/kWh}} = 10.14 \text{ kWh/sf/yr} \times 1.670 \text{ lb/kWh} = 16.94 \text{ lbs/sf/yr}$$

For Gas

$$\frac{0.08 \times 37.6 \text{ kBtu/sf/yr}}{3.412 \text{ kBtu/kWh}} = 0.88 \text{ kWh/sf/yr} \times 0.510 \text{ lb/kWh} = 0.45 \text{ lbs/sf/yr}$$

17.39 lbs/sf/yr

4. The Green Globes Material Approach

It is no longer enough to assume that individual material attributes, such as recycled content, the use of rapidly renewable materials, or local purchasing, automatically deliver the desired environmental benefits. Instead, those who design or build green buildings are increasingly being asked to look at a range of real environmental performance indicators or measures. This is done through a process called life cycle assessment (LCA), which takes into account the cradle to grave effects of manufacturing, transporting, using and ultimately disposing of products using a range of environmental impact indicators. Global warming potential (GWP in LCA parlance is the same as CO_2e) is one of the most important of those indicators. In the past, LCA's practical use was limited by the fact that it was perceived as too complex or time consuming for widespread use. That is no longer the case.

The Athena Institute recently introduced an online tool — the ATHENA® *EcoCalculator for Assemblies* —that provides instant LCA results for hundreds of common building assemblies. Developed by the Athena Institute in association with the University of Minnesota and Morrison Hershfield Consulting Engineers, the *EcoCalculator* provides LCA results generated using its parent software, the ATHENA® *Impact Estimator for Buildings*. The results take into account resource extraction and processing, product manufacturing, on-site construction of assemblies, all related transportation, maintenance and replacement cycles over an assumed building service life of 60 years, structural system demolition and transportation to landfill of those materials that are currently land filled as opposed to being recycled or reused. In addition, all energy use at every stage is factored up to account for the energy and other environmental effects of manufacturing and transporting different energy forms, termed pre-combustion effects in LCA.

The *EcoCalculator* was originally developed for use with the Green Globes and will be incorporated into the GBI/ANBSI version of the Green Globes. Because of its value as an indicator of climate change potential and other effects, the GBI also supported the team's creation of a generic version for use by the entire sustainable design community. This version is available free of charge from the Athena web site (www.athenasmi.ca), and is therefore available to other green building rating systems and programs that want to encourage greater use of LCA in material selection.

The *EcoCalculator* can be used for new construction projects, retrofits and major renovations on industrial, institutional, office or residential designs, either to compare specific assemblies or to assess all building assemblies. Building assemblies are evaluated in the following six categories, with the number of assemblies in each category varying widely depending on the possible combinations of layers and materials:

- Exterior Walls
- Interior Walls
- Roofs
- Windows
- Intermediate Floors
- Columns and Beams

Design results are available in spreadsheet form and show real time changes as the inputs are adjusted (see Figure 3.). This allows different assembly options to be considered in light of their environmental impacts and provides the information necessary to make informed, scientifically-based choices. Individual assembly impacts are then summed to determine whole building impacts for each of the following categories: primary energy, GWP (CO_2e), weighted resources, air and water pollution (see Figure 4).

In the development of specific assembly LCA results using the Impact Estimator, one must provide basic dimensional and other information, such as the length of an exterior wall or the live load on a beam. The results are presented on a per unit area basis (e.g., per square foot), but the base Estimator runs used large quantities, such as 1000 linear feet of wall. In other words, the assembly effects are estimated in a whole building context to take account of end conditions, such as the additional stud at the end of a wall or the perimeter columns in a beam and column assembly, window-to-wall ratios, and other realistic aspects of building design.

We assumed that all assemblies would be installed in either low- or high-rise buildings, using components and loadings typical for central areas of the United States (i.e., no unique seismic loadings were considered), but with a differentiation between northern and southern climates in order to properly define assemblies in terms of thermal performance.

Other specific assumptions and definitions are provided on the Athena Institute web site at www.athenasmi.ca.

4.1 The Material CO_2e Calculation

Figure 3 presents the LCA results for the same 60,000 square foot Academic Administration building that was benchmarked in Section 3.1. Figure 4 sums the whole building impacts for each of the six building component categories; here we see that the GWP (CO_2e) is 3306 tons or 110.2 lbs/sf. If we divide this value by the assumed 60 year service life for this building we get 1.84 lbs/sf/yr which is approximately 10% of the annual operational CO_2e for this same building. Correcting for the fact that this building is benchmarked to be 50% better then CBECS, a 1 to 10 ratio is very consistent with studies that found a similar ratio between embodied and operational energy (Cole and Kernan 1996).

5. Conclusion

This paper illustrates that both operational and materials CO_2e can be easily calculated, providing an opportunity for whole building CO_2e analysis. For our 60,000 square foot Academic Administration building example, the whole building CO_2e analysis amounted to 19.23 lbs/sf/yr. After the GBI/ANSI version becomes automated, like the current version of Green Globes is, this protocol will operate in a seamless manner. In addition, we envision that this protocol could be easily introduced into a Building Information Modeling (BIM) environment. Thus, as thermal properties and material assemblies are entered into a BIM program, the results of the whole building CO_2e calculation would automatically appear in a performance window.

We are sure that the protocol outlined here will move towards increased comprehensiveness; however, the trick will be to be comprehensive without becoming too complex or time consuming. As our knowledge increases, CO_2(e) calculation methods will undoubtedly improve. It is clear that the building industry is transitioning away from energy to CO_2(e) as a metric. This is an important transition in that it eliminates several issues that were problematic with energy as a metric. For example, the site vs. source energy issue that was current in the energy circles for so many years diminishes because site energy gets converted into source CO_2(e), thus, allowing the environmental impact of buildings to be accounted for more rigorously. However, new issues are beginning to emerge that may take some time to resolve, such as allowing fuel switching to take place between the benchmarked and proposed building or how on-site vs. off-site renewables are properly accounted for. While these are policy questions, they will have to be answered before we can develop a more definitive CO_2 calculation protocol, and they will undoubtedly get resolved. We believe the protocol outlined here will help us frame that discussion and become an important new tool for promoting sustainable buildings that move us toward carbon neutrality.

References

ASHRAE (2007). *ASHRAE Standard 90.1-2007, Energy Standard for Buildings Except Low-Rise Residential Buildings*, ASHRAE, Atlanta, GA.

Row	A	B	C	D	E	F	G	H	I	J	K
1		Academic Administration Building -- As Built		Assembly R-Value	Square footage	Percentage of total	Primary Energy per SF (MMBtu)	GWP per SF (lbs) (tons in total)	Weighted Resource Use per SF	Air Pollution Index	H2O Pollution Index
2											
3	A. COLUMNS AND BEAMS										
4		ASSEMBLY TYPE Column	ASSEMBLY TYPE Beam	AVERAGE:			0.05	5.30	20.23	0.40	0.01
5	14	Wide-flange Steel	Wide-flange Steel		70,084.00	100%	0.09	8.19	21.55	0.57	0.0107
6				TOTAL	70,084.00		6,006	287	755	55,625	753
7											
8	B. INTERMEDIATE FLOORS										
9		Floor Structure	Interior Ceiling Finish	AVERAGE:			0.08	11.51	72.18	1.18	0.0056
10	1	Concrete Flat Plate and Slab Column System 25% flyash	gypsum board; latex paint		22,523.00	36%	0.15	31.98	210.51	2.50	0.0025
11	5	Concrete Hollow Core Slab	none		36,075.00	57%	0.06	14.14	30.33	1.51	0.0025
12	11	Open Web Steel Joist w/ Steel decking System and Concrete Topping	gypsum board; latex paint		3,005.00	5%	0.03	12.67	66.66	1.03	0.0139
13	15	Steel Stud Joist and OSB Flooring System	none		1,462.00	2%	0.01	9.42	27.00	0.77	0.0217
14				TOTAL	63,065.00		6,005	641	4,121	107,678	220
15											
16	C. EXTERIOR WALLS										
17		Assembly Type		AVERAGE:			0.13	21.51	70.01	2.07	0.69
18	4	Concrete block, EIFS, vapor barrier		16.51	22,116.00	43%	0.12	19.52	32.63	1.66	0.0014
19	30	Concrete Tilt-up, EIFS cladding, vapor barrier		16.15	5,421.00	11%	0.10	15.34	111.11	1.60	0.0010
20	48	2x4 steel stud 16" oc, steel cladding (26 ga) gypsum board sheathing, batt insulation, vapor barrier, gypsum board, latex paint		7.23	8,378.00	16%	0.17	35.98	29.36	3.00	4.4034
21	65	Curtainwall Opaque Glazing (with insulated backpan)		0.00	4,548.00	9%	0.18	32.16	50.19	3.86	0.0046
22		Steel Siding			10,964.00	21%	0.11	20.21	5.35	2.27	4.3900
23				TOTAL	51,425.00		6,587	636	933	113,402	85,081
24											
25	D. WINDOWS										
26		Assembly Type		AVERAGE:			0.41	65.83	97.28	8.03	0.0031
27	5	Curtainwall viewable glazing		1.61	14,166.00	100%	0.27	61.60	91.70	7.30	0.0010
28				TOTAL	14,166.00		3,990	455	677	107,781	15
29											
30	E. INTERIOR WALLS										
31		Assembly Type		AVERAGE:			0.06	7.11	17.64	0.87	0.0012
32	4	Steel stud (16" oc) gypsum board + latex paint each side			24,684.00	98.04%	0.03	3.51	10.51	0.47	0.0034
33	8	6" concrete block; latex paint each side			492.36	1.96%	0.09	14.22	24.74	1.25	0.0000
34				TOTAL	25,176.36		888	47	137	12,164	85
35											
36	F. ROOF										
37		Assembly Type		AVERAGE:			0.25	23.16	70.05	3.07	0.0053
38	4	Concrete flat plate slab and column 4-ply built-up roofing, vapor		22.21	23,257.00	73%	0.88	69.71	294.23	3.13	0.0044
39	14	Open-web Steel joist w/ steel decking 4-ply built-up roofing, vapor barrier, rigid insulation, gypsum board, latex paint		24.88	6,284.00	21%	0.71	62.51	81.91	7.14	0.0046
40				TOTAL	29,541.00		25,300	1,240	3,680	274,858	194
41											

Figure 3. EcoCalculator's Assembly Spreadsheet for Example Building

Academic Administration Building -- As Built **TOTAL IMPACTS BY BUILDING COMPONENT**	Primary Energy (MMBtu) TOTAL	GWP per (tons) TOTAL	Weighted Resource (tons) TOTAL	Air Pollution Index TOTAL	H2O Pollution Index TOTAL
COLUMNS AND BEAMS	6,006	287	755	39,625	753
INTERMEDIATE FLOORS	6,005	641	4,121	107,678	220
EXTERIOR WALLS	6,587	636	933	113,402	85,081
WINDOWS	3,990	455	677	107,781	15
INTERIOR WALLS	888	47	137	12,164	85
ROOF	25,300	1,240	3,680	274,858	194
WHOLE BUILDING	**48,776**	**3,306**	**10,302**	**655,509**	**86,349**
PER SQUARE FOOT	**0.8129**	**0.0551**	**0.1717**	**10.9252**	**1.4392**

Figure 4. EcoCalculator's Impact Summary Spreadsheet for Example Building

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FROM THE ENERGY EVALUATION TO THE ASSESSMENT OF THE WHOLE BUILDING PERFORMANCE

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Keywords: certification, assessment of building performance, energy performance certificate

Summary

Buildings are significant factors of all national economies. In order to label their quality and building performance, standardized evaluation methods are necessary. These methods should contain a high level of detail on one hand, and be as clear as possible and easy to understand for the user on the other hand, priorities differ according to the building type (housing, office, etc.). The following report will show the actual situation and the further development in Germany: the way from the energy evaluation (energy performance certificate) to the future assessment of the whole building performance (certification).

1. Functions of buildings

Buildings have numerous functions. Essentially, these are technical as well as social and cultural functions that are performed under the consumption of resources. The minimization of this resource consumption under consideration of the function and the location is named sustainable building.

The most important technical functions are:

Protection against:
- People and animals (safety need)
- Fire in the neighbourhood and on one's own premises
- Moisture in the form of precipitation, formation of surface condensation and mould, frost effects, swelling and shrinking processes
- Cold, when the outdoor temperature is low
- Heat, under mid-summer conditions and/or high internal heat loads
- Noise from the outside and from neighbouring other, or own, home or working areas
- Electric fields and radioactivity
- Glare problems due to direct or reflected solar radiation

Provision of:
- Light, preferably using a maximum share of daylight and high energy-efficiency artificial lighting
- Heat, to ensure thermal comfort when outdoor temperatures are low
- Cooling, to prevent overheating
- Humidity, in particular for use(r)-related requirements
- Fresh air, as available or conditioned
- Room acoustics, to ensure sufficient speech intelligibility and/or the requested auditory sensation of music

Removal of:
- Harmful substances (contained in building materials, released during use)
- Moisture (built-in moisture from the construction process, moisture generated during use)

These diverse tasks are fulfilled by numerous components and systems that are in general separately evaluated, labelled, and optimized. This scalar approach frequently leads to partial optima, but, however, not to an overall optimum. In part, it also produces contradictory statements. In many instances, only the investment costs for the insulation of the building or the heating system (and, for some time now, also the energy consumption during the use of the building) are used for the assessment. Other aspects, such as comfort, effects on performance, cleaning and maintenance costs and similar are not taken into account.

In addition, social and cultural functions must be fulfilled and aesthetic aspects must be considered. Quite often, these functions are not represented in a quantifiable assessment, although their importance may be dominant. This problematic situation makes the approach more difficult; consequently, it leads to a vectoral consideration with quantifiable “hard” and non quantifiable “soft” assessment quantities, with the inclusion of individual user wants and possibly the individual weighting of parameters.

2. Energy labelling of buildings

Now that the energy labelling of new buildings (and, in numerous cases, also of existing buildings) by means of an Energy Performance Certificate has been made obligatory by the Energy Saving Ordinance of 2007 (EnEV 2007) - almost two decades after the first presentation (Hauser and Hausladen 1990) - an important element in the description of a building's quality can finally be considered to have been worked out. Now, the approach of a holistic building assessment should be adopted, which is to include as many further criteria as possible.

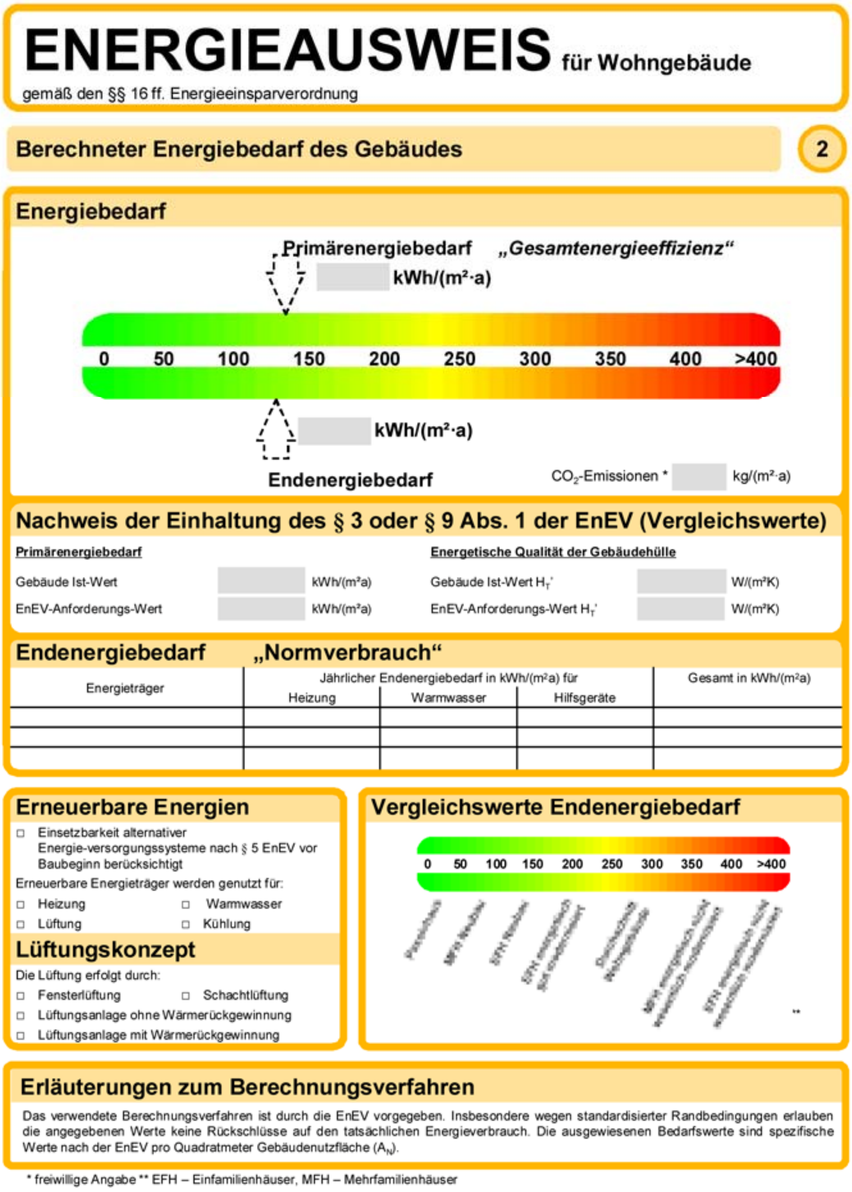

Figure 1: Reproduction of the second page of the Energy Peformance Certificate for residential buildings (EnEV 2007)

3. Holistic labelling of buildings

A room-conditioning assessment vector (RcA vector) is suggested in Hauser (2003) for at least the primary introduction of an overall holistic consideration of the “Room conditioning“ partial building function quantity. The principle structure of this vector is shown in Fig. 1.

From this and for each assessment criterion, the number of which can be very different according to the specific task, an objective assessment factor B will be introduced that can, however, be supplemented by an individual weighting factor W, so that the planner can better fulfill his particular wants and expectations in co-operation with the investor. The result is normalized to 1.

For the clear presentation of the complete vector, the form of a vectogram, as shown in Fig. 1, is suggested in Hauser (2003). This procedure enables any number of assessment criteria (which are if possible brought together in groups) to present the results obtained so that they are clearly and quickly recognizable, also allowing the comparison with alternatives. The definition and representation of reference curves from similar building projects simplifies the categorizing of the resulting solutions in respect to customary ones. Similarly, minimum standards can be pictured, as shown in Fig. 1.

The quality of a building can be clearly presented by the system described, which simplifies the processing of the flood of information. The task that is still to be done is therefore the definition of the criteria that are to be identified and the working out of methods for their objective assessment. For simpler implementation of the system, the designation "Sustainability Vector", or "Building assessment vector" is suggested.

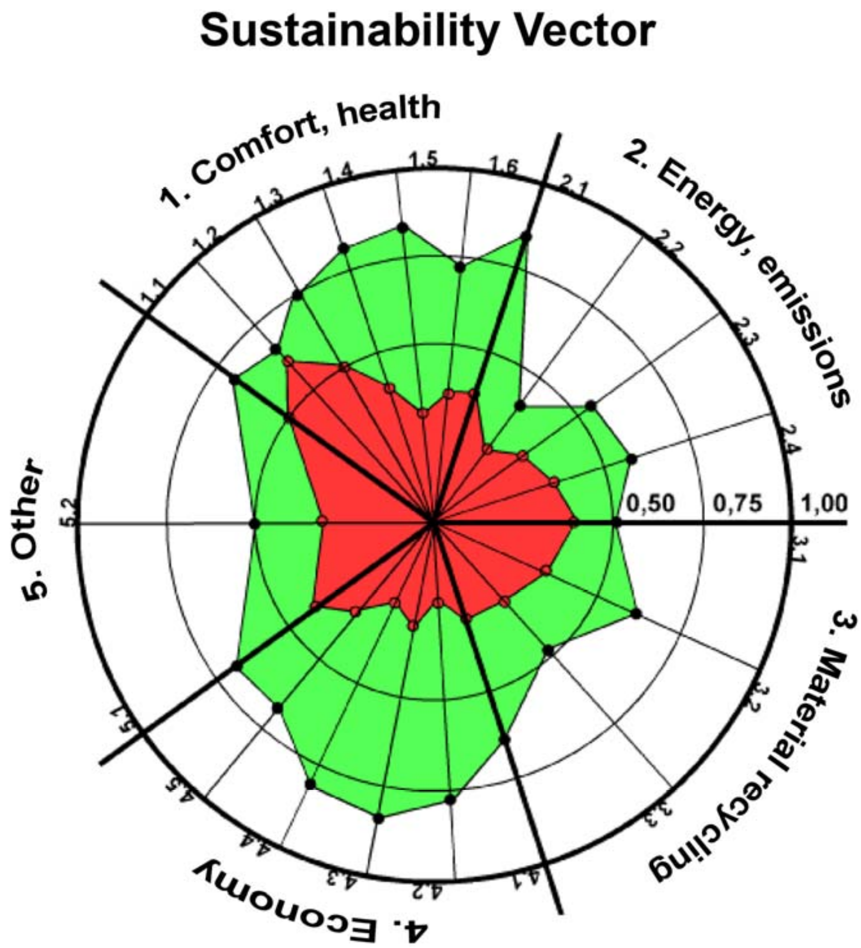

Figure 2: Reproduction of the room conditioning assessment vector (RcA vector) suggested in Hauser (2003), but named sustainability vector here.

There are already several international approaches to holistic building assessment methods, such as, for example, the assessment tools:

- BREEAM Building Research Establishment Environmental Assessment Method, GB
- SBTool Sustainable Building Tool (former GBTool), international
- LEED Leadership in Energy and Environmental Design, USA
- CASBEE Comprehensive Assessment System for Building Environment, JP
- EPIQR Energy Performance Indoor Environmental Quality Retrofit, GER, FhG-IBP
- ÖÖB Oekonomische und oekologische Bewertung (Economic and Ecological Assessment), GER
- EcoPRO Oekobilanzierungsprogramm (Life-cycle Analysis), GER, TH-Karlsruhe
- LEGEP Lebenszyklus Gebaeude Planung (Life-cycle Building Planning), GER

An illustrative labelling prepared with the methods described above has already been introduced in some countries, but the methods used have deficits. Programmes and evaluation schemes have also been developed at a national level in recent years. They have not yet been completely established in the planning process, however, and deal only with partial aspects of the overall assessment. For example, the EPIQUR and ÖÖB programmes (which were developed in Germany and Europe) are only for new buildings or for existing ones; programmes such as LEGOE and sirADOS are limited to the ecological life-cycle analysis or to the purely economic point of view.

Against this background, the development of a holistic assessment tool for buildings, which includes procedures used in Germany and Europe for the assessment of energy efficiency, user comfort and many more, and additionally takes methods that are already internationally used into consideration, is of great importance. A label that can be successful in the market - the Energy Performance Certificate (that has now at last been introduced) could serve as a good example here - and which is agreed upon in close co-operation between all building participants, is not only necessary but would also promote the aspects of sustainability in the construction sector (Hauser 1991, Hauser et al. 2007).

For this reason, the BMVBS (German Federal Ministry of Transport, Building and Urban Affairs) established the so-called “Round Table” several years ago. Here, experts first developed and then revised the “Guideline for Sustainable Building“ (Federal Ministry of Transport, Building and Urban Affairs 2001). In 2007, the “German Society for Sustainable Building” (German abbreviation DGNB) was founded. The focus was on the following five paramount protection targets for a certification system that is to be developed and is based on German environmental standards and environmental targets:
- Protection of resources
- Preservation of the natural environment
- Securing and preservation of worth
- Improvement in the surroundings and protection of public property
- Health and comfort of building users

With regard to the future German system, it is becoming apparent that the following areas will flow into the assessment of the whole building performance:
- Ecological Quality
- Economic Quality
- Social-cultural and functional Quality
- Technical Quality
- Process Quality
- Site Quality

These are presented in model shown in Fig. 4.

The individual areas on their part again comprise numerous criteria. Depending on the choice which criterion area is to be used 60 individual criteria are listed.

From the author's point of view, a 3-column model would make good sense as, for example, the “Acoustic comfort“ criterion is listed under “Social, cultural and functional quality“ and so already covers the “Noise control“ aspect subsumed under “Technical Quality“, which makes the “Technical Quality” column un-necessary. Fire protection, for example, could be categorized under “Functionality“, and so on.

Aspects	Criteria group	No.	Criteria
Ecological Quality	**Resource utilization and waste accumulation**	1.	Primary energy demand, non-renewables
		2.	Primary energy demand, renewables
		3.	Other use of non-renewable resources
		4.	Waste
		5.	Drinking-water consumption
		6.	Land consumption
	Effect on the local and global environment	7.	Greenhouse potential (GWP)
		8.	Ozone-layer destruction potential (ODP)
		9.	Ozone generation potential (POCP)
		10.	Acidification potential (AP)
		11.	Eutrophication potential (EP)
		12.	Risks for the local environment
		13.	Other effects on the local environment
		14.	Other effects on the global environment
		15.	Microclimate – Heat island effect
Economic Quality	**Life-cycle costs**	16.	Life-cycle costs (Building-specific)
	Value performance	17.	Value stability
		18.	Thermal comfort in winter

		19.	Thermal comfort in summer
		20.	Indoor air quality
		21.	Acoustic comfort
		22.	Visual comfort
		23.	Exertion of influence (user)
		24.	Landscaping quality (building)
		25.	Safety and failure risks
	Functionality	26.	Barrier-free accessibility
		27.	Area efficiency
		28.	Conversion capability
		29.	Public accessibility
		30.	Bicycle comfort
	Design Quality	31.	Ensurement of design and urban quality through competition -
		32.	Art in buildings
Technical Quality	Technical Quality	33.	Back-up ability of technical facility equipment
		34.	Operability of technical facility equipment
		35.	Fire protection
		36.	Noise protection
		37.	Maintenance and repair friendliness of the construction
		38.	Durability
		39.	Performance of the thermal and moisture protection of the building envelope
		40.	Deconstruction and recycling friendliness
		41.	Performance of technical facility equipment
		42.	Resistance against hail, storm, high water
Process Quality	Planning Quality	43.	Quality of the preliminary planning
		44.	Participation
		45.	Integrated planning
		46.	Operational concept
	Construction Quality	47.	Building site/ Construction progress
		48.	Quality assurance measures
		49.	Putting into service/ Briefing of the users
		50.	User brochure
	Operating Quality	51.	Monitoring
		52.	Management
		53.	Systematic inspection, maintenance and repair
		54.	Qualification of the operating personnel
Site Quality	Site Quality	55.	Risks at the micro-location
		56.	Loads/ Pollution at the micro-location
		57.	Market compatibility
		58.	Traffic connection
		59.	Nearness to usage-related objects and facilities
		60.	Planning law situation

Figure 3: Compilation of all individual criteria that are under discussion.

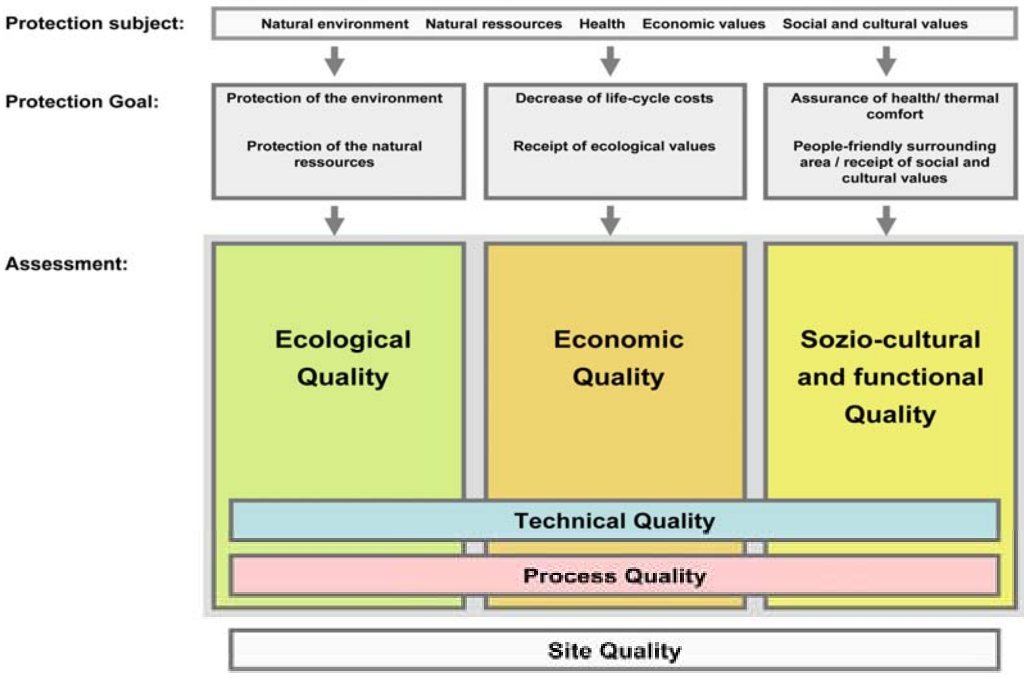

Figure 4: Presentation of the "Sustainability pillars" worked out by BMVBS and DGNB.

It must be possible to quantify all criteria comprehensibly (hard criteria) or to describe them qualitatively according to uniform points of view (soft criteria).

The form of a sustainability vector shown in Fig. 5 is suggested to enable a quick communication of the results to interested parties. The larger the particular area, the higher the sustainability of the building with respect to this criterion.

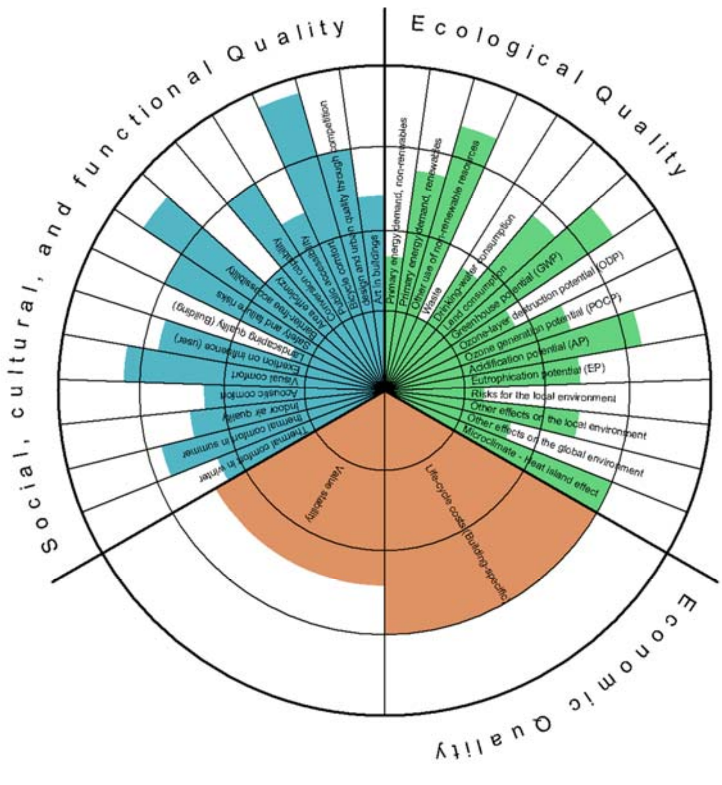

Figure 5: Suggestion for a sustainability vector for clear identification of the sustainability of buildings.

5. Added value and market chances of a holistic labelling

The Federal Ministry of Transport, Building and Urban Affairs (German abbreviation BMVBS) and the German Society for Sustainable Building, which was founded in 2007 in Stuttgart (German abbreviation DGNB), are working on a quality qualification for particularly environmentally friendly, healthy and resource-considerate buildings as the most important instrument for promoting sustained yield building. This new instrument for holistic building assessment takes up from agreements on international standardization and has as its motto, transparency and orientation to practice. Particularly important bases of information for the new system are quality and grade certificates for building products as well as environmental declarations on the basis of the ISO 14025 (EPD) international standard. The building assessment is based on an overview of the building and its life-cycle perspectives as basis for efficient sustained yield building.

The certificate that is being worked on proves the maintenance of the sustainability criteria both to the owner of the building and to the user of it. The demand for environmentally conscious ecological products is continuously increasing and is resulting in an enormous market shift. Up to now there is very little knowledge on the purchased real estate and it is limited to a general description of the building. Extensive information is provided for lower value products, but such information is lacking with long-lived real estate, although it is more and more frequently asked for.

Not only the owner and the user of the building can profit from this, however, but also predominantly the German and European building industry, whose environmental competence is rated very highly in international comparisons. This strength should be acknowledged in the international market with the new quality qualification.

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NIST BusiBEES METRICS AND TOOLS FOR GREEN BUILDINGS*

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Summary

Building stakeholders need compelling metrics, tools, data, and case studies supporting major investments in sustainable building technologies. Proponents of green building widely claim that these buildings are cost-effective, but often these claims are based on incomplete, anecdotal evidence that is difficult to reproduce and defend. The claims suffer from two main weaknesses: (1) buildings upon which claims are based are not necessarily "green" in a science-based, life-cycle assessment (LCA) sense and (2) their measures of cost-effectiveness often are not based on standard methods for measuring economic worth. Yet the building industry demands compelling metrics to justify sustainable building designs. The problem is hard to solve because, until now, neither methods nor robust data supporting defensible business cases were available. The U.S. National Institute of Standards and Technology (NIST) Building and Fire Research Laboratory is beginning to address these needs by developing rigorous metrics and tools for assessing the life-cycle economic and environmental performance of buildings. Economic performance is measured using standard life-cycle costing methods. Environmental performance is measured using LCA methods that assess the "carbon footprint" of tall buildings as well as 11 other sustainability metrics including fossil fuel depletion, smog, water use, habitat alteration, indoor air quality, and human health. Carbon-efficiency ratios and other eco-efficiency metrics are established to yield science-based measures of the relative worth, or "business case," for green buildings. The approach is illustrated through a realistic tall building case study. Finally, NIST activities and future plans in this area are described.

1. Introduction

A wave of interest in sustainability gathered momentum in 1992 with the Rio Earth Summit, during which *sustainability* was agreed to mean "meeting the needs of the present generation without compromising the ability of future generations to meet their own needs." In the context of sustainable development, needs can be thought to include the often-conflicting goals of environmental quality, economic well-being, and social justice. While the intent of the 1992 summit was to initiate environmental and social progress, by the 2002 Johannesburg Earth Summit, it seemed to have instead brought about greater debate over the inherent conflict between sustainability and economic development.

This conflict is particularly apparent within the construction industry's sustainable building efforts. Frequently, well-intentioned environmental improvement plans are not executed for economic reasons, and economic development plans fail to materialize over concerns for environmental protection. Thus, an integrated approach to sustainable building—one that simultaneously considers both environmental and economic performance—lies at the heart of reconciling the conflict.

This paper describes and illustrates, through a tall building case study, an approach that addresses the need to justify environmentally-friendly, or "green," building in economic terms. It suggests a framework for quantifying the "returns" on sustainable building using performance-based, science-informed thinking. The results refine and expand on preliminary results reported in early 2008 (Sunder, 2008).

1.1 Sustainable Building Metrics: A Review

A limited number of comprehensive, national-scale studies have been conducted to assess the benefits and costs associated with green building. A review of the U.S. literature finds that business cases for sustainable building typically evaluate commercial or residential buildings meeting benchmarks for green certification established by building industry stakeholders. A popular example of such a certification system is the Leadership in Energy and Environmental Design (LEED) rating system, developed by the U.S. Green Building Council (USGBC). LEED designates green buildings based on criteria including water, materials, and energy use, siting, and indoor environmental quality (USGBC, 2004). While other U.S. benchmarking systems have been established, LEED currently leads the way in defining guidance for green building attributes for the U.S. building sector.

Most published green building business cases are based on a certified green building's life-cycle costs, including: initial capital construction, operation and maintenance, repair, and replacement costs, which are typically collected through post-occupancy surveys. These cost data are used to determine the long-term economic merit of constructing a new building or retrofitting an existing one with green features, which usually requires higher initial construction costs. While the use of a life-cycle costing framework is common, different case studies often measure and collect these data in different ways.

The consensus among business cases is that building to environmentally-friendly guidelines is financially sound in the long run. Aside from the most commonly cited benefit—reduced energy costs—increased water efficiency and property values are among the other leading financial incentives for designers, builders, and owners to build green. When "soft" economic benefits, such as productivity increases, are monetized and included in life-cycle costs for office buildings, financial returns can increase significantly.

While approaches and conclusions in published business cases have been similar, their overall value is uncertain. These studies suffer from two major weaknesses: First, the buildings upon which these cases are based are not necessarily "green" in a science-based, life-cycle assessment (LCA) sense. Secondly, cost-effectiveness measures often are not based on standard methods of economic worth. A credible sustainable building metric first and foremost must be based on rigorous assessments of environmental and economic building performance.

1.2 Performance-Based Sustainable Building Metrics

1.2.1 Environmental Performance Measurement

Two quantitative, science-based approaches can help determine the environmental performance of a building: process-based life-cycle assessment (LCA) and input-output-based LCA. Both take a similar life-cycle approach, but each tackles the measurement challenge in a different way.

LCA is a holistic approach which considers the consequences of raw material, water, and energy inputs from, and releases to, the environment throughout the life-cycle of an "industrial" system. An industrial system is broadly defined: for the building sector, it can be limited to individual building products, components, or systems, or it can apply to an entire building or building sector. The term "life cycle" refers to the major stages in the life of the industrial system; these stages include raw material acquisition, manufacture, transportation, installation, use, and final disposal.

As standardized by the International Standardisation Organization (ISO), LCA clearly identifies and accounts for transfers of environmental impacts from one environmental medium (e.g., air, land, or water) to another and from one life-stage to the next. The ISO 14040 series of standards identify three steps in any LCA process: (1) *inventory compilation*, (2) *impact assessment*, and (3) *interpretation,* which lead to measures of environmental performance (ISO, 2006). During the first step, quantification of inputs, such as raw materials and energy, and outputs, in the form of environmental releases such as carbon dioxide and carcinogens, results in an *inventory* of environmental flows. During the *impact assessment step*, the environmental consequences of the identified inventory flows are assessed. In the third step, *interpretation*, impact assessment results may be synthesized to facilitate comparison of environmental performance across competing industrial systems.

A *Process-based LCA* begins by drawing *system boundaries* defining specific industrial processes to be included for the industrial system under study (e.g., ethylene production for input to the manufacture of the styrene-butadiene bonding agent for stucco walls). Since some of these "unit" processes involve additional, subsidiary unit processes, process-based LCAs follow system boundary-setting rules based on the magnitude of mass and energy contributions to the system from subsidiary unit processes. While compiling inventory flows for numerous industrial processes requires extensive, detailed data collection, the unit process-based compilation permits analysis of virtually any building product, component, or system imaginable. For this reason, the process-based LCA can be thought of as a “bottom-up” approach.

By contrast, the *Input-Output (IO)-based LCA* approach is a “top-down” approach which has its origins in macroeconomics. To assess the practical issues faced by governments and firms, economists have translated general equilibrium analysis for a competitive economy into a functional form. Economic IO Analysis recognizes and characterizes the interdependence of different economic sectors, and represents that interdependence by national IO tables quantifying, in monetary terms, inter-industry exchanges of goods and services throughout industrial supply chains. In other words, IO Analysis provides a macro-level view that includes secondary, and even tertiary-level, effects of consumer and producer spending decisions.

In the early 1990s, industrial ecologists began extending the IO Analysis approach. They developed physical IO tables corresponding to the existing monetary IO tables that tracked environmental inputs and releases among industrial sectors. By so doing, this tracking permits environmental inventory compilation following the “metabolic structure” of an economy. While IO-based LCA provides a straightforward and logical framework for inter-industry analysis of economic and environmental exchanges, its level of resolution is limited by the specificity of industrial categories in national IO tables. The North American Industry Classification System (NAICS) used by the U.S. Bureau of Economic Analysis to develop U.S. economic IO tables, for example, distinguishes fewer than 1,000 industries and commodities. Furthermore, IO tables are static in the sense that they represent current technology mixes and industrial practices. Thus, while IO-based LCA has a reasonable level of breadth, it is lacking in specificity and flexibility.

The respective strengths of the “bottom-up”, process-based LCA and “top-down” IO-based LCA complement one another’s weaknesses. While IO tables do not provide a level of resolution permitting analyses of new technologies, their breadth readily provides baseline inventory data representing complex industrial systems, such as buildings.

NIST has developed a new “hybrid” approach for analyzing the environmental performance of alternative building designs. By drawing on the specificity of the process-based approach and the comprehensive accounting framework of the IO approach, a meaningful comparison of traditional and alternative building designs can be made; one that systematically and scientifically compares life-cycle environmental performance at the building scale.

1.2.2 Economic Performance Measurement

Measuring the economic performance of buildings is more straightforward than measuring environmental performance. Published economic performance data are readily available, and there are well-established standard methods for conducting economic performance evaluations. The most appropriate method for measuring the economic performance of buildings is the life-cycle cost (LCC) method, standardized for building investment analyses by ASTM, International (ASTM, 2005a).

Economic performance is evaluated over a fixed period (known as the study period) that begins with the design of the building and ends at some point in the future. For a private investor, its length is set at the period of product or facility ownership. For society as a whole, the study period length is often set at about 25 years. While many buildings have much longer lives, a shorter study period is selected because technological obsolescence becomes an issue, future data become too uncertain, and the farther in the future, the less important the costs.

The LCC method sums over the study period all relevant costs associated with a building. Alternative designs for the same building can then be compared on the basis of their LCCs to determine which is the least cost means of fulfilling the building function over the study period. Categories of cost typically include costs for purchase, installation, operation, maintenance, repair, and replacement.

The LCC method accounts for the time value of money by using a discount rate to convert all future costs to their equivalent present value. Discounting accounts for the time value of money stemming from both inflation and the real earning power of money over time.

1.2.3 Business Case Measurement

By combining a building design’s life-cycle costs with its hybrid LCA performance measures, eco-efficiency metrics can be developed based on comparisons of alternate designs. The design alternatives will include both traditional and so-called “green” alternatives, resulting in eco-efficiency metrics that can be used to assess the “business case” for sustainable building.

2. Performance-Based Sustainable Building Metrics: A BusiBEES case study

The NIST technique is illustrated through a "BusiBEES" case study — a "Busi"ness case extension of the popular NIST process-based LCA/LCC tool known as Building for Environmental and Economic Sustainability (BEES) (Lippatt, 2005). The BusiBEES case study evaluates a tall commercial building with and without energy-saving technologies. Based on current U.S. industry practice, the following prototypical design is used to represent the baseline, "business as usual," tall building (RS Means, 2005):

- 20-story office building
- 3 m (10 ft) story height
- 43,000 m^2 (468,000 ft^2) of floor area
- 187 m (612 ft) perimeter
- steel frame
- double glazed, heat absorbing, tinted plate glass panel exterior walls
- heating, ventilation, air conditioning (HVAC) energy supply: oil fired hot water
- HVAC cooling generating system: chilled water, fan coil units
- HVAC energy intensity (EIA, 2003):
    - 290 MJ/m^2/y (25.6 kBtu/ft^2/yr)
    - 840 MJ/m^2/yr (74.4 kBtu/ft^2/yr)

The Missing Inventory Estimation Tool (MIET), version 3.0, is used to apply the IO LCA approach to develop inventory data for the baseline building (CML, 2004). Based on U.S. IO tables, MIET requires as input the dollar value of an industrial sector's economic activity, and reports as output an inventory of resulting environmental flows throughout the U.S. economy. Two industry sectors are of interest for the BusiBEES case study: (1) New office, industrial and commercial buildings construction (U.S. Bureau of Economic Analysis Input-Output Industry Code 110800) and (2) "Refrigeration and heating equipment" (BEA Input-Output Industry Code 520300).

The following published costs for construction of the baseline building, and for purchase and installation of its heating and cooling system, are applied respectively to the two industrial sectors (RS Means, 2005):

- Building Construction: $43,531,500
- HVAC Installation: $8,664,500

The IO-based life cycle inventory quantifies environmental flows from the materials production life-cycle stages (raw materials acquisition, manufacture, and transportation) and from the construction process. In other words, the IO inventory can be said to represent the baseline building's life-cycle flows from "cradle to site."

Next, the NIST Building for Environmental and Economic Sustainability (BEES) tool, which employs a process-based LCA approach, is used to compile inventories for the following four energy technology scenarios (Lippiatt, 2007):

- Conventional heating and cooling technology (represented by the baseline building)
- 30 % energy-saving HVAC technology, at a cost of $10.4 million ($10.4M)
- 50 % energy-saving HVAC technology, at a cost of $13.0M
- 100 % energy-saving HVAC technology (i.e. "net-zero energy" building), at a cost of $ 26.0M

For lack of reliable data, cost premiums for purchase and installation of the 30 %, 50 %, and 100 % energy-saving technologies—20 %, 50 %, and 200 %, respectively—are purely hypothetical. For the same reason, each energy-saving technology is assumed to be a higher-efficiency application of the same technology, installed in the baseline building with relatively minor changes to the overall design. While this assumption may be realistic, at least at the 30 % and 50 % energy savings levels, note that the BusiBEES approach permits refinement of these data. Indeed, NIST is in the process of developing additional data and case studies permitting development of these and other interesting scenarios. Otherwise, the BusiBEES case study uses current U.S. average data. Table 1 reports annual heating and cooling energy consumption and costs for the four case study energy technologies, based on U.S. average energy data for the baseline building design (EIA, 2003; Rushing et al. 2007).

The construction-to-site, IO-based life-cycle inventory is combined with each BEES inventory representing design-specific operational energy flows. Applying the BEES impact metrics to the hybrid inventory for each design in the second LCA step, impact assessment, permits calculation of life-cycle environmental performance for each building design.

Table 1 Annual energy consumption and costs for BusiBEES case study building design alternatives

Units	Base Case	30 % Energy Savings	50 % Energy Savings	100 % Energy Savings
MBtu/yr (MJ/yr)	4.68E+04 (4.94E+07)	3.27E+04 (3.45E+07)	2.34E+04 (2.47E+07)	0.00E+00 (0.00E+00)
$M/yr	1.22	0.86	0.61	0.00

Considering operational energy use over a 50-year study period, BEES life-cycle environmental performance results are summarized in figure 1. The figure displays weighted environmental impact category scores and their sum, the environmental performance score. The weights are based on those developed by a BEES stakeholder panel, and assign a relative importance weight of 29 % to global warming (Gloria et al., 2007). The results for each environmental impact—expressed in terms of the reference flow corresponding to the impact (e.g., carbon dioxide-equivalents for global warming)—have been placed on the same scale by dividing by total reference flows for that impact from all U.S. economic activity on an annual, per-capita basis.

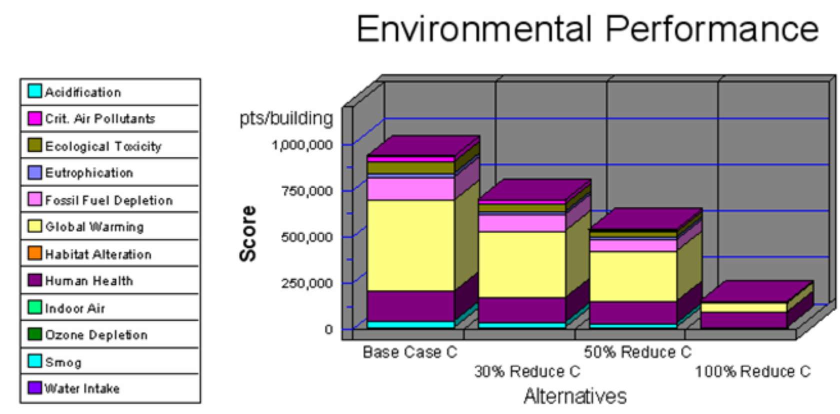


Figure 1 Life-cycle environmental performance for alternative tall building designs over 50 years

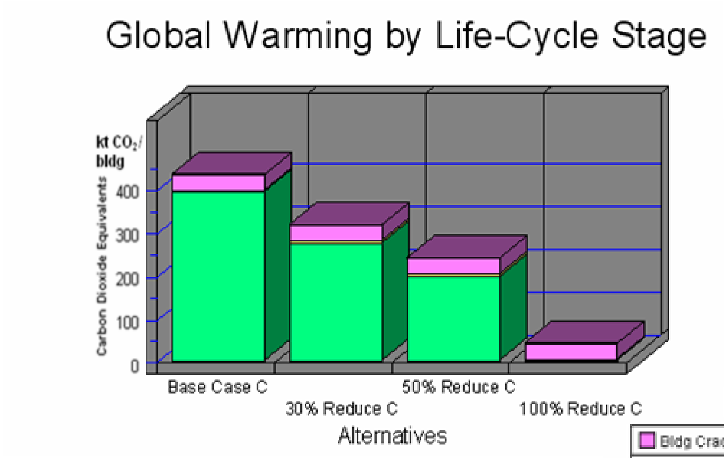
Buildings with lower BEES scores are greener. Over 50 years, the baseline design contributes about 900,000 times as much as each American contributes annually to U.S. environmental impacts, while the 50 % energy-saving design contributes about 500,000 times as much, yielding a reduction of 45 %.

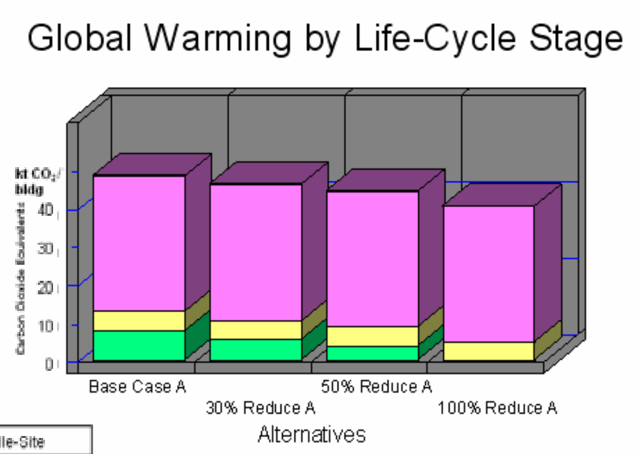
These BusiBEES case study results show a close relationship between environmental performance and operational energy savings. The explanation is straightforward: The cradle-to-site, IO-based LCA results for raw material acquisition, manufacturing, transportation, and construction of all four building designs—which are assumed similar in all respects except HVAC technology efficiency—drive a fixed amount of the BusiBEES Environmental Performance Score, leaving the rest for operational energy performance over 50 years. Given that each HVAC design uses the same fuel type, it stands to reason that environmental performance savings on a Btu-by-Btu basis (MJ-to-MJ basis) would not change, leading to building scale savings that are closely related to the efficiency improvement.

Figure 1 indicates that global warming constitutes the largest share of the BusiBEES Environmental Performance Score, which prompts further analysis in this case study. As shown in figure 2, the global warming impact from operational energy use over 50 years is a decreasing proportion of the life-cycle global warming impact as energy efficiency improves. The combined impact from building materials production and building construction (labeled “Bldg Cradle-Site”) constitutes the rest of the global warming impact. The global warming impact from *production* of the HVAC system alone is negligible.

By contrast, the relative global warming impacts for the four case study building designs, adjusted downward to reflect just *one year* of operational energy use, are quite different. Figure 3 clearly demonstrates the importance of the time horizon in the context of green building: the shorter the time period, the less important are future energy savings.

The same can be said for life-cycle economic performance, as shown in figures 4 and 5. While construction costs (i.e., First Costs) for the four case study buildings dominate life-cycle costs when considered over just 1 year of building operation, operational energy costs (i.e., Future Costs) become an important share of life-cycle costs over 50 years of operation. Based on a 3 % real discount rate, U.S. Department of Energy energy price projections, and LCC calculation methods prescribed by ASTM, International (ASTM, 2005a), 50-year operational energy costs range from $0M (net-zero building) to $97.8M in present value (PV) terms for the four building designs.





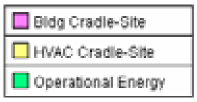
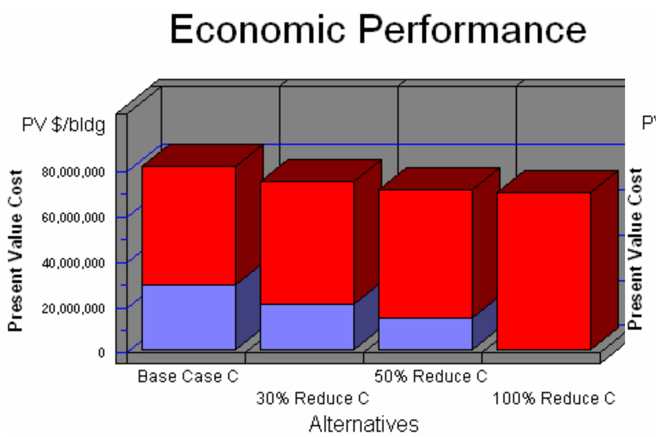


Figure 2 Global Warming impact over 50 years of building operation

Figure 3 Global Warming impact over 1 year of building operation



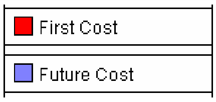


Figure 4 Life-Cycle Costs over 50 years of building operation.

Figure 5 Life-Cycle Costs over 1 year of building operation.

With estimates of life-cycle environmental and economic performance in hand, a rigorous metric quantifying business cases for the energy-saving designs may be developed. Since the global warming impact dominated all others in the BusiBEES case study, a carbon-based metric would be particularly meaningful. The metric, a "carbon efficiency ratio", indicates the change in life-cycle costs per metric ton of carbon saved.

As shown in Table 2, the carbon efficiency ratio ranges from a $1,580/t cost increase for the 100 % energy saving option, over just 1 year, to a $60/t cost savings for the 30 % option over a 50-year time horizon. Ratios for the two time horizons are shown to illustrate the importance of this parameter to investment decisions; when making actual investment decisions, the time horizon will be fixed. For a private investor, its length is set at the period of building ownership. For society as a whole, the time horizon is often set at the useful life of the longest-lived design alternative. However, when alternatives have very long lives, (e.g., more than 50 years), a shorter study period may be selected for three reasons: technological obsolescence becomes an issue, data become too uncertain, and the farther in the future, the less important the costs.

In accordance with ASTM, International E1185 (ASTM, 2005b) guidance, BusiBEES Carbon Efficiency Ratios are computed in a pairwise fashion. First the ratio for the lowest incremental cost alternative is evaluated with reference to the base case design alternative. If its Carbon Efficiency

Ratio is greater than 1.0, then the alternative is preferred on economic grounds and it becomes the base case design alternative against which the next-most expensive design alternative is evaluated. Based on this guidance, the ratio for the 100 % energy saving design alternative over 50 years is computed with reference to the 50 %, 50-year alternative.

Table 2 BusiBEES case study savings and carbon efficiency ratios, by time horizon

Time Horizon	Building Design Alternative	Incremental Life-Cycle Cost Savings ($PV)	Incremental Carbon Savings (t)	Incremental Carbon Efficiency Ratio (=$PV/t)
1 year	30 % energy savings	-1,380,000	2,300	-590
	50 % energy savings	-2,360,000	3,900	-600
	100 % energy savings	-12,410,000	7,800	-1,580
50 years	30 % energy savings	6,990,000	117,500	60
	50 % energy savings	3,220,000	78,300	40
	100 % energy savings	1,550,000	195,800	10

3. Carbon Footprint Metrics

The carbon efficiency ratio developed in the BusiBEES case study is a life-cycle carbon footprint metric. The carbon footprint of a building is the total amount of greenhouse gases produced directly and indirectly through its construction and operation, and is usually expressed in equivalent tons of carbon dioxide (CO_2). The carbon footprint of long-lived structures, such as tall buildings which require extensive operational energy use, can be significant as demonstrated in the case study.

The 2006 *Stern Review* on the Economics of Climate Change recognizes that while markets tend to deliver least-cost, carbon-inefficient short-term options, they may ignore technologies that could ultimately deliver huge carbon savings in the long term. As the BusiBEES case study demonstrated, there may be alternatives with positive BusiBEES Carbon Efficiency Ratios—those both financially superior *and* with reduced carbon footprints in comparison with conventional designs when considered over the long term. Furthermore, should carbon trading markets become widespread, even alternatives with negative ratios may become cost effective when the carbon market trades at prices above the alternative's incremental life cycle cost. Finally, designing buildings to low and even zero-carbon footprint standards on a large scale is likely to result in economies of scale that bring to competitive levels the investment costs for technologies and innovation which help to drive down existing levels of atmospheric carbon.

4. Conclusion

The carbon efficiency metric described in this paper is a meaningful business indicator for investments in reduced carbon-intensive building products, components, and systems. The value of the carbon efficiency ratio lies in its use as a metric for designing and sizing *cost-effective sustainable building investments*, particularly those for energy-saving technologies. While the most cost-effective choice is not necessarily the investment alternative saving the most life-cycle carbon, the ratio can be used to motivate investment toward measurable carbon reductions. The higher the ratio, the greater the financial gain per ton of carbon saved.

For investments geared toward less obvious environmental improvements, such as from building material selection and other major design decisions, global warming will likely not dominate all other life-cycle environmental impacts. In these cases—when cradle-to-site processes are the primary drivers for environmental performance—an overall "eco-efficiency" metric should be used as the decision criterion. BEES Environmental Performance Scores may be readily substituted for carbon savings in the ratio denominator, resulting in a measure of dollars saved per unit improvement in life-cycle environmental performance.

NIST is currently applying the BusiBEES protocol to about a dozen additional prototypical building types in the commercial and residential building sectors, as well as refining and developing additional data and case studies permitting variation of BusiBEES parameters that were fixed in this case study. These parameters include important variables such as fuel types for technology alternatives and U.S.

climate region-specific energy loads and costs. An effort also is underway to better harmonize the MIET and BEES life cycle inventory databases.

The NIST BusiBEES approach combines a hybrid LCA performance metric with standard measures of economic worth. It enables calculation of carbon- and eco-efficiency ratios comparing the business value of alternative sustainable building investments. Building industry decision makers routinely make investment decisions with potentially significant impacts on the environment. By supporting their decisions with life-cycle, science based metrics, represented by a single value expressed in the monetary terms they are accustomed to using, they can better allocate scarce global and financial resources to investments having reduced long-term negative consequences on our environment.

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LIFE CYCLE INVENTORY OF FOREST PRODUCTS

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Summary

CSIRO in collaboration with the FWPA (Forest and Wood Products Association) is developing a life cycle inventory (LCI) of Australian timber products. This LCI will be used to quantify inputs and emissions of alternative building materials and conduct life cycle analyses on their impacts on the environment, resources and human health.

The basis of the timber LCI is the forestry production process. Forestry covers the growing and management of forests, harvesting of trees and transportation of logs to processing facilities. Since this forms the basis of LCIs for all downstream timber products, it is important to ensure the appropriate methodology is used and that the data collected is representative and accurate. Forestry is a unique process in that a) the time periods between management inputs and wood product outputs are relatively long (eg. rotation lengths for sawlog production typically span 25-160 years), b) activities usually occur over large land areas, and c) it involves a variety of inputs and outputs which may impact other land uses not directly related to wood production (eg. water supply, biodiversity management, road construction, fire control etc.). Thus, there is a challenge to obtain robust, generalized LCI data for forest production systems.

The research focussed on seven forestry case studies Australia-wide – three native forest hardwood systems and four plantation softwood studies – to understand variations in stand management and productivity, harvesting methods and transport distances. Within each region, all inputs (fuel, consumables, machinery etc.) and outputs (emissions and wood products) across the entire forest estate were quantified and apportioned across the range of products produced, assuming that the forest was in a steady state.

The study has provided the first comprehensive dataset for inputs and emissions for key forest systems in Australia. This paper discusses the methodology applied in this project, some preliminary results and their implications for the LCIs for timber products.

1. Introduction

1.1 Background

Although there have been a number of studies accounting for GHG (greenhouse gas) emissions from forestry operations overseas (eg. Berg and Lindholm 2005; Schwaiger and Zimmer 2001; Seppala et al 1998; Sonne 2006), few have accounted for use of water, land, and materials used in forest growth and management. This is the first comprehensive LCI study undertaken in Australia on softwood plantations or hardwood native forests. The significance of this study is that all environmental impacts from growing, harvesting and transporting wood to sawmills and other processing facilities are addressed, providing an objective overview of log production in terms of their environmental profiles. It forms part of a larger study, funded by CSIRO and FWPA, which will produce a complete life cycle inventory of representative wood products produced from Australian forests and used in the construction industry. The forest production stages reported in this paper cover the growth, management, harvest and transport of forest products to processing facilities and include all direct and indirect energy, materials and emissions associated with these processes. This paper discusses the methodology applied in this project, some preliminary results and their implications for the LCIs for timber products.

1.2 Industry overview

The timber industry in Australia is primarily based on a mixture of native hardwood regrowth forests and softwood plantations. The primary areas of native forest that continue to be harvested are located in Tasmania, Victoria, NSW and south-west WA. These include a wide range of eucalypt species and cover 11.4 million ha; ABARE 2007), although only a small proportion of this is available for harvest. Softwood plantations have been established in all states and cover an area of just under 1 million ha (ABARE 2007). *Pinus radiata* (radiata pine) is the predominant species planted across southern Australia, while *P. caribaea*

(Caribbean pine), *P. elliottii* (slash pine) and their hybrids are planted in Queensland. Smaller areas of *P. pinaster* (maritime pine) in Western Australia, and native *Araucaria cunninghamii* (hoop pine) in Queensland, are also grown. Hardwood plantations have been established across all states in the past 10-15 years and now cover 740,000 ha (ABARE 2007). However, these are primarily being grown for woodchip production and thus are not included in this forestry and wood products LCI.

The average volume of logs (including sawlogs and pulplogs) harvested from 2001-07 was 26.2 million m^3 with 36% from native forests and 54% from softwood plantations (ABARE 2007). The average gross value of annual forest production was $1.6 billion including $599 million (38%) from hardwood native forest and $790 million (50%) from softwood plantations (ABARE 2007). On average, 35% of the production from native forests is saw and veneer logs, 63% is pulpwood and 2% other products. In contrast, 63% of the production from softwood plantations is saw and veneer logs, 34% is pulpwood and 3% other products.

1.3 Scope of this study

The focus of this study is the seed to sawmill LCI of wood production from native hardwood forests and softwood plantations. The primary information used in this report incorporated site-specific data collected from seven Australian case study regions (three hardwood and four softwood) primarily using surveys. Surveys were specifically targeted at forest growers, forest managers, harvesting and haulage contractors. The data have been collected using records spanning from 2002–2007. Secondary data for inputs and emissions associated with forest growth and management was obtained from relevant literature where this was not available from managers and contractors. Data for CO_2 and other emissions from upstream processes (eg. production and transport of energy, fuels and fertilisers) was sourced from LCI forestry and wood products SimaPro database.

A key component of all LCIs is the recording of the source of raw data and the processes used to derive final results. This study adheres to the ISO 14040 guidelines (ISO 2002) and the broader LCI Project's Quality Assurance (QA) requirements.

The benefits of this study include:

- Providing a benchmark average for forests to which will allow consistent comparisons of the environmental impacts of forestry and wood products with other land-uses and materials.
- Allowing foresters to provide verified environmental information. For example, assisting the forestry industry to better understand its processes from a life cycle perspective.

2. Methodology

2.1 Case studies

This study used a case study approach to cover the variation in stand management and productivity, harvesting methods and transport distances in Australian forestry. The studies included:

- Radiata pine plantations in the Tumut/Tumbarumba region of NSW;
- Radiata pine plantations in the Green Triangle border region of South Australia / Victoria;
- Radiata and maritime pine plantations in south-west WA
- Slash/Caribbean pine plantations in the Fraser Coast region of south-east Queensland;
- Regrowth native forests in the north coast of NSW;
- Regrowth native forests in the Central Highlands of Victoria;
- (Largely) regrowth native forests in south-west Tasmania.

2.2 Forest production processes

The production process for both softwood plantations and hardwood native forests include the following common operations:

- Seed or seedling production: collection and processing of seeds (native forests) or planting and growing seedlings and cuttings (plantations);
- Establishment: burning of harvest residues and or mechanical cultivation followed by planting (plantations) or aerial seeding (native forest under clearfell systems);
- Chemical application: application of fertiliser, herbicide or insecticide (plantations only);
- Fire protection and control: fuel reduction burning, fire surveillance and control;
- Road construction and maintenance;
- Harvest: thinning (plantations) and clearfelling or selective harvest (some native forests) of stands;
- Haulage: transport of different products from forest to processing facilities.

These operations and associated inputs and emissions during a forest rotation (period from planting to final harvest) are illustrated in Figure 1.

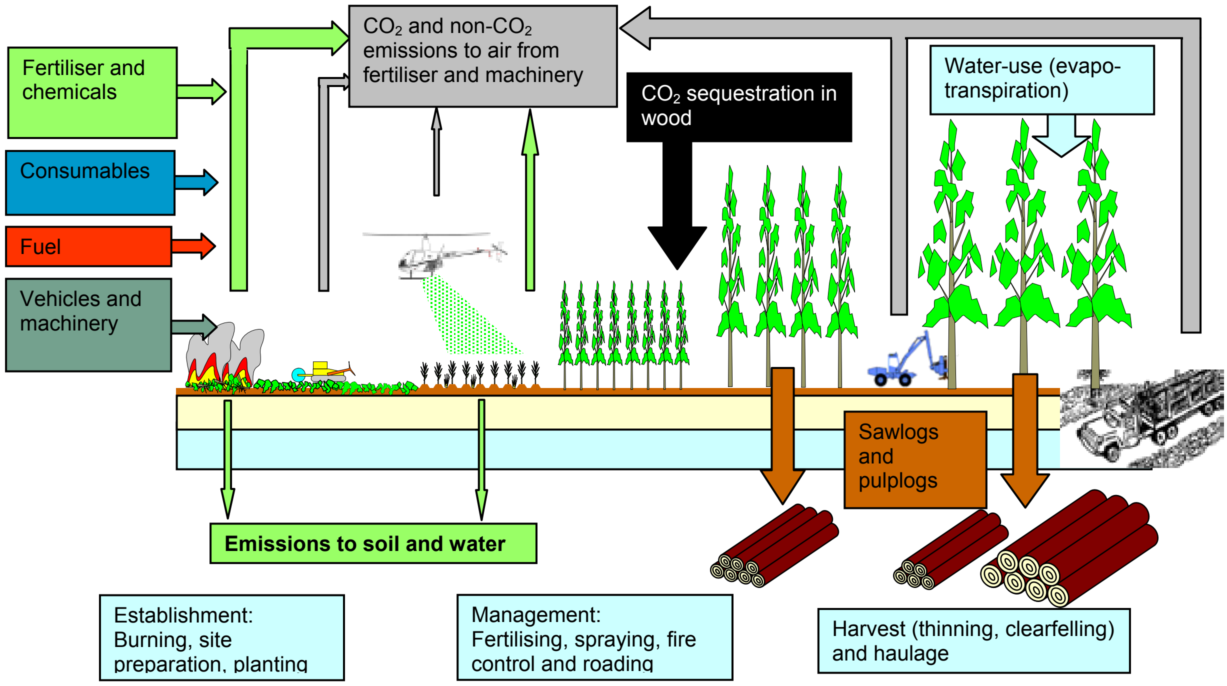

Figure 1: Example of a typical plantation softwood production system showing the inputs and emissions from the various processes. The production system for native forests is similar except there is generally no chemical application or thinning.

2.3 Reference unit

All inputs and emissions were expressed in terms of 1 m^3 of wood production to allow comparisons of the relative contributions of different processes to total inputs or emissions. Within individual operations, the reference unit was the relevant unit for the particular operation, e.g. for seedling production the reference unit was 1 million seedlings, and for forest management and fire control it was 1 ha of total forest area.

2.4 Forest products

The primary products from softwood plantations are sawlogs and pulplogs. However, native forests (and, to a lesser extent, softwood plantations) are managed for a wide range of products and services including wood production, water supply, biodiversity and recreation. This multiple use of native forests creates a problem for LCIs because most of these additional products are difficult to value in economic terms. For this study, it was assumed that wood was the primary product of both native forests and plantations, but that the results should be interpreted with regard to both wood and non-wood products.

Forest wood product classifications vary widely, both within and between different forest regions depending on the requirements of the local processing industry, as well as forest management objectives (James 2001). For this study, softwood product classes were based on those used in the Australian Pine Log Price Index (KPMG 2007), while hardwood products were classified according common categories across the different case study regions (Table 1).

Table 1 List of products covered in the softwood plantation and native forest hardwood case studies.

Softwood Plantation Products	Hardwood Native Forests Products
Large Sawlog/veneer log (< 44 cm)	Veneer log
Medium Sawlog (24-44 cm)	High quality sawlog
Small Sawlog (<24 cm)	Low quality sawlog
Pulplog	Pulplog
Other log	Other log

2.5 Assumptions

2.5.1 Allocation to products

Wood was assumed to be the only product of economic value from native forests and plantations. Other products including biodiversity, water, carbon storage, recreation and landscape value were noted as being important both in terms of the intrinsic value of forests as well as their influence on management operations especially for native forests but these were not included.

2.5.2 Steady state

A key assumption was that the forest system is in a steady state both with respect to carbon in pools of debris and to management operations (i.e. there is no change in land use or management systems over time). This avoided complications caused due to changes in soil carbon associated with conversion of previously unharvested forest or agricultural land to plantation or forest managed for wood production. It also avoided including inputs and emissions associated with expansion of the forest estate as the additional wood produced from this land would only be harvested some years in the future. Thus, where possible, only second rotation or regrowth forest was considered in the study. In some cases (eg. thinning or general management operations), it was not possible to separate activities on first rotation from later rotation stands, while for native forests in SW Tasmania a small proportion of old growth stands were included.

2.5.3 CO_2 emissions from burning and decomposition

A complex approach to CO_2 emissions would involve detailed accounting of decomposition and carbon turnover. However, existing data indicate that there is little change in soil carbon in forests that are at steady state. Thus, for this project, a conservative approach was been taken regarding soil carbon whereby any inputs from litterfall and root turnover were assumed to be converted back to CO_2 (i.e. have no effect on net CO_2 emissions). Further, because it is assumed that the forest carbon balance is in steady state, the CO_2 emissions from fuel reduction burns and post-harvest burning of slash can be ignored. Emissions from fire suppression efforts (e.g. tankers, aircraft, etc.) were included, but those from wildfire were not.

2.5.4 Non-CO_2 greenhouse gas emissions

Non-CO_2 GHGs, include nitrous oxide (N_2O), other nitrogen oxides (known as NO_x), carbon monoxide (CO) and methane (CH_4), can impact on global warming either directly (as in the case of CH_4 and N_2O) or indirectly (as in the case of NO_x). The impact of direct GHGs on global warming are indicated by emission factors which show their effective equivalent in terms of amount of CO_2 (IPCC 2006). Non-CO_2 GHGs from native forests and plantations include those arising from burning of slash and forest debris, application of fertiliser, burning of fossil fuels, tree growth and decomposition of forest debris. Emissions from burning were estimated from the amount of material burnt and emission factors published by the IPCC (IPCC 2006). Emissions of N_2O from fertiliser were based on rates of N_2O production per unit N fertiliser applied (IPCC 2006). Emissions from normal decomposition, growth and wildfires were assumed to be zero.

2.5.5 Emissions from herbicides, pesticides and fertiliser

As a result of the stringent controls placed on pesticide and herbicide use in forestry operations, emissions to air and water were assumed to be minimal (Jenkin and Tompkins 2006). However, amounts of herbicides, pesticides and fertilisers applied in nursery and plantation operations were included. Emissions from fertiliser to air covered in this study include NH_3 and N_2O. Emissions of NH_3 arise from urea volatilisation and amounts (in terms of N) are assumed to average 30% of the applied N in urea (May and Carlyle 2005). Emissions of N_2O are assumed to average 1% of applied N (IPCC 2006).

2.5.6 Water use

Water use by the total forest estate was estimated from a relationship between total rainfall and evaporation for forests developed by Zhang (2001) and allocated to harvested wood products. These estimates were validated with actual measurements of rainfall and catchment water yield for forested catchments (Benyon et al. 2006; Bubb and Croton 2002; Brown et al. 2005; Cornish and Vertessy 2001).

2.5.7 CO_2 sequestration in wood

Total CO_2 sequestration in this study was defined as the CO_2 sequestered by the tree to produce the biomass removed as wood products from the forest. This was estimated from average basic densities (sourced from Ilic et al. 2000) for the species (or species mix) relevant to each case study with an assumed carbon content of 50%. Net CO_2-e (CO_2 equivalent) sequestration was defined as the total CO_2 sequestration minus the total GHG emissions either directly or indirectly associated with forestry.

2.5.8 Wood price

For economic allocation of inputs and emissions to products and co-products it is necessary to know the relative prices as well as volumes of the various products from the system (in this case logs). Softwood log prices were based on average values published in the Australian pine log price index (KPMG 2007). For native forests, both mill door and stumpage values for logs were provided by forest growers.

2.6 Data collection

Most data were collected directly from forest owners and harvest contractors by means of surveys and interviews. It was important to define the scope of each case study spatially (the area that was covered), temporally (the time period included), as well as physically (the start and finish of the process). The spatial extent of the plantation study was based on the extent of the forest region as defined by the owner or manager. The temporal scope consisted of data collected from 2002-07. One difficulty was that data needed to be obtained from a sufficient sample of the numerous operators especially for softwood plantations. These are often small family owned businesses which lack the time and resources to provide the detailed information required by an LCI study. To reduce the time needed to compile the sometimes complex information a reference year of 2005-06 was selected for the data.

2.7 Calculations

In forestry, a large proportion of operations are undertaken by external contractors. Typically, for softwood plantations, roading, site establishment, planting, fertiliser and herbicide application, aerial surveillance and fire control, harvesting and haulage are all undertaken by individual contractors that may vary from single operator businesses to large companies. In native forests, harvesting and haulage are usually the main contracted operations.

A representative sample of contractors was selected from each case study region and information on machinery usage, production rates and fuel consumption was collected from each contractor. Average usage and fuel consumption rates were then calculated for each operation for each forest owner. Averages across the case studies for each operation were weighted on the basis of total production for each region.

2.8 Allocation method

Allocation was based on the economic value of each of the products. Thus, all forest inputs up to and including harvest were assumed to be for the combined production of all forest products, inputs associated with these activities were distributed across products according to their weighted average unit value ($ m^{-3}). Allocation of inputs and emissions excluding CO_2 sequestration was based on the total value of production of each product. Thus, high value products (such as veneer logs or large sawlogs) were allocated a larger proportion of inputs than low values products (such as pulplogs). CO_2 sequestration was allocated on a volume basis because the carbon sequestered is a physical part of the wood. Inputs and emissions associated with processes subsequent to harvest (i.e. chipping and haulage) were allocated to individual products with which they were associated. Thus, 100% of inputs and emissions associated with chip production were allocated to woodchips.

3. Preliminary Results

3.1 Survey coverage

The seven case studies covered approximately 50% of the average wood production from softwood plantations (2002-07) and 22% of the average wood production from hardwood native forests. Coverage of forest operations included 10 forest owners or managers, 18 harvesting contractors, 18 haulage contractors, five site preparation contractors, three aerial spraying companies two roading contractors, and two fire control agencies. Average coverage for these operations within the case studies varied from about 30% for native forests harvesting operations to 80% for seedling production for softwood plantations.

3.2 Inputs

3.2.1 Land

Land use efficiency as estimated from the total annual volume harvested divide by the total softwood plantation area varied from 10 to 20 m^3 ha^{-1} y^{-1} and averaged 17 m^3 ha^{-1} y^{-1}. .Land use efficiencies for hardwood native forests ranged from 1 to 9 m^3 ha^{-1} y^{-1}. The lower land-use efficiency, in terms of wood production, for native forests is a direct result of lower management intensity (eg. longer rotation lengths, no fertiliser or pesticide use) due to the multiple benefits for which native forests are managed (eg. biodiversity, water, recreation).

3.2.2 Water

Estimated total evapo-transpiration for forests relative to pasture (assumed to represent baseline water use) expressed in terms of total harvested product removal ranged from 0.07 to 0.23 ML m^{-3} (average 0.13 Ml m^{-3}) for softwood plantations and from 0.4 to 2.7 Ml m^{-3} (average 0.9 Ml m^{-3}) for hardwood native forests. The greater water use per unit of wood harvested from native forests is due to several factors: firstly, the lower management intensity in native forests results in lower growth rates and therefore lower production per unit water used compared with plantations; secondly, the native forests covered by the study were all located in high rainfall environments and water use generally increases with increasing availability of water (Zhang et al. 2001); and thirdly, the recovery of harvested product tends to be lower in native forests than in plantations as a result of a greater proportion of defective or unsuitable material, especially where there are limited markets for pulpwood. Importantly, because native forests are managed for multiple benefits, the impact of wood production on water yield (in terms of Ml ha^{-1} used by the forest) is lower than if they were managed to simply maximise wood production as with plantations.

These results should be viewed as indicative only, as the relationship on which they are based use data from forests in equilibrium (Zhang et al. 2001). In reality, evapo-transpiration varies with stand age (due to changes in leaf area) and management (thinning, time between harvesting and replanting etc.). Furthermore, while pasture may be an appropriate land-use with which to compare plantation water use, it is probably not so for native forest. However, data for a more appropriate comparison, unharvested native forest, is lacking.

3.2.3 Fuel and energy

Virtually all direct energy use was a result of diesel combustion in vehicles and machinery. Total fuel use in management, harvest and haulage of softwood plantations was 4.5 L m^{-3} (174 MJ m^{-3}) and for native hardwood forest was 8.7 L m^{-3} or 334 MJ m^{-3}. The greater fuel and energy use in the native hardwood forests per unit wood harvested was largely a result of differences in fuel use for haulage (3.3 L m^{-3} vs. 2.1 L m^{-3}) and harvest (4.4 L m^{-3} vs. 1.9 L m^{-3}). This was due to longer haulage distances, steeper terrain for harvesting machinery and lower harvestable volume per hectare in native forests compared with softwood plantations.

3.2.4 Chemicals

In softwood plantations a wide range of pesticides and fertiliser are applied either pre-or post planting or, for fertilisers only, near canopy closure or after thinning. The most commonly used herbicides included: atrazine (6.2 g m^{-3}), glyphosate (3.7 g m^{-3}), simazine (3.1 g m^{-3}) and hexazinone (2.2 g m^{-3}). Major fertilisers included triple superphosphate (0.83 kg m^{-3}), ammonium sulphate (0.54 kg m^{-3}), urea (0.36 kg m^{-3}) and potassium sulphate (0.11 kg m^{-3}). The amounts applied were equivalent to 0.29 kg N m^{-3}, 0.20 kg P m^{-3} and 0.06 kg K m^{-3}. Pesticides or fertilisers were not used in the native hardwood forest case studies.

3.3 CO_2 sequestration

Estimated CO_2 sequestered in softwood products ranged from 810 kg m^{-3} to 860 kg m^{-3}, depending on the average density for different species, and averaged 830 kg m^{-3}. For products from native hardwood forests, the amount of sequestered CO_2 ranged from 1,000 to 1,300 kg CO_2 m^{-3} and averaged 1030 kg CO_2 m^{-3}. Although basic density of wood varies with tree age and location up the stem (eg. butt versus top logs), it was assumed to be the same for different products due to lack of available data.

3.4 Emissions

Direct CO_2 emissions as a result of combustion of fossil fuel during vehicle and machine use in forest operations averaged 12 kg CO_2 m^{-3} for softwood plantations and 23 kg CO_2 m^{-3} for hardwood native forests. Direct non-CO_2 emissions including emissions of CH_4, N_2O and NO_x from slash or fuel reduction burning and N_2O and NH_3 emissions from nitrogen fertiliser application averaged 6 kg CO_2-e m^{-3} for softwood plantations and 36 kg CO_2-e m^{-3} for hardwood native forests. Thus, total direct CO_2-e emissions from softwood plantations averaged 18 kg m^{-3} compared with 59 kg m^{-3} for hardwood native forests. For softwood plantations, log haulage was the highest contributor to total CO_2-e emissions (32%), followed by harvest (29%), burning (23%) and nitrogen fertiliser (8%, Fig. 3a). For native hardwood forests, burning contributed 61%, harvest 20% and haulage 15% of the total CO_2-e emissions (Fig. 3b). The contribution of burning to total CO_2-e emissions varied considerably among case studies depending on the amount of slash left after harvest and whether fuel reduction burning was used as a fire management tool.

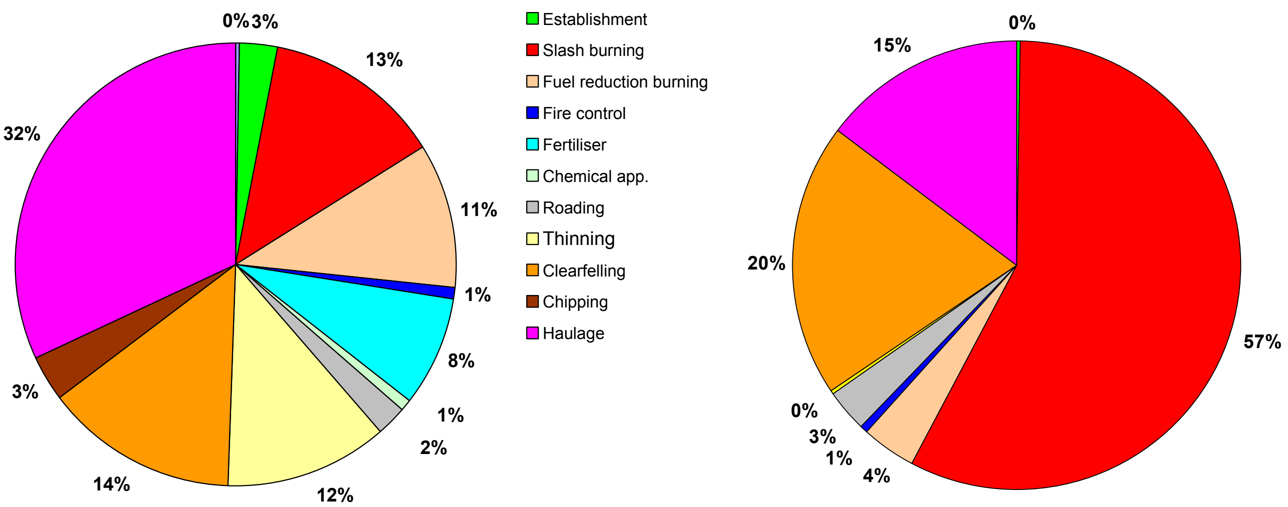

Figure 3: Contributions of different forest operations to total direct CO_2-e emissions for an average log from a) softwood plantations and b) hardwood native forests.

3.5 Direct plus indirect emissions

Indirect emissions include those from upstream processes used to obtain and process raw materials, produce and distribute fuel and energy, and manufacture machines and infrastructure. The SimaPro model was used to estimate total indirect plus direct emissions arising from wood production. This has LCIs for most upstream processes already developed for Australia and these were linked to our forestry LCI to provide a full forestry life cycle up to the point of delivery of products to downstream processing facilities.

Preliminary results for total direct plus indirect GHG emissions arising from growing, harvesting and hauling an average plantation softwood log were estimated to be about 23 kg CO_2-e m^{-3} (excluding the CO_2 sequestered from the atmosphere contained in the form of carbon in the log) compared with about 64 kg CO_2-e m^{-3} for an average native hardwood log.

In terms of allocation to individual softwood products, total emissions varied from 10 kg CO_2-e m^{-3} for pulplogs to 39 kg CO_2-e m^{-3} large sawlogs (Table 2). These represented between 1 and 5% of the total CO_2 sequestered in the logs. For hardwood products, there was wider variation in allocation of CO_2-e emissions as a result of the greater variation in product value. Emissions varied from 41 kg CO_2-e m^{-3} for pulplogs or 4% of the total CO_2-e sequestered to 330 kg CO_2-e m^{-3} for pulplogs or 25% of the total CO_2-e sequestered.

Thus, for both softwood and all but the highest value hardwood logs, total emissions of CO_2-e and other GHGs arising either directly or indirectly from production, harvest and transport of those logs represented only a small fraction (<12% for hardwood and <5% for softwood) of the amount of CO_2 sequestered and stored as carbon in the same logs (Table 2). If we convert these amounts to average rates per ha based on the land use efficiencies of the two forest types, these figures are equivalent to a net rate of CO_2 sequestration of 13.7 t ha^{-1} y^{-1} for products from softwood plantations and 5.5 t ha^{-1} y^{-1} for hardwood native forests. If we assume this is effectively permanently sequestered in wood products, then the total amount of emissions sequestered over 100 years would be equivalent to 1370 t CO_2-e ha^{-1} for softwood logs and 550 t CO_2-e ha^{-1} for hardwood logs in addition to the amount of CO_2-e sequestered in the standing forest biomass.

Table 2 Summary of SimaPro outputs for total (direct and indirect) CO_2-e emissions by product for softwood plantations and hardwood native forests. Values are averages across the three case studies.

Forest type and product		CO_2-e sequestered	Total CO_2-e emissions		Net CO_2-e sequestered	Growth rate	Net CO_2-e sequestration
		kg m^{-3}	kg m^{-3}	%	kg m^{-3}	m^3 ha^{-1} y^{-1}	t ha^{-1} y^{-1}
Softwood	Sawlog, large	812	39	4.8	773		
	Sawlog, medium	824	30	3.6	794		
	Sawlog, small	863	21	2.5	842		
	Pulplog	828	10	1.2	818		
	Woodchips	812	24	3.0	788		
	Other log	823	21	2.5	802		
	Average log	829	23	2.8	806	17.0	13.7
Hardwood	Veneer log	1227	170	13.8	1057		
	Sawlog, high quality	1050	123	11.7	927		
	Sawlog, low quality	1114	47	4.2	1067		
	Pulplog	1003	41	4.1	962		
	Other log	1301	330	25.3	971		
	Average log	1029	64	6.2	965	5.7	5.5

4. Knowledge gaps

This study revealed significant knowledge gaps in terms of the environmental loads and impacts of a variety of forestry-related activities in Australia. One of the most important of these is emissions of non-CO_2 GHGs from slash and fuel reduction burning. At present, data on the volume of residues left or burnt following harvest are not recorded, and non-CO_2 emissions from burning this material are based on international figures which have large uncertainties. Other major sources of GHG emissions which lack data include harvesting, haulage and fertiliser application. Additionally, further studies of CO_2 emissions from hardwood plantations, and harvest of old growth native forest, non-CO_2 emissions from burning, decomposition, fertiliser and pesticides, and impacts of plantations and native forest management on water availability are required.

5. Conclusions

This LCI study is the first of its kind for forestry in Australia. This work will allow consistent comparisons to be made between environmental impacts of forestry with those from other land uses. It also provides a means for identifying operations, such as slash burning, where relatively minor changes could lead to substantial reductions in these impacts. In terms of wood products, the study forms the basis for LCIs of wood product manufacturing processes, many of which have been developed as part of the overall project. These LCIs will be used to compare the potential impacts of wood products with those of other materials such as steel and concrete.

There is significant potential for forestry as a means of carbon sequestration, not just in the standing forest biomass, but also in the products removed. Net carbon sequestration potential of forest products ultimately depends on energy use, emissions and, product recovery in downstream processing, as well as their longevity and ultimate disposal. However, the results here show that CO_2-e emissions associated with the production and transport of saw and pulplogs represent only a small proportion of the total amount of sequestered CO_2 stored as carbon in those logs. If it is assumed that a large proportion of this carbon will remain in these products in the medium to long term, then sustainable harvest of wood products represents a means for substantial ongoing sequestration of CO_2 from forests. However, if, as is the current practice, this carbon is assumed to be lost after harvest, then much of the potential benefit of forestry as a potential carbon sink may remain unrealised.

6. Acknowledgements

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TITLE: APPLYING RATING TOOLS TO DEVELOP AN AUTONOMOUS HOUSE

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Autonomous = not subject to control from outside; independent; self-governing; existing and functioning as an independent organism; free from external control and constraint

Summary

Increasing awareness of climate change has heightened understanding that human behaviours have contributed to the situation; this has influenced an increased desire by some members of the community to reduce their individual impacts.

In our consultancy work, Sustainable Built Environments (SBE) has noted a marked increase in the number of home owners seeking to go beyond the regulatory requirements of the 5 Star standards by minimising, or negating, their reliance on traditional infrastructure, that is, to become autonomous.

To inform strategies and assess various options for how this can be approached, and achieved, there are simple to use, freely available tools that can be employed by building designers.

SBE will discuss these tools and how they can be used in the design process to optimise environmental outcomes. Three case studies will be presented to illustrate how tools can be used through the design process with an analysis of a post construction assessment of one of the dwellings.

1. Introduction

An autonomous house operates independently of any inputs other than those from its immediate environment. The concept of the Autonomous House was developed and championed by Brenda and Robert Vale as part of a philosophical shift resulting from the oil crisis or “doom debate” of 1972 – 73. The Vales extended the idea to include: self-sufficiency in food, using on-site materials for building, and reducing building services and technology to a level where they can be operated and maintained by the home-owner.

The recent drought in Australia has once again sharpened community concerns about water security and further highlighted the effects that climate change may have. As concern has grown, SBE has noticed a marked increase in the number of our clients wishing to go beyond 5-Star energy rating compliance, with many seeking to become autonomous in terms of water and energy use. As we have seen with the “green bag” phenomena, if society is presented with achievable actions to improve the environment, people are happy to embrace them.

SBE believes that the ultimate environmental design aim for our built environment is to create comfortable buildings that use no energy, no water, produce no waste in operation or construction, and are made of materials that are derived from fully sustainable sources. Whilst this is very difficult to achieve in practice, this aim acts as a theoretical lighthouse for the opportunities that should be considered in any project.

2. Process

The process to develop an autonomous house is the same as for most design projects, with the main difference being an iterative process of assessing various design options in order to optimise overall environmental performance. Simple and publicly available tools, such as energy modelling, STEPS and STORM, can be used through the design process to predict energy and water demands for the site. These tools provide the means by which various reduction strategies can be assessed, so that the most effective ones can be integrated into the project.

2.1 Briefing

From the outset of the project it is essential to have an understanding of the climate and micro-climate of the site (including extreme events), in order for the design to utilise the free attributes available such as solar heat gains and prevailing winds.

In formulating the performance requirements of the site it is also important to again an idea of the client's motivation for sustainability and their willingness to be involved in operating systems for the house. The level of involvement that the client is prepared to have with building systems will help to define what systems should be used and their potential success.

Also important is gaining an understanding of the client's architectural objectives, such as priority values, function, aesthetics, special experiences, financial constraints, use of building and occupancy patterns. These objectives must balance sustainable design with the client's expectations in terms of comfort and commitment to operate active or passive control systems. The level of involvement that the client is prepared to have with building systems will help to define what systems should be used and their potential success.

2.2 Sketch Design Stage

The early design stages of a project are the ideal time to investigate the affect that various options will have on the potential operational performance. The architectural design should respond to the climate and site analysis by integrating best practice passive solar design concepts where possible; these include window sizing and orientation, and shading. Optimising passive design elements will reduce the need for active systems to provide heating, cooling and ventilation.

Energy rating tools can be used to assess some of the passive design attributes and optimise the building fabric so that it responds to its environment appropriately, and the heating and cooling energy requirements are reduced. Using energy rating data, Sustainable Tool for Environmental Performance Strategy (STEPS) can then provide a base case for reducing greenhouse gas emissions from the operation of the site based on the building services and systems selected.

From this exercise, design targets can be developed for the potential energy required for the operation of the house which will guide the sizing of renewable energy systems. Detailed steps and tools used for the main environmental impact areas are shown in Table 1 below.

Table 1 Early ESD Considerations

Energy	Water	Materials and Waste
Passive solar design principles – solar heating, shading, natural ventilation, daylighting	Demand management through specification of efficient fixtures and fittings	Use Ecospecifier to select environmentally preferable materials
Preliminary energy rating to optimise building fabric and reduce heating and cooling loads	Assess rainwater harvesting potential, most appropriate use, and storage requirements	Construction waste – consider pre-fabricated elements
Determine base case for overall energy requirements with STEPS	Grey and Blackwater harvesting potential and potential reuse strategies	Green waste
Optimise appliances using SBE Autonomous House Calculator	Develop water reuse hierarchy eg: rainwater for potable water and showers, recycled greywater for toilet flushing	Waste separation
Work out how much renewable energy is required	Assess site runoff through use of STORM to achieve best practice	
Establish costs to provide renewable energy systems		
Buy green power to meet the remaining energy needs		

2.3 Design Development

Through the development stage, system sizes are determined to match performance requirements. Life-cycle costings and maintenance considerations are weighed up at this stage so that the systems selected complement the intent of the design. Design decisions should continue to be re-evaluated as the design progresses to ensure that the project objectives developed in the briefing stage are met and to fine tune the performance targets. New servicing options may be explored.

For a standard project, building systems and services are generally selected on the basis of their capital costs and payback times. For an autonomous house project, the analysis of individual systems is based on criteria of environmental benefits (quantified where possible), capital costs (and possible rebates), maintenance costs, payback time, predicted savings and client priorities.

3. Rating Tools

3.1 ENERGY RATING - NatHERS

The Nationwide House Energy Rating Scheme (NatHERS) family of software includes: FirstRate, Accurate and BERS. The scheme is administered by the Federal Government and the tools engine was developed by the CSIRO. In Victoria, FirstRate is administered and owned by Sustainability Victoria.

NatHERS software is used to assess the energy performance of residential buildings by assessing the effect that building fabric will have in influencing potential heating and cooling loads.

In addition to providing formal building code compliance, energy rating tools can be used as a design tool to assess the impact of various building fabric options and inform a cost benefit analysis allowing more informed design decisions to be made. There is often a point at which the improvements to the building fabric outweigh the benefits to be achieved in terms of reducing energy use.

3.2 STEPS

Moreland STEPS was developed by Moreland City Council to assess the environmental impact of residential developments and to promote early integration of sustainable design initiatives at planning stage. The web-based tool is available for the public to use and assesses the key areas of their project including: energy, peak demand, water, stormwater and materials on a scale of percentage improvement above the average residential development. Targets are set for each of these aspects with innovation encouraged through credits awarded at council discretion.

SBE uses this tool at design stage to assess various strategies for their ability to reduce environmental impacts for greenhouse gas emissions, or to improve water run-off quality across the site to meet best practice, for example.

3.3 Ecological Footprint

According to EPA, Victoria: *the ecological footprint measures how much nature we have, how much we use and who it is used by*. In general, it measures the resources consumed by human activities across the lifecycle of a service, product or building, and interprets this information as the biologically productive land and water required to support that activity. It can be used to inform a residential project by measuring the quantity of the planet's resources required to construct and operate a residence. Typically, the Footprint is reported in "global hectares" (gha). Ecological Footprint calculations consider the following factors: biological value of land, materials, waste, water, greenhouse emission, transport, residents. The tool identifies areas where resources could be used more efficiently to ensure a sustainable future.

3.4 STORM

STORM has been developed by Melbourne Water to assess stormwater treatment levels on a site and determine whether stormwater treatment measures achieve best practice water quality objectives. It is a simple correlation tool based on the more complex tool, MUSIC, Model for Stormwater Improvement conceptualisation v3.

The tool can analyse seven treatment measures: rainwater tanks, ponds, wetlands, rain gardens, infiltration, buffer strips and swales and compares the treatment against best practice standards. A 100% STORM rating relates to a 45% reduction in typical annual total nitrogen loads. The tool is designed for general public to assess simple Water Sensitive Urban Design issues through the simple input of impervious area and selected treatment measures for runoff water from that surface.

3.5 Ecospecifier

Ecospecifier provides a knowledge base for building designers, specifiers and homeowners to source, assess and specify environmentally preferable and healthy products, materials and design processes. It is a subscription based service however, 10% of the data base is available in public domain to increase knowledge of sustainable materials choices. Ecospecifier identifies products with improved performance in the areas of greenhouse gas emissions, human health impacts and pollution impacts.

3.6 In-house water calculator

SBE has developed a water calculator to determine the potential water demand of a residential project and analyse the efficiency of various options for water recycling and re-use systems. The water calculator takes into consideration: local rainfall data, building type and occupancy rate, number of building users, efficiency of appliances and fittings, irrigation requirements and swimming pool top-up needs. Water demand data has been synthesised from a number of sources including the Yarra Valley Water, Residential End Use Study, 2004, Peter Roberts. SBE uses more recent rainfall patterns from the last two decades rather than long term historical data to inform tank sizing.

3.7 In-house autonomous house calculator

SBE's in-house autonomous house calculator analyses the proposed building services systems (e.g. heating and cooling, water heating, appliances, pool heating, lighting) and calculates CO2 emissions / energy demand of each system type. The tool assists in optimising the space heating, cooling, water heating, mechanical ventilation systems as well as proposed appliances by primarily focusing on reducing their energy use and CO2 emission during operation. The tool also calculates the energy generated by systems utilising renewable energy sources.

4. Case Studies

4.1 Broome Sustainable House

The Broome House was designed as a competition entry for the West Australian Office of Housing. The brief was to develop an sustainable, affordable detached social housing model dwelling that could be used as a template for future design of housing in tropical climate of Broome. The home was constructed in 2003.

4.1.1 Climatic response

The Broome climate is a tropical characterised by cooling winds from the coast to the west and blustery hot winds from the east. In the context of Broome's tropical climate, a design priority for cooling performance often took precedence solar heat gains over winter. This cooling objective led to the development of a low thermal mass building fabric, designed to shed heat quickly.

While the site places constraints on optimal orientation for the house, the design prioritises living areas and the main bedroom to receive direct solar access to the north with calculated solar eaves. The outdoor living areas are oriented to the north-west with full rain and shade cover provided to the deck by an insulated roof. To avoid this deep roof cover to the deck from cutting off solar access to the living room, filtered northern light is made available by north facing clerestory windows above it. Passive ventilation has been extensively used in the project's cooling strategy with thermal stack ventilation encouraged by the placement of high set vent clerestory windows in both pavilions. Fully openable louvre windows are positioned to maximise direct cross ventilation control from the full range of prevailing wind directions. The building is of lightweight composition so that it is able to respond quickly to changes in external temperature conditions. Any heat gained may be quickly purged via cross and chimney ventilation. The living and sleeping areas are heavily insulated to act as "cool cells"; they can be isolated from the outdoor environment and cooled or heated to maintain temperature as desired.

4.1.2 Air-conditioning and heating

Air-conditioning and heating represent about 26% of household energy use. To meet the competition briefing requirement of maintaining internal temperatures between 17 and 27 degrees Celsius, an efficient reverse cycle unit was specified to satisfy heating and cooling requirements of the living and sleeping areas only. Optimising the building fabric to these areas resulted in reduced heating and cooling loads which in turn reduced the size and energy consumption of the reverse cycle unit. Further efficiencies are gained by using the system to heat or cool one cell at a time with active occupant switching or automatic timed controls to service the preferred area.

4.1.3 Water supply

The major response to reducing water usage is the provision of tanks to catch rainwater for non-potable water demands and AAA rated fittings with aerators used in all tapware. The in-house water calculator was use to size three 23,700 litre poly-tanks are required to catch 100% of roof rainwater and maximise the mains water supply reduction. A constant pressure pump below the meter cupboard feeds rainwater into the house supply. First flush devices are fitted to divert initial salty run-off from the downpipe systems.

4.1.4 Solar hot water

Hot water uses approximately 31% of household energy. To reduce this, 3.5 m^2 of solar hot water collectors are mounted on north façade at the eastern end of the Living pavilion. Collectors are mounted at 18 degrees, which is the latitude of Broome, to give optimal performance. A standard domestic Solar Hot Water system with 300 litres storage tank, split panel system and gas boosting was used.

4.1.5 On-site electrical production from photovoltaic system

Eleven photovoltaic solar panels are mounted on the northern façade of the building, and are linked to a grid connected inverter that maintains grid availability, whilst also feeding excess supply back to grid. The regulator, inverter and reversing electronic meter are located in a ventilated meter cupboard.

4.1.6 Results based on on-site measurement of energy and water use

Data loggers were installed in the house post-occupancy to monitor energy and water use. A similar sized social housing dwelling was also monitored for comparison purposes. As a result it was found that in comparison to the documented average energy use of a residence in Broome in 2004 (6,154 kWh per annum), the Broome Sustainable House used 14% less electrical mains power (5,281 kWh per annum). Much larger savings were achieved in comparison to the Reference House, with the Broome Sustainable House residents using 60% less mains power.

Table 2 Broome House - energy use comparison between predicted and measured data

Broome average annual usage	Predicted average annual usage	Predicted saving	Metered usage for 12 months	Metered saving for 12 months
6154 kWh	1,500 kWh	76%	5,281 kWh	14%

Interestingly, the reference house used more than twice the amount of mains power (12,992 kWh per annum) than the average residence in Broome (6,154kWh per annum). We would expect a variation in the order of 30% due to the vagaries of occupant behaviour. If we assume that the reference house occupants are at the extreme of this range, you would expect the average household in Broome to consume ~9000kWh, 50% higher than the original figure provided in the competition brief. It is likely that the Broome average energy use figure supplied was either dated (as energy use has increased in recent years due to increased reliance on air-conditioners) or, based on the energy use of houses in milder climates. It is also noted that the demand based load calculations did not include heating and cooling, this is likely to have led to an underestimation in the predicted electricity load.

The energy generated by the PV's was only half of the amount anticipated. Reasons for this are likely to include: overestimation of the hours that 80W can be provided due to less sunny days or overshadowing; dust coverage and other maintenance problems; inefficiencies in the inverter.

The mains water use for the house was 54% less than the average daily use in Broome, which is extremely close to the predicted reduction of 51%. It is also interesting to note that the total water use in the house was higher than expected, but this was buffered by the fact that the rainwater tank provided 30% more water than predicted, possibly a result of higher water demand or higher rainfall. Aside from difference in behaviour, one known factor for the higher than expected demand is the change in the landscaping away from the originally intended indigenous planting.

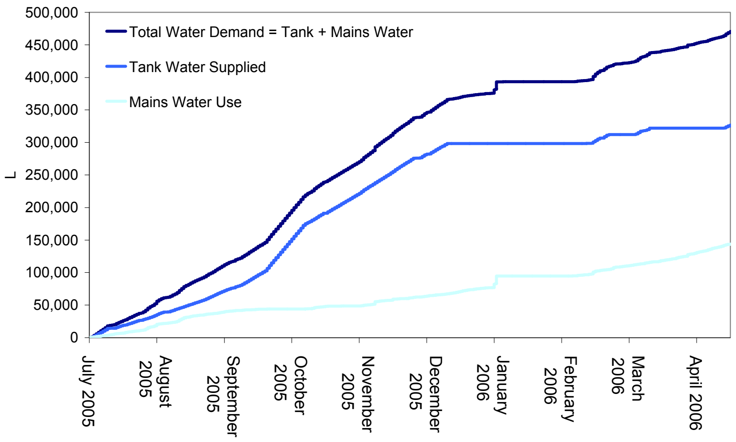

Figure 2: Measured total water demand, rainwater supply and potable water use

4.2 South Yarra House

The South Yarra House is a relatively large (553m^2), 5 bedroom dwelling located in Melbourne inner suburbs and is about to undergo construction. To optimise the potential performance of the residence, SBE used energy rating tools in conjunction with STEPS, STORM and SBE in-house calculators.

4.2.1 Climatic response

Melbourne is in a temperate climate with warm to hot summers, mild spring and summer and cool winters. The building design focused on ensuring the retention of heat over winter whilst eliminating the need for active cooling on Melbourne's numerous hot summer days. The building was designed to maximise exposure to the northern orientation by elongating the building on an east-west axis. This strategy allows for the most effective control of solar access throughout the year. FirstRate energy modeling was used to optimise heating and cooling loads. As a result, the building is to be heavily insulated with R3.0 total insulation to external walls and R5.4 total insulation to the roof. To reduce heat loss from a heavily glazed southern wall, glazing was replaced with 2 layers of multi-celled polycarbonate. Remaining windows are specified to be double glazed with a low-e coating to retain heat. To avoid overheating in summer, shading strategies include adjustable louvres to north facing windows and fixed shading to other windows. To add to the passive building performance, exposed concrete flooring and internal brick walls will provide thermal mass to temper indoor temperatures.

4.2.2 Air-conditioning and heating

As a result of the passive design principles employed in conjunction with optimised building fabric, zoned reverse cycle air-conditioning systems were installed to the up-stairs bedrooms only. Gas hydronic heating, using panel radiators with individual thermostats, has been specified to provide for greater efficiency in zoning areas to be heated. Hydronic heating has the ability to have individual room control, higher operating efficiency, low noise levels, reduced indoor air contaminants and other health benefits.

4.2.3 Water supply

High star rated efficient fittings and appliances were selected to minimise the potable water demand. To supplement the potable water supply, rainwater is to collected from roof and deck and conveyed to a 25kL storage tank plumbed to the cold water tap of the washing machine and to supply water for toilet flushing. Rainwater will also be used to water the vegetable and herb garden by hand. The benefits of rainwater collection for these uses is that no treatment required and no health concerns in case of direct human contact. In addition, greywater collected from showers is to be filtered through a greywater diversion system plumbed to sub-surface garden irrigation for the remainder of the garden. Sub surface irrigation has been specified to improve efficiency, minimise water required for landscaping and to mitigate health risks.

4.2.4 Solar hot water

Solar hot water is provided to both the domestic hot water supply and the pool water. The domestic system is gas boosted solar with high efficiency (a 315L SunPlus CPC solar hot water system). Pool water heating is provide by a separate low level heating system consisting of black piping equivalent to 200% of the pool surface area.

4.2.5 On-site electrical production from photovoltaic system

With the above initiatives and the use of compact fluorescent lighting a 3kW photovoltaic system would be required to negate the need for grid electricity (however, natural gas would still be used). In the first instance the client has decided to install a 1.0 kW photovoltaic system with 3.0kW inverter, allowing for increased capacity at a later stage.

4.2.6 Results

A combination of STEPS, STORM, energy rating tools and our own in-house calculators were used to make recommendations on this project and to predict demand. The predicted greenhouse gas savings are 71% and if the client purchases Green Power for the remaining mains gas and electricity supply, the house aims to be carbon neutral in operation.

Table 3 Annual energy use savings between preliminary and final design

	Baseline Annual Energy Use	Predicted Design Energy Usage	Predicted GHG saving	Annual GHG Saving	Annual Cost saving
Heating	9,900 kWh (gas)	800 kWh (gas)	11%	1,700 kg CO2	$1,600
Cooling	2,500 kWh	1,900 kWh	6%	900 kg CO2	$100
Hot Water	13,100 kWh (gas)	4,700 kWh (gas)	13%	2,000 kg CO2	$1,900
Other	18,300 kWh (mix)	8,900 kWh (mix)	32%	5,100 kg CO2	$2,300
Total Electricity	**6,400 kWh**	**5,300 kWh**			
Total Gas	**36,000 kWh**	**10,100 kWh**			
Renewable Supply	0 kWh	- 3,300 kWh	9%	3,300 kg CO2	$200
TOTAL	**42,400 kWh**	**12,100 kWh**	**71%**	**8,000 kgCO2**	**$6,100**

The potable water demand for the dwelling has been reduced by 36% through the use of alternative supplies.

Table 4 Water use savings from alternative water supplies

	Baseline Demand	Final Design Demand	Predicted saving	% Saving
Domestic	400 kL/yr	275 kL/yr	125 kL/yr	31%
Irrigation	30 kL/yr	0 kL/yr	30 kL/yr	100%
Total	430 kL/yr	275 kL/yr	155 kL/yr	36%

4.3 Upper Beaconsfield House

4.3.1 Climatic Response

The site is located 50 kilometres south east of Melbourne in the Dandenong Ranges in an urban residential area with large residential blocks, tree lined streets, varied eucalyptus forests, wet-lands, fern gullies and secluded creeks. Flora and fauna are protected. The climate is temperate to cool temperate with prevailing winds from the southeast in winter and temperatures varying from 22°C maximum in summer to 5°C minimum in winter. An existing house on the site did not meet the family requirements spatially or spiritually; it is to be demolished with the new residence built on the existing cleared area to minimise further site disturbance. Existing site infrastructure, such as rainwater tanks will be reused. The brief required the residence to respect the environment, open up to the bush (rather than the road) and consider views of Port Phillip Bay and Melbourne to the west, Westernport Bay to the SSE, and treed valleys to the NNE and SE. In conjunction with principles of passive solar design, the late David Oppenheim developed an axis mundi for the layout of the plan. The majority of the windows are located on the north side to maximise solar exposure and enable simple and effective shading solutions. The proposed residence is elongated from east to west. As a previous house on the site was destroyed by the 1883 bushfires, bushfire hazard management was another aspect of the detailed design.

4.3.2 Air-conditioning and heating

The building fabric has been optimised using FirstRate. To reduce energy used for heating and cooling, high levels of thermal mass are integrated in the internal spaces of the building. This includes R7.0 ceiling insulation and R3.5 wall insulation has been specified to ensure protection from outside temperatures. The area of thermal mass is approximately three times the area of north glazing. The need for cooling will be reduced through solar calculated shading to the north facing windows. Natural ventilation will be encouraged through operable facades and narrow floor plates. Cooling is aided by roof-overhangs or sun-shading above windows and natural ventilation through openable louvres above interior doors and at the centre breezeway. On hotter days, ceiling fans will be used. Air-conditioning will not be installed. The only heating is from the wood stove in the living room that will burn firewood from the site.

4.3.3 Water

The site is connected to mains water, however, the intention is for it to be self-sufficient in its water supply. There are 2 existing tanks that can collect a total of 30 kL of water and a designated fire fighting tank of 20 kL. The client's current experience of living on the site has proven that rain water is sufficient to meet all their potable water needs. Rain water will be collected from the large winged roof and stored to supply drinking and washing needs. A new black water treatment system (NOVA Clear Sewage System) will be installed to treat grey and black water from the site. The class A water obtain will then be used for flushing, irrigation and fire-fighting purposes.

4.3.4 Onsite energy production

Solar hot water will be used for with the default switching being with the gas boosting being turned off. The intention is for a PV system to be installed in future to supplement the electricity supply.

4.3.5 Results

The walls of the building were originally specified as double masonry to increase thermal mass. However, budgetary constraints have required walls to be brick veneer with increased levels of added insulation too provide similar performance. Thermal mass is, fortunately, still sufficient for passive heating & cooling. A 2kW photovoltaic system and Green Power for the gas use for hot water heating in winter will deem the house autonomous in operation.

Table 5 Energy use savings between preliminary and final design

	Baseline Annual Energy Use	Predicted Design Energy Usage	Predicted GHG saving	Annual GHG Saving	Annual Cost saving
Heating	9,900 kWh (gas)	200 kWh	12%	1,600 kg CO2	$1,600
Cooling	2,500 kWh	100 kWh	26%	3,500 kg CO2	$400
Hot Water	13,100 kWh (gas)	3,700 kWh (gas)	6%	900 kg CO2	$800
Other	5,200 kWh (mix)	3,200 kWh (mix)	23%	3,100 kg CO2	$300
Total Electricity	**6,400 kWh**	**3,300 kWh**			
Total Gas	**23,000 kWh**	**3,900 kWh**			
TOTAL	**29,400 kWh**	**12,900 kWh**	**67%**	**9,100 kgCO2**	**$3,100**

As the site will not be connected to mains water the site will be fully autonomous in water supply.

Table 6 Water use savings from alternative water supplies

	Baseline Demand	Final Design Potable Demand	Predicted saving	% Saving
Domestic	320 kL/yr	0 kL/yr	320 kL/yr	100%
Irrigation	700 kL/yr	0 kL/yr	700 kL/yr	100%
Total	1020 kL/yr	0 kL/yr	1020 kL/yr	100%

5. Conclusions

The path to achieving an autonomous home is relatively simple as described above. The process provides a quantitative understanding of sustainable performance against which the operations of the completed home can be assessed. Measuring the results is easy and low cost (energy meter and water meter for each residence).

By investing in the design process, clients are more motivated to engage with the building to maximise its operation. The impacts that it can have on lifestyle may outweigh the positive benefits of the building itself. Of course, the building also acts as a demonstration to the wider public of what it is possible to achieve. It is realistic for this approach to reach a critical mass in a relatively short timeframe with major benefits accruing to the environment.

The lessons from SBE's Autonomous House projects generally relate to the data used to calculate predictive performance. Predicted performance at the design stage will always differ from that in operation due to the necessity to make preliminary assumptions on usage patterns and behaviors. Resident behaviour and the appliances and systems used have a significant impact on overall environmental performance. Neither of these factors can be controlled by design, but can be influenced through effective communication during the design process. Further post occupancy studies are required so that baseline performance figures can be better correlated with actual performance to guide future projects.

The clients to whom we have provided Autonomous House advice are normal people with a concern for the future of the planet and with the moral responsibility to act to reduce their own footprints. The ESD initiatives included in their projects are aligned with architectural quality and aesthetics, they deliver the message of sustainability in a subtle and stylish manner.

It is more difficult to achieve autonomy for larger residences. While they may use the same amount of energy or water per m^2 as a reference home, due to their size they may still have a greater ecological footprint than a smaller home designed with less focus on optmising energy or water use.

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BUSINESS HOTEL UTILITY CONSUMPTION AND SAVING OPPORTUNITIES

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Keywords: Hotels, energy, water, energy efficiency

Abstract

The utility consumption of business hotels is a key contributor to the overall environmental footprint of the commercial sector, but is less well explored than the office sector.

In this paper, the results of a preliminary energy and water use benchmarking study for business hotels in Australia are presented. The benchmarks demonstrate the feasibility of benchmarking as a means of indexing energy and water efficiency performance in this sector.

The results of 15 energy audits of business hotels conducted by the author's company are used to develop a characterisation of energy use and savings potential for this sector. The breakdown of energy and water consumption into end-use categories is identified and the key functional drivers for these end uses are identified, including space-conditioning, domestic hot water, laundry, meal preparation and swimming pools. Within each of these categories, common energy efficiency opportunities are identified and briefly discussed in terms of the scale of opportunity and the barriers that arise to implementation.

Introduction

The commercial sector is recognized as being one of the key areas for climate change action, owing to its significant impact on the international greenhouse budget. In areas such as office buildings, there is a long history of effort and a good deal of commercial activity towards the improvement of energy efficiency, but this activity is not uniform across the commercial sector as a whole. In this paper, the energy and water consumption of business hotels – one of the less thoroughly researched or commercially worked sub-sectors – is reviewed. For the purposes of this paper, business hotels are defined as typically multi-storey hotels, generally in city locations, with facilities geared towards business travelers and short-stay recreational travelers, i.e. without significant in-room cooking facilities and with only small recreational facilities (such as a small swimming pool and a gym). In the Australian context, this is particularly differentiated from the resort hotel and apartment hotel sector, which respectively have far larger recreational facilities and significant in-room kitchens.

The approach taken in this paper is firstly to examine some preliminary benchmarks developed in Australia for energy and water consumption, and then to examine savings opportunities as identified in a batch of 15 energy audits undertaken in Australia. The nature of the savings opportunities identified is then discussed in the context of the institutional and operational parameters of hotels.

1. Benchmarks for Energy and Water

Benchmarking is becoming recognised as a key methodology for the assessment of energy efficiency opportunity. This is evidenced by initiatives such as the European Building Performance Directive, Energy Star in the US [US EPA 2008] and the Australian Building Greenhouse Rating (ABGR) scheme in Australia [DECC 2008a]. The benchmarking study presented in this paper is derived from a preliminary benchmarking study conducted by the authors for the Department of Energy, Utilities and Sustainability of the New South Wales Government as part of the National Australian Built Environment Rating System (NABERS). NABERS is the broader environmental rating suite within which ABGR operates [DECC 2008b].

There are some international precedents for hotel energy and water benchmarks, including Energy Star for Hotels [US EPA 2008], UK Construction Industry and Research Association benchmarks (CIRIA) [Wagget and Arotsky 2006], World Wildlife Fund (WWF) benchmarks [WWF 2008]. Within Australia there has also been previous work conducted by the Department of Industry, Tourism and Resources (DITR)

[DITR 2002]. These benchmarks include a range of measures based on typically GJ per room per annum, MJ/m² and m³ per room, typically indexed by some form of basic categorisation of hotel type. While clearly useful in the context they were designed for, these benchmarks lack the detail and/or local specificity required for the NABERS scheme.

As a consequence, the preliminary benchmarking study reported in this paper was commissioned in 2007, with a view to establishing the feasibility of developing NABERS ratings for energy/greenhouse and water for the hotel sector. The pilot of this scheme, based on the full benchmarking study undertaken as a follow-on to that reported here, will be launched in mid-2008.

1.2 Benchmark Development

1.2.1 Compensation for Service Levels

The establishment of a hotel energy or water benchmark is considerably more complicated than for offices, because of the diversity in the sector even within notional categories of hotel. Most existing benchmarks have avoided this issue by retaining a highly simplified approach. However, this reduces the degree to which the resultant benchmarks can be used to assess efficiency, as an individual hotel that may be efficient but provides a greater range of guest services will be penalised relative to a potentially less efficient hotel with fewer guest services.

One well-known indicator for service level is the hotel quality star rating, which is an externally managed system with auditable standards. While there are some technical issues with the use of this, it noted the key purpose is to provide a means of ensuring that resultant benchmarks provide peer-to-peer comparisons.

In addition to the hotel star rating, the following factors are feasible as sources of additional corrections:

- **Number of rooms.** This is a preferred variable for benchmarking, as it is relatively well defined;
- **Number of beds.** This is a further size variable but with greater ambiguity due to the variable relationship between guest numbers and the number of beds actually provided.
- **Floor area.** This factor is strongly correlated to the number of rooms but is not measured to any consistent metric by the industry and as such is not a preferred index for hotel size.
- **Scale of meeting/conference facilities.** This varies independently of other factors and can be a significant contributor to the overall energy use of an individual site.
- **Scale of restaurant facilities**. While this is to some extent correlated to hotel quality, other independent factors also play a strong role.
- **Swimming pools.** The scale of swimming pools offered varies widely, again with a marginal correlation to the hotel star rating.
- **Laundries.** While most hotels have some form of house laundry, this may range from a small facility for washing a few select items (such as uniforms or a guest valet service) to a large facility washing sheets, towels and other linen for more than one hotel.
- **Retail operations.** Many hotels also house some limited independent retail operations. These are typically but not always sub-metered.
- **Level of occupancy.** In principle, the level of occupancy should have a large influence on hotel energy and water consumption, although in practice for energy at least this is not as significant as might otherwise be the case due to the propensity of hotels to provide service to empty rooms in preparation for unexpected arrivals.

Other factors that may be significant for individual hotels include: the provision of staff accommodation, water supply pumping and on-site power generation in more remote locations, the presence of a casino on site, and the provision of supplementary guest services such as health spas, valet cleaning services and executive club facilities.

1.2.2 Data review

The data for this study was assembled from commercial client information in the possession of the authors based on site studies and other works. As a result, the overall accuracy of source information is considered to be good. The data included: forty business hotels, typically of 4-5 star rating and located in major centres around the country; seven regional hotels of 3 star rating, all of which are located in regional Western Australia; and sixteen budget hotels, of 2 star rating, located around Australia.

The data sample is considered preliminary and is not adequate for use in generating a finalised benchmark due to the limitations of the data set with respect to the range of hotel groups and geographical diversity in the sample, as well as some limitations in the range of actual information gathered.,. Nonetheless, the data set is considered to have sufficient validity to be able to obtain a valid insight into the nature of the hotel sector energy and water consumption prior to a more complete survey.

1.2.3 Energy/Greenhouse benchmark

As hotels use both electricity and fuels, and there is some interchangeability between these, the energy benchmark was developed in the format of a greenhouse gas benchmark. This allows combination of the different fuel sources in a meaningful manner, and fits with the approach used in the ABGR and NABERS programs. For the purposes of this study, the total greenhouse gas emissions associated with the sites was calculated using 2005 New South Wales coefficients for all states (0.985 kg/kWh for electricity and 0.0713kg/MJ for natural gas; no other fuels were reported in any significant quantities).

A strong primary relationship was observed in the data between the hotel star rating and the emissions per room. This was used as the basis for the establishment of the benchmark. In addition, the following preliminary compensations were made to the data:

- Presence of laundry. This was determined by t-test (a statistical test to determine whether the difference in mean between two samples of data has significance) as being a significant correction at 6000MJ/room of gas.
- Presence of heated pool. This was determined by t-test as being a significant correction at 19,000MJ/room of gas. In application this was multiplied by the average number of rooms per site (171) and applied as a fixed figure to all sites as it is expected that pool size does not in practice correlate strongly with the hotel size.
- Food covers. A weak relationship between food covers (a hotel operational variable roughly proportional to meals served) and energy was determined. The equation of correlation was $\Delta=6708-14.7f$ where f is the number of food covers per room and Δ is the difference between the benchmark and the actual greenhouse emissions per room (after laundry and pool corrections).
- Conference facilities. No data were gathered on conference facilities in the original data sample so no compensation has been provided.

To determine the impact of star rating on the greenhouse per room, the median, seventy fifth percentile and twenty fifth percentile in greenhouse per room data (after pool and laundry corrections) were calculated for each of the star ratings, to give an aggregated view of the data. Only the median is used for the benchmark, as the benchmark is intended to provide an indication of the performance of the mid-point of the population. The results are shown in Figure 1.

Based on the data, the overall benchmark for median performance *M* (kg/room per annum) is:

$$M = 5772S + 14.7f + \frac{P}{r} + l - 14171 \qquad (1)$$

where *S* is the star rating, f is the number of food covers per room, *P* is the pool correction (=232,000kg if a heated pool is present) and *l* is the laundry correction (=463kg/room if a laundry is present) and *r* is the number of rooms.

The benchmark is a reasonable representation of the data, with an r^2 of 0.66 between the median benchmark and the data set. This relationship becomes stronger (r^2=0.81) when evaluated in terms of total greenhouse emissions. In either case a degree of spread is expected, as there is a range of efficiency levels. Indeed, in this context, as anecdotal but important confirmation of the benchmark approach is that a brief review of the position of hotels relative to the author's studies of the individual hotels indicates that the majority display the correct behaviour relative to the median, i.e. the energy audits indicate that sites with large potential energy savings tend to have above-benchmark emissions per room.

It is emphasised that the benchmark is preliminary only and that further data are needed. Further work is also required to allow climate effects to be included in the benchmark.

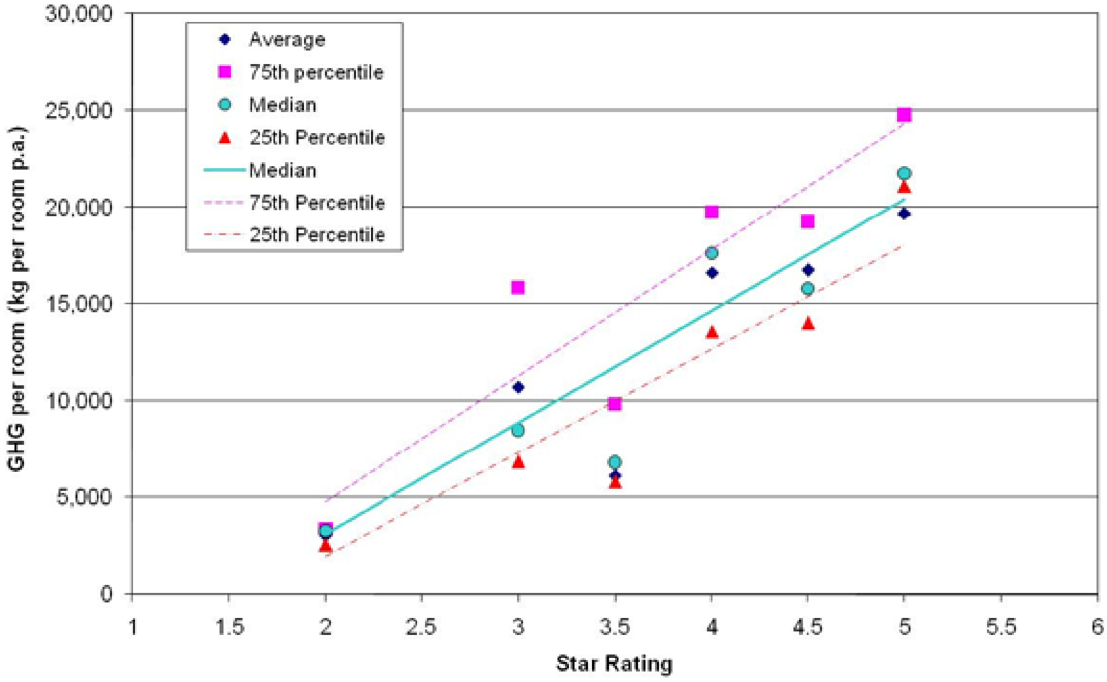

Figure 1 Relationship between laundry and pool corrected greenhouse emissions and star rating. The median relationship shown on the graph was determined using figures weighted for the sample size in each star rating. (noting for instance that the 3.5 star sample consisted of only three hotels).

1.3 Water Benchmark

A similar approach was used to generate water benchmarks, due to strong similarities in the data. Nominal correction factors were derived for laundries and swimming pools as follows:

- Large frontloading domestic washing machines use around 10 litres of water per kg of washing (as can be identified from www.waterrating.gov.au). The washing of a set of sheets and towels therefore would be expected to use around 30-40 litres of water per room night. This compares with the average water use of 590 litres per room night. As a result the approximation of 40 litres per room night has been used as an adjustment for sites with laundries. This is, however, not a significant adjustment.
- An approximate estimate of pool water consumption is around 60% of pool water volume [NAEEP 2004]. For the purpose of this analysis, a pool water correction factor has been allowed in the proposed rating equation and has been set to 120 kilolitres, based on an assumption of 60% loss from a 200m³ pool. Expressed against the range of actual water consumption for sites (2,200-109,000 kl) this is clearly only a minor adjustment.

As with the greenhouse benchmark, it was found that a significant level of variability in the data could be accounted for by assuming that different hotel star ratings have different water consumption characteristics. No significant correlation could be determined from the balance of the data with respect to food covers or climate, and so no correction was developed for these factors.

The overall equation for the median annual water use per room in kilolitres based on the current analysis is as follows:

$$M = 45.5S + \frac{P}{r} + L\rho \qquad (2)$$

- where S is the star rating of the hotel, P is the pool correction (120 kl), r the number of rooms, L the laundry correction (40 litres per room night) and ρ the annual occupied room nights.

The fit of the data to this median (expressed in terms of water use per room) is moderately poor, with an r^2 of only 0.41. This improves to 0.54 if the 3 star regional hotels – which have high irrigation requirements relative to the balance of the data set because of the nature of the individual sites involved - are removed from the analysis. The relationship on a total water consumption basis is somewhat better, with an r^2 of 0.85 being achieved across the full data set.

As with the greenhouse benchmark, this is a provisional benchmark only and is not suitable as a means of directly proceeding towards the development of the rating without further data collection.

2. Energy Use and Savings Opportunities

The author's organisation has been involved in a significant number of energy audits of hotels. In this section, the results of the 15 Australian sites within this group are summarised, comprising 3.5-5 star hotels in major centres (mainly state capitals) with a total energy consumption of 370 TJ of electricity and gas.

2.1 Energy End-Use Breakdown

As part of the audit process, detailed energy end-use breakdowns were generated. These breakdowns comprised a build up of all energy-using equipment on an hourly basis, reconciled against known usage patterns and, if available, half-hourly utility consumption data. The aggregate of these figures across the 15 hotels is shown in Figure 2 below. It can be seen from the figure that HVAC is a dominating factor; lighting and food-related equipment are also important (the latter supplemented somewhat by the presence of in-room fridges at typically 30-70W continuous load per room). Domestic hot water is also a significant load. Laundries and other loads (including pools) are minor overall although on an individual site the laundry may be more significant.

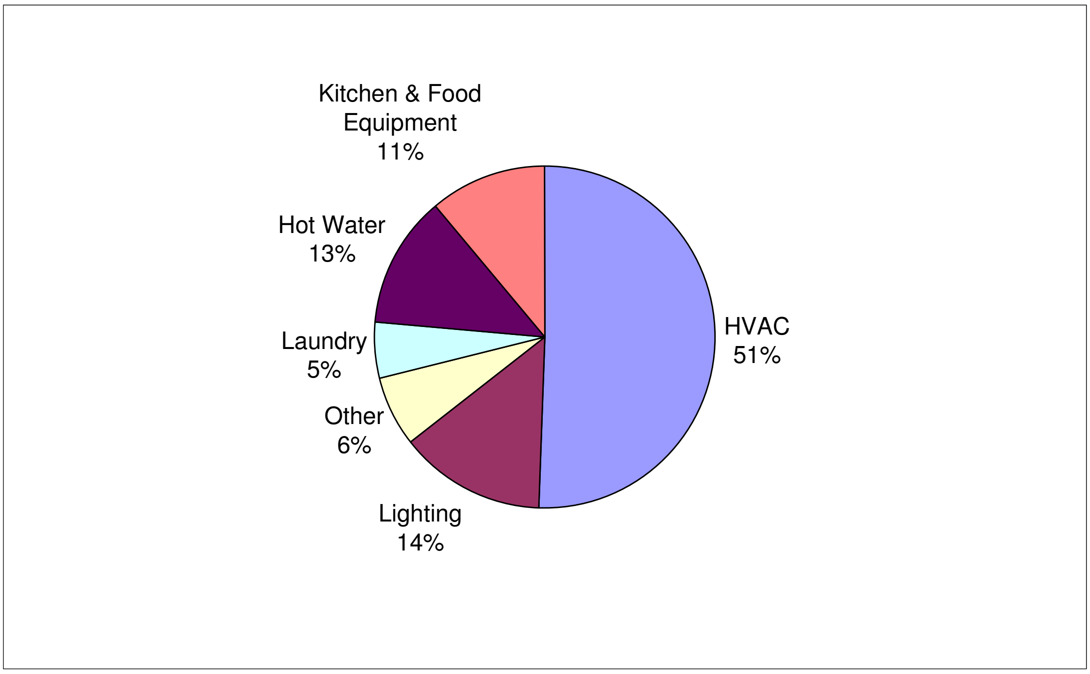

Figure 2 Energy end-use breakdown, aggregated across 15 audited hotels. All fuel sources are included within this figure

2.2 Energy Savings Opportunities

The focus of the energy audits was on the generation of energy savings within relatively short term pay backs (typically under 3 years aggregate across a whole site), reflecting the commercial parameters of the clients involved. While this ruled out the use of more innovative measures, such as renewable energy or more deep-seated modification of existing systems, it does provide a useful review for commercially acceptable measures. Savings measures from these audits have been categorised as follows:

- **Lighting (power density).** Upgrade of lights comprising mainly simple lamp replacements and fitting refurbishments. There is a general perception that halogen and incandescent lamps provide a certain "ambience", resulting in the liberal application of these lamp types throughout hotels for area lighting, particularly in meeting rooms and foyers. Replacement of these lamps with fluorescent alternatives or through the use of the more efficient IRC halogen lamps and electronic transformers was found to be a significant measure at many sites. Other measures included the refurbishment of fluorescent light fittings using delamping, reflectors and/or autotransformers.
- **Lighting (time of use).** Upgrade of lighting control systems to achieve turn-off out of hours. Typical measures included the installation of occupancy sensors in toilets, car parks and back of house areas and the use of timer controls in some locations.
- **HVAC (control).** Upgrade of air-conditioning systems through improvement of control. Hotel HVAC control was found to be poor at all levels, and in particular: building management and control systems were uncommon and where implemented were often very old and poorly programmed; unitary controls were often poorly configured and subject to ad-hoc modifications by the hotel maintenance staff; and time of use control was generally very poor, with an underlying assumption of 24/7 operation being prevalent even in areas that have little or no overnight use. Furthermore, the presence of significant levels of control failure due to lack of maintenance led to the availability of significant savings through the rectification of items such as broken valve and damper actuators and valves failing to provide full shut-off of flow upon closure. In some cases, equipment failure was so prevalent that upgrade to normal operational levels could not be justified on the basis of energy savings alone. In such cases, measures were limited to "work-around" solutions that were economically viable but far from optimal in terms of total savings. Other measures included: modification of chilled water and condenser water control to optimise chiller efficiency, changes to air-handler control algorithms to reduce simultaneous heating and cooling and to improve economy cycle utilisation, changes to chiller staging algorithms and the introduction and control of variable speed drives to pump circuits.
- **HVAC (plant).** Upgrade of air-conditioning plant. Savings in this area were dominated by the replacement of life-expired chillers with new high efficiency (typically magnetic bearing) chillers. The cost of such measures could only be justified because the replacement of the chiller was imminent, and thus the economics could be assessed on the basis of incremental capital cost for high efficiency chillers rather than the full cost. The presence of significant amounts of life-expired equipment was fairly typical of most hotels visited. Other measures in this category included revisions to or deletion of steam generation and distribution systems and modification of boiler systems.
- **Domestic hot water.** Upgrade of domestic hot water generation, distribution and end-use. The most common measure in this area was the reduction of shower flows to below 10l/minute. One of the 5 star hotels in the sample has had 10l/minute showers in place for several years without problem, indicating that the significant numbers of sites with 12-15l/minute shower heads could be upgraded without compromising service levels.
- **Pool.** Upgrade of pool efficiency. This was a minor category as most pools were unheated. However where pools were heated, measures included pool covers and upgrades to the pool heating system (typically through the replacement of gas heating by heat pump or waste heat heating).
- **Laundry.** Upgrade of laundry efficiency. Where sufficiently large laundries were present, laundry heat recovery was considered, primarily as an option to be adopted upon replacement of existing equipment rather than as a retrofit to existing equipment.

Energy savings were calculated for the energy audits through the calculation of the energy end-use breakdown, application of savings estimates to the individual components and aggregation of estimates. Where multiple savings measures affected a single end-use, the savings were estimated by applying the most strongly recommended (typically lowest payback) measure first, followed by remaining measures in order of priority. This approach avoided double-counting of savings. The overall savings identified constituted 22% of electricity consumption and 7% of gas consumption, equating to approximately 13,000 tonnes per annum of CO_2. These savings figures are estimates only and are not based on post-implementation measurements.

The breakdown of savings for electricity and gas can be seen in Figure 3 and Figure 4 below. It can be seen that HVAC control measures and lighting power density measures strongly dominate the available savings. This reflects the poor maintenance and capital upgrade practices in the hotels, plus the widespread use of inefficient light sources.

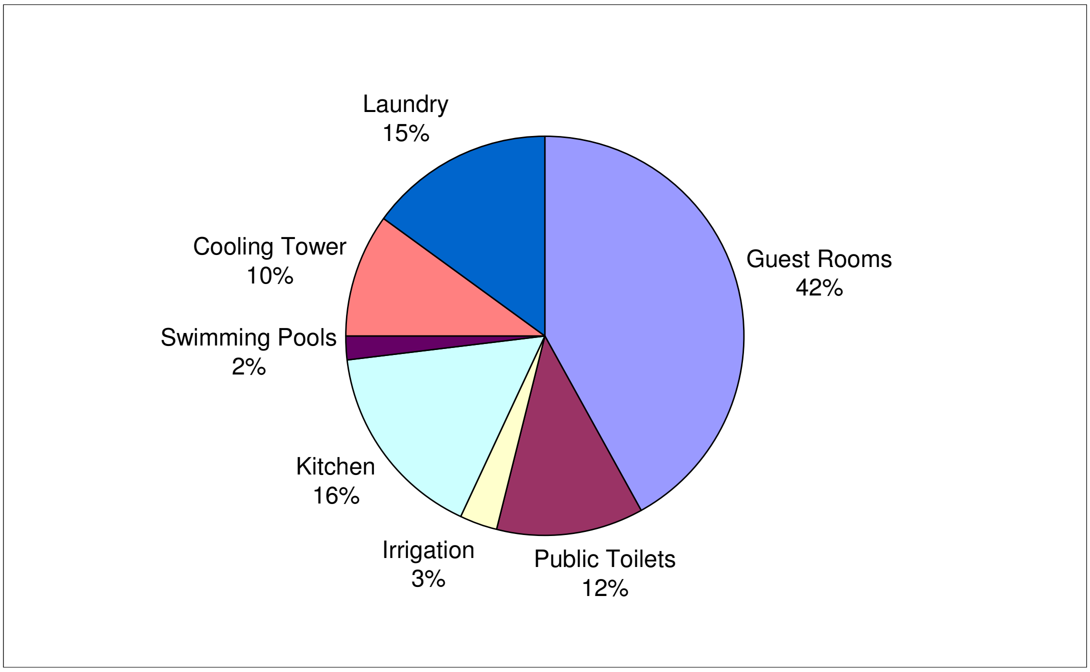

Figure 3. Electricity savings across the audited hotel sample

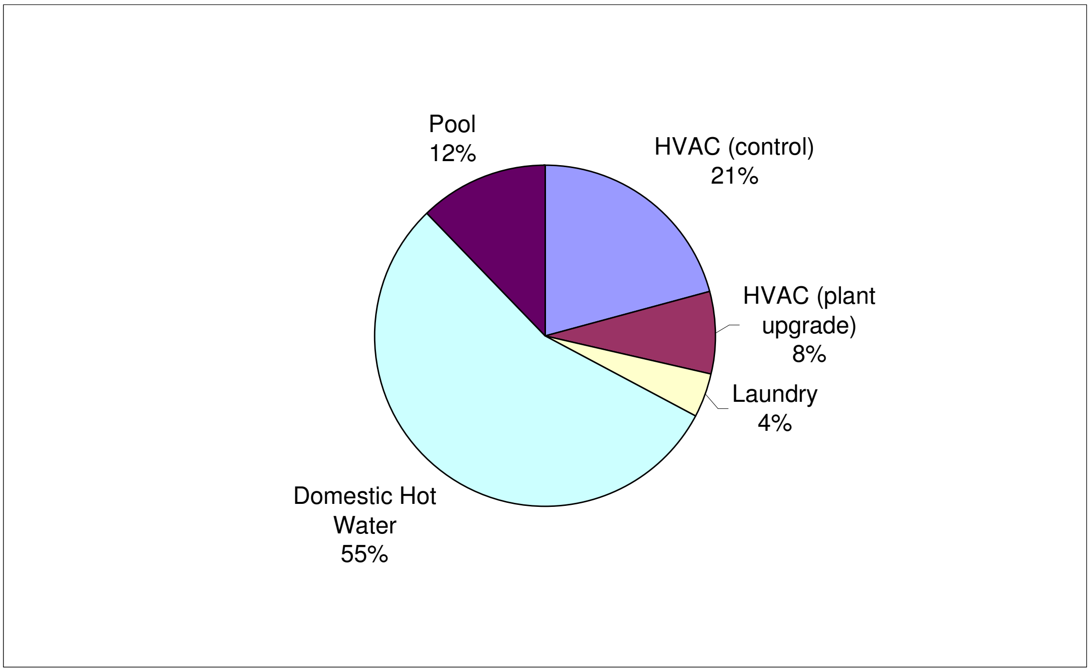

Figure 4. Gas savings across the audited hotel sample.

3.0 Conclusions

In this paper draft benchmarks have been presented for water and energy consumption in Australian business hotels. It has been shown that the hotel quality star rating has a significant impact on utility consumption. Results from 15 energy audits of Australian hotels have been summarised, demonstrating the availability of significant savings within relatively short payback periods.

Overall, it is concluded that the hotels sector is a unique sub-sector of the commercial buildings sector and that it has significant opportunity for improved energy efficiency.

3.1 Acknowledgements

The benchmarking study was conducted for, and fully funded by the NABERS program, which is currently operated by the NSW Department of Environment and Climate Change. The ongoing input of Matthew Clark from this department is gratefully acknowledged. With respect to the audits, the work conducted by Chris Bloomfield and Erica Kenna in completing many of these audits is gratefully acknowledged, as is the assistance of Erin Davies and Lawrence McIntosh in compiling the audit data for this paper.

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A COMPARISON OF TWO ENVIRONMENTAL RATING SYSTEMS USING DUAL CERTIFIED BUILDINGS

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Summary

The environmental rating system tools presently available to the design community in North America are limited in numbers. Before green buildings can become mainstream more systems need to emerge, however equivalency between these rating systems must be determined. Thus this paper will attempt to compare the environmental attributes of the two most popular environmental rating systems in use today in North America. The comparison will be performed by means of seven dual certified buildings and use the official submission summaries from each system to determine their relative robustness to various individual environmental criteria as well as to the overall rating systems performance.

1. Introduction

Architects, builders and developers have many tools at their disposal to improve the environmental performance of buildings. Two such environmental rating systems that are being widely promoted in the North America are the LEED (Leadership in Energy and Environmental Design) Green Building Rating System® developed by the U.S. Green Building Council (USGBC) (www.usgbc.org/leed) and Green Globes,™ a web-based tool being advanced by the Green Building Initiative (GBI) (www.thegbi.org). Green Globes has been operating in Canada for several years and has been widely used by several of their federal agencies. Green Globes is the basis for the Building Owners and Managers Association of Canada's "Go Green Plus" program for assessment of existing buildings. Adopted by BOMA Canada in 2005, it has been used to assess more than 500 buildings, over 300 of which were from Canada's Department of Public Works and Government Services national portfolio of buildings.

However the GBI did not introduce Green Globes into the U.S. until 2005. The first year of its introduction was spent in a pilot phase to ascertain if Green Globes was appropriate for the U.S. market. During this pilot phase a number of buildings were evaluated, of these seven had or were in the process of also undergoing LEED certification. Thus the Green Globes pilot also offered an opportunity to undertake a comparison of these two environmental rating systems using dual certified buildings. While both of these systems offer a range of rating products for new and existing buildings, for this comparison only Green Globes for New Construction and LEED-NC (New Construction) will be used. The aim of this paper is to use the official submission summaries for each system that was generated by the rating authority to compare their relative robustness to various environmental criteria (see Figures 1 and 2). Although these two systems address slightly different levels of detail (for example Green Globes includes an integrated design process, life-cycle assessment and noise criteria which are not addressed in LEED), the general comparison between the two systems indicates a similar rating nomenclature. Table 1 compares the rating nomenclature use by these two systems.

Table 1. A comparison of the four levels of ratings that are used by Green Globes and LEED

Green Globes	LEED
One Globe (>35%)	Certified -- 26 to 32 points (>37%)
Two Globes (>55%)	Silver -- 33 to 38 points (>47%)
Three Globes (>70%)	Gold -- 39 to 51 points (>56%)
Four Globes (>85%)	Platinum --52 to 69 points (>75%)

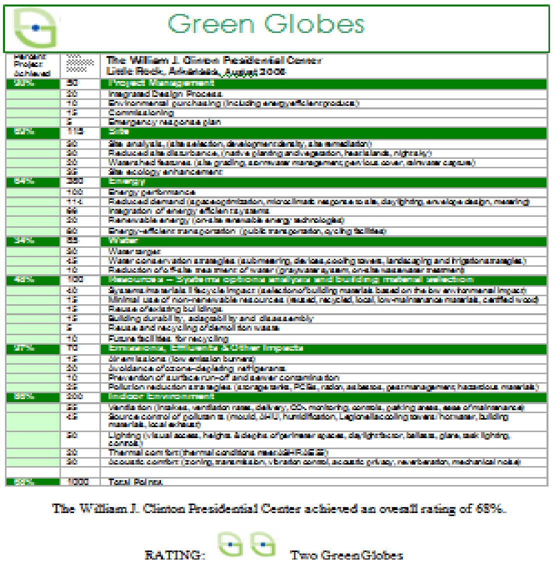

Figure 1. Typical Green Globes Summary Sheet

Figure 2. Typical LEED Summary Sheet

Beyond the issue of nomenclature, both systems are similar in regards to the number of credits and point assignments to each of the categories. While LEED has six categories and Green Globes has seven categories, it is possible to reassign the Green Globes credits from categories that do not exist in LEED. For example, the Emission & Effluents category in Green Globes has a credit for the prevention of site run-off, a similar credit appears in LEED within the Site category making reassignment a relative easy task. There is only one relatively minor category that does not line up well, which is the Innovative and Design Process category. The closest category that Green Globes has to this is their Project Management category. Table 2 shows the percentage of points assigned to each of the categories. While the percentage of points assigned to categories vary somewhat, the relative importance, as shown by the ranking of the categories based in the point assignment are identical.

We did not need to undertake a comparison of individual performance criteria for each system because of the excellent study that the University of Minnesota did on this subject. Their study, “Green Building Rating Systems: A Comparison of the LEED and Green Globes Systems in the U.S.,” report nearly 80 percent of the points in the Green Globes system were also addressed in the LEED system, and more that 85 percent of the points in LEED were addressed in Green Globes (Smith, et. al., 2006).

2. The Pilot Project

In 2006, eight buildings were selected to undergo certification under GBI’s U.S. pilot of Green Globes. All eight were also planning to undergo LEED certification, however one project dropped out of the LEED process. The remaining seven buildings included: the William J. Clinton Presidential Center, Little Rock, AR., which achieved Two Green Globes and LEED Silver, the Alberici Headquarters, Overland, MO., which achieved Four Green Globes and LEED Platinum; the Pfizer Clinical Research Unit, New Haven, CT., which achieved Three Green Globes and LEED Silver, Blakely Hall, Issaquah, WA., which achieved Two Green Globes and LEED Silver, the Wisconsin Electrical Employees Benefit Fund Office, Madison, WI., which achieved Two Green Globes and finally the Home Savings Bank, Madison, WI., which achieved Two Green Globes and LEED Silver. The green features for all seven of these buildings have been verified by third-party agents. LEED requires systems commissioning to be undertaken by a third party. While Green Globes requires that all their certified building undergo a comprehensive on-site verification by a third-party verifier.

2.1 The William J. Clinton Presidential Center

This 150,000-square foot building, located in Little Rock, Arkansas, is constructed on an old underutilized industrial site and has become a stimulus for adjacent development. This Center incorporates the use of

Table 2. Percentage of points assigned to system categories

LEED	Points	% of Total	Green Globes	Points	% of Total
Energy & Atmosphere	17	25	Energy	325	33
Indoor Environmental Quality	15	22	Indoor Environment	220	22
Sustainable Site	14	20	Site	220	22
Materials & Resources	13	19	Resources	100	10
Water Efficiency	5	7	Water	85	9
Innovative & Design Process	5	7	Project Management	50	5
Total	69	100	Total	1000	100

environmentally sensitive systems, uses low impact materials, renewable energy and the purchase of green power. This building achieved the same rating level in both systems, Two Green Globes and LEED Silver. However, within that second rating level, Green Globes rated this building slightly higher than did LEED. This was due to the fact that the Center scored well in Green Globes' Project Management and Emissions categories; LEED does not have such categories.

2.2 Alberici Headquarters

This two story, 110,000-square foot Class-A office building, located near St. Louis, Missouri, is constructed on a previous industrial site. This building reused much of the previous structure, it remediates previously contaminated land, has exceptional energy performance, an on-site wind generator, significant reuse and recycling of construction waste, uses low impact materials and exceptional attention was paid to IEQ issues. Both systems gave this building their highest rating, Four Green Globes and LEED Platinum. It achieved 93% and 87% of all possible points within the Green Globes and LEED systems, respectively.

2.3 Pfizer Clinical Research Unit

This 62,500-square foot clinical research building, located in New Haven, Connecticut, is constructed on an existing Brownfield site. This building remediates previously contaminated land, significant reuse and recycling of construction waste, uses low impact materials, and significant attention was paid to IEQ issues both during construction and operations. This building received a one level rating difference between the two systems, Three Green Globes and LEED Silver. This difference was due to the fact that the Clinic scored very well in the Green Globes' Project Management and IEQ categories. The integrated project team that Pfizer formed for this project was highly valued within Green Globes; LEED has no equivalent category. In addition, the level of IEQ quality that exists in a clinical building such as this one seems to have scored much better under Green Globes (scored 80% in their IEQ section) than it did under LEED (scored 60% in their IEQ section).

2.4 Blakely Hall

This 7,000-square foot mixed use building, located in Issaquah, Washington. Blakely Hall is part of the 2,200 acre Issaquah Highlands Community, a community noted for making a strong commitment to environmental stewardship. This building incorporates the use of daylighting, natural ventilation, uses low impact materials and significant reuse and recycling of construction waste. Blakely Hall achieved the same rating level in both systems, Two Green Globes and LEED Silver. However, within that second rating level, Green Globes rated this building slightly higher than did LEED. This was due to the fact that Blakely Hall did not have the resources to perform energy modeling, thus they did not achieve any energy points. Green Globes requires a much easier energy performance exercise, which is why there was a slight difference between these two systems for this building.

2.5 Wisconsin Electrical Employees Benefit Fund Office

This 12,000-square foot office building, located in Madison, Wisconsin, is constructed on a previously undisturbed site. The WEEBF building incorporates an innovative use of prairie grass landscaping to reduce run-off, has a high level of energy performance, use of recycled and local materials, use low impact materials and green power. This building received a one level rating difference between the two systems, Two Green Globes and LEED Certified. This difference was due to the fact that the WEEBF building scored very well in

Table 3. Results of the comparison

Evaluated Buildings	Green Globes	LEED
Clinton Presidential Center	Two Globes (68%)	Silver (34 out of 69 points (49%))
Alberici Headquarters	Four Globes (93%)	Platinum (60 out of 69 points (87%))
Pfizer Clinical Research Unit	Three Globes (70%)	Silver (33 out of 69 points (47%))
Blakely Hall	Two Globes (64%)	Silver (34 out of 69 points (49%))
Wis. Elect. Employees Benefit Fund	Two Globes (55%)	Certified (26 out of 69 points (38%))
RenewAire Facility	Two Globes (66%)	Silver (33 out of 69 points (49%))
Home Saving Bank Branch	Two Globes (55%)	Silver (33 out of 69 points (49%))

the Green Globes' Project Management category. The integrated nature of a design build project was highly valued within Green Globes; LEED has no equivalent category.

2.6 RenewAire

This 37,000-square foot office/industrial building, located in Madison, Wisconsin, is a major remodeling of an existing building. The RenewAire Building reused much of the previous building, has air-to-air heat recovery, has a high level of energy performance, significant reuse/recycling of construction waste, use of low impact materials and green power. This building achieved the same rating level in both systems, Two Green Globes and LEED Silver. However, within that second rating level, Green Globes rated this building slightly higher than did LEED. This was due to the fact that this building scored well in Green Globes' Project Management; LEED does not have such categories.

2.7 Home Savings Bank

This 5,000-square foot branch bank building, located in Madison, Wisconsin, is constructed on a pre-developed site. The Home Saving Bank building incorporates the use of daylighting, provides space for use by the local community, has air-to-air heat recovery, has a high level of energy performance, a rain garden, significant reuse and recycling of construction wastes, use of low impact materials and green power. This building achieved the same rating level in both systems, Two Green Globes and LEED Silver.

3.0 Results

Table 3 presents the results from the seven individual building comparisons that were undertaken. Although, each of these systems addresses slightly different levels of detail, these seven buildings represented a good range of building type, size and geographical location. Both rating systems in their assessment of each of the seven dual certified buildings seemed to have identified similar reduction in environmental impact. Thus, the detailed side-by-side comparison presented in Table 3 indicates a high level of equivalency between the two systems. Where differences exist, they are much more a result of minor criteria differences than with overall system differences.

4.0 Conclusion

The application of LEED within North America has been well documented in the professional press. However, it is becoming increasingly clear that we need a much more rapid uptake of green buildings (since April 2000 only 1500 buildings have actually been LEED certified) and that "one size does not fit all." It seems that many architects, builders and developers that deal with smaller sized projects do not have access to the level of resources, expertise or consulting services necessary to successfully navigate the LEED preparation, documentation and submittal process. A system such as Green Globes, which uses a web-based questionnaire approach with its lower entry threshold and immediate feedback not available from a primarily paper-based system, seems much more appropriate for this audience. Thus, having competing systems that have a recognized level of equivalency is an important prerequisite in moving green buildings into the mainstream of North American building practices. It is hoped that this comparison and the high level of equivalency that was shown between Green Globes and LEED can help achieve this outcome.

Reference

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Life Cycle Costing as part of decision making - use of building information models

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ABSTRACT: Building Information Modelling (BIM) is a new approach for being able to describe and display the information required for design, construction and operation of buildings. More extended use of BIMS, with the development of Information Delivery Manuals (IDMs) for environmental assessments, energy calculations and LCC, ensuring more automatically data flow between different data bases, calculation tools and Building Information Models (BIM), will simplify the use of LCC in design. More extended use of LCC, and storing the results for future use may also improve the Facility Management. Several projects have dealt with cost information flow, as information exchange between the BIM and LCC-tool and improving cost data bases, simplifying the data access as well as storage possibilities to ease and extend the use of LCCA. This paper will present the current stage of the different project aiming at increased use of LCCA by use of BIM and IDMs.

1 INTRODUCTION

Building and construction projects may benefit by use of Life Cycle Cost Assessment at early stage of the design process, the results contributing to decision support taking both investment and operation costs into account. Qualitative good results demand good input data to the calculations, even at stages where few decisions are taken.

Building Information Modelling is a new approach for being able to describe and display the information required for the design, construction and operation of constructed facilities. It is able to bring together the different threads of information used in construction into a single operating environment thus reducing, and often eliminating, the need for the many different types of paper document currently in use.

Realistic LCCA, as a good basis for decision making, requires easy accessible data in all phases from brief to construction, where statistic information, key numbers and experience data is valuable information. A well defined classification system for the categorisation of costs and other input data is important for a successful use of LCCA. Increased use of LCCA at several stages in the decision process also requires increased data exchange and storage possibilities. Extended use of LCCA may improve the decision process towards more economic as well as environmental and energy efficient buildings.

More extended use of Building Information Models (BIM), with the development of Information Delivery manuals (IDMs) for environmental assessments, energy calculations and LCC, ensuring more automatically data flow between different data bases, calculation tools and Building Information Models (BIM), will simplify the use of LCC in design. More extended use of LCC, and storing the results for future input to Facility Management may also improve the Facility Management.

Easy access to comparable data gives the building owners' possibilities to benchmark their buildings, with emphasis on energy use and operation cost. This will lead to more focus on operation of buildings, as well as improvement of energy efficiency.

Several projects have worked with improves cost information flow, as information exchange between the BIM and LCC-tool and improving cost data bases, both key number bases and cost data bases related to building parts, and further information flow from FM-information into cost data bases. Key numbers may be found from statistical treatment of collected data. For instances energy use/energy costs pr m2, cleaning costs pr m2, or cost used for management or maintenance for different building categories (function and age). Key numbers may be used for benchmarking, as all users may compare their actual data with the collected data, and hence know how their use and management of the building is compare to others.

2 BUILDING INFORMATION MODELING

2.1 *IFC, BIM, and buildingSmart*

The development, maintenance, implementation and dissemination of Industry Foundation Classes, IFC and IFC enabled products is part of the buildingSMART initiative of the International Alliance for Interoperability, IAI, and its affiliated organizations and companies. “buildingSMART is integrated project working and value-based life cycle management using Building Information Modeling and IFCs”

The purpose of IFC as part of the buildingSMART initiative is "enabling interoperability between AEC/FM software applications". It is embedded in a broader scope of achieving beneficial change in industry, using Building Information Modeling (BIM) and IFCs as the trigger to smarter ways of working. IFCs target both the software development community and the practitioners in the AEC/FM industry.

- Developing software that benefits from the international, single and interoperable schema of construction elements, specifications and structures is the task of software companies. Software developers have to understand the detailed structure, content, and processing of IFC.
- Applying interoperable and IFC compliant software within construction processes requires users that are knowledgeable about their processes, the exchange requirements within each process, and its relevance to the technical, commercial and legal side of the operation. Practitioners have to understand how to map general concepts or parts of the IFC to the detailed exchange requirements within their projects and how to assess and use IFC compliant software.

IFC and use of BIM will have great potential for cost reduction and utilize effects in the value chain at least in these areas:

- Focus on the customers and end-users requirements within the building process and life cycle phases.
- Re-engineering of the building process with new opportunities for new and existing actors.
- A comprehensive and common international knowledge model database with standardized ICT tools, objects and communication rules and available best practices examples.
- Cost reduction and better project economy in the supply chain, between the suppliers and the contractors.
- Improved possibilities for early stage analysis about: best practice design, construction cost, energy consumptions, environmental impacts and lifecycle cost.

2.2 *Planning and construction process*

Planning and design of buildings and constructions are phases in a process with many actors and an intensive process of sharing and/or repeating information. Figure 1 shows the information flows between the different actors in a construction process, both a traditional process and by use of Building Information Models.

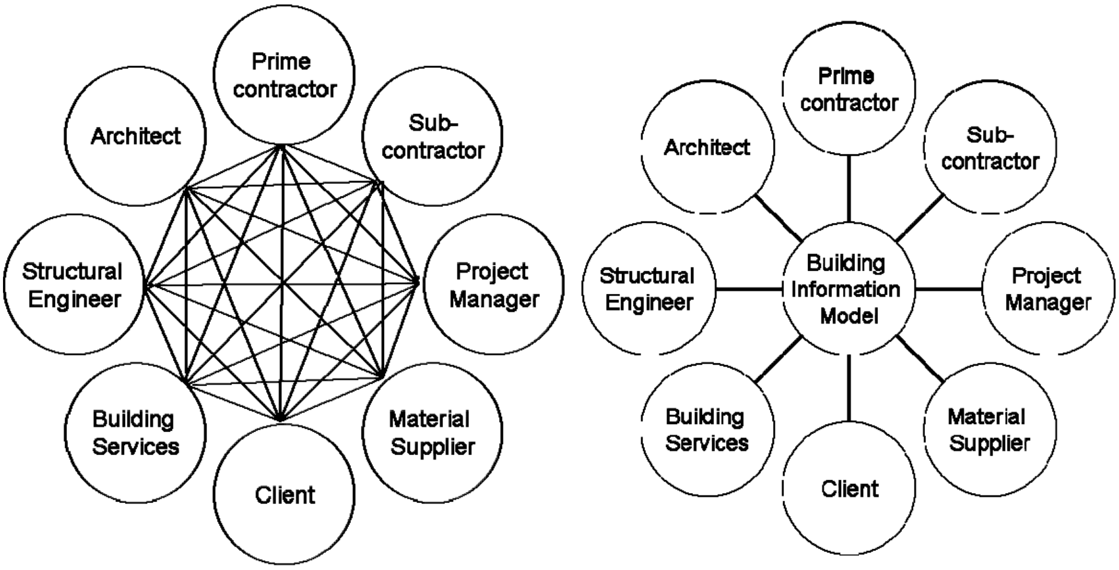

Figure 1 Information flow between actors in a traditional project and by use of Building Information Model

When all actors have access to the same information, and the possibility to transfer information from the model to the different calculation and analysis tools, all decision making can be based on up to date analysis of the interesting aspects. More analysis may be done in an early phase of the project, while it is still possible to make changes. Analysis may also be done on different alternatives.

Life cycle costs analysis or assessment may throughout all stages be done by use of information in the BIM, information from different cost databases, and with application that is ifc compatible ensuring a seamless data transfer. Results from the analysis are then fed back to the BIM for use in other analysis, decision making or for later use in facility management in the operation phase.

3 LIFE CYCLE COSTING ASSESSMENT

3.1 *Life cycle costing used in decision making*

Life cycle costing assessment should benefit that the perspective of decisions is moved from investment costs to the total costs for the whole life cycle of the building or constructed work. Life cycle costing should not be used with the intention of decreasing the costs, but for ensuring the lowest cost over the life cycle when still fulfilling the performance requirements (functional and technical requirements). The assessment should also be used to show the estimated yearly costs before investments are done.

Using LCC as part of decision making requires good accessibility to reliable input data to the analysis at all stages of the planning and design process, starting with generic information (statistic, key numbers) to more and more specific information. Reliable statistic and generic information can be produced by collecting actual costs from management of buildings, using specified and standardized cost classification. The Norwegian Standard NS3454 Life cycle costs for building and civil engineering work – Principles and classification (NS, 1997) does, as also similar German and Austrian standards, give a cost classification system. The Norwegian database owned by Network for benchmarking yearly collect actual costs from their members' buildings, then providing a database with costs to be used for benchmarking and input to LCC calculations. Table 1 shows the main categories in a proposition to a new common Nordic standard.

Table 1 Cost classification for Life Cycle Costs in proposition to new Nordic standard

No.	Main Item	Definition	Sub-categories
1	Capital	All investments towards completion including	11 Project costs 19 Remaining costs

		decommissioning by the end use of the facilities	
2	Administration	Activities for administration, required payments and insurance costs	21 Taxes and fees 22 External costs 23 Administration and management 24 Insurance 29 Various
3	Operation	Include daily, weekly and monthly activities that are repetitive within a one year period for building and technical installation systems that shall satisfy given functional demands and requirements	31 Operation and inspection executed by own employees 32 Operation and inspection executed by external companies 37 Outdoor operation and inspection executed by own employees 38 Outdoor operation and inspection executed by external companies 39 Various
4	Maintenance	Include all activities and efforts put forward in a period of more than one year. For example, planned maintenance, replacement and emergency repairs, so that the building and technical systems satisfies the original level of quality and functional requirements.	41 Periodical maintenance of exterior of the building 42 Periodical maintenance of internal of the building 43 Replacement of exterior 44 Replacement of interior 45 Emergency repair work for exterior 46 Emergency interior repair 49 Outdoor
5	Developing	Includes activities as a result from change in demand from core activities, the authorities, total refurbishment, or all activities to raise the construction standards in relation to the original level	51 Development and upgrading of exterior of the building 52 Development and upgrading of internal of the building 59 Development and upgrading outdoor
6	Consumption	Consumption includes resources in terms of energy, water, and waste handling	61 Energy 62 Water and Drainage 63 Waste Handling 69 Various
7	Cleaning	All activities inside and outside for satisfactorily meeting cleaning demands	71 Daily/Periodic 72 Main cleaning 73 Special cleaning 74 Window cleaning 75 Façade cleaning 79 Outdoor cleaning
8	Service	All non-building related activities in support of the core activity	81 Security and safety 82 Reception/switchboard 83 Mail 84 IT service 85 Moving 86 Catering 87 Accessories/copying 88 Administrative support 89 Furniture and inventories

Life cycle costing can be presented as Net Present Values or Net Present costs, while other options are available, as Annual Cost or Annual Equivalent Value, or Payback. Definition of cost categories and calculation rules are given for example in ISO/DIS 15686-5 “Buildings and constructed assets – Service life planning. Part 5 – Life cycle costing” (ISO, 2006).

3.2 *LCC in different project stages*

The standard exchange requirements published in IDM are identified against project stages defined within the Generic Process Protocol (GPP) (Michail Kagioglou et al, 2000). These are identified below with their stage number as used in the exchange requirements documents, description and definition from the GPP. Stage 10 (disposal) is a modification to the standard GPP list to handle the final stage of a project lifecycle. These are shown in Table 2

Table 2 Project stages defined in Generic Process Protocol

Stage	Description	Definition
Pre-project stages		
0	Portfolio requirements	Establish the need for a project to satisfy the clients business requirement
1	Conception of need	Identify potential solutions to the need and plan for feasibility
2	Outline feasibility	Examine the feasibility of options presented in phase 1 and decide which of these should be considered for substantive feasibility
3	Substantive feasibility	Gain financial approval
Pre-Construction stages		
4	Outline conceptual design	Identify major design elements based on the options presented
5	Full conceptual design	Conceptual design and all deliverables ready for detailed planning approval
6	Coordinated design (and procurement)	Fix all major design elements to allow the project to proceed. Gain full financial approval for the project
Construction stages		
7	Production Information	Finalise all major deliverables and proceed to construction.
8	Construction	Produce a product that satisfies all client requirements. Handover the building as planned.
Post-construction stages		
9	Operation and maintenance	Operate and maintain the product effectively and efficiently.
10	Disposal	Decommission, dismantle and dispose of the components of the project and the project itself according to environmental and health/safety rules

3.3 *Geometric and spatial structure*

A spatial project structure might define as many levels of decomposition as necessary for the building project. The costs might be added to any element. Elements within the geometric and spatial project structure are:

- site as IfcSite
- building as IfcBuilding
- storey as IfcBuildingStorey
- space as IfcSpace
- building elements as IfcBuildingElement
- components as IfcBuildingElementComponent
- products as IfcProducts

The structure from site, building, elements, components, and products is further used as cost levels.

3.4 *Performance requirements*

Before doing the life cycle cost assessment it is important to have the performance requirements for the facilities to study. The BIM makes it possible to start the process by having a performance requirement model, which later will be used as part of the checking systems, analyzing which requirements that are fulfilled. The performance requirement model will then be further developed and improved throughout the planning stage. The alternatives compared should always fulfill the performance requirements.

3.5 *Intangible costs – extra value*

Intangible costs is usually not included in LCC, but if possible, value might be given and used as an additional part of the decision process. There might also be given values to extra functions or performances, for instance based on experience, but these values should also only be used as an additional part of the decision process.

3.6 *Examples of LCC in different stages*

LCC in pre-project stages is used for studying the consequences of the performance requirements, before any decisions are made. In the early stage of a project, LCC forecasting may use 'benchmark costs' based on historical costs of previous projects. As design evolves and more detailed information becomes available, benchmarks should be substituted with first principle project-specific estimated costs. Often (but not always) life cycle costing will include a single lump sum which represents all the acquisition costs (e.g. the purchase cost) and may also take account of residual value/disposal costs. The analysis in pre-project stages are aiming at assign different alternatives, where continuing as to day may be one option.

One example is increasing school capacity, where the alternatives may be as follows:

- Continuing as today – some pupils sent to other schools
- Extension of existing school, with or without refurbishment of existing building
- New school in addition to existing school – different location
- New school with higher capacity instead of existing building

Comparing the different alternatives it is important to include differences in costs for running the core business (school), not only the building related costs. This may be included in category 8 costs. Table 3 shows examples of sources for information at this stage, number of m2 may be statistic information based on number of pupils. At this stage the comparison is on main alternatives, not design, construction, or installations. The main cost differences may be in category 8, the decision at this stage might not be building related, but taking into account the differences in costs for the core business. Almost all costs are statistic or historic information, updated for extra m2. All costs as on building or site level.

Table 3 Cost categories and sources for information

Cat.	Alt 0	Alt 1a – 1b, 2, 3, and 4
1	No investments	Generic information – investment costs pr m2 for new buildings and refurbishment
2	Existing costs	Existing costs – corrected for number of m2 or key number for costs per m2 or per pupil
3	Existing costs – higher costs in future?	Key number for school buildings, per m2, for building from same time period – and new buildings
4	Existing costs – higher costs in future?	Key number for school buildings, per m2, for building from same time period and main materials – and new buildings
5	No costs	Upgrading of existing building – key numbers for upgrading buildings from the same period
6	Existing costs	Existing costs and key numbers, energy use as in regulations
7	Existing costs	Key number for school buildings, per m2, for building from same time period and main materials – and new buildings
8	Existing costs Transport costs pupils to other schools Costs for pupils at other schools	Existing costs Changes in use of staff compared to Alt 0, need for more teachers, need for more administrative staff if 2 schools etc.

The calculated life cycle costs are used for choosing alternative – more than one if more detailed comparison is necessary to decide – and to get financial approval. If the costs for all alternatives are too high, this is also the stage for redefining the requirements.

As alternatives it is possible to add extra requirements to the alternatives, for instance a swimming pool. Results from alternatives with or without swimming pool should then not be directly compared, but results used for deciding whether the value of the gain swimming pool exceeds the costs.

3.7 *Life cycle costing in conceptual and design stage*

With a database for facility management costs from existing buildings, where building information as age, main construction systems and materials, types of ventilation etc are given, statistic cost information can be tagged with those technical and functional descriptions.

When comparing different designs and technical installations, where the performance requirements always are fulfilled, many calculations still can be based on statistic information. Cost information might still be used as input on building levels, adding some specific information on system or building part level. Examples of relevant input costs, sources and level where they are to be used are shown in Table 4.

Table 4 Examples of relevant costs and level to be used in LCC in design stage

Cost category	Site/building	Room	Element	Component	Product (usually not selected at this stage)
Capital	Investments aggregated from element. Demolition costs		X Cost data bases	(X) Cost data bases	Cost data bases
Administration	X Key numbers				
Operation	X Key numbers				
Maintenance	Key numbers, “corrected” for statistic information fro certain systems and installations		X Statistic information/experience	(X)	
Developing	X				
Consumption	X Regulations or energy calculations for different designs	(X) Separate calculation for certain rooms/functions?			
Cleaning	X – aggregated from room, key numbers	(X) Key numbers or experience for different levels of cleanliness			
Service	X				

Information about elements, areas, numbers, etc will at this stage be extracted from the design model(s). As the table shows, statistic information on building level, where tagged information is used, will be sufficient for LCC at early stage, comparing different main alternatives. The LCC calculations will then also give for instance total and annual cost for the whole building life cycle.

Further in the design stage, as more and more information can be linked to elements, components and products, mainly investments and maintenance.

4 CONCLUSION

Using BIMs, from performance requirement models to design models, and different ifc compatible cost data bases, LCC calculations will be more useable as input data will be available and can be automatically transferred between the model, databases and applications. LCC can be done at every stage, and hence be a part of the decision making process early in the design process.

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ISO (2006) ISO/FDIS 15686-5 Buildings and constructed assets – Service life planning Part 5 – Life cycle costing.

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TITLE: NOVEL PCM MICROCAPSULES FOR RESIDENTIAL HOUSES

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Keywords: PCM, microcapsules, paraffin wax, nano-composite materials, gypsum board, cement

Summary

This report describes the development of novel phase change material (PCM) microcapsules made with paraffin wax, the introduction of a new apparatus for producing the capsules, and outlines the results of a preliminary study undertaken at an experimental house.

We have developed a PCM microcapsule which uses polyurethane resin as the shell material instead of conventional acrylic resin. To improve the durability of the microcapsule, nano-composite materials are dispersed into the shell. Unlike acrylic-type PCM microcapsules, the novel PCM microcapsule can be used in combination with a variety of matrices such as gypsum and cement.

Gypsum boards containing the PCM microcapsules obtained by using the newly developed apparatus were produced at a gypsum board manufacturer. The gypsum boards have a thickness of 12.5 mm and contain 3kg/m^2 of the PCM microcapsules.

The gypsum boards made with PCM were installed at an experimental house in Tsukuba City, northeast of Tokyo.

A computer simulation program has also been developed to predict the effect of gypsum boards containing PCM in terms of energy consumption and indoor thermal fluctuations. In the simulation program, thermal properties around phase change temperatures were taken into careful consideration.

1. Introduction

The Kyoto Protocol came into effect in February 2005 and addressed the urgent need to reduce CO_2 emissions. In Japan, however, such reduction lags behind in the residential sector.

Thermal environmental needs have conversely been augmented in terms of health and safety, accompanied by an ongoing increase in energy use by residential houses. As society becomes an increasingly aged one, there are concerns over health and safety, such as preventing heat shock, and the thermal environment of residential houses must be maintained to ensure that temperature differences do not exceed a certain value regardless of location and time. This will result in increased operation space and operating time of existing air-conditioning equipment, and lead to increased energy use if no measures are taken.

Reducing the amount of energy consumed by detached owner-occupied housing stock is also a major problem. Enhancing heat insulation offers one solution, but may require the addition of heat-insulating material to outside the building or increasing the fill thickness of insulating material inside the walls. As a result, this may involve extensive renovation work for the entire building at high cost. To spread and promote energy saving, it is necessary to alleviate the level of building frame changes in such renovation work through the combined use of insulation enhancement and other air-conditioning load reduction techniques.

2. PCM microcapsules and gypsum board with PCM

2.1 Development of PCM microcapsules

Paraffin wax stores and releases its latent heat upon undergoing a phase change, and the PCM microcapsules of this paraffin wax are encapsulated in a resin shell layer into a microcapsule form.

2.1.1 Examination of shell resin composition

As a two-liquid mix setting resin, three kinds of resin (urethane-based, epoxy-based, and modified silicone-based resin) were examined. Shell layer formation (loss on heat at 100°C for one hour assuming a gypsum board production line) offers barrier performance—an important quality for sealing the core material of heat storage wax. In terms of this quality, the urethane-based resin was found to be superior.

2.1.2 Trial production and examination of urethane-based particles

The problems posed during manufacture of the gypsum board with PCM must be understood, and the ease of working the board obtained and its effect on housing work predicted by applying the board to a model house. For these reasons, PCM microcapsules with a shell layer of urethane resin were produced on a trial basis using the above-stated basic composition by using a batch-type disperser (of 700-liter capacity).

Table 1 lists the physical properties of the PCM microcapsules produced. Productivity is improved as the solid content increases; however, the solid content was set to 33 percent in considering the ease of handling the PCM microcapsule emulsion on the gypsum board production line. In terms of thermal conductivity, a particle diameter of 50 micrometers or less is desirable. In this trial production, the dispersion conditions in water were examined and the mean particle diameter was taken at 6 micrometers. From the optical microscope image shown in Figure 1, one can see that the PCM microcapsule obtained has a diameter of about 6 micrometers with a shell layer being successfully formed.

The amount of heat stored is uniquely determined by the heat fusion of the wax used and the wax content. It was set to 70 kJ/kg considering the size of the shell layer and the particle dispersibility in water.

The reference is an emulsion of particles with the shell layer made of an acrylic-based resin with a solid content of 40 percent. Its particle production method is inferred to be batch-type suspension dropping radical polymerization, which apparently takes about 10 hours to form PCM microcapsules. Its amount of stored heat was 70 kJ/kg, unchanged from that of the particles, and its loss on heat was 3 percent, inferior to the particles.

Table 1 Properties of batch-type trial product of PCM microcapsules

Item	Trial product for molding by actual machine	(Reference)
Solid content	33%	40%
Mean particle diameter	6 μm	10 μm
Shell composition	Urethane-based resin	Acrylic-based resin
Amount of heat stored	70 kJ/kg	• 70 kJ/kg• •
Loss on heat	1%	3%

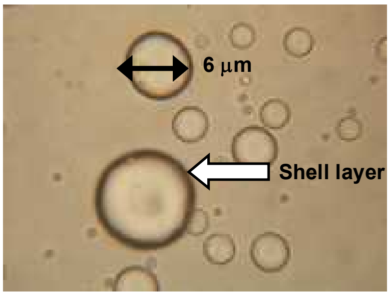


Figure 1 Optical microscope image of PCM microcapsules (in water)

2.1.3 Examination of VOC reduction methods

A test piece was used to confirm that VOC emissions could be reduced using a nano-composite material such as clay (a clay compound in plate form) treated with organic ammonium salt. The baffle effect of clay is believed to improve the sealing performance of the wax and reduce VOC emissions. As shown in the cross-sectional TEM (transmission electron microscope) image below, the depositing of nano-dispersed clay on the inner wall of the PCM microcapsule shell layer can be confirmed.

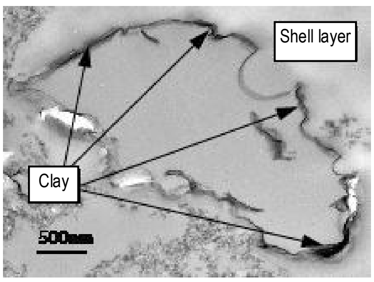


Figure 2 Cross-sectional TEM image of clay-added PCM microcapsule (1)

2.2 Development of manufacturing process of PCM microcapsules

2.2.1 Development and design of new continuous fabrication method

A pilot production machine was developed. This machine can be synchronized with gypsum board production to supply PCM microcapsules continuously.

Table 2 PCM microcapsule formation process and equipment introduced

Process	Equipment introduced	Description
(a) Continuous supporting process of wax on silica	Continuous powder mixer	Sends wax support of a homogeneous composition to the next process continuously.
(b) Continuous fast dispersion process of shell layer urethane resin and wax support in water	Continuous mixer-disperser	PCM microcapsule emulsion (liquid) can be produced continuously and instantly.
(c) Continuous heating and cooling process	Continuous heating and cooling tank	Can heat or cool continuously by moving the liquid from below to above.

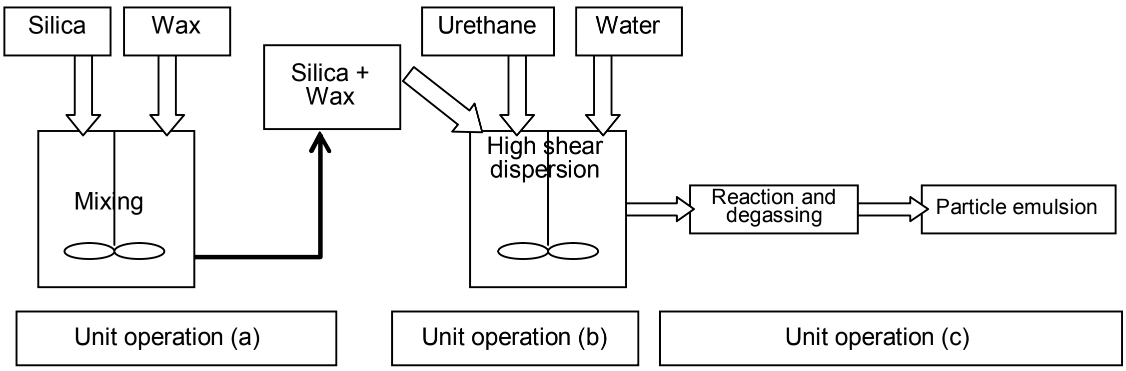


Figure 3 Process flow of PCM microcapsule emulsion

2.2.2 Examination of pilot facility

The pilot facility has a production capacity of 250 kg per hour of solid particle content. Table 3 below lists the examination results.

Table 3 Examination results of pilot facility

Reaction method	Conventional acrylic resin-based process	Fast dispersion and continuous reaction
Reaction method	Batch polymerization	Fast dispersion and continuous reaction
Reaction time	About 10 hours	5 minutes
Facility cost	Up to 800,000,000 yen	Up to 200,000,000 yen
Note: One-hundred tons per month of solid content. Does not include stock supply, product conveyor systems, and building.		

Assuming an operating time of 400 hours per month, a capacity of 100 tons per month is equivalent to about 30,000 square meters of gypsum board with PCM (assuming a mix proportion of 3.1 kg per square meter). Because the developed process is continuous, it offers high potential, including easy scaling-up.

2.2.3 Continuous powder mixer

The role of the continuous powder mixer is to make silica (powder) to support wax (liquid) for a continuously and stable supply to the continuous mixer-disperser in the next process

As the continuous mixing method, the process of constantly feeding silica using a weight-based feeder and feeding wax using a gear pump to charge both in a mixer was examined.

In the continuous powder mixer shown in Figure 4, silica is scattered by centrifugal force of the attrition plate (a disk fitted with blades), with wax flowing down to the blades and being scattered to form fine droplets comparable to a spray. Thus, silica and wax are mixed instantly to obtain a homogeneous wax support.

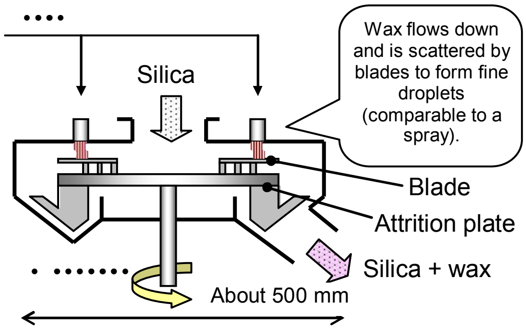


Figure 4 Schematic diagram of continuous powder mixer

2.2.4 Continuous disperser

As the peripheral speed of the continuous disperser's moving blades was increased, the mean particle diameter of formed PCM microcapsules decreased, showing a sharp diameter distribution. Diameter control is possible in our target range of 5 to 20 micrometers.

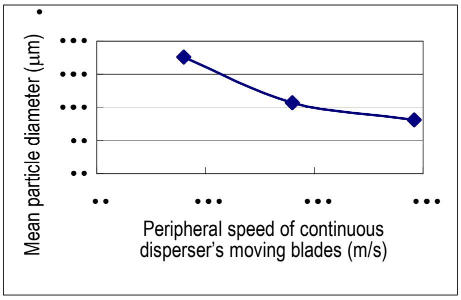


Figure 5 Mean particle diameter versus peripheral speed of continuous mixer-disperser

2.2.5 Continuous heating and cooling tank

In a continuous production process, it is desirable to suppress a rise in liquid level and prevent particle aggregation by increasing the reaction rate of urethane. A tube method and tank method were examined as such a process.

Table 4 Comparison of tube method and tank method

	Tube method	Tank method
Features	PCM microcapsule emulsion flows in the tube. Heating and cooling take place using water around the tube.	PCM microcapsule emulsion is heated and cooled in one tank, then agitated to overflow into the next tank.
Pressure loss	2 Because liquid feeding is done through tubing 200 meters or more in length, there is large pressure loss under high flow velocity.	Because liquid feeding is done only up to the level of one tank, there is low loss of pump pressure.
Scale removal	Removal is virtually impossible. Anti-deposition agent cannot be used.	Can be removed. Anti-deposition agent can be used.
Carbonic acid gas	Because gas cannot be vented at other than outlets, it blows out of outlets intermittently.	Because gas is released from the top of each tank, it has no effect on other tanks.
Particle aggregation	Particle aggregation cannot be avoided by feeding motion in the tubing only.	Particle aggregation can be prevented because cooling occurs while stirring.

As shown in Table 5 below, the tank method can address all problems in the process, and is thus considered suitable for the continuous heating and cooling process.

2.3 Performance confirmation of PCM microcapsules and gypsum board with PCM

Table 5 Properties of PCM microcapsules made by trial production

Item	Unit	PCM microcapsule A	PCM microcapsule B
Particle formation method		Batch	Continuous
Nano-composite	%	0	1
Fusion peak temperature	°C	22	22
Peak particle diameter	μm	11	10
Heat stored quantity	kJ/kg	70	72

For facility validation, PCM microcapsules were produced on a trial basis twice. A continuous pilot production machine added clay (nano-composite material) to particle B. Neither particle had trouble-free properties.

In terms of construction, the gypsum board with PCM contains unwoven glass cloth in its outer surface. For a charge rate of 1.8 tons per hour of plaster of paris and 2.7 tons per hour of emulsion, the mixed particle content was 3.2 kg/m^2.

Table 6 lists the results of a physical property test of gypsum boards with PCM. For all samples made by trial production, the bending failure load satisfied the JIS standard value for gypsum boards.

A formaldehyde and VOC emission test was conducted at a test temperature of 28°C according to JIS A 1901. Table 7 lists the results. Because no melamine-based resin is used in the shell layer, only a small amount of formaldehyde is emitted. A comparison of particles A and B confirmed that VOC emissions tended to be reduced by nano-composite treatment. For TVOC, however, the target value of 400 (standard in Japan) was not attained.

Table 6 Main properties of gypsum boards with PCM

		Unit	PCM microcapsule A	PCM microcapsule B	JIS standard value for gypsum boards
Thickness		[mm]	12.69	12.61	12.5•±•0.5
Weight per unit area		[kg/m^2]	11.5	11.5	7.5 to 11.3 (for information only)
Bending failure load	Length	[N]	668	641	500 or more
	Width	[N]	391	375	180 or more
Thermal conductivity		[W/mK]	0.20	0.22	0.17 to 0.20 (for information only)

Table 7 VOC emission test of gypsum boards with PCM (after 7 days) [μg/m^3]

	PCM microcapsule A	PCM microcapsule B
Formaldehyde	5.6	7.3
Toluene	78.3	61.9
Ethylbenzene	9.3	7.7
Xylene	40.6	34.4
Styrene	5.4	4.5
p-dichlorobenzene	22.9	18.8
n-tetradecane	76.8	13.6
n-heptadecane	548.0 (main ingredient of particle)	499.1 (main ingredient of particle)
n-octadecane	58.5	18.5
TVOC	453.7	450.5

2.4 Compatibility with cement

PCM microcapsule B was mixed with cement and allowed to harden. Because the shell layer of PCM microcapsule B is a urethane-based resin having alkali resistance, heat storage performance was maintained for a long period. For the particle with a shell layer of acrylic-based resin, it was confirmed that the shell layer was affected by alkali and wax exuded from the cement surface immediately after hardening.

3. Thermal evaluation of use in residential houses

3.1 Verification of thermal performance in outdoor experimental building

An evaluation was made in an outdoor experimental model house from September to November 2006 to obtain basic data for understanding and predicting the effects of the produced gypsum board with PCM on its use in a residential house. The model house had two rooms subject to the same external influences, In one room (9.1 m^2), the board was installed on the walls in a two-ply configuration over a total area of 24 m^2.

Table 8 Installation of heat storage building material in outdoor experimental model house

Floor area	Installed area	Installed volume	PCM microcapsule	Latent heat of board	Heat stored/floor area
9.1 m^2	24 m^2	48 m^2	PCM microcapsule A	224 kJ/m^2 of one ply	1,182 kJ/m^2

* Building body heat insulation performance: Equivalent to Q = 2.4 W/m^{2}K, Floor area: 9.1 m^2, Ventilation frequency: 0.5 time per hour

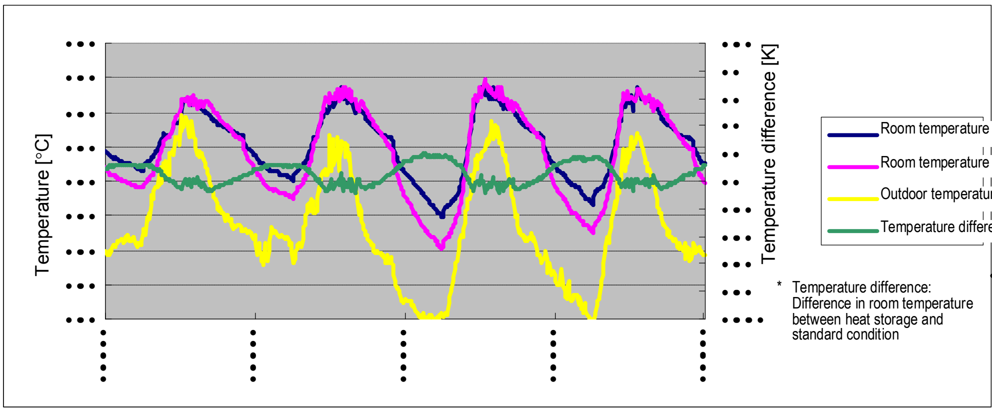


Figure 6 Temperature change for 27°C air-conditioner cooling plus outdoor air cooling at night

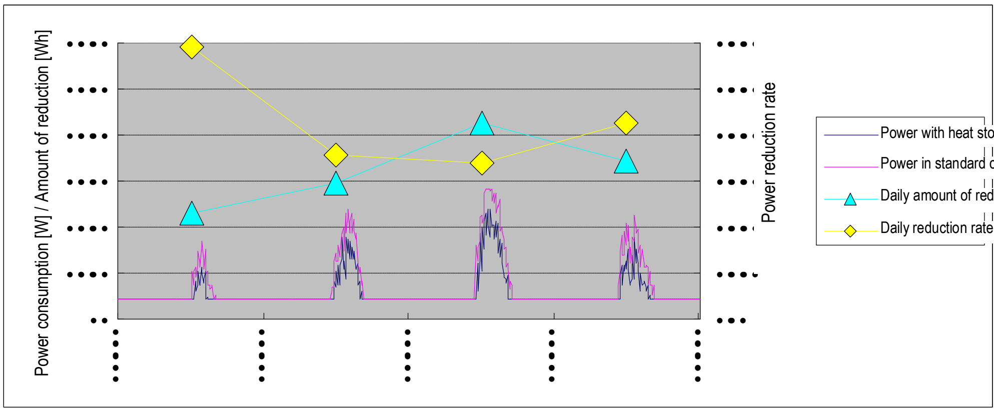
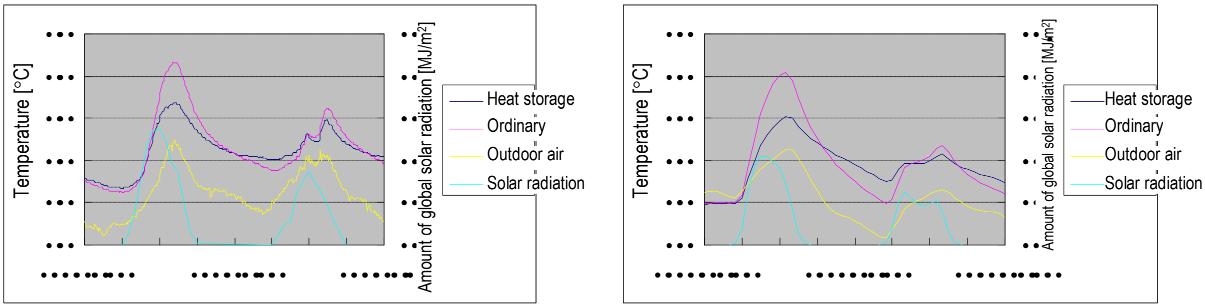


Figure 7 Power consumption of air conditioner for 27°C air-conditioner cooling plus outdoor air cooling at night

From the experiment results shown in Figures 6 and 7, a reduction in the range of room temperature fluctuations and a reduction in air-conditioner power consumption were confirmed.

3.2 Si Confirmation of consistency

To verify consistency between the above-stated experiment results and thermal simulation, the experimental house was modeled by using thermal simulation software, and a comparison was made of the calculation results on a day having weather conditions approximating those on the day of the experiment. Figure 8 shows that the simulation well reproduced the temperature characteristics obtained as an experiment result. Thus, the possibility of prediction by using the simulation software was confirmed.



Measured results

Simulation results

Figure 8 Measured results and simulation results

3.2.2 Estimation of effects

The effects of the gypsum board with PCM installed in an ordinary residential house were estimated by simulation. The building and conditions were set according to the standard problem model (floor area = 120 m^2 and building body heat insulation performance: Q = 2.7 W/m^2K) provided by the Architectural Institute of Japan. The gypsum board with PCM was installed on the walls and ceiling of the living-dining room (28 m^2) over a total area of 72 m^2.

During the heating period, the solar radiation heat in the daytime was held over; during the cooling period, the cold in the nighttime was held over, thus producing an energy saving effect. From the results, it was estimated that the air-conditioning load of the living-dining room could be reduced by about 10 percent.

Table 9 Amount of heat storage building material set for simulation

	Floor area	Installed area	Latent heat of board	Heat stored/floor area
PCM microcapsule A	28 m^2	72 m^2	224 kJ/m^2 of one ply	583kJ/ m^2

Table 10 Simulation results (air-conditioning load of living-dining room)

	Air conditioning load			Load reduction rate		
	Heating	Cooling	Heating and cooling	Heating	Cooling	Heating and cooling
No PCM microcapsule	5.3 GJ	4.5 GJ	9.7 GJ	—	—	—
PCM microcapsule A	4.5 GJ	4.5 GJ	9.0 GJ	15%	0%	8%

4. Conclusions

4.1 PCM microcapsules and gypsum board with PCM

The basic compositions and production processes for the PCM microcapsules and gypsum board with PCM were successfully established.

- For the shell layer, a urethane-based resin was used instead of an acrylic-based or melamine-based resin.
- This allows the continuous production process of PCM microcapsules to be directly coupled with a gypsum board manufacturing facility.
- Although the use of a nano-composite material in the shell layer reduced VOC emissions, the target value in Japan was not attained.
- This point requires further study in the future.
- The gypsum board with PCM made by trial production satisfied the strength properties prescribed in JIS A 6901 and therefore can ensure functioning as an interior building material (wall material).

4.2 Thermal evaluation in residential house

- A reduction in the range of room temperature fluctuations and reduction in air-conditioning power consumption were confirmed.
- The possibility of prediction by simulation software was confirmed.
- Thermal simulation software estimated the effect on reducing air-conditioning load in the living-dining room at about 8 percent over a full year.

5. Acknowledgment

The contents presented herein were developed based on the following subsidized project. We would like to express our sincere gratitude to those concerned.

2005-2006 House and Building-related Advanced Technology Development Subsidized Project (Ministry of Land, Infrastructure and Transport) "Technical Development Contributing to Efficient Energy Use in Residential Houses, etc."

Subject name of technical development: "Technical Development of Heat Storage Building Material Using Latent PCM microcapsule"

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TITLE: TRANSPARENT INSULATION MATERIAL FOR RESIDENTIAL HOUSES AND BUILDINGS

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Keywords: Daylighting performance, heat-insulating performance, sound-insulating performance, heat transmission coefficient (K-value), cold draft

Summary

The objective of the research presented here is to develop transparent insulation material for residential houses and buildings. The key feature of the transparent insulation material we have developed is to achieve a low K-value without using any low thermal conductive gases such as argon, krypton and xenon. In addition to this simple feature, it does not need any Low-E coating film. It just consists of multi-layer films with multi air layers, which form cavities inside the insulation material.

The K-value for transparent insulation material can be set from 0.4 (thickness of 150mm), 1.0 (thickness of 30 mm) to 3.5 (thickness of 4 mm). As for non-flammable types, achieved K-value ranges from 1.3 (thickness of 30 mm) and 3.5 (thickness of 4 mm).

The newly developed apparatus has been designed and introduced to make samples with a maximum width of 910 mm, length of 2,300 mm and thickness of 30 mm, which can be attached to most residential houses in Japan

Six types of applications using the novel transparent insulation materials have been proposed, based on their properties such as K-value and thickness. Of the 6 types, 3 are being tested at an experimental house in Iwamizawa City in the northern part of Japan.

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1. Introduction

Household energy consumption and CO_2 emissions from business facilities are increasing every year, thus posing an urgent need to reduce CO_2 emissions as a measure to address the global warming problem. In this situation, energy consumption must be reduced by, for example, improving the thermal performance at openings where heat loss is particularly large. Thus, we began developing techniques and products to improve the thermal performance of such openings without adversely affecting daylighting performance, transparency, or other features

An efficient technique to improve the thermal insulation of an opening is placing transparent insulation material on the panes of the opening. To construct said transparent insulation material, several layers of a translucent plastic film were stacked, between which a spacer was placed in part to form a thin layer of air. This multi-layer air sandwich structure was found to be effective (Figure 1).

• •

2. Outline of transparent insulation material

2.1 Construction of transparent insulation material

The transparent insulation material under investigation consists of a thin film and resin spacer, with no special restrictions on the material, provided that the film is translucent and the spacer can maintain the space. In addition to inexpensive transparent film or design film of various decorative patterns, heat-reflective film, light diffusion film, a prism sheet, and similar films can also be used, making it possible to create an optical design for the efficient use of sunlight.

Although the spacer features a typical stripe pattern with a pitch of 50 mm, this can be changed to discontinuous lines or a narrower pitch. Choosing the proper spacer material and pattern makes it possible to create a sound insulation design. Structures satisfying the noncombustibility requirements prescribed by the Building Standard Law of Japan are possible by limiting materials to the special film and spacer. Moreover, heat insulation design is possible with a K-value of 3.5 W/m^2K (comparable to that of double glazing) to 0.4 W/m^2K (comparable to that of a typical exterior wall in Japan) according to overall thickness and the number of air layers.

As stated above, this transparent insulation material offers a high degree of design freedom and can be selected to suit the needs of residents, both of which embody the major appeal of this material.

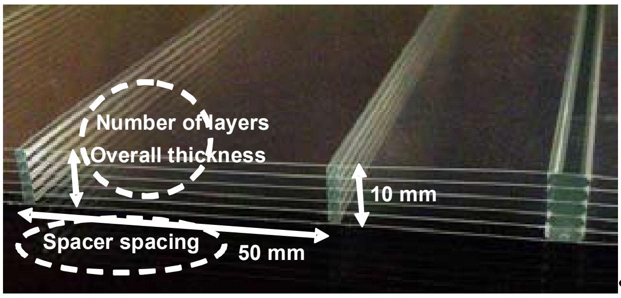


Figure 1 Component details

2.2 How to use

This transparent insulation material does not replace the panes of openings of a building, but is used as an attachment to those panes.

In one application, the transparent insulation material is framed around a frame fixed to the panes of an opening by direct bonding. In another application, the material is placed between hard plastic or glass plates and then framed around this component, which is fit in as an inner window or block. In either case, an attaching method is proposed so as not to damage the house, and components are designed to accommodate this component inside an existing railing or architrave without narrowing the living space. Therefore, it is suitable for renovation and also makes a novel residential house design possible as a new light-transmitting wall, so its deployment in new construction is also considered to be possible.

Applications were broadly divided into six types and research was conducted on Japanese consumers. As a result, three of the six applications were deemed highly necessary, and are being developed not only as a stock material but also as a building component, including the sealing method and related frame materials (Figure 2).

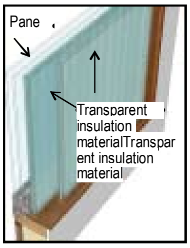
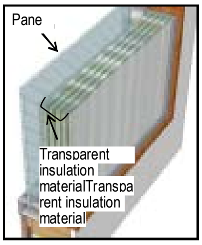
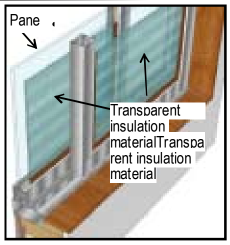
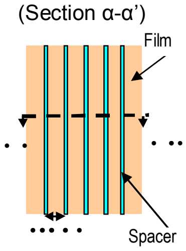
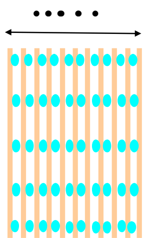
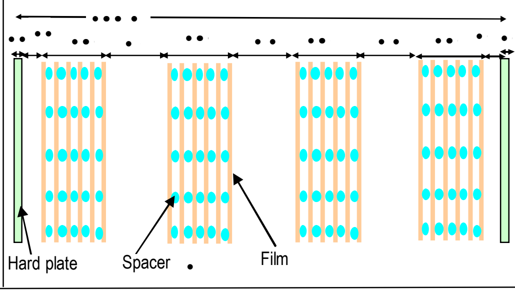
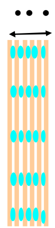
Application	Double-glazed window (inner window)	Daylighting block	Double-glazed window (simplified fixing)
Attaching to the pane of an opening			
Typical construction of heat-insulating daylighting	10 layers, 18-mm thick	5-layer 10-mm thick construction installed at 4 places	5 layers, 5-mm thick
Schematic (Section α-α') 			

Figure 2 Three core concepts and construction details

3. Manufacturing process

A process study was conducted using PET film−a general-purpose clear film−as the base film, and a transparent acrylic elastomer having heat resistance of 80°C for the spacer resin.

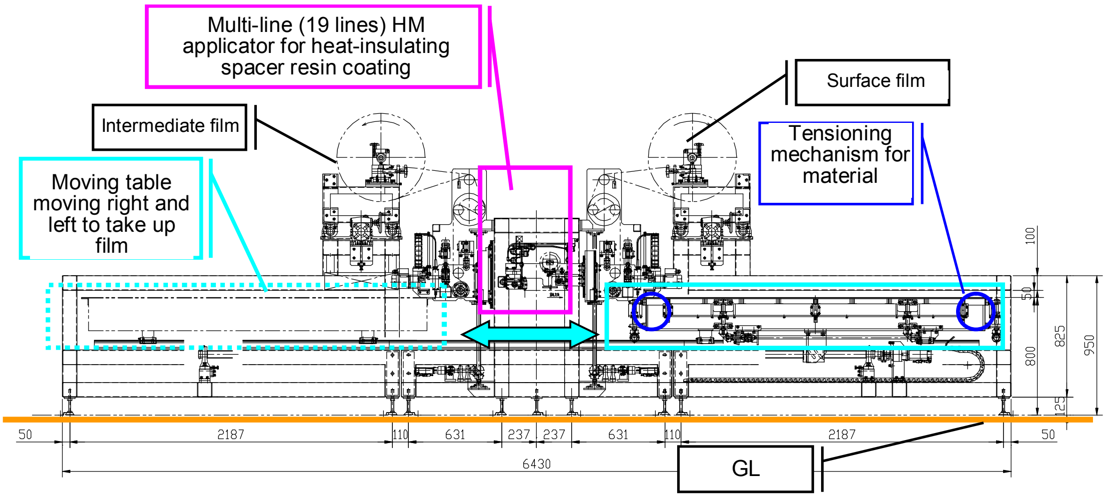


Figure 3 Schematic diagram of multi-layer laminator

The spacer is placed in part on the base film with the prescribed thickness and at the prescribed spacing. For this partial spacer formation, the direct bead application method was employed for its high manufacturing efficiency.

In this method, a hot-melt applicator applies adhesive in beads on the film. A multi-layer laminator was designed and introduced to simultaneously perform spacer formation and lamination, and multi-layer film lamination is now done using this machine (Figure 3). The film end is fixed to the end of the moving table, with film being drawn out of the film wind-off portion. A multi-line bead nozzle (with 17 bead lines) and a film end fixing and sealing coater (with two lines at the right and left ends in the transverse direction) apply the heat-insulating spacers on the film drawn out and fixed to the table as the table moves. Samples up to 910-mm wide, 2300-mm long, and having a maximum thickness of 30 mm can be formed.

4. Heat-insulating performance

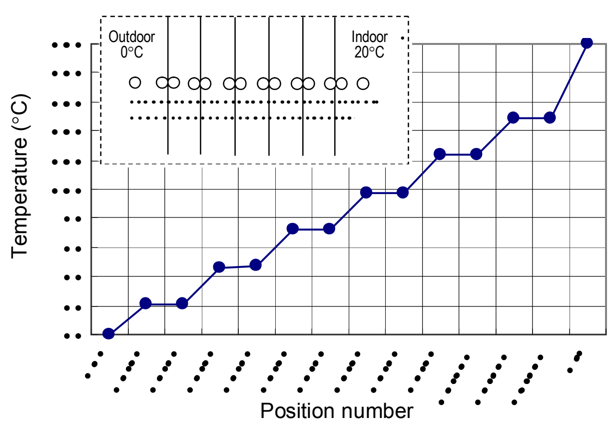
This transparent insulation material employs a multi-layer structure consisting of layers of thin film, between which a thin layer of air is maintained. This structure offers high heat-insulating performance (K-value of 0.4 to 3.5 W/m^2K) without using special deposited film such as a Low-E film or filling the space with argon, krypton, or other gas of low thermal conductivity. Its mechanism is described below.

4.1 Mechanism of heat transfer

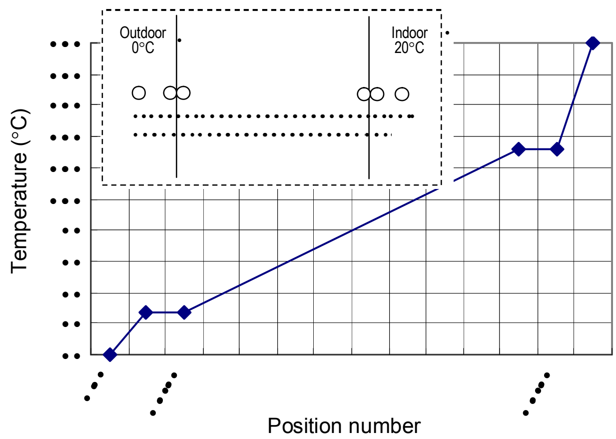
The mechanism of heat transfer via the transparent insulation material has three features: (1) causing no convection due to the set layer spacing, thus restricting heat transfer to conduction and radiation, (2) reduced solid heat conduction due to the use of thin film and partial spacers, and (3) reduced heat radiation due to the multi-layer construction. The third feature of reduced heat radiation follows the Stefan-Boltzmann law of "radiation heat = α x (surface temperature difference)^4".

Figure 4 below shows the film surface temperature of each layer in the case of five and two layers 10 mm in overall thickness. In case (a) of five layers, the temperature difference is about 2.5°C on average, so heat radiation is $\alpha \times 2.5^4 \times 5 = 195\alpha$, while in case (b) the temperature difference is about 10°C, so heat radiation is $\alpha \times 10^4 \times 1 = 10000\alpha$. Thus, for daylighting material of a multi-layer construction, it can be seen that heat radiation is reduced by more layers as long as the overall thickness remains the same.

Through this effect of reducing radiation heat, it is possible to achieve not only the heat-insulating performance of a low K-value in winter, but also the heat-insulating performance of low solar radiation heat gain, which is effective in summer.



(a) 5 layers



(b) 2 layers

Figure 4 Surface temperature of each layer

For a multi-layer structure, the layer spacing is correlated with the K-value, which serves as an index of heat-insulating performance, and this correlation has been clarified by simulation for different overall thicknesses (Figure 5). These simulation results largely agree with the results of a simplified heat-insulating box laboratory test.

For the same overall thickness, the K-value tends to decrease due to the effect of reducing radiation heat as the number of layers increases, provided that the same constituent materials are used. However, this tendency is reduced as the number of layers increases. This is believed attributable to the fact that, as the number of layers increases, the number of films used also increases, thereby increasing the proportion of film material occupying the layers of air, resulting in increased solid heat transfer by the films.

The optimum construction was determined for different overall thicknesses by considering the optimum number of layers in terms of heat-insulating performance, optimum number of layers in terms of daylighting performance described above, and the cost. The shaded area in the figure is considered the optimum region.

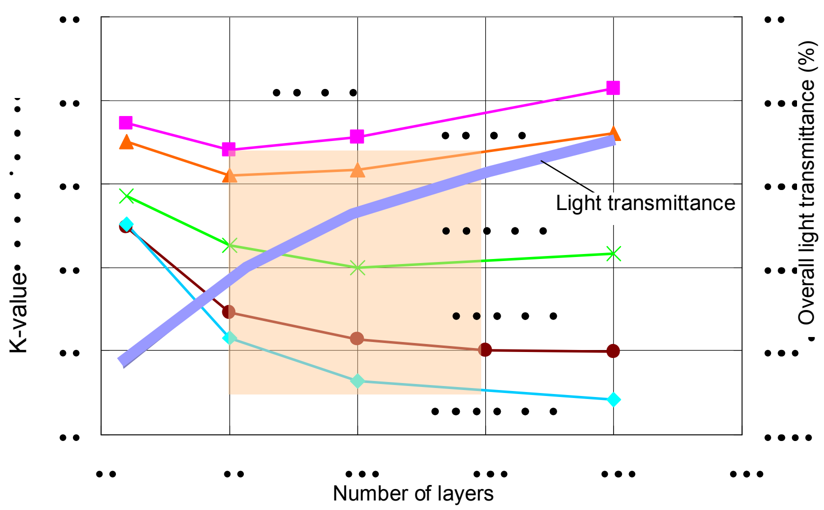


Figure 5 Optimum construction of transparent insulation material

4.2 Verification of heat-insulating performance through field evaluation (in winter)

4.2.1 Surface temperature observation

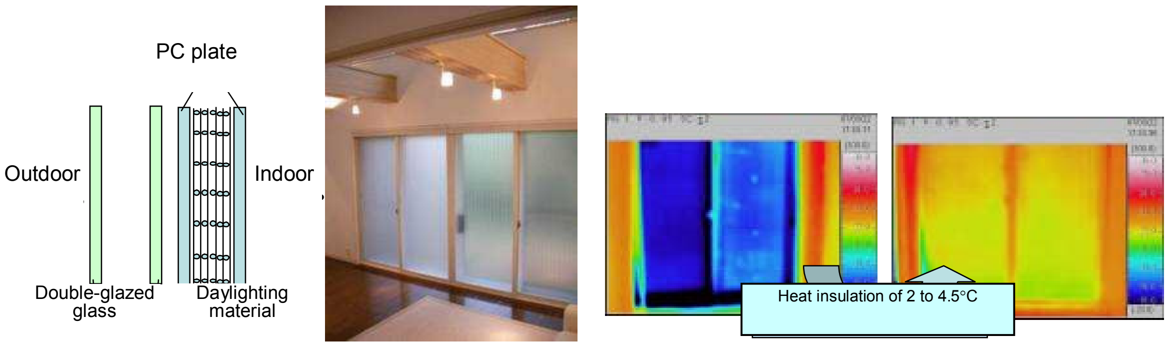
An experimental house in Iwamizawa City (near Sapporo) in Hokkaido, a cold region of Japan, was used to observe surface temperature distribution in winter (February) for case (1) where an inner window was installed and case (2) where a daylighting block was installed.

Figure 6 shows an example of the installed inner window. The transparent insulation material used had a K-value of 2.1 W/m^{2}K, a solar radiation heat gain rate of 47 percent, and consisted of a five air layer construction 10 mm in overall thickness. This transparent insulation material was sandwiched between embossed polycarbonate plates 3 mm in thickness and fit into a resin sash frame. A resin sash railing was then installed in front of the opening, so that the material was assembled as part of an inner window. The pane construction of the opening consisted of heat-reflective glass 3-mm thick, argon 12-mm thick, and float glass 3-mm thick, and its size was 910 by 1820 mm. The transparent insulation material of the inner window had the same size. The surface temperature was measured and, as a result, heat insulation was found to take effect at a temperature of 2 to 4.5°C after installing the transparent insulation material as compared to before installation (Figure 6).

Figure 7 shows an example of the installed daylighting block. Four units of daylighting material of five-layer construction 10 mm in overall thickness (in the daylighting block pattern shown in Figure 2) were set in a frame that was sandwiched between an acrylic plate 4-mm thick on the glass surface side and a ground glass plate 4-mm thick on the indoor side to form a block.

The pane construction of the opening consisted of heat-reflective glass 6-mm thick, argon 12-mm thick, and float glass 6-mm thick, and its size was 1920 by 2500 mm. A total of 42 blocks about 350 by 350 mm in size were attached on this pane surface. The blocks had a K-value of 0.5 W/m^{2}K, solar radiation heat gain rate of 25 percent, and K-value of 0.37 W/m^{2}K at the opening including the panes. This is equal or superior to the K-value of an external wall of 0.4 W/m^{2}K.

Figure 7 also shows the opening's surface temperature on the indoor side after installing the daylighting blocks. From this figure, one can see that the insulation performance is at least equal to or superior that of to the surrounding wall (Figure 7). The block frame temperature of concern was about 1°C higher than the block surface and did not drop below the wall temperature.



(a) (b) (c)

Figure 6 Example of installation as inner window, (a) schematic, (b) photograph of installation, and (c) surface temperature data

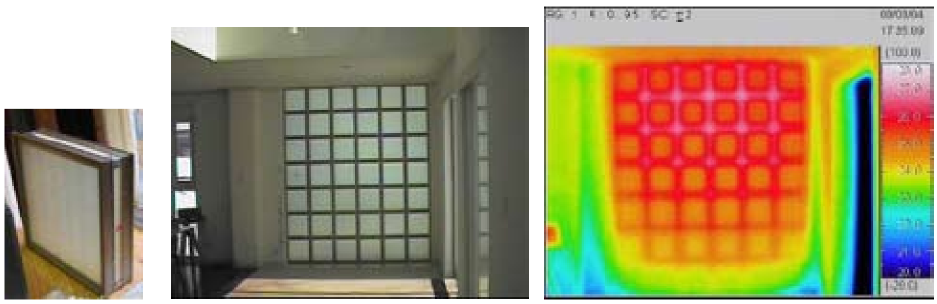


Figure 7 Example of installation as blocks, (a) photograph of blocks, (b) photograph of installation, and (c) surface temperature data

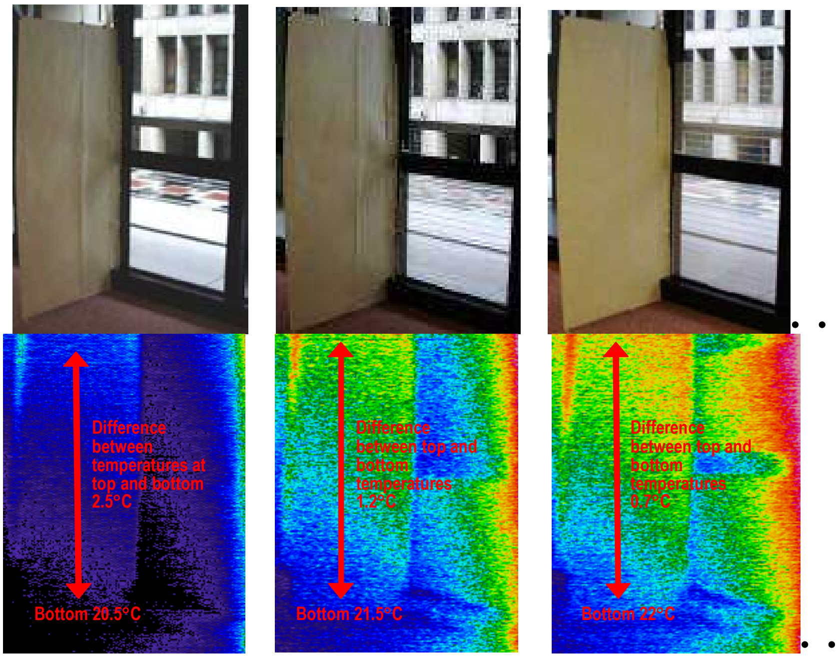
4.2.2 Cold draft phenomenon

Besides its numeric value of K-value, the transparent insulation material has appealing points relative to physical sensation. Among these points is the suppression of a cold draft (i.e., phenomenon of cold air falling near windows from the ceiling to the floor in winter). People who feel chilly near windows can be cited as an example.

Transparent insulation material consisting of five layers 10-mm thick (with a K-value of 2.1 W/m^{2}K and solar radiation heat gain rate of 47 percent) was installed at an opening at a height of 2700 mm in a building in Kyoto Prefecture as a simple fixed inner window, and a confirmatory experiment was then conducted to determine the extent to which the cold draft phenomenon could be ameliorated.

In the evaluation method used, the daylighting material was attached to the opening in question with a screen placed at right angles to that plane, and the state of the screen cooled by cold air falling from the ceiling was observed by using a thermocamera.

Figure 8 shows temperatures measured at the top and bottom. Maintaining a difference within 1°C between the top and bottom temperatures by attaching the material and interposed railing to the lower 1500-mm portion of the opening was successfully confirmed as being possible.



(a) None (b) Installed in 700-mm portion (c) Installed in 1500-mm portion

Figure 8 Confirmatory experiment of cold draft

4.3 Verification of heat-insulating performance through field evaluation (in summer)

A time-lapse observation was conducted in summer (July and August) on the inner window shown in Figure 6. Although the rise in temperature due to heat buildup in the installed daylighting material was of concern, the rise in surface temperature on the indoor side was suppressed (1 to 5•) compared to a blank not fitted with the daylighting material. The material was considered effective because its solar radiation heat gain rate was 47 percent.

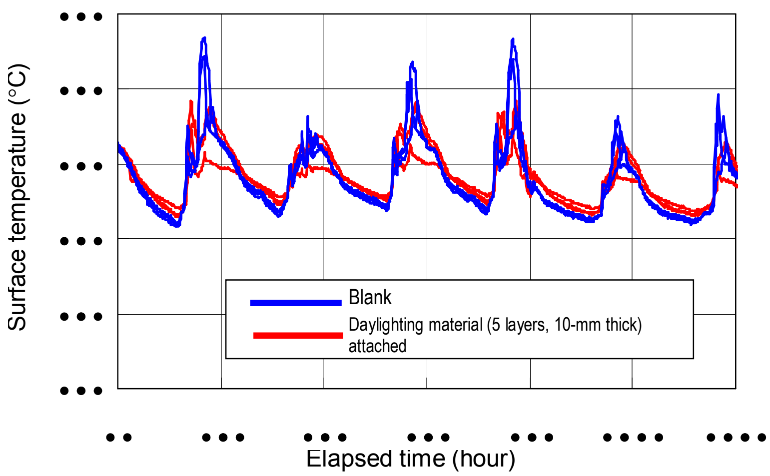


Figure 9 Surface temperature of heat-insulting daylighting material (inner window type) in summer

5. Other performance

Performance other than heat-insulating performance is described below.

5.1 Mechanical properties

The modulus of elasticity in bending of the transparent insulation material is 120 to 290 MPa; thus, the material is sufficiently flexible before being framed. Moreover, the material can also be bent to fit into a curved portion as well.

5.2 Sound-insulating performance

Installing transparent insulation material for use in a sandwich construction between hard plates has the effect of suppressing the transmission of sound, which would otherwise occur if this material had no layer of air between two hard plates. An improvement of at least 5 dB is possible near 500 Hz, which is within the frequency range of human voice.

5.3 Durability

Regarding durability, weathering resistance, water resistance, chemical resistance, and other properties are now under review. Because this is a component to be fit in an opening, weathering is of special concern. Thus, weatherability testing is under way using a xenon weather meter at an irradiance of 180 W/m^2. Even after an elapsed time of 2000 hours, discoloration, cracking, and other remarkable appearance changes have not been seen. Evaluation will continue after this testing to ensure a guaranteed service life of 10 years for use of this material in openings.

6. Energy saving effect

SMASH (Simplified Analysis for Housing Air Conditioning Energy)—thermal load calculation software developed by the Institute for Building and Energy Conservation—was used to estimate the energy saving effect on a detached house (for a family of four) according to its standard schedule and based on the following preconditions:

[Preconditions]

- Outside air condition: Tokyo
- Model plan of 141 m^2 (opening ratio = window area/gross floor area of 29%)
- Ventilation frequency: 0.5 time per hour
- Equipment COP: 4.19 during heating; 3.89 during cooling
- K-value of daylighting material used: 1.0 K/m^{2}K, solar radiation heat gain rate of 37 percent, with lace curtains installed

Compared to the typical combination of aluminum sash and single float glass 3-mm thick (FL3), an energy saving effect of 38 percent in term of annual power load (2.8 GJ/house) can be expected when using daylighting material having a K-value of 1.0 W/m^{2}K and solar radiation heat gain rate of 37 percent (Figure 10).

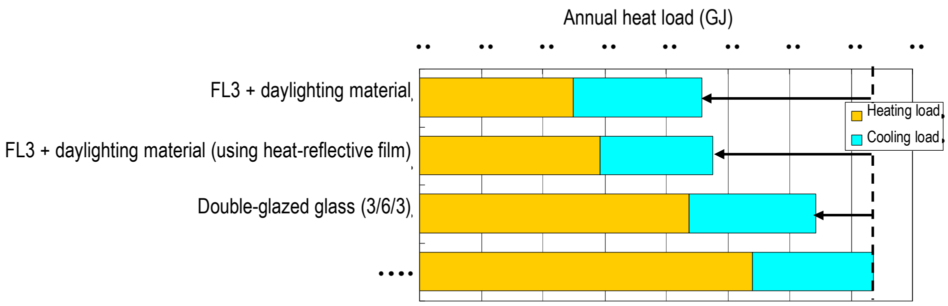


Figure 10 Estimation of energy saving effect on detached house

7. Conclusions

This transparent insulation material has a high energy saving effect combined with high sound-insulating performance. Therefore, the material can be used not only for renovating the openings of an ordinary residential house, but also as a partition member or translucent wall. This material may also be used in a wide variety of applications, such as deployment in commercial buildings (Figure 11).

For this material, a study is under way to make it possible to simulate not only heat insulation but also optical design or sound insulation design through construction and material. Regarding the three applications of this material as a high performance inner window, daylighting block, and simple fixed inner window, future tasks include devising a sealing method and attaching method to suppress dew condensation (Figure 11).

Figure 11 Imaginary pictures of installed transparent insulation material

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OVERVIEW OF A CEMENT-STABILISED FLAX-FIBRE REINFORCED RAMMED EARTH (UKU) BUILDING SYSTEM FOR NEW ZEALAND INDIGENOUS COMMUNITIES

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Keywords: earth building, design guide, Uku, sustainable housing, Maori, indigenous, rammed earth

Summary

This paper outlines research that has been undertaken to create an accessible, low-cost, sustainable earthen building solution for Māori (the indigenous people of New Zealand) living in rural communities. Many individuals and families in rural Māori communities live in overcrowded dwellings with a low, inadequate standard of living. Reasons for the poor housing condition that exists can be attributed to legal issues regarding 'Māori land' and land ownership, the urbanization of Māori, and the financial cost of constructing on isolated, undeveloped Māori land.

In July 2003, a four year research grant was awarded to develop a low-cost flax-fibre reinforced rammed earth housing concept into a commercially viable building technology. An important measure of the value of the research was the ability of rural Māori communities to be able to use the outputs of the research directly. Consequently a community reference group was created comprising of representatives from potential Māori user groups/areas. During the research, an optimized Uku soil mix was determined comprising of 8% cement and 0.075% flax fibres. Material tests have also been conducted to determine the lower 5% compressive, flexural and shear design strengths of the material. The construction process was optimized throughout the research with the development of such devices as a mobile flax stripper and a custom-made formwork system. Improvements in construction methodology were also implemented.

The research concluded in April 2008, with the construction of a full-size Uku house on the foreshore of Lake Rotoiti. This research has resulted in the development of a technology that rural Māori communities can immediately benefit from and has created a platform for future research and development of the Uku building system.

1. Introduction

Māori are the indigenous people of New Zealand and migrated to New Zealand as early as 800 AD from Polynesia (Howe 2007). StatisticsNZ (2001) has indicated that there are approximately 84,000 Māori currently residing in rural areas of New Zealand (2.3% of the national population). Slightly more than 5% of the total land area in New Zealand remains in the control of Māori, but many rural Māori communities are unable to fully utilize 'Māori land' owned by their hapu (sub-tribe) to provide adequate housing and living conditions for their members. A report published by Housing New Zealand (2005) showed that a disproportionately high and unacceptable number of individuals living in rural Māori communities reside in overcrowded, substandard dwellings. The New Zealand Housing Research Centre (NZHRC) has identified obstacles (Forrest 2007) that are obstructing the provision of quality and affordable housing developments on rural Māori land. Aid in the form of local government housing funds, accommodation benefits and boosting of state housing around New Zealand have had limited success in increasing the standard of living for rural Māori (Forrest 2007). Uku, a flax-reinforced soil-cement construction technology (Segetin et al. 2006) is a practical housing solution that is being researched at the University of Auckland to address this issue. The difficulties and limitations that rural Māori communities encounter when building on Māori land and how the Uku building system has been developed to manage and overcome these barriers are addressed.

1.1 Māori Housing Obstacles

Obstacles preventing the adequate provision of housing to members of rural Māori communities can be grouped into 3 areas: financial barriers, legal issues and the urbanization of Māori.

'Māori land' is subject to specific laws in New Zealand (Te Ture Whenua Māori Act 1993). One example is the inability to alienate the land from Māori. This has created lending issues because Māori land cannot be used by financial institutions as a security. The majority of Māori land is located in rural areas. A photo of Māori land under the guardianship of the Waimango Papakainga Trust is shown in Figure 1. Papakainga refers to land used for housing a hapu or whanau (extended family). In many areas, especially coastal, plots of Māori land are remote and in a nearly natural undeveloped state. This is desirable because the land is, for the most part, untouched by human activity, but disadvantageous because it often elevates the access costs and the overall cost of developing building infrastructure on Māori land to an insurmountable level. Machinery and building resources are expensive to access, transport, and use, not just because of the distance, but because of other reasons including inadequate road infrastructure and lack of access to amenities and utility networks (e.g. telecommunications, water and electricity). Financial barriers are one of the main obstacles hindering rural Māori communities from utilizing their land to provide adequate housing for members of their community.

Figure 1 Photograph of Māori land owned by the Waimango Papakainga Trust (Morgan 2005)

The Māori population is urbanizing rapidly. Many Māori, particularly young unmarried Māori, have relocated into urban areas in order to secure work, earn money and live a more modern lifestyle. Before the Second World War more than 80% of Māori lived in rural areas. Today 84% of Māori live in urban areas (Meredith 2007). As a result, many rural Māori communities are depopulated and lack a younger Māori labour force. This has increased the cost of building on Māori land because technically-trained skilled labour has to be sourced from surrounding regions to fill shortages that have developed in the local workforce.

Legally, Māori land is owned by the local Māori hapu with historic ties to the land. Māori land is collectively owned, often by over a thousand people spanning several generations. Managing building developments on Māori land is further complicated by the relocation of many owners into urban centres. These distant owners often have weak ties to their ancestral lands and lack the knowledge of genealogical links that are vital to understand in order to make progress towards a meaningful outcome (e.g. building a house).

1.2 Background of the Uku Project

The Uku research aims to develop a cement-stabilized, flax-fibre reinforced, rammed earth building system to provide a method of domestic house construction that overcomes the legal and financial obstacles preventing rural Māori communities from utilizing their ancestral lands to provide adequate dwellings and good standards of living for their members (Morgan 2006). The name given to the building system 'Uku' is the Māori language translation for earth. In 1996 the Waiariki Area Research Unit undertook research investigating the viability of a rammed earth housing solution for rural Māori communities. Two rammed earth panels were constructed and tested, and revealed the potential to develop a low-cost earthen housing solution for Māori. The construction workshops with Uku (2003-2005) developed the earth housing concept further by building two simple rammed earth dwellings on Māori land. The first dwelling was constructed on a rural Māori papakainga located on the foreshore of the Firth of Thames (Waimango Papakainga) shown in Figure 2. The second dwelling was built on urban Māori land in Otara, Auckland City (Kokiri Te Rahuitanga). In June 2003, the Foundation for Research, Science and Technology (FRST) awarded a 4 year grant to develop Uku, an accessible low-cost rammed earth housing solution for rural Māori communities. A major output of this research was the construction of the full-size Uku house in Rotoiti.

Figure 2 Photograph of Te Ahuone - a simple rammed earth dwelling built on rural Māori land owned by the Waimango Papakainga Trust (Morgan 2005)

1.3 Advantages of Building with Earth

Houben and Guillaud (1994) estimated that a third of the world's population lives in earthen structures, with the majority residing in the developing world. For many millennia earthen structures have been the most common building solution in the world and it is still true of earthen structures today. The reasons why earthen construction has remained so widely used are due to:-

- Material availability – In the majority of areas where human settlements are established, there is a nearby source of soil that can be used for earthen construction.
- Low-cost – Earth material is abundant and easily extractable. It requires minimal material processing and is locally sourced.
- Easy to work – Earthen dwellings can be built using simple hand tools.
- Simple and intuitive – Earth buildings can be built without design guides and technical training.
- Strength – Earth has adequate strength for use as a structural material.
- High thermal mass – Earthen materials are capable of absorbing a large amount of heat energy. During hot days the earth keeps the building cool. During the night the heat is slowly released, keeping the building warmer.
- Durable – Earthen structures have long-term permanence. Many well designed and constructed earth heritage structures are still in use centuries later, like the Potala Palace, Tibet and the Great Wall of China (Jaquin et al. 2006).
- Low toxicity – Earthen structures generally do not require significant processing and mixing with chemical additives. Earthen structures are naturally pest and fire resistant. As a result the material is generally non-toxic or of low toxicity (North 2006).

1.4 Seismic Design Requirements of Earth Building in NZ

Morgan (2005) outlined how earth building in New Zealand started with Māori construction of pa (strategic military settlements) and pit houses. Earth building usage as a method of housing increased during the European settlement of New Zealand (Walker et al. 2003). However, following the magnitude 7.5 Marlborough earthquake in 1848 (Grapes et al. 1996) and the magnitude 8.2 Wairarapa earthquake in 1855 (in which many earthen structures were badly cracked or completed destroyed) (GNS Science 2007), earthen construction quickly fell out of favour. Only recently, since 1980, has the earth building industry in New Zealand experienced a significant revival as interest in sustainable construction methods and environmentally friendly buildings has increased.

New Zealand is located at the active boundary of the Australian and Pacific tectonic plates (The New Zealand Landforms 2007). GNS Science, a government owned research institution, records 100 to 150 national earthquakes annually that are large enough to be felt (GNS Science 2007). The majority of earth building knowledge transferred to New Zealand has come from countries where seismic design was not a relevant design consideration. Due to the lack of national research and knowledge of the seismic performance of earth buildings, the majority of earthen designs, particularly before 1998 (when the New Zealand Earth Building Standards were released), had to be certified by a Registered Professional Engineer.

In 1998 three earth standards were released in New Zealand by Standards NZ:-

- NZS 4297 Engineering Design of Earth Buildings
- NZS 4298 Materials and Workmanship for Earth Buildings
- NZS 4299 Earth Buildings Not Requiring Specific Design

The earth standards have simplified the process for gaining building consents for earthen structures in New Zealand but still require the input of professional engineering expertise for non-specific design compliance to certify the suitability of the soil and the construction approach. The lack of professional engineers in Māori communities is an obstacle preventing Māori communities from accessing earthen construction technologies. The Uku project addresses this issue by creating a design guide that provides rural Māori communities with the tools and knowledge to uptake the Uku technology as well as by reducing the need for external input into the design and construction of dwellings built on Māori land. The design guide is a tool that provides greater accessibility to rural Māori communities to build safe structures using the Uku building system.

2 Unique Elements of the Uku Building System

The Uku building system has been conceptualized with the idea of creating a system that is an accessible and sustainable housing solution for rural Māori communities as well as a technology that can be transferred and used independently by the rural Māori community.

2.1 Māori Community Reference Group

The Uku research was conducted with input from a Māori community reference group (MCRG) comprised of representatives from Māori communities and organizations who were potential end users. An important measure of the research value resided in the ability of the target end users to directly apply the research to provide for their own housing needs. By meeting with potential end users throughout the research the Uku technology was developed to better utilize the resources available to Māori communities and to address their specific needs and issues. Working with the MCRG provided a way for the representatives of the Māori groups to gain an understanding and affinity with the Uku project, and relay the research to the people in their community. Relationships have been formed with tribal groups from Taitokerau (Northland), Tairawhiti (East Coast) and Waiariki (Bay of Plenty) shown in Figure 3.

Figure 3 Diagram showing Taitokerau, Waiariki and Tairawhiti Iwi (tribe) locations (Te Puni Kokiri 2008)

2.2 Sweat Equity Financing

A financing concept that uses sweat equity as a mechanism to make the Uku building system more affordable has been incorporated into the building process. The sweat equity concept uses labour and time, invested by the owner (and family) during the construction process, attaches a monetary value to their involvement and uses the monetary value of their work as part of the down payment for the house. The Uku system is able to utilize unskilled labour and as a result, labour contributions are not limited to residents who have undertaken formal technical training. Morgan (2005) documents the success in past trials using volunteer labour and/or residents from the local Māori community during construction to provide the majority of the labour required during construction of the wall elements of a building.

2.3 Use of Local, Low-energy, Renewable Resources

The use of local resources (labour and building materials) was maximized where possible. For the dwelling built at Waimango, local soils were tested and a suitable soil source located 0.5 km away from site was chosen. The soil required a 30% sand addition (sourced 10 km away) in order to reduce the soil shrinkage to within the limits imposed in the earth standard NZS 4298 (Standards NZ 1998).

The soil located on site proved troublesome to use for construction. In total the soil took five weeks to extract, transport and mix in preparation for use in the Uku walls. The additional sand required to reduce shrinkage was mixed into the soil at a local quarry. Using local soils increased the labour and time required for construction. After the Waimango project, earth extracted from a soil quarry was preferred because it required less labour and time, and provided a more consistent soil composition. The soils on the urban site in Otara were not suitable due to a high organic content. For the Otara dwelling, soil was sourced from the Lyons quarry located at Woodhill and the Stevensons Quarry at Waimauku.

Flax leaves were processed into flax fibres using a mobile flax stripper that was developed as part of the Uku project. The fibres used for construction were manufactured from leaves harvested at a flax plantation at Te Hapua, near the Rotoiti Uku house.

It is important to acknowledge that not all the materials used in the Uku building system were locally sourced, low-energy, renewable materials. New Zealand is a very seismically active country and in order to satisfy the seismic demand requirement using the Uku wall panels, vertical D12 reinforcing bars were installed in all structural Uku wall panels at approximately 500 mm centres (e.g. 1200 mm long wall panels have three D12 vertical reinforcing bars). The introduction of steel reinforcing bars was not a desired result but was necessary to satisfy the moment demands on the wall panels. Further testing of the Uku wall system, when subjected to seismic loading, will reveal whether a less conservative ductile design is appropriate. Until this is demonstrated the wall design will assume an elastic system response without a significant displacement or ductile capacity. The Uku mix contains an 8% (by weight) addition of Golden Bay Ordinary Portland Cement which has a high embodied energy. The addition of cement was considered necessary to provide resistance against moisture and advantageous as it improved the strength of the Uku material.

2.4 Machinery and Equipment Requirements

The soil, flax fibres and cement can be mixed and rammed using only hand tools and hand rammers. However access to a large supply of low-cost labour is needed to make this option commercially viable. Mixing, transporting and ramming the Uku mix is a highly labour intensive task. In practice a pneumatic rammer (and air compressor) has been used in conjunction with a hand rammer to compact the Uku soil. Similarly when mixing the soil, in order to minimize labour requirements and decrease the mixing time, a compact loader (and driver) is hired to mix the soil onsite and transport it to the ramming location. The Uku building system requires a minimum of four people on site (including the compact loader driver). Measurements of site-task durations show that, by using the machinery and mechanical devices mentioned above, the shuttering system can be dismantled and erected in 1.5 hours and the ramming process can be completed in less than 3.5 hours.

The use of a pneumatic rammer and a compact loader during construction was not originally envisioned as a part of the Uku construction system. These additions require fuel and machinery / mechanical components that are less accessible to isolated rural areas and greatly increase the energy input during house construction. However due to the practical advantages of constructing buildings in a short period of time and the cost savings achieved by reducing labour requirements, it was decided to use machinery and mechanical equipment during construction where it would make the construction of an Uku dwelling easier to build and more affordable to the owner.

2.5 Design Guide

One of the objectives of the Uku project was to create a design guide that allowed rural Māori communities to make use of Uku technology without needing professional engineering expertise during the design, consenting and construction stages. A design guide was authored that currently is able to show how to verify the structural aspects of the dwelling. The current design guide was used successfully for the Uku house built at Rotoiti. The building consent was issued in November 2007. The design guide is undergoing refinement and will continue to be developed to improve aspects such as the seismic and thermal design methodology (as the performance of the Uku wall system is better understood) and other aspects like defining practical / empirical preliminary soil tests and being translated into the Māori language.

3 Uku Research Objectives

The primary objectives of the FRST funded Uku research project were to:-

- Develop the technology for the earth fibre composite material;
- Optimize end-user adoption of the technology and trial the results;
- Build full scale trials and develop a commercialization strategy.

The FRST funded Uku research was completed in April 2008. A summary of each stage is covered below.

3.1 Developing the Technology

The research has optimized the Uku (flax/cement/soil) mix composition initially proposed by Haab (1998). The present Uku mix (by weight proportions) consists of 8% cement and 0.075% flax fibres (cut to 60-70 mm lengths), mixed with soil at a moisture content of approximately 22%. Haab (1998) proposed a 0.75% flax component but the Uku research found a 0.075% flax proportion was more practical on a large scale because it reduced clumping of the flax and made it easier to mix the fibres homogenously into the soil. The flax content reduction also decreased the labour requirement for separating and cutting the fibres to length.

Testing of the Uku material was conducted following standard test procedures defined by the American Society for Testing and Materials (ASTM). A summary of the results is shown below in Table 1. NZS 4298 specifies that rammed earth material that is used in construction needs to exceed 1.3 MPa in compression and 0.25 MPa in flexure. The measured compressive strength of the Uku material easily satisfied the requirements with an average strength of 7.6 MPa and a lower 5% characteristic design strength of 4.6 MPa. In flexure the material also passed with an average strength of 0.35 MPa. Although the design strength in flexure was below 0.25 MPa (0.18 MPa), all seven test beams failed above 0.25 MPa. The low flexural design strength was due to the spread of the results and the low number of flexural samples tested.

Table 1 Summary of Material Tests of the Uku Material

	Average Strength [MPa] ($\bar{x}$)	Coefficient of Variance [%] ($\sigma / \bar{x}$)	Design Strength [MPa] ($\bar{x} - 1.65\sigma$)
Compression	7.6	23.7	4.6
Flexural	0.35	28.9	0.18
Shear	0.73	17	0.52

3.2 Optimizing End-user Adoption

In order to optimize end-user adoption of the technology, aspects of the construction process were refined as constructability issues were identified. In addition to this a design guide was developed. Following traditional Māori methods, the flax fibres were initially extracted by hand but this proved to be too slow and labour intensive. Consequently the process was moved to the Foxton Museum flax threshing machine. Working in collaboration with various weavers, a mobile trailer-mounted prototype flax stripping machine was designed and constructed at the University of Auckland. This machine now provides the flax fibre used during Uku construction. Another optimized aspect was the shuttering system used to restrain the formwork against the high lateral loads developed when ramming the earth. The formwork system developed by David Easton (a prominent rammed earth expert residing in California, USA) was adopted initially. Using this system the 300 mm wall panels at Waimango took three working days to ram each, including time to set up the formwork. The development of a modular formwork system (used for the Otara dwelling) decreased the wall panel build time to 10 hours. Reducing the wall thickness to 150 mm in combination with the modular formwork further decreased the wall build time to 5 hours (used for Rotoiti house). The modular formwork system developed is shown in Figure 4 and allowed wall panels up to 2.2 metres in length to be constructed per setup. The Otara dwelling and Rotoiti house construction progressed at one wall panel per working day.

Figure 4 Photograph of the modular Uku formwork system developed by the research team

3.3 Full Scale Trials

Construction of the Rotoiti Uku house (90 m^2) in April 2008 satisfied the FRST requirement to build a full scale house using the Uku building system. The plan for the Uku house is shown in Figure 5. Another house with the same floor plan was built 100 metres away from the Uku house using conventional timber frame construction. Both dwellings were built on a reinforced concrete floor and with an exposed rafter timber diaphragm roof. The timber house will be used as a reference point to evaluate the thermal performance of the Uku house. A photograph of the Uku dwelling in Rotoiti under construction in March 2008 is shown in Figure 6. Both houses feature two bedrooms, a lounge, kitchen, laundry, toilet and carport. The construction inputs of both structures have been recorded and a detailed comparative analysis of the embodied energy and environmental impact of the timber and Uku construction methods will be evaluated. Each dwelling will be equipped with 15 thermal sensing buttons located on the interior and exterior of the walls. A memorandum of understanding (MOU) has been signed between the Uku research team and the occupants of the two houses to allow the dwellings to be monitored for two years.

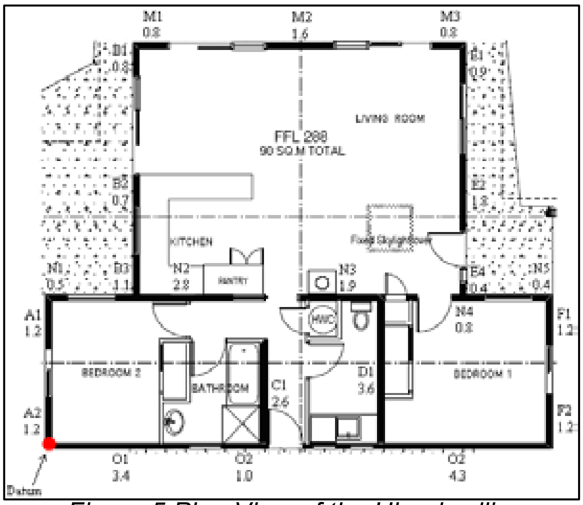

Figure 5 Plan View of the Uku dwelling.


Figure 6 Uku dwelling in Rotoiti under construction.

4 Conclusion

In New Zealand there is an issue with providing adequate housing and standards of living for individuals and families living in rural Māori communities. Issues of land ownership, the cost of construction on Māori land and the urbanization of the Māori population have created obstacles to land development that result in overcrowded and sub-standard living conditions for many residents living in these areas.

The Uku research has been conducted with the purpose of creating a low-cost, sustainable building system that is accessible to rural Māori communities. The Uku technology was developed to take advantage of local resources and materials and address issues preventing the adequate provision of housing on Māori land. To ensure that the developed technology was practical and usable by rural Māori communities, the research progressed with input from a community reference group. An important measure of the research project's value was the ability of rural Māori communities to directly apply the outputs of the research.

As a result of the FRST funded research, an optimal Uku soil mix has been determined (8% cement, 0.075% flax and soil) and the construction process has been improved through the optimization of the building process and the introduction of machinery and mechanical devices where appropriate. The completed construction (in April 2008) of an Uku house on the foreshore of Lake Rotoiti using local labour and materials has demonstrated that the proposed solution is constructible and practical.

The Uku building system incorporates a minimal proportion of high embodied energy and/or manufactured materials (cement and steel reinforcement). These additions were required to satisfy the NZ Earth Building Standards and provide adequate seismic capacity in the structure. The use of machinery (compact loader) and mechanical devices (pneumatic rammer and air compressor) was necessary because it improved the constructability of the house and reduced labour costs. Although these devices and materials detract from the original vision of developing a sustainable, low-energy construction system that uses local resources, tools and materials exclusively, compromises were necessary in order to create a practical building system that could benefit the rural Māori community end user.

The FRST funded research has been completed and a usable building system has been created. Aspects of the Uku building system can be refined; there is always scope for improvement and optimization. However the research has successfully provided a working baseline technology, upon which further research can be conducted and which rural Māori communities can begin to use, to benefit their members now.

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FIELD EXPERIMENTS ON THE USE OF PHASE CHANGING MATERIALS, INSULATION MATERIALS AND PASSIVE SOLAR RADIATION IN THE BUILT ENVIRONMENT

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Summary

This paper describes the development of an experimental research facility to assess the effectiveness of Phase Change Materials (PCM), that can be used for passive solar heating. Four test boxes are constructed representing the conventional and future Dutch building practices regarding insulation and glazing. In the future scenario materials to cover walls and floors in the test boxes will be partly filled with PCMs. In this paper the theoretical framework of thermal behaviour of PCMs in buildings, the realisation of the experimental set up and the design of the monitoring system will be explained.

1. Introduction

During the last decade many energy saving concepts have been developed to enable sustainable building design. In Western Europe, with its moderate climate, passive solar energy forms the most promising measure for reducing the consumption of fossil fuels for heating of houses. Traditionally the (Dutch) building designs were not optimized for using solar energy. With the introduction of the Energy Performance Coefficient in December 1995 as part of the formal Building Code (Staatsblad, 1995) the use of passive solar energy became indirectly more appreciated. This paper results from the research project on "exergy in the built environment" at the University of Twente. Within this research project the adoption of conventional energy saving measures and future low cost measures, such as passive solar energy, in building processes are important issues.

On first sight The Netherlands does not seem suitable for passive solar heating, because the average outside temperature of 9.5 °C is relatively low and the incoming solar radiation on a windowpane of, depending on its orientation, is just 1,313 to 2,881 MJ/(m^2·y) (364.7 to 800.3 kWh/(m^2·y)). However, the passive use of solar radiation offers many opportunities in low exergetic heating applications. In common Dutch houses solar irradiance enters the room by large windows oriented to the south, therefore less heating and electric power will be used. Solar irradiance will mostly be transmitted and a small part will be absorbed or reflected by the glazing. Behind the glazing the air in the room will absorb a small part of the energy, before irradiance will be absorbed by the floor covering and constructions beneath it. On the north side of the buildings it is common to install smaller windows than on the south side, since the energy losses by outside transmission are larger than the input of irradiance. Not much is known though about the heat absorption capacity of the interior of buildings and the speed of release of captured solar heat for interior heating during cold evenings or nights.

The specific energy performance of glazing and windows has been regarded by Nielsen et al. (2001). He perceived the issue as a combination of thermal transmittance and total solar energy transmittance. However, it might be more accurate to consider the actual energy performance of glazing and windows within the building design in relation to the absorption factors and heat capacity of the materials used in the interior of the building.

Three major factors to be considered are:

1. <u>The absorptivity of the internal constructions</u> of a building, for example materials used, thickness or mass of internal construction parts, installation of extra internal heat absorption walls, color of the interior, and introduction of Phase Change Materials (PCM, e.g. Peippo et al., 1991, Nepper et al., 2000, Nagano et al., 2006, Shilei et al., 2007);

2. The absorptivity of the external constructions of a building in which the distance of the insulation to the outer surface of the exterior wall and the mass in this section can be regarded (e.g. Yumrutaş et al., 2007);
3. The internal transport system for heat which is normally used to convey heat to the rooms, but in some cases it can be used to stabilize the temperature through the whole object by conveying heat from the one room to the other.

Being substances that are able to store latent heat PCMs might improve the first factor: the absorptivity of the internal constructions. Thermal energy transfers in PCMs take place during melting and solidification (Sharma et al., 2008). Inorganic (e.g. salts) and organic (e.g. paraffins and fatty acids) substances can be suitable to be a PCM (Zalba et al., 2003). Because little is known about the application of PCM and their potential to save exergy[1] within building designs, this paper describes the development and execution of an experimental research project on the use of PCM in concrete floors and gypsum plasterboards. They will accumulate solar energy to obtain a constant indoor temperature during day-night cycles.

The use of a latent heat storage system, which PCMs provide, is an effective way of storing thermal energy (Sharma et al, 2008). Research on the use of PCM in energy-storing wallboard of Chen et al. (2008) shows that energy savings for heating a room are starting at 10% or 17%, and higher percentages are conceivable. In this paper an experimental setup is presented that can be used to gain more insights in the effectiveness and efficiency of these measures. The results of this research can help to improve the energy performance of both new and existing buildings.

In the second section of this paper the background on the use of solar radiance in Dutch dwellings will be given. After that the development of the test boxes will be explained in which the dimensions and used materials will be considered. In the fourth section the test site will be addressed in close relation with the monitoring system that is explained in the fifth section. Finally, the conclusions, recommendations and prognosis on future research will be elaborated on.

2. Basic assumptions in researching solar radiance in Dutch dwellings

The goals of the proposed experiment are to gain insights and data on how solar radiation can be absorbed, buffered and distributed effectively and efficiently within the building shell and how this thermal energy affects the indoor temperature. Before developing an experimental setup to achieve this goal, the following specific considerations need to be stated regarding the thermodynamic aspects of Dutch houses:

- The living room is regarded as the most important room within residential real estate from an energetic point of view. In this room the radiators are controlled by one thermostat that often regulates the working of the heating system for the whole house. The experiment will focus on simulating this space. The inside temperature is in Dutch standards fixed to 18 °C for the heating season. The necessity to cool the building exists, according to Dutch standardization references, when the indoor temperature rises above 24 °C (NNI, 2005);
- The residential building stock in the Netherlands, consisting out of 7 million houses, offers enormous possibilities to save energy. The characteristic row house will be used as point for departure for simulation. This means that in theory there will be no heat transmission to the neighbours. The Dutch agency for sustainability and innovation, SenterNovem, has specified six different residential real estate reference objects to use for energy analysis, of which one constitutes the considered row house (SenterNovem, 2006);
- The ceiling of the ground floor is normally not insulated and consists most of the time solely out of a concrete hollow-core slab with a height of 200 mm. In dwellings where the floors are carried by wooden beams, plasterboard is sometimes used to finish off the ceiling.
- In existing houses the ground floor, roof and walls are often insulated. Starting from 1992 it is compulsory to install insulation in the building shell with R ≥ 2.5 $(m^2{\cdot}K)/W$, but many older houses have been refurbished by installing floor insulation with the same heat resistance. Nowadays insulation with R = 3.5 to 4.0 $(m^2{\cdot}K)/W$ is often applied in the floor and roof of new houses.

The feasibility of the proposed experimental research can be demonstrated by using standardized Dutch figures on solar radiation (NNI, 2004) and the specifications of a standardized reference dwelling for new row houses (SenterNovem, 2006). The energy balances at the glass surface on the south side, north side and roof are shown in Figure 1. On a yearly base more than 33,000 MJ (= 9,167 kWh) of solar radiation could enter through the windows of the referred standard house. The thermal resistance of windows is however quite low (U = 1.8 $W/(m^2{\cdot}K)$) compared to the insulated walls of new buildings. Therefore, more than 11,000 MJ will leave the building, when the temperature inside is set to be 18 °C and average outside temperatures

[1] The concept of exergy is used, because it can better express the effect of low temperature heat and the qualitative difference between solar irradiance and fossil fuels than energy.

are taken of 2.5 to 17 ℃ (depending on the month). Nevertheless, even in The Netherlands the gains (33,000 MJ – 11,000 MJ = 22,000 MJ) are not negligible and can especially during spring and autumn in houses offer great opportunities to reduce the natural gas consumption. Natural gas is the most commonly used fossil fuel to heat houses in the Netherlands. Figure 1 also shows that during winter solar radiation through glazing will not surpass its heat transmittance and that during the summertime a large surplus is available demanding additional measures. With these considerations in mind the setup for the experiment is further developed. The living room of a standard Dutch row house will be modelled in the form of a test box.

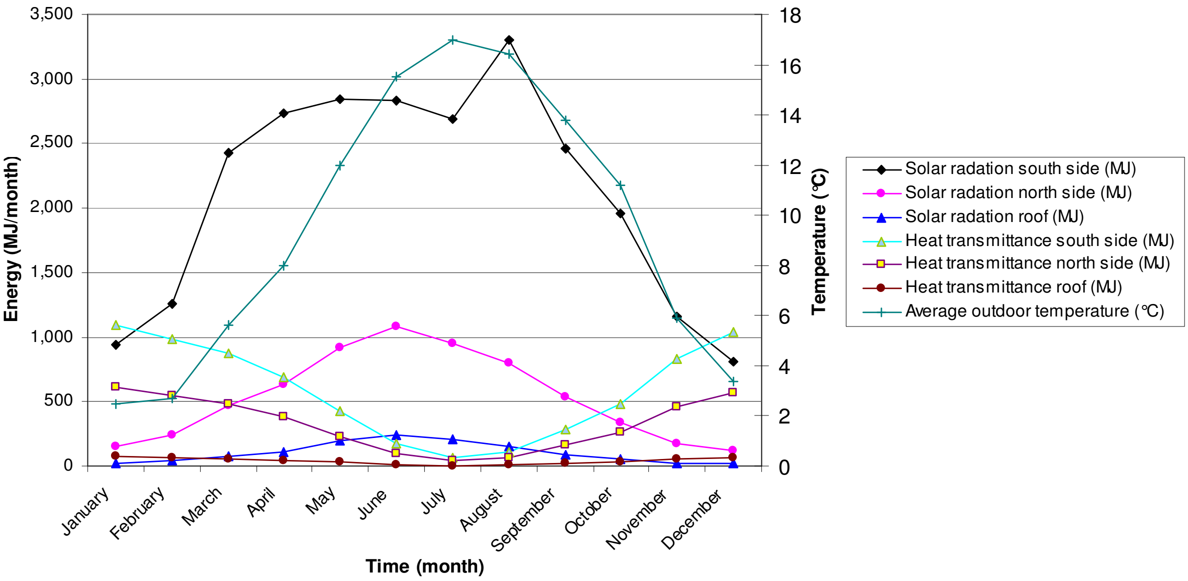

Figure 1 *Accumulated monthly solar radiation and heat transmittance through glazing into a standard Dutch row house (computations are based on NNI, 2004 and SenterNovem, 2006)*

3. Development of the test boxes

In the field of building physics only little research has been published about experiments with test boxes. The use of test boxes for an experimental study of PCM has for example already been described by Kissock et al. (1998). The dimensions of such a box are essential to represent real buildings. In the calculations on the heat capacity of buildings by Nishikawa and Shukuya (1999), the volume of the researched system seemed to be too small. Desta et al. (2005) used in their research on heat phenomena a whole chamber. In this case it was fully constructed out of plexi glass to have a clear view on the ventilation flows. In this paragraph, first the size of the test boxes will be discussed. Secondly, the materials that are involved in constructing the test boxes are addressed.

3.1 Size of test boxes

Because the experimental research has to represent phenomena in real sized houses, the sizing of the test boxes has to be considered. However representative down-scaling of both volumes and surfaces is limited by differences in their scaling factors which are based on resp. cubed and squared relations. The area of surfaces, walls, windows and floors in our test box in relation to the volume of the test box can not represent real(size) houses or living rooms. This will result in a floor surface that is relatively large in relation to the volume of the test box compared to a real size dwelling. This means that the capacity to store heat of a real size living room should be larger than the capacity of the test box. Because of the manageability of the setup, the size of the test field, costs and time restraints, it is obvious that real size testing was not possible and therefore scaling is necessary. The references for the dimensions of the scaled boxes are the living room of the standardized row house of SenterNovem (2006) and the test boxes used by Kissock et al. (1998).

The ground floor of the row house has a surface of 8.92 m by 5.10 m (l × w). The living room takes 26.1 m^2 of the ground floor. The adjacent window in the southern façade of the reference house is 4 m long and 2.4 m high. The internal height of the first floor is 2.6 m. The sizes of the test boxes of Kissock et al. (1998) are 1.22 m x 1.22 m x 0.61 m (l × w × h). To approximate these sizes the test box could be built on a scale of 1 to 5. In that case the size of the test box should be 1.024 m x 1.020 m x 0.520 m (l × w × h). A plastic container with sizes that approaches these dimensions is used as a base for the test boxes (see Figure 2). These dimensions will result in an air volume that is 115 times smaller and a floor surface that is thirty times smaller than the original living room. The impact of this down scaling is expected to be relatively small, because the mass of air and heat capacity per kilogram are low compared to the mass and heat capacity of the floor.

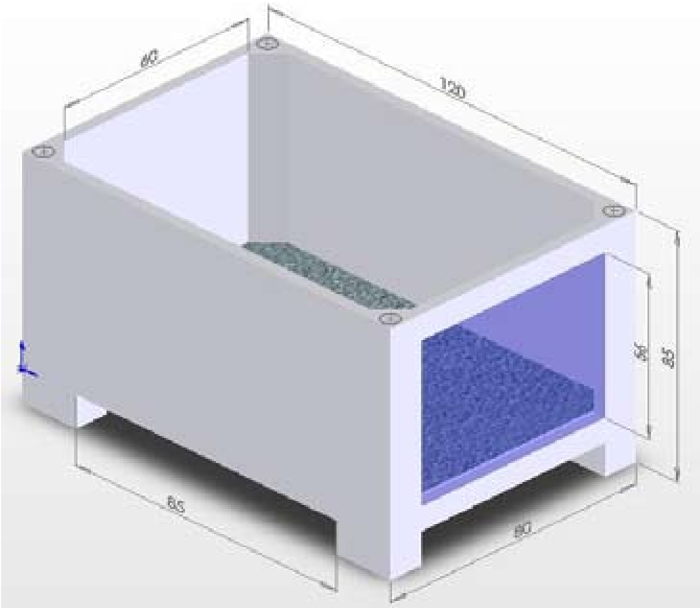

Figure 2 The basis for the test box will be a plastic container (dimensions in cm).

3.2 Materials for the test boxes

The experiment will focus on thermal exergy flows resulting from exposure to solar radiation. The boxes will have at one side a window to let solar energy in. All other sides will be strongly insulated to mimic adiabatic conditions. In this paragraph the materials to construct the test boxes will be specified.

3.2.1 Glazing

The front side of the test box will consist out of 0.36 m^2 glass. Nowadays in Dutch building practice high performance glazing is used with a U-value of approximately 1.2 W/(m^2·K) and a g-value of 0.60. Window frames of wood or plastic have a higher U-value than the glass; approximately 2.4 W/(m^2·K). For windows an overall U-value of 1.8 W/(m^2·K) results (NNI 2004, SenterNovem 2006). The conductivity of the glazing in the test boxes will be 1.1 W/m^2·K and 0.5 W/m^2·K to reflect on the standard Dutch situation and best practice situation. Based on the size of the windows computations on the overall U-values led to 1.3 W/m^2·K and 0.6 W/m^2·K respectively, their glazing have g-values of 0.47 and 0.60 respectively.

3.2.2 Insulation materials

Five sides of the box will consist of a hard insulation material. In this experimental setup fibreglass insulation or mineral wool are not desirable materials, because the homogeneity of the material and a fixed thickness can not be guaranteed after their installation. Furthermore, the heat resistance of these soft materials can unintentionally be lowered by the absorption of rainwater. Therefore a hard and heavy insulation material being cellular glass will be used with a thermal resistance of 3.81 (m^2·K)/W.

In Europe there is a debate on the effectiveness of light insulation products compared to heavy forms of insulation. Our research will contribute to this debate by using also a light form of a homogenous insulation. This product consists of fourteen thin layers of reflective and insulating materials. The producer claims that this product has a R-value of 5.6 (m^2·K)/W, when on both sides a cavity is applied of at least 20 mm deep. The exterior of both types of boxes will be finished by using plywood of 15 mm. They will be painted white, because of its high reflection and low absorptivity.

3.2.3 Phase Change Materials

Sharma et al. (2008) distinguishes three main groups of PCM: organic, inorganic, and eutectic. Within the group of organic PCM there are two different types: paraffin and non-paraffin compounds. In our research a mixture of paraffins in powder form encapsulated in polymethyl methacrylate microcapsules will be used, that has a melting point of 23℃ (BASF, 2005). This micro encapsulated PCM has already been used in gypsum board that is also able to store heat, and that will be used to cover the interior of the test box with exception of the floor and the window frame.

The same micro-encapsulated PCM (Micronal DS 5008 X) will be used to increase the heat capacity of the concrete floor (see Table 1). The amount of PCM in the concrete mixture will firstly be determined by computations on the amount of heat entering and leaving the box. The first target to be set is to avoid temperatures below 0℃. More favourable is a higher target to maintain an indoor temperature of at least

15°C and 25 °C at maximum. Based on local irradiation and temperature data of 2007, the specifications in Table 1, and the dimensions and materials of the box, the concrete floor needs to store at least 3.2 MJ and the PCMs in the concrete floor and gypsum walls needs to store at least 1.4 MJ. This means a floor with a height of 60 mm containing 5 % of encapsulated PCM and 2.7 m^2 of gypsum board having a latent heat of approximately 330 kJ/m² (Knauf, 2006) will be installed.

Table 1 Specifications of the materials involved in the experiment that are able to store heat

	Latent heat capacity (at room temperature)	Specific heat capacity	Bulk density
Concrete	0 KJ/kg	3.3 KJ/(kg·K)	2,400 kg/m^3
PCM	110 KJ/kg	Negligible	250-350 kg/m^3
Gypsum board	0 KJ/m^2	0.85 KJ/(kg·K)	700 kg/m^3
Gypsum board	330 KJ/m^2	1.20 KJ/(kg·K)	770 kg/m^3

Compressive tension tests will demonstrate the impact of this 5 % Micronal on the strength of concrete. It is possible that during the hardening of concrete the Micronal already avoids temperature peaks due to cement hydration heat. This could offer great advantages, when large amounts of concrete are needed. A case (see Fig. 3) was developed to store four concrete cubic moulds during hardening. To approach adiabatic conditions during temperature monitoring this case is closed and well insulated.

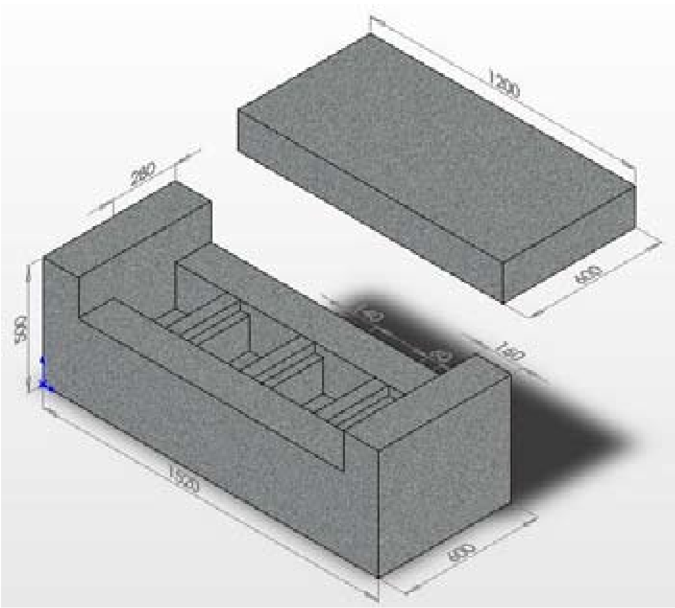

Figure 3 Case to monitor the temperatures of four molds of concrete during hardening (dimensions in mm).

4. Test site

Based on the different materials that need to be tested, four different test boxes will be constructed with the characteristics that are summarized in Table 2. These boxes will be placed outdoors on a test site for a whole year. This enables monitoring of the behaviour of the box and the materials during all seasons. The test site (see Fig. 4) will be located at the Campus of the University of Twente (Enschede, The Netherlands). To give an impression of the solar irradiance at this university Figure 5 shows the daily irradiance on a clear sunny day on different facades of a building. To make sure that there are no obstacles, which can cause shading, the boxes will be placed 2.5 metres above ground level in an open area. A weather station (WS) will be installed behind the boxes to measure the weather conditions.

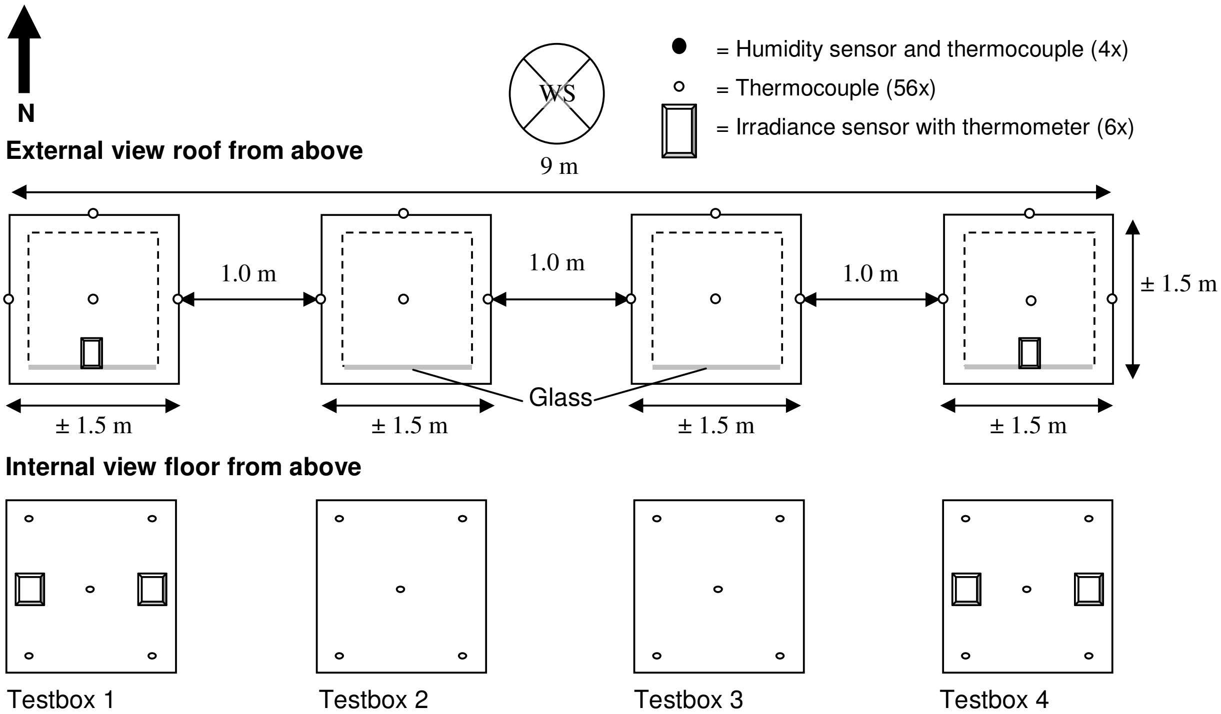

Figure 4 Layout of the test site with an external (roof) and internal (floor) view of the four boxes with their sensors.

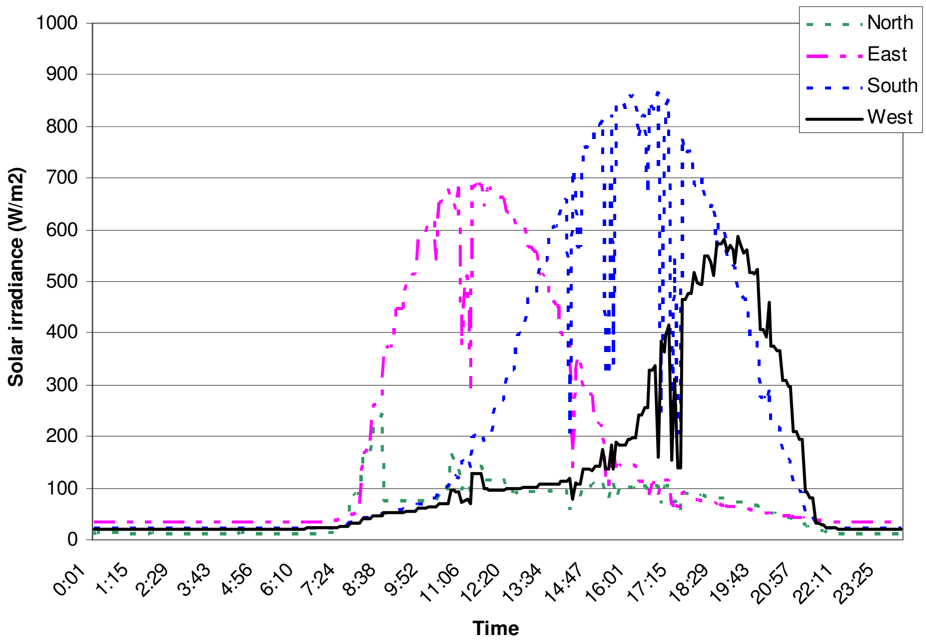

Figure 5 Solar irradiance on a sunny clear day at the four facades of one of the buildings of the University of Twente. Total irradiances are: North 1.41 kWh/m², East 4.39 kWh/m², South 5.57 kWh/m², and West 3.09 kWh/m² (measurements collected on April 26th, 2007).

Table 2 Building physical constitution of the test boxes in the experimental setup

	Testbox 1	Testbox 2	Testbox 3	Testbox 4
Insulation material (thermal resistance)	Cellular glass 3.8 $(m^2 \cdot K)/W$	Cellular glass 3.8 $(m^2 \cdot K)/W$	Light 5.6 $(m^2 \cdot K)/W$	Light 5.6 $(m^2 \cdot K)/W$
Phase Changing Materials in concrete floor (weight percentage)	Present ± 5%	Absent 0%	Present ± 5%	Absent 0%
Thermal resistance glazing (thermal transmittance)	High 1.1 $W/(m^2 \cdot K)$	Low 0.5 $W/(m^2 \cdot K)$	High 1.1 $W/(m^2 \cdot K)$	Low 0.5 $W/(m^2 \cdot K)$

5. Monitoring system

The boxes will be continuously monitored with a sampling interval of 5 minutes. On top of the floor the surface temperature will be measured at five different points. The surface temperature at the underside of the floor will also be measured. Two thermocouples will be located in the middle of both sides, in the middle of the roof and in the middle of the backside. In the middle of the box the humidity degree and temperature are measured. The temperatures at the internal and external sides of the glazing will also be measured. In total twenty thermocouples will be used per box (see Figure 4). Data acquisition will take place by using two USB TC-08 of Pico, two USB 6218 (offering 32 channels each) and two USB 6215 (offering 16 channels each) of National Instruments. Two personal computers will be used to store this data.

All thermocouples will be made out of 400 metres Teflon insulated TX wire. The amount of solar irradiance is measured by six silicon irradiance sensors type Si-01 TC-T of Mencke & Tegtmeyer placed horizontally on top of and within the test boxes. These irradiance sensors each have a sensor to measure their temperature. The humidity of the air inside the boxes will be measured by four A05 Basic Capacitive Humidity Modules with sensor type P14 SMD of LinPicco. The weather conditions are measured by a WS. The weather station is a Vantage Pro 2 of Davis Instruments with thermometer (°C), humidity meter (%), anemometer (m/s and 0° - 360°), and solar sensor (W/m^2).

6. Conclusions and future research

In this paper the use of solar irradiance for saving fossil fuels consumption for residential heating is investigated. Advanced glazing and PCM can offer the necessary storage capacity for heat obtained from solar irradiance.

At this moment strength tests are conducted to determine the appropriate mixture of Micronal with concrete so that construction's strength is not significantly decreased. In the forthcoming months the developed boxes will be put to the test in the open air and data can be collected. The results will give more insights in how buildings can be heated by making use of a passive solar technique. The experiment comprehends different elements, which in former research were considered in stand alone conditions. The interaction between irradiance & window frames, heat & concrete floors and conductivity & insulation are now all brought together in one situation.

In this experiment downscaled models of a living room are used, but future research with real(size) houses could confirm if downscaling is an acceptable method to do this type of experimental research in building physics. In other fields of scientific research this is already common practice.

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BEST PRACTICE CLEANING – REDUCING COSTS, WASTE AND USE OF CHEMICALS BY INTRODUCING A MODERN CLEANING CONCEPT

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Summary

A new cleaning concept has been introduced in the buildings managed by the Norwegian Defense Estates Agency. The aim was to establish cleaning systems, benchmarks and measuring systems that could assure reduced cleaning costs, higher quality of cleaning, reduced environmental load, and improved working environment. The project included analysis of status, establishing a set of benchmarks, development of a new cleaning concept with accompanying tools & systems, and introduction of the concept in buildings. Evaluation of results revealed a "win-win" situation with 27 % reduction in cleaning costs, 86 % reduction in plastic waste, 46 % reduction in use of cleaning chemicals, 40 % reduction in sick leave among the cleaners, 32 % reduction in dust load on surfaces, and satisfied cleaners, users, and customers. Of the remaining chemicals, more than 70 % fulfilled the criteria for the Nordic ecolabel, The Swan. The project was awarded the Norwegian environment prize "The Glass Bear", which was handed out in Oslo by the Norwegian Minister of Environment Protection in May 2006.

1. Introduction

A survey of the environmental impact from professional building cleaning performed in the 4 Nordic countries in 2001 revealed that professional cleaning consumes approximately 73.000 tons of cleaning chemicals annually, whereof 11.000 tons dry matter, 4.500.000 tons of water, 140 million kWh electricity for cleaning machines, and 100.000.000 liters of fossil fuel for transport (Nilsen, 2002). The survey also revealed that cleaning produced annually more than 35.000 tons of waste in the Nordic countries and that 45 % of this waste was from plastic bags for insertion in dustbins.

Cleaning consumes 20-30 % of the facility management budget of Norwegian office buildings, and is often the most costly budget item. Cost reductions are continuously searched for, and can usually be accomplished by introducing more effective cleaning methods (Schneider, Nilsen and Dahl, 1994) together with reduced cleaning frequency. These cleaning methods require a smaller amount of cleaning chemicals and water, and are assumed to be more environmental friendly (Nilsen, Dahl, Jørgensen et al., 2002). On the other hand, reduced cleaning frequencies may result in lower cleaning quality and higher dust load, which increases the risk of Sick Building Syndrome-symptoms (Skov et al., 1987). New tools (Schneider, Løbner, Nilsen et al., 1994; Nilsen, Dahl, Schjønning et al., 2000; Standards Norway, 2000) have made it possible to quantitatively measure cleaning quality, and thereby avoid quality reduction when re-adjusting cleaning systems in buildings (Nilsen, Blom, Rydock, Nersveen and Fostervold 2002).

The Norwegian Defense Estates Agency was established in 2002 as a result of a merger of the facility management organisations for all the properties of the Norwegian Defence and the former Norwegian Defence Construction Services. The vision of the new company was "To make visible all costs related to properties and constructions, and at the same time have focus on the environment and the society". One of the first targets of the new organisation was to reduce cleaning costs, and as a result of this a benchmarking-project called "Best Practice Cleaning" was established. The object of the project was "To establish cleaning systems and benchmarks that can contribute to environmental friendly and cost-effective cleaning of the Defence's buildings". This paper gives a brief summary of the project, which started in 2002 and ended in 2005.

2. Methods

The project was carried out in three steps:

1. Survey of status for cleaning services in the Defence's buildings, compare with other buildings, and develop benchmarks and accompanying measuring system.
2. Develop a new cleaning concept and accompanying tools and support systems.
3. Introduce the new cleaning system in all buildings and measure effects.

2.1 Survey

The survey covered 10 of the Defence's establishments, with a total cleaning area of 340.000 m^2. This represented 20 % of the total cleaning area of the Defence's buildings. Three of the establishments had cleaning services delivered by private cleaning companies. A questionnaire was developed to collect the following data:

- Building related factors: age, maintenance status, traffic load, dirt load, cleanability.
- Cleaning system: frequencies and main methods for regular and periodic cleaning.
- Cleaning time: performance in m^2 cleaned area per hour.
- Cleaning costs: material costs, total costs for regular and periodic cleaning, per m^2 floor surface and year.
- Human resources: number of cleaning personnel, working time, age, length of service, education, turnover, short time and long time sick leave.
- Cleaning quality: visual quality and measurements of dust on surfaces, according to Norwegian Standard NS-INSTA 800 (Standards Norway, 2000).
- Environmental factors: use of 20 kinds of cleaning chemicals, use of plastic bags, both calculated for the year 2001 as mg per m^2 cleaned floor surface, and portion of chemicals with ecolabel in %.
- Internal regulations and quality management system: calculation routines, handbooks for cleaning, quality assurance, trade union agreements.

The results from the survey were compared with other studies as seen below:

- Cleaning costs; survey carried out in 8 comparable buildings in the Oslo area.
- Performance; calculations of average performance in public and private sector carried out by a cleaning consultant as a part of this project.
- Human resources; statistics for sick leave, turnover and education levels for cleaners in public and private sector.
- Cleaning quality; results from measurements in office and school buildings in the Oslo area, carried out by SINTEF Building & Infrastructure and the National Institute of Technology.
- Cleaning system and environmental factors; results from a Nordic survey (Nilsen, 2002), and criteria for the Nordic ecolabel, The Swan, for cleaning services (Nordic Ecolabelling, 2002).

All calculations were done on a spreadsheet.

Based on the results, requirements for the new cleaning concept were developed, and a set of benchmarks were established.

2.2 Development

Step two included the following development activities:

- *Cleaning manual for the new cleaning concept*: 125 documents describing rules and regulations, requirements for cleaning technical products, methods to be used and method descriptions, cleaning surfaces, calculation principles, methods for quality control, and benchmarks and goals.
- *Material standard for cleaning products*: search for products and suppliers, make procurement agreement and select a set of environmental friendly products to be used.

- *Calculation software for cleaning*: develop users' requirements and tender based on this, and select system and supplier.
- *Education program*: develop requirements for an education program targeting three different levels of personnel, develop a tender based on this, and select supplier.
- *Information plan*: develop a plan to inform all customers, users of the premises, and personnel about the new cleaning routines.
- *Standardised tender with requirements, benchmarks, goals, and follow-up routines*: for procurement of cleaning services to be used where external delivery is desired.

2.3 Implementation and evaluation

The implementation process involved carrying out the following activities in all the Defence's establishments:

- Plan new cleaning routines and calculate cleaning time for all the Defence's buildings.
- Select and purchase cleaning materials (chemicals, equipment and machines).
- Carry out an education and information program for more than 800 cleaners, their leaders and their customers, by holding a total of 61 courses.
- Start-up cleaning according to the new concept.

Evaluation of results was carried out after 6 months. Some factors were evaluated again after another year. The evaluation was carried out in 20 of the Defence's establishments and included:

- *Cleaning costs*: total costs for regular and periodic cleaning, per m^2 floor and year, by using the new calculation software.
- *Cleaning quality*: visual quality and measurements of dust on surfaces, acc. to NS-INSTA 800 (Standards Norway, 2000).
- *Environmental factors*: use of chemicals and plastic bags, as described in the criteria of the Nordic ecolabel, The Swan, for cleaning services (Nordic Ecolabelling, 2002).
- *Human resources*: degree of completion of the education program, sick leave.
- *Evaluation of education program*: a questionnaire stating degree of satisfaction from 1–5 (1 = very satisfied), questions answered by all participants after each course.
- *Evaluation of employee satisfaction*: a questionnaire with 7 questions addressing information given, 14 questions addressing the new cleaning concept, and 14 questions addressing the implementation process, answered by all employees, stating degree of satisfaction from 1–5 (1 = very satisfied).
- *Evaluation of customer satisfaction*: a questionnaire with 5 questions addressing information given, 9 questions addressing the new cleaning concept, and 9 questions addressing the quality of the cleaning service, answered by all contact persons for cleaning services at the customers, stating degree of satisfaction from 1–5 (1 = very satisfied).

3. Results

3.1 Step 1 - Survey

Results for cleaning performance compared with average performance in public and private sector can be seen in Table 1.

Table 1 Average cleaning performance in m^2 cleaned area per hour

	Norwegian Defense Estates Agency	Public sector	Private sector
Average	141,5	198,8	261,9
Factor	100	137	185

Cleaning costs were high and showed large variations, see Figure 1. Average cost for internal delivery was NOK 195 per m^2 and year, and the total cleaning cost for all the Defence's buildings was NOK 340 mill. per year. Material costs were only 1,9 % of the total cleaning costs.

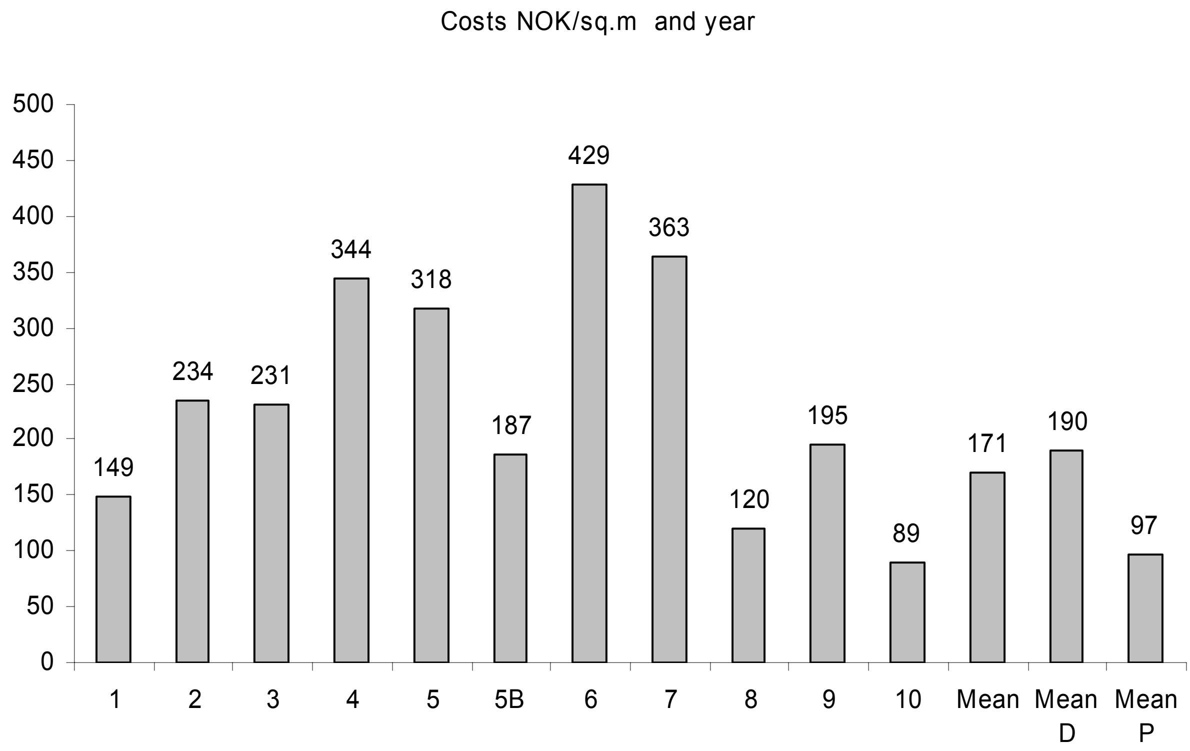

Figure 1 Cleaning costs. Mean D is average costs for internal delivery, Mean P is average costs for external delivery.

Results for human resources are shown in Table 2. The percentage with education in cleaning reflects cleaners with a certificate of completed apprenticeship.

Table 2 Human resources in the 10 establishments surveyed

Number of cleaners	Average age	Average employed	Portion with education in cleaning	Sick leave
215	47 years	18 years	40 %	20 %

The cleaning system was based on programmed cleaning with fixed cleaning methods and frequencies for different surfaces. Quality requirements and follow-up routines were not established. Measurements of cleaning quality revealed high visual quality on furniture and fixtures, walls and ceilings, but low quality on floors. Results from measurements of dust on surfaces in the 10 establishments can be seen in Table 3. Recommended maximum values are based on results from Schneider, Løbner, Nilsen et al. (1994).

Table 3 Dust on surfaces, dust coverage percentage

	Close to person surfaces	Accessible furniture and fixtures	Surfaces above 180 cm	Floors	Average dust load
Average	1,2	1,8	9,7	2,8	3,9
Recom. max.	1,0	1,5	5,0	3,0	2,6

The survey revealed that cleaning was carried out mainly by use of cleaning chemicals and wet or damp cleaning methods. Results from measurements of environmental factors are showed in Table 4. The points given reflect environmental points calculated according to the criteria of the Nordic ecolabel, The Swan, for cleaning services (Nordic Ecolabelling, 2002). Total use of cleaning chemicals was approximately 100 tons, and total use of plastic bags was 20 tons per year.

Table 4 Environmental factors

Property	Value	Points	Max. points given
Dry matter cleaning chemicals, mg pr m^2 cleaned floor	120	2	5
Portion of products with ecolabel	18 %	1	5
Use of plastic bags, mg pr m^2 cleaned floor	151	2	5
TOTALS		5	15

3.2 Step 1 – Develop benchmarks and cleaning concept

Benchmarks and goals for the new cleaning concept are given in Table 5.

Table 5 Benchmarks and goals

Costs	Quality	Environment	Sick leave
Max. NOK 125.- per m^2 and year	Dust-level 4 acc. to NS-INSTA 800	Fulfill the Nordic Swan criteria for cleaning services; min. 9 points	Less than 10 % (for cleaners)

The new cleaning concept was based on the following principles:

- Quality based cleaning system with quality requirements and control routines according to the internordic standard NS-INSTA 800 (Standards Norway, 2000).
- Regular cleaning shall cover all the surfaces up to 3 meters above the floor in all rooms and premises.
- Floor maintenance shall be included in the regular cleaning.
- Periodic cleaning shall only be performed in rooms with fatty deposits or on surfaces higher than 3 meters above the floor.
- Dust and dust depots shall have special attention.
- Cleaning shall be performed without use of water buckets according to the principles of “dryer methods” (Schneider, Nilsen and Dahl, 1994).
- Dustbin bags shall only be changed if contaminated with biological waste.
- The cleaning service shall have focus on the environment in all respects.

3.3 Step 3 - Evaluation

Table 6 shows results from evaluation of cleaning costs, cleaning quality and sick leave after implementation of the new cleaning concept. Visual quality requirements were fulfilled in 79 % of the inspected areas.

Table 6 Results after implementation; costs, quality and sick leave

Average costs	Quality Average dust load	Sick leave
NOK 153.- per m^2 and year (2004) NOK 139.- per m^2 and year (2005)	2,67 % (2004)	14 % (2004) 12 % (2005)

Results for environmental factors can be seen in Table 7. The reduced consumption of cleaning chemicals and plastic bags gave a 50 % reduction in material costs.

Table 7 Results after implementation; environmental factors

Property	Value	Ecolabel points
Dry matter cleaning chemicals, mg per m^2 cleaned floor	65	3
Portion of products with ecolabel	70 %	5
Use of plastic bags, mg pr m^2 cleaned floor	21	5
TOTALS		13

Results from evaluation of education program, employee satisfaction and customer satisfaction can be seen in Table 8. The table shows average score for the questions asked, on a scale from 1–5 (1 = very satisfied).

Table 8 Evaluation of education program, employee satisfaction and customer satisfaction

Factor	Average score
Education program:	
Course 1	2,0
Course 2	1,5
Course 3	1,5
Employee satisfaction	2,0
Customer satisfaction	1,9

4. Discussion

The survey carried out in Step 1 revealed that the cleaning costs for buildings cleaned by the Defence's own cleaners (internal delivery) were almost twice as high as the average costs for the 8 comparable buildings. This was caused by an old trade union agreement which limited cleaning performance to an average of 141,5 m^2 per hour. There was no correlation between cleaning methods used and cleaning costs, showing that there was a great need to introduce new calculation routines. Costs for cleaning delivered by cleaning contractors were at the same level as costs in 5 comparable buildings in the Oslo area. The contractors used mainly methods following the principles of "dryer methods" (Schneider, Nilsen and Dahl, 1994).

The cleaning personnel of the Norwegian Defence were very experienced and had long service time and high level of education compared to cleaners employed by contractors. Only 15 % of the cleaners employed by the two contractors had certificate for completed apprenticeship. The premises for introduction of a new cleaning system in the Defence's organization were therefore good.

The sick leave was high both among the Defence's and the contractor's personnel, and the sick leave was high compared to other professions. Statistics from Statistics Norway showed an average sick leave in Norway of 8 % for the first quarter of 2002.

Visual measurements of cleaning quality showed low quality on floors despite of dust measurements showing low levels of dust on floor. Low visual quality was caused by lack of cleaning related maintenance of the floors. Requirements established for visual cleaning quality for the new cleaning system was only fulfilled by one of the establishments surveyed in Step 1. Dust coverage was higher than recommended levels (Schneider, Løbner, Nilsen et al., 1994) on all surfaces except floors. High levels of dust on surfaces can have negative effects on sick leave among the users of the building and thereby affect the productivity and overall economy of the company (Nilsen, Blom, Rydock, Nersveen and Fostervold, 2002).

Results from measurements of environmental factors in Step 1 revealed high chemical load and waste load. Results from a survey performed in 8 Nordic cleaning companies in 2001 (Nilsen, 2002) can be seen in Table 9.

Table 9 Results from a Nordic survey of the environmental impact from professional building cleaning (Nilsen, 2002)

Property	Result
Dry matter cleaning chemicals, average	55 mg pr m^2 cleaned floor
Lowest / highest	24 / 198
Portion of products with ecolabel, average	37 %
Lowest / highest	16 % / 66 %
Use of plastic bags, average	127 mg pr m^2 cleaned floor
Lowest / highest	11 / 228

Only one of the companies surveyed in 2001 had higher chemical consumption than the 120 mg pr m^2 cleaned floor found for the Defence's establishments. Six of the companies surveyed had a higher portion of products with ecolabel than 18 %. Only one of the companies had higher result for use of plastic bags than the 151 mg pr m^2 cleaned floor found for the Defence's establishments.

Evaluation of the implementation process showed very good results both for the education program, employee satisfaction and customer satisfaction.

Evaluation of the benchmarks after implementation of the new cleaning concept revealed large reductions in cleaning costs, sick leave, environmental load, and dust load, and large improvements in cleaning quality. A summary for some of the factors can be seen in Figure 2. The benchmark for costs for internal delivery of cleanings services was not reached in 2004, but further reduction was achieved in 2005, and the estimate for 2008 is NOK 118.- per m^2 and year. The result for 2005 gave a total reduction in cleaning costs compared to 2002 of approximately NOK 50 mill.

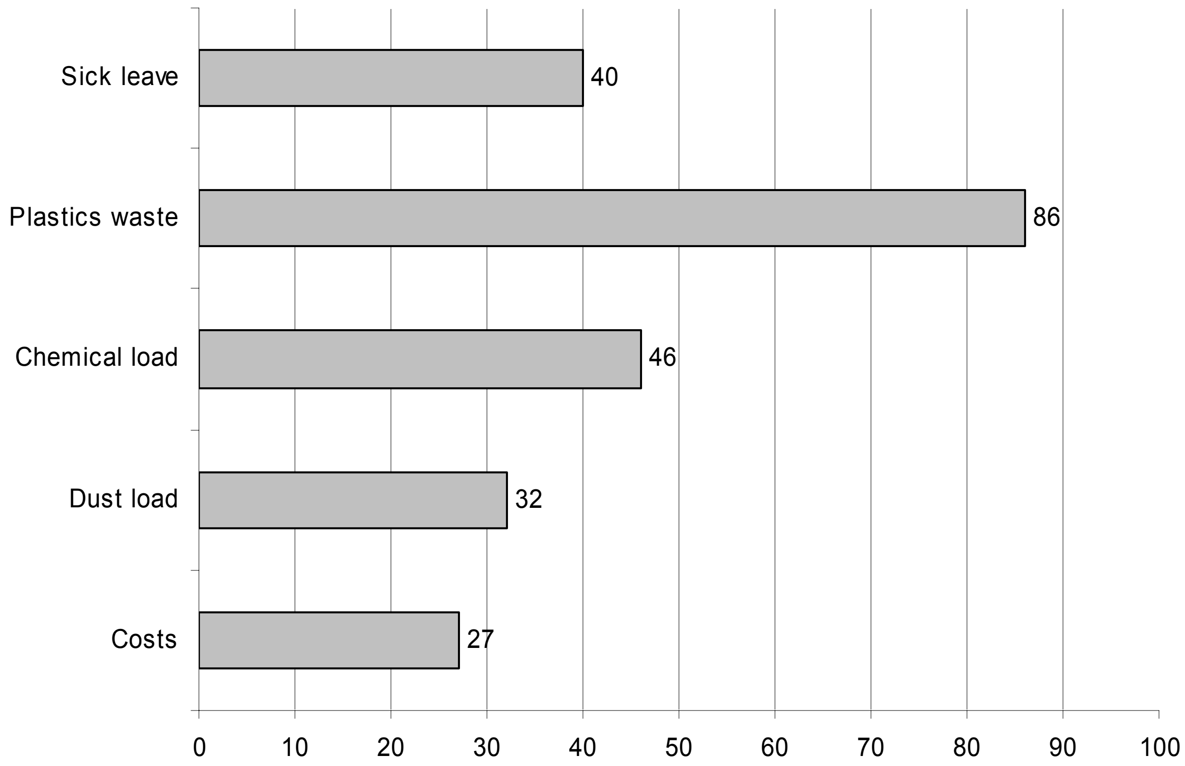

Figure 2 *Reductions in cleaning costs, environmental load, dust load and sick leave, in percent after implementation of the new cleaning concept. Figures for sick leave and costs are from 2005.*

The benchmark for cleaning quality was fulfilled in 73 % of the buildings surveyed, but the average dust load for all buildings was somewhat higher than the maximum level given in the benchmark. This was caused by high results in one of the establishments surveyed.

The benchmark for sick leave was not reached in 2004, but the survey from 2005 showed further improvements.

The benchmark for environmental factors was reached in 90 % of the establishments, and the total result was very good and better than for the 8 Nordic cleaning companies surveyed in 2001 (Nilsen, 2002). The minimum requirement of 9 environmental points was reached with good margin. The new cleaning concept gave a reduction in consumption of cleaning chemicals of 46.000 kg/year and reduction in consumption of plastic bags of 17.800 kg/year.

5. Conclusion

The project showed that introduction of a new and modern cleaning concept in buildings can give large environmental improvements. In addition, other cleaning factors can be greatly improved. Introduction of the new cleaning concept “Best Practice Cleaning” in all of the Norwegian Defence’s buildings revealed a “win-win” situation with 27 % reduction in cleaning costs, 86 % reduction in plastic waste, 46 % reduction in use of cleaning chemicals, 40 % reduction in sick leave among the cleaners, 32 % reduction in dust load on surfaces, and satisfied cleaners, users, and customers. The project was awarded the Norwegian environment prize “The Glass Bear”, which was handed out in Oslo by the Norwegian Minister of Environment Protection in May 2006.

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TITLE: CONNECTED, VIABLE, LIVEABLE - THE FACILITIES MANAGERS' ROLE IN DELIVERING BUILT ENVIRONMENTS

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Keywords: facilities management, sustainable built environment, sustainable building management

Summary

Building performance and design rating tools have helped the property industry evaluate an asset's performance capability. Their proliferation and promotion have offered a range of yardsticks for efficient design, but not without some confusion in the market place, especially as new building performance technologies continually supersede current best practice, locally and internationally. These tools have also mainly concentrated on rating the design principles to obtain efficiencies for *new* buildings, creating a presumption that all such buildings will be managed at an optimum design level.

This preoccupation with the 'new' has overshadowed the property industry's appreciation of gains available from effective management of the *existing* building stock. Whilst a building can be designed with improved technology, it is the expertise and capability of onsite facility teams who are best placed to realise the optimum performance efficiency of that building in a dynamic operating environment.

This presentation will explore two case studies which demonstrate the importance of the facility manager in delivering performance improvements: The KPMG Building in Sydney, with a 4.5 star Australian Building Greenhouse Rating (ABGR) Design Rating, now operating at 5 star ABGR; and the Jesse Street Centre, Parramatta, a building over 20 years old, currently undergoing major refurbishment which has incorporated significant energy and water savings, as a direct result of prudent asset management.

1.0 Introduction

Brookfield Multiplex Services (formerly Multiplex Facilities Management) is pleased to submit a nomination to the World sb08 Conference to be held at the Melbourne Convention Centre, Melbourne.

This paper proposes the importance of the Facilities Management Team in delivering a connected, viable, liveable built environment. Our first case study is on the KPMG Tower facilities team and their efforts ensure the KPMG building (located at Shelley Street, King Street Wharf Precinct, Sydney) achieved its design rating of 4.5 Stars under the Australian Building Greenhouse Rating Scheme (ABGR). Such was the effort, the team successfully improved the building's performance in November 2006 to a 5 Star ABGR rating. The second case study is on the Jessie Street Centre, located in the Parramatta CBD. Efforts from the facilities management team here led to not only improving the performance of an almost twenty year old building, but also provide valuable data for the retrofit to the building's major plant and equipment, commencing in 2007 with a final completion programmed for September 2008. Both case studies are viewed specifically from an energy efficiency measurement, although it should be recognised the facility teams consider all aspects of operating buildings in the most environmentally efficient way.

What is a facility management team? The definition according to the Facilities Management Association of Australia (FMA) is,

"a business practice that optimises people, process, assets and the work environment to support the delivery of the organisations business objective"

'Facilities' can therefore include buildings, properties and major infrastructure; collectively referred to as the "Built Environment".

The primary function of Facilities Management Teams (FMT) is to manage and maintain the efficient operation of facilities on behalf of users. This includes:

- Effective management of the organisation's built assets
- Ensuring services are delivered in a way that contributes to the productivity and profitability of the building's occupants
- Reducing environmental impacts
- Minimising life cycle costs, with repair and maintenance strategies
- Delivering business continuity through sustainable management practices

In Australia, there is a growing expectation about better managing and adapting to the risks of climate change. Australian corporations are increasingly being asked by institutional investors about their awareness and preparedness to manage the business risks of climate change. As part of that process, more businesses are taking steps to review and minimise their operating impact on the environment. In the Australian office market, the flow-on effect is the reframing of building robustness to more extreme weather events, as well as desired occupancy requirements, recognising the value of environmentally friendly work spaces that are not only energy efficient, but provide comfort and quality for a more productive workforce.

Supporting this move is a range of building performance and design rating tools, to help owners understand and evaluate the extent of an asset's energy efficiency capability. A key rating tool for building energy performance is Australian Building Greenhouse Rating (ABGR) Scheme, which measures from one to five stars, with the five stars rating as the highest or most efficient performance. The rating is based on actual energy consumed by a building over a calendar year. The rating reflects the way energy is managed during building operation as well as the efficiency of the building design. To assist Australian building owners and tenants benchmark their greenhouse performance, government agencies have implemented ABGR - now incorporated into the National Australian Built Environment Rating Scheme (NABERS).

Buildings account for a significant proportion of environmental impacts. The OECD has estimated that world wide; buildings consume 32% of the world's resources, including 12% of water use[i]. In Australia, the building industry which includes the residential and non-residential sectors comprises almost a quarter of the (23%) of the nation's greenhouse gas emissions (GHG)[ii]. The non-residential sector alone emits an estimated 10% of GHG in 2005, equal to approximately $130tCO_{2\text{-}e}$ of GHG (CIE 2007) largely through consumption of electricity used to operate the buildings.

It should be emphasised that whilst a building can be designed with improved technology for a high energy efficiency operation, it is the expertise and capability of the onsite facility teams operating the building who are best placed to realise the delivery of optimum performance efficiency of that building.

It is estimated existing Australian building stock, comprises 98% 'older' buildings and 2% being new stock[iii], the latter, designed with the consideration to building efficiencies in plant and equipment and green practices to limit the impact on the environmental resource use. Further, an estimated 61% of the energy used in the commercial sector buildings coming from the base building activities, with the remaining 39% generated from tenant lighting and power requirements[iv]. There cannot be more compelling statistics reinforcing the importance of a facility management team, who can directly impact on building operating efficiency by effectively managing the base building activities.

It is therefore imperative for an onsite team to be appropriately skilled and empowered to successfully deliver a building's optimum performance, to ensure all functions are managed to best practice.

"*Best practice energy efficiency can be defined as using the best available technology and methods to achieve the highest level of energy efficiency and management*"[v]

The attainment of 'Best Practice' in energy efficiency can be verified in this instance by the benchmarking environmental metrics like electricity and gas use and working to deliver progressive, targeted improvements from a clear baseline.

2.0 Case Study – KPMG Building, Sydney

The KPMG Tower was developed, designed, constructed and is now managed by the Services Division of the now Brookfield Multiplex Group, who are also part owner. The development comprises the North Tower on site 6 within the King Street Wharf Precinct. It provides a total of 27,722 m2 of 'A' grade office space in a tower comprising 15 levels, with four levels of underground car parking.

Brookfield Multiplex Group entered into an agreement with the NSW Department of Energy, Utilities and Sustainability to deliver a 4.5 Star ABGR rated conventional office building prior to construction commencing. The Base Building 4.5 Star rating was achieved in July 2005, 12 months after construction was completed.

The Facility Management Agreement provided for a fixed-cost solution for a majority of controllable outgoings, as well as risk transfer from the client to Brookfield Multiplex Services Division. The risk transfer features included responsibility for the capital replacement risk on building services.

The Facilities Management comprehensive responsibilities included conventional air conditioning system (chillers, Variable Air Volume controllers, pumps and cooling towers), ventilation, fire protection, lifts, pest control, building automation and energy management systems, repairs and maintenance, common area cleaning, security and access control, loading dock administration and management.

Brookfield Multiplex Group's 'integrated property model', that being, design, build, own, manage was key to Multiplex FM working with the Construction Division at the design stage and providing advice on core plant and infrastructure.

The result was a building design that had consideration to the long term maintenance and operating requirements at the beginning of the project, and continuation to the end of the construction phase, rather than the facilities service provider being handed a completed project with the initial capital cost of construction being the major driver towards completing the project.

2.1 Design principles employed at KPMG Tower

- Generally open floor layout
- Central Plant
- Conventional VAV air handling system
- Zoned control of the air handling system
- Electric re-heat
- T5 lighting to tenant areas
- Sun shades in varying concentration to the east, north and western faces of the building
- Perimeter light sensors
- Motion detectors for after hours corridor & toilet lighting

The above design criteria are less technologically advanced than some of the modern commercial buildings where chilled beam technology or cogeneration plant has been installed.

The ability of the KPMG Facility Team to firstly deliver the 4.5 Star design rating and secondly obtain the 5 Star ABGR rating was very much reliant on the commitment to energy efficiency and support from all stakeholders within the project:

- Developer Commitment Agreement
- Builder Design and construct in accordance with actual ABGR
- Managers Contractual Energy & Service Responsibility
- Owners Continued Commitment and Agreement Process
- Tenants Parallel commitment to energy conservation

2.2 How was the 5 Star ABGR rating achieved?

Our facilities management strategy for KPMG Tower included the following principles in respect to sustainability and energy efficiency. We employed:

- Accurate Modelling for the Design parameters
- Efficient Design which included installation of external shading systems to reduce the thermal
- impact on the building fabric, while allowing harvesting natural light to reduce the need of artificial reliance;
- Quality installation that meet the design criteria for example the installation of T5 energy efficient
- lighting throughout the tenancy areas and incorporated with this after hour zonings for minimum demand;
- Rigid Control of HVAC system, which included a building management control system which allows real time differential energy metering;
- Effective Management
- Staff with the right technical capability;
- Understand the building design and its relationship to ABGR Scheme;
- Determine where the energy is best used, ensuring measurements are in place, making operational changes based on verifiable data, and continuing to review the results periodically to modify the strategy where necessary;
- Passion for efficient energy management.

The KPMG Facilities Team were able to determine through the monitoring of the energy consumption within the Tower and the performance of individual plant and equipment the key areas to concentrate there efforts to make the greatest gains in reducing the energy consumption.

The main area of concentration was the HVAC system. The gains in energy reduction here have included monitoring operations of the main plant using the Building Management Control System (BMCS), by manually verifying the systems performance and adjusting original design set points, with tenant agreement.

The major gains identified during the twelve months between the initial 4.5 Star rating and gaining the 5 Star rating relate to reducing the chilled water requirements in summer and the heating requirements in winter. One of the key successful strategies was greater use of natural ventilation, modifying the temperature set points to reduce the need for the main air conditioning plant to come into play and relying more on the supply and exhaust ventilation systems, by changing the building purge cycles in summer to reduce the stored heat, and conversely making use of this stored thermal energy in winter to reduce the need to call on supplementary heating.

The Tower has been able to maintain 100% economy mode for the air conditioning system throughout the year, and, combined with the or enthalpy sensors, both exhaust and supply ventilation is used to 100% efficiency.

The resultant reduction in energy can be directly related to the actions of the Facilities Team efforts to manage the Tower services and equipment efficiently. The direct measure of their success can be demonstrated when the achievement of the 4.5 Star is considered the baseline of the buildings energy performance at 366MJ/m^2 p.a. and the achievement of the 5 Star ABGR Base Building rating at the improved energy consumption 347MJ/m^2 p.a. a saving of 19MJ/m2 p.a., or 5.5% reduction per annum.

The following results indicate the continued reduction in the energy consumption from 2004 up to 2008 which equates to a financial saving of approximately $33,648.

	March 04 – Feb 05	March 05 – Feb 06	March 06 – Feb 07	March 07 – Feb 08
Operating Hrs p/wk	54.1301281	54.81192308	54.717	55
Electricity per 12 mths (kWh)	2,772,067.861	2,428,729.16	2,451,702.89	2,397,809
Gas per 12 mths (MJ)	474,493.3794	423,295.35	453,799.22	426,814.88

- Kg CO_2/m^2/annum 83 - 74
- ABGR (Based on Calculator) 4.5

This saving represented a reduction in outgoings and a direct reduction for the tenant, achieved with consultation with the tenant and the owners, to ensure the contractual lease arrangements between the owner and the tenant were not jeopardised and the occupants comfort levels not reduced.

Table 1 below, indicates the environmental performance of the KPMG building using three data streams, electricity, gas and water across the operating years to date, and has a comparison from the building industry as a benchmark to verify both the success of the KPMG facility team and an efficient building and the resultant efforts of other facility management teams during the same period. It can be noted that water used in large commercial buildings can also be used as an indicator for energy use also due to the electrical infrastructure involved in the supply of this commodity, and from Table 1, it can be noted the performance in 2006 was energy increased, as there was an extraordinary high use of water during that period.

Table 1 KPMG Building Consumption Data 2004-2007: Industry Comparison

Electricity Consumption	2004	2005	2006	2007
Electricity per 12 months (kWh)	2,741,620	2,476,999	2,423,789	2,341,459
Consumption Intensity (kWh/m2)	98.89	89.35	87.4	84.4
Industry portfolio average (kWh/m2)vi	135	123	116	108

Water Consumption	2004	2005	2006	2007
Water per 12 months (kL)	41,947	28,041	38,872	30,395
Consumption Intensity (kL/m2)	1.49	1.00	1.38	1.08
Industry portfolio average (kL/m2)	1.12	1.01	0.08	0.77
Brookfield Multiplex average (kL/m2)	1.09	1.18	1.21	0.93

Natural Gas Consumption	2004	2005	2006	2007
Gas per 12 months (MJ)	474,493.3794	423,295.35	453,799.22	426,814.88
Consumption Intensity (MJ/m2)	16.36	15.26	16.3	15.3
Industry portfolio average (MJ/m2)	139	121	87	82

3.0 Case Study - Jessie Street Centre

Jessie Street Centre comprises of a 20-storey freestanding commercial office complex (circa 1988), comprising a single level of basement parking for approximately 342 vehicles, ground floor retail and office tower. The complex also includes two low-rise office wings (North and South) and a magnificent five level-vaulted atrium that links the south wing with the high rise tower. The north wing is stepped from George Street and rises to seven levels while the south wing fronts Macquarie Street.

The Jessie Street Centre provides office accommodation with the following services:

- The Property Service Centre – who is the point of contact for tenants with building service requests, operating 24 hours a day, seven days a week.
- Ground Floor concierge providing security and direction during working days between the hours of 6.00am and 6.00pm.
- 24 hour on-site security.
- 24 hour building access.
- Loading dock attendant providing loading dock services during working days between the hours of 7.00am and 5.00pm.

- A separate goods lift and loading dock facilities.
- After hours air-conditioning is available on a floor by floor basis.
- Emergency power back up for all essential services.
- In-house maintenance staff.
- On-site day cleaner available on working days between the hours of 7.30am and 5.00pm.

The Jessie Street Centre comprises a net lettable area of 54,336m².

Brookfield Multiplex Services provided property management and facilities management to the buildings base building services since 2005. The building can be described as of conventional design for the period, with centralised core, columns supporting each floor level with major chillers and plant rooms servicing indoor air quality and space condition, and building management control software to control the HVAC system.

The original Property Management Agreement provided a management contract with all costs recoverable from tenants and the management fee reviewed against the industry benchmark. The agreement included the facility management responsibility to manage the base building services including, air conditioning system (HVAC), ventilation, fire protection, lifts, pest control, building automation, repairs and maintenance, common area and tenancy cleaning, landscaping and access control.

A key part of the original transition plan and on-going building management was to gather data on the ongoing operations of the building which included a number of environmental metrics, with the focus on electricity, gas and water use. Table 2 represents the data between the commencement of management in 2005 to date, excluding the 2007 data. At the time of writing, the normalised results based on the difference between the retrofit activities to the Jessie Street Centre commencing during this period, and the normal operations were still being compiled and not available.

Table 2 Jessie Street: Consumption Data

Electricity Consumption	2004	2005	2006	2007
Electricity per 12 months (kWh)		6,994,940	6,817,814	
Consumption Intensity (kWh/m^2)		130	126	
Industry portfolio average (kWh/m^2)[1]	135	123	116	108

Water Consumption	-	2005	2006	2007
Water per 12 months (kL)		61,688.0	68,099.9	52,435.3
Consumption Intensity (kL/m^2)		1.25	1.13	0.91
Industry portfolio average (kL/m^2)	1.12	1.01	0.08	0.77

Natural Gas Consumption	2004	2005	2006	2007
Gas per 12 months (MJh)		4,355,978	4,297,486	
Consumption Intensity (MJ/m^2)		80.1	79.8	
Industry portfolio average (MJ/m^2)	139	121	87	82

To obtain energy data, consumption was metered within areas to determine the actual performance of individual plant and equipment. With the availability of hard data, operational changes could be made, and continuing review of results undertaken to identify areas of improvement and modify the management strategy.

Areas where improvements were identified included the BMCS operation, performance of the major plant and equipment, lighting controls and hardware. Further improvements to amenities were also considered, with efficiency initiatives around water consumption including the trialling of waterless urinals. The resultant works and investigations delivered the data helped form the basis of the business case to prepare a retrofit project. This has involved working in conjunction with tenants to deliver a major upgrade of the building to a PCA 'A' grade standard and improve the baseline ABGR 3.5 Star rating to a targeted ABGR of 4.5 stars which is currently in progress.

Close liaison with tenants and owners is required to ensure the floor by floor work program occurs seamlessly and with minimal interruption to the tenants operations.

The project scope includes a major upgrade of the base building amenities, lifts, lighting, facade window treatment to reduce thermal inflow, BMCS and HVAC system which has been integrated with the tenant's fit out. The latest technology is being utilised to improve the building ABGR performance to 4.5 stars.

The future Contracting Model being employed across the portfolio includes the on-site facility team supported by region-based Operations Manager and shared service centres. Performance is monitored and reported against a comprehensive regime of key performance indicators (KPI) at the building level. These KPIs include environmental initiatives, which can also form part of the carbon emissions reporting at a corporate level.

4.0 Financial and Community Value

If as estimated by the Department of Climate Change, stationary energy is estimated to contribute 50% of $C0_2$ emissions[vii] towards global warming in Australia, then initiatives to reduce the energy consumption for the commercial office space are critical contributions to the overall domestic greenhouse gas emission reduction targets.

The potential efficiency impact can be compared on average, to a medium-sized 6 cylinder car traveling 20,000kms per year emits 6.4 tonnes $C0_2$ per year[viii]

The resultant reduction of greenhouse gas emitted yearly when the KPMG Tower facilities team went beyond the 4.5 star ABGR design rating in November of 2006 to achieve the 5 Star ABGR equated to a saving of 291462 kgCO_2/year, or the equivalent to removing 45 medium sized vehicles per year off our roads.

The KPMG Facilities Management Team is evaluating a number of future initiatives including upgrading a number of the base building lighting elements to the T5 efficiency globes. It should however be noted the team takes into consideration the embodied energy already expended in the relatively new equipment installed, against the energy saving that retrofitting equipment with new updated technology will deliver as one part of the decision making process.

Further energy reductions are expected, as both the KPMG and Jessie Street Centre facility teams work through assessing the performance of smaller plant items.

Non-energy related initiatives also being considered at the moment by the team include water reductions and waste minimization, both of which will again, ultimately require the cooperation of the tenant.

5.0 Conclusion

In summary, facility management teams have a number of initiatives available to reduce the impact that the existing built environment has on production of carbon emissions. A key tool is the preparation and implementation of sustainable building management plans.

Developing these plans involves data collection of a range of environmental metrics (electricity, gas, water, waste streams, HVAC leakage and fuel used); determining the baseline data and monitoring against that baseline, rectifying building performance loss identified by variances to the baseline and setting the appropriate reduction targets. Other key areas are conducting audits, performing a re-commissioning of the buildings' major HVAC and control equipment at regular intervals, and conducting indoor air quality audits, especially important when you consider indoor air quality can significantly affect human health, given people tend to spend 90% of their time indoors[ix].

A facility team is also on hand to provide awareness and training programs for the building occupants. This should ideally include preparation of a building users guide, induction packages, fit out guidelines and providing graphical performance data on the environmental measures regularly to the occupants. Successful on-site engagement, includes a communication loop back to the facility team on issues and potential reasons for a variance to baseline data. On site facility teams can also have a positive influencing effect to other building users, tenants, and building visitors.

Whilst a building can be designed with improved technology for a high energy efficiency operation, it is the expertise and capability of on onsite facility teams who are best placed to realise the optimum performance efficiency of that building. The asset owner/manager who has foreshadowed the need for front-end investment to deliver efficient operations across the built assets will need assurance the asset is being managed to its optimum, but must be prepared to take a longer term view on payback, or make a calculated risk weigh against potential obsolescence and ultimately erosion of capitalisation value as a domestic price on carbon is identified within the next two to three years.

The intent is to manage future risks, market perception, operating costs, carbon emissions. All of these elements will have an effect on the value of the asset and therefore the bottom line. At a tactical level, the facility management teams will be key to ensuring older building stock can be efficiently managed. Without enlightened operational expertise, the potential for an existing building to actually realise measurable energy efficiency and reduced operating costs becomes somewhat academic.

The case studies outlined above pro vide a snapshot of the benefits of expertise, capability and dedication of the onsite facility teams. With their expertise, a conventional older office building can also be managed to deliver both dollar savings and energy efficiency, without unduly compromising occupant comfort. There is still more to be done, but the future for opportunities in smarter tactical innovations becomes all the more exciting.

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WHAT ENCOURAGE CLIENTS AND CONTRACTORS TO TAKE COMMON ACTION ON SUSTAINABLE ISSUES?

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Summary

This paper identifies incentives and barriers for future development of sustainable building practice in Sweden out of three perspectives. The first concerns *business advantages* from increased environmental work in construction and property management companies. The second concerns *how environmental action is legitimated and controlled* within these organizations. The third focuses on cooperation and interrelation between them in their relation as *client and contractor in construction projects*. The results are based on a questionnaire survey and an interview study with environmental managers in companies with more than 50 employees.

It is shown that although environmental managers have knowledge to influence strategic decisions their actual influence is constrained by a predominating cost and time efficient culture. In addition, environmental managers perceive that their organisation have too limited control over the market to make a difference as a whole. Notwithstanding, there seem to be a lack of interest for deeper interaction between clients and contactors. In fact both parties, as profitable organisations, experience few business benefits from undertaking an active environmental work. As a key for improved environmental performance in the Swedish building industry it is suggested that companies need to start cooperate more widely and on a long-termed basis.

1. Introduction

Over the last two decades the Swedish building industry has made much effort to develop sustainable building practices. Researchers within the field have provided theoretical knowledge on how to design green buildings and environmental management tools have been developed to guide the practitioners (Gluch, 2005). Nevertheless, the building sector at large is still using similar building techniques and materials as before and green building projects are viewed as one-off experiments (Femenías, 2004).

Development of managerial environmental tools and practices necessitates an understanding of how environmental issues are dealt with in organizations. Resent research show that many environmental managers struggle and devote much time to construct new communicative structures of meaning that objectify, reify, legitimize, and institutionalize corporate environmental management (Meima, 2002). For instance, this is reflected in that environmental managers within both construction and property management companies often experience a conflict of interest. A conflict where they have to middle between their own beliefs based on experience-like knowledge and on weak environmental interest. This weak environmental interest within organizations has been shown in studies to have a strong relation with the interest to finish the project with as little interruptions as possible (Gluch, 2006). There is however a tendency that environmental management techniques and managerial aspects, such as organizational and behavioural aspects, have been handled separately, both by researchers and by practitioners (Baumann, 2004).

This paper identifies incentives and barriers for future development of sustainable building practice in Sweden out of three perspectives. The first concerns *business advantages* from increased environmental work in construction companies and in property management companies. The second concerns *how environmental action is legitimated and controlled* within these organizations. The third focuses on cooperation and interrelation between especially these two parties as *client and contractor in construction projects*. The objective is to provide environmental professionals (such as environmental managers and coordinators) support on how they in their daily work can increase the understanding and knowledge of environmental issues in construction projects. Therefore this paper provides suggestions on measures that improve and strengthen both intra-organisational and inter-organisational cooperation and interaction. To reach the aim, attitudes towards environmental management issues related to environmental impact and strategic decision making are explored through a questionnaire survey and through an interview study.

2. Environmental and project management practices in the Swedish building industry

In her review of environmental management in the construction industry Gluch (2005) found a large amount of methods, techniques and tools, suggested for the management of the sector's environmental problems. Today, many of the companies within the building sector (73%) have developed an environmental management system (Gluch et al, 2007). According to the same study also more than half of them have chosen to certify their environmental management system, where ISO 14001 has shown to be the preferred certification system. A study of the corporate value of an ISO-certification during a tendering process, made by Carrick *et al* (2006), showed that the certification logotype, as an artefact, was used to create an image based on visual impressions rather than on actual performance. According to Schein (2004), it is dangerous to try to infer deeper assumptions from artefacts alone since one's interpretations will inevitably be projections of one's own feelings and reactions. More, Gamson (1994) suggest that the reputation of an organisation might be of more importance as a potential source for performance rather than proof of an organisations actual performance. The over-reliance on the certification as proof for a certain organisations' environmental performance is naturally dangerous.

Moreover, studies have shown that practitioners within the Swedish building industry views environmental issues as something outside the actual construction project or as a sometimes unwanted detail in a contract (Gluch, 2006). In practice, this means that environmental issues are sub ordered money. As a result, many researchers have advocated a need for a paradigm shift in order to promote sustainable development within the building industry. The main objective advocated for this shift is that the building industry needs to reconceptualise and rethink construction in order to handle environmental issues. One suggested way is to increase the number of cooperative actions so that the project scope is widened (Gluch, 2005). This could facilitate a closer relationship between the client and the contractor.

Kadefors (1997) has studied the interaction between client and contractor in the Swedish building industry as this relationship often gets neglected in studies, as opposed to relationships within organizations. An explanation for this lack of research interest given by Kadefors (1997) is the relay race in the building industry, where one player after finishing his part leave the responsibility to carry out the plan for the next part to someone else, and little interaction occurs between the two parties. More, the parties' internal organizations as well as the interaction patterns between them have a great impact on the distribution of power and responsibility in the relationship. Kadefors conclude that lack of knowledge can be a strategic advantage for especially the construction companies in negotiations and that this advantage serves as a reason for not increasing the knowledge on other parties' areas of expertise. Kadefors (1997) continues by pointing out that informal and, to a large extent, intuitive decision processes are a very important aspect for the contract relationship between the client and the contractor. The building practice in Swedish building industry are by Stenberg (2006) explained as an institutionalizing process, where standards and rules for perceiving, interpreting, believing and acting, are inherited from one generation of builders or property managers to another by an apprentice-like system. This process is carried out through the interaction and relationship between parties involved. These informal processes are influenced by individuals personal values and perceptions on a reality based on personal experience and knowledge.

3. Research methods

This paper is based on a questionnaire survey sent to environmental managers within the Swedish building industry and on a interview study with seven environmental professionals. The questionnaire was based on the International Business Environmental Barometer (IBEB) that surveys the state of environmental work in industry in different countries. In order to suite the Swedish building industry, small alterations, mainly wording were made in the original questionnaire. It was directed to environmental managers or alike at all companies within construction, property owners and property management in Sweden with at least 50 employees. Results from the questionnaire survey are based on a population of 453 companies active within either property management (151 companies) or construction (302 companies). The group called "Property management company" consist of companies who either own and manage their buildings or manage buildings on commission. The response rate for property management companies was 52.8% and for construction companies 41.1%. The answers were analyzed in the statistic program SPSS (version 13.0 for Windows).

In order to gain deeper understanding on environmental management in the Swedish building industry, in depth interviews were carried out with seven environmental professionals. To ensure a reliable outcome of interviews it was necessary to take several aspects into account; the selection of interviewees, the design of the interview guide, the interviewing process and the transcription to prepare the data for the analysis. The interviewees were selected from respondents of the questionnaire survey out of the criteria that they represented various sizes of construction companies and property management companies. The interviewees were employed at companies located in Stockholm or Gothenburg. All interviews were carried out in March and April, 2007, with all recorded, except for one where notes were taken instead. The questions asked in the semi-structured interviews originated from the questions in the questionnaire survey. However, the questions were open-ended, meaning that the interviewees were aloud to further elaborate around the issue on environmental management in the Swedish building industry. Interviewees were asked to give suggestions on incentives they believed would improve the handling of environmental issues within the building industry. Answers were later summarized and their relevance was discussed with an environmental professional who had filled out the questionnaire but had not previously been interviewed.

The combination of study methods ensure the reliability and the validity of the results presented in this paper. The results were also discussed with fellow researchers at the department for Building Economics and Management at Chalmers University of Technology, as well as with practitioners.

4. Results from the questionnaire survey

4.1 Business advantages

Table 1 Barriers for environmental performance – related to business advantage

Question	Construction companies, %	Prop. man. company, %
No market demand for green products/services	53%	50%
No competitive advantages	57%	40%
Possibility to increase market share	25%	20%
Opportunity to create and/or enter new markets	43%	20%
Lack of laws and other legal demands	20%	13%
We have performed green marketing	10%	12%
Lack financial recourses	37%	34%

Table 1 shows that especially construction companies perceive lack of competitive advantages to be the business barrier that hinders the environmental work within the company the most. The most hindering business factor for property management companies is that the market does not ask for green products. Lack of a market asking for green products is also a significant hinder for construction companies. On the other hand have few companies, within both groups, performed green marketing. Also, a large majority of both groups have not seen any effects from the environmental measures taken regarding market shares or the possibility to explore new markets.

Many environmental managers within construction companies (37%) experience that lack of financial resources hinders the companies' environmental work to some or a large extent, the corresponding figure for property management companies is 34%. Environmental managers within neither one of the two groups think that lack of laws or other legal demands hinder the internal environmental work.

4.2 Legitimacy and control of environmental issues

Table 2 Barriers for environmental performance – related to legitimacy and control

Question	Construction companies, %	Prop. man. company, %
I lack knowledge to affect strategic decisions	8%	13%
I lack authority to influence strategic decisions	20%	33%
I lack mandate to stop activities that cause environment impact	18%	39%
Environmental concern are integrated in the company's strategic decisions	70%	70%
Lack of information	42%	25%
Lack of support from top management	31%	34%
The organizational structure contradicts with the environmental work	36%	34%

As seen in *Table 2*, most environmental managers perceive that they have enough knowledge to affect strategic decisions in an environmentally sound way. About 80% of the environmental managers within construction companies perceive that they can influence strategic decisions and promote environmental issues. The corresponding figure for environmental coordinators within property management companies is 67%.

Most environmental managers within construction companies experience that they have a mandate to stop activities that causes negative impact on the environment. The figure here is a little bit lower for environmental managers in property management companies. However, environmental managers within both groups experienced that they lack authority to influence strategic decisions.

Neither lack of information nor lack of managerial support seems to be a major hindrance for the environmental performance within the building sector. More than one third of the environmental managers in both types of companies experienced that the organisational structure work in contradiction to the companies environmental work to some or a large extent. Most companies in both groups have integrated environmental concern in their strategic decisions.

4.3 Cooperation and interrelations

Table 3 Barriers for environmental performance – related to cooperation and interaction

Question	Construction companies, %	Prop. man. company, %
The sector lack spirit to cooperate	31%	22%
Our clients/customers lack interest to cooperate	32%	30%
We have set environmental demands on our suppliers	90%	93%
We consider environmental performance when choosing suppliers	85%	80%
Our suppliers lack interest to cooperate	36%	32%
We have performed cooperation projects with other organisations	20%	35%

Table 3 reveals that most property management and construction companies have set environmental demands on suppliers. The majority of the companies in both groups have also taken environmental performance into account when choosing supplier. More, one fifth of the construction companies and little more than one third of the property management companies have used cooperation projects to minimize negative environmental impact.

One third of the companies within both groups think that lack of cooperation between client/customer hinders the company's environmental work to some or a large extent. Also, lack of cooperation with suppliers is viewed by 36% of the construction companies and 32% of the property management companies as a hinder to the company's environmental work.

4.4 Summary of the results from the questionnaire survey

The questionnaire survey shows that environmental managers within construction companies experience that they have a greater possibility and knowledge to influence strategic decisions. Nonetheless, more environmental managers in property management companies than within construction companies experience that they have support of higher management to pursue environmental issues. However, the situation appears to be the opposite when it comes to financial resources to work on environmental issues in a sufficient way. In all, the view environmental managers within construction companies and property management companies have on their situation at work are quite similar. Both groups also experience major hindrances concerning lack of competitive advantages, the possibility on entering and/or creating new markets. In sum, the questionnaire survey show that the companies within the building sector have a similar attitude as well as approach towards the environmental challenge and which barriers one face.

A questionnaire survey can only provide a general picture of which barriers that hinders sustainable development within the Swedish building industry. To gain deeper understanding on which consequences these barriers may have for the organisations we have performed interviews with environmental managers.

5. Results from the interviews with environmental managers

Environmental managers within property management companies often have some kind of environmental education from a university. Also, most of them have for some time during their career been working at construction companies to get practical experience.

Within construction companies on the other hand it is more common that one works ones way up from foreman on site to a managerial position. Higher positions often come with other responsibilities than just managing production on site and making profit. Environmental work is traditionally viewed by the construction companies as a sideline position and most environmental managers have no formal environmental education. Instead they gather information and experience by practically working with the issues. Also, environmental managers within construction companies often have multiple tasks of for example quality, safety, purchasing, and cost estimations.

5.1 Business advantages

None of the interviewed property management companies had performed market investigations concerning for example the attitudes towards environmentally friendly products and services. They also had in common that they all viewed money as the largest external hinder for more environmentally sound working routines. Most interviewees believed that environmental solutions are connected with increased costs.

Results from governmentally controlled demands were well illustrated by the effect from the prescribed demand on energy declarations on all properties. All interviewees from the property management companies especially emphasized that they had carried out optimization of energy systems measures, i.e. the right usage of the system, and the choice of materials. Since the law on energy declarations for properties, interviewees witness an intense focus on this issue which the following quote illustrate:

"Energy use is in a class of its own…"

[Interviewee, Property Management Company]

The environmental managers at construction companies think that property management companies view the financing of the project as the largest barrier for environmental issues. In fact, all interviewed environmental managers from both construction companies and property management companies agreed that financial incentives would be an effective driving force for sustainable development within the Swedish building industry. They also agreed on that the economical benefit from working in an environmentally benign way is not evident today, which the following quote illustrates.

"99% of all choices have to do with money, if it is more expensive it is not considered, we can only give them options but the decision is not ours to make."

[Interviewee, Construction Company]

5.2 Legitimacy and control of environmental issues

The interviewed environmental managers in property management companies emphasized lack of authority to steer and control the environmental work performed within the organization to be internal hinders. Interviews with environmental mangers in property management companies showed that little room is given to environmental issues in the company's strategic efforts. Even though an environmental policy exists and an environmental management system to ensure that the policy is followed is in place, its use and integration is scarce in daily practice and routines. Also mentioned as a large internal hinder was the difficulty for each worker, despite competence and position, to make decisions on environmental issues.

A reason stated by the interviewees for not using the environmental management system more consistently was lack of time and to some extent also because of economic reasons. According to the interviewees, the environmental system is mainly used when planning a project, especially during the tendering process, i.e. when purchasing a construction contractor. Moreover, in most cases, few attempts are later made to follow up the demands put on the construction companies through out the realisation of the project.

Interviewees from the construction companies stated that environmental management systems often have been developed out of current quality management systems. This way of developing an environmental management system is believed to facilitate and fasten the implementation of the system into the organization. However, as mentioned by one interviewee, environmental management systems may only be a demand on paper, with the risk of not being used in practice as indicated. The following quote indicates the amount of space environmental issues are given in negotiations before the production starts and why so little may be realised throughout the project.

"The environmental issues are often talked about, but more seldom considered, especially not by our clients…."

[Interviewee, Construction Company]

The above quote may also be an indication on a perception that the environmental work is an inflated issue and perhaps an illusion of active environmental work. More, interviewees from both parties pointed out the lack of evaluation of completed projects. The consequence from this, as said by the interviewees, is not only a disrupted learning process but also a running risk that environmental management tend to become paperwork without substance. Especially contractors expressed an annoyance with clients who demanded environmental management systems during tendering, but later did not follow up the actual environmental performance during the execution of the project.

Moreover, the interviewees from the construction companies found it hard to describe what exactly sufficient environmental knowledge is. They in fact seemed pressured when asked to estimate if they had enough knowledge on environmental issues to lead and predict environmental outcomes of measures taken. Many referred to television programs, daily press and environmental reports as main information source for keeping themselves updated on news and changes in environmental issues and legislations. In addition, most interviewees saw lack of knowledge among their own staff as an internal hinder for improving the environmental work of the company.

5.3 Cooperation and interrelations

The interviewed environmental managers in property management companies said that they assume that, in order to last in the Swedish building industry, it is in the construction companies' interest to maintain their environmental performance as well as their environmental management system. Hence, the interviewees trust their appointed construction companies to fulfil their environmental obligations and also to ensure that those they in turn use as sub-contractors do the same.

“We don’t have time and we lack the competence to compare the contractors’ environmental management system with our demands, we have to trust them…”

[Interviewee, Property Management Company]

However, when asked what they thought the construction companies viewed as the largest external hinder for their environmental work, the interviewees with property management companies mentioned themselves to be a large hindrance, since they set the budget for each project. In addition, interviewees with property management companies thought competence development on environmental issues among employees to be the largest internal hinder for construction companies. Also, according to these interviewees, smaller actors on the property market considered it up to the whole of the property industry to improve a collective environmental behaviour among the industry.

Although the interviewees from the construction companies said that the environmental knowledge within their company was deficient, they did not find this to be a large hinder. Furthermore, they were also of the opinion that few environmental decisions are made on site anyway. Instead, environmental decisions are made by the client in early phases of the construction project why the responsibility also is theirs. The interviewees form the construction companies therefore saw the clients limited environmental knowledge as the largest external hinder also for the construction companies’ environmental work, which also coheres with the property management companies’ conclusion.

Measures to pursue environmental improvements are, by the interviewees from the construction companies, said to be controlled by the client. Interviewees from the construction company also think that they have worked harder to fulfil environmental demands than their clients have, e.g. the property management companies.

More, even if cooperation projects are viewed by all interviewees as a positive way of constructing buildings, monetary and not environmental reasons are given for the positive outcome of cooperation projects.

5.4 Summary of results from interviewees

The interviewees agree with the researchers that there is a need for a shift of focus in the Swedish building industry in order to be sustainable. However, they also see themselves as too small actors on the building market to make a difference by taking action alone. This in turn results in a “wait-and-see” strategy, i.e. no one take on the role as first-movers. As a solution the environmental managers set hopes on governmental policy directives. From the interviews, one can discern two types of policy directives that are perceived as fruitful enough to strengthen the knowledge and position of environmental issues within building projects and organizations; subsidies and legislative measures.

Subsidies that stimulate knowledge and technology development - Several interviewees expressed the need to further educate their project members, such as project leaders and foremen, in order to better communicate the impact of environmental performance in projects. As money is one of the main drivers in the Swedish building industry, interviewees felt that a governmental subsidy would help stimulating an increased environmental knowledge. This would be beneficial for all companies in the Swedish building industry. The interviewees also express the need for subsidies on sustainable materials, passive house techniques and handling of natural water. Interviewees believed these actions would steer the way the Swedish building industry handle environmental issues in projects and organizations.

Legislative measures - Many interviewees, with both parties, expressed the need for more environmental legislations in order to legitimize to their own organization the importance of handling environmental issues in day-to-day business. Also, according to the interviewees, environmental legislations should be followed up by project external inspectors, preferably an agency appointed by the government.

The Swedish building industry has throughout decades been subject to different governmental subsides and legislative initiatives in order to stimulate numerous measures, e.g. energy use. Hence, these suggestions are not revolutionary and would probably not be enough for any larger changes to occur. They would surely not be a sufficient trigger towards the necessary shift in perspective as claimed by, for example, researchers.

6. Discussion

Results from the questionnaire survey show that most environmental mangers perceive themselves having enough knowledge, authority and mandate to affect strategic decisions that have a negative environmental impact. However, the interviews reveal another reality where respondents found it hard to describe what sufficient environmental knowledge was. Many even appeared stressed when asked to estimate whether or not they felt they had enough knowledge to predict environmental outcomes of decisions. In fact, somewhat contradictory to the questionnaire survey, the interviewees stated that little room is given to environmental issues in strategic decision making.

The interviews also indicated a lack of interest in environmental issues in the interaction between client and contactor. Even though meeting protocol for projects and internal meetings handle environmental issues, little was made use of in day-to-day practice. The reason given was primary time and money constrains. It also seemed as if there is no pressure on having environmental routines and little attention is given to these issues. As a result, the person or department responsible for environmental issues, even though highly competent, lack mandate to interfere in daily work or develop effective routines followed by the whole organization. Another finding was that the practice where parties through silent negotiations agree on not perusing certain issues in projects (Kadefors, 1997) also has bearing for environmental issues. Lack of knowledge among employees at all levels within the Swedish building industry has, according to the interviewees, made both clients and contractors perform follow-ups on irregularities. As a consequence the importance of the environmental work performed by environmental managers is belittled. So what can be done to ensure environmental issues enter and get a righteous place on the project agenda? The interviewees have suggested subsidies and strengthen legislation as a solution.

Subsidies for environmental education for all personnel are suggested by the interviewees as mean to improve both the common knowledge of, and the competence on, environmental issues within the Swedish building industry. However, there is an imminent risk that the action, i.e. the education of personnel, will stop as soon as the subsidy disappears. Also, the environmental managers demanded more environmental legislations in order to justify the importance of handling environmental issues correctly to their own organization and in projects. To secure that these laws and demands are followed there is a need for increased control of the environmental performance. This could be a work task for environmental managers that could strengthen their authority in the organisations, which today not always is strong (Gluch, 2007). However, legislation implacably nurtures bureaucratization and standardization, which is known to restrain the companies' incentive to approach the challenge out of different (and innovating) perspective. Previous research has, for example, shown that regulation may hamper innovation, especially if the regulatory process is too complex and too prescriptive (Gann *et al.*, 1998). In addition, as long as time and money are key success factors for construction projects, the incentive in form of subsidies for improving environmental knowledge, or the penalty for not following environmental legislation, must exceed the delay fine in order to not be neglected. Thus, it takes more to improve the status of environmental issues in the Swedish building industry than the incentives suggested by the interviewees. Both parties are aware of the impact their business has on the environment. However, neither one of them perceive that there is a market for green products and services.

The need for cooperative activities, both within and between different organisations, has also been emphasized as important for innovation (Harty, 2005; Keast and Hampson, 2007; Ling *et al.*, 2007). Ling *et al*. (2007), for example, conclude that for a successful implementation of innovations there is a need for involvement of a variety of organisational units. Partnering is a cooperative mode that during the past years has become more common in Sweden (Kadefors, 2005). However, although the interviewees state that they are positive to cooperation projects, they see primarily monetary benefits from creating such an alliance with their counterpart. Thus, since increased focus on sustainable development has not been acknowledged as a possible benefit from partnering, the issue most likely will not become an important issue to consider in the negotiating process preceding the partnering contract.

7. Conclusion

We have investigated barriers for future development of sustainable building practice in Sweden out of three perspectives; business advantages, how environmental action is legitimated and controlled within organizations, and cooperation and interrelation between especially the client and contractor in construction projects. The objective was to provide suggestions on measures that support sustainable development within the Swedish building industry.

One conclusion made is that the property management companies and construction companies would benefit from a more long termed cooperation. A long-termed cooperation would signal that poor environmental work has negative effect on corporate profit for both organisations in a construction project. Hence, as an incentive to emphasize environmental issues in the relationship between property management companies and construction companies, a 10 year environmental guarantee on all work performed in the Swedish building industry is suggested. The increase of project costs, that both parties believe would be the out come of a more thorough environmental work, would be a good motivation for the Swedish building industry to increase the number of partnering-like cooperation projects. Also, the need for cutting costs caused by the effect the Swedish building industry has on the environment will, in turn, enhance the knowledge on environmentally sound materials and techniques. Part from avoiding the problems caused by the relay race in the Swedish building industry, as a result, this incentive could also nurture and contribute to an increased market for green products and services.

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THE ECONOMIC BENEFITS OF SUSTAINABLE PRIVATE FINANCE INITIATIVE: A CASE STUDY OF NEWPORT SOUTHERN DISTRIBUTOR ROAD

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Summary

The purpose of this paper is to examine the sustainability performance of an individual highway Private Finance Initiative (PFI) scheme in the UK, mainly to scrutinize its economic benefits at three levels: project, local and national. The fieldwork was undertaken through a detailed and specific set of semi-structured interviews in the case study of Newport Southern Distributor Road (SDR). Five main drivers for the sustainability approach are identified and the transferability is analysed. Research finds that the Newport PFI case demonstrates whole life cost savings for both the client and the contractor. The social-economic contribution of the PFI project is critical to the local urban regeneration programs and sustainable community development. Furthermore, effectively applying the government's financial incentives and advanced technology could efficiently reduce the capital cost without negative impact on the project's quality and time. The sustainability aspects of this project could be extracted and transferred to other highway projects, in particular through the PFI procurement system.

1. Introduction

Internationally, sustainable construction has become the hottest research topic in the built environment over last decade. However the argument for the importance of sustainability is now won and the emerging and fundamental issue is how to embrace the practical implication of sustainability into both public and private estates, particularly under a tight budget (Zhou, 2004). In practice, there is a critical economic challenge of sustainable construction (Bon and Kutchinson, 2000 and Zhou and Lowe, 2003). Many projects avoid a sustainable solution because economic benefits are unidentified. Their concern is that the assumed extra cost of sustainable construction might shrink profits and bring extra risks. Although most recent research works express the benefits of whole life costing and highlight that the long-term benefits are more important than the capital cost, there is still a lack of direct incentives and evidence to make obvious short-term financial benefits for both the client and the contractor.

This type of problem commonly appears in the UK too. In order to achieve their ambitions of sustainability, the UK central government employs political and fiscal tools to stimulate the construction industry, particularly through the public procurement practice. Nonetheless, figures reveal public buildings were far short of their sustainability targets (NAO, 2007). One of the main reasons is that there is little clear evidence to demonstrate the short-term business benefits from sustainable construction and it lack of interest in practitioners to promote sustainable innovation in their projects. At the same time it should be noted that traditional procurement methods have failed to support sustainability (Zhou, 2004) while literature reveals that PFI/PPP has natural advantages in delivering sustainability due to the long-term contract and stronger partnership between the client and the supplier (Zhou, 2004). In principle, PFI is predicted as an effective delivery mechanism for sustainable construction that demonstrates a high sustainability performance along with an acceptable price level (Logan and Mills, 2003).

This paper attempts to fill the knowledge gap and provide demonstrative evidence to prove that a sustainable PFI project would not cost more but at the same time could reduce capital cost and provides a significant contribution to support local economy growth and environment enhancement.

2. The Economic Challenge of Sustainable Construction

In 1994, Kibert defined sustainable construction as *"The creation and responsible management of a healthy built environment based on efficient resources and ecological principles."* Hill and Bowen (1997) then divided Kibert's principles in four 'pillars': social, economic, biophysical and technical and successfully explained the four themes of sustainable construction. In 1998, the International Council for Research and Innovation in Building and Construction (CIB) created a global agenda for sustainable construction – 'Agenda 21 on Sustainable Construction' at the World Building Congress in Gävle, Sweden. Agenda 21 is a conceptual framework that defined the links between the global concept of sustainable development and the construction sector.

In principle, sustainable construction has a number of benefits. Yates (2001) explored the business benefits of sustainable construction and concluded that the benefits are diverse and potentially very significant. Heerwagen (2000) highlighted that green building contributes positively to business performance and organisational effectiveness. First, green buildings are relevant to business interests across the full spectrum of concerns, from portfolio issues to enhanced quality of individual workspace. Second, the high performance of green buildings will influence the outcomes of organisations such as workforce attraction, retention, quality of life, work output, and customer relationships. Third, green building can provide cost reduction benefits and value added benefits.

While sustainable construction has many potential economic benefits, difficulties and barriers still exist in practice. Literature shows that there is an apparent lack of evidence of market demand for sustainable development that together with a lack of information and expertise are recorded as the most important obstacles to a more sustainable built environment (Zhou, 2004). Keeping (2000) argued that few investors have a significant desire to own sustainable buildings. Moreover Bordass (2000) found that the UK's pioneering green buildings have often been procured by owner-occupiers, who are less constrained by market norms. One of the main reasons causing such market failure is unidentified short-term business benefits. For example the clients widely believe that sustainable construction will cost more and bring high risks (Johnson, 2000; Landman, 1999; Hydes and Creech, 2000; Bon and Kutchinson, 2000, Castillano, et al, 2000 and Zhou 2004) and they believe that cost will increase by using new technologies and green materials. There is little market incentive for clients to put more additional money into the innovation without extra return over the short-term period. Smith et al (1998) argued that developers were encouraged to think of short-term profits rather than the long-term consequences of their action.

3. The UK Approach and the Advantages of PFI

3.1 The UK approach for sustainable construction

In 1999, the UK government published the first sustainable construction strategy and it outlined 10 themes for the industry action plan. In addition to setting up the policy the government also applied the fiscal instrument to motivate the construction industry (Addis and Talbot, 2001), for example:

- The Landfill Tax (1996) is influencing waste management practices by encouraging greater diversion of waste from landfill. Costs of disposing of construction and demolition waste to landfill can be minimised through more efficient construction and innovative re-use and recycled materials.
- The Aggregate Levy (2002) is introduced to reflect the environmental costs of aggregate quarrying and encourages demand for and supply of alternative materials, such as mineral waste and recycled construction and demolition waste.

In addition, the Government's Sustainable Procurement Group recommended setting requirements for recycled content in the procurement of Government construction (for projects > £500K) in 2003 and in particular that a requirement for 10% of the materials value to be derived from recycled content should be in Building Regulations and a higher standard adopted as a minimum requirement in the Code of Sustainable Building (DTI, 2003). However, a recent government survey shows that 80% of public building failed their sustainability target (NAO, 2007). One of the most important reasons is that widespread perception of conflict between sustainability and value for money – partly because the project team fails to access the long-term costs and benefits of more sustainable approaches

3.2 PFI and its Sustainability Advantages

The Private Finance Initiative as a modern public procurement system was firstly introduced by the UK government in 1992. The International Project Finance Association (2002) defined PFI as:

"*The procurement of public services and assets by government and local authorities where the private sector is responsible for the design, construction, finance and operation of an asset or service for a specified period of time after which it is transferred back into the public sector..*"

According to the latest figure from the HM Treasury Website (HM Treasury, 2007), 747 projects had been signed as PFI contracts, amounting to a total capital investment of over £47.56 billion. Almost every central government department and local authority is now using PFI contracts. They include most types of public estates, for example, roads, prisons, hospitals, schools and office buildings, etc. Furthermore, £26 billion of PFI investment across 200 projects is currently in the pipeline to close by 2010 (HM Treasury, 2006).

In terms of sustainability PFI could offer real scope to promote sustainable construction (Addis and Talbot, 2001; Logan and Mills, 2003 and Zhou, 2004). The long-term and integrated nature of PFI contracts offers incentives to the contractors to consider the synergies between the design of an asset and its ultimate operating cost (OGC, 2002). The stronger partnership between the client and the contractor make it possible to apply a holistic approach to achieve their common sustainable objectives. However, as in other sustainable construction studies, most research examine the sustainability performance from the environmental aspects for instance energy efficiency or reducing use of natural resources. In general they lack consideration of economic benefits especially in a short-term life span. For its wider acceptance it is critical to find out what direct business benefits there are from the existing PFI projects.

4 Research Methodology

The previous section of this paper examined the concepts of sustainable construction and the UK's approaches. It highlights that that one of the biggest barriers is the assumed high cost of sustainable construction. Contrasting with traditional methods, literature finds that PFI procurement had the potential to deliver sustainable construction, but there is a lack of practical evidences of its economic benefits.

This paper is based on a part of a PhD research programme which was designed to investigate the sustainability performance level of the whole UK PFI market. It endeavors to develop a sustainability framework for PFI procurement system and its practice. Based on the systematic literature review, the PhD research was designed to use a combined method to gather both quantitative and qualitative data and provide a more complete picture of the sustainability issues addressed in PFI industry. It includes a national level questionnaire survey, follow up in-depth interviews and case studies. The initial national level survey examined over 65 existing PFI projects' current sustainability performance level and then 12 follow up in-depth interviews scrutinized the clients and project directors' willingness; and also value and risks to implement the sustainable approach. Moreover, four representative cases was selected from the national survey to gather information on successful experience in sustainable PFI projects from different aspects (economic, social, environmental and technical). This paper summarizes the findings in the case of Newport Southern Distributor Road. Four interviews were conducted with senior representative from the Newport Southern Distributor Road (see table 1). The first three interviewees are directly involved in the Newport SDR project. The fourth interviewee was indirectly involved with the project but was in charge sustainability strategy plan and day-to-day sustainability business management of the operating company (Ringway). The interview was designed to find out:

- Key stakeholders' experience and attitudes in terms of sustainability
- The project's objectives, client sustainability priorities and how the supplier responded
- The project's sustainability performance level and benefits from social, economic, environmental and technical aspects

A secondary study is used to gather other data to identify the impact of this PFI project on the construction industry and local community.

Table 1: Interviewee's background

No	Type of Stakeholders	Interviewees' occupation	Organisation
1	Client's Project Management Consultant	Project Manager	Capita Gwent
2	Special Purpose Vehicle (SPV)	Project Director	Morgan Vinci Ltd
3	Operator	Operator Manager	Ringway
4	Operator	Sustainability Manager	Ringway

5 Case Study of Newport Southern Distributor Road (SDR)

5.1 The Context

Newport is the third largest city in Wales, a traditional small city on the bank of the River Usk. Following the UK central government's sustainable development strategy the Newport City Council created its own 21 agenda action plan and devised a new sustainable urban regeneration strategy for the residents for next decade in 2000 (NCBC, 2000). However, the existing transport network did not fulfill the demand especially on the south side of the city.

In order to relieve the transport congestion and improve the local transport network, the Newport County Borough Council (NCBC) decided to adopt the PFI model to develop a new road on the south side of the city. The proposed plan was to build a dual carriageway link from Junction 24 of the M4 (Coldra roundabout) to the east Junction 28 (Tredegar roundabout) on the Southern edge of Newport and it includes a major crossing of the River Usk. The Morgan Est, one of the largest civil engineering contractors in the UK, together with Vinci, an international contracting company, formed a joint venture 'Morgan Vince Ltd' which won the £55 million contract and undertook Design, Build, Finance and Operation (DBFO) of the project over a 40-years life span. This project is the biggest local authority PFI project in Wales and also recongised as a pathfinder project by the Welsh Assembly Government. The principal objectives of the scheme are:

- To enable traffic to avoid the town centre and inner residential areas
- To improve the environment of the inner residential areas
- To improve road safety
- To improve access; and
- To contribute significantly to achieving the emerging integrated transport policy for Newport

Construction started during summer 2002 the road was made fully open to traffic in December 2004. As such the Southern Distributor Road (SDR) was finished half year ahead of schedule (May 2005). Ringway Highways Service Ltd has carried out the operation and maintenance work.

The Southern Distributor Road is Newport City Council's highest priority scheme for the improvement of Newport's highway network. The project brings major economic and environmental benefits to the city including improved access to major investment opportunities in the southern areas of the city.

5.2 Perceived Economic Benefits

In brief the Newport SDR project demonstrates outstanding economic benefits. Table 2 categorises the economic benefits at three levels: project, local and national and divides them for different stakeholders and the wider community.

At the project level, approximately £1 million initial cost was saved through the use of around 450,000 tonnes of recycled and secondary aggregates instead of purchasing primary materials. A variety of secondary aggregates is used as granular fill materials and unbound sub-base. In the recycle programmme, specific cost savings included:

- The avoidance of waste disposal charges and Landfill Tax
- The avoidance of Aggregates levy payments, from which recycled and secondary aggregates are exempt

- The lower costs and improved performance of maintenance techniques such as 'crack and seat', Rhinopatch and cold-lay foamed asphalt mix
- Reduced costs of transporting aggregates when recovered materials are available locally

Table 2 Perceived Economic Benefits of Newport SDR

Outcomes Levels	Perceived Economic Benefits and Business Value	Beneficiaries
Project Level	• Capital Cost saving • Whole Life costing saving	Newport City Council (Client) Morgan Vinci Ltd (Developer) Ringway (Operator)
Local Level	• Support local urban regeneration • Attract new business investment in Newport • New business opportunity between the supplier and Local Authority	Newport City Council Local Community Local Residents Road Users
National Level	• Reducing government borrowing and increasing investment in public infrastructure • Support Wales Economic development • Support Recycle Scheme in the UK • Increasing the PFI firms' competition rate	Welsh Assembly Government Newport City Council UK Central Government Morgan Vinci Ltd Ringway UK Construction Industry Capita Gwent Consultant

The Action Sustainability (2006) has examined both capital cost saving and whole life cost saving of the project in detail. They outline:

"*the use of recycled material did not incur additional capital or maintenance expenditure for the project; however, it did result in direct cost savings in construction costs (£1,034,135), carbon emissions (£106,481), avoiding landfill costs (£941,360) and health benefits from reduced emissions of PM10 (particles measuring 10mm or less).Overall, £2,098,801 was saved, offset by no costs, which amounted to 3.82% of savings of the total project cost or to £219,609 per kilometer of road constructed.*"

At the local level: the Newport SDR helps to release the congestion of Newport Transport Network and reduces the traffic in the city centre. These outcomes provide massive benefits to promote new business investment to Newport. Figure shows that the new attracted business investment is about £1bn after the Southern Distributor Road completed (Newport Unlimited, 2007)

More evidences from the interviewee and secondary data shows that the SDR project also supports the local urban regeneration programme: the Old Town Dock Development and the re-use of Brownfield Land..

'It maximises the potential for the development, enhancement and re-use of inner urban land in order to improve the vitality and attractiveness of area such as town centre and encourages development of the available Brownfield land' – the client's consultant project manager, Capita Gwent,

The current upgrade of the Southern Distributor Road is of significant benefit to Newport. The road provides a main arterial route and is considered to be of vital importance to the future success and regeneration of Newport and also will assist in the creation of a gateway to the south of the City (Knight Frank, 2003)

At the national Level, this project is the first pathfinder PFI project in Wale. It serves as a successful model for future PFI development reducing government borrowing and increasing investment in public infrastructure. It has observed the green standards by using recycled aggregates and winning a number of national and international awards. For instances, the PFI project has been selected by the Department of Trade and Industry as a flagship case study. Newport recently won a Green Apple award – presented for environmental best practice around the world. The Newport SDR has become an exemplary case study on the Waste and Resource

Action Programme (WRAP) website as a shining example of environmental best practice within the industry for other companies to follow (NCC, 2004a). The positive publicity gives Newport city a fresh image as a sustainable city and also improves the Morgan Vinci Ltd's business opportunities in the high competitive PFI market.

5.3 Perceived Social and Environment Benefits

In addition to environmental benefits derived from the construction process that has been already noted the project reduced traffic in the city centre. In addition using recycled materials reduced local waste and use of natural resources. Green Transport plan and video meeting technique helped to reduce energy use and cut down on CO2 emissions. Moreover, the road project relieved the traffic congestion problem in the city centre and reduced air pollution and noise level. This is encapsulated by the client's project manager who noted that the aim of the project is to:

'Enable traffic to avoid the town centre and inner residential areas and improve the environment of the Inner Residential Areas: avoid traffic noise and air pollution' – The client's consultant project manager, Capita Gwent

This project provided massive social benefits and support for local sustainable community development too. Firstly it enables the south area of Newport City to be a safe place for all residents to live, work and play. It changed local residents' behaviours and helps to promote sustainable trips to work and school by encouraging alternative modes of transport such as cycling, walking, public transport and car-sharing and avoided the travel route through city centre. Second reduction of traffic noise and air pollution improved the local residents' health and wellbeing. Thirdly the £55 million 40-years project employed local labours and increased the local employment rate. And finally, the SDR project regenerated the community spirit. Without this project, both the city centre regeneration and Old Town Dock regeneration programmes could not be established. They are vital to support Newport City Council's strategic ambition in building a sustainable community and economic growth.

This is reflected in the council's aspiration for the project when they write:

Old Town Dock will be transformed into a new neighborhood, creating a new gateway into the City Centre from the south. The completion of the Southern Distributor Road (SDR) and the new bridge, along with improvements to Usk Way will provide a significant new level of connectivity in southern Newport. Old Town Dock and Pill provide an excellent opportunity for development close to the City Centre building on the land assembly work carried out previously by the Newport Development Board. (Newport Unlimited, 2007)

5.4 Main Drivers for success

The reasons for the perceived success of the Newport SDR PFI are many and varied. Five main drivers are discussed below:

Client Demand

The Newport City Council has a strong commitment to sustainability and implements this in its transport policy. The City Council also provides a strong demand in sustainable construction. Waste Minimisation and Recycling has a high priority in its Local Agenda 21 as all recyclable waste should be recycled (NCBC, 2000). Secondly it is recognized that an integrated transport network is crucially to support the local economic development and to reduce the city centre pollution level. The SDR is recognized by Newport City Council as its highest single priority scheme for the improvement of Newport's principal highway network as an essential component of its integrated transport policy and as key project which will enable its delivery.

Financial Incentives

Evidence shows that this project utilized both Aggregates Levy and Landfill Tax extremely efficiently. As WRAP (2004) highlights:

"*The Landfill Tax and Aggregate Levy together provide a tangible financial incentive. In effect, an authority can save money twice: by recycling highways waste to eliminate waste charges, and by using this recovered materials on new schemes to cut the cost of buying virgin materials*"

In this project effectively using financial incentives and achieving maximum cost saving has been seen as the biggest internal driver for both the main contractor and the operator to achieve sustainable development.

Whole Life Costing

Whole life costing was employed in this project to test value for money by examining the public sector comparator (The PSC is the total whole life cost of the project if procured through the traditional route). This unique route ensures the PFI project is at an acceptable price level and would not increase the expenditure of Newport City Council in the long term. Secondly whole life costing is used in choosing the alternative material, for instance the selection of street light columns. As one of interviewees highlights:

The use of whole life costing can provide cheaper solutions in the long term e.g. the use of stainless lamp columns which have a residual life of approx 70 years whereas conventional galvanized columns although cheaper in terms of initial capital have a life only of approx 25-30 years

Advanced Technology

Another exceptional feature of this project is that it applies an advance green technology: foam base to deal with the recycled aggregate. Foambase is a new type of cold-mix plant. It uses recycled materials in premium bituminous mixtures that take the place of hot mixes in the base and binder layers of highways. Effectively use of advanced technology could stimulate the business benefits of sustainable construction.

Use less bitumen and energy, fewer lorry movements and we divert waste from landfills. We also save taxpayers up to 25%, material using crushed asphalt, concrete and recycled aggregates. Most Foambase is laid as road base now. It's proved a very economical form of construction - Sustainability manager, Ringway

Effective Procurement Model

Without PFI funding, Newport City Council could not afford the highway project and would not be able to design, build and operate it over 40 years as a small local authority. Hence Newport City Council did both 'value for money' test and the affordability test in the early procurement stage. Through the options appraisal they identified that PFI is the most suitable option for the delivery of this project (NCBC, 2002). Moreover, in PFI the project's profit is at risk depending on private sector performance. Therefore, there is a very strong incentive for the private sector to maintain high and reliable service standards throughout the life of the contract. It forces the contractor involving earlier and working closer with the client and building a robust partnership to deliver the best outcomes and add value to this project. On the other hand, the partnership has aligned both its objectives and benefits, so it allows all parties - client/designer/contractor - to work together early in the scheme's development and design towards a shared sustainable goal till the end of the contract.

6. Discussion

a) Capital Cost vs. Whole Life Cost

Interestingly, through this case, evidence shows that capital cost saving is extremely important. Making initial cost saving is one of the ultimate motivations for applying the sustainability principles. The Client project manager argues:

In my limited experience in the PFI field it appears that contractors are only interested in the bottom line of their accounts and are not interested in sustainability unless it improves their financial position!

More interestingly, after comparing the capital cost saving, whole life cost saving and predicted new business investment the capital cost saving (£1m) is equal to the long term saving (£1m), but the social-economic value (£1bn) appears at the highest level. The total project cost saving becomes relatively tiny at the local outcome level (See figure 1, figure sourced from ActionSustainability 2006 and Newport Unlimited, 2007).

b) Transferability

Comparatively, economic benefits can be easily checked against valid financial figures and the cost-benefit analysis and risk management models can easily demonstrate to both client and developers willing to use of recycled materials and the advanced technology: *Foambase*. Evidence shows that those successful sustainable construction practices, for example the use of the new technology Foambase at highway project are directly transferred to the operator's daily business due to its massive economic benefits. As the Ringway's internal magazine (Ringway, 2006) highlights:

There is a big marketing push on (Foambase) and a big opportunity to recycle the huge amount of waste generated by our term maintenance works

Furthermore, the best practice in this project is currently disseminated by the UK central government through its sustainable construction initiatives, such as WRAP, the UK government recycle scheme (WRAP, 2004).

However, some special conditions in this project are not able to transfer to others; for instance, the local availability of cumulated recycled materials might not exist in other circumstances. In addition the reward from the financial incentive from both aggregate levy and climate change tax will be limited if applied to building projects due to the additional need of the quantity of secondary aggregate.

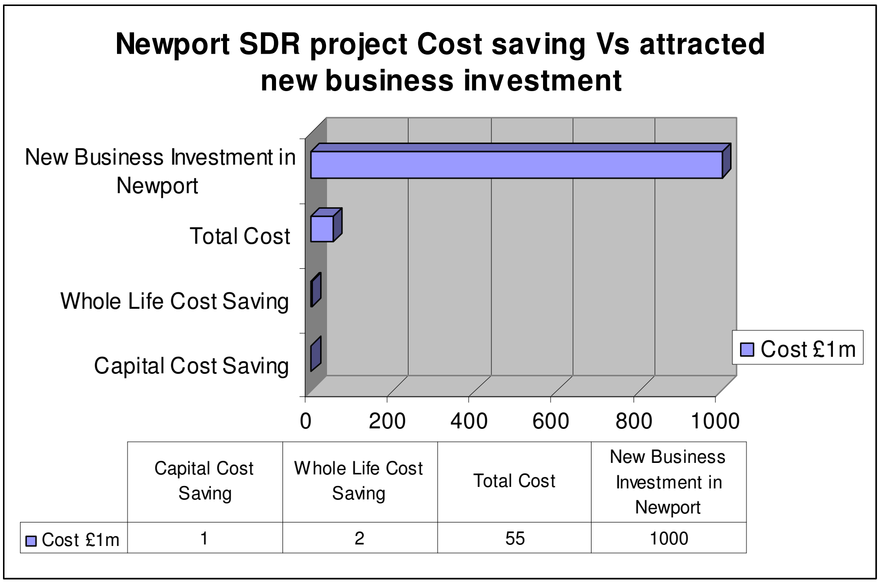

Figure1. Comparing of the direct cost saving in the Newport SDR and the value of new business investment

c) Research Limitation

The case study provides significant evidence to prove that sustainable construction could save money if applied effectively within the government financial incentive and advanced green technology. The transferability of the economic benefits is also identified. However due to research findings based on the individual case it is difficult to generalise in terms of the average sustainability performance level in the whole PFI industry.

7. Conclusion

The analysis in this paper has highlighted the successful experience of Newport Southern Distributor Road in cost saving and five main internal and external drivers of the sustainable approach in the context of this project. Without PFI model, New City Council could not afford this project and the main contractor and its suppliers might not have the motivation to adopt the advanced green technologies and financial incentives to achieve the maximum financial return. It also demonstrates that financial incentives could be the most important internal driver for both the main contractor and its suppliers to push themselves towards more sustainable and innovative solutions. This paper also discusses the economics at three levels: project, local and national. Sustainability has different meanings to different stakeholders. For the private sector, the positive impacts of sustainable solution could increase the business profit capacity and win new business opportunity. For the public sector and its service users, the economic benefits could save taxpayer's money. For the central government, sustainable PFI project could ensure reducing their short-term financial expenditure, increase investment in infrastructure and assist in achieving their ambitious sustainability target in public buildings within a longer period. In addition to economic benefits, the PFI project has also made a major contribution to local sustainable community development and environment enhancement. Moreover, the Newport PFI project provides qualitative evidence to support the PhD study's in-depth investigation, particularly in the economic impacts. Comparing with traditional procurement methods it concludes that PFI is undoubtedly the best mechanism to delivery sustainable development in the public building. As a result, this paper adds value to the existing limited work on the capital cost of sustainable construction. It demonstrates the cost of sustainable construction is lower than conventional method and also for the first time demonstrates in detail that PFI has practical advantages to lead the sustainability revolution in public procurement.

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INFLUENCE OF PAST POLICIES ON TODAY'S ENERGY SAVING INITIATIVES

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Summary

In this paper the Dutch situation regarding national policies influencing the energy performance of dwellings is analysed by using Mahlia's theory on the hierarchy of energy policies.

The National Insulation Program is the first policy to be discussed. It was developed from 1974 to 1978 and remained in force till 1987. The objective of this program was to (re-)insulate 2.5 million dwellings to save 1.6 billion m^3 of natural gas per year. This high ambition required a broad scope affecting consumers, industries and institutions. Consumers received information on energy saving techniques and subsidies. Industries flourished, because of the increasing demand on insulation materials, and at institutions the administration of the policy and research on energy saving techniques were executed. By the end of the program annual energy savings had risen to 50 PJ.

With the proclamation of the National Energy saving Plan in 2007 a new annual objective of insulating 200,000 to 300,000 buildings was formulated for the next ten years. To achieve this goal, in a country with approximately 7 million dwellings, more information should be needed about the current physical state of buildings. However, the Energy Saving Plan does not consider yet the achievements of former policies, such as the National Insulation Program.

1. Introduction

The Dutch energy supply changed radically when at the 22nd July of 1959 the extraction of natural gas from the earth started at the small village of Slochteren. The reserve of natural gas of $2.7 \cdot 10^{12}$ m^3 was to be one of the biggest in the world. Because of this apparently endless supply of natural gas, social housing was provided with central heating systems based on natural gas already in the sixties. The use of natural gas was strongly stimulated by the government, because its price was expected to drop rapidly as soon as cheap nuclear energy would set in.

However, the price of electric energy never dropped and nowadays the existing building stock receives much attention in energy saving policies around the world. In Europe the built environment accounts for more than forty percent of the energy consumption (EC, 2002). Especially the existing building stock that was constructed before energy saving policies were commissioned, offers many opportunities to implement measures, which lower the energy consumption and which rely on renewable energy sources. Nevertheless, little is known about which policies were commissioned when and how these past policies influence the effectiveness of new energy saving regulations or objectives.

In this field Mahlia et al. (2002) aimed at developing a comprehensive theory on energy efficiency standards and labels usable for policy makers. They specified a hierarchy of test procedures, standards and labels (see Fig. 1). They claimed that their theory can be used for revisions in a country that already has standards. In this regard The Netherlands forms an interesting research field, because two standards to express the energy performance of dwellings already were introduced more than seven years ago, namely the Energy Performance Advice (SenterNovem, 2003) and the Energy Performance Coefficient (NNI, 1995). An official label was only recently, i.e. January 1st 2008, introduced and the conditions of incentive programs in adopting energy saving or renewable energy techniques were changed multiple times.

The foundation of the triangle is formed by energy test procedures, which are, according to Mahlia et al. (2002), well-defined protocols or laboratory test methods. Using these protocols or methods a relative ranking of the energy efficiency among alternative technological designs that provide an energy consuming service can be obtained. The standards form the next level of the triangle. They can define a minimum level of energy performance or maximum level of energy use. Labels are the visualization of the standards. The top of the triangle is formed by incentive programs that can influence the adoption of labels and standards among consumers, being the users of the energy consuming product, and manufacturers, being the developer and/or producer of the energy consuming product.

Using this triangular model this paper will explain the Dutch situation regarding the energy consumption in residential real estate, in which a major energy saving policy plan from the past with the name of National Insulation Program (NIP) influences the feasibility of recently set targets in the National Energy saving Plan (NEP). In the time period between the NIP and NEP, which both have an effect on existing buildings, other regulations in the national Building Code were introduced to lower the energy consumption of new buildings. Combining the results of these different governmental initiatives can provide insight in the constitution of the Dutch building stock.

Although Beerepoot et al. (2007) have already paid much attention to the energy performance regulation in the Dutch residential building sector, they did not include in their analysis the former policy that influenced the energy performance of existing residential buildings, i.e. NIP. Furthermore, the NEP forms a new policy variable to be regarded in this paper, that will describe and relate the initiatives regarding residential real estate in a chronological sequence. Firstly, the intentions and results of the NIP will be presented. Secondly, the impact of the Building Code will be discussed. And thirdly the targets and presumed effectiveness of the recently presented NEP will be related to the current residential building stock. In doing so, the number of policy independent and dependent variables of the research model of Beerepoot et al. (2007) can be chronologically extended.

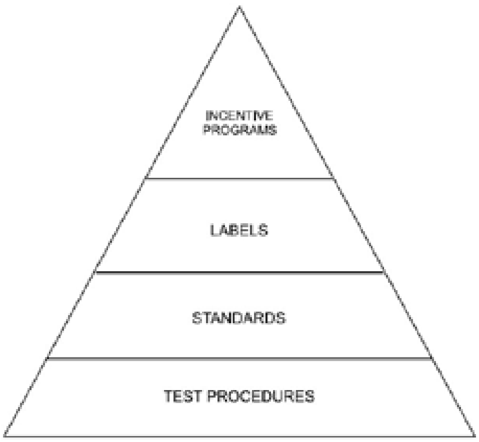

Figure 1 Hierarchy of test procedure, standards and labels according to Mahlia et al. (2002).

2. National Insulation Program (1978-1987)

In the year 1973 the first oil crisis quadrupled the Dutch oil price and therefore the costs of living were increasing tremendously. The finiteness of fossil fuels, mentioned by the Club of Rome (Meadows et al., 1972), in combination with the present increasing needs for them had its financial impact. The consensus to save energy in the built environment was growing in those early seventies, in which the first national Note on Energy was proclaimed. The global and national energy situations were discussed in this note and guidelines were set for the nearby future. There were also chapters written about the main energy sources: natural gas, oil, coal, and nuclear energy (Min. EA, 1974).

However, this political act did not provide the practical action that was needed in the built environment. An organizing committee was established, consisting of officials of different ministries and public utilities. In February 1978 they presented their program with the target to annually improve the insulation of 250,000 houses to an adequate level for the next ten years. The residential building stock counted approximately 4.6 million objects at that moment. Before presenting the program, the feasibility of this task was being tested from 1974 to 1977 by insulating 400 public housing units in the city of Enschede, 292 low-rise dwelling in the city of Apeldoorn, and 274 single-family dwellings in the city of Delfzijl (SNIP, 1988).

2.1 Scope and targets

The National Insulation Program was discussed by the Dutch cabinet. At the 30th of June 1978 it was decided that the following main items would give the program its final shape (SNIP, 1988):

1. The target of improving the insulation of 2.5 million houses in total was adopted, but the annual target of 250,000 was reduced to 200,000 dwellings. The total duration would therefore increase from 10 to 12.5 years;

2. The average subsidy on insulating techniques to be provided was stated to be € 1089,- with the possibility to increase the maximum sum of subsidy from € 1361,- to € 1815,- per dwelling[1];
3. Until 1980 the maximum amount of subsidy per dwelling could only be 30% of the investments, instead of the originally proposed $33^{1}/_{3}$%.
4. Dwellings without central heating system could also apply for the subsidy on insulating techniques;
5. Social housing corporations were enabled to invest in insulation by offering them a special type of loan in cooperation with the banks;
6. The available budget for the program was set on € 157 million for 1978 and 1979. This budget included the costs for the organisation, information and execution of the program. The national budget of 1978 showed that total governmental expenditures were € 50,145 million and total revenues were € 45,663 million (SN, 2008);
7. Furthermore, it was decided that the Association of Dutch Municipalities became member of the organizing committee.

The foreseen reduction in energy consumption was estimated to be 650 m^3 per dwelling (SNIP, 1980). At the end of the program the total target was to save annually 1.6 billion m^3 of natural gas. Using a caloric value of 31.65 MJ/m^3 to 35.17 MJ/m^3, this would mean an annual reduction of 50.6 to 56.3 PJ. In 1978 the total energy consumption of the Netherlands was 2,797 PJ (SN, 2007). The energy use of dwellings in that year was approximately 381 PJ. The NIP could reduce this by 14%.

2.2 Experience and the development of knowledge

Approximately 400,000 dwellings were already insulated in the Netherlands, before NIP was introduced (SNIP, 1988). This meant that not even ten percent of the Dutch dwellings were insulated at that time. Three quarters of these insulated dwellings were privately owned and one quarter was owned by social housing corporations. Therefore, not much experience or knowledge was available on how to insulate dwellings properly, and knowledge that was available was not centralized. In four fields research was needed (SNIP,1988):

1. The effectiveness of the use of insulation in buildings;
2. Alterations in comfort caused by the use of insulation;
3. The influence of insulation on the technical quality of the buildings (for example rotten wood caused by condensation);
4. The occurrence of physical phenomena, for example thermal bridging.

In 1979 the first publications for consumers came available regarding the effectiveness of building insulation. Because insulating a dwelling was and is a technical matter, this brochure explained the effectiveness and application of common insulation materials. The consumers were able with help of this brochure to calculate the investment costs and benefits of double glazing and insulating floor, walls, and roof (SVEN, 1979).

Although the first attempts to come to standardisation regarding the thermal insulation of dwellings originate from 1964, it would take to 1992 before national regulations were drawn up. The norm of 1964 demanded insulation values of 0.43 up to 1.29 $m^2 \cdot K/W$ for outer walls, depending of the weight of the wall and of the aspired classification; moderate, sufficient or good. According to that norm a heat resistance of 0.17 to 0.52 $m^2 \cdot K/W$ for floors was considered to be sufficient. The roof insulation was rated between 0.69 and 1.29 $m^2 \cdot K/W$ (NNI, 1964). In 1981 a new standardisation was suggested incorporating the average heat transmittance coefficient of a building and a thermic insulation index (NNI, 1981).

In addition to the four fields of research mentioned, research had also been undertaken to limit the dependence of fossil fuels. The possibilities to use solar energy were explored to heat space and tap water. An early report mentions four interesting results (TPD, 1975):

- When using a solar collector with a surface of 60 m^2 and a low temperature heating system, a Dutch dwelling of approximately 400 m^3 and an average heat transmission coefficient of 0.8 $W/m^2 \cdot K$ could be supplied of energy for 70% of its needs at that time;
- The additional investment to construct a dwelling conform Figure 2 could be financially compensated for when the parts were fabricated en mass and the price of natural gas would exceed € 0.136 /m^3;
- The use of collective heat storage systems for several dwellings could be profitable starting from € 0.182 /m^3. These systems were designed to store enough heat for a period of six months;

[1] Price levels are generally related to the year mentioned in the lines.

- The development of low temperature heating systems based on 35℃ was considered to be favourable, because the efficiency of the collectors would be maximised. Nowadays, low temperature heating systems are already quite common, but in most cases the temperature does not drop below 55℃;
- The use of solar energy to heat space seemed to be less practicable for constructions of more than four floor levels.

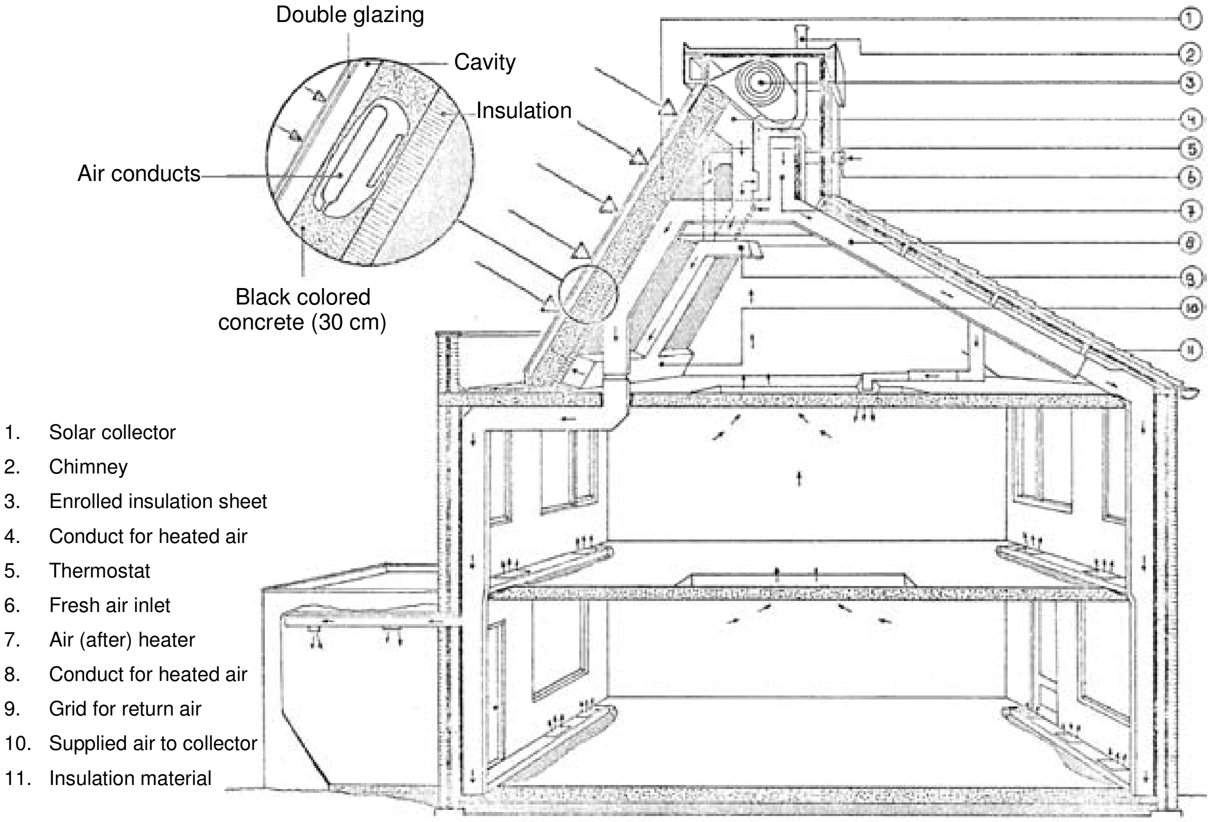

Figure 2 Design of an early solar air heated Dutch dwelling (TPD, 1975).

2.3 Financial and economic considerations

The decreasing consumption of fossil fuels should reduce the import and benefit the Dutch economy directly. The Dutch economy was also supported by generating economic activity. By producing insulation materials, installing insulation measures, conducting research, and manning the staff the employment was estimated to be stimulated by 7,500 years of labour (SNIP, 1980). A report on the evaluation of NIP even speaks of 12.500 years of labour (SNIP, 1988). The annual turnover in the new industry of re-insulation was in 1979 € 280 million, which was € 6.2 million higher than predicted (SNIP, 1980).

On micro scale the Dutch households would benefit from reduced costs on energy consumption. At least if they were willing to invest. In 1979 the average investment was € 1385 per participating dwelling. The value of the investment rose up to € 1,833 in 1987. Originally the average subsidy per dwelling was € 309 that increased to € 733 (SNIP, 1980, St. NIP, 1988). The payback period of these investments was strongly related to the natural gas price, which increased in the time period 1974-1987 from € 0.052 /m^3 to € 0.209 /m^3. In that period the highest price for natural gas was paid in 1985 with a price of € 0.300 /m^3 (SNIP, 1988).

2.4 Results

The NIP offered a broad range of stimuli to reduce the energy consumption of dwellings. The target to improve the insulation of 800,000 private dwellings and 1,700,000 rented dwellings was almost reached. The program was however brought to an end in 1987, by that time 1,803,000 subsidies with a value of € 820.9 million were approved (see Table 1). The provided subsidies formed 91 % of the total costs. At the end the annual energy consumption was reduced by 45.9 PJ to 51 PJ, depending on the use of the low (31.65 MJ/m^3) or high (35.17 MJ/m^3) caloric values of natural gas. Considering that the Dutch natural gas price nowadays is € 0.55 per m^3, then the reduction in natural gas use of $1.45 \cdot 10^9$ m^3 per year still offers consumers an annual cost reduction of almost € 800 million.

Table 1: Results of the National Insulation Program at the end of 1987

	Targets 1978-1990	Results 1978-1987	Relative Performance
Natural gas	$1.6 \cdot 10^9$ m^3	$1.45 \cdot 10^9$ m^3	90.6 %
Private houses	800,000	602,000	75.3 %
Rented houses	1,700,000	1,201,000	70.6 %

3. Building Code (1992-…) and the Energy Performance Certificate (2008-…)

The Dutch Building Code was instituted in 1992, when the buildings stock comprised 6 million dwellings. The Building Code prescribes the minimal quality a construction needs to comply with. Originally the Building Code mainly focused on the safety of constructions. Since 2001 a chapter on the environmental impact of constructions has by name been included, but this chapter has not been given any contents yet. In other words the chapter only consists of a title at this moment. The minimal thermal resistance of buildings is specified and should be at least 2.5 $m^2 \cdot K/W$. This regulation was already introduced in 1992. The total energy consumption of buildings has been regulated since 1995 by using a so called Energy Performance Coefficient (Building Code, 2003).

3.1 Minimal thermal resistance of buildings

The construction process of a new building is not allowed to start without a permit from the municipality. However, some refurbishment projects or small extensions are allowed to be constructed without a permit. In general all these projects should be subject to the minimal thermal resistance of 2.5 $m^2 \cdot K/W$. Where different construction parts are joined, a minimal heat resistance factor should also be obtained. However, often thermal bridges do occur when small extensions and bays are constructed (see Fig. 3); especially when a permit is not a necessity. In the existing building stock the connection between gable roof and walls often shows infiltration leaks.

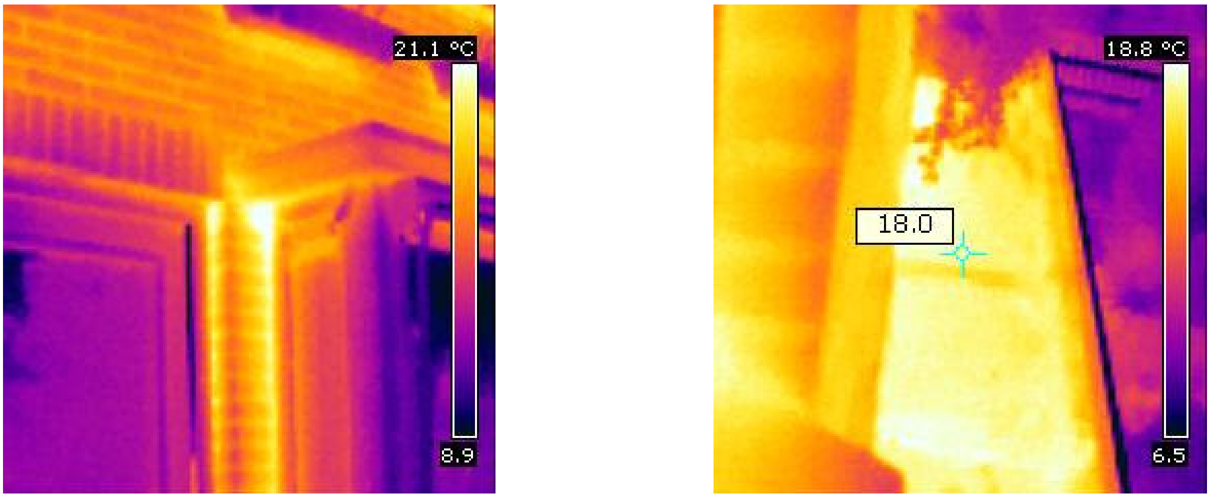

Figure 3 Pictures demonstrating the lower heat resistance of the side and roof of a bay.

3.2 Energy Performance Coefficient

Since 1995 the Energy Performance Coefficient (EPC) is being used to express the energetic quality of new buildings by relating the forecasted building related energy use to a permissible energy use based on the surface area of the object. The building's related energy use roughly includes space heating, water heating, ventilation, lighting, cooling and (renewable) generation.

During recent years the coefficient has been gradually reduced and therefore the energetic quality of new buildings has been improved. The reduced energy consumption of new dwellings resulted in a lower average on natural gas consumption of all dwellings. The average annual energy consumption per dwelling was 2,000 m^3 in 1997 and reduced to 1,736 m^3 in 2004 (SenterNovem, 2007). Nowadays, offices need to comply with a maximum EPC of 1.5 and dwellings with a maximum of 0.8 (Building Code, 2003).

Since 2008 the energy label, expressing the energy performance of houses by using letters, is compulsory in The Netherlands when dwellings are sold (see Fig 4). This label is based on the certification process of the Energy Performance Building Directive of the European Council (EC, 2002). A so called Energy Index has been developed to express the energy performance of existing and new buildings. This Energy Index leads to a specific label. The best performance is expressed by A and the worst by G. Dwellings with an EPC of 0.8 will be labelled with the status A++.

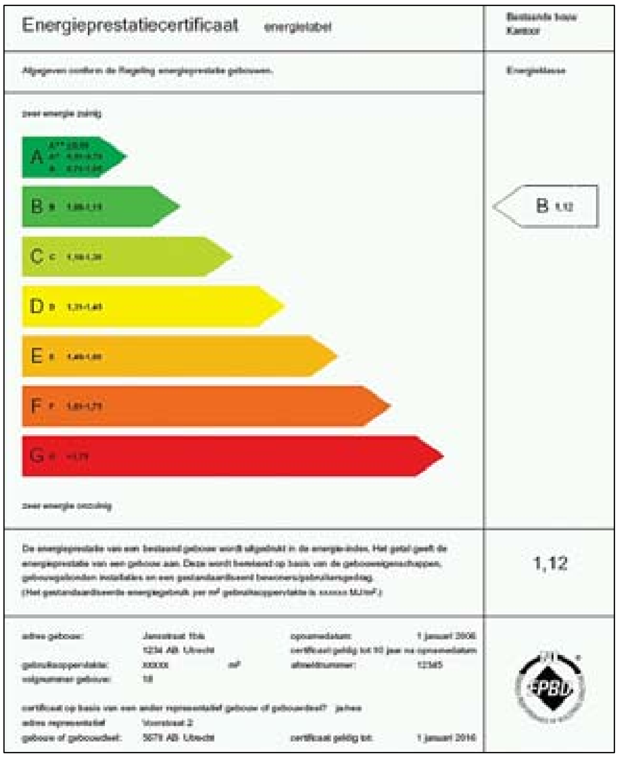

Figure 4 The energy performance of dwellings has been labelled since the 1st of January 2008.

3.3 Results

The Building Code has been stimulating the reduction of the energy consumption of buildings since 1992. In the last fifteen years around 1 million dwellings were newly constructed and were therefore provided with insulation having a heat resistance of at least 2.5 m^2·K/W. The EPC has already exerted influence on 720,000 dwellings. The Dutch government plans to have energy neutral dwellings and offices in 2020. Therefore the EPC will be further reduced to 0.6 for dwellings in 2011. In 2015 the EPC for dwellings needs to be 0.4. For offices similar reductions are planned (Min. HSPE, 2007).

Although the energy performance certificate is not addressed in the Building Code, the label can be based on the EPC, provided that the building license of the dwelling was submitted less than ten years ago. In that case the EPC has a value of 1.2 or less. In 2007 it was already possible to voluntarily obtain a label. At the 31st of December 2007 more than 50,000 dwellings had received a label. Most dwellings (23%) of this group have a D-label and only 1.75% has an A-classification or better (SenterNovem, 2008). According to Gram-Hanssen et al. (2007), the energy labels should be seen as one input, among others, to people's own knowledge and communication about their house and its renovation. Their vision is based on the Danish and Belgium experiences among homeowners regarding energy labeling.

4. National Energy saving Plan (2008-2020)

In June 2007 a proposal was prepared by EnergieNed (the Dutch Federation of Energy Companies), PeGO (the organisation for Energy Transition in the Built Environment), and Aedes (Association of Housing Corporations) to reduce the energy consumption in the built environment with 100 PJ/year in 2020. Although they gave it the name of National Energy saving Plan (NEP), it was more a proposal than a plan. In this chapter no results can therefore be included yet.

4.1 Scope and targets

The NEP proposes to annually improve the energetic performance of 200,000 to 300,000 buildings during twelve years. The investments needed for these improvements are estimated to be € 15 to 25 billion. By implementing the plan approximately 10,000 jobs are expected to be created within the construction industry. The value per dwelling is expected to increase with € 4,000 to 6,000. In 2020 the annual natural gas consumption should be reduced by 2.0 billion m^3 and the electric energy use by 3.9 billion kWh. This reduction is based on the assumption that the energy consumption without changing current policies will increase to 1140 PJ/year in 2020 (PEGO et al., 2007).

At the 23th of January 2008 the Netherlands ministries of Economic Affairs and of Housing, Spatial Planning, and the Environment adopted the National Energy saving Plan by signing an agreement to have saved 100 PJ in 2020. Till 2011 the energy performance of at least 500,000 existing buildings should be improved. Besides reducing the energy use, also the adoption of renewable energy techniques will be stimulated. In 100.000 dwellings renewable energy techniques should be applied before 2012 (Min. HSPE, 2008). However, it should also be mentioned here that renewable sources do not decrease the energy consumption. They only offer a sustainable way of fulfilling this need for energy.

4.2 Proposed approach

The suggested approach focuses on rearranging the economic market for investments in energy saving. Thresholds need to be taken away and proper policies should be adopted. Commercial organisations are asked to commit actively in reaching the objective. A new organisation by name of Energiecentraal (Energy Central) will facilitate and monitor this process.

Within NEP privately owned dwellings and offices are hold responsible for the highest energy consumption in the built environment of 310 PJ/year each. In total the energy consumption in buildings was estimated to be 950 PJ/year. Most of the savings should be accomplished among the privately owned dwellings, namely 43 PJ/year in 2020 (PEGO et al., 2007).

5. Conclusions

In this paper three important Dutch policies in reducing the energy consumption in the built environment were addressed:

1. National Insulation Program (1978-1987)
2. Building Code (1992-…) and the Energy Performance Certificate (2008-…)
3. National Energy saving Plan (2008-2020)

According to Mahlia et al. (2002) a hierarchy is manifested among energy saving policies. It seems however that the regarded policies lack elements of this hierarchy. Ad 1; The highly profitable National Insulation Program, saving up to 51 PJ and € 800 million per year, did not incorporate a label for example. Standardization developed before and during NIP still forms the basis to specify the quality of thermal insulation in social housing and therefore the permissible amount of rent. Ad 2; Since 1992 the Building Code refers to standards regarding minimum thermal insulation and energy performance, but does not refer to a label either. The EPC, specified in the Building Code, can however be used to obtain an energy performance certificate, being the compulsory Dutch energy label for buildings part of a transaction since 2008. Ad 3; The NEP forms the latest addition in reducing the energy consumption of the building stock. It tries to be an incentive program, but does not comprise research activities on the current state nor account for diversity of the building stock, does not incorporate any standards, and lacks financial resources.

However, the combination of the former two policies has resulted in a residential building stock with a large diversity regarding its adoption of energy saving measures. The annual energy consumption of dwellings was lowered on average. One out of four dwellings has been partially energetically improved by the National Insulation Program. One out of seven dwellings was built conform the Building Code and the EPC had its impact on one out of ten dwellings. Furthermore, many houses have been extended to create more living space. These extensions should also be insulated conform the Building Code. Furthermore, in the time period between NIP and NEP, there were, regarding budget and geographical considerations, some smaller incentive programs stimulating the adoption of energy saving measures. Accordingly it can be concluded that the target of NEP to improve the energy performance of 3 million houses is unfeasible, when not a proper inventory is made and no financial incentives tailored to individual cases are provided.

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MODELLING THE RELATIONSHIP BETWEEN ENERGY EFFICIENCY ATTRIBUTES AND HOUSE PRICE: THE CASE OF DETACHED HOUSES SOLD IN THE AUSTRALIAN CAPITAL TERRITORY IN 2005 AND 2006

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ABSTRACT

In a world that is increasingly moving to mandate the disclosure of building energy performance, does the market recognize the benefit of better energy efficiency?

The thermal performance of building shells of houses in Australia has been modelled for voluntary and regulatory purposes using software under the Nationwide House Energy Rating Scheme since the mid-1990s. In 1995 the Australian Capital Territory (ACT) introduced a requirement that new houses reach a 4 star energy standard, and this stringency was increased to 5 stars through the Building Code of Australia in 2006.

From 1999 mandatory disclosure of energy performance was required for all houses sold in the ACT, as a policy to influence the energy performance of existing houses. The resulting data represents a unique opportunity to establish whether information on house energy efficiency rating (EER) affects sale price. This policy analysis was undertaken in the context of commitments by all governments in Australia in 2004 to develop mandatory disclosure of energy performance for all residential and commercial buildings.

The Analytical Services Branch of the Australian Bureau of Statistics was commissioned to undertake a project using Hedonic analysis. The prices of detached houses sold in the ACT in 2005 and 2006 were modelled as a function of land, distance, neighbourhood, socio-economic and EER data. The results provide a clear indication of a robust Hedonic price model (R^2>0.8), with a highly significant coefficient for EER, and evidence that the market values energy performance.

This research will be of strong interest to all countries considering disclosure as a means to drive energy efficiency improvements in the existing building stock.

1. Policy context

Governments in Europe and elsewhere have recently considered that mandating the disclosure of energy or environmental performance of buildings would facilitate a more efficient real estate market where all players could recognize the inherent performance characteristics and be better able to determine value.

In Europe, the Energy Performance in Buildings Directive has moved mandatory energy performance disclosure to the forefront of the energy and climate change policy agenda.

Securing Australia's Energy Future, the Energy White Paper released by the Australian Government in 2004, committed to ensuring that all commercial and residential building owners disclose the building's energy performance prior to sale or lease. This concept has been supported by all Australian State and Territory jurisdictions through the Ministerial Council on Energy, and is part of the National Framework for Energy Efficiency (NFEE).

The Department of the Environment, Water, Heritage and the Arts (formerly the Australian Greenhouse Office), on behalf of all jurisdictions, was asked to develop a nationally consistent framework that will allow the mandatory disclosure of energy performance on sale or lease of buildings. This study of the relationship between house price and energy efficiency was conducted as a key part of that research with the goal of understanding the effectiveness of providing energy performance information to a mature housing market place.

2. The ACT housing market

In 1999 the government of the Australian Capital Territory (ACT) mandated that the energy performance be calculated and disclosed as a part of all house sales, as a policy to encourage improvements in the energy performance of existing houses. This policy has created a large data set of building energy performance and sales information unparalled in the world, and represents a unique opportunity to establish whether the provision of information on house energy efficiency rating (EER) affects sale price.

Mandatory disclosure of building energy performance ratings, as required in the Australian Capital Territory, is designed to provide accurate and standardised information about inherent building energy efficiency to the market, similar to energy labelling of appliances such as refrigerators.

The ACT housing market is small but robust, servicing the needs of a population just over 330,000 who live in Canberra, Australia's national capital. Canberra was settled from 1912 but grew rapidly during the 1960s and 1970s.

The ACT market represents a relatively homogeneous stock of detached housing in suburban neighbourhoods. Over 87 per cent of existing homes sold in 2005 and 2006 were detached dwellings, mostly with 3 to 4 bedrooms. The average dwelling size in the study sample was around 141 m^2 on a block of 836 m^2 located in a suburban setting averaging 11 km from the central business district.

The cool temperate climate of the Australian Capital Territory is one of extremes. With its major city Canberra elevated at 580 metres above sea level in the Great Dividing Range, winter night-time conditions can reach minus 10^{o}C while summer daytime temperatures can exceed 35^{o}C. The main climate characteristics that impact energy efficient design are: low humidity; high diurnal temperature range; four distinct seasons; summer and winter conditions that regularly exceed human comfort range; cold to very cold winters; hot dry summers; and variable spring and autumn conditions.

3. Process of disclosure

The process of disclosure in the ACT consists of an energy efficiency rating (EER) of the building fabric using a nominated thermal performance software package. The disclosure is provided in the form of a star rating, from 0 to 6 stars (recently extended to 10 stars) in half star increments, 0 stars being very poor and 6 stars being significantly more thermally comfortable.

The EER rating is required to be provided to consumers in all advertising material, and the full certificate which also indicates possible energy performance improvements to the building, is required to be provided during the sales transaction process.

The thermal performance of building shells of houses in Australia has been modelled for voluntary and regulatory purposes using software under the Nationwide House Energy Rating Scheme since the mid-1990s. In 1996 the Australian Capital Territory (ACT) introduced a requirement that new houses reach a 4 star energy standard, and this stringency was increased to 5 stars through the Building Code of Australia in 2006.

Prior to the introduction of minimum energy performance standards homes were typically built to a standard lower than 2 stars. The study sample of over 5,000 house sales, which excluded those impacted by new building standards, found that the average performance of existing homes was just below 1.7 stars, with examples ranging from 0 to 6 stars.

The disclosure of energy efficiency performance in the ACT does not include the assessment of the hot water system, lighting system or other fixed appliances.

4. Purpose of the study

This study examines the relationship between the energy efficiency rating and house price. In other words, does a higher EER rating lead to a higher sales price? For example, if a person buying a house knows from the disclosed energy performance rating that a building is energy efficient relative to available alternatives, they may be willing to pay more for the property because the additional cost will be offset by expected savings in energy bills, or conversely, they may wish to pay less for homes with a low rating, recognising the ongoing energy costs to maintain thermal comfort.

If it could be established that there is a positive relationship between EER and sales price, knowing there may be a return in a higher sale price creates an incentive for property owners to invest in improved energy efficiency. This in turn could drive improvements in the energy performance of the existing housing stock, and encourage builders of new residential buildings to create homes above the minimum energy performance requirement.

5. Unique data set

To build the data set the ACT Planning and Land Management Agency (ACTPLA) was commissioned to examine all house data files that matched house sales records in the calendar years 2005 and 2006 to collate relevant house characteristics necessary for the hedonic model. These characteristics included house size, block size, window area, floor and wall material, the number of floors, the potential for cross ventilation, the presence of shading schemes, and many others. ACT Government held sales information was collated for the same dwellings including settlement date, transfer date, and transfer price. After the necessary data cleaning and quality checks, removal of unexplained outliers, and the linking of the ACTPLA and EER records using the suburb, block and section information, the final dataset consisted of 2,385 and 2,719 house records for 2005 and 2006, respectively.

The years 2005 and 2006 were considered for this study because they represented the latest possible complete data set for a mature market. Earlier periods were avoided to reduce the likelihood of program start-up influences. All houses built after 1995 were excluded from the dataset to avoid any impact of the new minimum performance standards.

As per all hedonic models, it is impossible to collect a dataset that contains every possible influence in the sales price, and the limitations of the dataset are acknowledged. However, it should be emphasised that, despite these limitations, it is nevertheless a large, high-quality sample, probably unique in the world, certainly in Australia.

6. The hedonic model

The Analytical Services Branch of the Australian Bureau of Statistics (ABS), the Australian Government's primary statistical collection and analysis agency, was commissioned to undertake a project using hedonic analysis (Chen *et al* 2004, Hansen 2006). The prices of detached houses sold in the ACT in 2005 and 2006 were modelled as a function of land, distance, neighbourhood, socio-economic and EER data. This study was careful to allow all major influences such as location, size and construction of house, value of land, etc, to be treated in a consistent manner to that of the energy efficiency rating.

Hedonic regression regresses price against a host of explanatory variables, where in this case it decomposes the house price into its constituent characteristics, and obtains estimates of the value of each characteristics. For this study, five main categories of variables were considered: (a) structural variables which covered the design and construction features; (b) distance variables which described the relative location to shops, schools, hospitals, and the central business district; (c) neighbourhood variables which cover key social and economic conditions surrounding the home; (d) locational variables which can explain elements of suburb prestige; and (e) energy efficiency characteristics.

The impact of house price inflation was removed from the house price data using the ABS house price index for the ACT.

7. The results

The study has found that there is a statistically significant relationship between the house price and the following house characteristics: floor area, block area, distance to CBD, socio-economic advantage, window area, percentage of 5 bedroom homes in local area, whether the house had previously been a government rental property, and the energy efficiency rating.

EER was found to be positively associated with house price and had a strongly significant relationship. The association on average for 2005 was 1.23 percent for each 0.5 EER star, and 1.91 percent in 2006, holding all other variables constant.

The results provide evidence of a powerful hedonic price model ($R^2>0.82$), with a highly significant coefficient for EER ($p < 0.0001$, t-Statistic > 4), and substantiates that the market values energy performance.

Factors such as double glazing, which also provides a noise benefit, was found to have a strongly positive benefit, while ceiling and wall vents were found to have a negative relationship with house price. Attributes pertaining to the EER such as brick wall, timber flooring, largest window facing north, were not found to have a significant relationship with price.

8. What do the results mean?

While there is a statistically significant relationship between EER and house price, the energy rating explains only a small proportion of the total value of a house. As is to be expected, factors such as block and house size, and location have a greater influence on house price. However, *other things being equal,* a house with a high EER will command a higher price than one with a lower EER.

This study shows that mandatory disclosure of energy performance on sale of property in the ACT has been a successful mechanism for allowing the housing market to recognize the value of energy efficiency. It is clear that the ACT market place has shifted from the traditional real estate industry trio of factors *location, location, location*, to a scenario that rewards *location, location, EER*.

This study concludes that if the energy performance of a house is improved by one star level, on average its market value will increase by about 3 per cent (range 2.5 – 3.8). For example: for a detached house sold in Canberra in 2005 at the median price of AUD365,000, increasing the EER rating by one star would be associated with, on average, an additional price increase of about AUD11,000.

This creates multiple incentives to invest in energy efficiency. First, there are benefits of reduced operational energy costs. Second, the higher capital value of the property due to the improvement in energy efficiency is likely to be greater than the cost involved in achieving the improvement. Third, there are direct and indirect consumer benefits of energy efficiency including thermal comfort, physical health, and mental satisfaction associated with lower environmental impacts.

For example, installing R4 ceiling insulation will cost approximately AUD1,200 and will on average improve the energy performance of a poorly insulated home by at least 1 star. That increase in energy performance corresponds to an average increase in sales price of over AUD11,000. Of course, each house sale transaction is impacted by many circumstances and the exact premium for performance can not be calculated from this study, nevertheless, the study has found that the ACT market strongly favours better energy performance when the information is disclosed.

The research will be of strong interest to all governments considering disclosure as a means to drive energy efficiency improvements in the existing building stock.

9. Thanks

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EVALUATING POLICY INSTRUMENTS FOR REDUCING GREENHOUSE GAS EMISSIONS FROM BUILDINGS – DEVELOPED AND DEVELOPING COUNTRIES

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Summary

Approximately one third of the GHG emissions from buildings can be saved at a net benefit to society (IPCC 2007). However, this substantial potential is not realized due to numerous barriers. Various policy instruments such as building codes, subsidies and information campaigns are applied to overcome these barriers. Since they differ considerably in their effects and costs, 20 commonly used policy instruments were assessed in this study according to their emission reduction effectiveness, cost-effectiveness and success factors, based on over 80 case studies and evaluations of their implementation from over 50 countries.

Many policy instruments achieved high savings at low or even negative costs for society. The highest GHG emission reductions were achieved in the sample by appliance standards, building codes, DSM programs, tax exemptions and labelling. Appliance standards, energy efficiency obligations, DSM programs, public benefit charges and labelling were found as the most cost-effective instruments. Regulatory and control instruments were revealed in the sample as the most effective and cost-effective category of instruments if enforced well. Economic and fiscal instruments and fiscal incentives lead to diverging results. The effectiveness of voluntary and information instruments was usually lower, but depended on the context as well as on accompanying policy measures.

However, as no single policy instrument can overcome the numerous barriers alone, appropriate combinations of policy instruments are most effective. Developing countries require an integrated policy framework including regulations, incentives, capacity-building as well as measures to increase awareness and the trust of stakeholders such as demonstration programs. Choosing the most appropriate policy instruments is very difficult and requires a detailed analysis of the barriers present, the local environment in terms of institutions and existing energy market, the available resources and goal of the action.

1. Introduction

In 2002, 33% of all energy-related CO2 emissions worldwide were due to buildings (Price et al. 2006). However, buildings offer important energy saving potentials through technical, educational and other means: approximately 30% of this energy consumption can be saved economically or at a net benefit to society even at zero carbon price (IPCC 2007, Urge-Vorsatz and Novikova 2008). Considering the baseline projections, this estimate represents a reduction of approximately 45 EJ for buildings in 2020 (IPCC 2007).

Although this large cost-effective potential has been known for decades, many of these energy efficiency possibilities have not been realized. Actually, certain characteristics of markets, technologies, and end-users make difficult rational, energy-saving choices in building design, construction, and operation, as well as in the purchase and use of appliances. These market barriers and failures can be divided into six categories (Carbon Trust 2005): financial hurdles, hidden costs and benefits, market failures, behavioural constraints, information barriers and institutional/ structural barriers.

In order to overcome or limit the impact of these barriers, a wide variety of policy instruments and programs are used by policy-makers worldwide. However, the effectiveness and cost-effectiveness of these various policy instruments is poorly understood and rarely compared on an international level. Thus, this study developed at the Central European University originally for the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) (2007) and deepened for the UNEP Sustainable Buildings and Construction Initiative (UNEP-SBCI) (Urge-Vorsatz and Koeppel 2007) reviews comprehensively the policy mitigation options for the buildings sector.

This paper aims at assessing and comparing the various policy instruments available for CO2 mitigation in buildings through improved energy-efficiency, according to evaluation criteria such as emission reduction effectiveness and cost-efficiency. A special focus is placed on developing countries. The paper presents information on 20 policy instruments from around the world and provides an overview of the effects, strengths and weaknesses of these policy instruments. It also briefly presents the ongoing follow-up project which aims at elaborating a tool for supporting policy-makers in choosing the most appropriate policy instruments.

2. Methodology

First, the most important policy instruments to promote energy efficiency in the buildings sector were identified in the general literature on policy tools for energy efficiency (Crossley et al. 1999, Crossley et al. 2000, Verbruggen 2003, Grubb 1991, EFA 2002, Vine et al. 2003, and Wuppertal Institute 2002), classified into the following four categories and included in the first column of the table: regulatory and control mechanisms, economic/ market-based instruments, fiscal instruments and incentives and support, information and voluntary action.

Subsequently, we searched for as many ex-post evaluations of these instruments from as many countries as possible. Only a few ex-ante assessments were included in the analysis. In total, over 80 studies, review articles and other relevant publications from over 50 countries, covering each inhabited continent except for Africa were identified. All findings were collected in a database and a table showing the evaluation of the instruments, based on selected best practice examples – see Table 1. Due to space limitations this paper only shows the short version of the table, the long one is included in the report (Urge-Vorsatz and Koeppel 2007). The second column assesses the effectiveness in reducing emissions of each policy instrument in the buildings sector in a qualitative way either in absolute or in relative terms (i.e. compared to a logical baseline, such as the total national emissions in the particular location). The collection and analysis of all cases included in our database was used to assign grades such as “High”, “Medium” and “Low” to policy instruments for their effectiveness in reducing energy use and GHG emissions. Ideally, such grades should be assigned in a systematic objective way based on numerical limits of emission reductions, but this method was not possible due to lack of baselines in some cases. In addition, due to differences in the temporal and spatial scale the numerical values of emission reduction, even in relative terms, as well as the total emission coverage of the case studies and of the policy instruments could not easily be compared, even in relative terms. Thus, this criterion was evaluated in a qualitative way, based on emission reduction figures, but taking into account the overall applicability and potential of the instrument. According to the Delphi technique, an internationally recognized method for obtaining comments from experts in at least two rounds, the results of the comparative evaluation table were circulated several times for review to numerous experts recognized as leading scholars or practitioners in this field.

Column 3 of the table evaluates the cost-effectiveness of each policy instrument with qualitative verbal grades similarly to Column 2. In our study, the cost-effectiveness is viewed from a societal perspective, taking into account, when possible all the direct costs and benefits from the policy-making perspective, but excluding the indirect or external costs. However, many policy evaluations assessed the cost-effectiveness of energy savings only according to the cost required to conserve energy (capital costs and investment costs). These figures are often used to compare the costs of demand and supply side investments for “producing” a unit of energy, and therefore are not corrected for the benefits, i.e. saved energy costs. However, assessing societal cost-effectiveness requires including these financial benefits (Koomey and Krause 1989; Atkinson et al.1991). For this reason, in our calculations we subtracted the country-specific energy price from the cost per unit of saved energy before multiplying with the emission factor.

The final columns present success factors or success conditions, co-benefits and other remarks.

3. Results

3.1 Comparative assessment of policy instruments

As can be seen on table 1 and on figure 1, our study does not characterize any single policy instrument as the most effective or most cost-effective one, but it shows that many of the policy instruments can be effective and cost-effective when certain criteria are respected during their design, implementation and enforcement (success conditions). Appliance standards, building codes, voluntary labelling and tax exemptions achieved the highest CO_2 emission reductions in our sample. Costs per tonne of carbon dioxide saved varied widely ranging from a net benefit of 216USD, i.e. a negative cost, to a positive cost of 109USD/ tCO_2 saved. Appliance standards, utility DSM programmes, public benefit charges, energy efficiency obligations and mandatory labelling were identified as the most cost-effective policy tools in the sample, achieving significant GHG emission reductions at negative costs. Appliance standards were very cost-effective with negative costs of 65-190USD/tCO_2. Appliance standards, energy efficiency obligations and tax exemptions were identified as most effective and cost-effective policy tools in our sample (see highlighted rows of table 1).

When comparing the four broad categories of instruments (see table 1), regulatory and control instruments have been found to be among the most effective policy instruments with particularly high negative costs (i.e. very low costs) of mitigation, although the rebound effect can limit the overall effectiveness and correct enforcement is necessary. Within this category, appliance standards, energy efficiency obligations and building codes were especially effective. Appliance standards and energy efficiency obligations were also very cost-effective.

Economic instruments are still difficult to evaluate since some of them such as Kyoto Flexible Mechanisms and White Certificate are still relatively new; but their effectiveness and cost-effectiveness seems to depend significantly on the instrument and the country. The effectiveness and cost-effectiveness of project-based mechanisms, such as the Kyoto flexible mechanisms (JI and CDM) are currently limited, probably due to high transaction costs involved with small projects in the building sector.

Fiscal instruments and incentives also lead to very diverging results: subsidies are not cost-effective in contrast to the reviewed cases in tax exemptions (income taxation). However, they are useful to kick-start the market for new energy efficient products especially in developing countries where funding is often lacking.

Table 1: Table summarizing the effectiveness and cost-effectiveness of policy instruments

Policy instrument	Emission Reduction Effectiveness	Cost-effective-ness	Special conditions for success, major strengths and limitations, co-benefits
Regulatory instruments			
Appliance standards	High	High	Factors for success: periodical update of standards, independent control, information, communication, education
Building codes	High	Medium	No incentive to improve beyond target. Only effective if enforced
Public leadership programs, incl. procurement regulations	Medium/High	High/Me-ium	Can be effectively used to demonstrate new technologies and practices. Mandatory programs have higher potential than voluntary ones. Factors for success: ambitious energy efficiency labeling and testing.
Energy efficiency obligations and quotas	High	High	Continuous improvements necessary: new energy efficiency measures, short term incentives to transform markets
Mandatory audit requirement	High, but variable	Medium	Most effective if combined with other measures such as financial incentives
Demand-side management programs (DSM)	High	High	Tend to be more cost-effective for the commercial sector than for residences.
Economic instruments			
Energy performance contrac-ting (EPC)/ESCO support	High	Medium/ High	Strength: no need for public spending or market inter-vention, co-benefit of improved competitiveness.
Cooperative procurement	High	Medium/ High	Combination with standards and labeling, choice of products with technical and market potential
Energy efficiency certificate schemes/white certificates	Medium/ High	High/Me-dium	No long-term experience. Transaction costs can be high. Institutional structures needed. Profound interactions with existing policies. Benefits for employment.
Kyoto Protocol flexible mechanisms (CDM and JI)	Low	Low	So far limited number of CDM &JI projects in buildings
Fiscal incentives			
Taxation (on CO_2 or fuels)	Low/ Medium	Low	Effect depends on price elasticity. Revenues can be earmarked for further efficiency. More effective when combined with other tools.
Tax exemptions/ reductions	High	High	If properly structured, stimulate introduction of highly efficient equipment and new buildings.
Public benefit charges	Medium	High	Success factors: independent administration of funds, regular monitoring &feedback, simple &clear design.
Capital subsidies, grants, subsidized loans	High	Low	Positive for low-income households, risk of free-riders, may induce pioneering investments.
Support, information and voluntary action			
Labelling and certification programs	Medium/High	High/ Medium	Mandatory programs more effective than voluntary ones. Effectiveness can be boosted by combination with other instrument and regular updates.
Voluntary and negotiated agreements	Medium / High	Medium	Can be effective when regulations are difficult to enforce, combined with financial incentives, and threat of regulation
Public leadership programs	Medium/ High	High/ Medium	Important as demonstration programs. Mandatory programs are usually more effective than voluntary ones.
Education and information programs	Low / Medium	Medium/ High	More applicable in residential sector than commercial. Success condition: best applied in combination with other measures.
Detailed billing and disclosure programs	Medium	Medium	Success conditions: combination with other measures and periodic evaluation.

Support, information and voluntary action instruments vary significantly in their effectiveness. However, awareness raising instruments are nevertheless important to complement other instruments by limiting the rebound effect. Voluntary instruments are usually less effective than mandatory ones. Public leadership programs are often effective and important, not only for the public sector.

These results can be explained by the especially numerous barriers to energy efficiency in the buildings sector which are probably higher than in any other sector (Urge-Vorsatz et al. 2007). Among them, high transaction costs for information search for example is a major barrier. Regulatory and control instruments eliminate these transaction costs by simply mandating the same measures for all actors which seems to be one of the reasons for their high effectiveness and cost-effectiveness.

These results are confirmed by other studies such as the Mure database (MURE 2007) which contains numerous policy instruments from various European countries (but usually not with quantitative values). According to this database, legislative – normative instruments for buildings, such as building codes, are most often ranked as effective compared to other instruments.

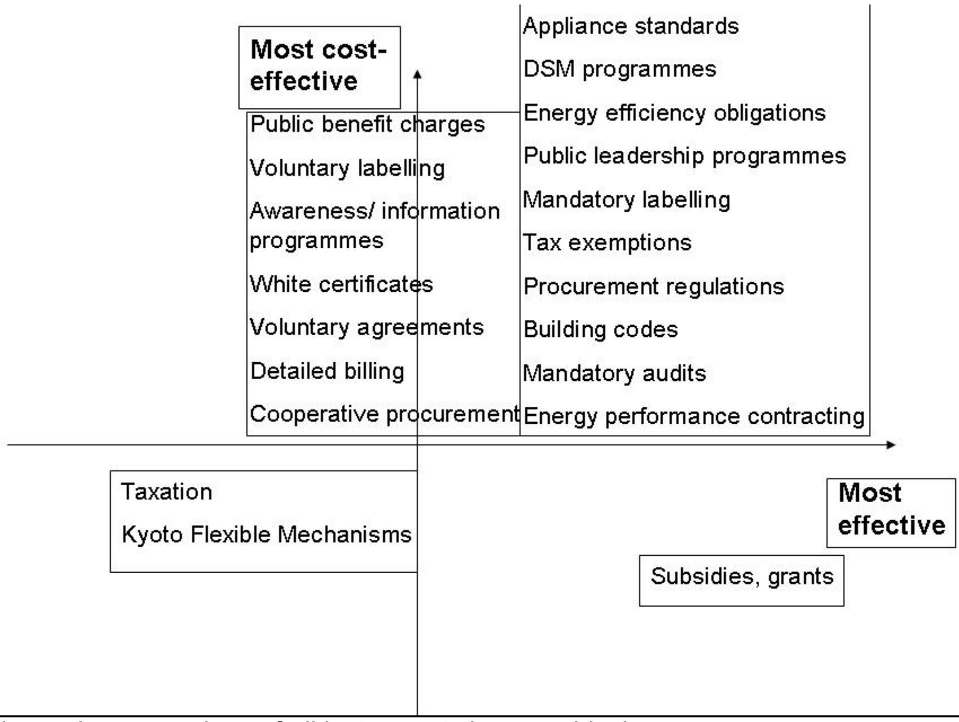

Figure 1 shows the comparison of all instruments in a graphical way.

Note: The positions of the instruments towards each other don't indicate differences in effectiveness- only the position of the instruments in one of the corners is important.

3.2 Combination of policy instruments

However, no single instrument can capture the entire or even a large part of the economic and low-cost mitigation potential in the sector alone. Due to the especially numerous and diverse barriers in the buildings sector, and to the variety of local conditions and cultures, a portfolio of instruments is necessary to overcome several barriers, to take advantage of synergistic effects and thus to maximize the impact of policies. Informative and financial as well as, to a lesser extent, market-based instruments are usually implemented in combination with other instruments which makes assessments of single policy instruments as we presented very difficult. The following policy instruments can for example be successfully combined:

- Standards and financial incentives
- Regulatory and information programs
- Public leadership programs and energy performance contracting
- Financial incentives or procurement initiatives and labeling

Combinations of policy instruments are especially important to achieve a market transformation which is however much less frequently aimed at and achieved for buildings than for appliances for example. In order to stimulate the market it is recommended to aim at and implement measures for achieving 3 different levels of building performance: a minimum performance level, mandatory for all buildings which can be reached through minimum standards; a best practice level which is often used as a basis for defining subsidies, tax exemptions, loans etc.; and finally a state-of-the art level which is often set a long-term target to provide incentives to industry to further improve (Klinckenberg et al. 2007). Table 2 shows possible combinations of instruments.

Table 2: A selection of possible policy instrument packages and examples of commonly applied combinations

Measure	Regulatory instruments	Economic instruments	Financial /Fiscal Incentives	Information instruments	Voluntary Agreements
Regulatory instruments	Building codes and labelling	Standards and ESCO support	Building codes and subsidies	Standards and information programs	Voluntary agreements with a threat of regulation
Economic instruments	Energy efficiency obligation and ESCO support		Cooperative procurement and subsidies	EPC and information campaigns	Cooperative procurement and information campaigns
Financial/Fiscal Incentives	Appliance standards and subsidies	Cooperative procurement and tax exemptions	Taxes and subsidies	Energy audits and subsidies Labelling and tax exemptions	Technology procurement and subsidies
Information instruments	Appliance standards and voluntary labelling	EPC and information campaigns	Labelling and subsidies	Labelling, campaigns, and retailer training	Voluntary standards and labelling
Voluntary Agreements	Voluntary agreements with a threat of regulation		Industrial agreements and tax exemptions	Industrial agreements and energy audits	

Source: adapted from IEA 2005b

3.3 Measures recommended for developing countries

Table 3 shows which policy instruments can overcome which type of barriers. Developing countries are facing special barriers such as lack of awareness, lack of financing for energy efficiency measures, shortage of qualified personnel and insufficient energy service levels (Urge-Vorsatz and Koeppel 2007). Stakeholders sometimes don't trust energy efficient technologies because of negative experiences with these. In addition, frequently, subsidized non-cost reflective energy prices provide little incentive for energy efficiency improvements (IPCC 2007). In many developing countries, the priority of the government is to improve access to electricity without understanding that energy efficiency improvements are also important in order to start with efficient technology from the beginning and thus limit the expected increase in demand to manageable levels. Often, energy shortages provide a good incentive to improve energy efficiency which happened for example in Brazil and South Africa where compact fluorescent lamps are already widely used (Glynn pers. Comm., Gomes, per. Comm.).

Table 3: Barriers to energy efficiency and selected policy instruments as remedies

Barrier category	Instrument category	Policy instruments as Remedies
Economic barriers	Regulatory-normative/ regulatory-informative	Appliance standards, building codes, energy efficiency obligations, mandatory labelling, procurement regulations, DSM programs
	Economic instruments	EPC/ESCOs, cooperative procurement, energy efficiency certificates
	Fiscal instruments	Taxation, public benefit charges, tax exemptions, subsidies/rebates/grants
Hidden costs/benefits	Regulatory-normative	Appliance standards, building codes
	Economic instruments	EPC/ ESCOs
	Support action	Public leadership programs
Market failures	Regulatory-normative/ regulatory/informative	Appliance standards, building codes, energy efficiency obligations, mandatory labelling, procurement regulations, DSM programs
	Economic instruments	EPC/ESCOs, cooperative procurement, energy efficiency certificates, Kyoto Flexibility mechanisms
	Fiscal instruments	Taxation, public benefit charges, tax exemptions, subsidies/rebates/grants
	Support, information, voluntary action	Voluntary labelling, voluntary agreement, public leadership programs, awareness raising, detailed billing
Cultural/ behavioral barriers	Support, information, voluntary action	Voluntary labelling, voluntary agreement, public leadership programs, awareness raising, detailed billing
Information barriers	Support, information, voluntary action	Voluntary labelling, voluntary agreement, public leadership programs, awareness raising, detailed billing
	Regulatory/informative	mandatory labelling, procurement regulations, DSM programs, mandatory audits
Structural/ political	Support, information, voluntary action	Public leadership programs

Sources: Adapted from IPCC 2007, Carbon Trust 2005, Urge-Vorsatz *et al*. 2007b

Due to these special barriers developing countries require an integrated policy framework combining regulations, (financial or other) incentives, demonstration initiatives, capacity building and measures to increase not only the awareness about energy efficiency, but also to increase the trust of stakeholders (Urge-Vorsatz and Koeppel 2007). Capacity-building, technical assistance and training are indispensable to educate experts in these countries. As this will take time, external experts are needed at least for a transitional period (Lihidheb, pers. Comm.). In addition, demonstration projects in the public and private sector such as those selected and supported by MED-ENEC are important to overcome barriers such as the lack of knowledge and trust (Wenzel pers. Comm. 2007). Similarly, information and awareness raising programs can inform the population about the possibilities and potential for energy saving measures. To support, design and implement such programs, institutions specifically dealing with energy efficiency are needed. For example, most developing countries which are considered as relatively successful in terms of energy efficiency improvements such as Tunisia, Thailand, South Africa, Brazil and Mexico have created either energy efficiency agencies or departments dedicated to energy efficiency at the relevant ministries or even special ministries to publicize the importance of energy efficiency among the population (Wenzel pers. Comm. 2007).

Regulatory measures are important also in developing countries. However, compliance is often low due to lack of information, lack of political will, lack of enforcement, high share of black or grey economies (esp. in the construction industry) and especially lack of funding (Mueller pers. Comm. 2007). Thus, enforcement activities and financial resources to support implementation and compliance are necessary, but not sufficient: special efforts and incentives are needed such as awards, subsidies, loans or tax exemptions to facilitate energy savings. In fact, the lack of available financing to cover the investments necessary for energy efficiency measures is often the major barrier in developing and transition countries. Banks are often not willing to finance energy efficiency measures due to lack of knowledge and trust. Some countries such as Thailand or Tunisia have therefore introduced funds for energy efficiency measures which are fed by taxes on cars for example (du Pont 2006). In Brazil, utilities are obliged to spend 1% of their annual revenues for DSM-measures ESCO-financing is another possibility which is already widely used in some developing countries such as China, but much less in others such as India. However, energy performance contracting requires certain institutional structures for being successful which are not present in all developing countries (Urge-Vorsatz and Koeppel 2007). A number of less developed countries completely lack funds and therefore, international funding is thus one of the only options in these cases for reducing energy efficiency.

Finally, there is a need for regular monitoring and evaluation of energy efficiency programs and subsequent revision of programs- in developing as well as developed countries.

3.4 Development of a tool for helping policy-makers to choose most appropriate instruments

Current research (April 2008) is focusing on developing a software tool for supporting policy-makers in choosing the most appropriate combination of policy instruments under particular circumstances and policy targets. Since this is very difficult the tool includes a detailed analysis of the present barriers, the local environment in terms of institutions and existing energy market, available power and capacities and the available resources. The policy goal as well as the target area and target group of the action are also important factors determining the choice of the most effective policy tool package.

Finally, no policy instrument will be effective if its most important success conditions are not fulfilled. Success conditions depend on the instrument and may include regular update, appropriate enforcement, and combination with other policy instruments etc. Despite of the development of such a generic tool it has to be recognized that all policy instruments always must be adapted to the local context in their detailed design.

4. Conclusion and recommendations

This study has probably for the first time comparatively assessed 20 policy instruments for reducing GHG emissions from buildings in terms of their effectiveness and cost-effectiveness based on more than 80 quantitative evaluations of their implementation from over 50 countries. The highest GHG emission reductions in the sample were achieved by appliance standards, building codes, DSM programs, tax exemptions and labeling. Among the most cost-effective instruments were appliance standards, energy efficiency obligations, DSM programs, public benefit charges and labeling. In general, regulatory and control instruments such as appliance standards and building codes were revealed as most effective and usually also cost-effective category of policy instruments for the buildings sector if they are correctly enforced. Economic and market-based instruments as well as fiscal incentives vary widely in their effectiveness and cost-effectiveness: the latter are especially useful for stimulating the market for new products as well as for developing countries. Voluntary, support and information instruments are often essential in combination with others.

Developing countries require specific measures and support due to their lack in financing and human resources. However, each of these instruments can only overcome a limited number of barriers. Thus, in order to capture synergistic effects and address the broad range of barriers always present in every country, they have to be combined appropriately in policy packages. Since evaluations of policy packages are very rare, they could not be included in the paper. It is therefore recommended that a few typical, often used, well-matching combinations of instruments as well as some combined but actually confronting instruments should be evaluated in several countries. The paper summarized a new initiative to develop a tool that develops optimal policy package recommendations for particular circumstances. Finally, further comparative studies focusing also on developing countries as well as evaluations of (new) policy instruments for mitigation options in buildings such as white certificates are needed in order to confirm our preliminary conclusions.

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ESTIMATING ELECTRICAL PEAK LOAD DEMAND AND RELATED MODELLING OF POLICY OPTIONS

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Summary

A growing number of energy supply authorities now struggle to meet summer electrical peak load demands. In Australia, these demands, driven largely by recent increases in air-conditioner ownership (see figure 1) now pose an immediate threat to the security of supply.

Traditionally, supply side solutions have been used to deal with peak load issues. However, these have proven very costly and place a drain on limited resources that some argue would be better directed towards demand side solutions. Unfortunately, benefits in terms of reduced peak loads accruing from demand side measures, particularly those relating to building shell improvements, have in the past proven difficult to accurately quantify.

In 2006/7 the then Australian Greenhouse Office (AGO) (now Department of the Environment, Water, Heritage and the Arts), in collaboration with Energy SA, engaged Energy Efficient Strategies (EES) to develop and test an appropriate model of peak load demand in South Australia. The aim was to establish a relationship between weather conditions and the weather sensitive component of the state electrical load as estimated through building simulation analysis.

When gauged against actual demand, the model that was developed was found to provide an average maximum demand error of ±2.8%. The model is now being harnessed to estimate future peak load reduction as a direct consequence of energy efficiency programs. Consequently, this model will allow claims of additional economic benefits for energy efficiency measures to be incorporated into future benefit/cost analyses.

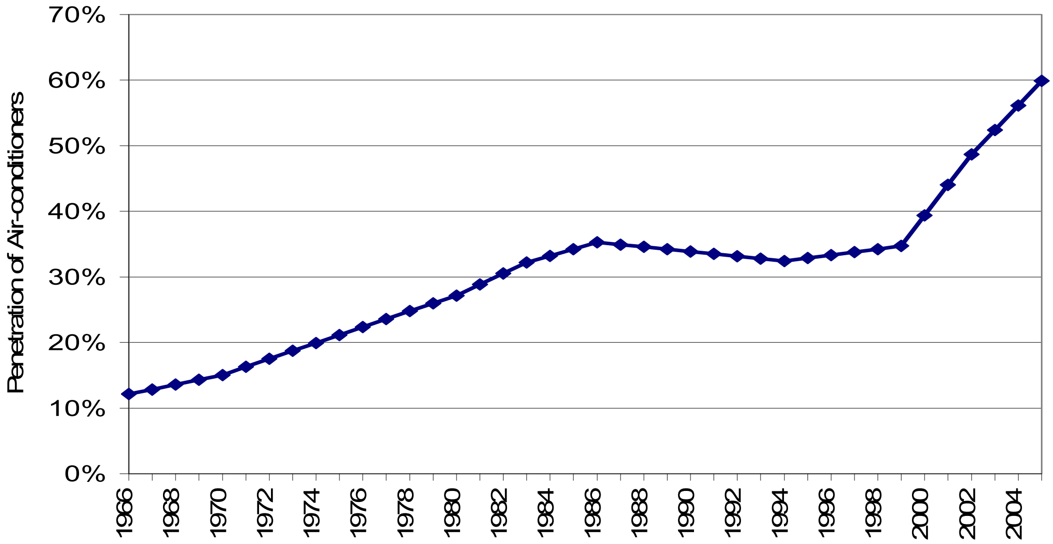

Figure 1 Percentage of Australian Households with One or More Air Conditioners (EES 2008)

1 Background

In Australia, summer electrical system peaks in demand invariably coincide with severe weather conditions (high temperatures). The ten highest peak demand days between 2000 and 2004 in South Australia all had maximum daytime temperatures in excess of 35C. Whilst other factors play a part, it is apparent that these peaks in electricity demand are being driven largely by the use of space conditioning equipment (principally refrigerative air-conditioners). Generation capacity and transmission and distribution capacity can also be reduced by extremely high temperatures, further exacerbating the problem.

In 2004, EES was commissioned by the Victorian Energy Corporation (VENCORP) to assist them to develop a new model of electrical peak demand in that state. Up until that time VENCORP had relied upon a largely econometric model for forecasting state electrical maximum demand. The incumbent model was proving to be less and less reliable and a new approach was sought.

Energy Efficient Strategies undertook the development of a new model. This model utilized building shell simulation tools to model expected cooling loads at a state level, these forecast cooling loads were then matched to a model of space conditioning equipment ownership and attributes to derive estimates of actual electrical demand arising from space conditioning use. These estimates were then added to estimates of the weather insensitive component of the load to derive a maximum demand value. Modeling was undertaken on an hourly basis.

The model was tested/calibrated by applying historical yearly weather data for the previous 5 year period to the simulation model. The outputs of the model were then compared to actual hourly electrical demand data as provided by VENCORP and the accuracy of the model was found to be very good.

In 2006/7 EES were commissioned to apply the same modeling techniques to South Australia. South Australia, the state with the highest ownership of air-conditioners in Australia (excluding the Northern Territory), suffers the worst state electrical load factor of any state or territory. A mild day in South Australia typically produces a daily maximum electrical demand of just over 1500MW (2000-2004) whereas a series of days of extreme weather during the summer can push maximum demand to more than 2800MW

For the purposes of short term forecasting of likely peak demand, supply authorities in Australia have tended to rely on the use of simple metrics such predicted dry bulb temperature. Longer term forecasting has also included some econometric modeling. But the correlation between dry bulb temperature and maximum daily demand is not as strong as one might expect (see Figure 2) and as such these existing models have been proving less and less reliable in recent times. Furthermore, these models have little or no value as a tool for developing demand side policy options. The model detailed in this paper has sought to redress these shortcomings.

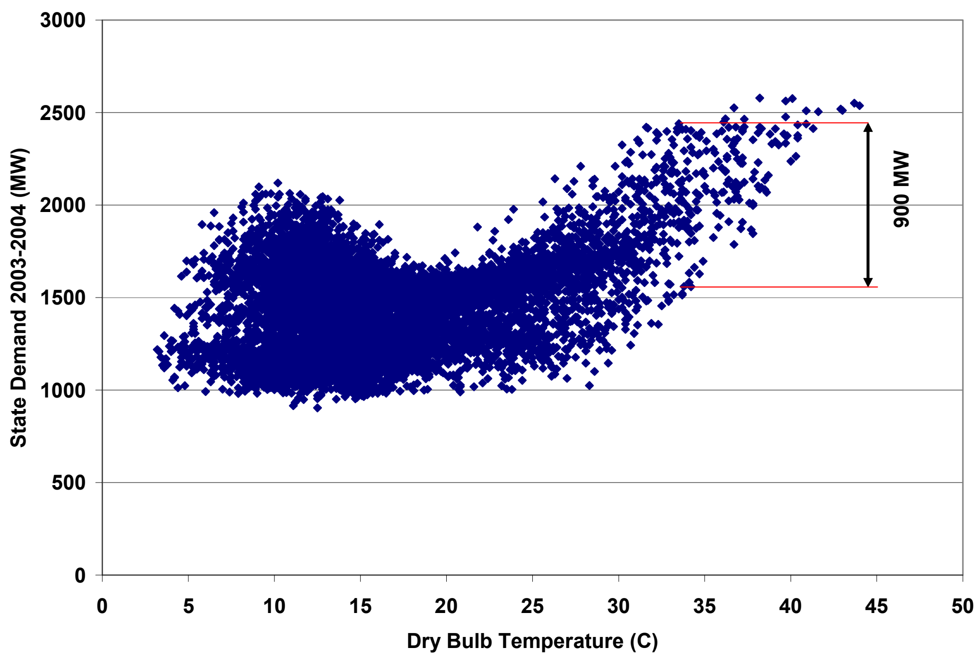

Figure 2 State Maximum Daily Electrical Demand V Maximum Daily Dry Bulb Temperature - SA

2 The Concept

Building shell simulation software has now been used for decades to estimate the expected heating and cooling loads associated with a range of building types. To accurately simulate space conditioning loads these models synthesize a diverse range of relevant parameters including:

- Building Design/Form
- Building construction characteristics
- Thermal properties of construction materials
- Shading geometries
- Air flow characteristics
- Climate data
- User Behavior

Using the above factors and applying the principals of thermodynamics many models are now available that can provide reliable estimates of expected space conditioning loads. In the early days of model development (1970s) these tools were primarily the domain of researchers. In more recent times in Australia the most common use for these tools has been as the basis for rating tools such as the Nationwide House Energy Rating Scheme (NatHERS).

Whether used as a rating tool or for research purposes these tools have primarily been used to make estimates of annual cooling and heating loads. That is, the annual quantum of heat that will need to be added to the internal spaces or removed from the internal spaces of a building in order that an agreed set of thermal comfort conditions will be maintained.

Primarily these tools were intended to simulate the space conditioning loads associated with an individual building. However, some researchers (including EES) have coupled these building shell simulation tools[1] with building stock models and appliance stock models to produce models of energy demand from space conditioning at a state or even a national level. Such analysis can facilitate the benefit/cost analysis of building shell improvement policy options. In this form of analysis, benefits can be described in terms of expected reductions in annual energy demands associated with a particular building improvement policy option (eg retrofitting of ceiling insulation to older housing stock for instance) and this can be further translated into benefits in terms of greenhouse gas emission abatement potential.

Increasingly however, a significant cost associated with the supply of electricity in Australia is the cost of meeting demand for electrical supply during periods of maximum or "peak" demand. During times of peak demand the supply cost in Australia typically grows by a factor of 100! Added to this cost is the cost of providing the necessary distribution infrastructure to deal with these relatively short periods of elevated demand. In South Australia, almost half its generating and transmission capacity could in theory be avoided if not for the need to deal with other than favorable (mild) weather conditions.

Because benefit/cost analysis of building improvement policy measures have not in the past adequately accounted for potential benefits arising from reductions in peak demand, the scope and stringency of such measures that could be justified on economic grounds has been to some degree constrained. Sophisticated building shell modeling software (such as the CSIRO's AccuRate) now offers the researcher the capacity to accurately simulate space conditioning loads on an hourly basis. Consequently, state level models of energy demand can also be configured to provide outputs on an hourly basis. By inputting historical weather data into such models then comparing the outputs with the matching historical records of the weather sensitive component of the state electrical load the accuracy of the model can be assessed.

3 The Model

Modeling of state electrical demand was undertaken by splitting the electrical load into two discrete components:

- The "Weather insensitive component" ie that portion of the state electrical load that remains relatively constant despite fluctuations in weather conditions (particularly temperature). These loads would include such things as lighting, appliances other than space conditioning appliances, water heating, cooking, industrial processes, pumping and so on.

[1] The standard rating tools are typically modified to more closely match reality. Default settings, as adopted in these simulation programs, whilst adequate for comparative rating purposes were not considered adequate for the purposes of estimating expected space cooling loads

- The "Weather sensitive component" i.e. that portion of the state electrical load that varies according to the prevailing weather conditions. These loads primarily consist of space conditioning loads from the commercial and particularly the residential sectors but would also include minor fluctuations in process refrigeration and heating loads.

Modeling of each component was undertaken separately on an hourly basis then the outputs summed. To prove the model, historical hourly state electrical data was obtained for South Australia for the period 1999 to 2004, this data was then compared to the output of the model over the same period.

3.2 Estimating the Weather Insensitive Component

Estimation of the relatively constant weather insensitive component of the load is important as it provides the basis for quantifying the magnitude of the significantly more variable weather sensitive component.

For this component, the approach was to examine historical records of the state electrical system demand. In particular, periods where the weather sensitive component was reasonably neutral were examined. Naturally this required the exclusion of any periods of overly warm or cool weather. In addition, holidays and the Christmas period needed to be excluded as atypical.

In each of the study years a period of one week (known as a reference week) was identified during the summer months during which mild conditions prevailed (see figure 3). It was important that the "reference weeks" occurred during the summer months as the profile during other seasons was found to exhibit subtle differences (e.g. time at which street lighting is activated for instance).

This process lead to the development of a standard set of 24 hour profiles for the weather insensitive component of the load. Load shapes were found to be very similar for Monday to Thursday, so a single shape was developed for those days. Separate shapes were developed for Friday, Saturday and Sunday. Load shapes were developed for each of the years in the study period, noting however that there was little variation year to year.

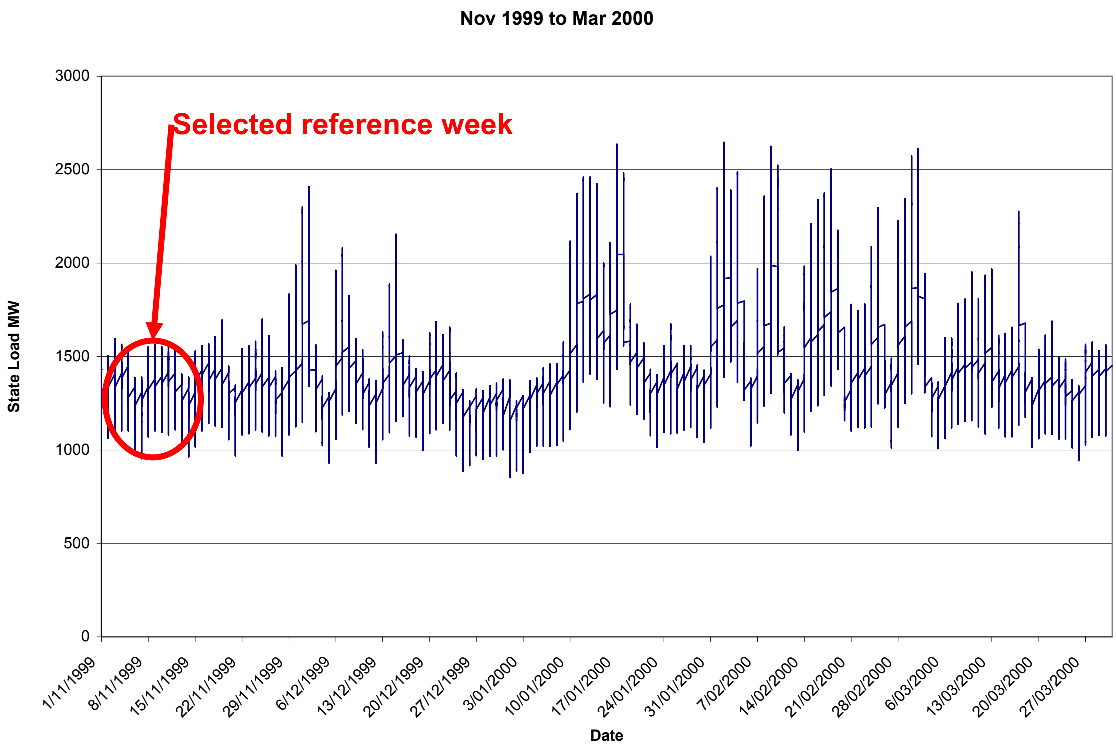

Figure 3 State Maximum Daily Electrical Demand - Summer 1999 to 2000 - SA

3.3 Estimating the Weather Sensitive Component

2.3.1 Overview

Estimates of the weather sensitive component of the state electrical load began with a model of the state's building stock. This was derived from various statistical sources. The main forms of building type in the stock model were identified and representative sample buildings were then selected to represent these forms.

Each building form was then input into the building shell modeling software (AccuRate) along with the historical weather files to derive outputs of unconstrained space conditioning load for each building type.

Using the building stock model, the modeled loads for individual buildings were then scaled up to state level loads. These loads were then constrained using a model of the states space conditioning equipment stock (including number and type) to derive an estimate of actual state space conditioning load. Finally this load estimate was input into a space conditioning performance model that converts the cooling load into an electrical load based upon the average efficiencies of the various equipment types. The overall process is described in Figure 4.

The model was largely constructed as a set of interrelated Microsoft XL spreadsheet files. However, the data outputs from the building simulation modeling were significant (i.e. hourly load data for each zone within each sample building) and generated approximately three hundred million data points (40 GB of data). The volume of this data was beyond the capacity of XL to manage so this data was loaded onto an SQL server database and queries applied to that database to derive weighted outputs suitable for use in the spreadsheets.

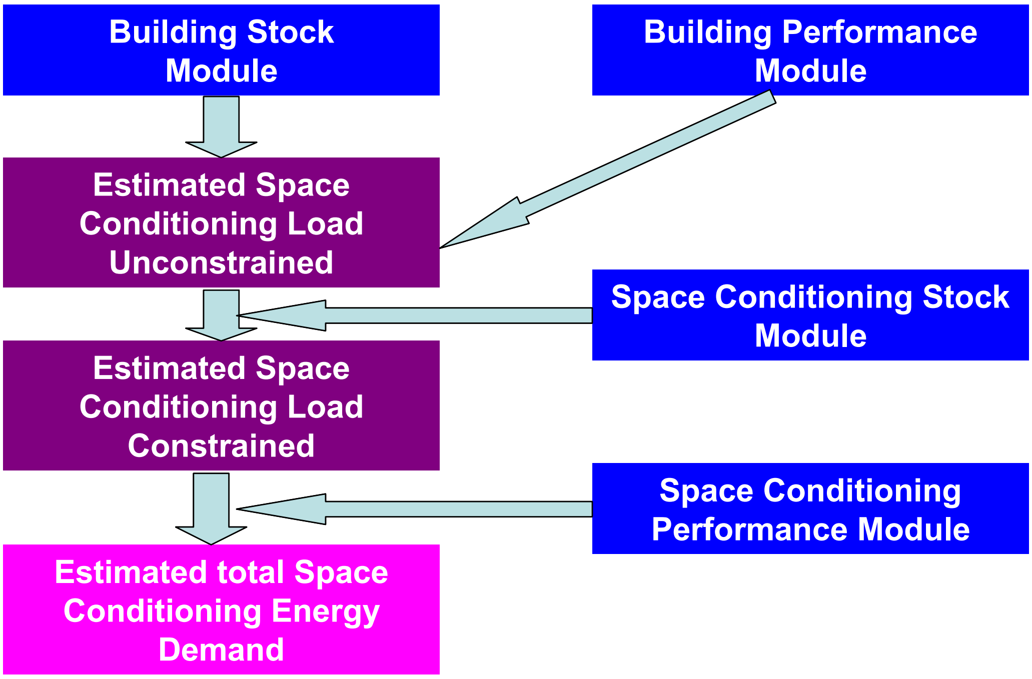

Figure 4 Schematic of Peak Load Weather Sensitive Component Model Structure

2.3.2 Building Stock Module

The building stock model developed for this study drew upon available data to establish a profile of buildings[2] in South Australia over the past 20 years with projections into the future.

The major inputs into the model included:

- *New Buildings Entering the Stock*
- *Retirements of Existing Stock*
- *Conversions of Existing Stock* - Stock numbers for particular construction types were adjusted to account for the retrofitting of insulation to their roof spaces.
- *Augmentation of Floor Area Through Renovations* – Floor areas were adjusted upwards annually according to the rate of floor area augmentation through renovations

[2] A detailed model of residential buildings was developed, this being the major source of peak load demand in South Australia. A simpler model of commercial buildings was also included, although data regarding the profile of such buildings is scarce.

2.3.3 Building Performance Module – Cooling Load Estimates

The models cooling load estimates are based upon simulation modeling outputs from the thermal performance modeling software developed by the CSIRO known as "AccuRate". Thermal performance modeling was conducted upon a sample of buildings selected to be broadly representative of the stock of conditioned buildings in South Australia. This sample also included performance based housing as has become the norm in recent times.

For the purposes of this study the default assumptions within the AccuRate software relating to occupancy profiles and the operation of thermostats were varied to more closely match reality. Settings as adopted in AccuRate whilst adequate for comparative rating purposes were not considered adequate for the purposes of estimating expected space cooling loads.

By default, for each climate zone, AccuRate software uses a set 12 month weather profile based on a "typical mean year" (TMY) as the basis for making comparative assessments of building shell thermal performance. For this study actual weather data for the period 1998-99 to 2003-04 was substituted for the TMY data. This substitution allowed the impacts of actual weather conditions to be compared with observed changes in maximum electrical demand over the same period.

Figure 5 below provides a graphical outline of the space conditioning load model and its key inputs.

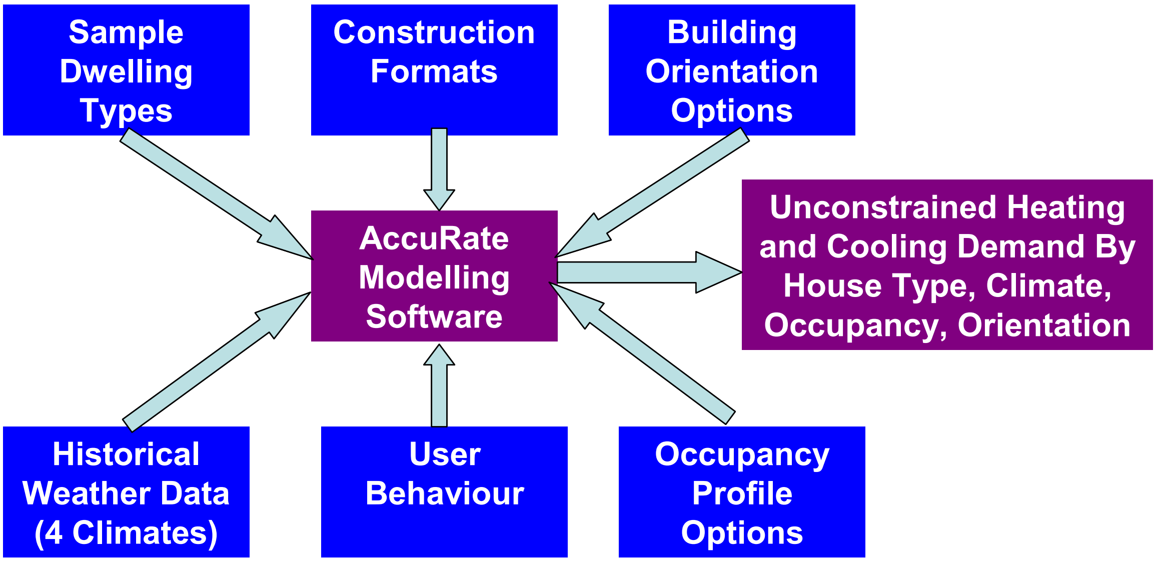

Figure 5 Schematic of Building Performance Load Module

2.3.5 Space Conditioning Stock / Performance Module

An end use stock model of space cooling equipment was developed to take into account the average technical characteristics of both new appliances entering the stock and old ones leaving the stock to provide a stock weighted average for each year during the modeling period.

The main inputs into the appliance end use model were:

- Ownership of space conditioning equipment in South Australia
- Appliance attributes, in particular the efficiency (EER) of the space conditioning appliance and its capacity which can limit the extent of conditioning
- Appliance usage parameters

2.3.6 Climate Zones/Files

For the study period, actual climate files for the 4 main SA climates (as identified in the AccuRate software) were used. The 4 climate zones incorporated into the model were, in order of significance:

- Adelaide
- Mount Lofty
- Mount Gambier
- Mildura

Modeling was undertaken using the climate files from each of these climate zones then the results weighted according to the proportion of building stock in each zone. The climate files included data relating to:

- Dry bulb temperature
- Humidity
- Wind speed and direction
- Direct and diffuse radiation
- Cloud cover

Whilst elevated dry bulb temperatures was found to be the main driver for increasing cooling loads, solar radiation levels were also found to be a significant determinant.

4 Performance of the Model

As noted, the model developed for this study was tested by inputting actual weather data for the period 1998-99 – 2003-04 and then comparing the model outputs (predicted hourly state electrical demand) with actual observed demand over the same period. The modeling tool included a graphical output facility that could plot over any three day period hourly plots of; the actual state electrical demand, the state electrical demand as simulated by the model and the dry bulb temperature in the dominant climate zone (Adelaide). A sample of the output can be seen in figure 5.

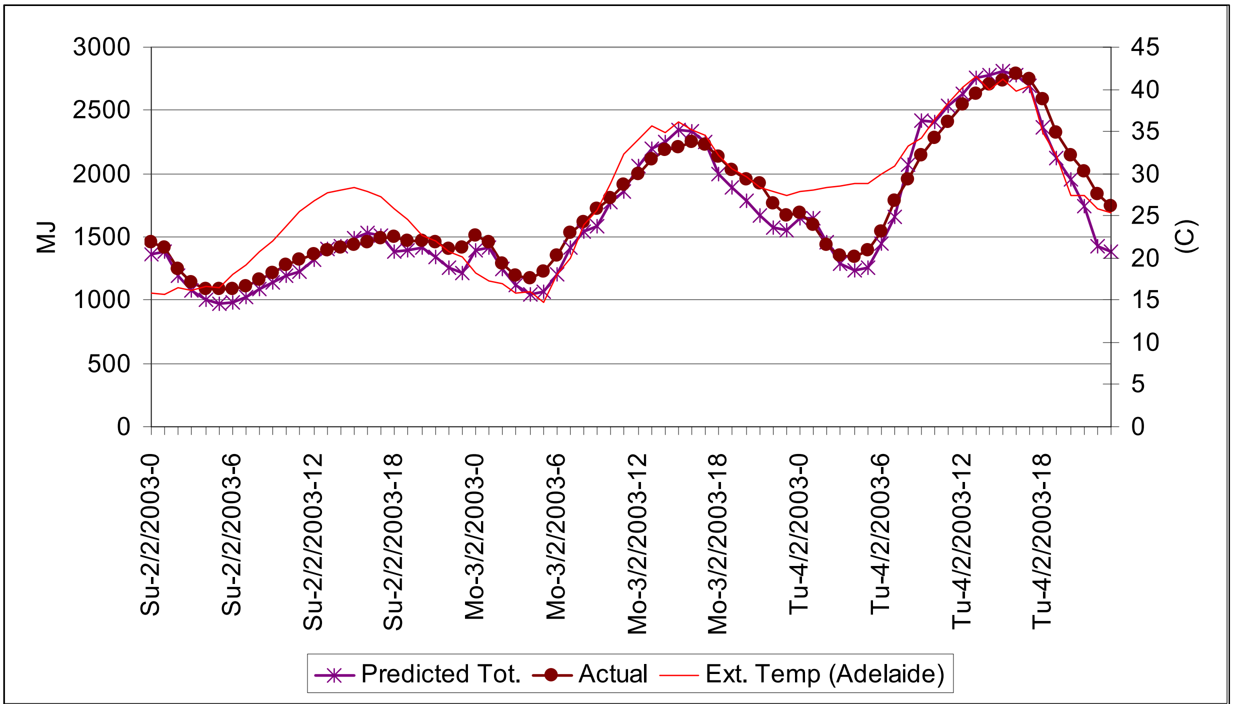

Figure 5 Modeled Demand V Actual Demand – South Australia 02– 04/02/2004

As can be seen from the sample output, the modeled electrical load closely aligned with the actual observed load. The precision of this match was found to be best during the most extreme weather events. The accuracy of the model tended to decline both overnight and during minor peak load events. Whilst accuracy throughout the range of peak load events is desirable, in terms of the objectives of this study it is only the accurate modeling of load during the most severe weather/peak load events that is important.

An assessment of the models accuracy was undertaken on each of the 50 days of maximum electrical demand (>2200MW) during the study period. The model was found have an average accuracy of +/- 2.8% with a standard deviation of 55MW (noting that the maximum demand over the period was in the order of 2800MW). Further improvements to the accuracy of the model may be achievable. Better modeling of occupancy profiles already appears promising and improved modeling of the commercial sector (if and when better data becomes available) would also assist. But such improvements are likely to have only a minor impact on the models accuracy which is now considered to be adequate for policy assessment purposes by the South Australian government.

6. What Next?

The next phase in the development of this model is the application of the model to determining the projected reduction in peak demand arising from various policy measures. The range of measures that can be modeled include:

- Building shell improvements to the existing stock, particularly shading and insulation options.
- Improved building shell performance standards for new stock – particularly summer performance standards.
- Improved performance standards for space conditioning equipment.

Various scenarios relating to growth trajectories for the number, type and size of the building stock as well as the ownership and type of space cooling equipment can also be modeled. Even scenarios relating to climate change could be modeled provided the necessary climate files could be made available.

As a test of the modeling capabilities, modeling was undertaken on the available data (1998-99 to 2003-2004). Various scenarios were modeled as if they had been implemented 20 years prior to this period such that the stock in this period met the improved standard. These results were then compared to the business as usual case (i.e. without improvements).

In the scenario shown in figure 6 below it was assumed that by 2003 all housing stock had been retrofitted with both ceiling and wall insulation. The model predicted that such a policy would have reduced the maximum demand in that year (which occurred on 4/2/2003) by 261 MW or almost 10% of total load. Effectively this means that the cost of a 260MW power station (and associated infrastructure) could have been avoided had that policy been implemented. Further modeling revealed that, if by 2003, the performance of all building stock had been raised to a 6 star NatHERS performance standard and the performance of the space cooling stock to an EER of 3.0, then double these savings would have been yielded!

Modeling of actual policy options proposed for the next 15 years in South Australia are now scheduled to be completed in 2008.

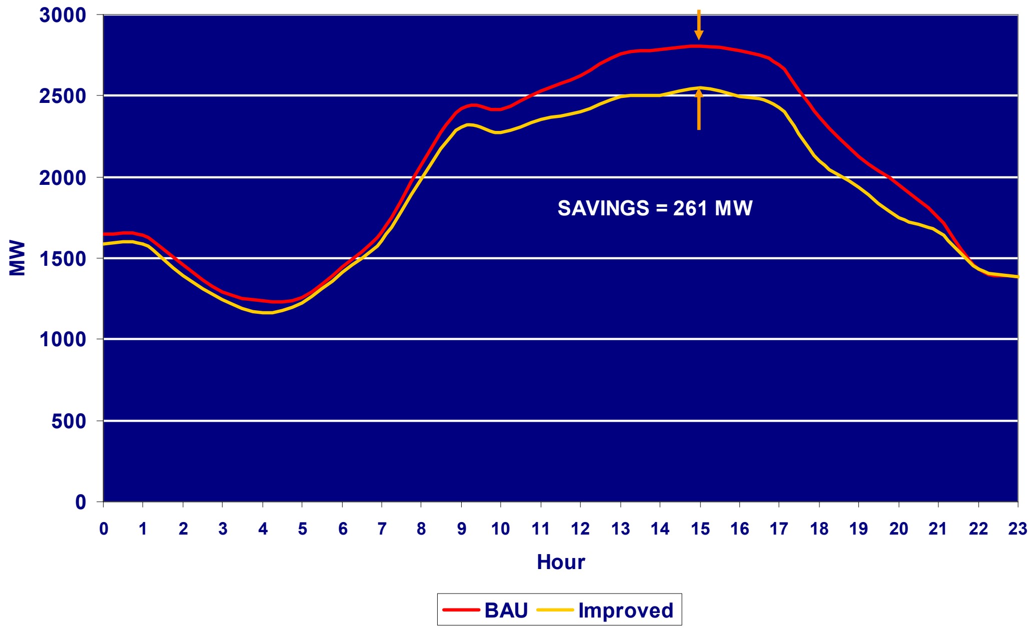

Figure 6 Hypothetical South Australian Peak Demand Reduction Following Ceiling/Wall Insulation Retrofit 4/2/2003

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DESIGNING WITH REUSED BUILDING COMPONENTS

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Keywords: reuse, recycling, reclaimed materials, design process

Summary

It is generally recognized that the use of recycled materials and the reuse of components in buildings can lead to lower environmental impacts. However there are many reasons why construction professionals do not embrace the wider reuse of components. The practical implications of component reuse strategies on the way buildings are designed and procured are not well understood. How does the design team have to adapt its working methods to maximize the potential for reusing components? What are the contractual and liability issues?

Designers need additional information to effectively design with reclaimed components for new projects. They need to understand the risks, economics and implications to the program. The design process needs to accommodate more flexible design and specification. The design team may need additional skills and collaborations to source and evaluate components. Appropriate construction contracts are needed to accommodate component dismantling and reuse. The paper is based on a survey and other data collection that was undertaken as part of a study at Ryerson University funded by the Natural Resources Canada and Canadian Institute of Steel Construction. It highlights the lessons learned from reusing salvaged and reclaimed materials in these Canadian construction projects as well as providing a summary of issues important to the success of re-use in the construction industry based on survey results.

1. Introduction

The widespread adoption of the green building rating systems such as Leadership in Energy and Environmental Design, or LEED^{TM}, (USGBC 2002) has had a considerable impact on the industry in North America and has increased interest in reuse and recycling in construction. In addition, difficulties with waste disposal and limitations on land filling have stimulated interest in the potential economic benefits of alternatives. Waste is becoming regarded as a lost resource and a loss of potential profit. Processes that add value to waste materials can lead to significant financial benefits. This has driven considerable interest and research into issues of deconstruction, design for deconstruction, and reuse of components and material recycling. Publications such as “Old to New – Design Guide for Salvaged Materials in New Construction”, published by the Greater Vancouver regional District (Kernan 2002), and “Design for Deconstruction SEDA Guide for Scotland” (Morgan & Stevenson 2005) illustrate the increased interest from local government in North America and Europe for the potential for building material reuse to address waste minimization. In California, the Integrated Waste Management Board published a Technical Manual for Material Choices in Sustainable Construction (IWMB 2000) which outlines the opportunities for reuse in construction, and lists potential components that can be successfully reused. In 2001 the IWMB also published a Deconstruction Training Manual (IWMB 2001) which aims to grow a viable industry and reduce the amount of construction and demolition debris that makes its way into California’s waste stream.

Existing buildings are huge reservoirs of materials and components which can potentially be mined to provide much needed resources. Reuse of many components from old buildings can significantly reduce the life cycle environmental impact of new buildings. It can also create new jobs and business opportunities. There is increasing recognition that use of recycled materials and reused components extracted from an old building can potential lead to a reduction in waste that needs to be disposed of, a reduction in primary resources used and savings in greenhouse gas (GHG) emissions (Gorgolewski et al 2006).

However, current, standard construction and demolition practices focus on the fastest, easiest and most economical way to get the job done. When this is combined with a lack of clear information and guidance for designers and owners about the implications of specifying reclaimed components and recycled materials, it creates barriers to a more ecologically sound use of resources.

At present, in Canada the perceived difficulties inherent in the incorporation of reclaimed materials into new buildings often discourage clients and designers from embracing reuse unless it is for principled rather than financial reasons. Although materials costs can be lower through reuse, it must be recognized that these may be offset by higher labor costs and increased design time, and fees, resulting from more research required by the design team. In addition, there is likely to be greater uncertainty over costs and program as delays can occur if key components cannot be readily sourced or there are delays in the demolition process. Thus, using reclaimed components has significant implications on the "process" of how to design a building as well as its construction. Traditional relationships and design procedures may not be best suited to maximize material reuse. These issues need to be understood by the design team and client so that appropriate strategies are put into place.

Figure 1 In Canada the Mountain Equipment Coop has pioneered component reuse in many of its retail stores. This one located in Ottawa reused many parts of the previous building on site, including the foundations..

2. Methodology

This paper considers the implications of materials reuse strategies for the process of designing and procuring buildings. The intent is to understand the changes that a design team need to make to the design process to facilitate greater reuse of components in construction and to indicate strategies and recommendations about how to maximize reuse potential. The focus is on how the desire to use salvaged and reclaimed materials affects the design process, and what designers need to know and how they need to adapt their standard processes to fulfill the potential for component reuse.

This paper is based on work carried out to examine the processes used for building component reuse in Canada. The discussion below focuses on key aspects of the design process and how they are affected by component reuse, particularly those aspects that have been identified as potentially varying from standard design processes as outlined in the Canadian Handbook of Practice for Architects (RAIC 2003). The work is based on a survey that was carried out of the Canadian construction industry. This survey focused on Canadian projects that included significant amounts of component reuse. Key participants in these projects were interviewed or filled out a questionnaire, and this information was analyzed. In addition, a literature review was carried out of international practices for integrating reused components into buildings. A full report of this project is available elsewhere (Morettin & Gorgolewski 2008).

3. Types of reuse

Reclaimed and salvaged materials and components (RSMC's) available for reuse can be generally categorized into 4 types:

- On site reused component - which may be whole structures or individual components such as bricks from an old building on a site into a new building.
- Salvaged from other sites – components such as bricks, timber or steel taken from a demolition site and used in another project (usually local), and requiring little reprocessing.
- Reconditioned components – these are components that are taken from a demolished building and require some improvement to be sold again for use in a new location. This may include radiators, doors, staircases, etc.
- Recycled content building products (RCBP's) – these are often readily available building products that include significant amounts of feedstock material that is taken from demolition or other reuse sources. This may include some gypsum boards, steel components, etc.

It is important to keep in mind that use each of these in a building project requires different tasks and strategies that happen at different stages of the design. In addition, current market conditions have an impact on the availability of all these components. Recycled content building products have the least impact on the design process as they are often available directly from manufacturers "off the shelf". Components salvaged from other sites are often the most difficult to integrate as they need to be identified and sourced at the appropriate time in the design process which may be difficult. On site reuse allows the design team to assess what is available and design the new building around the components that are already at the site.

Therefore, assessing the potential for different types of reuse and the sources that are available at the pre-design stage of a project is essential for future scheduling, resource planning and cost estimating.

4. Lessons from completed projects

4.1 Commitment

In the absence of a legal compulsion to reuse and recycle, it is essential that the client or developer is supportive of the principle of component reuse. Projects quickly founder when the client has doubts about this strategy, as inevitably there will be times when the standard product option looks tempting. Also, the client may have to fund the purchase (and thereby securing) of materials and components as they become available throughout the project, which may occur earlier than in a typical project. For this reason it may be helpful to appoint a contractor as part of the design team. This will have implications on the form of contract used, so alternative contractual arrangements need to be discussed with the client, particularly if high levels of salvaged material use are planned.

Expectations for the design may require some tolerance to the duration of the design and construction phases since they will depend entirely on the supply of suitable materials and goods.

The survey of projects that reused components clearly indicated that the decision to focus on RSMC needs to be made early in the design process. Approximately 80% of respondents stated that the decision in their projects was made at the Concept Design stage, with a few making the decision right from the beginning during the Design Team Selection. It appears from evidence of completed projects that if a decision to use RSMC is left until the outline or detailed design stages it is far more likely to have a detrimental effect on costs during construction and schedule while material was being procured. This is often because the design of the building has progressed too far without consideration of what components may be available.

4.2. Costs

Almost half of responses to the survey indicated no impact on design fees, but others did indicate a significant increase in workload for the design team which should be recompensed. It is to be noted that the projects which had higher design fees also had a higher proportion of RSMC and were considered to be pilot or ‘test’ projects.

There is a strong consensus that material cost (including refurbishment/reprocessing) are decreased by use of RSMC – 95% of responses indicated a decrease of either minimal or significant savings most likely attributed to the lower costs of used materials even when refurbishment was factored in. Conversely, there is a strong indication that construction labor costs increase, possibly due to additional dismantling and handling costs. Particular cost savings were noted when major components of an old building are reused on the same site in a new structure as they are directly offsetting the purchase of new materials. However, good documentation of the old components is useful to avoid unexpected surprises. It was also noted that transportation costs and the consequent environmental impacts are reduced if components are reused close to their original location, and this is usually the case as most reused components are sourced locally.

Surprisingly, the survey did not identify issues and additional costs related to storage of reused materials. Since purchase may have to occur at a time when materials are available rather than when they are needed on site, there may be longer storage times, but these were not identified as a problem, nor were there additional costs identified as linked to this.

4.3. Setting goals

There is inevitably hesitance to set ambitious goals for reuse without previous experience of salvaged materials use. The decision as to what level of use of salvaged material should be determined based on some or all of the following criteria:

- Because of the nature of the supply of salvage materials and the different acquisition processes involved salvaged materials are most readily and cost effectively obtained in relatively small volumes. More efficient use can therefore be achieved in smaller buildings.
- The knowledge and experience of the design team about how and where to located and acquire salvage materials can improve the efficiency and cost effectiveness of the process. Therefore, previous experience of the design team and contractor with the use of salvage materials is significant.
- The process of locating and acquiring salvaged materials can be longer and more unpredictable than regular construction materials. Therefore, flexibility in time available during both design and/or construction phases is helpful.
- Opportunities for up to 25% use of salvaged materials can easily be achieved provided that the design uses readily demountable materials such as steel or heavy timber construction since these products represent the largest category of salvaged materials. It is not uncommon to reach 50-75% salvaged material on small to medium sized projects of this nature although these targets may increase the time and effort needed to achieve them.

4.4 Design process

A factor that clearly emerged from the survey was the importance of integration in the way the design team functions as a key reason for utilizing a higher than average amount of RSMC’s into their project as well as achieving building energy performance exceeding normal standards. Design teams that employ the Integrated Design Process (Larsson 2003) provide a clear benefit, as this leads to early involvement and buy in from the whole design team. Furthermore, it is important for the design team to be enthusiastic about the reuse/recycle route, and to accept that this may require the team to adapt the normal working practices, and be prepared to take the initiative when it comes to overcoming the unpredictable hurdles that may present themselves. This is clearly linked to remuneration and design fees, but as noted above, if decisions are made early enough the additional design costs need not be substantial.

Previous experience of design consultants with the use of salvaged materials, or willingness to accept the concept and adapt their processes is important. Some firms hire a specific person to source reused materials which may be an opportunity for new specialist roles within design consultancies and for young and enthusiastic employees to learn and benefit from the process. Similarly, the commitment of contractors and sub-contractors to reuse/recycle is recommended as they can assist or be responsible for the sourcing of suitable materials and components. This may require that contractors become involved during the schematic design/design development phases since material acquisition happens much earlier than for typical projects. Beyond having potential contractual implications, inexperienced or disinterested contractors may have a negative influence on the project team in their use of pressure tactics such as increasing the construction costs due to 'unfamiliar practices' or by not being able to properly locate salvaged/recycled materials. This results in the undermining of the project's intentions by reverting back to new materials and components, albeit with more familiar methods. Thus, the goals of the project need to be clearly explained to, and embraced by, potential contractors before or during the time of tender or contract negotiation.

When reusing buildings and their parts in situ a structural engineer is needed with expertise or past experience in appraising the existing structure and, if necessary, defining work to be undertaken to make the structure reusable, and adapting the existing building for the incorporation of new uses and features (e.g. staircases, lifts, building services plant and distribution). Again however there is the potential issue of an engineer's reluctance in using RSMC by disputing or dismissing the need to properly assess and approve the conditions of potential materials and components. It may be necessary that other building science expertise be sought to also appraise the existing building services, envelope and other features, and to define work to be undertaken to make them reusable, depending on the scope of the reuse.

Figure 2 It is often most practical to reuse components or whole structures on the same site. This directly offsets costs and environmental impacts of primary materials.

4.5. Factors deciding what to reuse

When selecting which reused components of a building or recycled materials to use, one starting point that has been used is to base decisions on embodied energy content. It would be appropriate, therefore, to concentrate on reusing and reclaiming goods and materials with high embodied energy as savings will have the greatest potential energy saving impact. This would suggest reuse of metals, plastics, bricks and generally high value processed components. Another approach could be based on the quantity of material available and if used, could theoretically be the total amount diverted from landfills. For this environmentally beneficial scenario, determining the quantity would then be based on the weight or volume of the materials used. In this instance, the focus would be on larger components and concrete which represent the heaviest/bulkiest items to divert.

Unlike traditional projects where designing the structure, mechanical and electrical and other main systems take precedence over final material selection and procurement, when incorporating RSMC the task of sourcing materials is often the driver during the schematic design phase and one of the key influences on the layout, structure and other systems used.

4.6. Sourcing reused materials and components

Sourcing RSMCs required designers to foster new relationships with organizations they may not traditionally be in touch with. Some demolition contractors, and salvage companies now have sales staff specifically intended to identify and market construction components they have identified as of value to the building industry. These may range from whole buildings, such as prefabricated industrial buildings that can be readily dismantled, to individual components such as beams, stair cases, doors, etc. They often know beforehand when existing buildings are scheduled to be demolished, so establishing contact with them can provide sources for appropriate materials. However, briefing demolition contractors to ensure minimum damage to components scheduled for reuse is sometimes necessary. The UK's National Green Specification (NGS), for example, calls for demolition contractors to indicate what is to be reclaimed and produce a method statement indicating how the goods will be extracted in good condition, palletized and protected during transportation and storage.

Designers may have to visit local used building materials yards, demolition contractors and salvaged materials suppliers to establish general availability and quality of materials, and to discuss the scope of their project and provide a preliminary list of materials that they are looking for. Larger, or more committed design firms are beginning to develop an expertise in locating salvage components, and may have dedicated staff for this purpose.

Local municipal departments may know when demolitions are likely to occur and can direct design teams to potential sources of materials and components. Furthermore, there are an increasing number of locally based materials exchange schemes often web based that provide access to a range of materials sometimes for free.

Both reconditioned goods and recycled content building products (RCBPs) can generally be sources in the same way as regular materials and components, although additional research may be necessary to identify appropriate suppliers. RCBPs and reconditioned goods are generally easier to acquire due to their availability, and can be incorporated and procured in a similar way to new material up to and during the schematic design phase. For reconditioned goods, during schematic design, responsibility for component acquisition would still need to be allocated as there may be additional tasks associated with locating appropriate supplies. It needs to be established who will source the particular components? Will the design team specify the performance requirements and pass this function on to the contractor with a general requirement that reconditioned components should be used, or will the design team locate the specific component? Most of the survey respondents suggested that in existing projects building components were generally defined by a performance specification and that the contractor was responsible to source the components. This would therefore require that the specification, in addition to a performance statement similar to goods made with new materials, indicate either the amount of recycled content required within the material or that the component be reconditioned.

If the intention is to reuse all or part of an existing building in situ, the search for available existing buildings for reuse in their entirety will need to commence at the pre design stage of the project. Once an existing structure is identified, a full survey of the building to be reused is needed and if possible, original drawings and specifications should be located to assist with identifying potential material re-use opportunities and dismantling efforts.

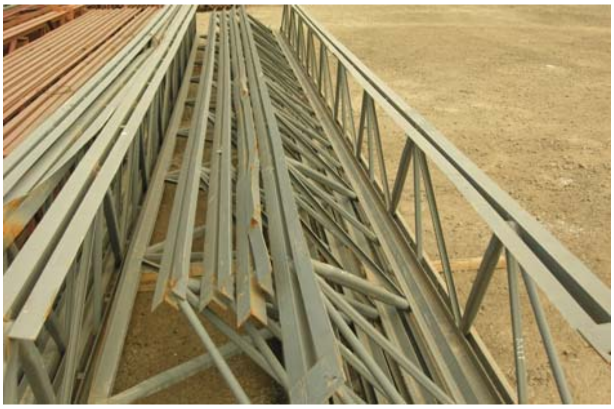

Figure 3 Open web steel joists can often be dismantled for reuse, but the new structure needs to be designed around the available spans.

4.7. Construction process

When reusing buildings and their parts in situ, preferably a deconstruction specialist should be hired if possible, or a contractor with an interest in deconstruction, in order to dismantle the salvaged materials designated for re-use. Some projects in Canada have used not-for-profit / youth programs / government job skills training program as sources for lowering the cost of dismantling and re-conditioning as well as providing economic opportunities for the less-fortunate.

The design team needs to establish procedures for grading salvaged components to ensure they meet functional requirements and regulatory standards. This may require visual inspection, structural or other testing, and possible refurbishment.

5. Conclusion

Certain key factors emerge from the pioneering projects that focus on reuse. These include:

- It is important to have commitment of the entire design team at the early stage of the process.
- Projects need clear goals with commitment of all the design team and client.
- The Integrated Design Process facilitates a great likelihood of successfully using RSMCs
- Sourcing RSMCs required designers to foster new relationships with organizations they may not traditionally be in touch with.
- Responsibility for identifying RSMCs needs to be clearly established - who will source the particular components?
- Procedures for grading salvaged components need to be established and any regulatory issues identified.
- Cost savings are possible in material costs, but some of these are offset by additional labour costs.
- There can be additional design costs. This can be due to redesign to suit when sourcing reused components.
- Projects with the highest savings usually focused on reuse of the existing building already on site.

Designers need to recognize that there are some significant differences to the design process if reuse of construction components is a goal of a project. Reused components have different patterns of availability which need to be accommodated. Also, the limited range of components requires the design team to be more flexible and to develop the building design around the available reused components rather than the traditional process of designing the main features of the building and then identifying the components that will meet the required specifications. This means that ideally the specific reused components need to be identified at an early stage in the design process, perhaps when traditionally a contractor may not yet be involved.

The standard design stages as outlined in the Canadian Handbook of Practice for Architects (and other similar manuals in other countries) will need to be adapted with new tasks included that focus on what needs to be achieved and at which stages, to facilitate successful component reuse. It is hoped that the next stage of this work will develop a manual of tasks to help design teams that wish to design with reused components.

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HOLISTIC APPROACH TO SUSTAINABLE CONSTRUCTION PROJECT MANAGEMENT

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Summary

The construction industry is characterised by a project-based organisation and deals with all phases of the life cycle of a building. Each of these phases requires specific methods for project planning and resource management. Moreover, regarding the trias of sustainability -ecologic, economic and social balance- integrated approaches are needed. In particular, these approaches have to focus on project planning as well as on resource management throughout the life cycle of a building. The efficient utilisation of these resources can be supported by optimisation models from Operations Research. The planning of construction materials can be tackled by methods known from supply chain management or, as far as deconstruction is considered, by methods adopted from reverse logistics to establish closed-loop supply chains. A holistic view on the various planning problems is given and solution approaches for sustainable construction are proposed.

1. Introduction

The construction industry can be considered as one of the oldest ancient industry built on a project basis. A well known example is, for instance, the Cheops pyramid in Egypt around 2500 years BC. Thereby, construction has always been characterised by taylorism due to the complexity of the products and the heterogeneous mix of materials and components as well as diversified construction activities. Hence, comparing the supply chain of the construction industry with those of the manufacturing industry, it can be observed that construction supply chains are more complex due to the unique nature of the projects, the highly uncertain planning environment and the numerous stakeholders involved in a construction project. Concluding, if the focus is drawn to individual construction standardized construction processes are not appropriate.

In construction, the project based organisation structure has mainly remained the same for centuries. Apart from recent achievements of standardization of construction with modular or pre-engineered housing and prefabricated standardized components -concepts taken over from the manufacturing industry- concepts in construction remain specific (e.g. Barlow et al. 2003; Gann 1996). However, although being one of the most established industries, construction still often suffers poor performance, mainly in terms of time and cost. Furthermore, approximately 30-40 % of global energy consumption as well as 20-30 % of greenhouse gas emissions can be traced back to the construction industry (UNEP 2007) and makes it to one of the industries that deserve special attention with regard to sustainability.

For construction project planning, methods such as the Critical Path Method (CPM), Project Evaluation and Review Technique (PERT) or Gantt charts are still applied and have maintained their role for many decades. However, these rather simple techniques do not pay sufficient respect to the complex planning environment in construction where more difficult planning problems are faced. This reaches from pure project characteristics, like simultaneous projects, to external constraints opposed to construction projects, such as different stakeholder interests, and environmental concerns, like waste accumulation and disposal. Concluding, sophisticated project planning approaches are required to tackle construction seriously taking the construction project environment into consideration. In contrast, the complexity of construction projects has lead to a research gap in production planning and control approaches tailored to the construction industry. While supply chains of the traditional manufacturing industry have been well researched and have been tackled with qualitative as well as quantitative approaches construction supply chains still deserve intensive research efforts.

In the following a holistic view on the various planning problems in construction is given and solution approaches for sustainable construction are proposed. The contribution of project planning models from Operations Research to construction project planning is stressed and it is shown how methods of supply chain management and reverse logistics can contribute to efficient project coordination and sustainable construction processes.

2. Project Scheduling and Materials Management

2.1 Construction Project Performance

The construction industry, more than any other industry, still suffers a poor image and is often faced with poor quality of its products. Moreover, construction projects often are over budget and beyond time. While some authors claim, that the main reasons for disputes cover aspects such as risk allocation, design changes and handling during project execution others mention fairness and clarity of contractual arrangements, payment as well as construction delays as main causes for disputes in construction (Assaf and Al-Hejji 2006; Al-Momani 2000; Kumaraswamy 1997). Both, the late delivery as well as cost overruns in projects jeopardise project success leaving the client of the construction project unsatisfied and the contractor with expensive and time consuming dispute resolution and extensive claim management efforts.

Several studies on causes of delays of construction projects have been conducted and it has been shown that approximately one-third of all construction projects are beyond time and budget although these are key competitive factors (see Yeo and Ning 2002). According to surveys among construction practitioners the causes are, among others, constant changes in project requirements, the development of multiple projects at the same time delaying less important projects, deficient communication between project partners, a lack of available resources,—e.g. a shortage of site workers and technical personal, late delivery of construction materials, insufficient number of equipment— and equipment allocation problems as well as a vague definition of the scope of project budget and schedules (Ogunlana et al. 1996; Yeo and Ning 2002). In a survey among owners, contractors and consultants the 10 most important causes of delays mentioned by owners are ineffective planning and scheduling of the project by the contractor as well as conflicts encountered with sub-contractors schedule in project, besides, for instance, a shortage and low productivity of labour and inadequate contractor's experience. Contractors however, mention the delay in progress payments by the owner, design specifications as well as late procurement of material as causes, while consultants refer to, among others, the type of project bidding and award, a shortage of labour as well as ineffective planning and scheduling of the project by the contractor (also mentioned by the owners) and a delay in material delivery (Assaf and Al-Hejji 2006). A similar result is gained in a survey among 150 construction practitioners (Sambasivan and Soon 2007). Hence, from several studies two major causes for delays which refer to the planning of the project as well as to materials management can be identified, i. e. delays are caused by insufficient scheduling and the non-availability of material and resources on-site. Causes which are related to the planning of projects, hence, to scheduling and materials management, are well known problems in many projects and significantly influence project success (Assaf and Al-Hejji 2006; Chan and Kumaraswamy 1997; Faridi and El-Sayegh 2006). Concluding, a key factor to ensure project success in addition to the selection of appropriate project partners, the experience of the project planner, the project organisation, and appropriate information flow between project partners is an (1) *efficient resource allocation during the scheduling of the project* and a (2) *proper materials management*. The latter aspects are considered in more detail in the following.

2.2 Resource-Constrained Project Planning

2.2.1 Resource planning with optimisation approaches

Project planning and scheduling in practice, especially in the construction industry, is still often conducted with rather simple techniques, such as common project planning approaches like the Critical Path Method (CPM), the Metra Potential Method (MPM), as well as the Program Evaluation and Review Technique (PERT) or Gantt charts focussing on time oriented objectives and network diagrams when activity durations and precedence relations are known and deterministic (e.g. Allam 1988 and related literature). Their main advantages are the explicit representation of activity relations and their easy application. Paradoxically, however, even though a lot of scheduling procedures have been developed and tested for construction purposes, the scarceness of resources is often either neglected in scheduling approaches or seen as of minor importance in initial schedule generation in practice (Herroelen and Leus 2005) and the project schedule has to be adjusted to limited resource availabilities afterwards.

Simulation or optimisation approaches from Operations Research, such as resource-constrained project scheduling with the well-known resource-constrained project scheduling problem (RCPSP) integrating the scheduling as well as the resource allocation process, represent an appropriate alternative to traditional planning methods, such as CPM, MPM and PERT. RCPSP models offer freedom for the integration of construction specific particularities into the generation of a construction project schedule. Thereby, various objectives are considered in the planning and resource allocation process. Common objectives in construction project management and scheduling are, for instance, the minimisation of project durations under multiple resource constraints (Moselhi and Lorterapong 1993), the minimisation of the total project delay (Tsai and Chiu 1996) as well as the minimisation of costs of total resource consumption, including time and a levelled resource distribution (Karshenas and Haber 1990). Furthermore objectives like maximizing the total project net present value by considering project delay penalties and early completion boni (Chiu and Tsai 2002) as well as finding the optimal resource selection optimizing time and cost objectives of a construction project (Burns et al. 1996) are pursued.

Additionally, considering the case of repetitive activities, objectives might address the minimisation of crew idle time (El-Rayes and Moselhi 1998). Finally, project management can address the generation of a schedule-dependent site layout planning (Elbeltagi et al. 2001).

2.2.2. Basic model formulation

The RCPSP in its basic formulation describes a single project which consists of activities, also known as jobs, operations or tasks, with a known constant duration of periods. It is characterised by a deterministic finish-to-start precedence relation in an activity-on-node (AON) network, which means, that an activity cannot be started before all its predecessors have been finished. In the RCPSP a job requires constant units of the renewable resource type during every period of its duration. The resource types are known and available in a constant amount over the whole planning horizon. Thus, jobs might not necessarily be scheduled at their earliest possible (precedence feasible) start time. The objective of the RCPSP is to find a non-preemptive schedule by assigning starting times to the jobs such that the precedence and resource constraints are satisfied following one or more targets. An early mathematical programming formulation was given in (Pritsker et al. 1969). Objectives of the RCPSP might be (Klein 1999; Kolisch and Padmann 2001; Tsubakitani and Deckro 1990): Minimisation of the project make span, resp. finishing time of the project, minimisation of the project delay, maximisation of the net present value, and minimisation of activity- and/or resource-costs.

The most commonly considered objective of the RCPSP is the minimisation of the project finishing time because, for instance, the majority of income payments of projects (e.g. in the construction industry) occurs at the end of a project or at the end of predefined project phases and finishing the project early reduces the amount of tied-up capital.

With the assumptions made the RCPSP can be modelled as mixed integer program (MIP) as introduced in the following:

$$\text{Min } \theta(x) = \sum_{t=EF_J}^{LF_J} t \cdot x_{Jt} \quad (1)$$

subject to

$$\sum_{t=EF_j}^{LF_j} x_{jt} = 1 \qquad j = 1,\ldots,J \quad (2)$$

$$\sum_{t=EF_h}^{LF_h} t \cdot x_{ht} \leq \sum_{t=EF_j}^{LF_j} (t - d_j) \cdot x_{jt} \qquad j = 2,\ldots,J; h \in P_j \quad (3)$$

$$\sum_{j=1}^{J} \sum_{\tau=t}^{t+d_j-1} q_{jr} \cdot x_{j\tau} \leq Q_{rt} \qquad r \in R; t = 1,\ldots,\overline{T} \quad (4)$$

$$x_{jt} \in \{0,1\} \qquad j = 1,\ldots,J; t = 1,\ldots,\overline{T} \quad (5)$$

with the following notation

j : activity j, $j = 1,\ldots,J$, with 1 = single source, J = single sink

d_j : duration of job j

EF_j: earliest finishing time of job j

LF_j: latest finishing time of job j

r : renewable resource type $r, r \in R$

q_{jr} : per period resource consumption of renewable resource type r by job j

Q_{rt} : availability of resource type r in period t

P_j : set of immediate predecessors of job j

$\overline{T}$: end of planning horizon

x_{jt} : $\begin{cases} 1 & \text{if job } j \text{ finishes in period } t \\ 0 & \text{else} \end{cases}$

The objective function (1) minimises the project finishing time with T being the end of the planning horizon. Constraints (2) ensure that every job is processed once. Constraints (3) are precedence constraints of jobs with P_j denoting the set of immediate predecessors of job j. The duration of job j is represented by d_j. Constraints (4) limit the resource demand q_{jr} of the renewable resource $r \in R$ of jobs j

which are currently processed in order not to exceed the constant resource availability per period Q_{rt}. Finally, constraints (5) define the decision variable $x_{jt} \in \{0,1\}$ as binary, with $x_{jt}=1$ if job j ends in period t, 0 else.

The basic model can further be extended to integrate various objectives, such as the maximisation of the net present value and the consideration of multiple execution modes for a project activity (Multi-Mode RCPSP). Furthermore, it can be adjusted to schedule multiple projects simultaneously (RC multi-PSP) and stochastic as well as fuzzy information on resource availability and activity durations can be incorporated.

2.2.3 Strength of resource-constrained project planning

In particular, the strength of the RCPSP refers to the integrated time and capacity planning and the consideration of various resources. This is especially important, as construction projects are characterised by a high consumption of a heterogeneous mix of different equipment and labour. Furthermore, it is applicable in construction for a wide variety of objectives, which accommodates the various direct and indirect stakeholders of a construction project. The possibility to extend the constraints of the model allow for the consideration of externally given limitations, such as regulations on waste management. The explicit representation of possibilistic values for the duration and resource consumption of activities compensates the lack of knowledge on the exact distribution of these occurrences.

In the construction industry, first case studies about the appropriateness of the RCPSP for project planning were undertaken, for instance, by Tsubakitani and Deckro (1990) and Chiu and Tsai (2002). Tsubakitani and Deckro originally developed a heuristic for multi-project scheduling under constrained resources for a Japanese operating firm in the housing industry building approximately 6000 custom-order homes per year. Chiu and Tsai develop an efficient search procedure for the resource-constrained multi project scheduling problem with discounted cash flows and apply it to home building company in Taiwan. Additionally, a successful implementation of the RCPSP with multiple modes was given by Schultmann and Rentz (2002), who applied the model to deconstruction projects considering environmental constraints.

2.3 Materials Procurement

Project success not only depends on an efficient resource allocation during the scheduling of the project but also on a proper materials management. The construction materials management is based on the construction activities schedule denoting the time, the amount and the location at which construction material or components have to be made available (Ibn-Homaid 2002). The underlying problem is to shorten processing times and lower inventory costs by an efficient communication, information flow and cooperation between the partners of the Supply Chain (SC), i.e. by Supply Chain Management (SCM).

SCM can be defined as “… a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system wide costs while satisfying service level requirements.” (Simchi-Levi et al. 2002) Materials to which SCM could be applied are bulk materials which require stock on site and are consumed in roughly known but still variable amount as well as materials with known amount and specification, high value and high on-site space requirements. Examples for bulk materials are concrete, insulation materials, aggregate, lime, technical gases, cement. High value and materials which require large space on site are, for instance, construction steel and pre-cast concrete units.

Current logistics practice involves the construction or site manager sending an order to the purchasing department if stock of materials on site reaches a certain level (Sobotka 2000). This causes additional permanently occurring control effort for the observation of the stock level. This additional effort could be reduced, if the responsibility for the refilling of stock could be shifted to the suppliers within the construction SC. Techniques suitable are, for instance:

- just-in-time
- continuous replenishment, or
- vendor managed inventory.

Just-in-time, a delivery right at the time and to the place of consumption without the need for inventory on site, is already applied for, e.g. pre-cast concrete units for bridges. In contrast, approaches like continuous replenishment with defined delivery intervals and vendor managed inventory, where the responsibility for material availability is shifted to the supplier while simultaneously realising small inventories, have not yet been acknowledged. This is, however, remarkable as space on site is limited and on-site congestion is to be avoided due to the accessibility of the site, the building as well as for on-site safety.

3. Sustainable Deconstruction of Buildings

3.1 Construction Planning and Sustainability

Research about sustainability in construction has up to now mainly focussed on the design and construction phases, the sustainability of buildings materials and their recovery. However, the highest amount of construction and demolition (C&D) waste over the life cycle of the building occurs during deconstruction. Taking into account limited dumping capacities, the depletion of scarce resources (e.g. wood, metal and natural gravel), the increasing amount of energy and resource consumption for the production of building materials, and emissions and hazardous substances released into the environment, the development of sustainable construction has to be extended to the planning of deconstruction projects. Current project planning approaches, however, mainly address the planning of construction projects with respect to time and cost objectives only. Environmental objectives, as aimed at with the establishment of closed-loop supply chains, need to become integral part of project planning. Hence, project planning procedures as common in construction practice significantly need to be upgraded or innovated. If logistic activities are considered as part of project planning procedures these activities can be treated summarised under the term of reverse logistics.

3.2 Reverse Logistics in Construction

The motivation for construction companies to participate in the establishment of closed-loop material cycles is likely the same as in the manufacturing industry. Regarding profit–orientation a reduction of costs for disposal by selective deconstruction and separation of C&D waste can be realised. Additional gains are expected from the resale or recovery of valuable components and materials, for instance deconstructed aluminium framed windows, steel bars, wood, or bricks. Legislative pressure is put on the enterprises by construction specific legislation. This legislation comprises regulations for the handling of C&D waste. In Germany, this is mainly laid down in the European Council Directive 91/156/EEC (revised Framework Directive on Waste, amending Council Directive 75/442 EEC) and Council Directive 91/689 EEC on Hazardous Waste, amended by national legislation as the Recycling and Waste Management Act (Kreislaufwirtschafts- und Abfallgesetz: KrW-/AbfG) in Germany. While the first two drivers for reverse logistic tasks focus on economic and legal aspects, the third factor addresses the society and the fact that an enterprise depends on the “license to operate” issued by the people and institutions in its living environment. Due to environmental concerns, also construction enterprises face pressure to act according to the principle of sustainability, i.e. waste avoidance and reuse in order to foster resource preservation and emission avoidance. The “green image” gained by environmentally friendly business operations can help to win the favour of the public.

Reverse logistics is not only considered to comprise logistic activities to move products from the point of use to the point of disposition but the phases from product acquisition to remarketing, depicted in figure 1 (Fleischmann et al. 2000).

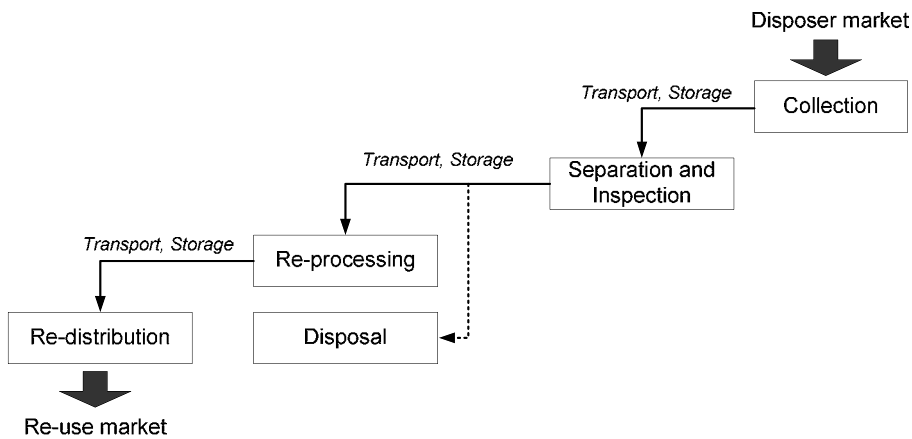

Figure 1 Stages of reverse logistics

Collection comprises all activities necessary to make products available and physically moving them to locations or facilities were further treatment takes place. Well known examples are the take back of electrical and electronic equipment as well as used batteries and cars (e.g. Daniel et al. 2003; Schultmann et al. 2006). Briefly, the collection includes the activities purchasing, transportation, and storage (Fleischmann et al. 2000). Inspection and separation includes all operations for the determination of the type of re-usability of a product. Therefore, the flow of used products is separated according to the various recovery or disposal options, e.g. inspection of goods for hazardous substances. The inspection and separation span disassembling, shredding, testing, sorting, and storing the products within the reverse logistic process. The recovery of a used product for further use in the same or another constitution is defined as re-processing. Re-processing or Recovering represent activities such as recycling, repair, or remanufacturing. Additionally, cleaning, replacement, and re-assembly activities are included. In comparison, disposal is applied to products not suitable for recovery due to technical or economic reasons; for instance, rejected products during separation level due to excessive repair effort or products without market potential due to their age. Thereby, disposal includes transportation, land filling, as well as incineration. After re-processing, products are re-distributed to the potential market place and future customers. Re-distribution encompasses the steps sales, transportation but also storage activities; e.g. sale of recycled materials or refurbished electronic equipment.

Furthermore, transportation and storage activity are usually required between each of the stages and are limited by a number of constraints, such as the availability and capacity of transport vehicles or storage space and inventory requirements. Thereby, transport and storage processes, like in the traditional manufacturing industry, also take place between all stages of reverse logistics in construction and significantly contribute to the complexity of the problem of establishing closed-loop construction supply chains. For deconstruction projects, two major fields of research were identified and are tackled in the following sections: (1) energy recovery from C&D waste and (2) material management in terms of logistic activities for the collection of C&D waste.

3.3 The Need for Deconstruction

In construction, major effort towards closed-loop material flows concentrated on the recovery of C&D waste from underground engineering. Problems occur with C&D waste and materials from the building construction sector arising during the deconstruction, modification or renovation of buildings.

Severe problems in deconstruction project planning occur when the building has not been designed and constructed with the intention to recover its used components and materials. Further complexity is added by the uncertainty of the composition of the buildings. As the recovery of components and materials depends on the deconstruction technique, deconstruction techniques have to be assessed for their ability to supply components and materials in a quality sufficient for the recovery purpose after the determination of environmental beneficial treatment of deconstruction waste.

However, although deconstruction and recovery generally permit the decrease of demolition waste which would otherwise be land-filled or incinerated, it can cause pollution and resource use which would not have occurred if the recovery of components and materials had not been processed. Hence, the various recovery options have to be weighted against the use of virgin raw or primary materials, and perhaps final disposal has to be preferred to recovery for the sake of environmental preservation when comparing the energy savings of the options. Schultmann and Sunke (2007) have developed an integrated deconstruction and recovery planning approach for deconstruction projects based on the multi-mode RCPSP mentioned before. They consider the energy embodied in construction materials and the advantageousness of recovery or disposal in dependency on the deconstruction technique to be employed. The application of quantitative planning models like the RCPSP thereby allows additionally considering external project constraints like time or budgeting limitations.

3.4 Collection and Handling of C&D Waste

The responsibility for C&D waste management in deconstruction projects is usually assigned to the general contractor, i.e. the construction enterprise or the responsible sub contractor. The aim of the contractor is to reduce disposal costs. This is usually realized by selective deconstruction and a high degree of C&D waste separation. After deconstruction and sorting, either the contractor delivers the waste to recovery facilities or disposal sites against a fee or directly contracts with a specialised reverse chain actor, e.g. a recycling company, who picks up the containers of C&D waste on site for money and resells, recovers or disposes the C&D waste itself. Thereby, the contractor usually sets orders (call services) to the waste management company to request pick up of C&D waste to avoid site congestion. As deconstruction projects are usually conducted using selective dismantling, i.e. C&D waste is separated right after deconstruction, the collection takes place as separate routing of shared resources. This means, that one vehicle collects one particular waste type, for instance wood or bricks. Additionally, in case of collection of C&D waste in containers, the delivery task of an empty container might be combined with the preceding pickup of a full container from the construction site. After the collection and transport to the recovery facilities or direct consumers in case of direct reuse, recovered components and materials are lead back into the material cycle, either as low quality material for road construction or as input for other production processes, such as glass or aluminium or insulation manufacturing.

Especially for reverse supply chain actors, the efficient transport of C&D waste is difficult. In contrast to the manufacturing, the location of the deconstruction sites is varying and usually the only accessible way is road transport mode. Hence, trucks with special equipment (for instance, special hangers to safely store deconstructed windows for resale) or container trucks are used. Thereby, also the composition of C&D waste hampers efficient reverse logistic activities. The size and quality of C&D waste is usually not standardised and the waste often contains unexpected hazardous substances. Deadheads cannot be avoided due to the missing planning certainty with respect to the forecast of the amount, place and time of the pick up of goods or collection from the construction sites and usually different role of the actor (a recycling plant usually does not deliver a deconstruction site with recovered components or recycled material). Instead, pick up tours have to be calculated every time an order is made by a contractor and complicated vehicle routing problems occur every time a new order arrives. Concluding, depending on the actors involved in reverse logistics processes in construction different networks of collection points (supply sources) and recovery facilities or disposal sites (demand points) for C&D waste exist. If third party service providers, like waste management companies (WMC), are authorized with the pick up and recovery or disposal C&D waste, numerous collection points (construction sites) exist and difficult transport problems, i.e. vehicle routing problems, occur. If the construction contractor itself is responsible for the collection and transport of C&D waste to the recovery facility or disposal site against some charge, easier network structures and planning problems occur. However, this situation is only evident for very small deconstruction projects usually processed by small construction enterprises, which are most commonly engaged in regional business and contracts with private persons. Therefore, also in construction common problems occurring are to be found in transportation activities, i.e. inefficient route planning and empty truck loads (Fleischmann et al. 2000).

For the collection of C&D waste it is necessary to develop an optimisation model which includes both the contractor's as well as the WMC's view. Due to the highly unstable planning environment and short time orders complex optimisation problems would arise. Hence, the decomposition of the resulting optimisation problem is advised. Two main planning problems can be differentiated in dependency on the material and actor:

- Construction contractor: determination of collection times and amounts for bulk C&D waste
- Waste management company: determination of optimal routing decision for specialised C&D waste

The objectives of the contractor as well as of the WMC are somewhat adverse. While construction contractors usually seek to have their site clean at minimum costs not exceeding maximum available space on site, WMCs try to minimise their transportation costs while servicing as many clients as possible. However, the contractor usually reports to the WMC when to pickup a certain amount of a waste type and does not pay respect to the available amount of vehicles and their related capacities of the WMC, i.e. the capacity utilisation of the WMC. Hence, the WMC can rarely define optimal routings for the vehicles nor can it properly assign vehicle capacities to contractor's orders in accordance to the available number of vehicles.

Methods from Operations Research can help tackle these problems. While in the first case, bulk material usually accumulates in such high amounts, that the vehicle capacity would be fully utilised, the WMC has the opportunity to service multiple deconstruction sites with one vehicle if the C&D waste consists of valuable or hazardous waste usually accumulating in low amounts. Especially the latter case can be depicted as a vehicle routing problem with time windows (VRPTW). In the VRPTW the contractor gives information on the amount and a possible time window for service while the WMC assigns its vehicles to the contractors to be serviced in accordance to its capacity.

4. Conclusion

The sketched planning problems in construction underline the need for an integrated consideration of the construction supply chain. Although the examples given rather highlight planning problems than present a solution, awareness is created for the need of a holistic consideration of the construction industry. Current practice usually differentiates between the different issues such as project planning, materials procurement and end-of-life aspects.

While the integrated time and capacity planning of the RCPSP serves the achievement of monetary and time objectives in construction projects, it can be extended and enriched with environmental aspects such as the selection of the most appropriate deconstruction technique for end-of-life considerations in construction to ensure proper material recovery. Furthermore, concepts of SCM from manufacturing industries can be applied to construction materials procurement and direct relations can be drawn to the collection of C&D waste at the end of the life time of a building.

To complement the problems addressed research effort in the future now has to investigate in detail, were the potential of the proposed solution approaches can be found and how they could be exploited.

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EVALUATION ON THE ENVIRONMENT FRIENDLY PERFORMANCE OF CONCRETE FROM THE VIEW OF CO_2 ABSORPTION

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Keywords: Carbonation, calculation of CO_2 absorption quantity, concrete, apartment

Summary

A cement which is used in construction and a concrete which is a hydration product of cement are considered anti-environmental materials because of lots of CO_2 emission in progress of producing and making it. But a concrete absorbs CO_2 gas in atmosphere from before and after hydration to its lifespan. It is called carbonation. Based on Papadakis' theses, this research is carried out to find out how to calculate of the CO_2 absorption quantity in concrete from the view of environment friendly performance. After research, we did an accelerated carbonation test for each specimen which has surface-finish. And then with using a carbonated depth and some equations, we calculated CO_2 absorption quantity in each specimens. At the conclusion, we simulate assessment income and outcome of CO_2 to an apartment building in Korea.

1. Introduction

1.1 Study background and objective

Recently, a rising in a temperature of atmosphere because of increasing CO_2 makes iceberg melted, as a result, it makes a level of the sea arise. This phenomenon is considered dangerous factor for people to live on in the future. So, all the nations are trying to reduce the quantity of CO_2 emission. By the way, a cement and a concrete which is used in construction need much energy to make and to produce them. Also they emit much CO_2 gas to the air. Therefore both materials are considered unfriendly-environmental ones. But people usually ignore that a concrete has a material that absorbs CO_2 in the air during its lifelong. And we call this phenomenon carbonation. That is enough to make people's thought change for the concrete from unfriendly one to friendly one.

Therefore, in this research we studied about method to calculate CO_2 absorption quantity in concrete theoretically through the carbonation. With using this method, we calculated CO_2 absorption quantity in specimens of concrete which has some kinds of surface-finishes and compared the absorption quantity according to surface-finishes in 100years. In the end, an assessment income and outcome of CO_2 to an apartment building were executed.

2. Reference study

Chemical reactions, models, equations and some datum which are used in calculation of CO_2 quantity refer to Papadakis' theses.[1),2),3)]

2.1. How to calculate CO_2 absorption quantity in carbonated concrete.

A mechanism of carbonation is well known to eq. (1). In this equation, we knew that $Ca(OH)_2$ is the only reactant related to carbonation. But under exiting moisture, reactants related to CO_2 in the air are C_3S, C_2S(before hydration), $Ca(OH)_2$, CSH.(after hydration).

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \qquad (1)$$

In order to calculating CO_2 absorption quantity in carbonated concrete, it is required to calculate these four reactants quantity. At first, the quantity of C_3S, C_2S like table 1 can be calculated with using oxide analysis[4] and Bogue's equations.[5] In this study, the concrete specimens are made of type I portland cements. So type I cement is only considered herein.

Table 1. Compound composition of Portland cements

Compound composition	Cement No.1 (%)
$C_3S(3CaO{\cdot}SiO_2)$	53.7
$C_2S(2CaO{\cdot}SiO_2)$	19.9
$C_3A(3CaO{\cdot}Al_2O_3)$	11.4
$C_4AF(4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3)$	8.8

After mixing, the molar concentration of each compound composition can be calculated as follows:

$$[i]_0 = \frac{m_i m_{cl} c}{MW_i} \qquad (2)$$

Where i refer to C_3S, C_2S, C_3A, C_4AF, m_{cl} is the weight fraction of clinker, c is the content of cement in 1m^3 concrete, MW_i is the molar weight of component i. MW_i of each compound composition refers to table 2. Like calculating [i], the molar concentration of gypsum as follows:

$$[C\bar{S}H2]_0 = \frac{m_{gy} c}{MW_{gy}} \qquad (3)$$

in which m_{gy} is the weight fraction of gypsum and the value is calculated by $m_{gy} = 1 - m_{cl}$.
At second, The molar concentration of $Ca(OH)_2$, CSH which is reactant with CO_2 can be calculated according to eq. (4)-(7).

$$\begin{aligned}[Ca(OH)_2]^0 &= \frac{3}{2}[C_3S]_0 + \frac{1}{2}[C_2S]_0 - 2[C_4AF]_0 F_{C_4AF}(t^*) - 4[C_4AF]_0(1 - F_{C_4AF}(t^*)) \\ &\quad - [C_3A]_0(1 - F_{C_3A}(t^*)) \\ &= \frac{3}{2}[C_3S]_0 + \frac{1}{2}[C_2S]_0 - 4[C_4AF]_0 - [C_3A]_0 + (2[C_4AF]_0 F_{C_4AF}(t^*) \\ &\quad + [C_3A]_0 F_{C_3A}(t^*)) \\ &= \frac{3}{2}[C_3S]_0 + \frac{1}{2}[C_2S]_0 - 4[C_4AF]_0 - [C_3A]_0 + [C\bar{S}H_2]_0 \end{aligned} \qquad (4)$$

$$[CSH]^0 = \frac{1}{2}[C_3S]_0 + \frac{1}{2}[C_2S]_0 \qquad (5)$$

$$[C_3S]^0 = 0 \qquad (6)$$

$$[C_2S]^0 = 0 \qquad (7)$$

Equation (4)-(7) are based on chemical reaction equation (8)-(13).

$$2(C_3S) + 6H \xrightarrow{r_{H,C_3S}} C_3S_2H_3 + 3CH \qquad (8)$$

$$2(C_2S) + 4H \xrightarrow{r_{H,C2_3S}} C_3S_2H_3 + CH \qquad (9)$$

$$C_4AF + 2CH + 2C\bar{S}H_2 + 18H \xrightarrow{r_{H,C_4AF}} C_8AF\bar{S}_2H_{24} \qquad (10)$$

$$C_3A + C\bar{S}H_2 + 10H \xrightarrow{r_{H,C_3A}} C_4A\bar{S}H_{12} \qquad (11)$$

$$C_4AF + 4CH + 22H \xrightarrow{r_{H,C_4AF}} C_8AFH_{26} \qquad (12)$$

$$C_3A + CH + 12H \xrightarrow{r_{H,C_3A}} C_4AH_{13} \qquad (13)$$

Among the equation (8)-(13), eq.(8)-(11) are reactions when the gypsum exists, eq.(12), (13) are reactions when the gypsum is used up. To calculate the hydration content of each compound, the time t^* when the gypsum is used up should be calculated. With using eq. (14)-(16), the value can be calculated.

$$F_i(t) = 1 - \frac{[i]}{[i]_0} = 1 - \left[1 - k_{H,i} t (1 - n_i)\right]^{1/1-n_i} \tag{14}$$

$F_i(t)$ is fraction of compound i, which has been hydrated at time t(in sec) after mixing.[1)] Every $F_i(t)$ can be calculated by substituting $k_{H.i}$,n_i for value in table 2. t^* is the time when gypsum is used up. So formula (15) means at time t^*, initial concentration of gypsum is equal to sum of terms in left side which multiplies concentration by Fraction. The second term in Eq. (15) is almost zero[1)]. Combined Eq.(14),(15), we can calculate the value t^* such as Eq.(16).

$$[C_3A] \cdot F_{C_3A}(t^*) + 2[C_4AF]_0 \cdot F_{C_4AF}(t^*) = [C\bar{S}H_2]_0 \tag{15}$$

$$t^* = \frac{1}{k_{H,C_3A}(1-n_{C_3A})}\left[1 - \left(1 - \frac{[C\bar{S}H_2]_0}{[C_3A]_0}\right)^{(1-n_{C_3A})}\right] \tag{16}$$

The process of concrete carbonation can be described by eq.(17)-(20).

Table 2. Parameters of major constituents of ordinary Portland cement[1)]

	C_3S	C_2S	C_4AF	C_3A	$C\bar{S}H_2$
Exponent n_i, Eq. (9)	2.65	3.10	3.81	2.41	-
Coefficient $k_{H,i}$ (20C)×10^5(s^{-1}), Eq. (9)	1.17	0.16	1.00	2.46	-
Molar weight MW*10^3(kg/mol), kg/mol	228.3	172.22	485.96	270.18	172.17

$$Ca(OH)_2 + CO_2 \xrightarrow{r_{CH}} CaCO_3 + H_2O \tag{17}$$

$$3CaO \cdot 2SiO_2 \cdot 3H_2O + 3CO_2 \xrightarrow{r_{CSH}} 3CaCO_3 \cdot 2SiO_2 \cdot 3H_2O \tag{18}$$

$$3CaO \cdot SiO_2 + 3CO_2 + \cdot rH_2O \xrightarrow{r_{C_3S}} SiO_2 \cdot rH_2O + 3CaCO_3 \tag{19}$$

$$2CaO \cdot SiO_2 + 2CO_2 + \cdot rH_2O \xrightarrow{r_{C_2S}} SiO_2 \cdot rH_2O + 2CaCO_3 \tag{20}$$

The calculation of carbonation depth as follows:

$$x = \sqrt{\frac{2 \cdot D_e^c \cdot [CO_2]^0}{[Ca(OH)_2]^0 + 3[CSH]^0 + 3[C_3S]^0 + 2[C_2S]^0}}\sqrt{t} \tag{21}$$

Where, $[Ca(OH)_2]^0 + 3[CSH]^0 + 3[C_3S]^0 + 2[C_2S]^0$ is the content of CO_2 absorbed in 1 m^3 concrete. (mol/m^3)

$$D_e = 1.64 \times 10^{-6} \cdot \varepsilon_p^{1.8} (1 - \frac{RH}{100})^{2.2} \tag{22}$$

$$[CO_2]^0 = \frac{P_{CO_2} V}{RT_0} = \frac{C_0 \cdot 1000}{0.08206 \cdot 298} = 40.89 C_0 \tag{23}$$

$[CO_2]^0$ is a molar concentration of CO_2 in atmosphere, T=25℃, R=0.08206 is constant, C_0 is equal to 0.03% (CO_2 content in atmosphere).

3. Evaluation for the resistance of concrete which has various surface-finishes.

3.1 Experiment Plan

Each surface-finish was constructed on the surface of concrete whose size is 100mm×100mm×400mm such as table 3. Constructed specimens were carbonated in acceleration condition like table 3. And the carbonated depth of each specimens were estimated according to terms of carbonation.

Table 3. Experimental factor and outline

	Surface finishes	Material depth (mm)	Term of carbonation	Acceleration Condition
1	No finish	×	7day 14 day 28 day 42 day 70 day	- Concentration of CO_2: 10% - RH: 40% - Temperature: 20℃
2	Water Repellent	0.1		
3	Water paint	0.2		
4	covering material	0.5		
5	Recovering material	10		
6	Remitar	10		
7	Bon-tile	0.5		

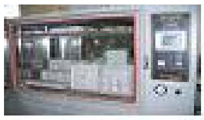


Table 4. Mixing proportion of concrete

W/C (%)	S/a (%)	Unit weight (kg/㎥)				
		W	C	S	G	AD
55	50	181	326	895	890	1.63

3.2 Experiment Result

3.2.1 Measurement of carbonated depth in concrete which has various surface-finishes.

After experiment, carbonated depths according to materials are like Figure 1. From term and carbonated depth, eq.(23), the value A can be calculated. And using eq.(24),(25), we can change the value A(accelerating condition) into A_{air}(general air condition). The changed values are like table 5, with using these, we estimated the carbonation depth after 100years.

$$x = A\sqrt{t} \qquad (23)$$

In which, x is a carbonation depth(mm), t is accelerating term(week). A is carbonation velocity coefficient.

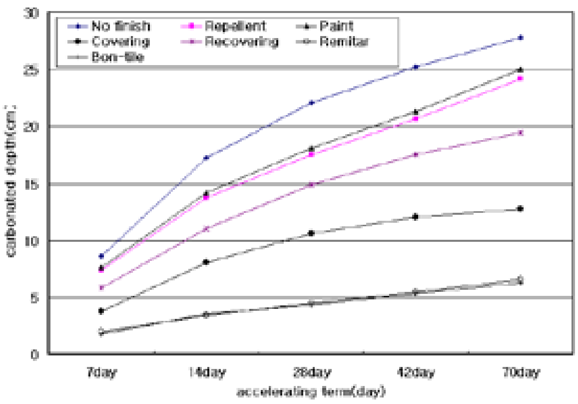


Figure 1. Carbonated depth according to materials

$$A_{STD} = A_{size} \cdot A_{mcure} \cdot A_{icure} \cdot A_{idry} \cdot A_{Tem} \cdot A_{CO_2} \cdot A_{Hu} \qquad (24)$$

A_{STD} is a carbonation velocity coefficient in standard carbonation condition. With using eq. (24), A_{STD} can be calculated.[6)]

Table 5. Calculation of velocity coefficient according to conditions and estimating carbonation depth.

	No finish	Bond-tile	Remitar	Recovering	Covering	Paint	Repellent	unit
A(20℃, RH: 40%, CO_2:10%)	3.33	0.78	0.93	1.76	2.31	2.87	2.88	
A_{STD}(20℃, RH: 60%, CO_2:5%)	5.89	1.38	1.64	3.11	4.08	5.07	5.09	$\frac{mm}{\sqrt{year}}$
A_{air} (CO_2:0.03%)	8.73	2.02	2.45	4.62	6.06	7.5	7.5	
Carbonation depth in 100yrs	87.3	20.2	24.5	46.2	60.6	75	75	mm
CO_2 absorption quantity	100.5	23.3	28.2	53.2	69.8	86.4	86.4	g

$$x = A_{air}\sqrt{\frac{CO_2}{5}} \cdot \sqrt{t} \qquad (25)$$

A_{air} is a carbonation velocity coefficient in general air condition. With using eq. (25), A_{air} can be calculated.[6),7)]
Eq.(23)-(25) refers to reference (6),(7).
After experiment 3.2, we found that Bon-tile is the most resistant surface-finishes against carbonation, and the resistant function of Paint and Repellent against carbonation is poor among them.

3.2.2 Calculation CO_2 absorption quantity in carbonated concrete and comparison the result.

With using datum in table 5, CO_2 absorption quantity in carbonated concrete according to surface-finishes was calculated and the result is in table 5.

From this result, after 100years, the specimens whose section size is 100mm×100mm is to absorb CO_2 in the air is like figure 2. With no doubt, no finish specimen is to absorb CO_2 most among them, and the absorption content of CO_2 is about 100.5g. Bond-tile which has the most resistance against carbonation absorbs about 23.3g of CO_2. This value is one-fifth one of concrete with no finishes. The more surface-finishes have resistance against carbonation, the smaller concrete absorbs CO_2.

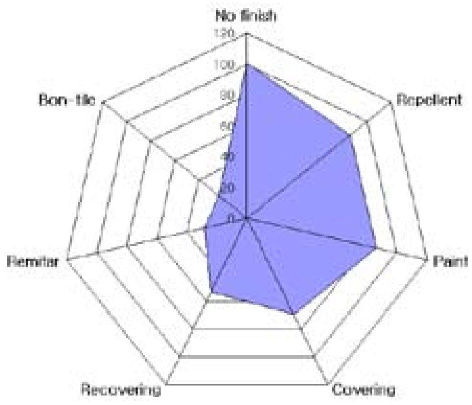


Figure 2. CO_2 absorption quantity according to finishes after 100 years (unit:g)

3.2.3 How to calculate CO_2 emission quantity

CO_2 emission quantity to produce concrete can be calculated by using datum of concrete component that indicate emitted CO_2 quantity when they were produced. Table 6 shows that how much each component emit CO_2(kg-CO_2) when they were used(m^3). Therefore, if the amount of concrete that was used in producing building, CO_2 emission quantity to a building can be calculated with using this table and concrete mix table.

Table 6. CO_2 emission quantity to concrete components when they used in amount of m^3 (Unit : kg-CO_2/m^3)

Component	Water	Cement	Fly ash	Fine Aggregate	Coarse Aggregate	AE reducing water agent
kg-CO_2/m^3	-	0.7466	0.6197	0.0037	0.0028	0.25

3.2.4 Assessment income and outcome of CO_2 to a real apartment.

3.2.4.1 Calculation CO_2 emission quantity

To an apartment whose plan is like figure 3, considering concrete strength to each story zone like table 7, with using and calculating amount of a concrete mix table according to strength(table 8), CO_2 emission quantity was calculated and the result is table 9,10.

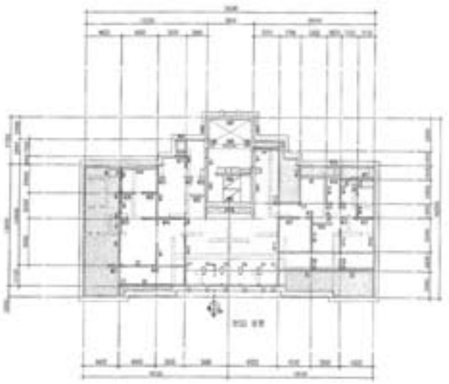


Figure 3. Base floor plan

Table 7. Calculation amount of concrete to strengths (m^3)

Story	Column+Wall	Slab	Total	Strength(MPa)	W/C(%)
Basement 1st	185.96	0.00	185.96	35	39
1st~ 9th	178.40	155.73	334.13		
10th~19th	178.40	155.73	334.13	30	43
20th~26th	178.40	155.73	334.13	27	46
27th~32th	178.40	155.73	334.13	24	50
Roof floor	152.90	58.27	211.17		
Penthouse 1st	191.06	33.23	224.29		
Penthouse 2st	25.61	9.19	34.80		

Table8. Mix table to strengths (kg)

MPa	W/C (%)	B/S	W	C	F/A	S	G	AE Reducing agent
24	50	0	174	304	45	848	944	2.09
27	46	0	175	328	49	832	934	2.64
30	43	0	178	348	61	797	935	3.07
35	39	0	179	394	69	759	926	3.7

Table 9. CO_2 emission quantity to strengths per m^3

MPa	W/C(%)	CO_2 emission quantity per m^3 (kg-CO_2/m^3)
35	39	342
30	43	303
27	46	281
24	50	261

Table 10. CO_2 emission quantity to strengths

strength	CO_2 emission quantity (kg-CO_2)	
35MPa	1,152,689	**3,527,227**
30MPa	1,013,033	
27MPa	657,102	
24MPa	704,405	

3.2.4.2 Calculation CO_2 absorption quantity

To calculate CO_2 absorption quantity to the apartment, it is required to know surface area exposed to air, carbonation depth to time. To estimate carbonation depth, time should be defined. In this study, 40, 60, 80 years are considered. Carbonation depth to each strength was estimated by using equation proposed by Ko Kyung Taek(Fig.4) and the results are like table 12. And amounts of concrete to strengths and planes according to story are like table 11. And surface area to strength are like table 13. CO_2 absorption quantity to strength in time are like table 14. Molar concentration of CO_2 to each strength are like table 15. With using these datum, CO_2 absorption quantity can be calculated and figure 5, equation 26 shows the concept to describe how to calculate it.

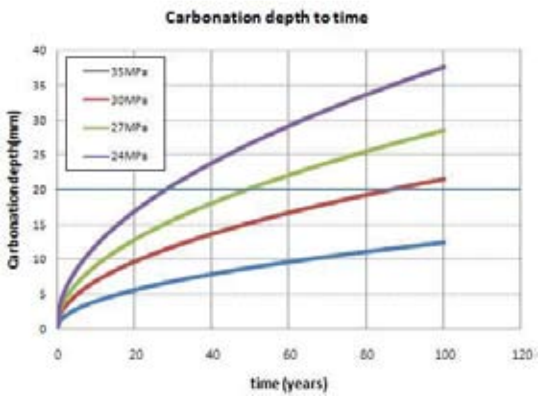


Figure 4. Carbonation depth to strength in time

Table 11. Amounts of concrete to strengths, planes(m^3)

Story	Left Wall	Rear Wall	Right Wall	Front Wall	Slab	Inner Wall	strength (MPa)
basement	0	0	0	0	596.15	947.00	35
1st	0	0	0	0	596.15	549.26	
2nd	53.22	60.96	53.22	76.53	596.15	631.88	
3rd	54.13	62.01	54.13	77.85	596.15	642.78	
4th	53.22	105.10	53.22	105.10	596.15	1123.98	
5th	53.22	105.10	53.22	105.10	596.15	1116.44	
~10th	53.22	105.10	53.22	105.10	596.15	1116.44	30
~20th	53.22	105.10	53.22	105.10	596.15	1116.44	27
~27th	53.22	105.10	53.22	105.10	596.15	1116.44	24
~32th	60.56	119.59	60.56	119.59	596.15	1355.05	
Roof	50.32	98.08	61.63	98.08	596.15	484.91	
Penthouse	50.32	73.37	50.32	73.37	596.15	292.32	

Table 12. Carbonation depth to strength in time

strength	40years	60years	80years	unit
35MPa	0.00784	0.0096	0.01109	m
30MPa	0.01367	0.01674	0.01933	
27MPa	0.01804	0.0221	0.02552	
24MPa	0.02387	0.02924	0.03376	

Table 13. Surface area to strength

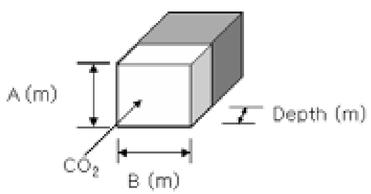
Strength	Surface area	unit
35 MPa	17,830	m^2
30 MPa	20,292	
27 MPa	14,204	
24 MPa	14,386	

Table 14. CO_2 Absorption quantity to strength in time

Strength \ times	40yrs	60yrs	80yrs	unit
35MPa	19,460	23,828	27,527	kg-co_2
30MPa	34,107	41,767	48,229	
27MPa	29,696	36,380	42,010	
24MPa	36,885	45,183	52,167	
Total	**120,148**	**147,158**	**169,932**	

Table 15. CO_2 molar concentration to strength

strength (MPa)	CO_2 molar Concentration	unit
35	3,164	mol/m^3
30	2,794	
27	2,634	
24	2,441	



$$m_{CO_2} = [CO_2] \times A \times B \times Depth \times 44 = \frac{mol}{m^3} \times m \times m \times m \times \frac{g}{mol} = g \quad (26)$$

Figure 5. Calculation CO_2 absorption quantity

3.2.4.3 Assessment income and outcome of CO_2 to an apartment in times

The amount of CO_2 emitted to produce this building was calculated and the the result are like table 10. And the amount of CO_2 absorbed in concrete was calculated in 40, 60, 80years and the result are like table 14. Therefore, using these two result and equation (27), income and outcome of CO_2 to an apartment in times 40, 60, 80 years can be assessed quantitatively. And the ratio of absorption to emission can be calculated using the equation (28). And the result are like figure 6,7, table 16.

income and outcome of CO_2 = emitted CO_2 – absorbed CO_2 (27)

Ratio of absorbed CO_2 to emitted CO_2 (%) = absorbed CO_2 / emitted CO_2 × 100 (28)

Table 16 Assessment result of income and outcome of CO_2

contents / time	40yrs	60yrs	80yrs	unit
emitted quantity		3,527		
absorbed quantity	120	147	169	kg-co$_2$
(emitted - absorbed) of CO_2	3,407	3,380	3,357	
ratio of emitted to absorbed of CO_2	3.4	4.17	4.81	%

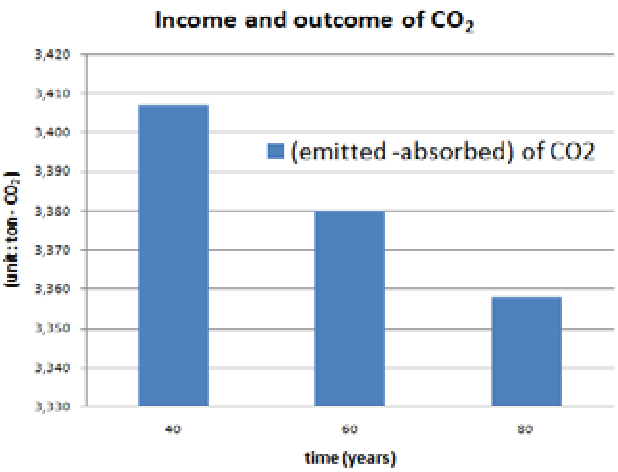


Figure 6. Result of income and outcome of CO_2

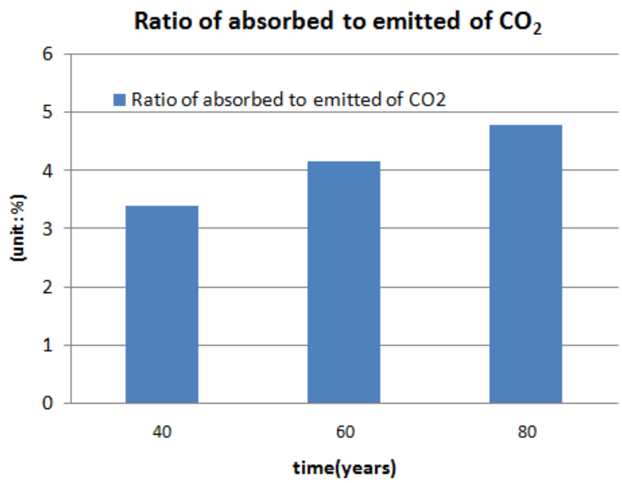


Figure 7. Result of ratio absorbed to emitted of CO_2

After assessment income and outcome of CO_2, the amount of concrete that was used in building apartment will absorb about 5% to emitted CO_2. This figure may be thought to be very small amount. But this study is important to evaluate the amount of absorbed and emitted CO_2 quantitatively. Besides this study is important in that these result can change people's thought to concrete that is an unfriendly-material. In another research[8)], there are another try for concrete to absorb CO_2 much more by increasing surface area of concrete after its demolition by crashing it in northern Europe countries. Therefore in further study, it is important to consider and study increasing surface area of concrete exposed to the air.

Conclusions

In this study, we studied how to calculate CO_2 absorption quantity in carbonated concrete and we did an experiment that which surface-finishes has more resistance against carbonation, compared with other specimens. And emission of CO_2 when $1m^3$ of the concrete was produced was calculated with using reference. Finally, with using these method, emitted and absorbed of CO_2 in the concrete was calculated to an apartment building.

From this study, conclusion are as follows:

1) Absorption and emission quantity of CO_2 can be calculated quantitatively.

2) Restraining effect of surface-finishes against carbonation can be also calculated and compared among them.

3) Using building longer is also another important factor because the amount of emitted CO_2 is much more than that of absorbed CO_2 when a concrete was used the amount of $1m^3$.

4) The surface area of concrete is a important factor to increase the amount of absorption CO_2.

5) After building demolition, it is required to use crushed concrete actively because they have so much larger surface area that can absorb CO_2 in the air with time.

Acknowledgement

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MATERIAL EFFECTIVE STRUCTURES – THE WAY TOWARDS SUSTAINABLE BUILDINGS

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Summary

Development of progressive materials, structures and technologies for sustainable buildings is based on the struggle for the reduction of primary non-renewable material and energy resources, while keeping safety and durability of the structure on the required high level. Material effective structures for buildings can be based on several structural principles and their combinations: optimization of structural form, use of recycled waste materials, use of natural and renewable materials, use of composite and high performance materials. New composite high performance silicate materials can be used for thin "shell" elements enabling design with significantly reduced use of materials and leading to reduction of environmental impacts. Several preliminary research results followed by applications in construction practice showed already possibilities of the reuse of waste materials (preferably from municipal waste) for lightening fillers used in optimized concrete structures. Experimental investigation and case studies performed by authors in the frame of long term research, focused to environmental optimization of building structures, support the expectation that it will be possible to reach factor 3 or even more while keeping structural reliability on the needed high level. Developed structural concepts have been proved not only by theoretical and experimental results, but also by practical application in construction of several buildings.

1. Background

During the twenty years from 1974 to 1994 the world population increased by 40%. Cement and steel production and municipal waste generation are increasing even faster (Hajek 2006) (Fig. 1).

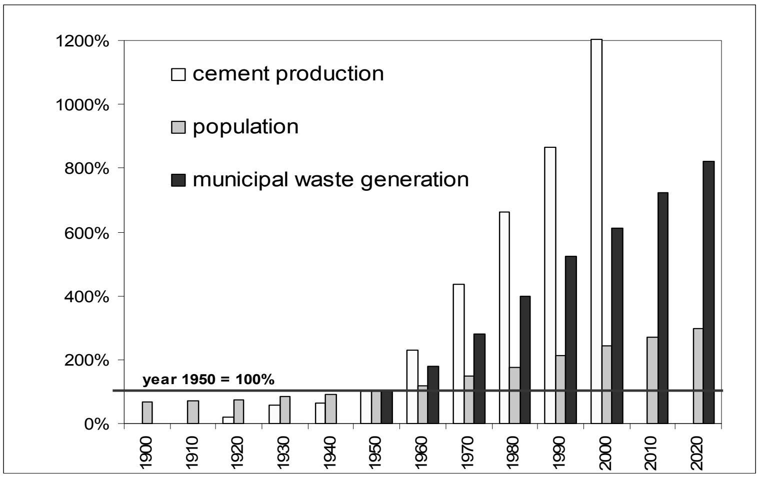


Figure 1 Tendencies of cement production and generation of municipal waste (OECD data) are compared with the population growth and its expected development up to the year 2020

The need for material saving was clearly specified in general Rio Agenda 21 (Changing Consumption Patterns) published in 1992: "To promote efficiency in production processes and reduce wasteful consumption in the process of economic growth".

Buildings in EU and other developed countries are responsible for more than 40% of the total energy consumption, and the construction sector generates approx. 40% of all man-made wastes (CIB 1999). The extraction of raw materials for construction of buildings, manufacturing of building products and waste landfill or incineration are associated with corresponding environmental impacts, including greenhouse gas emissions. Buildings are thus consequently responsible for more than 30% of released CO_2 emissions.

Development of new materials, structures and construction technologies for construction of buildings should be thus based on the struggle for the reduction of primary non-renewable material and energy resources, while keeping performance quality, safety and durability on a high performance level.

Performance quality and safety of construction in all its life cycle stages, including exceptional situations (natural disasters, explosions, fires, etc.) comes to prominence in the hierarchy of the design criterion importance. This is also due to the increasing risk level resulting from the rise of exceptional situations caused by global climatic changes, as well as terrorist attacks.

Both, the requirements, (i) the reduction of material consumption (leading to more slender structures) and (ii) the increase of performance quality, reliability, durability and safety can be at first sight considered as being in contradiction. Using traditional construction materials and technologies, the typical result of the effort to ensure a higher level of structural reliability and safety is the robust structure (which needs more construction materials). However, using high performance materials it is possible to design more slender structures, while performance quality, structural reliability and safety is kept at the required high level.

2. Optimization of material consumption in building structures

The problem of sustainability of structures is very complex and includes a large number of parameters and criteria from different areas of technical as well as non-technical sciences. One of the most important criteria in the optimization of load bearing structures is consumption of non-renewable materials and associated consequences during the whole life cycle of the structure (transport and manipulation with material during construction, demolition, recycle ability etc.).

Material effective structures (with reduced amount of structural material) can be based in general on several structural principles and their combinations:

- optimization of structural form and shape of structural elements,
- use of high performance silicate materials,
- use of recycled waste materials (including municipal waste),
- use of renewable materials.

The reduction of primary non-renewable resources and consequent reduction of waste amounts can also be achieved by the use of waste from construction, as well as other industries as a secondary material for production. Some secondary materials (such as fly-ash, silica fume, slag, etc.) can be used in production of new concrete. The initial optimization steps, covering the use of the ribbed or waffle shape and use of recycled materials, result in the reduction of embodied values (CO_2, SO_2, energy). The cut in consumption of natural (non-renewable) sources (limestone, granite, oil, etc.) is evident, and can be very significant.

2.1 Optimization of structural form and shape of structural elements

The typical outcome of the shape optimization of the concrete structure with the objective to reduce structural material consumption (while high level of reliability is kept) is the ribbed or waffle structure. The basic structural advantages of waffle and ribbed elements are demonstrated in the layout of the structural material in a cross-section. The “T” shape of RC ribs allows a convenient distribution of the structural material, saving material in the tension part of the section. In comparison with the full RC slab, the basic shape of waffle or ribbed slab structures reduces concrete use by 40-55%, and also the corresponding steel use. Consequently, the reduction of the total self-weight acting on vertical bearing structures and foundations can decrease their sizes.

Due to their shape, the reinforced concrete waffle and ribbed structures represent the effective types of structures given by the relation between the material consumption and structural characteristics. This principle is traditionally applied in construction of floors (e.g. ribbed and waffle RC slabs) and walls (e.g. timber framed structure) and could be thus used in sustainable optimized design.

2.2 Use of high-performance silicate materials

The process of optimization of structures from silicate materials (different types of concrete, ceramics, geopolymers) is generally based on the following principles:

- optimization of production technologies of components,
- optimization of concrete mix composition,
- optimization of the shape and reinforcement of structural elements,
- life cycle optimization of the whole structure

There is a good chance to achieve the required reduction of primary material sources and simultaneously the increase of structural reliability and safety (mainly in the case of exceptional load cases) by the use of new high performance fiber concrete (with optimized mechanical properties) in an optimized shape of the structure (which uses less structural material in a cross section in a more efficient way).

Using new types of composite materials with programmed mechanical properties, it is possible to achieve significant improvements in environmental parameters of the structure. This can be achieved mainly by the design of more slender shell structural forms saving primary resources and by the reduction of environmental impacts from depositing and recycling the structure at the end of its life cycle.

Several examples from abroad show, that new composite fiber silicate materials and corresponding technologies can be used for realization of thin "shell" elements with the thickness less than 30 mm (e.g. Ductal – France).

2.3 Use of recycled waste materials

Building construction typically uses large amounts of materials in relatively less demanding techniques. Therefore, there is a high potential for the use of secondary materials obtained from recycling of waste generated by other industrial processes and from municipal waste (Hajek 2006). This approach permits to keep materials in the material cycle longer (considering usually longer service life of the building compared to the service life of the primary product disposed in municipal waste). This results in reduction of consumption of primary material sources and reduction of waste generation and emissions including GHG emissions. Using recycled materials including recycled municipal waste it is possible to keep once used primary material in a many times longer life cycle, and therefore considerably support saving of natural resources.

The main concern should be paid to those waste materials which are produced in large amounts and just a small amount is recycled. Such waste materials are e.g. non-sorted plastics (yellow collecting containers) and laminated carton drink boxes from municipal waste.

The technical value of recycled material is often lower than that of the material when first used in the primary product (down-cycling). Preference should be given to the high-value reuse of recycled materials replacing high-quality primary non-renewable raw materials. In some specific cases, new products from recycled waste can have a higher performance value in comparison with the primary product (up-cycling).

The most of plastic waste and drink boxes from laminated paper are still as a part of mixed municipal waste incinerated with all consequential negative environmental impacts. However, separated salvage of municipal waste particles (plastic, glass, paper, laminated carton) is becoming common in developed countries.

Further recyclability of the newly developed construction with recycled waste materials represents an important aspect that has to be considered. A feasible, effective and environmentally-sound recycling technique should be available for the specific case to avoid the necessity and uncertainty of development of a special recycling procedure. Preferably, the technology process should not limit the number of recycling cycles. An example in Figure 2 shows the potential of use of recycled plastic from throwaway plastic drink bottles for production of plastic shell elements to be used as a permanent formwork in construction of ribbed or waffle RC floor slabs. The utility period of primary raw material could be thus prolonged several thousand times in comparison with waste disposal (incineration) of used plastic bottles in non-sorted municipal solid waste.

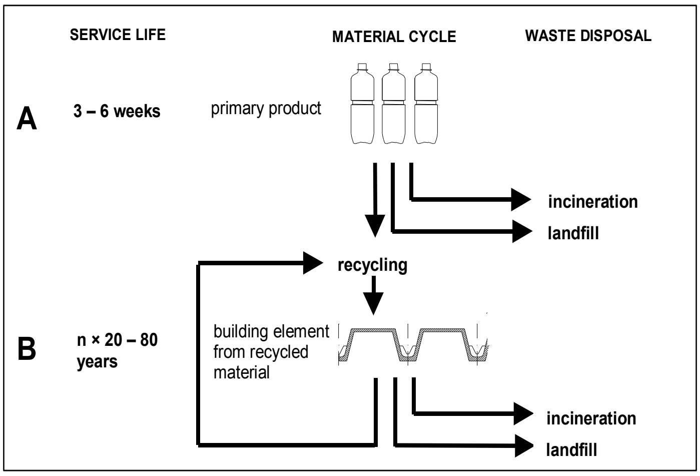


Figure 2 Life cycle of plastic throwaway bottles. A – without material recycling – lifetime 3 – 6 weeks, B – recycled plastic is used for production of building elements – lifetime n x 20 – 80 years

Another material that utilizes waste products is geopolymer concrete. Geopolymer concrete is formed by the alkali activated polymerization of aluminosilicates. Fly ash or granulated blast furnace slag (GBFS) are used as cementitious materials instead of Portland cement. There are two motives for replacement of Portland cement in concrete. Firstly, its production consumes large amount of energy (3.7MJ per kg) and secondly, there is a need for utilization of waste materials that are recently being dumped in landfills. Geopolymer concrete gives significant carbon dioxide emissions reduction while having some excellent properties such as high strength, durability and acid resistance. The disadvantage of this material is that efflorescence can appear on its surface as a result of leaching alkalis reacting with atmospheric carbon dioxide and forming carbonates.

2.4 Use of renewable materials

There is a wide range of possible applications in building construction for renewable materials. The use of wood, wooden based materials, clay unburned bricks and or non-traditional natural materials like palm tree fronds, bamboo etc. leads to reduction of environmental impacts, including savings of natural non-renewable natural materials. Especially wood is due to its properties and availability the most challenging material. However, the utilization of wood and wooden based materials is limited by fire safety, strenght and durability and thus large multistory buildings, buildings for heavy industry or transport will be still dominantly built from more strong and more fire resistant materials like concrete or steel.

3. Comparison of environmental profiles of building structure alternatives

Two presented case studies – one comparing alternatives of RC floor slabs, the second comparing alternatives of external walls - show the potential for reduction of environmental impacts by optimization of material concept of basic structural components. The alternatives have been designed for the same performance quality (spans, imposed load, flat surface etc.). The results show differences associated just with the structural alternatives themselves. However, several additional savings can be expected in supporting structural elements (columns, walls, foundations) due to lower self weight of optimized lightened structures. Further savings in the case of lightened alternatives is in construction and demolition phase due to lower transport demands.

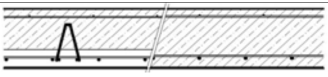
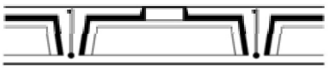
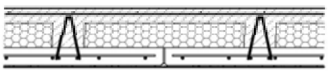
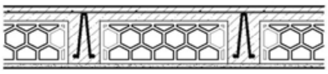
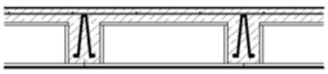
Evaluation of environmental impact of any structure is highly determined by the quality of available data. There is no standard data set of unit embodied values for all components used in construction. In the both analyses was used data set updated according to currently published Passivhaus-Bauteilkatalog by Waltjen (2008). These data were used in the following studies for evaluation of embodied energy, embodied CO_2 and embodied SO_2. Unit embodied values for recycled non-sorted plastic were calculated using energy and production statistical data provided by recycling company Transform a.s. The data used for UHPC (Ultra High Performance Concrete) were taken from Schmidt (2007).

3.1 Case study 1: Environmental assessment of selected alternatives of RC floor structures

Several previously performed LCA (Life Cycle Assessment) analyses of RC floor structures showed that using the optimized shape and recycled materials it was possible to reduce environmental impacts, such as consumption of non-renewable silicate materials, the resulting level of embodied CO_2, embodied SO_x and embodied energy. Some results of previous LCA analyses have already been presented by Hajek (2006 and 2007). The goal of the current analysis is to show how the use of different material base and optimized shape of an RC floor slab can contribute to the reduction of environmental impacts.

In total, six alternatives of RC floor structures have been analyzed. All alternatives were designed for the same performance – live load 2.0 kN/m^2, span 4.5 m, same thickness 200 mm and final flat ceiling finish. The overview of all the analyzed alternatives is presented in Table 1.

Table 1 Floor slab alternatives used in the environmental analysis

Floor slab alternative			Self-weight Kg/m^2
A		composite / monolithic full RC slab from ordinary concrete	478
B		precast RC panel with lightening shell elements from recycled non-sorted plastic	302
C		precast UHPC panel with lightening shell elements from recycled non-sorted plastic	212
D		composite floor slab with filligran panels and lightenning fillers from polystyrene	305
E		RC ribbed floor slab with ceramic hollow core fillers	311
F		RC ribbed floor slab with lightening fillers from recycled laminated carton boards	213

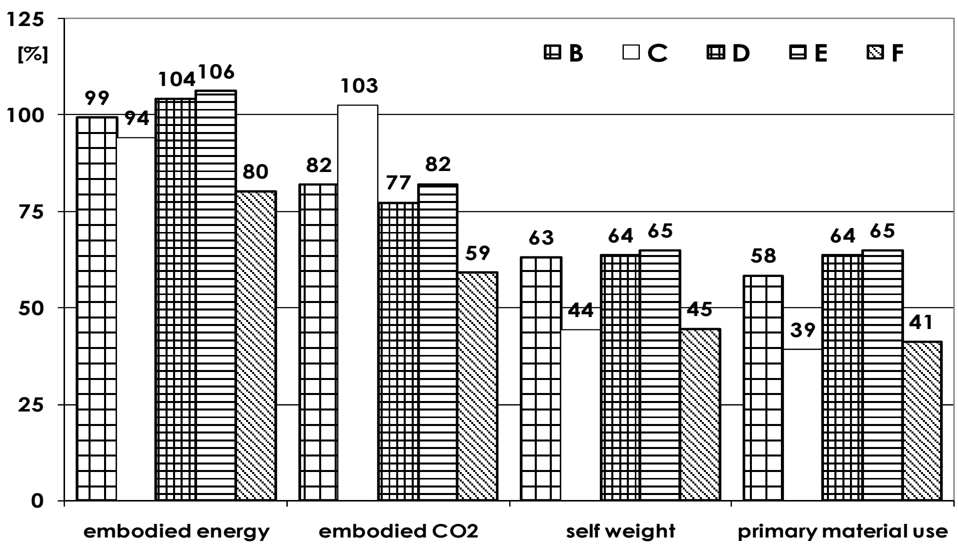


Figure 3 Comparison of environmental parameters of RC floor slab alternatives. Reference level 100% is represented by a full RC floor slab – alt. A

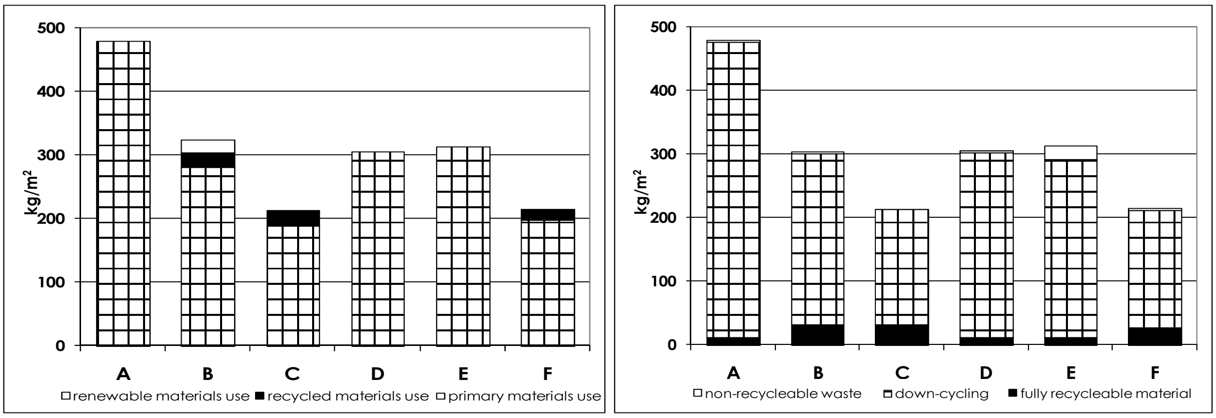


Figure 4 Input and output material flows for analyzed RC floor slab alternatives

Fig. 3 and 4 present graphs showing potential savings of environmental impacts. The reduction can be in some cases more than 50 %. These results cover just the floor structure itself. More savings are associated with the reduced use of material (savings in transport) and lower load from lighter structure acting on supporting structures (columns, walls, foundations). From this point of view major savings will be for alternatives C and F.

3.2 Case study 2: Environmental assessment of selected alternatives of external walls

The basic idea of this case study was a complex comparison of different external wall structures that are more or less typical for family and residential houses. All designed structures have the thermal performance set to recommended U values according to the Czech national standard ČSN 73 0540-2, Thermal protection of buildings - Part 2: Requirements. This means that the structures with weight per unit area over 100 kg/m^2 have the U value set to 0.25 W/m^{2}K, the structures with weight per unit area less than 100 kg/m^2 have the U value set to 0.20 W/m^{2}K.

All the structures are designed with ETICS (External Thermal Insulating Composite System) which consists of mineral wool thermal insulation and a thin silicate glass-fiber reinforced plaster (except alternative 8 which uses porous wood fiberboard as an insulation). The decision to use mineral wool as the thermal insulation have several reasons. Namely the perfect fire resistance enabling universal use, better water vapor permeability, and finally a good sound proofing. Concerning the load bearing part of the structure, there are several types of massive structures i.e. reinforced concrete wall (1), concrete hollow block wall (2), aerated concrete block wall (3), calcium silicate block wall (4), and honeycomb brick (5) wall and also lightweight structures i.e. load-bearing laminated wood panel (6), timber frame panel with mineral wool insulation (7), and another timber frame panel with cellulose fiber insulation (8).

Table 2 Exterior wall alternatives used in the environmental analysis

	Exterior wall alternative		**Thickness** mm	**Weight per unit area** kg/m^2
1	Reinforced concrete wall with ETICS *	Interior plaster, Reinforced concrete wall 150 mm, ETICS (mineral wool 170 mm, silicate glass-fiber reinforced plaster)	334	403
2	Concrete hollow block wall with ETICS *	Lime cement plaster, concrete hollow block 250 mm, ETICS (mineral wool 140 mm, silicate glass-fiber reinforced plaster)	410	346
3	Aerated concrete block wall with ETICS *	Lime cement plaster, aerated concrete block 250 mm, ETICS (mineral wool 120 mm, silicate glass-fiber reinforced plaster)	390	207
4	Calcium silicate block wall with ETICS *	Lime cement plaster, calcium silicate block 250 mm, ETICS (mineral wool 160 mm, silicate glass-fiber reinforced plaster)	430	483
5	Honeycomb brick wall with ETICS *	Lime cement plaster, honeycomb bricks 240 mm, ETICS (mineral wool 150 mm, silicate glass-fiber reinforced plaster)	424	258
6	Laminated wood panel with ETICS *	Laom plaster 30 mm, laminated wood panel 100 mm, ETICS (mineral wool 130 mm, silicate glass-fiber reinforced plaster)	270	128
7	Timber frame panel with ETICS */**	Gypsum plasterboard 12,5 mm, OSB panel 18 mm, timber studs 60/150 mm filled with mineral wool, MDF panel 15 mm, ETICS (mineral wool 60 mm, silicate glass-fiber reinforced plaster)	260	64
8	Timber frame panel with ETICS (wood-fiber board) */**	Loam plaster 30 mm, OSB panel 18 mm, timber studs 60/150 mm filled with cellulose fibers, MDF panel 15 mm, ETICS (wood fiberboard 60 mm, silicate glass-fiber reinforced plaster)	278	85

* ETICS - External Themal Insulating Composite System; ** U = 0,20 W/m^{2}K; in other cases U = 0,25 W/m^{2}K

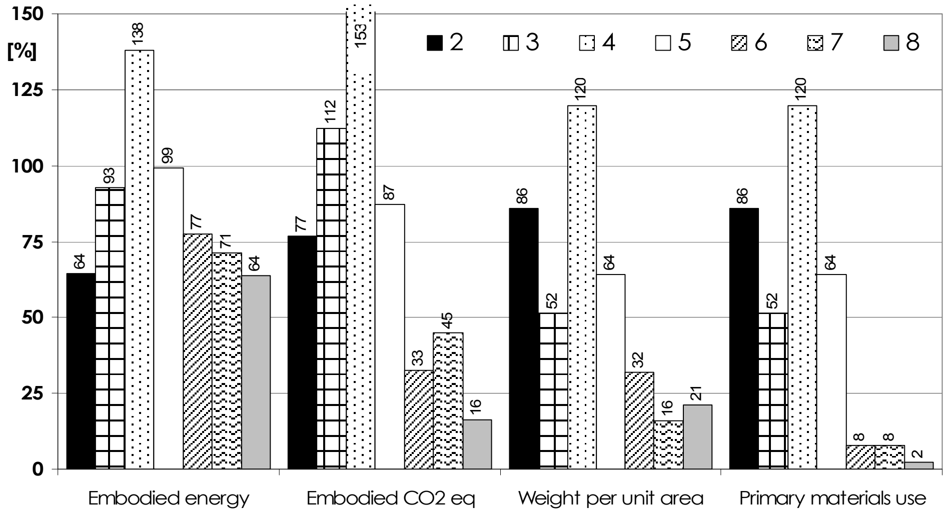


Figure 5 Comparison of environmental parameters of exterior wall alternatives. Reference level 100% is represented by a RC wall with ETICS mineral wool 170 mm – alt. 1

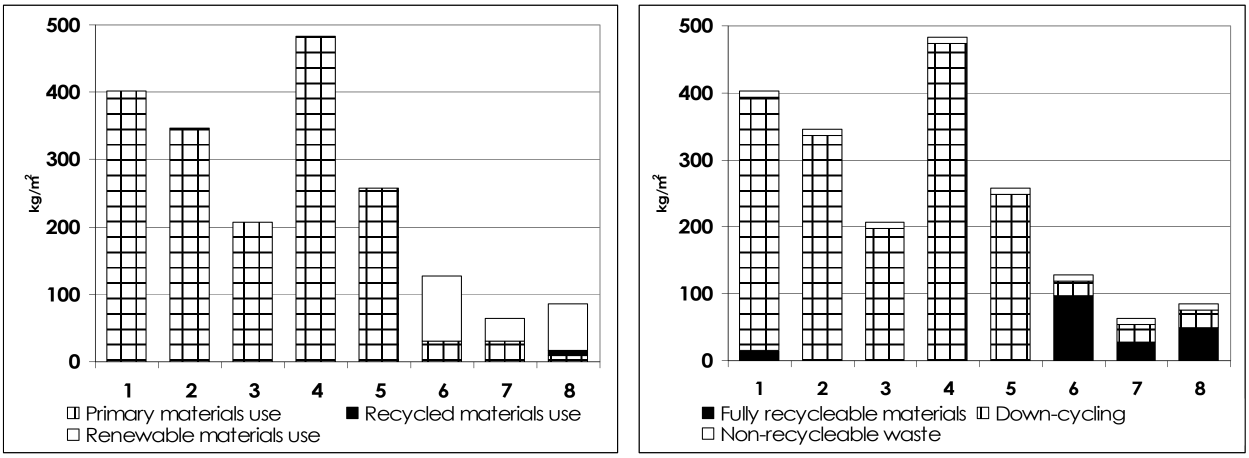


Figure 6 Input and output material flows for analyzed exterior wall alternatives

Fig. 5 and 6 present graphs showing potential savings of the environmental impacts. There are significant differences between massive and lightweight structures. The lightweight structures benefit from the low weight per unit area, small thickness, and its renewable nature that result in the superb values in all the evaluated criteria. Concerning the massive structures, good results show the alternative with concrete hollow-blocks (2) even though having a pretty high weight per unit area. On the contrary, the alternative with calcium silicate blocks show relatively bad results namely due to its high weight per unit area.

4. Application in construction practice

Two types of lightening fillers from recycled waste plastic and one type from structural boards from recycled laminated cartons were developed. The shapes of fillers were determined as a result of integrated environmental design and optimization considering environmental criterions, as well as structural parameters of the resulting composite RC structure. The initial optimization steps, covering the use of the ribbed or waffle shape and use of recycled materials, resulted in the reduction of embodied values (CO_2, SO_2, energy).

Three selected alternatives of fillers for waffle and ribbed slabs were experimentally produced and tested:

- shell installation fillers from recycled non-sorted plastic from municipal waste,
- waffle fillers from recycled non-sorted plastic from municipal waste,
- waffle fillers from structural boards from recycled laminated cartoons from municipal waste.

Installation shell plastic fillers were used in the construction of the two storey building of Senior Centre in Moravany near Pardubice in the Czech Republic. The original design of the floor structure – a composite RC slab was changed to a composite RC slab with shell installation fillers. This resulted in reduction of concrete consumption up to 0.08 m^3 per m^2, i.e. 34%. The self weight of the floor structure was reduced by 2.0 kN/m^2. The installation space inside the floor structure was used for the wiring and for the heating system in plastic tubes. This brought additional cost savings compared to the originally assumed installation system to be placed in the upper layers - inside the flooring (Fig. 7a).

The reconstruction of the two storey RC factory hall into a storage hall required an increase of the load bearing capacity of the intermediate floor structure so that the new structure would facilitate a new function with a higher live load of 5 kN/m^2. The existing cast-in-place RC slab with a thickness of 120 mm did not meet such requirements; moreover, there were a lot of openings unsuitable for the new way of use. The removal of the inconvenient RC floor slab was, due to the time limits, technological demands and total costs, unfavourable.

With respect to the limited load bearing capacity of the existing vertical load bearing RC structure, the originally expected alternative (solid full RC slab) would require strengthening of RC columns and footings. Thus, a specific solution was requested to lighten the floor slab compared to a solid one.

The new RC waffle floor slab was placed directly on the existing floor structure (Fig. 7b). Plastic fillers were placed on the floor so that the existing RC floor structure provides sufficient fire safety. Plastic formwork fillers were made in the Transform Lazne Bohdanec Company in a total amount of 650 m^2 of the fillers.

Figure 7 a - Construction of Senior Centre Moravany – composite RC slab lightened by installation fillers from recycled non-sorted plastic from municipal waste, 2000, b - Reconstruction of floor slab in Skoda factory hall. Slab is lightened by waffle fillers from recycled non-sorted plastic, 2003-2004

5. Conclusions

The theoretical analysis, optimization and performed case studies have supported preliminary assumptions about the undisputed significance of the selection of materials, including recycled materials and optimization of the shape of the structure. The performed case studies have showed that using recycled waste materials and the optimized shape of the floor structure, it is possible to reduce environmental impacts, such as consumption of non-renewable silicate materials, the resulting level of emissions (embodied CO_2, embodied SO_2) and embodied primary energy. The evaluated factor of environmental impact reduction in the range 1.2 – 1.8 can be considered insufficient, compared with the range of the needed improvements (factor 4 and more). However, these impact reductions are associated just with material savings in a structure itself and do not cover other related impact reductions in supports and transport.

Nevertheless, there is a big potential for the use of high performance silicate materials to form thin shell (ribbed, waffle, etc.) structures with reduction of the use of primary raw materials, and correspondent reduction of associated environmental impacts. Consequently, there are other possibilities how to reuse waste materials, preferably from municipal waste.

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CAD INTEGRATED ESTIMATION OF THE QUALITY OF INDOOR AIR IN ENCLOSED SPACES

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Summary

Current assessment of the indoor air quality in buildings focuses on the measurement of pollutants for comparison with air quality standards. The potential impacts of new building materials and contents on Indoor Air Quality can be controlled by labelling programs for low-emission materials but, with only limited materials labelled, especially in Australia, being able to estimate the impacts on indoor air quality of choices of building materials, contents and ventilation practices at the design stage can serve a similar purpose and be much more flexible. Such an innovative approach to estimating indoor air pollutant concentrations at the design stage, based on emissions over time from large area building materials, furniture and office equipment has been developed to consider volatile organic compounds, formaldehyde and airborne particles from indoor materials and office equipment and the contribution of outdoor urban air pollutants affected by urban location and ventilation system filtration for a single, fully mixed and ventilated zone in an office building. Criteria levels of pollutant exposure were derived from Australian and international health-based standards. The model acquires its dimensional data for the indoor spaces from a 3D CAD model via IFC files and the emission data from a building products/contents emissions database. This paper outlines the approach to estimating indoor air quality in enclosed spaces, describes the development of the emissions database and demonstrates the tool by its use with a new building.

1. Introduction

Current assessment of indoor air quality (IAQ) focuses on the measurement of pollutants in the constructed building to assess compliance with mandatory or advisory guidelines. Pollutant emissions from indoor materials and products are known to exert a significant influence on IAQ (Brown et al. 1994, Brown 1999a) while the building is new (up to about six months old) from paints, adhesives, floor-coverings, and furniture, and over the life of the building from office equipment and some reconstituted wood-based panels.

At the design stage, experience is used to select low emission materials, if available, but the prediction of indoor air quality is poor. No model or tool exists which is specifically aimed at predicting the indoor air quality of a building at the design stage, yet such a method/tool would assist designers in creating optimum indoor air environments. A method for estimating optimised indoor air quality would allow key decisions on the selection of materials during design to minimise environmental and occupant health consequences. Such a method would support the implementation of IAQ guidelines in building codes (Brown 1997).

This paper describes the development of a design tool, the IAQ Estimator (Tucker et al. 2007), with which the impacts of major pollutant sources in office buildings can be predicted and minimised. The prediction is made using a software tool for building designers so that they can select materials and appliances that, in combination, are sufficiently low emitting to prevent guidelines for indoor air pollution from being exceeded.

IAQ Estimator consists of:

- A database of air pollutant emission rates for typical large area building materials and contents, with typical examples of paints, adhesives, floor coverings, plasterboard, reconstituted wood-based panels, office furniture and copiers/printers;

- A procedure to estimate urban particle and air toxics levels in mechanically ventilated office buildings from outdoor urban air pollution, emissions from copiers/printers, and ventilation system filter efficiency;
- Combining the effects of product selection and ventilation scenarios on indoor air quality for a single level one zone office building;
- Integrating the above three factors to estimate indoor air pollutant levels within a building directly from the products information available in a 3D CAD model; and
- Promoting design decisions on product selection according to the relative impacts of products on IAQ estimates in comparison to health-based IAQ exposure guidelines.

2. Emissions to indoor air

The primary sources of indoor air pollution in office buildings, as illustrated in Figure 1, are considered to be:

- Emissions from large-area building products;
- Emissions from office furniture and equipment; and
- Pollutants from urban air introduced by ventilation.

Emissions from large area building products are Volatile Organic Compounds (VOCs) and formaldehyde from paints, floor-covering systems, painted plasterboard and wood-based panels (Brown 1999a, Brown 2002) and from office furniture such as work-stations (Brown 1999b). These emissions are generally proportional to the area of product exposed indoors and are expressed as an Emission Factor in units of pollutant mass/area/time.

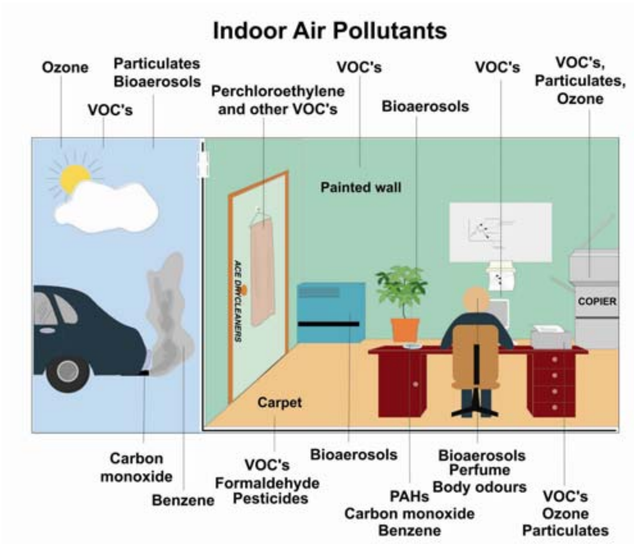

Figure 1 Primary sources of indoor air pollution

Emission Factors of building products are highly variable from product to product and generally decrease rapidly to background levels in the first weeks to months after construction, as illustrated in Figure 2. An exception to this behaviour is formaldehyde emission from wood-based panels with emissions reducing only to elevated steady-state levels within a few months of manufacture, this emission then persisting for some years (Figure 3). For IAQ Estimator, estimates were considered for the first 1 to 28 days for product emissions that decay rapidly and additionally at 6 months for persistent product emissions.

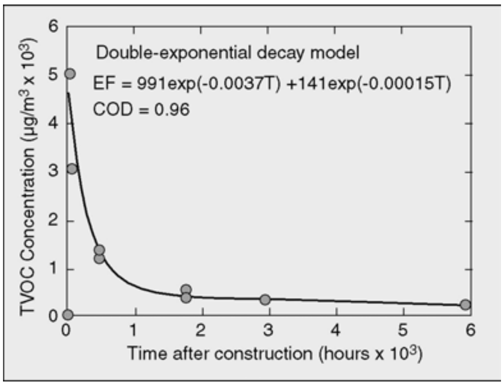

Figure 2 Total VOC decay in a new building after construction (Brown 2001)

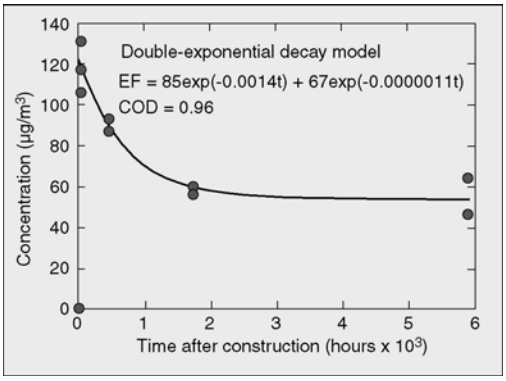

Figure 3 Formaldehyde decay in a new building after construction (Brown 2001)

Emissions from office equipment are VOCs and respirable and sub-micrometre particles (Brown 1999c,d; He et al. 2007). Such emissions occur predominantly while the equipment is operating, linked to the number of copies produced. Emission Factors for these products are in units of pollutant mass/copy/time. The impact on IAQ depends on the frequency of operation of the equipment but is independent of equipment age. For IAQ Estimator, the designer must know what office equipment will be used and its frequency of operation.

Pollutants in ventilation air for mechanically ventilated office buildings are from outdoor urban respirable and sub-micrometre particles and air toxics pollution. In Australia, there are health-based National Environmental Protection Measures for these pollutants (NEPC 2007). Generally, these urban air pollutants will occur at higher levels in city centres or close to busy roads. Ingress of these urban air pollutants into buildings will depend on the type of ventilation used (e.g. natural or mechanical), the ventilation rate, and the efficiency of filtration. For the IAQ estimator, the designer needs to input the building's location, the ventilation rate and the filter efficiency.

3. Indoor air emissions

IAQ Estimator considers the basic IAQ factors described above but also simplifies the building scenario by:

- Considering only key, large area materials and contents;
- Identifying the dominant VOCs and airborne particles present in indoor air of office buildings;
- Developing a database of Emission Factors for the selected product types and pollutants;
- Loading the building space, considered as a single fully-mixed zone, at quantified ratios with materials and contents;
- Interfacing with pollutants introduced from outdoor air and the effect of ventilation filtration;
- Aggregating each pollutant contributed from the indoor sources and outdoor air to estimate a profile of pollutant levels over time after construction; and
- Comparing the estimated pollutant levels with guidelines derived from health-based criteria, such that products causing guidelines to be exceeded can be easily identified and substituted.

3.1 Emissions for selected building materials and pollutants

A list of twenty key VOCs (including formaldehyde) was derived from existing knowledge of the VOC species found in Australian buildings and emitted from materials and equipment (Brown 1999a-d; Brown 2002). It was essential that a health-based environmental guideline existed for each (NHMRC 1996, WHO 2000, NEPC 2007, California EPA 2005, Calabrese and Kenyon 1991, Nielsen et al. 1998, ISIAQ 2004); where more than one guideline existed, values were averaged to provide a criterion for IAQ Estimator. No pollutant was included if such a guideline was not established. The compounds and maximum concentration goals within IAQ Estimator are presented in Table 1. Available Australian air emission data for building and furniture products for these twenty VOCs were collated into a database of representative products, covering emissions considered to be low, typical and high:

- Paints (zero emission, low odour and acrylic, solvent-based) on plasterboard or other substrates;
- Floor covering systems (carpet/underlay/low and high emitting adhesives, tile, wood panel floorboards, timber pre-coated with lacquer);
- Wall boards (plasterboard and reconstituted wood-based panels, including medium density fibreboard (MDF)); and
- Fixed furniture materials (shelf units, workstations).

Table 1 Pollutants and goal values for IAQ Estimator

POLLUTANTS	IAQ Estimator Goal (μg/m³)		IAQ Estimator Goal (μg/m³)
VOCs:			
Acetaldehyde	300	Isobutyl methyl ketone	500
Benzene	60	Naphthalene	30
2,6-Di-tert-butyl-4-methylphenol	500	Phenol	300
1,4-Dichlorobenzene	800	Styrene	500
1,2-Dichloroethane	700	Tetrachloroethylene	100
Dichloromethane	1,100	Toluene	300
Diethylene glycol ethyl ether	6,000	Trichloroethylene	150
Ethylbenzene	800	Total VOC (TVOC)	500
Ethylene glycol ethyl ether	200	m-/p-Xylene	300
Formaldehyde	40	o-xylene and o-/m-/p-xylene	300
Particles:			
PM2.5	25	PN1 Particles	5,000 particles/cm^3

3.2 Emissions from operating equipment

Previous research (Brown 1999c,d) developed a room chamber methodology for assessing emissions from office equipment and showed that VOCs (ethylbenzene, xylene isomers, styrene, toluene) and respirable particles were the dominant emissions from dry-process copiers and printers, these being proportional to the number of copy operations. However, office equipment changed shortly afterwards to digital copier technology, in which documents were scanned one time (instead of one scan per copy) and then reproduced in multiples as needed. A recent study of laser printer emissions (He et al. 2007) reported the emissions from some printers of high levels of sub-micrometre particle numbers (0.02 to 1 micrometre diameter, and referred to here as PN1).

IAQ Estimator emission data for office equipment includes VOCs, respirable fine particles PM2.5 (mass concentration of particles smaller than 2.5 micrometre (µm) cut-point) and sub-micrometre particle numbers as PN1 from the studies described above (goals for the latter two are also presented in Table 1). Since emissions data were lacking for the currently produced digital copiers, further assessment was undertaken with the same chamber method used previously, but including PN1 emissions. While both copiers were below detection for formaldehyde emission and exhibited very low ozone emissions (old printer emissions were previously found to emit ~70 µg/copy), they exhibited similar emission levels for VOCs. However, the 2007 copier exhibited lower respirable particle emissions by an order of magnitude. This copier was also a high emitter of PN1, emitting at a similar level to the high-emission printers reported by He et al. (2007).

Generally, estimates should be based on actual emission data for specific office equipment, but default values based on the higher emission equipment were recommended for equipment absent from the database. IAQ Estimator requires an estimate of copy rate per hour for copier or printer operation. Ideally, actual copy rates would be imported into the estimate, but in practice (especially at the design phase) IAQ Estimator provides the following guidance on specifying copy rates:

- a high usage value (2,000 copies per hour) should be applied to multifunction copiers unless actual usage data is available; and
- medium-use (18-35 copies/minute) and low-use (15-20 copies/minute) copiers and personal printers should apply a usage value based on the average copy rate for office workers of 50 copies per day for each person sharing the equipment.

3.3 Emissions from office furniture

Typical air emissions of the twenty key VOCs from office furniture were included in the database. Office furniture emissions can be expressed as pollutant mass/workstation/time, but the approach used here was to estimate workstation areas (a typical workstation included desk, desk return, drawers, shelf unit, chair) and express the emissions as pollutant mass/area/time. This proved a useful approach where additional furniture items (fixed shelving, work benches etc) were included.

3.4 Pollutants in urban air used for building ventilation

Three real-world categories of outdoor pollution were incorporated into IAQ Estimator according to building location (busy road, urban and rural), as in Table 2.

Table 2 Pollutant levels outdoors (µg/m³ unless specified)

Location	PN1 (p/cm³)	PM2.5	Benzene	Toluene	Ethyl-benzene	Xylenes	TVOC
Busy Road	100,000	25	6	17	<2	10	150
Urban Area	10,000	15	4	4	<1	3	60
Rural Area	1,000	10	1	1	<0.5	1	20

The particle filtration system of mechanically ventilated office buildings was linked to the PN1 and PM2.5 levels to estimate the impact of different filtration performances on indoor particle levels, as in Table 3. Particle deposition was ignored in estimates for simplification purposes.

Note that urban air levels for VOCs of health concern, commonly referred to as BTEX (Benzene, Toluene, Ethylbenzene, Xylenes) and total VOC (TVOC) levels were also included in IAQ Estimator, but with no removal process considered.

Table 3 Filter efficiencies

Filter Type	Filter Efficiency(E)	
	PN1	PM2.5
Bag (95%)	0.65	0.65
Bag (85%)	0.55	0.58
Bag (65%)	0.23	0.28
Pleated	0.035	0.092

3.5 Product emissions database

A product emissions database was constructed for individual products within the classifications: Paints, Floor coverings, Furniture/wood-based panels, and Copiers/printers. For each product, an Emission Factor (EF, mass of pollutant/area/time, or mass of pollutant/copy) was documented for each pollutant at specific times considered relevant to occupancy of new buildings: 1 day, 3 days, 7 days, 14 days, 28 days and 6 months, with data at the latter two times often being unavailable and having to be extrapolated from measurements at earlier times. IAQ Estimator estimated an indoor air concentration for each pollutant at each of these times by aggregating the pollutants contributed by the indoor products and outdoor air, with consideration of the product loading, the filter efficiency and the ventilation rate and air recirculation strategy.

Generally, this required a simple summation for VOCs and formaldehyde for products x_1, x_2, …, as follows:

$$\text{Estimated Concentration} = \Sigma(EF_x.Area_x)/(\text{Indoor Volume.Ventilation Rate})$$

but a more complex treatment was required for particles due to filtration in the mechanical ventilation system.

3.6 Particle filtering of air

IAQ Estimator is based on a general ventilation system design used by most mechanical ventilation systems operating in an air recirculation mode (Figure 4) whereby:

- Outdoor air, at a flow rate (Q_{OA} m^3/h) specified in building codes, is drawn into the building through one filter (Filter 1, particle efficiency E_1); and
- Building air is recirculated through the system at a return rate (Q_{RA} m^3/h) with the combined return air plus the outdoor air being passed through a second filter (Filter 2, particle efficiency E_2).

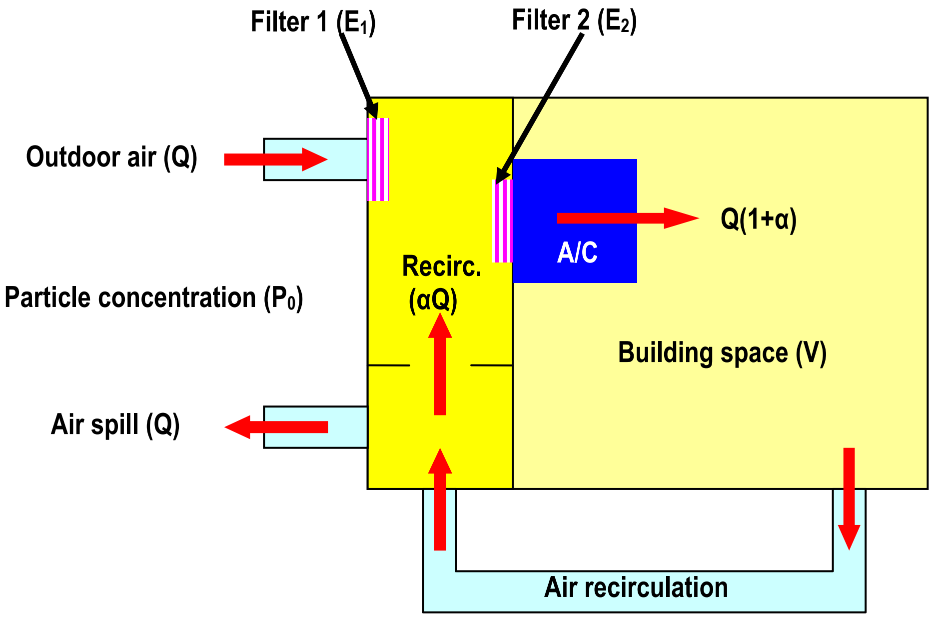

Figure 4 Schematic diagram of air circulation and filtering (Tucker et al. 2007)

Note that an estimate can be made for a natural ventilation scenario by setting particle efficiencies to zero. The indoor particle concentration (C) over time (t) for this ventilation system can be simplified to (Jamriska et al. 2003) to steady state conditions. Also note that this model ignores deposition losses of particles to interior surfaces since this was considered to be too variable a factor, and such simplification prevents the under-estimation of particle levels. Similarly, it was assumed that there would be no removal of VOCs and formaldehyde by the ventilation system, or by surface losses ('sink' effects) within the building. As for particles, this prevents under-estimation of pollutant levels.

4. IAQ Estimator

The computer model was assembled as an integration of:

- acquiring dimensional data for the indoor spaces from a 3D CAD Building Information Model via IFC files, an application of DesignViewTM software (Egan et al 2007);
- pollutant emissions from products within office buildings;
- impacts of outdoor air quality, ventilation rate and filtration efficiency; and
- comparison of IAQ estimates with goals such that the designer can identify unacceptable products.

The prototype software acquires its dimensional data for the indoor spaces either from a 3D CAD model or alternatively from manual entry of building components and their sizes. Specific building products in the 3D CAD model and the types of office equipment are identified by the user. The user also inputs outdoor air and return air flow rates which then link to the building volume as ventilation rates. Ventilation system filtration was limited to three scenarios of typical particle filtration. Outputs are indoor air pollutant concentrations that are estimated at six times after construction. The tool then designates a pass/fail scenario for each time by comparison with IAQ goal concentrations (Table 1).

The use of the DesignViewTM platform as the driving engine of the workbench for IAQ Estimator provided powerful functions besides the ability to view IFC files, such as:

- A plug-in architecture based on the Eclipse Rich Client Platform (Eclipse 2007a) and Eclipse Modeling Framework (Eclipse 2007b) which allowed multiple analysis applications to sit alongside and interact with DesignViewTM;
- A navigator panel which allowed selection of a particular model for viewing;
- A "tree view" which allowed the user to rapidly select sections of the building model to visualise, synchronised with the viewing panel;

- A properties panel which displayed tabular information which was attached to a selected building component in the viewer panel or the tree view;
- A problems list which displayed a list of missing information that had been identified by DesignViewTM on loading a building model; and
- A tasks list that allowed people to enter “to do” lists to ensure that things were not forgotten during design development.

The open and flexible plug-in architecture of DesignView^{TM} provides a foundation for other tools to be built on top of it, allowing developers to concentrate on the particular problem that the tool addresses. The key feature of DesignViewTM which was attractive to IAQ Estimator was the ability to add finishes to any building object in the 3D CAD model and see the object visually. The system was modified to add paints and panels from the material emissions database and expanded to be able to add office furniture and equipment into the space. These finishes could be visually inspected in the 3D Viewer (Figure 5).

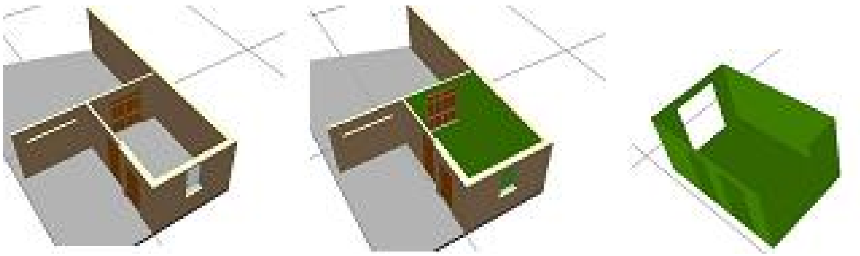

Figure 5 3D viewer of DesignViewTM (Tucker et al. 2007)

The key features of DesignView^{TM} most useful in IAQE are the 3D Viewer, the Model Outline and the Navigator views:

- The 3D viewer displays a real-time, fully rendered 3D view of the active building model. The user may explore and interact with the model. The camera can be panned, zoomed and orientated in any direction, and the user can select individual building elements using the mouse;
- The Model Outline displays the hierarchy of the building model in a tree structure. The model may be traversed according to four different hierarchies; Building, Element Type, Space Type and Material Type. Selecting elements in the Outline will highlight their visual representations in the 3D Viewer (if they are visible). Conversely, selections made in the 3D Viewer will be reflected in the Outline; and
- The Navigator view is used to display and navigate through the workspace and functions just like Explorer in MS Windows.

5. Proof of concept

Validation of the IAQ Estimator tool was limited to comparing estimates with published building data (Brown 2002) and specific data collected for one test building. Currently available, IAQ Estimator is considered a proven concept tool and a significant step towards a commercial product. For hypothetical buildings, it showed the impacts of high-, medium- and low-polluting sources; and it was possible to refine the building design to meet goals by not only selecting low-emission products, but by reducing surface areas, increasing ventilation rates or delaying time to occupancy.

Proof of the tool in a test building is a complex task since it requires documentation of all of the following:

- the building materials used, their quantities, date(s) installed;
- the building furniture used, their quantities, date(s) installed;
- office equipment and its frequency of use;
- pollutant emission properties of all the above;
- the ventilation rate (fresh air exchange rate) of the building;
- air filtration used in the ventilation system, its efficiency for the IAQ pollutants;
- levels of pollutants in urban air;
- the time schedule for the building construction in relation to its occupancy; and
- indoor air quality measurements for the building at several times after construction.

Proof-of-concept for IAQ Estimator was sought with one building (Brown 2007) and was based on a restricted number of materials and pollutants for which data were available or were specifically measured. The building was a nine storey office building in a central city location, designed to be a landmark, green building. Most wall and ceiling surfaces were bare concrete and it used a low-VOC paint on a small proportion of walls. Low emission carpet tiles, mechanically fixed (i.e. no adhesive), were used throughout.

Shelf units and work benches consisted of a low-formaldehyde plywood sealed with a water-based lacquer. Workstations were constructed from powder-coated low-formaldehyde MDF panels. Pollutant concentrations estimated for one Level of the building, and based on emissions from only the above products, are presented in Table 4.

Table 4 Pollutant concentrations estimated for one Level of a green office building

Pollutant	Pollutant Concentration (μg/m³) at time after product installation					
	1 day	3 days	7 days	14 days	28 days	6 mo
Formaldehyde	0.7	0.8	0.8	0.6	0.8	0.08
Octyl acetate	2	3	1	0.4	0.4	0.4
Ethyl hexanol	>0.2	0.2	0.4	0.4	0.4	0.4
Acetaldehyde	n.a.	n.a.	n.a.	1	0.5	0.3
4PC	n.a.	n.a.	n.a.	0.2	0.2	0.2
TVOC	26	>6	>4	>3	>2	>2

Formaldehyde and VOC measurements in the building are presented in Table 5. Note the limitation that the time from occupancy will differ from the time after installation due to construction schedules; it is considered likely that delays of 1-6 weeks occurred between installation of some products and building occupancy.

Table 5 Pollutant measurements for one Level of a green office building

Pollutant	IAQ Goal (μg/m³)	Concentrations (μg/m³) at ~time from occupancy			
		15 days		4.5 months	
		range	average	range	average
Formaldehyde	40	-	9	<5-16	11
Octyl acetate	n.a.	-	<6*	<2	<2
Ethyl hexanol	n.a.	-	n.a.	3-4	3
Acetaldehyde	300	-	n.a.	n.a.	n.a.
4PC	n.a.	-	n.a.	<2	<2
TVOC	500	-	18*	110-160	130

** the 15 day VOC measurements are likely to be under-estimated due to use of a different analytical procedure*

Generally, IAQ Estimator predicted that the concentrations of formaldehyde, acetaldehyde and TVOC would be much below the IAQ goals. The formaldehyde measurements agreed with this, the levels being much below those typically found in office buildings (20-100 μg/m³; Brown 1997), showing that formaldehyde pollution in the building was very low, probably due to the low emission building products used. Quantitatively, IAQ Estimator has underestimated the formaldehyde and VOC levels, probably because there are other sources of these pollutants in the building that were not considered in the estimation. Table 4 and Table 5 also show the following:

- Ethyl hexanol was found in the low emission paint used in the building; its six month estimate was 0.4 μg/m³ in comparison to a measurement of 3 μg/m³, both considered very low indoor air concentrations;
- Octyl acetate was also emitted from the low emission paint (in fact, at higher amounts than ethyl hexanol) but was not detected in measurements;
- 4-Phenyl cyclohexene (4PC), the odorant commonly found with new carpets, was below detection (<2 μg/m³) in both estimates and measurements;
- Despite differences described above, in no case did estimates and measurements differ in showing that IAQ goals were met;
- Overall, it is clear that proof-of-concept for IAQ Estimator requires;
- A building where medium to high pollutant levels will be measured so that the comparison to estimates will have a broader range of pollutants, more of which will be in a measurable range; and
- A scenario where the materials used in the building are fully characterised for emissions over a 6 month period.

6. Comments

IAQ Estimator will enable building designers to estimate the impacts on indoor air quality of different materials, finishes, office equipment and ventilation practices. By selecting different scenarios, the possibility of IAQ goals being exceeded can be understood, different strategies can be adopted (short-term increase in ventilation, delayed occupancy) and pollutant exposures can be reduced. The tool has many simplifying assumptions, such as:

- A building level is treated as one, fully-mixed zone;
- Only large area materials are included;
- The emissions database is not extensive in the materials considered (though it can grow with applications);

- Only the 'dominant' VOCs found in building air or product emissions are included;
- Pollutants without health-based goals are not included;
- Losses of pollutants to surfaces are not considered; and
- Filtration efficiencies are for new filters.

In general these assumptions will lead to overestimates of indoor air pollution and so this should not be considered a fully predictive tool. The key benefit of IAQ Estimator is that it will allow avoidance of polluting products at an early stage. It is not expected to replace the need for IAQ assessment of new buildings but it should reduce the likelihood of indoor air quality being found to be unacceptable.

7. Acknowledgements

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STUDY ON AIR-CONDITIONING CONTROL WHICH CONSIDERS HUMAN COMFORT CORRESPONDING TO THERMAL ENVIRONMENT CHANGE FROM OOUTDOOR TO INDOOR

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Keywords:building, hall, comfort, physiology, experiment

Summary

This paper shows the evaluation of thermal comfort of human who moves from outdoor to indoor by experiments in summer. And it also shows a building example which positively uses the environmental change to improve the thermal comfort in destination, and it's evaluation by field experiments in summer.

1 Introduction

With the rapid development of office automation in recent years, non-uniform thermal office environments occur with the increasing adaptation of partitioned space. It has become more difficult to ensure thermal comfort for all office workers simply by use of an air-conditioning system set to a fixed indoor temperature.

There are some widely used practical comfort standards, such as SET* (Gagge et al. 1971) and PMV (Fanger 1972). However, these are static standards, which are intended to optimize the thermal acceptability of users in a steady condition in an indoor environment. On the other hand, in the adaptive model hypothesis, people's contextual factors and past thermal history affect their thermal expectations and preferences (de Dear et al. 1997).

This paper shows the evaluation of thermal comfort of persons moving from outdoors to indoors by experiments in summer. And it also shows building example which makes positive use of environmental change to improve the thermal comfort in destination, and its evaluation by field experiments.

1.1 Evaluation of thermal comfort of persons moving from outdoors to indoors

Climatic conditions usually change when a person moves from cold or hot outdoor space to an air-conditioned indoor space. Thermal comfort also changes according to the climate change. These changes incur both physiologically and psychologically influences. Sometimes people experience different levels of thermal comfort even under the same thermal conditions.

In this study, as the first step, these changes were measured by experiments in summer. They were measured by using questionnaire survey, a mobile measurement device which analyzes the environmental conditions around the subject, and a near infrared oxygenation monitor which measures the oxygen saturation level of blood in the brain to examine the subject's physiological condition.

Results of these experiments show that real thermal comfort differs from the stationary standard, and that it is important to know the history which the person experiences.

1.2 Building example which makes positive use of environmental change to improve the thermal comfort in destination, and its evaluation by field experiments

A performing arts center including a Grand Hall used both for opera and concerts was analyzed in this study. The visitors pass thorough several spaces including the Main Entrance, Piazza and Foyer as they move from outdoors to the Grand Hall, and they experience several different environments. In this study, effectiveness of human thermal comfort during movement from outdoors to indoors and optimization of air-conditioning control were investigated by field experiments.

2 Evaluation of thermal comfort of persons moving from outdoors to indoors

2.1 Outline

Each space on the path along which a person moves has its own thermal environment, and he/she perceives the change of thermal environment. Not only in the movement from outdoors to indoors, but also in the movement through indoor space, the air and temperature distribution changes. Perceiving the thermal change, sometimes a person feels more comfortable. However, sometimes he/she feels discomfort. To provide thermal comfort and energy saving, task-ambient air-conditioning systems and personal air-conditioning systems have been introduced in buildings. These systems use the spatial distribution positively. For appropriate HVAC control and thermal comfort, it is necessary to know the influence of thermal change on human perception both physiologically and psychologically.

In this study, human comfort was examined corresponding to the thermal environmental change by the field experiment and questionnaire survey in summer for the first step.

2.2 Method

Three kinds of spaces with different thermal environment, a cold space, a hot space, and a comfortable space respectively, were prepared (see Table 1). Five subjects, all healthy adult males, wore clothing ensembles consisting of a long-sleeved shirt, trousers and socks. All subjects wore their own underwear. The clo value was estimated to be 0.7 clo. To keep their metabolic rate at 1.4 met, subjects were asked to walk on walking machine for 10 minutes.

Table 2 shows the measurement items.

Table 1 Thermal condition of each space

Space / Condition	Cold Space	Comfort Space	Hot Space
Temperature	19-20 °C	24-26 °C	30 °C
Humidity	70%	55-60%	65%

Table 2 Measurement items

Items		Measuring instruments
Tissue oxygenation index (TOI)		Tissue oxygenation monitor used near infrared spectroscopy NIRO-200 (Hamamatsu Photonics)
Normalized tissue hemoglobin index	Concentration change in the oxygenated hemoglobin	
	Concentration change in the deoxygenated hemoglobin	
	Concentration change in the total hemoglobin	
Body temperature	Groin	NR-1000 (KEYENCE)
Skin temperature	Arm, chest, thigh	
Air temperature		101AM (Kyoto Electronics)
Relative humidity		
Radiant temperature		
Wind velocity		
PMV, PPD		
Thermal comfort	Comfort sensation : +3 (comfort) - -3 (discomfort) Thermal sensation : +3 (hot) - -3 (cold)	Questionnaire survey

TOI shows the oxygen saturation level. In this study, because the correlation had been observed between the TOI and the the stationary state temperature in the surrounding, TOI was used as a monitor of the temperature in the surrounding that a person felt.

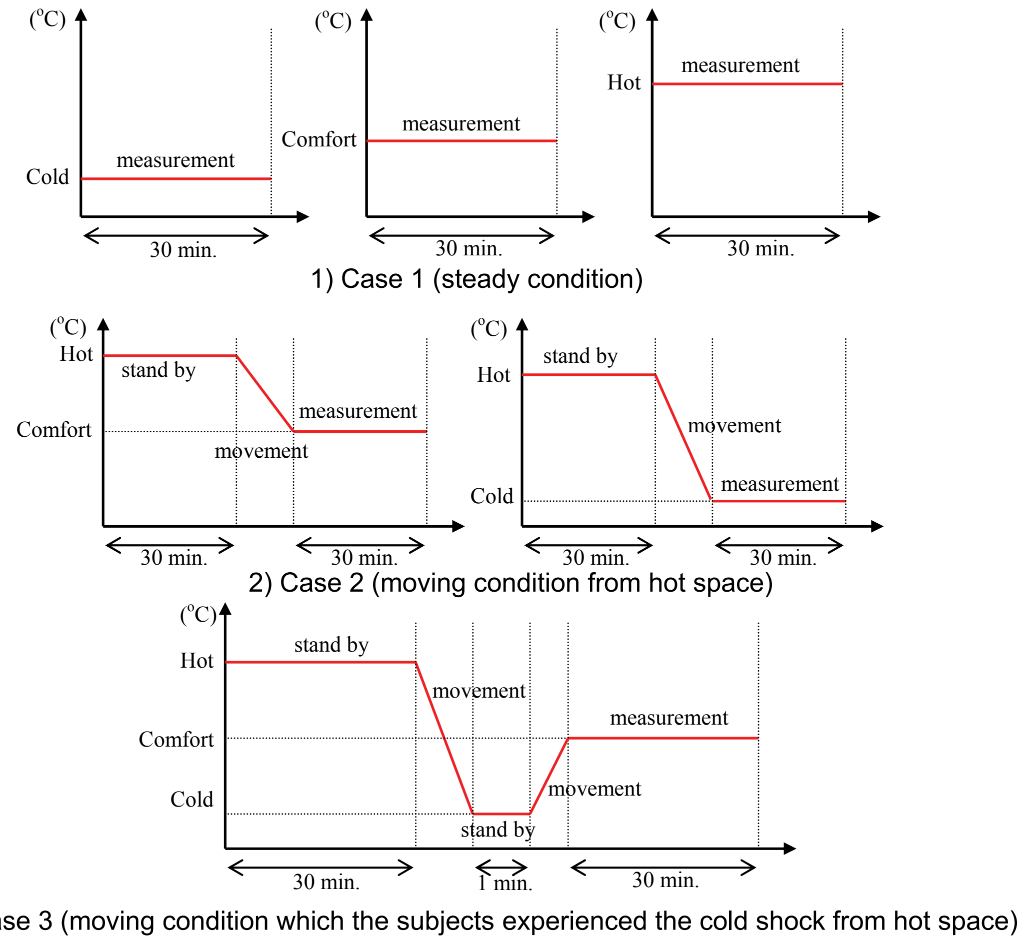


Figure 1 Cases analyzed

Cases analyzed are grouped into 3 according to the movement situation (see Figure 1).

1) Case 1

Measurement was conducted at each space, cold space (Cold), comfortable space (Comfort) and hot space (Hot).

2) Case 2

Measurement was conducted after the subjects moved to Comfort or Cold from Hot.

3) Case 3

Cold shock case. Measurement was conducted at Comfort after the subjects experienced the cold condition.

2.3 Results

1) Case 1 (steady condition)

The result of thermal comfort is shown in Table 3, and the result of Tissue Oxygenation Index (TOI) is shown in Figure 2. A-E mean 5 subjects. The difference of each subject's thermal comfort was small.

Concerning the thermal sensation declaration, valid results were obtained at each condition. A high TOI value was indicated in order of temperature.

2) Case 2 (moving condition from hot space)

In the movement from Hot to Comfort, average value of comfort sensation was 1.8 and thermal sensation was 0.0. These values were similar to those of Comfort steady condition (Case 1). However, average value of TOI was 70%, which was smaller than that of Comfort steady condition, approaching the value of Cold steady condition. It means that the psychological reaction did not correspond with the physiological response.

In the movement from Hot to Cold, average value of comfort sensation was 0.0 and thermal sensation was -2.2. The subjects felt cold, however they did not feel discomfort even in cold condition. Average value of TOI was 71%, which was close to that of movement from Hot to Comfort and different from that of Cold steady condition.

3) Case 3 (moving condition which the subjects experienced the cold shock from hot space)

Average value of comfort sensation was 2.0 and thermal sensation was 0.0. These values were very similar to those for Comfort steady condition (Case 1). Average value of TOI was 71%, which was also very close to that of Comfort steady condition. In this case, the psychological reaction corresponded with the physiological response.

2.4 Conclusion of Evaluation of thermal comfort of human who moves from outdoor to indoor

Thermal environmental change in pass space, human experienced, affected his thermal comfort. Sometimes, the psychological reaction did not correspond with the physiological response.

However, the appropriate change, ex. cold shock, may lead to the coincidence of the psychological reaction and the physiological response. There are possibilities of using these effects for energy saving.

Table 3 Thermal comfort

Thermal comfort / Case	Case 1			Case 2		Case 3
	Cold	Comfort	Hot	to Comfort	to Cold	Cold shock
Comfort sensation	-1.4	2.2	-0.8	1.8	0.0	2.0
Thermal sensation	-2.2	0.0	1.2	0.0	-2.2	0.0

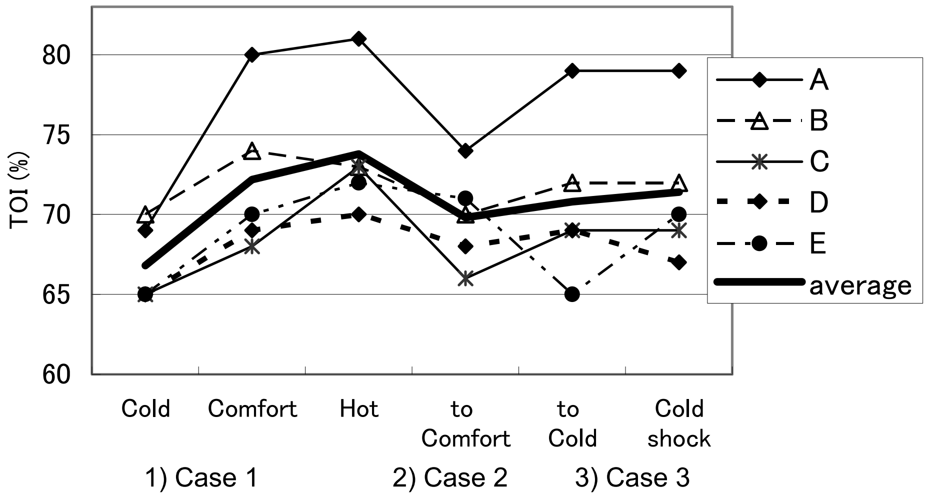


Figure 2 TOI values

3 Building example which makes positive use of environmental change to improve thermal comfort in destination, and its evaluation by field experiments

3.1 Outline

This performing arts center, which opened in 2005, has three state-of-the-art halls - the Grand Hall (2,001 seats), the Theater (800 seats), and the Recital Hall (417 seats) - capable of accommodating concerts, operas, ballets, plays and various other performing arts events (see Figure 3). Most visitors walk from the station on the Pedestrian Deck, then enter the Main Entrance, passing through the Piazza to reach the Grand Hall. The piazza has a light ceiling using natural sunlight like an atrium. It was designed for visitors to use as an intersection of the traffic line to three halls and as space in which to stay for a while, providing information of concerts, operas, ballets, plays and other performing arts.

Thermal sensations according to the movement were measured for the Grand Hall. While the room temperature, the illuminance, and residence time etc. of path space from outdoor to the hall were changed, a questionnaire survey was conducted and the influence of thermal sensation on the human body was investigated.

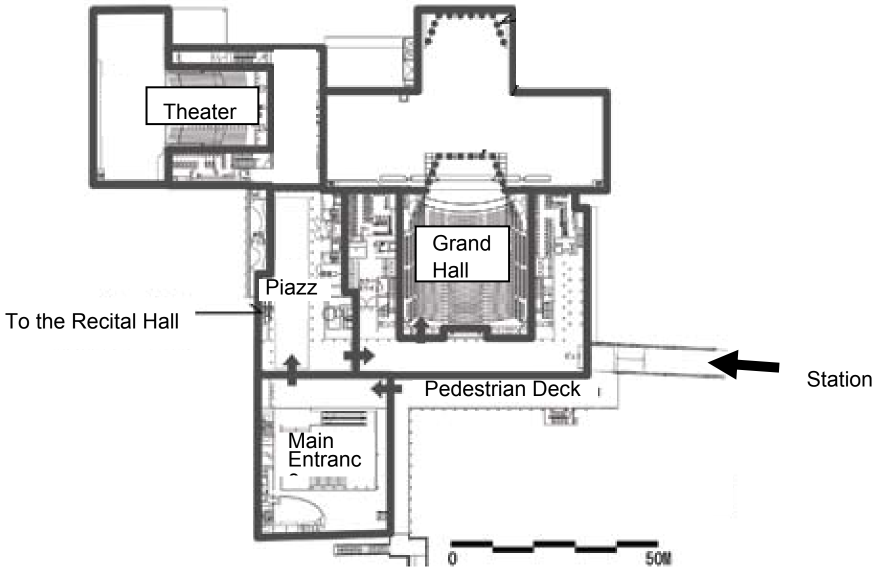


Figure 3 Plan of the performing arts center

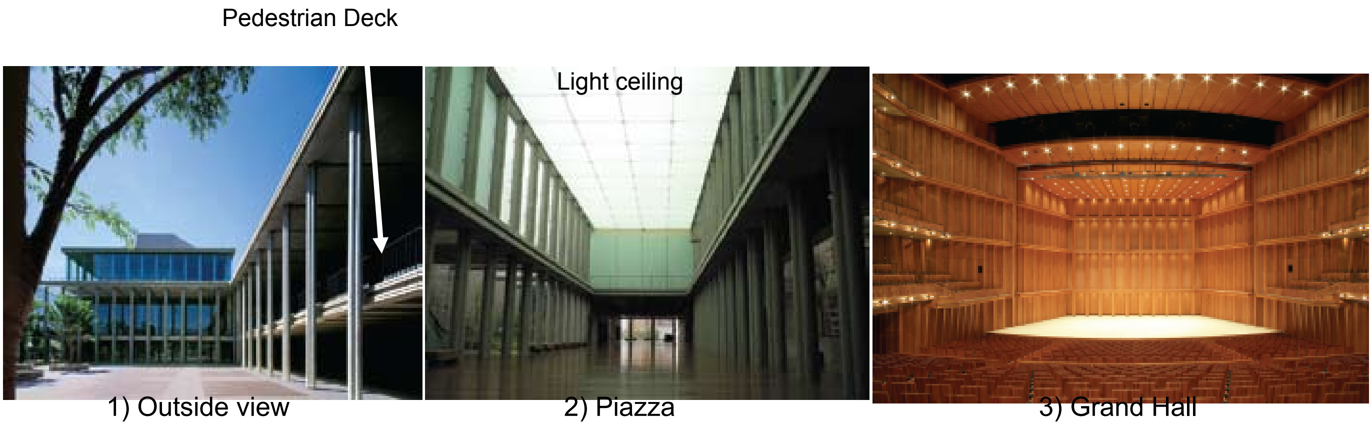


Figure 4 Picture of each area of the performing arts center

3.2 Method

Measurements were conducted on August 22-25, 2006. The change of the thermal environment and other factors from outdoors to the Grand Hall, and its influence on the human body were focused on in this study.

Measurement item and outline of measuring instrument are shown in Table 4.

Table 4 Measurement items

Items		Measuring Instruments
Tissue oxygenation index (TOI)		Tissue oxygenation monitor used near infrared spectroscopy NIRO-200 (Hamamatsu Photonics)
Normalized tissue hemoglobin index	Concentration change in the oxygenated hemoglobin	
	Concentration change in the deoxygenated hemoglobin	
	Concentration change in the total hemoglobin	
Body temperature	Groin	NR-1000 (KEYENCE)
Skin temperature	Arm, chest, thigh	
Air temperature		101AM (Kyoto Electronics)
Relative humidity		
Radiant temperature		
Wind velocity		
PMV, PPD		
Luminance		T10M (Konica Minolta)
Solar radiation		MS-601 (EKO Instruments)
Noise		NL20 (RION)
Density of carbon dioxide		GM70 (VAISALA)
Thermal comfort	Comfort sensation : +3 (comfort) - -3 (discomfort) Thermal sensation : +3 (hot) - -3 (cold)	Questionnaire survey

Mobile measurement apparatus for measuring the environment around subjects was set up for this experiment. It consisted of a mobile measurement cart and the measurement items shown in Table 4 and Figure 5. Using this system, transient thermal environment and other factors around the subject walking to the Grand Hall were measured in summer. The questionnaire survey and the measurement of body and skin temperature were also conducted. Just after the subject reached the Grand Hall, the Tissue Oxygenation Index (TOI) etc. were measured by tissue oxygenation monitor using near infrared spectroscopy to assess the subject's physiological condition.

Figure 5 Picture of the mobile measurement apparatus

Measurement cases are shown in Table 5. Eight cases were conducted. In the adaptation group (Cases 1.1-1.3), whenever a subject passed through the room, the temperature gradually falls. In the cold shock group (Cases 2.1-2.3), subjects experienced the cold environment before entering the Grand Hall. In each group (Cases 1.1-2.3), staying time in passing through the room between outside and the Hall was set as the parameter of the experiment. We also set the luminance as a parameter. In low luminance case (Case 3.1), subjects experienced low luminance at the Main Entrance before entering the Grand Hall. In the high luminance case (Case 3.2), subjects experienced high luminance at the Piazza.

Firstly, subjects walked around at the Pedestrian Deck for 10 minutes to keep their metabolic rate at 1.4 met. Then they stayed in each area for the time shown in Table 4. Finally, they entered the Grand Hall.

The 5 subjects were healthy adult males, and wore clothing ensembles consisting of long-sleeved shirt, trousers and socks. All subjects wore their own underwear. The clo value was estimated to be 0.7.

Table 5 Measurement cases analyzed

		Pedestrian	Main Entrance	Piazza	Grand Hall
Case	Outline Parameter	32 °C	22 °C Case 4.2 :27 °C	28 °C Case 4.1 :25 °C	26 °C
Case 1.1	Adaptation	10 min	---	10 min	30 min
Case 1.2		10 min	---	30 min	30 min
Case 1.3		10 min	---	1 min	30 min
Case 2.1	Cold shock	10 min	10 min	---	30 min
Case 2.2		10 min	30 min	---	30 min
Case 2.3		10 min	1 min	---	30 min
Case 3.1	Low luminance	10 min	---	10 min	30 min
Case 3.2	High luminance	10 min	10 min	---	30 min

3.3 Results

Two kinds of comparisons which provided the clearest results are shown as follows.

One is the comparison between Case 1.2 (adaptation group, 30 minutes stay at the Piazza) and Case 2.2 (cold shock group, 30 minutes stay at the Main Entrance).

Another is the comparison between Case 1.2 and Case 2.3 (cold shock group, 1 minute stay at the Piazza).

In the comparison of these cases, the difference between the adaptation and cold shock were evaluated.

Case 1.1 (adaptation group, 10 minutes stay at the Piazza) showed the tendency to look like Case 1.2. And Case 2.1 (cold shock group, 10 minutes stay at the Main Entrance) showed the tendency to look like Case 2.2. Therefore, in this paper, 30 minutes and 1 minute stimulation cases are presented.

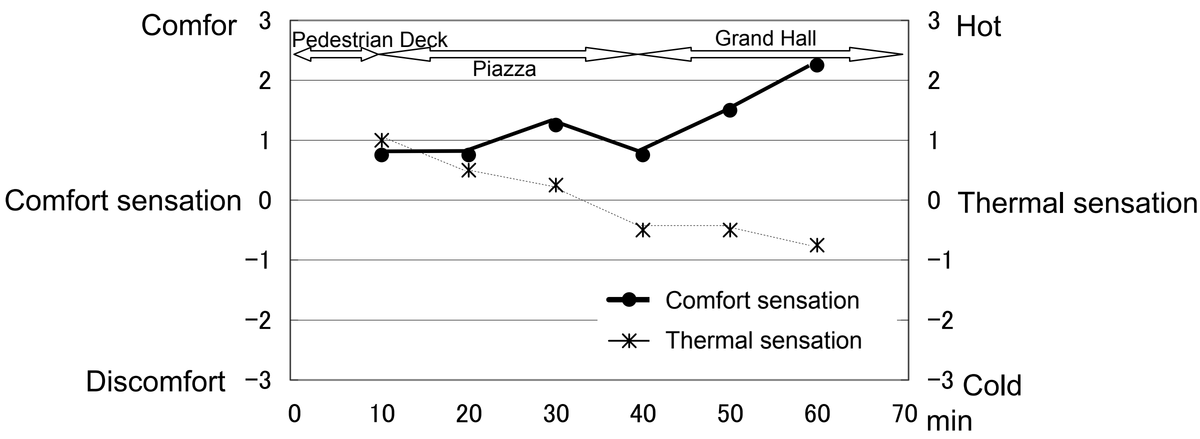
We have not yet obtained clear results in low and high luminance cases (Cases 3.1-3.2).

1) Comparison between Case 1.2 (adaptation group, 30 minutes stay) and Case2.2 (cold shock group, 30 minutes)

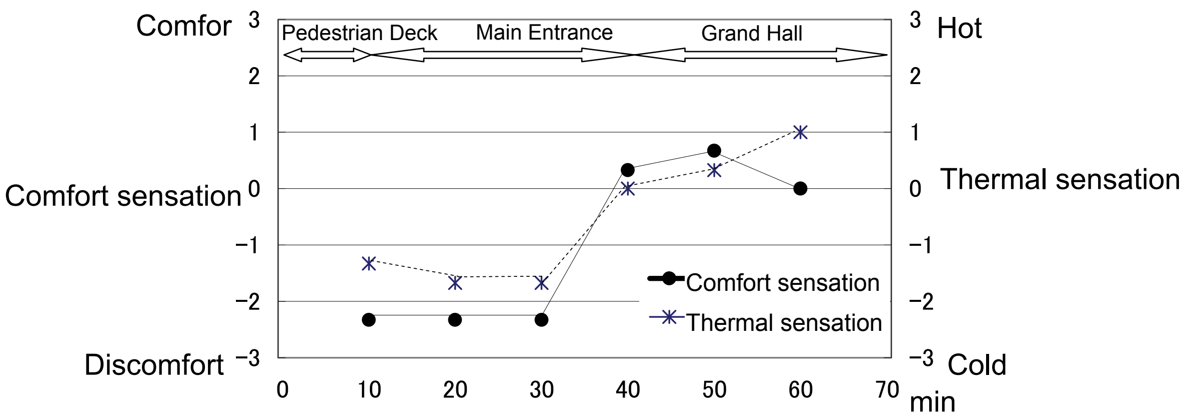
The results of thermal comfort in Case 1.2, 2.2 and 2.3 are shown in Figure 6.

In Case 1.2 (adaptation), thermal sensation was cool (changed to -0.8 from -0.5) in the Grand Hall (Figure 6 (1)). On the other hand, in Case 2.2 (cold shock), it approached to warmth (changed to 1.0 from 0.0) (Figure 6 (2)). Subject felt different thermal sensation in the same thermal condition between 2 cases.

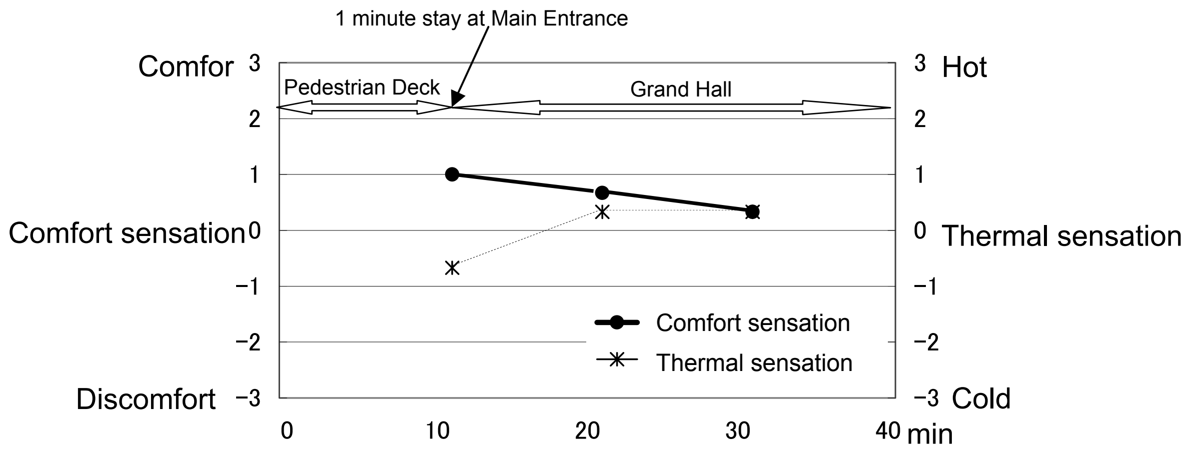
In Case 1.2, just after the subject entered the Grand Hall, comfort sensation approached to comfort from neutral (changed to 2.2 from 0.8) and even if time passed, this inclination still continued (Figure 6 (1)). On the other hand, in Case 2.2, there was not so much difference (changed to 0.0 from 0.3), even though he felt cold for long time before he entered the Grand Hall (Figure 6 (2)). It is assumed that the warm feeling while staying in the Grand Hall decreased the sensation of comfort.



(1) Case 1.2 (adaptation group, 30 minutes stay at Piazza)



(2) Case 2.2 (cold shock group, 30 minutes stay at Main Entrance)



(3) Case 2.3 (cold shock group, 1 minute stay at Main Entrance)

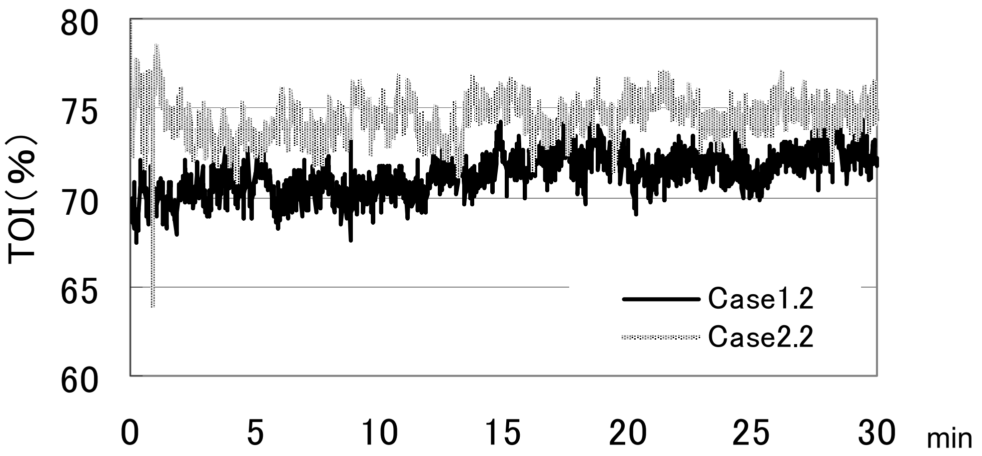
Figure 6 Results of thermal comfort

(Starting time of 10 minutes walk on Pedestrian deck was set as 0 minute in Figure 6)

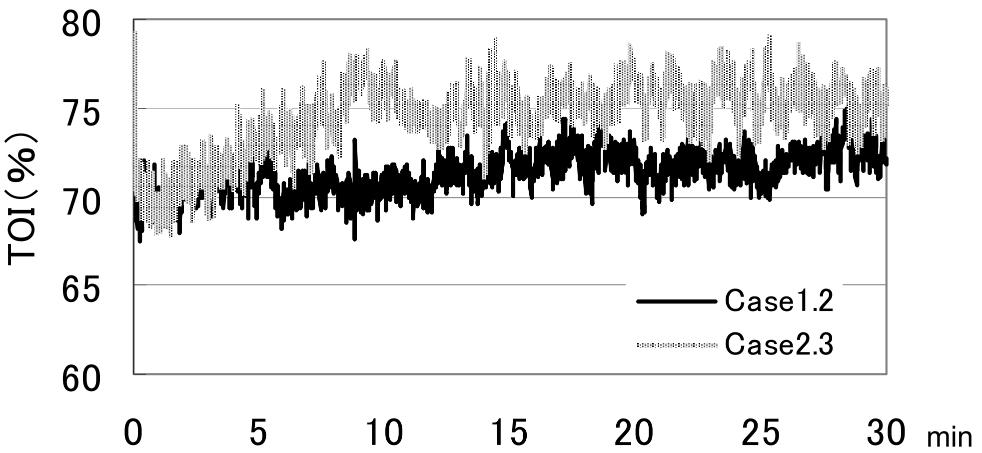
The results of TOI in comparison of Case 1.2 and 2.2, and 1.2 and 2.3 are shown in Figure 7.

In comparison of Case 1.2 and 2.2, TOI value of Case 2.2 was higher than that of Case 1.2 (see Figure 7 (1)). TOI value indicates the oxygen saturation of the hemoglobin. In Case 2.2, the subject was forced to be in a cold situation, and he felt the cold sensation, therefore it was assumed that the oxygen saturation of the hemoglobin rose to maintain the body temperature. Because of the high TOI value and high physiological activity, the subject felt warm after he entered the Grand Hall, then it was assumed that his comfort sensation was decreased.

30 minutes cold shock may be considered to be excessive stimulation.



(1) Comparison between Case 1.2 (adaptation group, 30 minutes stay at Piazza) and Case 2.2 (cold shock group, 30 minutes stay at Main Entrance)



(2) Comparison between Case 1.2 (adaptation group, 30 minutes stay at Piazza) and Case 2.3 (cold shock group, 1 minute stay at Main Entrance)

Figure 7 Results of TOI

(Starting time of measurement in the Grand Hall was set as 0 minute in Figure 7)

2) Comparison between Case 1.2 (adaptation group, 30 minutes stay) and Case 2.3 (cold shock group, 1 minute)

n Case 2.3 (cold shock, 1 minute), thermal sensation approached neutral closer than that of Case 2.2 (Figure 6 (2), (3)). However, it was also warmer than that of Case 2.1 (Figure 6 (1), (3)). Furthermore, the trend of thermal sensation of Case 3.2 after subjects entered the Grand Hall was similar to that of Case 2.2.

In Case 2.3, comfort sensation did not approach to comfort (changed to 0.3 from 1.0).

In comparison with Case 1.2 and 2.3, TOI value of Case 2.3 was also higher than that of Case 1.2 (see Figure 7 (2)). In this experiment, high TOI value and high physiological activity occurred with the stimulation of only 1 minute cold shock.

3.3 Conclusion of the building study which makes positive use of environmental change to improve the thermal comfort in destination, and its evaluation by field experiments

The influence of adaptation and cold shock on the way to the hall from outside was evaluated in the experiment. In this case, adaptation was more effective in the thermal comfort improvement than cold shock. However, there is a possibility that the effect changes depending on the amount and the time of stimulation. Therefore, it is thought that further quantification is necessary.

The Piazza in the performing arts center was designed with much sunshine from the light ceiling. Therefore indoor climate in the Piazza seems to be located in between uncontrolled outdoor climate and controlled indoor climate. By the experiment conducted in this study, the Piazza contributed to the thermal comfort of the visitors coming to the Grand Hall. Raising the preset temperature of the air-conditioning system in the Piazza would also lead to energy saving. In the Piazza, the preset temperature is 28 oC in summer, which is 2 degrees higher than in normal systems, and the measured temperature was almost 28 oC during summer. However, there were no complaints about thermal comfort from the visitors. In the Piazza, transmission heat has been reduced by at least 43 GJ/year in the cooling season.

4 Conclusions

This paper showed the experimental evaluation of thermal comfort of people moving from outdoors to indoors in summer. It also showed a building example which makes positive use of environmental change to improve thermal comfort in destination, and its evaluation by field experiments in summer.

Results of these experiments showed that actual thermal comfort was different from the stationary standard, and that it is important to know the history which the person experiences.

It is necessary for appropriate HVAC control and thermal comfort to understand the influence of thermal change on human perception both physiologically and psychologically.

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INDOOR ENVIRONMENT QUALITY AND OCCUPANT PRODUCTIVITY IN THE CH2 BUILDING

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Keywords: Indoor environment quality, occupant productivity, sustainable office buildings

Summary

This paper presents a summary of the results from a post-occupancy evaluation study on indoor environment quality (IEQ) and occupant health, wellbeing and productivity in the Council House 2 (CH2) building, which is owned and occupied by the City of Melbourne. This case study has highlighted that the productivity of office building occupants can potentially be enhanced through good building design, and provision of a high quality, healthy, comfortable and functional interior environment, that takes account of basic occupant needs.

1. CH2 Building

Council House 2 (CH2) is a 10-storey office building which houses around 500 City of Melbourne staff, and some ground-floor retail space. CH2 was officially opened in August 2006 and occupied by staff in October 2006.

CH2's gross floor area of 12,536m² comprises:

- Nine floors of office space (9,373m² total; 1,064m² per floor typically)
- 1,995m² of basement areas
- 500m² of ground floor retail

CH2 was conceived, designed and built with a substantial focus on setting a new standard for ecologically sustainable office buildings. It has a raft of sustainable technologies and design philosophies incorporated throughout the entire building, services and fit-out. Key sustainability-related features of CH2 include:

- Low energy, passive cooling systems
- Low energy, integrated electric lighting and daylighting systems
- Co-generation, photo-voltaic cells, and wind-driven turbines
- Active louvres on West facade and vertical garden on North facade
- Sewer mining, water recycling, rainwater collection
- Use of recycled materials
- Extensive facilities for cyclists

A key element of the business case for CH2 was that provision of high levels of IEQ, along with other design features, would result in significant benefits to City of Melbourne through improved health, wellbeing and productivity of staff in the building. Key IEQ features of CH2 include:

- 100% fresh air ventilation is introduced at floor level, and is then exhausted at ceiling height using natural convection.
- Radiant cooling is provided by the thermal mass of concrete ceiling panels, and also through chilled panels which use a mechanical chiller in combination with phase change material stored in the basement, to charge the coolant. Night purging of the building is used to store the night 'coolth' in the concrete ceiling which is then released during the day. Evaporative cooling through shower

towers on south face is used to cool the retail areas on the ground floor, and to remove some heat from the coolant used in the chilled ceiling panels.

- Lighting is provided through a mix of high-efficiency recessed luminaries in the ceiling, suspended strip lighting, daylight penetration, and extensive task lighting.
- Low toxicity materials used for all furnishings and finishes
- Extensive use of indoor plants

The Interior design was also intended to produce productivity benefits through increased communication and collaboration between staff. The fit-out of CH2 is based on a modern open-plan philosophy, with no enclosed offices and low adjustable partitions between workstations. There are relatively unobstructed lines of sight throughout each floor, with the only enclosed spaces being the formal meeting rooms. Informal meeting and social spaces are provided throughout the building. Occupants also have access to external balconies, a winter garden, a summer terrace and a rooftop garden. An external view of the CH2 building is shown in Figure 1, and some interior views are shown in Figure 2.

Figure 1 Exterior views of CH2

Figure 2 Interior views of CH2

1. Methodology

Evaluation of IEQ and productivity is based on a program of physical IEQ measurements, occupant questionnaires, focus group interviews, and sick leave and staff turnover data. A three page modified 'Building Use Studies' (BUS) occupant questionnaire was conducted in both CH2 and in a 'baseline' City of Melbourne building located next door (CH1). More than 260 responses were received in each building. Assessments for CH2 are compared against Australian and international benchmarks and against the CH1 baseline for productivity assessments. Physical measurements and spot health-symptom questionnaires were also conducted in summer and winter seasons. Measurements and occupant responses are averaged over spatial and organisational boundaries to allow overall assessments to be made.

The impact of the IEQ on occupant productivity is determined through a single question on the occupant questionnaire which uses a discrete nine-point scale, and asks the respondent to estimate how productivity at work is decreased or increased by the environmental conditions in the building. Although this may not necessarily translate directly to an equivalent increase in work output, it is the most appropriate way to measure the building's impact on productivity in a diverse organisation like City of Melbourne, which encompasses a wide range of job-types which have context-specific productivity dependencies that cannot be clearly defined or measured. The BUS self-assessment methodology has been widely used in Australia and internationally as it provides a consistent measure which enables comparison and benchmarking of productivity effects within and between buildings. Additional questions were added to the standard BUS questionnaire to obtain extra data on wellbeing, indoor plants, and other contextual factors which may impact on productivity assessments. Further details on the methodologies used are given in a separate report (Paevere & Brown, 2008)

2. Summary of Measurements and Questionnaire Findings

CH2 occupants are highly satisfied with the **building overall**, and its **facilities, furnishings and fit-out**. More than 80% of occupants prefer CH2 to their previous accommodation. A broad summary of the data collected is shown in Figure 3. Full details of the measurements and questionnaires used in the evaluation are given in a separate report (Paevere & Brown, 2008).

Thermal comfort is generally good in CH2 based on both physical measurements, and also occupant perceptions for all variables except ventilation, as a result of the airflow being perceived to be too still. The monitoring of center 'building core' comfort levels over the course of a three day period on three different floors of the building was extraordinary in terms of its consistency during both winter and summer periods. This indicates the building's capabilities to provide outstanding, continuous and a consistent level of thermal comfort. (see Figures 4 & 5). This is a good outcome given the relatively complex and inter-connected nature of the various cooling and ventilation systems, and the fact that the systems were being tuned during the period of the study. Further tuning may result in better performance in the future, but diligent management of the systems must be continued.

Air quality in CH2 is excellent in terms of measured pollutant levels, and is good based on occupant perceptions. Formaldehyde concentrations in CH2 were much lower than normally found in office buildings. This result can be primarily attributed to the use of 100% fresh air ventilation, and low emission furnishings and finishes throughout the building. Air quality was identified by many occupants as having a positive effect on their productivity.

Measurements of ambient **noise levels** and reverberation times were considered ideal in CH2, however occupant satisfaction ratings for noise are average to poor and are generally worse than benchmarks. The low satisfaction scores are primarily due to unwanted interruptions and distractions from other people in the building. The hindrance of noise from interruptions must be contrasted against the potential productivity enhancement due to the open plan layout, as improved communication has been reported by some occupants and managers. Satisfaction with speech privacy in CH2 may be improved through tuning of the white noise system installed in the building. Trials in which white noise levels were increased on one Level in the building resulted in better satisfaction scores for noise when compared to the rest of the building (10-18% better for relevant noise variables), however this result is not conclusive, given that satisfaction ratings for most other variables were also higher on this Level. Careful consideration of workgroup layout, circulation routes, and the separation of quiet and noisy activities may also lead to improvements in occupant satisfaction with noise.

Lighting is considered to be satisfactory in CH2 overall with some question marks against task lighting and satisfaction with daylight levels. The integration of task lighting into the overall lighting strategy, with lower general illuminance levels, as is the philosophy in CH2, is considered good practice from both a sustainability and user control perspective, however the initial configuration for the CH2 lighting resulted in some complaints about the building being too dark. Measurements shown in Figure 6 indicate that the lux levels for desktop illuminance often fall below the desired level. The background luminance (brightness) was thought to be problematic due to large variations between the electric light sources and the adjacent darker-toned ceiling surfaces, which results in a ‘starry-night’ effect where a dark surface background prevails against a bright source. These issues were addressed by building management during the study period by incorporation of additional direct/indirect lighting in several places, providing better light diffusion and reducing this problem, although the effect of the changes on occupant satisfaction are not clear. Grey concrete ceilings and darker-toned furnishings and plants are a part of the interior design of CH2 and these may have an impact on occupant perceptions of lighting. Given the improvements and adjustments made to the lighting systems during the study, further assessment of the lighting is warranted.

Perceived **user control** over IEQ was rated poorly by occupants in CH2, but only a small portion of occupants indicated this as important to them, and hence for this study, this is not considered as a major factor in assessment of the IEQ.

CH2 is rated very highly by it’s occupants for perceived **healthiness**, and is considered to have low levels of occupant-reported rates for building-related **health symptoms**, when compared to levels in the general population. **Absenteeism** and **staff turnover** have not changed significantly during the first 12 months of occupation of CH2, compared to previous years, however given the year-to-year variability, and the possibility that organisational restructuring may have had some impact, a longer period of monitoring is required before any solid conclusions can be made about the effects of the building on absenteeism and staff turnover.

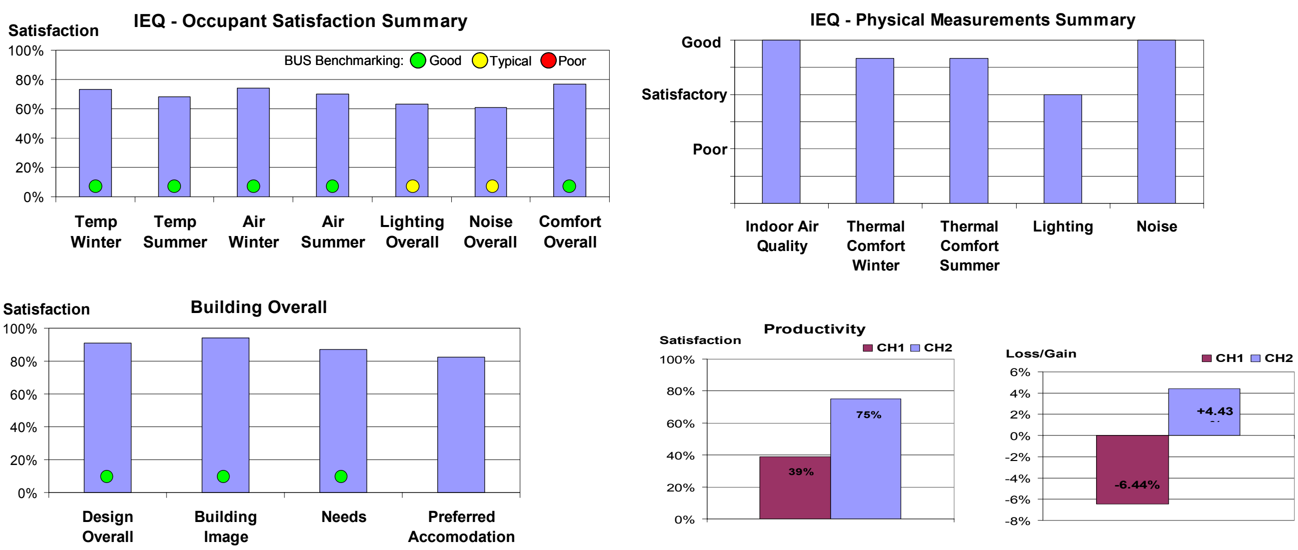

Figure 3 Summary of key findings on IEQ and Occupant Productivity

3. Impact of Building on Occupant Productivity

Based on the first 12 months of CH2 occupation, there has been a significant improvement in perceived health and productivity when compared against the CH1 baseline. Given the importance of health and productivity in the business case for sustainable buildings, it is useful to examine the differences between CH2 and CH1, as perceived by the occupants, to try and gain some insights into the impact that different aspects of the building have had on the positive productivity ratings for CH2. It must be noted however that it is not possible to make quantitative conclusions about the impact that any particular aspect of building design will have on health and productivity based on a study of only two buildings, in which many variables have been changed simultaneously. The results and analysis presented herein apply only to the context of CH2 compared to CH1.

The following categories have been adopted to represent the broad range of factors which could potentially have an impact on occupant productivity: Building Overall; Furnishings, Facilities, Fit-out & Equipment; IEQ (Thermal Comfort, Air Quality, Lighting, Noise); Health Symptoms; Other Factors

When the major variables from the occupant questionnaires are categorised in this manner, it can be seen which aspects of CH2 stand out as the biggest perceived improvement, relative to the CH1 baseline. Table 1 outlines the variables that are assigned to the different categories, the satisfaction differences between CH2 and CH1, and the correlation coefficient of each variable with Perceived Productivity in CH2. Figure 7 shows the averaged difference in satisfaction ratings between CH2 and CH1 for these different categories of variables.

The main conclusion that can be drawn from this analysis, is that in the case of CH2 compared to CH1, the 'Building Overall' category of variables is likely to be the most significant, in terms of impact on Perceived Productivity. All of the variables under this category correlate better with Perceived Productivity, in relative terms, than all of the other variables in all of the other categories (although it should be noted that the correlations are not very strong in absolute terms, with R in the range 0.5 to 0.6). This category also exhibits the largest difference in satisfaction ratings between CH2 and CH1. Other variables and categories in Table 1 which show a relatively stronger correlation with Perceived Productivity are Thermal Comfort (summer more than winter), Noise Overall, Air Quality, Space Layout, Workstation Usability and Privacy, although none of these are as strongly related to the Perceived Productivity rating as the 'Building Overall' variables.

Interestingly, if the averaged satisfaction differences for each category are summed together (they add to 36.5%), this value is very close to the difference in the Perceived Productivity satisfaction rating (which is 36%). Although this is most likely a coincidence, it demonstrates conceptually how different aspects of the building and its design may either enhance or hinder productivity depending on whether they are perceived as satisfactory, or not by occupants.

The analyses presented herein cannot be used to prescribe quantitative relative importance or weightings for the impact of individual variables (or categories of variables) on perceived productivity. However, they reinforce the notion that occupant productivity is likely to be dependant on a range of factors related to the overall building and it's fit-out, the different aspects of IEQ, and possibly other contextual factors which may not be related to the building itself, such as experiences in previous accommodation. In the case of CH2, it would seem that satisfaction with the 'building overall' is likely to have had a greater impact on occupants perceived productivity than any specific aspects of the IEQ. As far as the IEQ impact on perceived productivity is concerned, when the data is considered in light of occupant comments, it is likely that air quality and thermal comfort have enhanced productivity, whereas some issues with lighting and noise due to interruptions may have had a hindering effect

Assessment of various **contextual indicators** shows that there has been a reduction in perceived workgroup morale due to workplace restructuring, but there have not been any major contextual shifts in terms of happiness, autonomy and communication during the study period. It is therefore concluded that contextual changes are unlikely to have resulted in any 'false-positive' effect on perceived productivity ratings.

Further analyses of the productivity findings are given in a separate report (Paevere & Brown, 2008)

4. Business Case for CH2

In setting up the original Business Case for CH2 and convincing the Council to provide the necessary finance for sustainability and productivity enhancing features, there were two distinct components: 1) The energy and water savings which were conservatively measured at $330,000 per annum and; 2) Productivity and wellbeing of staff again conservatively measured at 4.9% and valued at $1.12M per annum.

These components were significant for reasons beyond the simple financial model to prove to the wider industry, the viability of CH2. By placing the emphasis on sustainability and IEQ, the Council was strategically targeting the occupants of future buildings as the most important change agents. Developers would naturally argue to minimise costs, and given they had no long term stake in the completed building, its running costs and occupant conditions, it became evident that if the Council was to promote change it would need to be via an education process of future tenants. This strategy has proved to be effective in that high profile tenants like the National Australia Bank and the ANZ Bank are now insisting on 5 and 6 star buildings with an emphasis on good IEQ.

The conclusion of this study has indicated that the productivity and wellbeing in CH2 is in fact 10.9% higher than the baseline building CH1.This represents a $2.4M per annum benefit to Council and reduces the payback time of the sustainability and IEQ features of the building ($11M) to around 5 to 6 years. Given the life expectancy of the Building, 50-100 years, this study has demonstrated that the business case for incorporating these features is compelling.

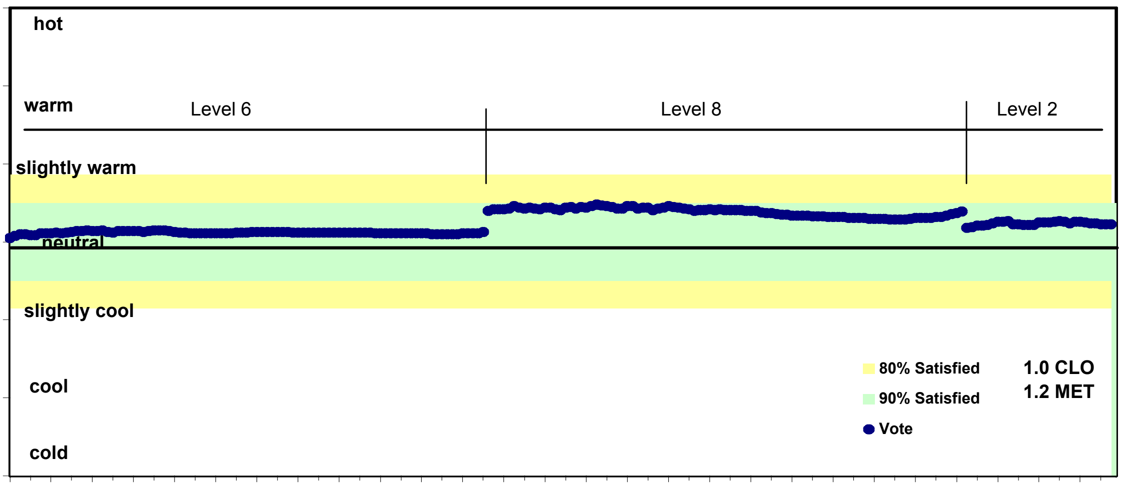

Figure 4 Continuous thermal comfort measurement during a winter period – MABEL

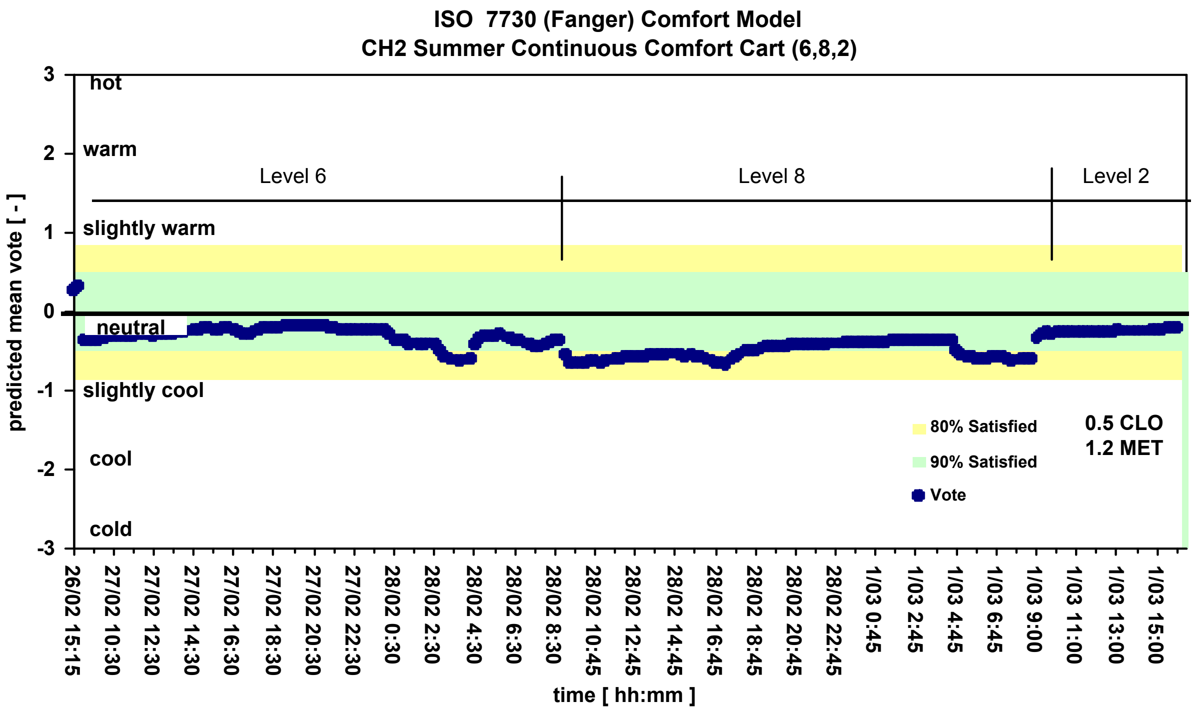

Figure 5 Continuous thermal comfort measurements during a summer period – MABEL

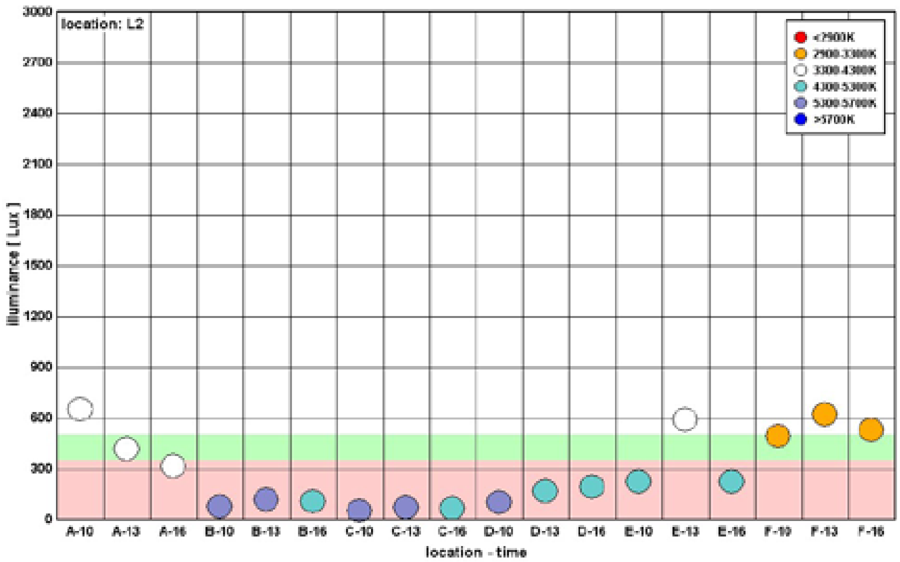

Figure 6: Level 2 – Horizontal Lux and Colour Temperature at Workplaces (Summer) - MABEL

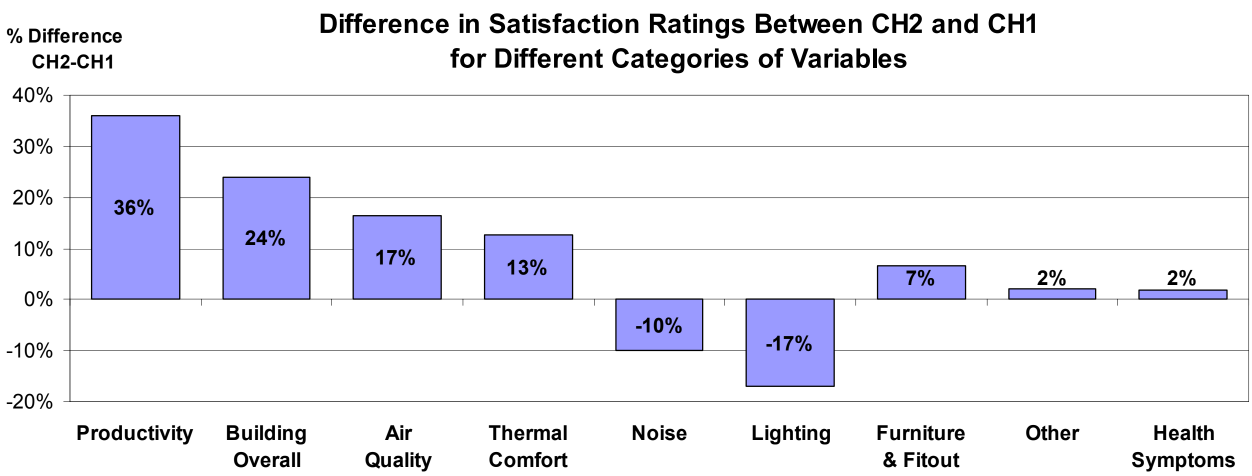

Figure 7 Difference in satisfaction ratings between CH2 and CH1 for specific categories of variables.

5. Acknowledgements

This paper draws on a range of coordinated studies as follows:

- Occupant Surveys of CH1 and CH2: Conducted by Adrian Leaman of Building Use Studies Ltd. in association with Leena Thomas, University of Technology, Sydney, and Monica Vandenberg, Encompass Sustainability.
- Indoor Environment Quality Monitoring of CH2: Conducted by Mark Luther and the MABEL team (Mobile Architecture & Built Environment Laboratory), Deakin University.
- Indoor Air Quality Monitoring of CH2: Conducted by Stephen Brown of CSIRO.
- Focus Group Interviews of CH2 Occupants: Conducted by Monica Vandenberg, Encompass Sustainability and Leena Thomas, University of Technology, Sydney in association with Adrian Leaman, Building Use Studies Ltd.
- A research project commissioned by the Cooperative Research Centre for Construction Innovation, 'Regenerating Construction to Enhance Sustainability'

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6. References

Paevere, P. and Brown, S. 2008, Indoor Environment Quality and Occupant Productivity in the CH2 Building, CSIRO Report No. USP2007/23, CSIRO Sustainable Ecosystems. Australia.

Table 1 - Difference in satisfaction ratings between CH2 and CH1, and correlations with Perceived Productivity in CH2 for different categories of variables

Category *(Avge % Diff; Avge R_{prod})*	**Variable**	**% Difference Satisfaction CH2-CH1**	**Correlation With Productivity in CH2**
Productivity *(36% Better)*	Perceived Productivity	36%	1.00
Building Overall *(23.8% Better; R=0.56)*	Comfort Overall	13%	0.61
	Design	20%	0.53
	Image	47%	0.54
	Facilities Meet Needs	16%	0.53
	Perceived Healthiness	35%	0.59
	Space use in the building	12%	0.47
	Comparison with Prev. Accommodation	NA	0.65
Furniture & Fit-out *(6.5% Better R=0.32)*	Furniture / Workstation	13%	0.42
	Meeting Room Availability	22%	0.32
	Plants	8%	0.19
	Space at Desk	-10%	0.30
	Space Layout	-6%	0.42
	Storage	12%	0.25
Health Symptoms *(1.9% Better)*	Health Symptoms: Summer	4%	NA
	Health Symptoms: Winter	0%	NA
IEQ: Air Quality *(16.5% Better; R= 0.38)*	Air Freshness: Summer	15%	0.36
	Air Freshness: Winter	18%	0.40
IEQ: Lighting *(17% Worse; R=0.28)*	Lighting: Artificial	-16%	0.15
	Lighting: Overall	-18%	0.32
	Lighting: Natural	-17%	0.38
IEQ: Noise *(10% Worse; R=0.4)*	Noise: Overall	-10%	0.40
IEQ: Thermal Comfort *(12.8% Better; R=0.44)*	Thermal Conditions Overall: Summer	17%	0.48
	Thermal Conditions Overall: Winter	13%	0.42
	Temperature: Summer	13%	0.47
	Temperature: Winter	8%	0.39
Other *(2% Better; R=0.29)*	Cleaning	13%	0.40
	Communication	6%	0.18
	Happiness	-6%	0.31
	IT	15%	0.25
	Privacy	-12%	0.42
	Autonomy	-2%	0.23
	Morale	0%	0.24

A BIO-INSPIRED VENTILATING ENVELOPE OPTIMIZED BY AIR-FLOW SIMULATIONS

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Keywords: ventilation, simulation, distribution, breathing, bio-inspired, mean-age-of-air.

Summary

A bio-inspired ventilating envelope is presented. The ventilating envelope consists of a distribution and arrangement of a basic component. In order to examine and optimize the performance of the ventilating envelope, we simulated the airflow inside two different rooms for different cases of component numbers, locations and distributions. For the simulations we used the computational fluid dynamics (CFD) solution tool, *Fluent*, with the re-normalization group (RNG) $k-\varepsilon$ and second order discretization schemes. Distribution of velocity profiles and mean age of air over various virtual planes for the different cases were analyzed and compared to the comfort level of a *standard* ventilation system. The analyzes show that, for specific cases, the fresh air is uniformly distributed due to a good mixing layer close to the inlet. Moreover, by choosing the right configuration of the components, it is possible to have either a diagonal or a vertical distribution of the mean age of air (MAA) in the middle of the room, thus, the ventilating envelope has the characteristics of two different standard systems being placed on the wall or at the ceiling.

1. Introduction

The primarily focus in current ventilation system developments is reducing indoor air quality problems with minimizing energy use (Addington 2000). Ventilation in buildings is provided either naturally or mechanically. In natural ventilation, the flow process is induces by wind and temperature (Liddament 1996), and the main negative aspect is the difficulty to control air flow. However, natural ventilation could be found in many buildings in order to provide fresh air. Mechanical ventilation controls air flow via systems that respond to the needs of the occupants. There are different ways to ventilate mechanically, such as extract-only, supply-only, supply and exhaust or balanced, and recirculation (Roulet 2008). Some of them have the risk of back draught from flues, and others require empty floor spaces in order to allow air flow from diffusers places in the floor (Liddament 1996). Mechanical ventilating systems include several components: fans, ducts, diffusers, air-intakes, air-inlets, air grilles, and silencers (Liddament 1996), where they have to be maintained from time to time (Roulet 2008).

The bio-inspired ventilating system acts as a breathing skin that has the ability to control the amount of intake and outlet of air through it (Badarnah et al 2007). The evaluated system in this paper could be considered as a combination of natural and mechanical ventilation, where the components create pressure differences in order to suck the air inside and the fresh air is moved from outside to inside through and via the skin. The integration of the system in the envelope creates a situation where the envelope is permeable, but still controlled.

The application of computational fluid dynamics (CFD) has been widely used in recent years with aiding in predicting ventilation strategies. One of the first studies using CFD methods for predicting air movement and heat transfer in buildings was done by Nielsen (1974).

In the present work, airflow simulations for rooms (3×3×3 m³ and 1×1×1 m³) with integrated ventilation system are presented. The 3×3×3 m³ room was chosen due to its minimal size as an occupied room, and the 1×1×1 m³ room was chosen for initial simulation tests that can be used later to compare with experiments in a similar room. The simulation tool, *Fluent*, was used with re-normalization group (RNG) $k-\varepsilon$ turbulence models. Details on the $k-\varepsilon$ model are given by Gatski et al (1996).

The tested ventilation system consists of components that suck air from outside to the interior spaces; these components are part of the building envelope. Section 2 presents the breathing skin with its components for ventilation, and it is based on the work done by Badarnah et al (2007). In the simulations section, different variation of intake and outlet distributions are shown, which resulted in determining the effective distributions of components for better air-flow circulation and lower mean-age of air (section 4). Finally, a discussion and the conclusions are presented in section 5.

2. Background

The bio-inspired ventilation system is part of the envelope and reacts to changing environmental conditions and influences the air pressure at the surface to perform a process of inhaling and exhaling, and it consist of a basic component with a special arrangement.

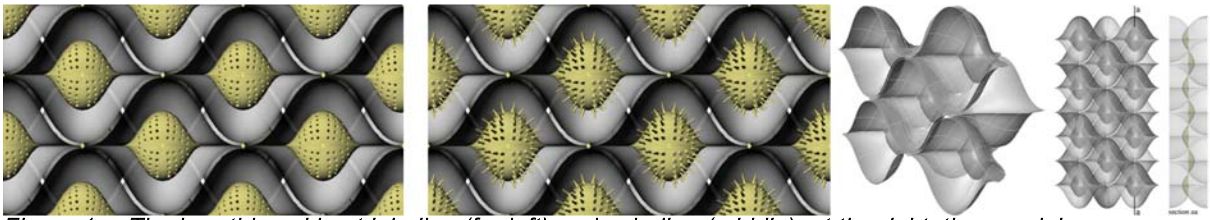

Figure 1 The breathing skin at inhaling (far left) and exhaling (middle); at the right: the special arrangement of the components and a cross section.

The *Lung-Like-Chamber* (LLC) consists of two surfaces attached to each other at their edges creating a specific volume in the basic component (Figure 2a). Piezoelectric wires are attached on the sucking surface of the lung like chamber. The sucking surface is controlled separately (Figure 2b&c). When a voltage is applied to the piezoelectric wires on the sucking surface, the lung expands and increases its volume and by that it increases the inner and outer surface area. A low pressure is created in the lung which results in sucking the air inside the lung (Figure 5b). The air flows into the lung through shafts on the surface of the lung. The shafts are designed in a way that allows the air to flow in one direction; valves are attached to the inner surface of the shafts, when the air pushes on the inner surface outwards, the valves are contracted and closed. Stopping the voltage from the surface results in contraction and creating over pressure (Figure 5c), which results in expelling the air out of the LLC through the other side, where the air pushes on the inner side of the expelling surface and results in opening the valves. By this action the air flow is controlled to flow through the lung in one direction.

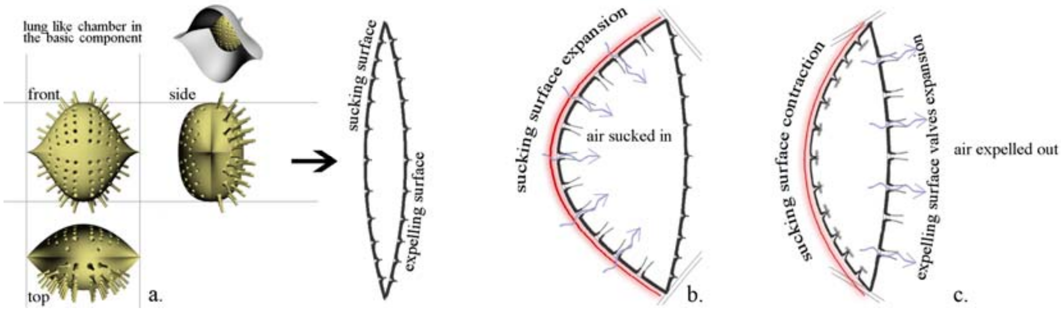

Figure 2 The expansion and contraction of the Lung-Like-Chamber (LLC).

The expansion and contraction of the LLC is combined with the movements of the basic component (Figure 3a-d). When the lung expands the basic component deforms and opens to create a bigger volume on that side where the lung had expanded (Figure 6b). Creating a bigger volume increases the low pressure and increases the air sucking from the surrounding environment. When the lung contracts and creates over pressure inside (Figure 3c), the basic component is deforming and closing the side where the air was sucked inside the lung, and opening the other side (Figure 3d). In this way the skin sucks air from one side and expels it to the other side. The skin consists of LLCs that take air from outside to inside, and LLC's that take air from inside to outside. In this way the air is exchanged continuously through the same system.

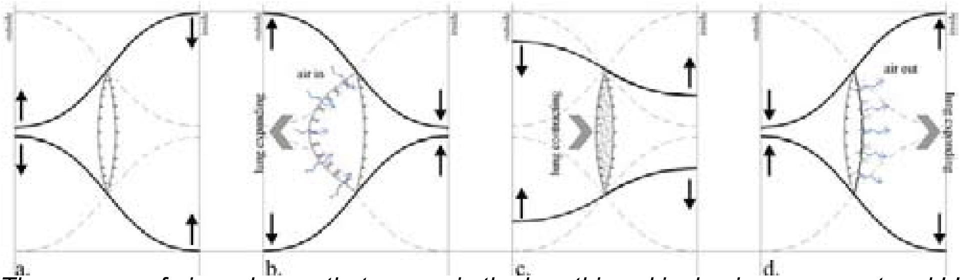

Figure 3 The process of air-exchange that occurs in the breathing skin, basic component and LLC combination.

The main advantages of this ventilation system are its direct contact with the fresh air, where the air doesn't have to flow through ducts and long distances to get to the occupied places, and the system has fewer components involved in the ventilation process than other standard systems. The system creates a controlled permeable envelope, where its porosity reacts to the interior needs and requirements of the occupants in terms of air quality.

3. Simulations

3.1 Geometry of Rooms

Two different rooms were considered in the simulations. The first room is a 1 m³ *testing room* with equal width (x -direction), length (z -direction) and height (y -direction). The second room is a *standard room* with width, length and height being all *3 m*. The origin (0,0,0) was placed on the right back bottom corner of the rooms. The components of the simulated ventilating systems, such as the LLC or the openings of a standard ventilating system, were placed on the front wall for both rooms, the xz plane.

3.2 Lung-Like-Chamber (LLC)

3.2.1 Geometry and Inlet Conditions

A schematic representation of LLC geometry is given in Figure 4. Each LLC consists of 17 openings with velocity vectors being inclined in x -, y - and z -axis as shown in the figure. Each opening has a velocity vector of 0.2 and 2 m/s in the case of the testing and standard room, respectively. It is notable that the simplified representation of the geometry of the LLC was considered. Thus, velocity vectors with different angles were considered expelling air in or out, while the original spherical shape of the component was neglected. It is also noticeable that there are two types of LLC's, the first expels air inside the room (LLC-in), and the second expels it outside (LLC-out). In principle the two types are identical, except that the direction of the velocity vectors is flipped. The airflow angles at the openings, as shown in Figure 4 for any axisymmetric line, relative to the axisymmetric line are 30^0, 60^0, 90^0, 120^0 and 150^0.

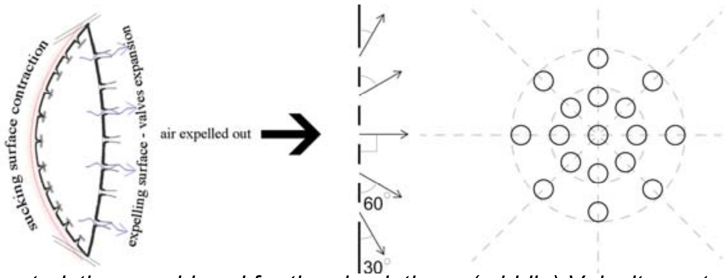

Figure 4 LLC characteristics considered for the simulations. (middle) Velocity vectors through the middle section. (right) LLC's holes distribution and amount.

3.2.2 Configuration

Equal numbers of LLC-in and LLC-out were considered in all of the simulations for each room. A summary of the different cases simulated is given in Table 1, and the configuration and number of the LLC's for the different cases is shown in Figure 5.

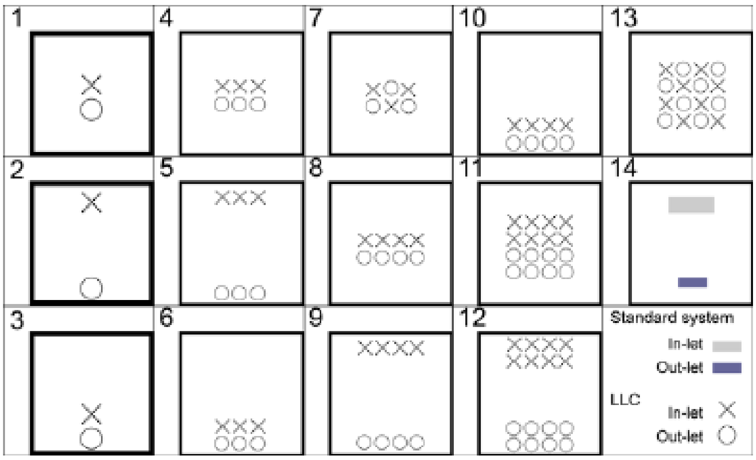

Figure 5 Numbers 1-13 present different cases of LLC configurations; Number 14 is a scheme of a standard ventilation system.

3.3 Standard Ventilating System

An additional simulation of the airflow in the standard room with a rectangular ventilating system was carried out for comparison matters. The height of the inlet and outlet is 0.2m and the width is 0.4m. The inlet has a flow rate of 0.0855 m³ (equal to the flow rate of cases 11-13). The inlet and outlet were placed in the middle of the front wall at distances 0.2m from the ceiling and floor, respectively (see Figure 5).

3.4 Solution Setup

3.4.1 Grid Spacing

A hexahedron cell has been chosen due to its homogeneity with the rooms. Different types of grid spacing were chosen: 0.01-0.05m for the testing room; and 0.1-0.3m for the standard room. The number of elements and nodes of the hexahedron cells are given in Table 1.

3.4.2 Approach

The approach that was used to treat turbulence in the rooms is the Reynolds averaged Navier-Stokes equations (RANS). The assumption in this approach is that flow quantities are averaged in time allowing fluctuating quantities from the mean term. These fluctuating terms produce additional turbulence terms that require closure models. Among these models, we chose the zero-equation model and the re-normalization group (RNG) $k-\varepsilon$ in order to treat turbulence near the openings.

Convergence was reached when the normalized residuals reached below 10^{-3}, and below 10^{-7} for temperature. Details on the computational time and number of iterations for the different cases are presented in Table 1.

Table1 A summary of the computational parameters of all cases.

Room (m³)	1×1×1			3×3×3										
Airflow rate (m³/s)	0.0011			0.032				0.0427			0.0855			
Configuration case (Figure @)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Maximum Grid spacing (m)	0.05	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3
Number of elements (×10³)	141	162	146	653	739	661	653	817	951	885	835	932	835	470
Number of nodes (×10³)	153	174	157	685	775	694	685	857	996	927	894	996	893	527
Computational time (min)	20	10	10	90	60	60	30	100	120	80	45	45	30	30
Number of Iterations	85	70	80	520	125	120	50	185	160	120	85	135	45	245

4. Results

Results of the mean age of air (MAA) for the different cases of LLC configurations are presented in Figures 6 and 7. It is observed, in Figure 6, that the MAA is strongly related to the configuration of the LLC. Cases 3, 6 and 10, where the LLC's were placed at the bottom of the wall, have the highest MAA compared to the other cases with the same number of LLC's. However, larger number of LLC's, and thus higher flow rates, doesn't guaranty a lower MAA. As an example, in cases 4 and 8 the flow rates entering the room are, respectively, 0.032 and 0.0427 m³, even though, the MAA in case 4 is lower than in case 8. The circulation near the inlet, of case 8, causes the fresh air close to the front wall to be expelled through the outlet at higher flow rates than the rates at which air enters further inside the room.

Figure 7 compares between two different solutions for cases 11-13. In the first solution the zero equation with first order scheme was applied, and in the second the $k-\varepsilon$ solver was addressed with the following discretization schemes: standard pressure; first order momentum; second order temperature; and second order turbulent kinetic energy and turbulent dissipation rate. The zero equation can be used as an initial solution of the problem, then $k-\varepsilon$ with second order discretization schemes is used in order to account for convection and diffusion of turbulent energy in the solution. Nevertheless, it is possible to use the zero equation for case 12 if only the MAA over the total volume is of interest.

It is notable that the MAA of case 12 is the lowest among all other cases with LLC's. However, this doesn't necessarily mean that the distribution of the *comfort level* of case 12 is the best. In order to evaluate the comfort level of case 12, additional simulation for a standard ventilating system, such as case 14, was considered for comparison matters.

Results of the MAA and flow velocity profiles for cases 12 and 14 are presented in Figures 8 and 9. The values in Figures 8(A) and 9(A) were calculated on the central vertical line, and in Figures 8(B) and 9(B) on the central horizontal line in the z-direction. In Figure 8 it is shown that the MAA of case 12 is higher than case 14, along the chosen line, however, the distribution of the MAA of case 12 is uniform. This means that fresh air is more uniformly distributed in case 12 than in case 14. This can be explained by the better turbulent mixing produced in case 12 due to the distribution of the inlet openings over larger distances with varied angles of airflow inlet and outlet. As a result, a noticeably lower mean air speed is obtained in case 12 as shown in Figure 9.

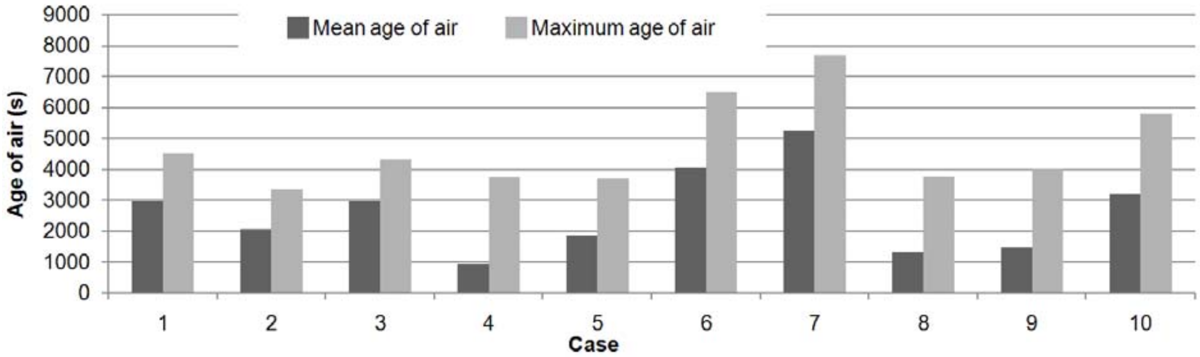

Figure 6 Mean and maximum age of air for cases 1-10.

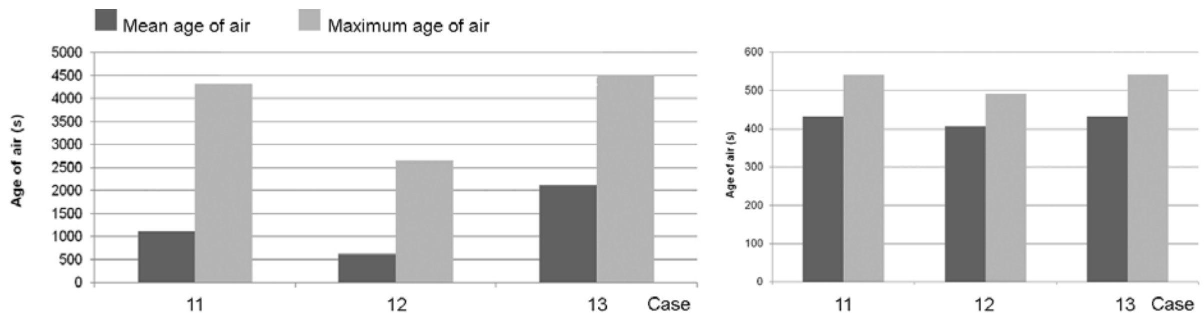

Figure 7 Mean and maximum age of air for cases 11-13; left: zero-equation; right: RNG with second order discretization schemes.

Figure 10 and 11 show isolines of the MAA in the $(-x)$ and $(-z)$ planes respectively. The figures compare isolines from case 12, on the right, with isolines from case 14, on the left. It is also notable, in Figure 10, that more isolines of the fresh air, in case 14, are located in the upper part of the room. Except this observation, the two plots in Figure 10 seem to have similar trend. However, a basic difference is noticed in Figure 11 between the isolines of cases 12 and 14. The change in the MAA isolines is diagonal in case 14 (left plot of Figure 11), whereas vertical in case 12 (right plot).

Figure 12 presents particle trace from the upper LLC plane (inlet) colored by MAA. The airflow enters at different angles and then, due to the LLC's that are situated at the bottom and expel air at different angles, the airflow moves almost vertically in the middle part of the room.

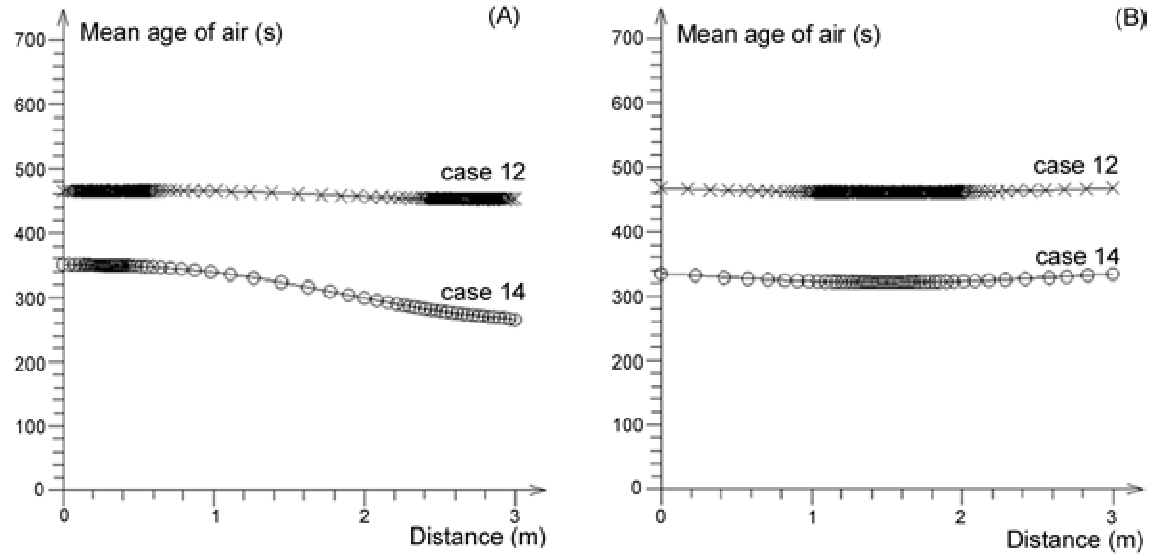

Figure 8 *Variation of the mean age of air (MAA): (A) along the central vertical line; (B) along the central horizontal line in the z -direction.*

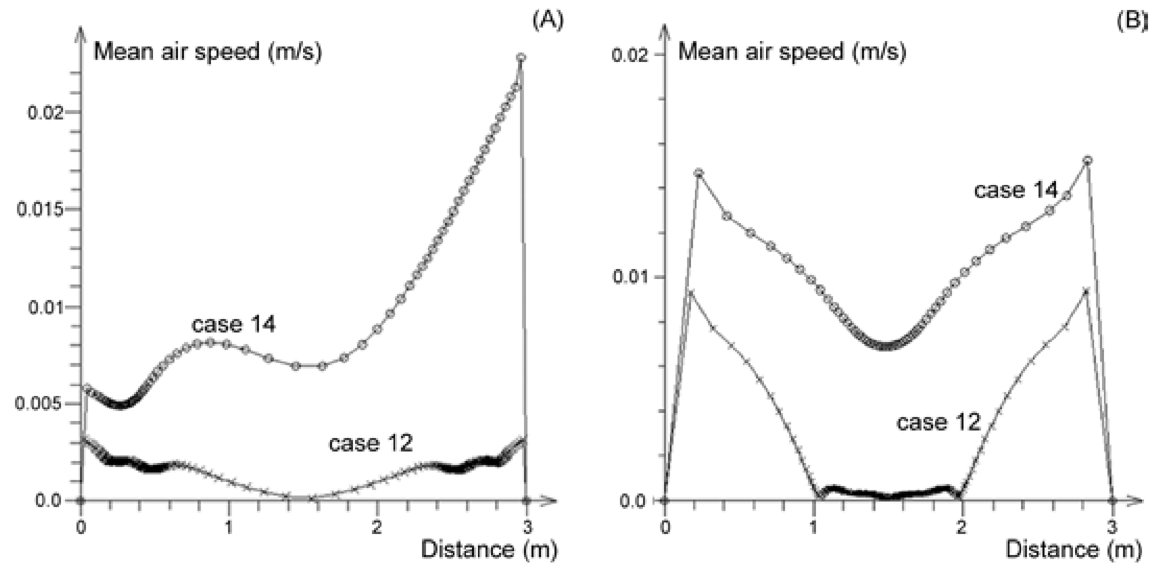

Figure 9 *Variation of the mean air velocity profiles: (A) along the central vertical line; (B) along the central horizontal line in the z -direction.*

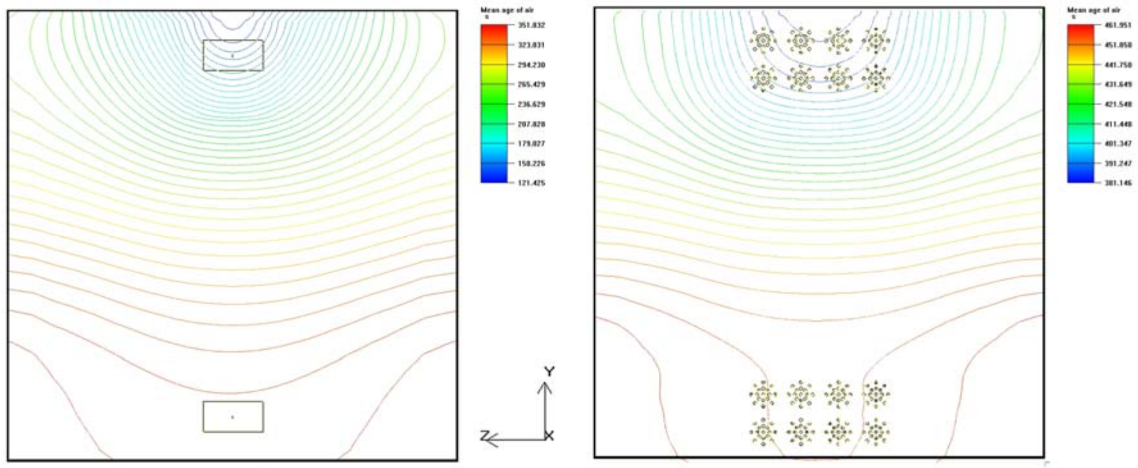

Figure 10 Isolines of mean age of air (MAA) in the $(-x)$ plane at $x = 2.5\ m$; left: case 14; right: case 12.

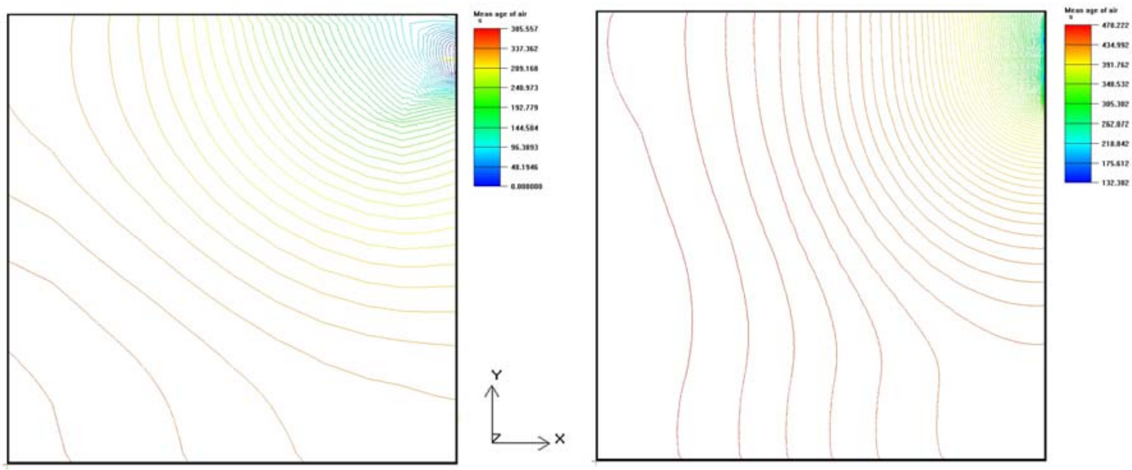

Figure 11 Isolines of mean age of air (MAA) in the $(-z)$ plane at $z = 1.5\ m$; left: case 14; right: case 12.

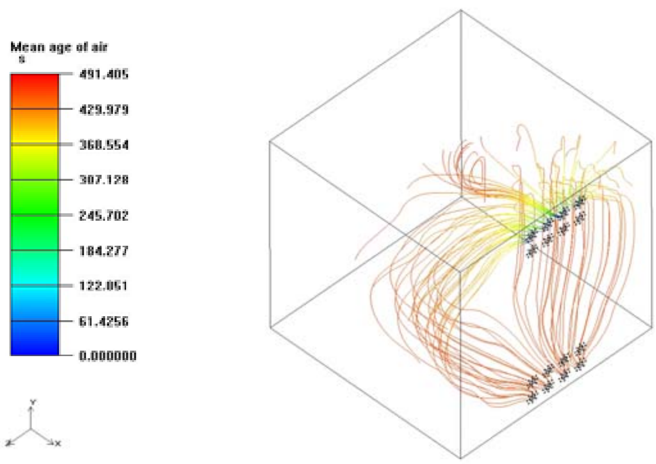

Figure 12 Particle trace from the upper LLC planes of case 12, coloured by mean age of air.

5. Discussion and Conclusions

Simulations of 13 cases of different configurations, locations and numbers of components in a bio-inspired ventilating envelope have been carried out. By analyzing the MAA, of the different cases, it has been observed that increasing the amount of LLC-in and LLC-out does not guarantee a better distribution of the fresh air. Thus, the location of the different components has a significant effect on the distribution of the fresh air. For example, in case 13 there are almost three times the amount of components found in case 4, however, the MAA of case 13 is only a factor of two times lower.

Among the simulated cases we found that by increasing the amount of components, a larger distance between the LLC-in and LLC-out is required for effective ventilating. At short distances between the LLC-in and LLC-out, increasing the number of components results in higher rate at which fresh air is being expelled outside before mixing, in this case the component special property of sucking and expelling air at varying angles might become a disadvantage. Whereas, given the 'right' balance between the number of components and the distance separating the inlets and outlets results in a turbulent mixing layer which distributes the fresh air almost homogenously at each constant horizontal line parallel to the inlet plane.

An interesting result is the fact that when the LLC-in and LLC-out are, respectively, situated at the top and bottom of the wall, the isolines of the MAA show vertical distribution, which is a characteristic property of ventilating systems located at the ceiling.

Furthermore, improving the fresh air quality inside the room could be achieved via standard sliding windows, but the bio-inspired ventilating system is considered as a ventilating wall, where there is no need to open windows and no requirements for temperature difference during its operation.

In order to further optimize the ventilating envelope for specific operating conditions, the effect of inlet-outlet distance, other configurations and possibly simulations of occupied rooms need to be investigated in more details. Moreover, in this paper we only considered the inlet and outlet being at the same wall, whereas it is possible to look at the effect of components distribution on multiple walls. This is left for future work.

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DRIVING FORCES AND BARRIERS FOR IMPLEMENTATION OF A BUILDING ENVIRONMENTAL CLASSIFICATION SYSTEM – EXPERIENCES FROM THE SWEDISH BUILDING/LIVING DIALOGUE PROJECT

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Summary

A review is performed dealing with different driving forces and barriers related to implementation of a national classification system developed according to fit the scope of the classification system to be applied by the Building/Living dialogue project group. The result is based on an enquiry to the project group within the Building/Living dialogue. The enquiry is based on the experience from earlier interviews performed and was resulting in a number of key aspects found crucial for the implementation and establishment of the B/L classification system focusing on non-technical aspects. The following barriers and opportunities related to the B/ classification system are analyzed and evaluated in the paper:

- Classification and incitements
- Other classification, declaration and labeling systems
- Communication and organizational matters
- Legal aspects.

As a result of the enquiry the most important driving forces and barriers are identified. A discussion is conducted of how to handle these driving forces and barriers.

1. Introduction

The dialogue project Building/Living is a cooperation between companies, municipalities and the Government with a signed agreement and commitment to take the lead to achieve a development of a sustainable building and property sector in Sweden. This will be achieved by the means of introducing a classification system. Furthermore, the system will be supported by incitements from insurance companies, credit institutions, banks and the Government. Besides these originally incitements there are other types of incitements identified. The goal was that by the year 2009 all new buildings and thirty percent of existing buildings are voluntarily classified. This goal will not be possible to meet since the development of the classification system has been delayed.

A first draft classification system to be adopted by the Building/Living dialogue has now been launched (Glaumann et al 2008) and is here referred to as 'B/L classification system' version 2008:1: The dialogue project Building/Living set up three prioritized areas for the aimed classification system: Healthy indoor environment, Efficient use of energy and Environmental impact. The latter area has been redefined in the B/L classification system and is now divided into chemical substances and other environmental requirements that include aspects that are relevant only for certain buildings or buildings applications.

The B/L classification system can be utilized for existing and new buildings, where most of the requirements have to be verified by the existing building's performance, why a classification for not constructed building only can be an interim classification.

Four rating classes; A to D are defined in the system. Rating class C means that the building fulfills the current building code in force or current building practice if not regulated. From class C up to the best class A, the incitements are planned to increase. Consequently the cost to perform the classification might increase. The classification system up to class C is performed as a self-certification without external experts. However, for class A or B it may be required a third party expert to get the increased incitements.

Since the dialogue project Building/Living's scope is to establish a common building classification system that will be widely used by in the building and real estate sector by voluntary means, it is crucial to identify driving forces and barriers for implementation of the now launched B/L classification system. This implies that barriers can be found in the B/L classification system as such as well as organizational matter. This paper describes such early experiences from the Swedish Building/Living dialogue.

2. Key issues for implementation of the Building/living classification system

The current version of the B/L classification system is about to be launched on the Swedish market. Earlier versions of the system have been set up and validated (Carlson and Erlandsson 2006, Carlson et al 2007) mostly focusing on the indicators selected and classification requirements. A number of other more non technical barriers and driving forces can be found and handled in this paper. The methodology selected to investigate the opinion of different actors in the Building/Living dialogue about the classification system is examined by the use of a fixed enquiry in this paper. Earlier work within the developing work by Carlson and Erlandsson (2006) and Sundkvist et al (2006), has used interview technique. A number of crucial key aspects were selected for the enquiry, based on frequent issues appearing within the development of the classification system in relation the Swedish Building/Living dialogue group. These key aspects and the evaluation of the enquiry result are reported below.

2.1 Classification and incitements

A number of incitements may be found to conduct and assist an environmental classification system like the B/L classification system outlined by Miljövårdberedningen (2000). An increased knowledge of the own building as basis for improvement is fundamental but not enough to become a system that has a goal to be applied by a majority of the buildings in the stock. In the Building/Living dialogue project group on classification by Sjöberg et al (2003), different economical incitements were regarded as the most crucial as driving force for improved environmental performance. The importance of economical incitements for a market penetration is also confirmed by Sundkvist et al (2006).

The building classification shall in the Building/Living context be regarded as a voluntary tool for continuous monitoring of the building performance and not as a goal as such. Nevertheless, the costs to conduct the classification may not only be motivated by increased knowledge, but also the fact that high performance building should ideally receive economical incitements. The most important economical incitements that were defined by the Building/Living dialogue project report on classification are (Sjöberg et al 2003):

- Reduced building tax
- Less insurance fee
- Better loan conditions

An obvious economical incitement is the fact that that the classification – especially if it is accepted by both the government and market actors – could be a proof of an environmental high performance building and therefore as a better investment and market value. This incitement was not mentioned separately as a driving force in the Building/Living dialogue project report by Sjöberg et al (2003). This report had the scope to investigate the basis to establish a Building/Living unique building classification system. The fact that increased market value not was pointed out as a separately incitement can be explained by the building tax system valid at that time, where an increased market price/value would result in an increased building tax, since this was found on the market value (i.e. a counterproductive in an environmental view point). Since then, the building tax system has changed to a municipal tax with a limited fee per building. Therefore, an increased market value may now be essential for carrying out the classification.

On a general level it was asked in the enquiry to rank the most important barriers where the lack of incitements was pointed out together with the fact that the system is not well known on the market as the significantly most important barriers. This implies that there has to exist more incitements than increased knowledge of the building, if the market shall use the classification voluntary. A follow up question where the Building/Living dialogue group ranked the number one most important factors if the classification system should become a national de facto standard was not surprisingly that the system must have a function for increased market value when a building is for sale or to rent.

In the Swedish market only limited economical incitements are given by banks or insurance companies that are related to the environmental performance of a building. An indicator of an improved discount rate can be found by analyzing the situation for green cars. The bank SEB offer 7,18% as discount rate for a car loan and if it's a green car the rate will be 6,18% (April 2008), i.e. 1,0 % lower. Another Swedish bank Swedbank gives building owner a discount rate of 6,35% if the use of the money is used fore energy efficiency investments. This could be compared to a loan without any security of 7,76% that may indicate a reduced rate of at least 1%. However, an environmental classification is not needed for carrying out an energy efficiency investment and not for short loans with a pay back time of about 5 years. Experience from low energy concepts like Passive housing illustrates that part of the success for such buildings is that they were supported with better loans. For instance in the Swiss Miniergie system a reduced discount rate of 0,6% or up to 1 % is achieved by Zürcher Kantonalbank and Bank COOP (April 2008) respectively.

The insurance company Länsförsäkringar has indicated that they think that the insurance fee for a single family house could be reduced by a third for building that fulfills the requirement with the best performance class in the classification system. This means in actually figures about 150 € per year. If the cost to perform the classification for a single family house is about 1500 €, as given as an example in the Building/Living report 'B/L classification system version 2008', the pay pack time will be fifteen years and maybe not worthwhile. Nevertheless, if the result of the environmental classification qualify for an reduced discount rate of 0,5% this would result in a pay pack time less than years for a building with a loan about 200 000 €. The importance of cooperation and involvements by financial actors like banks is therefore crucial for economical motivation to conduct a classification on the Swedish market.

2.2 Other classification, declaration and labeling systems

In Sweden a number of classification and labeling systems for buildings are used. There are two systems that are more widely used than the others. One is Miljöstatus för byggnader/MFB, (Environmental Status of Buildings) which was developed by a group of companies representing building owners, developers and consulting companies. This system has been used for both commercial buildings and multifamily houses. More than 20 million m^2 of floor area have been classified. The interest for this system has drastically dropped the last years.

Other systems on the Swedish market is Miljöinventering i befintlig bebyggelse/MIBB, (Environmental investigation of existing buildings) which was developed by four organizations for multifamily houses. The only LCA based system that are used regularly on the Swedish market is Anavitor (Erlandsson et al 2007) that for instance is used by the construction company NCC to create climate declarations for all residential buildings. In this climate declarations from NCC there are also an energy classification reported that are based on the energy criteria for delivered energy defined by the B/L classification system. This actually makes NCC also as the first user that applies parts of the B/L classification system regular. Other examples of methods used are Miljöbedömning av fastigheter/MBF (Environmental appraisal of buildings), LEAD, BREEAM, Green Building, P-märkningen (the P-label) and Svanen (the Swan ecolabel).

At the moment there seems to be a growing interest for methods focusing on energy, i. e. the European Green Building, the Swiss Minergie, the German Passive house. All those energy systems will be covered by the B/L classification systems, which also encompass indoor environment and dangerous substances.

According to the result of our enquiry there was a great consensus that systems used in Sweden must be adapted to circumstances that are specific for Sweden building codes and practice. This result combined with the assumption that the foreign system also includes economical incitements pointed out by 67% by the responders as non-interesting. The same question but where the system was used an several countries was consider as non-interested by 73% There was also frequent given comments to these questions in the enquiry that it is one common system that is wanted for the building and real estate sector. Several of the notes given to this question in the enquiry pointed out that they were waiting for the B/L classification system to be launched and have been unwilling to introduce other methods for some time.

2.3 Communication and organizational matters

A number of practical issues such as how the classification body (or non) shall be found or how the result of the classification should be verified and communicated are all part of a classification system that makes it operational in reality. The enquiry points out that how the verification is carried out as the most important aspect to handle reliability, in favor to how the public communication is regulated or the organization structure behind the classification body.

When developing the system it has been discussed very much who shall be allowed to do the classification. One option was that the owner himself should do it as a kind of self-claim/-certification, here called *self-declaration* (see ISO 14021 and EN ISO/IEC 17050-1), like the declaration that is used for income tax (where the figures are given on our honour). Another one was to have a certified person to do this. A key problem was that the B/L classification system should according to the initial approach by Miljövårdberedningen (2000) be a voluntary one, and in order to get many owners to use it should not be too expensive as stressed by Sjöberg et al (2003).

Table 1 Enquiry alternatives on verification alternatives

Alternative verification of the classification result	Interesting alternative
Self-declaration, no requirements of public documentation	14%
Self-declaration, documentation available on request	21%
A third party verification performed by anyone	43%
An (by the org. body) authorised third part verifier	29%
Several alternatives parallel	36%

Note that more than one alternative may selected by the responder. If e.g. 14% pointed out an alternative as interesting, we have interpreted that 86% do not think this as a relevant alternative. The same structure is used for all query questions within this section.

The enquiry does not give any single solution on how the verification of the classification should be performed. An interpretation of the enquiry result (see Table 1) is that there is a greater consensus of what kind of verification system that is not generally accepted by the Building/Living group, namely a self-declaration system. The reverse result had been more beneficial. Nevertheless, a self-declaration may be acceptable if it is one option where also a third party classification is possible. The experience from the up to now carried out building classifications by professional real estate owner is that often a consultant or an internal expert does the classification work. Both of these persons may act as a third party, why this verification alternative seems as reasonable for a professional real estate owner. However for non professional owners of single family houses or multi dwellings a Self-declaration is preferable according to the organization Villaägarna (i.e. the home owners' organization). Comments in the enquiry also indicate that a self-declaration may be suitable for internal use within a company.

In the enquiry we asked; How do you want the classification system to be organized and further developed, and by whom? There was a strong majority (73% pointed out this alternative) for the Building/living secretariat to take this responsibility and to manage the system for the future. Other possibilities were to start an economical association (do. 27%) or to let Kretsloppsrådet,(The Swedish Ecocycle Council) (do. 33%) manage the system. The future organization of a classification system is on the top of the agenda in the Building/living secretariat and has to be handled in such why that a long term solution is found, where the problem is that the Building/living secretariat existence is limited in time. It is interesting to notice that Boverket (The National Board of Housing, Building and Planning) or any other governmental body is mentioned by 50% of the responders in the query when they have the possibility to select an alternative body not given in the fixed list. This actually makes Boverket a rookie.

The classification system is built up of four elements: Topic (Energy, Indoor Climate, Chemicals), Aspects, Indicators and Classification criteria, see Figure 1. The result from the classification can be presented on all these levels, but to streamline the interpretation of the classification result it may suitable to only communicate an agglomerated result per topic. An alternative to introduce a scoring system that includes weights between the topics would make it possible to condense the building classification result to one single figure.

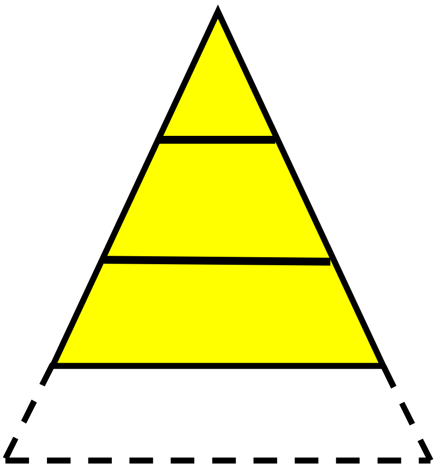

Figure 1 The structure of the classifications topics and the underlying aspect with indicators and the related classification criteria.

We asked in the enquiry how they wanted the classification result to be presented as a whole, from a single score and then following the structure in Figure 1 to the individual indicator result. A majority preferred to present the class for each topic (73 % pointed out this alternative, compare with the structure in Figure 1) and not to have one class for the whole building (do. 43%). Since more than one alternative was possible to point out in the enquiry also the possibility to introduce a single scoring system is not negligible. Especially some property owners (do. 60%) wanted to have one single class.

On the question how they wanted the classification to be designed and presented in a building, 71% preferred an A4, where the result was presented like a diploma or declaration, i.e. including the classification result. But also the alternative to design a label or similarly mark that indicate that the building was classified (but not the result of it) was pointed out by 64% as a good way to communicate to the visitors to an individual building. Regardless of how the result is shown in the building 57% think that the full classification result shall be available somehow to a document stored in the building.

Another aspect that was examined was how long time the classification should be valid. The majority, 85 %, meant that there must be a time limit. Some (do. 46%) argued that it should have the same time as the energy declarations, i.e. 10 years. Other (do. 38%) meant 5 years in a buying-selling situation.

2.4 Legal aspects

Since the system is voluntary the legal aspects of a classification is dependent on the status it has in the agreement between two parties. The classification could be seen as part of the information given in a situation of buying/selling or leasing a property according to the requirements in the Swedish legislation. However, the juridical importance according to the current legislation is limited for a declaration or classification like the B/L classification system. Such declaration or classification shall be regarded as a sort of risk warning (SOU 2004:109). The interpretation follows the interpretation of the classification result done by the Building/living group, where 67% of the responders in the enquiry didn't regard the classification result as a part of the juridical based information required in the buying/selling situation (mentioned above).

If the reverse appears that the classification results with high performance, i.e. class A for several topics. This can be seen as some kind of guarantee for the status of the building (SOU 2004:109) in the same situation. This will then have to be confirmed by the seller. The fact that the classification result was accepted as a guarantee was accepted by 75% of the responders in the enquiry. To be reliable in this kind of situation the classification should be done by a third party and not a self-declaration. There are special inspectors who investigate a building to be sold. They have technical and juridical education and are authorized by an organization (SBR). The inspectors have a responsibility insurance covering their business. The inspection follows a certain formula developed by SBR. So in this case the classification has a high degree of reliability. Though there is a disadvantage that these inspections is at the start focused only on an ocular inspection of the building itself and do not include water and electrical installations. If there are obvious risks the inspector can propose a deeper investigation.

In the situation of marketing and selling a house or apartment it has been pointed out that it could be a problem for the constructors to guarantee the highest, class A for indoor environment, since this class in the B/L classification system is dependant on the result from a questionnaire answered by the people living or working in the building (performed one year after they have moved in). They argue that the people can use this situation to their own advantage and affect the result of the classification by their answer to this enquiry. In the enquiry performed here a question asked if this indoor environmental declaration was a problem and therefore barrier for the use of the system, which resulted in a score of 3,5 where 1 is an important factor and 5 is a insignificant factor.

3. Conclusion and discussion

Based on the result of the enquiry it can be concluded that the significant identified non-technical barriers by the Building/Living group are as follows:

- The system is not well known
- The system is not yet related to any incitements
- The system is not reliable, since no organization is established
- The B/L classification system will not be applicable for all purpose why other (existing) environmental classification systems may be utilized parallel

Besides the non-technical barrier listed above, it is a frequent comment given in the enquiry that the system has to be simple to understand and to conduct. The Building/Living secretariat will start an information campaign about the B/L classification system during the spring 2008.

The lack of incitements and then for certain economical ones are a problem where no progress have been showed, even the fact that it has been part of the dialogue discussion at least since the first report on the aimed classification system (Sjöberg 2003). These kinds of incitement barriers can be handled by utilizing any governmental controlled system, as well as voluntary handled by commercial actors like the companies given in section 2.1. The problem in the latter case is if no win-win situation may occur. In the case of a bank it may be a case that the monetary risk is less for an environmental high performance building.

The discussion of the future origination of the project is now intensified by the Building/Living secretariat. The fact that Boverket was mentioned as a potential body to manage the system was surprising, since they have not so far been mentioned by this kind of people that take part actively in project meetings. Since the Building/Living secretariat is oriented as part of Boverket's organization and the mandate of the Building/Living secretariat is limited in time, this new information may be a door opener for new organizational solutions.

Other systems that may be used parallel to the B/L classification system (and therefore may not be regarded as competitors) are:

- Life cycle assessment (ISO 14040, -44)
- Building product declarations (type II/ISO 14021 or type III i.e. based on ISO 14025, ISO 21930)
- Climate declaration (a subset of product declarations type III given above)
- Energy declarations (following the EC building energy declaration directive)
- Other energy classification system that may be a subset of the best energy performance class A, such as Passive houses or Minimal energy houses that in Sweden are defined by FEBY (Erlandsson et al 2007, 2008)
- Due diligence
- Management systems like environmental systems like ISO 14001, or energy management systems like SS 627750.
- Different databases that give information like content declarations of building products.

Other systems with the same scope including all four classification topics that are part of the B/L system have more to be regarded as competitors to the B/L classification system. If a classification system (especially if it is non-mandatory like the energy declaration) it will always be a possibility for the B/L to adopt these kinds of specifications and/or give complementary classification criteria.

The following driving forces for the classification system are found on the enquiry answers:
- The system has to influence the market value of the building

- A class A building is related exclusively for (few) high performance buildings
- The system is adopted to/design for national conditions
- The national acceptance achieved is crucial (and much more important than a system based on international standards/work)

The added value for a building that has a B/L classification is not yet possible to evaluate, since no experience is available. Even if no precise figure can be established it seems quite reasonable that using the B/L classification system within our business will increase the good will of the origination as the value of the construction work where it is applied.

In the development work of the B/L classification system it was a common argument that class A should not be to tough (i.e. hard to achieve for all). So, we were a bit astonished when the enquiry indicated that a majority indicated that it has not to be a problem if class A is only reasonable to achieve expect for new or retrofitted buildings. However, this result seems to be sound and will support that the system is found pro-active supporting the “best in the class” and not a passive system only focusing on the opportunity to limit the worst ones.

Both the fact that the systems take national aspects into account and that it is part of a national dialogue project is a fact that supports the national acceptance of the system. The research team behind the classification system and their earlier experience from working in this field has hopefully also a positive impact of the acceptance of the system. However, even if the system is technically perfect concerning the definitions of classification criteria, it has also to be reasonable to conduct. This is an important aspect with the ongoing test of the B/L classification system 2008:1. If it is found as a problem to conduct the system it has to be improved by the project group behind the B/L classification system. Nevertheless, non-technical barriers included here have to be handled in a larger context and involves far more parties than the project group, and will be part for the future work to establish a classification tool that will contribute to a more sustainable future.

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THE INFLUENCE OF CONSTRUCTION MATERIALS ON THE LIFE CYCLE ENERGY USE AND CARBON DIOXIDE EMISSION OF MEDIUM SIZED COMMERCIAL BUILDINGS

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Summary

This paper describes the influence of construction materials on the life cycle energy use and carbon dioxide emission of medium sized commercial buildings. When describing buildings by materials, there is a tendency to label according to the main material used, however, the vast majority of commercial buildings use a large number of materials. Hence it is not clear which materials or combinations of materials can achieve the best performance, in terms of life–cycle energy use and carbon dioxide emissions.

In order to develop a set of 'benchmarks', this research modelled the performance of three similar medium sized commercial buildings, located in the temperate climate of New Zealand, each designed using primarily concrete, steel or wood.

The model was based on an actual six-storey 4250 m^2 floor area building, with a mixed–mode ventilation system, currently under construction at University of Canterbury in Christchurch. While the actual building is being constructed in concrete, the authors have designed alternative versions in which the structures and finishes are predominantly steel and wood.

The analysis of each case study includes the calculation of embodied energy and embodied carbon dioxide. The whole life-cycle energy used and carbon dioxide emitted in the operation of the buildings was simulated using DesignBuilder software.

The results indicate that for an office building in which inside temperatures are controlled by an HVAC system, materials do not drive the life-cycle energy performance. The total operational energy over a 60 year life results in about 90% of the total lifetime CO_2 emissions, the same figures applying roughly for all three buildings. Of the remaining 10% of CO_2 emissions due to initial and recurrent embodied energy the largest difference between the three designs is in the embodied CO_2 emissions from manufacturing the building materials.

Introduction

Participants in this conference will need little reminding of the environmental impact of buildings. Events such as these serve to reinforce the message that in the developed world around 40% the energy use and 24% of carbon dioxide emissions can be directly associated with buildings – their construction, operation, maintenance, renovation, and so on (IEA, 2008).

Architects are being forced to radically re-appraise the nature of their role. Having traditionally thought of themselves as enhancing the environment, they must now consider seriously the potential environmental impacts of their activities and those of the building industry generally. There is an urgent need for information that will enable architects and the building industry generally to assess these environmental impacts, and for tools that will allow them to make an unbiased assessment of any negative effects of their activities on the wider environment; and thus fulfill their professional responsibilities to both their clients and to the wider community.

This paper will attempt to provide some of that information by exploring the influence of concrete, steel, or wood as the main construction material for the sub-structure, super-structure and finishes of a six-storey commercial building, on the potential environmental impacts over a nominal 60 year life-cycle.

Scope and Methodology

Energy use and construction materials for commercial buildings

Considerable effort has already gone into addressing these issues for domestic scale buildings (Mithraratne & Vale, 2004) which because of their greater numbers tend to be perceived as having the largest impact at a national scale. In addition, residential construction tends to be simpler than commercial construction, hence it is more readily classified and standardised, making analysis of energy and materials impacts relatively straightforward. Commercial-scale buildings on the other hand tend to be 'one-off' buildings with a wide range of functions, making them much more difficult to classify and analyse; and while their total numbers may be less than residential buildings, they consume a significant proportion of most western nations' energy and materials resources.

In terms of energy consumption, much of the existing commercial building stock is made up of multi-storey, highly-glazed, thermally-lightweight developments which are totally dependent on non-renewable energy for heating cooling and lighting.

In terms of materials, most commercial building tend to make extensive use of steel, glass, and concrete, all of which can be energy-intensive to produce via processes with the potential to have adverse environmental impacts, using resources that are in shortening supply. More recently, developments in wood technology have enabled timber to be utilised more extensively for the basic structure of medium-rise buildings, and this is investigated in this paper.

In this connection, it is worth noting the commercial rivalries that can exist between the purveyors of competing materials, each promoting the potential environmental advantages of their respective products – the thermal mass properties of concrete, the recycle-ability of steel, the renew-ability of wood, and so on – and the necessity for independent academic researcher to remain detached from these influences.

While there is a tendency for commercial buildings to be labelled according to the main material used for their sub- and super-structures, the vast majority of buildings use a large number of materials. Hence it is often not clear which materials or combinations of materials can achieve the best environmental performance (in terms of life–cycle energy use and carbon dioxide emissions, for example). Nevertheless we will retain this labelling system (while conscious of its limitations), as it is current practice. Studies have indicated that on average the structural components account for between 16 and 65 per cent of initial embodied energy (Aye, Bamford, Charters, & Robinson, 1999; Cole & Kernan, 1996; Oppenheim & Treloar, 1995; Treloar, Fay, Ilozor, & Love, 2001).

Typical building life cycle and key environmental indicators

Buildings go through many stages throughout their useful life, none of which are particularly simple to analyse from an environmental point of view. From initial conception to final recycling, re-use or demolition a whole range of processes must be taken into account. These include 'transportation to site, site erection and construction, life time use of building or structure, repairs, maintenance and refurbishment, demolition or dismantling at end of life, transportation for reuse, and recycling or disposal' (Cole & Kernan, 1996; Eaton & Amato, 1998). In short, a full Life Cycle Analysis (LCA) is required if one is to properly and thoroughly assess the environmental impact of a building.

As far as the selection of appropriate indicators of environmental impact is concerned, energy has long been the measurement of choice (Alcorn, 1998; Baird & Chan, 1983; Stein, Stein, Buckley, & Green, 1980). Operational energy use is relatively straightforward to assess. With international protocols (IFIAS, 1974) in place for the assessment of the embodied energy of materials (which tend to be country-specific), embodied energy calculations have been the subject of considerable study, particularly following the various 'energy crises' in the latter part of the twentieth century.

Energy has often been seen as a useful surrogate for overall environmental impact for many people, given the implied relationship between energy use and several other deleterious impacts, the multi-faceted nature of these impacts, and the absence of some other common factor or indicator.

More recently, it has been suggested that carbon dioxide emissions may be a more meaningful single indicator of overall global environmental impact. In many cases it is feasible to calculate carbon dioxide emissions from energy data, though again this tends to be country-specific, depending on the energy mix and industrial base of the region. In this study, both energy use and carbon dioxide emissions have been assessed using the following four main stages in the life (and potential environmental impact) of a building:

- Initial production of the building materials and construction of the building
- Operation of the building (mainly in terms of its energy use)
- Refurbishment and maintenance of the building materials over the building's effective life

- Demolition/disposal of the building materials

The focus of this paper will be on the first three stages. Research related to the final is ongoing at the time of writing and will be reported verbally during the conference.

Case study description

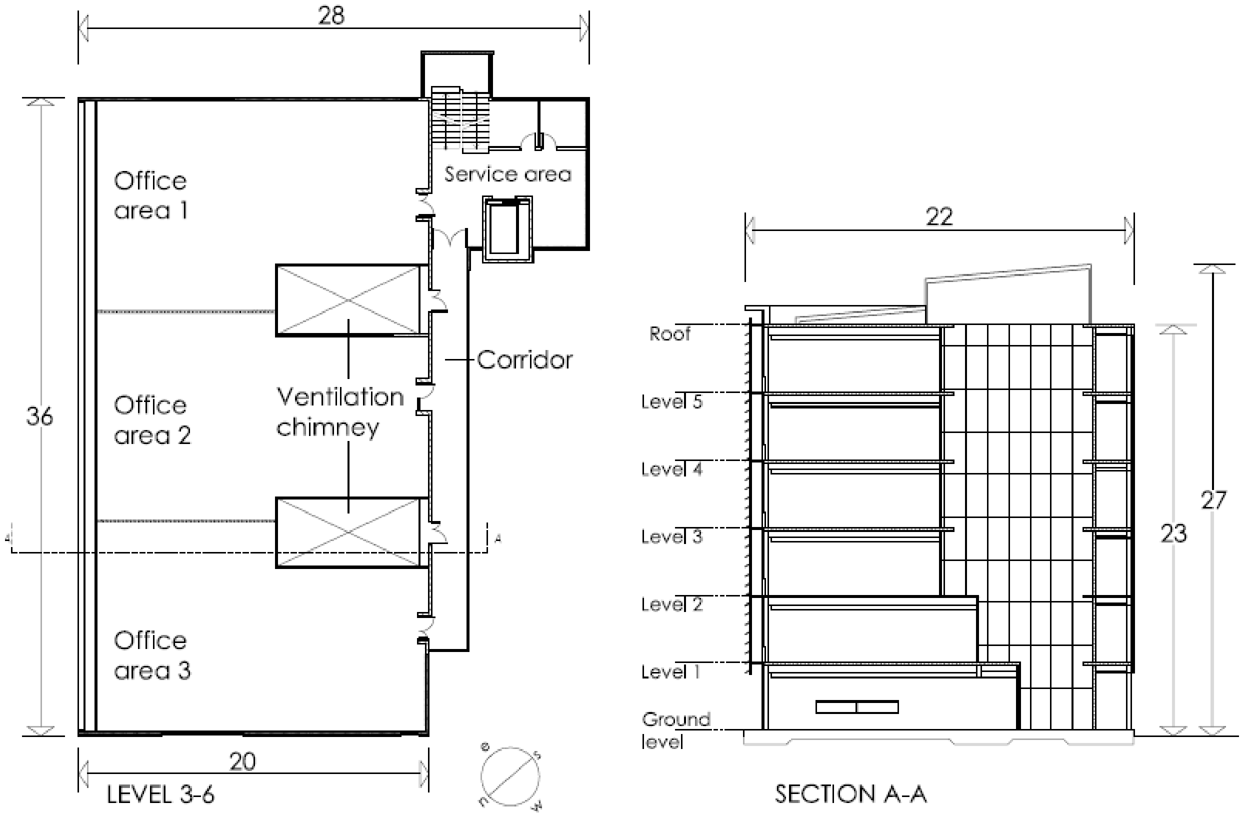


Figure 1: Plan of Timber building. This general plan is the same for all three buildings.

Building design

The buildings analysed in this research are based on an actual building, a new six-storey, 4250 m^2 floor area, laboratory for the School of Biological Sciences at the University of Canterbury in Christchurch. It was designed by local architects (Courtney Architects) with reinforced concrete as the main material for structure, envelope walls, floors and roof slabs.

The initial concrete building was used to produce architectural and structural drawings for three alternative buildings. The first alternative was a simplified reinforced concrete building, designed as a simple commercial building rather than a complex laboratory building. This building had the same structure and cladding as the real building, but open-plan commercial floor areas. The other two alternative buildings use steel and timber as the main materials for structure and many of the finishes.

For the steel and timber buildings, an objective was to use as much of the target material as reasonably possible, both in the structure and finishes. In order to maintain 'common practice', many interior and exterior finishes materials are common to all three designs. For example, most linings, ceilings, windows and other building components such as roof cladding and sun louvers are the same for all three case studies. External cladding on the timber building is fibre cement; a more detailed description is given below.

Design details

The building's envelope walls are the same at the east and west ends and different on the north and south faces. The north facade is a curtain wall made of double glass windows framed in aluminium mullions and transoms. The aluminium louvers outside the curtain wall cover all the façade from the ground floor up to the roof 'soffit'. North façade construction is the same for all three buildings in this research. The east and west façades are solid walls with only two narrow windows, one vertical (south corner) and one horizontal window centred in the façade.

The south side has an external corridor that connects the offices with the stairs, lift and toilets service area (see figure 1). Corridors are enclosed between a light wall (south façade of internal offices) and a single glass aluminium framed curtain wall. The south façade curtain wall is the same for all three designs.

Figure 1 shows the third floor plan of the timber building. This floor plan is the same for all three buildings. The floor is subdivided into four zones; three offices and one corridor and services area on the south side. Only the office zones have HVAC control. The corridors and service areas only have openable windows, set for natural ventilation. Two large ventilation chimneys were placed in the initial concrete design for the laboratory building, and these are retained in the three research designs. They continue through all floors from ground level up to the plant room on the roof slab. The ventilation chimneys are used for natural ventilation with automatic openable louvers set to be opened above 22℃ up to 26℃. When the louver openings are closed, the air conditioning keeps the temperature at 26℃ until 6pm.

Building description:

The following sections describe the components of the building that vary between each case. Components which do not change between buildings include the curtain walls and louvers in the north and south façades, as well as stairs, balustrades, and most of the internal finishes.

Concrete building:

The concrete building is a reinforced concrete column and beam structure. The floors are 300mm thick prestressed concrete hollow core slabs with 75mm reinforced concrete topping. The reinforced concrete roof slab supports a plant room for air conditioning equipment. The east wall, west wall and part of the south façade are a 310mm thick Thermomass wall which is a composite wall with 60mm concrete on the exterior, 50mm of extruded polyurethane insulation in the core, and 200mm of exposed reinforced concrete to the interior of the building. The service area walls are 200mm reinforced concrete walls. The light weight walls on the south face of the offices and the walls to the ventilation chimneys are timber framed walls containing 90 mm thick fibreglass insulation and a 25 mm air cavity for the exterior walls.

Steel building:

The steel building is a column and beam steel structure braced by eccentrically braced frames (EBFs) located beside the chimney voids. The floors and roof slab use the Comflor system, where a 0.9mm corrugated galvanized steel sheet supported by the structural beams, is topped by 150 mm of reinforced concrete. The roof slab has a 75mm thick fibreglass layer below the steel deck. The envelope walls on the east and south faces are supported between floors slabs, so that the heavy steel structure is exposed inside the building, and hence not able to act as a thermal bridge. The envelope and internal partitions are framed in lightweight galvanized steel studs and 90mm fibreglass insulation. The envelope walls have a 30mm air cavity for ventilation and the cladding is painted steel sheet profile.

Timber building:

The timber building is constructed from a new post tensioned structural timber system being developed at the University of Canterbury (Buchanan, Deam, Fragiacomo, Pampanin, & Palermo, 2008; Paleremo, Pampanin, Fragiacomo, Buchanan, & Deam, 2006; Smith, Pampanin, Fragiacomo, & Buchanan, 2008). The structural timber columns, beams and shear walls are prefabricated from laminated veneer lumber (LVL), and assembled on site with post-tensioned connections. The floors and the roof slabs are timber-concrete composite slabs build using prefabricated structural plywood and LVL decking supported on structural timber beams. The plywood decking supports a 60mm thick reinforced concrete composite topping, fixed to the LVL joists by embedded coach screws. The roof slab contain a 75 mm thick fibreglass layer. The structural LVL walls in this design are located within the east and west envelope walls, so must be considered as potential thermal bridges. The light weight envelope walls and the internal partitions are framed in timber studs with 90mm fibreglass insulation. The envelope walls have a 25mm air cavity for ventilation under fibre cement sheets.

Operational energy

Energy and CO_2 assessment:

An energy performance simulation was undertaken to assess the operational energy use of each building. The three buildings were designed to have similar operational energy consumption. This required different design of insulating materials, thermal mass, and heating and cooling equipment in each of the three buildings. With similar operational energy consumption, the final environmental performance of the three buildings was determined by the difference in the embodied and recurrent energy and CO_2 emissions in the materials used in each building.

The energy simulation was undertaken for the original concrete building using Design Builder software. That energy consumption was then used as a benchmark energy target for the steel and timber buildings. Subsequent energy simulations were undertaken with the alternative buildings, aiming to reach the benchmark set by the concrete building, with selection of improvement in insulation and some changes in finishes. Finally, once the benchmark was reached, simulations were carried out to assess the small differences between the energy performances of each of the three buildings.

Simulation method

The concrete building was designed initially to have low energy consumption, and perform better than the minimum requirements of New Zealand Standard NZS 4243 Energy Efficiency – large buildings (NZS, 1996). Subsequently all three buildings in this research had similar performance (85 kWh/m^2-year). This is particularly important because the aim of this project was to look at the influence of materials on the life cycle energy use and CO_2 emissions of the buildings. Several previous researchers have found that when the energy efficiency of building is code compliant, the effects of construction materials and embodied energy are negligible (Cole & Kernan, 1996; Page, 2006; Sartori & Hestnes, 2007; Suzuki & Oka, 1998).

For the simulation carried out in this study, many of the inputs are default data based on NZS 4243, but some data from the DesignBuilder software library database was also used as inputs (NZS, 1996).

An HVAC system operates when the inside temperature is below 22 °C and above 26°C. Between 22 °C and 26°C the buildings works under a natural ventilation mode with no heating or cooling. The buildings design includes two internal ventilation chimneys that under natural ventilation mode, are set in simulation to exhaust the air coming into the buildings through openable windows in the curtain wall of the north façade.

All three buildings were simulated as typical office buildings using schedules for simulation based on NZS 4243. Three schedules were developed to determine the percentage of loads for items such as occupancy, plugs, lighting and equipments and HVAC operation.

Buildings climate is controlled during week days from 8am until 6pm and on Saturdays from 8am until 11am with no occupancy during Sunday. HVAC runs from Monday until Saturday at 100% of the assigned load from 8am until 6pm, and for the rest of the time including all Sunday is set as 0% until Monday 8am.

Embodied energy

The drawings for the structure and architecture of the three buildings were submitted to a quantity surveyor (Davis Langdon) for measurement of material quantities, along with cost estimates. They were asked to measure the quantities of eleven construction materials, being: concrete, reinforcing steel, structural steel, other steel, glass, timber, aluminium, plasterboard, paint, particleboard/fibreboard and insulation. Subsequently each of these main materials was subdivided into specific items (eg timber was subdivided into plywood, LVL, sawn timber, MDF and imported cedar).

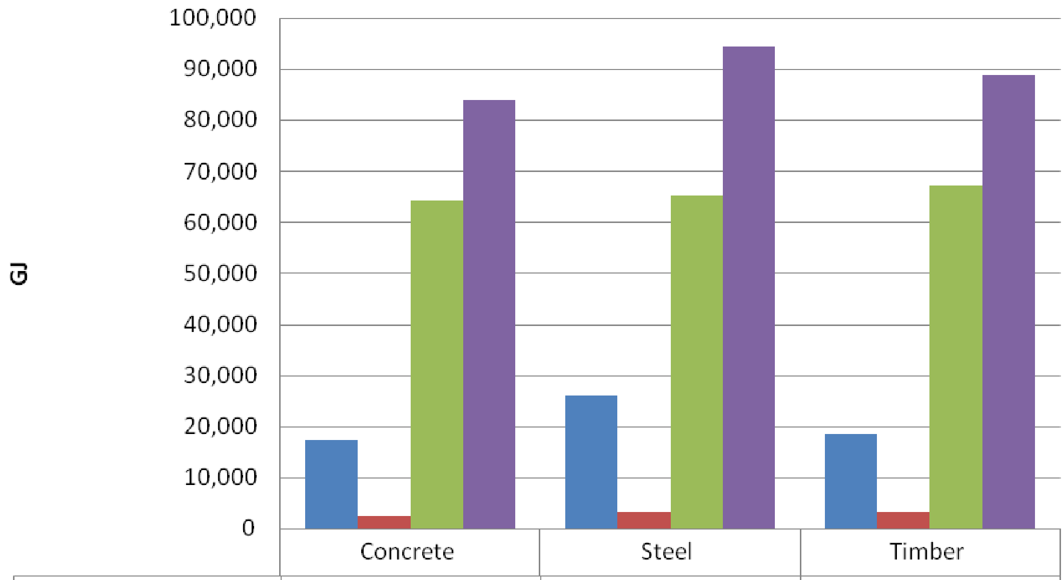
Once the quantities of materials for each building were calculated, the coefficients of embodied energy and embodied CO_2 of New Zealand buildings materials were assigned to each material for calculation of embodied energy and CO_2 emissions using data from (Alcorn, 2003). A schedule of material life spans, and resulting maintenance energy developed by SCION research (Love, personal communication, April 8, 2008) was used to estimate recurrent energy and CO_2 emissions of the buildings (involve the embodied energy and CO_2 emissions of all the materials used in the maintenance and refurbishment of buildings during its 60 years life-cycle).

Discussion of results:

Figures 2 and 3 respectively show the life-cycle energy consumption and the life-cycle CO_2 emissions for each building for a nominal life of 60 years. In all the cases the relative proportion of embodied, recurrent and operational energy are similar, except that the timber building has lower embodied and recurrent emissions than in the concrete and steel buildings.

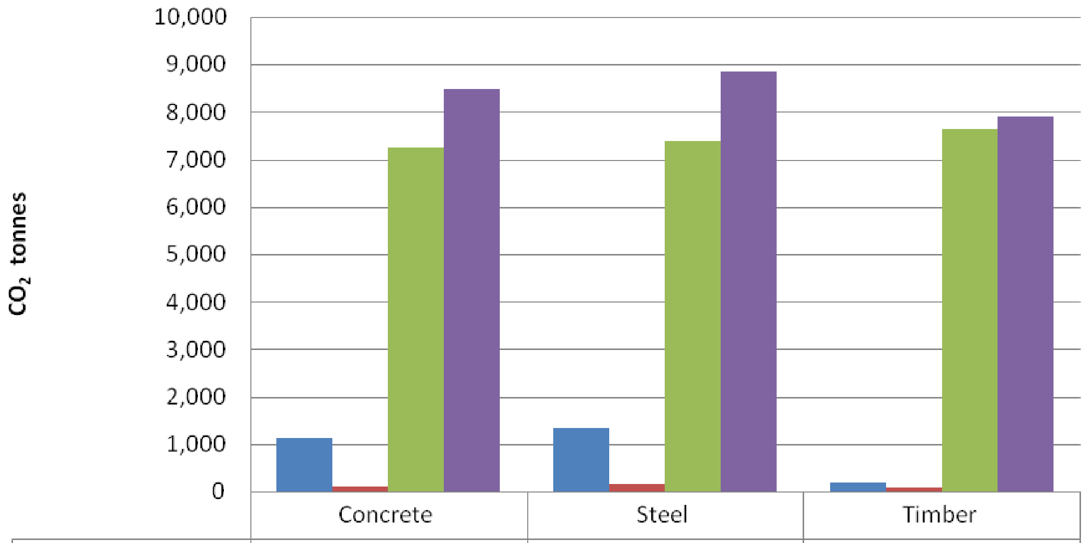
Figure 2 shows that the total operational energy over a 60 year life accounts for about 75% of total lifetime energy use, most of the rest being embodied energy in the materials. It can be seen that the embodied energy in the timber and concrete buildings is only about 70% of the embodied energy in the steel building.

Figure 3 shows that for the concrete and steel buildings, the total operational energy over a 60 year life accounts for about 85% of total lifetime CO_2 emissions. For the timber building, the operational energy accounts for almost all of the lifetime CO_2 emissions because the emissions from embodied and recurrent energy are negligible. The recurrent energy is only about 3% of total lifetime energy use, representing less than 2% of total CO_2 emissions.



	Concrete	Steel	Timber
Embodied energy	17,369	25,969	18,376
Recurrent energy	2,399	3,198	3,164
Operation energy	64,138	65,310	67,255
Total life-cycle energy	83,906	94,478	88,795

Figure 2: Life cycle energy consumption for 60 year life, including embodied energy, operational energy, and recurrent energy (GJ).



	Concrete	Steel	Timber
Embodied CO2	1,129	1,325	176
Recurrent CO2	116	149	82
Operations CO2	7,239	7,377	7,654
Total life-cycle CO2	8,484	8,852	7,912

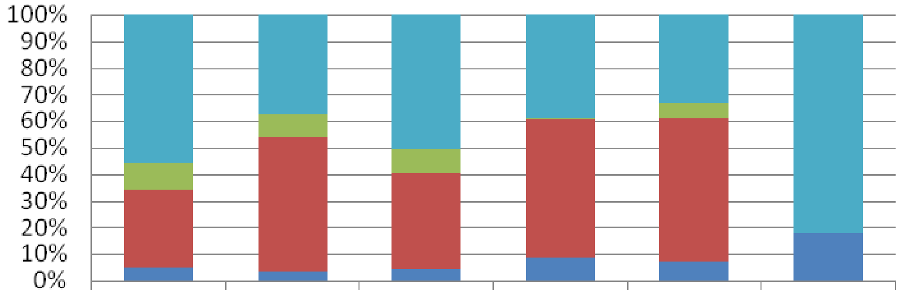
Figure 3: Life cycle CO_2 emissions for 60 year life, including manufacture of materials, operational energy, and recurrent energy (tonnes).

Figure 3 also shows that the largest difference between the three different buildings is in the CO_2 emissions from manufacturing the building materials. For the timber building, embodied CO_2 figure is very low so that the CO_2 emissions from manufacturing all of the materials in the building is almost completely offset by the carbon stored in the timber components of the building.

In order to justify this claim, it is necessary to consider the fate of the building materials at the end of the building's life. The carbon stored in the wood materials can only be used to offset other CO_2 emissions if we can be assured that the wooden demolition products will remain as solid wood, either re-used in another building or placed in a landfill (Micales & Skog, 1997) – in either case the carbon in the wood will not be returned to the atmosphere.

Another disposal option which can be considered for wood products is burning of waste wood in lieu of fossil fuel energy production. This bring even greater CO2 benefits than retaining the solid wood as a carbon sink (Gustavsson, Pingoud, & Sathre, 2006).

Figure 4 shows for the three cases in this research, the respective contribution of the building components (i.e. Windows and louvers, envelope walls and interior finishes, structure and foundations) to both, the initial embodied energy (EE) and the initial embodied CO_2 emissions (ECO2).



	Concrete EE (%)	Steel EE (%)	Timber EE (%)	Concrete ECO2 (%)	Steel ECO2 (%)	Timber ECO2 (%)
Windows and louvers	56	37	50	39	33	82
Envelope and Interiors finishes	10	9	9	0	6	0
Structure	30	51	36	53	54	0
Foundations	5	3	4	9	7	18

Figure 4: Percentage contribution of each of the five building components into the initial embodied energy and initial embodied CO_2 emissions of all three case studies

The energy figures in Figure 4 shows that the embodied energy in the structural materials ranges from 30% of total embodied energy in the concrete building to 51% in the steel building. The total embodied energy in the envelope, interior finishes and windows/louvers combined ranges from 46% of total embodied energy in the steel building to 66% in the concrete building.

The CO_2 figures in Figure 4 show that for the timber building, carbon is sequestered in the structural timber material, resulting in CO_2 absorption (hence the – negative value for emissions). For that building emissions are produced only in the finishing materials which are common to all designs.

For all three buildings, the structural materials (including foundations) account for roughly half of the initial embodied energy. Finishes all together account for the remaining half of initial embodied energy. This mean that embodied energy in the main structural materials accounts for only about 12% of the total lifetime energy use.

Conclusions

This paper describes the life-time energy and CO_2 analysis of a six-storey commercial office building designed in three alternative materials. The main conclusions are:

1. Regardless of whether the buildings are constructed mainly with concrete, steel or timber as the principal structural and non-structural materials, each building can be designed to have a similar indoor climate with roughly the same amount of operational energy for heating and cooling over the full life of the building.

2. When any of the three buildings are designed for low operational energy use (about 85 kWh/m^2-year), the total operational energy over a 60 year life accounts for about 75% of total lifetime energy use. This operational energy, results in about 85% of total lifetime CO_2 emissions for the concrete and steel buildings, and almost 100% of total lifetime CO_2 emissions for the timber building.

3. The embodied energy required for construction and maintaining the timber and concrete buildings is only about 70% of the embodied energy required for constructing and maintaining the steel building.

4. The largest difference between the three different buildings is in the CO_2 emissions from manufacturing the building materials. For the timber building, the CO_2 emissions from manufacturing all of the building materials is almost completely offset by the carbon stored in the timber components of the building.

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CLIMATE CHANGE IMPACTS IN NEW ZEALAND: A CROSS-DISCIPLINARY ASSESSMENT OF THE NEED TO ADAPT BUILDINGS, WITH FOCUS ON HOUSING

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ABSTRACT

The scientific evidence is very strong: climate change presents very serious global risks and it demands an urgent global response. This paper is part of the dissemination phase of a research project assessing the need to adapt buildings in New Zealand to climate change based on medium-low and medium-high climate change scenarios from research by the National Institute of Water and Atmospheric Research (NIWA). The overall purpose is to determine the impact of climate change on the built environment and to generate a set of options for adaptation. The building sector's vulnerability to climate change is assessed through:

- Topology and condition review of the national building stock;
- House overheating conditions and energy consumption simulations; and
- A scenario-based social impacts study.

Adaptation options and recommendations are presented for a broad range of building-related climate change impacts. Economic modelling and cost-benefit analyses are used to investigate the economic viability of thermal adaptation.

Although the effects of climate change are expected to be less severe in New Zealand than in many other parts of the world, the key message from this report is that the strong, early and coordinated action on climate change can limit potentially large social, cultural and economic costs in New Zealand.

KEYWORDS

Climate change, adaptation, buildings, cross-disciplinary, New Zealand.

INTRODUCTION

Climate change will have broad and far-reaching effects on New Zealand society and its lifestyles, economy and governance. Climate change is expected to impact buildings and the urban environment in a number of ways. These include: an increase in heavy rainfall leading to more flash flooding events and subsidence; and drier conditions leading to clay soil shrinkage and raised fire risk. Other expected effects are: a change in demand for space heating and summer cooling; increased immigration; regional redistribution of land and property values; reduced access to insurance; and higher cost of carbon-intensive goods and services.

This paper is a selection and summary of the results from a cross-disciplinary assessment of the need to adapt buildings to climate change. The overall purpose of the report is to determine the impact of climate change on the built environment and to generate a set of options for adaptation. The focus is on houses, and although non-residential buildings are not examined in-depth, many of the impacts that apply to housing will also affect non-residential buildings. Due to size restrictions for this document we refer to the complete report (Bengtsson et al 2007) for a full presentation of results and methodologies.

METHODOLOGY

Climate change scenario projections methodology

The climate change projections by the NIWA form the foundation for assessing the impacts of climate change on the New Zealand built environment (see Mullan et al 2006).

Climate scenarios are generated for a 50-year trend (2030s) and a 100-year trend (2080s). To represent uncertainties in future global socio-economic development two scalings – described as the 25th percentile (medium-low) and 75th percentile (medium-high) of the full IPCC temperature range – are simulated.[1] These

[1] The 25% and 75% limits were chosen to cover a reasonable range of possibilities while avoiding being alarmist by stressing extremes, in either direction, which some would view as unlikely.

scalings should not be considered extremes, but rather the lower and higher boundaries of probable developments. The climate scenarios in this report are based on two down-scaled global climate models: CSIRO and Hadley.

Social impacts scenario research methodology

This study used scenarios to construct strategically useful simulations of New Zealand's future housing system and its interactions with climate change. In common with other scenario methods, it seeks to initiate a *strategic conversation* (Van der Heijden 2005) about the future of housing by gaining input from experts in diverse sectors. Recent studies in New Zealand have explored the future of the housing sector with stakeholders (Saville-Smith 2000, Bates et al 2001, Bates and Kane 2006). This study employs a different approach to enrich the information available, but should be read in conjunction with these existing studies, especially the latter. The social part-study was carried out in four steps:

1. Key climate changes, potential social impacts and housing conditions were identified and projected for the years 2031 and 2081;
2. The projected changes were analysed and draft future scenarios were developed using qualitative/ soft systems analyses (Checkland 1981, Room and Britton 2006);
3. Draft future scenarios were explored with experts from diverse sectors to identify key impacts and adaptations, using one-hour phone or face-to-face interviews (sector experts) and a brainstorming group (householders). The experts explored the key influences that were identified in Steps 1 and 2. In total, 13 experts and eight householders provided strategic input into the development of this study. The total interview time was 17 hours.
4. Detail key social impacts and housing adaptations with respect to climate change.

The key changes in Step 1 above were the climate projections from NIWA, demographics, social variables, and wildcard variables. In summary, for the social scenarios we assumed an overall growth in the New Zealand population up to over five million people by the 2080s with larger Maori, Pacific Island and Asian ethnic proportions of the population and a decreased proportion of people with European ethnicity. The population was assumed to be ageing, with the median age rising from 35 years in 2001 to 55 years by 2081. An increase in single and couple households at the expense of two parent households was also expected.

Obesity and overweightness in the population were assumed to increase as a social problem, especially in the over 65 years age category. It was further assumed that there will be a rise in crime rate; immigration; percentage of the population working from home; development of telecommunication technologies; house mass production (with increasing imports lowering the price for householders and pressuring local manufacturers); the number and variety of sustainability initiatives (although they will be dependent for their success on the political, economical and social environment).

The wildcard variables used were: decline in global oil production (assuming virtually no production by the 2080s); percentage increase of the global population suffering from severe water stress (exceeding 75% by 2081); volcanic activity is assumed to remain significant enough to be included in civil defence and emergency management planning; and finally wars over access to natural resources and cultural/religious differences are assumed to continue to divert activity away from sustainability and quality of life which will engender economic hardship and shifts in migration patterns where New Zealand is typically viewed as an attractive alternative.

House thermal simulation and cost-benefit analysis methodology

A building stock analysis was used to identify two vulnerable and (for a large portion of existing buildings in New Zealand) representative building types.

For the identified house types the thermal performance and annual energy consumptions were simulated using the SunRel software modelling tool. These simulations were done for three locations (Auckland, Wellington, Christchurch) and five climate scenarios provided by NIWA (present day, and least change and most change for 2030s and 2080s respectively and abbreviated to PD06, C375, H325, H825 and C875 in the graphs). The simulations were performed for five insulation options per location. The base insulation assumed no wall, ceiling or floor insulation and single-glazed windows. The best insulation option assumed wall, ceiling or floor insulation (with R-values of at least 2.6 and up to 5.0 for the ceiling insulation in Christchurch) and with lowE argon-filled double-glazing. Exterior awning shades were placed just above all north-facing windows (and east and west-facing windows if they were in living areas or bedrooms) to reduce solar gains. Ventilation in the form of opening windows was incorporated to assist the heat pumps in cooling the house.

Each model used heat pumps to heat/cool the house, with the heating set at 16ºC from 11pm – 7am and 20ºC from 7am – 11pm. Cooling was set at 25ºC. The cost of a heat pump was $3,000 each (on average replaced every 10 years) and there was a coefficient of performance of 3. Windows were assumed to be replaced every 30 years and awnings every 10 years. Window prices[2] were obtained from the industry and window awning prices were obtained from Rawlinson's.[3]

Economic models were derived to analyse the effect of retrofitting these houses with different levels of insulation. A period of 55 years was used (2005–2060) for all models and it is assumed that it would take 10 years to retrofit all the existing houses with no or poor insulation. Three timeframes were modelled: start now; start in 2015, or start in 2025.

Using QVNZ data it was calculated that the Auckland model represents 54% of the existing stock, Wellington 21% and Christchurch 25%. The demolition model used assumes a 110 years average life for the existing house stock built prior to 1978 with little or no insulation. About 1,700 of these houses are currently being demolished per year now. This number is assumed to increase up to 5,000 demolitions per year until about 2075, after which it will start decreasing over the following years.

Health costs were based on research by Chapman *et al.* (2005) that found that a household would spend approximately $47 extra per year if they lived in an uninsulated house compared to in an insulated house.

Finally we used a 5% discount rate to get all figures into today's dollars, and we assumed an energy price escalation of 1% per year, with acknowledgement that the choice of discount rate for adaptations to climate change impacts is subject to debate and the development of energy prices is uncertain.

CLIMATE CHANGE SCENARIO PROJECTIONS FOR NEW ZEALAND

This section gives a summary of the climate change projections by NIWA (see *Table 1* below). The climate elements where we have the most confidence in expecting to see changes are: maximum and minimum temperatures; sea-level; drought and fire risk; and UV radiation. For a number of other elements, the future projections are either still uncertain (e.g. wind, storms, hail) or appear likely to be within the current range of inter-annual variability (e.g. solar radiation, relative humidity) at most sites. There is also a general expectation of increased rainfall extremes, but further research is required before we can be confident about differences between regions.

Table 1: Projected 50-year and 100-year climate change trends.

	2030s	2080s
Annual average temperature	+0.4°C to +0.8°C	+1.0 to +2.4°C
Mean sea-level rise	0.07 to 0.16 m	0.23 to 0.52 m
Frequency of days >25°C	Increase	Doubling or more (except Christchurch)
Drought (1-in-20 yr events)	More frequent (exc. Hokitika)	As frequent as every 5–10 years (exc. Hokitika)
Wildfire risk	Increase, especially eastern parts	>+50% near Christchurch and other eastern parts
Days with frosts	Decrease	Half as often in the South Island
Extreme rainfall events	Increase in frequency	Doubling in frequency
Average rainfall	Increase in autumn and winter, less over spring and summer	
Flood events	Increase in frequency	Doubling in frequency
Extra-tropical cyclones	Decrease in frequency and increase in intensity (still uncertain)	
Wind	Average westerly wind component +10% the next 50–100 years	

[2] Double-glazing prices have been reduced by 10% from current prices to reflect the expected economics of scale from the expanded market due to the proposed changes to the NZBC Clause H1 (energy efficiency) provisions, which will make double-glazing mandatory in climate zones 2 and 3 and possibly in zone 1. The use of double-glazing is widespread in the South Island, and the market size will more than double with the proposed changes.

[3] *NZ Construction Handbook* (Rawlinson, Auckland, 2005).

	2030s	2080s
Hail	Increase in hail occurrences (still uncertain)	
UV radiation (comp. to 1980)	2% higher	0% (i.e. recovered)

PHYSICAL VULNERABILITY ASSESSMENT OF THE BUILT ENVIRONMENT

The main identified physical vulnerabilities to climate change in the built environment are: indoor overheating; inland flooding; coastal hazards; droughts and fire. Projections for changes in intensity of ex-tropical cyclones and extreme wind conditions are also discussed in this section as they could have potentially catastrophic impacts, yet the climate science remain uncertain. Impacts and adaptations are largely based on research by Camilleri (2000).

Increased overheating risk

For the 2030s, annual-average temperature increases by about 0.4 to 0.8°C, depending on the scenario. By the end of the century (the 2080s), the temperature is projected to rise by 1.0 to 2.4°C. Projected temperatures increase everywhere, with the exception of Hokitika in summer for the 2030s Hadley scenarios.

High temperature extremes will increase in frequency and low temperature extremes (e.g. frost) will become less common. Extreme temperatures affect living comfort, and consequently the need for either space heating in winter or air-conditioning in summer. Table 2 below provides quantitative estimates of changes in temperature extremes calculated using *weather generators* (Mullan et al 2001).

Table 2: Number of days per year with daily maximum temperatures exceeding 25ºC in current climate, and changes for future scenarios.

Max. temp >25ºC	Present days	Additional days 2030s	Additional days 2080s
Auckland	21.3	6.9 to 14.6	25.9 to 52.6
Wellington	2.9	0.4 to 2.0	3.5 to 13.9
Christchurch	31.2	2.7 to 10.2	12.7 to 30.2

The future increases in Auckland and Christchurch would be enough to create a long summer *cooling season* lasting a month or more. Such prolonged discomfort is unlikely to be tolerated by many house-owners who would take adaptive measures, possibly by installing air-conditioning (and raising the greenhouse gas emissions from energy use). As will be discussed later in this paper, not all houses will be equally affected by overheating. Those houses with good solar design features such as properly shaded north and west-facing windows, minimal west-facing windows, or provision for effective ventilation should be least affected. Houses without such features, or poor solar design, could suffer severe overheating.

Increased rain and inland flooding

The amount of water held in the atmosphere increases with rises in temperature (about 8% more for every 1°C rise in temperature). What is an extreme rainfall in today's rainfall climate is projected to occur about twice as often by the end of the 21st century. Climate change is expected to reduce the Average Recurrence Interval (ARI) of high-intensity storms or, equivalently, for the same ARI and duration the rainfall amount increases. Rises in extreme rainfall are considered likely, even where the annual average rainfall changes little or even decreases.

In general, changes in frequency of flood events are expected to follow a similar pattern to extreme rainfall i.e. doubling by the end of the century. The relationship between flood events and extreme rainfall will vary with the characteristics of each catchment. For example, for small catchments or for the built environment with lots of paved surfaces run-off will be rapid, so fairly short accumulation periods of up to a few hours will be most relevant to local flooding. For more extensive flooding over large catchments, extreme rainfall totals of 2–3 days will be more important. Extra water can result in landslides which can directly undermine buildings or damage buildings.

The changes in heavy rainfall with climate change may result in more flooding with consequent water damage to houses, drain damage, erosion and slips, and damage to services such as roads, pipes, and cables. With climate change the historical flooding Annual Exceedence Probabilities (AEPs) are projected to increase, meaning a rise in the frequency of flooding and the incidence and extent of flood damage to houses. The actual cost of building damage is expected to equal or exceed the change in flooding AEP e.g. a 4-fold increase in the AEP could result in up to a 10-fold increase in the cost of building damage (Smith et al 1998). Even if the high end of these increases in flooding AEPs occur, it may take decades to determine if the AEPs have in fact changed. By this time it will be too late for changes in planning or Building Code requirements to reduce the impacts of climate change induced flooding on affected houses.[4]

Increased coastal flooding, erosion and rising water tables

Projected future global mean sea-level rises are consistent with the global mean temperature increases assumed in the scenarios of this report. Mean sea-level rises range between 0.07 and 0.16 m by the 2030s and between 0.23 and 0.52 m by the 2080s relative to sea-levels in 1990. In addition to mean sea-level rise due to global warming, the sea-level is determined by a number of components such as tides, storm surge and long period oscillations e.g. annual seasonal heating and cooling by the sun (±0.04 m to ±0.08 m), El Niño-Southern Oscillation cycles (±0.12 m), and Interdecadal Pacific Oscillation[5] (±0.05 m).

Coastal hazards tend to be a complex interaction of direct and indirect human impacts on the coastal zone and natural forcing processes, such as water levels, waves, currents and sediment supply and re-distribution. These interactions can operate over a range of different time and spatial scales, ranging from episodic storm events through to longer-term cyclic coastal change caused by seasonal, inter-annual and decadal variability (see MfE 2004a).

The increase in flooding risk with sea-level rise for a sheltered coast may be greater than for an exposed, stormy coast. Houses on a sheltered coast can be built closer to the sea-level than on an exposed coast as they do not need to have a large *safety margin* for storm surges and waves. As the likely sea-level rise is a large fraction of the safety margin for these houses, the risk of flooding could increase dramatically. For many exposed coasts, the rise in sea-level is much smaller than the storm waves, and so there would be less effects caused by changes in sea-level.

The water table is expected to increase in response to rising sea-levels. In areas with an existing high water table, surface flooding may become more frequent, leading to damage to foundations and walls. Unbalanced or changing ground-water pressure could damage foundations. Sewerage and stormwater systems may also be damaged or rendered inoperable by rising sea-levels (Mosley 1990), possibly causing flooding well inland in low-lying areas. Sea-level rise is potentially a big impact of climate change for vulnerable, low-lying areas of New Zealand.

Wind and ex-tropical cyclones

Recent work suggests a decrease in the frequency of *extra*-tropical (mid-latitude) storm centres passing over the North Island in winter, with a corresponding increase in frequency south of New Zealand. Under climate change arising from rising greenhouse gas concentrations, the change in *frequency* of occurrences of tropical cyclones is uncertain, but there is growing evidence that tropical cyclones will increase in *intensity*. On average a greater percentage of tropical cyclones will be in the higher strength category. It is likely that there will be some higher-intensity ex-tropical cyclones producing larger storm impacts as the 21st century progresses.

Changes in future storminess over New Zealand are still very difficult to quantify. The most robust feature is for poleward movement in storm tracks, which has its most marked effects in the winter season. On the other hand, in the current climate the westerly wind belt and embedded storms tend to move northwards to lie across New Zealand. There is currently low confidence in the projections for changes in strong winds (these vary between little change up to double the frequency of winds above 30 m/s by the 2080s – see MfE 2004b).

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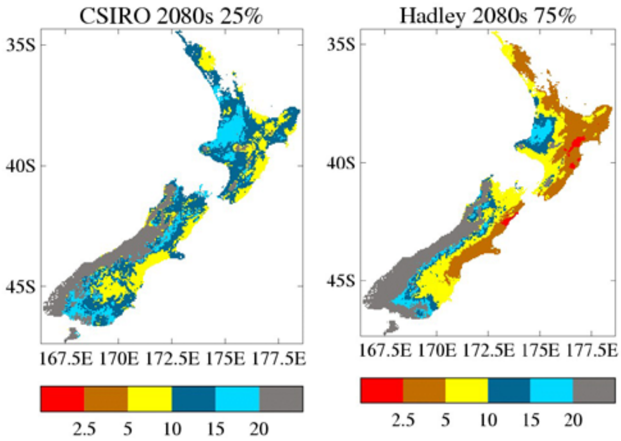
[4] See Camilleri (2000) section 6, page for a discussion.

[5] Longer "El-Niño–like" 20–30 year cycles of alternate positive and negative phases that effect the wider Pacific Ocean region, abbreviated as IPO. Since 1998 the IPO has been negative.

Drought and fire

Changes in drought risk are related to a combination of changes in evapo-transpiration and precipitation. Reduced rainfall is likely to increase the risk and severity of drought, particularly if the rain falls less evenly over time (i.e. falls on fewer days). Droughts are expected to become more frequent in all regions considered[6] except near the Hokitika site. A drought sufficiently severe to be ranked as a 1-in-20 year event under the present climate is likely to occur as frequently as every 5–10 years by the 2080s at all sites investigated in this study (except Hokitika).



Corresponding increases in fire risk are also considered likely over much of the country. Days per year of very high or extreme forest fire danger could rise by more than 50% by the end of the century around Christchurch and some other east coast locations.

The predicted increases in temperature, drought conditions and, in particular, wind have implications for the severity of exposure fires and external fire spread and the hazards of airborne embers and increased ember-strike in the urban environment (Bowditch 2006). The impact of climate change on the ignition of fire events that occur *within* occupied buildings may be more dependent on the changes in occupant behaviour (such as less use of active heating but greater use of active cooling) than directly relating to increases in climate conditions.

Recommendations, costs and benefits for physical adaptation

Regions with high climate change exposure from increased risk of bushfire, flood and coastal hazards should be avoided or developed with due consideration of future climate change impacts. Properties vulnerable to coastal erosion may need to be protected using measures to reduce wave energy or possibly move or abandon houses which cannot be economically protected. Territorial Authorities are usually in a better position than individual house owners to take preventative action to protect against flooding by using embankments, river straightening and similar measures. They should adopt a precautionary approach to coastal development and take increased vulnerability of coastal properties into account in modelling of flooding, coastal erosion and sea inundation. Territorial Authorities should also allow for possible sea-level rise in new drainage systems, coastal infrastructure and buffer zones.

The total climate change adaptation cost calculated for the existing housing stock in Bengtsson *et al*. (2007) is approximately $2.3 billion, which represents about 1.3% of the value of the housing stock. The expected benefit by the 2080s is estimated to at least $4 billion in present value dollars.

SOCIAL EFFECTS OF THE IMPACTS OF CLIMATE CHANGE

Background

From the previous section's review of projected climate changes and assessment of building-related impacts it is clear that New Zealand will experience significant changes and impacts. A part-study by Supplejack Ltd (McKernon 2006) was used to identify the social impacts of climate change in relation to housing. This social study was based on a background of local and international research into social change in relation to sustainability, global warming, climate change and a number of related topics such as energy use and waste management.

The social meanings and impacts of climate change can be expected to vary considerably, by community and over time. Empirical studies since the 1960s have detailed the dynamics of change in relation to the social impacts of industrialisation, and consumption in particular. One result is the often-observed tensions between communities that adopt new ways of living, or adapt to changed conditions, and those that do not.

While adaptation to climate change and sustainable behaviour change are increasingly understood through the social sciences, they occur for the public as loosely-framed media and interpersonal communications about,

[6] Auckland, Hamilton, Tauranga, Wellington, Nelson, Christchurch and Hokitika.

for example, bad weather and "being green". Further, they arise conversationally – as topics of discussion – and are not framed as calls to action. The systemic thinking required to grasp large-scale, diffuse, long-term issues such as climate change (or other social issues such as pollution, obesity, smoking-related cancer and drunk driving) is alien to everyday ways of accounting for personal, day-to-day experiences and activities. In recent years a range of international and local studies have shown awareness of climate change has grown rapidly, and with this has come an increase in attitudes favouring action and a concern to find solutions for living. A smaller set of studies have explored the specific meanings given to climate change and the specific behaviours that result: these show the well-known gaps between awareness, useful attitudes, and productive action.[7]

Social impacts on housing

Climate change is only one among a range of major future changes within the housing sector, be they political, social, cultural or economic. The social impacts study employed a scenario-building method to scope likely future societal and housing configurations in order to assess the range of likely social impacts of climate change. Some of the key impacts identified are:

- Social impacts result from climate and social interactions: in combination, house/household resilience and preparedness (including housing adaptations) reduce social impacts, while hazards and house/household vulnerabilities increase them. The interaction between these elements is an indicator of the relative social impact.
- Climate change promotes sector growth – and social tensions: external pressures could have a much greater effect on New Zealand society and its housing sector than anticipated local changes. The relatively benign impacts of climate change in New Zealand are likely to be a key driver of immigration with increasing ethnic diversity and social tensions. Climate and social adaptations are expected to co-evolve.
- An ageing population highlights key social impacts: this population increasingly remaining in their own homes could result in a rise in age-related vulnerabilities within housing. Research indicates other groups may be equally or more vulnerable such as: children; low income households; people with health problems or disabilities; and Maori or Pacific Island communities. Combinations of these variables with older age results in higher vulnerabilities.
- Key forms of resilience are psychological toughness and community cohesion: evidence available suggests older people, while physically more vulnerable, may also be psychologically stronger and more able to cope with crises. In addition, lower income neighbourhoods, immigrant groups and church communities, for example, may have levels of social cohesion that make them more resilient and speed their recovery.
- Social conflict is projected to be a major impact: climate change's social impacts are expected to include significant social disruption and conflict over changing patterns in the value of land in coastal areas, especially where wealthy enclaves suffer significant loss in value.
- Sector dynamics limit adaptation: housing as a business sector, as a householder investment, and as a key site for private consumption is highly vulnerable to external influences such as: global economic factors; the cost of capital; tax on capital gains; insurance sector policy in relation to housing; and local authority regulation. This means the sector's ability to develop a self-determined, coherent response to the social impacts of climate change may be limited.

Recommendations for social adaptation

In order to ameliorate the impacts from climate change housing it is recommended that, as a broader strategic platform, adaptations are oriented to the more vulnerable and socially-excluded groups. As climate change adaptation will progress in combination and in parallel with other social changes and drivers, behaviour change programmes need to make behaviour change easy, attractive, stylish and rewarding. Systemic programmes may need to span areas such as design, building, renovating, financing and insuring as well as ownership/dwelling.

[7] For example, research by EECA shows how difficult it is to get most people to do something as simple as turn out lights or close curtains to save energy – after decades of energy-related campaigns. It follows that adapting to climate change might be a slow process.

We recommend the development of a proactive approach that leverages research – such as this report – towards a coherent and effective sectoral response to climate change. Synergies may be achieved with initiatives that deal with health and other social issues. Housing adaptations can profitably be oriented to raise concern over storms/flooding/erosion/landslips as a threat to the New Zealand way of life, with particular impacts for coastal communities/houses. Loss of iconic housing locations, lifestyles and landscapes is a powerful motivator for public concern.

TOPOLOGY AND CONDITION REVIEW OF THE NATIONAL BUILDING STOCKS

This section summarises the building stock analysis which includes the typology describing the value of the segments, then details of the housing stock including numbers, location and other characteristics that are relevant to adaptation. The reviewed was in part done to identify building types in the building stock with specifically high vulnerability to climate change.

Capital value

Housing is a major capital asset with a replacement value of approximately $150 billion (in 2001 NZ dollars). The value of non-residential buildings is smaller but still significant at approximately $70 billion. This is followed by civil engineering structure (roads, bridges, other transport faculties, water/sewage/waste disposal, Telecom and energy infrastructure) at $50 billion. The focus of this assessment is on houses, and although non-residential buildings are not examined in depth, many of the impacts that apply to housing will also affect non-residential buildings. The inventory of non-residential buildings suggests that climate change adaptation should focus on institutional (hostel, health, education, social/cultural) and commercial (hotel, retail, office/administration) buildings. Industrial-type buildings (warehouse, factory and farm) can largely be ignored for climate change adaptation as they are usually fairly short-lived and simple buildings.

Housing overview

- Total number of dwellings were in 2001 approximately 1,435,000 units, of which stand-alone houses make up 80% and low-rise multi-units 18% of the stock.
- The largest proportions of houses are from the 1950s through to the 1970s and the most multi-unit dwellings are from the 1970s.
- Very few buildings (less than 10%) in New Zealand have more than two-storeys with the majority being single-storey buildings.
- Approximately 70% of houses are in the 100 to 200 m^2 floor area range.
- Concrete floor slab constructions are used in 92% of all new detached housings but only represent 27% of the total stock. Prior to the 1980s most (73%) new houses were constructed on a suspended timber floor.
- For all ages combined the predominant cladding is clay brick for walls, and sheet steel for roofs. Timber wall claddings are predominant for pre-1970 housings. Metal tiles and concrete tile are increasingly popular as roof cladding.
- Ceiling insulation data for Wellington, Auckland and Christchurch reveal that 45–65% of pre-1980 housings have 50 mm or less insulation.

A large number of houses constructed before the 1970s are in need of major maintenance within the next the next few years. Often the option is to replace the component rather than repair, in which case there is opportunity to provide wall insulation and double-glazed windows, provide stronger fixings for roof claddings, and install ceiling insulation for skillion roofs and other hard-to-access roof spaces.

From the analysis of the existing building stock it was noted that approximately 390,000 or 51%[8] of homes built prior to 1978 had not been fitted with any or sufficient insulation (this includes homes that have been retrofitted). Further, based on building stock analysis, we assumed that half of the existing pre-1980s stock can be represented by the small house and the other half by the medium house. The representative house types used are:

- small house – approximately 100 m^2, one-storey, timber weatherboard wall cladding, sheet metal roof cladding and timber floor

[8] Using QVNZ and HCS (Clark et al 2005) data.

- medium house – approximately 150 m^2, one-storey, masonry veneer wall cladding, sheet metal roof cladding and concrete floor.

HOUSE OVERHEATING AND ENERGY CONSUMPTION SIMULATION RESULTS

This section presents the results from thermal building simulations, primarily for the two representative existing building types as identified in the previous section. All of the explored building techniques outlined in the methodology section can provide energy savings and energy efficiency to reduce the risk of overheating.

The multi-variable thermal simulations, based on *medium-low* and *medium-high* climate change scenarios, show that all simulated types of housing in New Zealand will be negatively affected by climate change, in particular energy requirements for cooling (rather than heating as the climate is warming).

Without retrofit or new climate appropriate design, many New Zealand homeowners may find that temperatures during summer within their houses will be increasingly above the accepted comfort range (assumed 18–25ºC). However, the simulations showed that comfort temperatures can be achieved with significant energy savings through each or combinations of: window shading (particularly on the northern sides); upgrading to double-glazing or better; upgrading to base insulation or better; and use of natural ventilation rather than use of mechanical cooling i.e. air-conditioning.

Incorporating at least double-glazing into new housing and retrofitting into existing houses (with single-glazing) can significantly reduce energy consumption in New Zealand homes. The modelled step to lowE and argon-filled double-glazed windows does give additional energy savings, but of lower magnitude and at a higher material cost.

Window shadings can also play an important part in cooling interior spaces as the climate around New Zealand heats. Although on average this is expected to be only a few degrees, there will be a much higher demand for energy throughout the country. The use of window shadings on the sunnier sides especially will lower cooling loads.

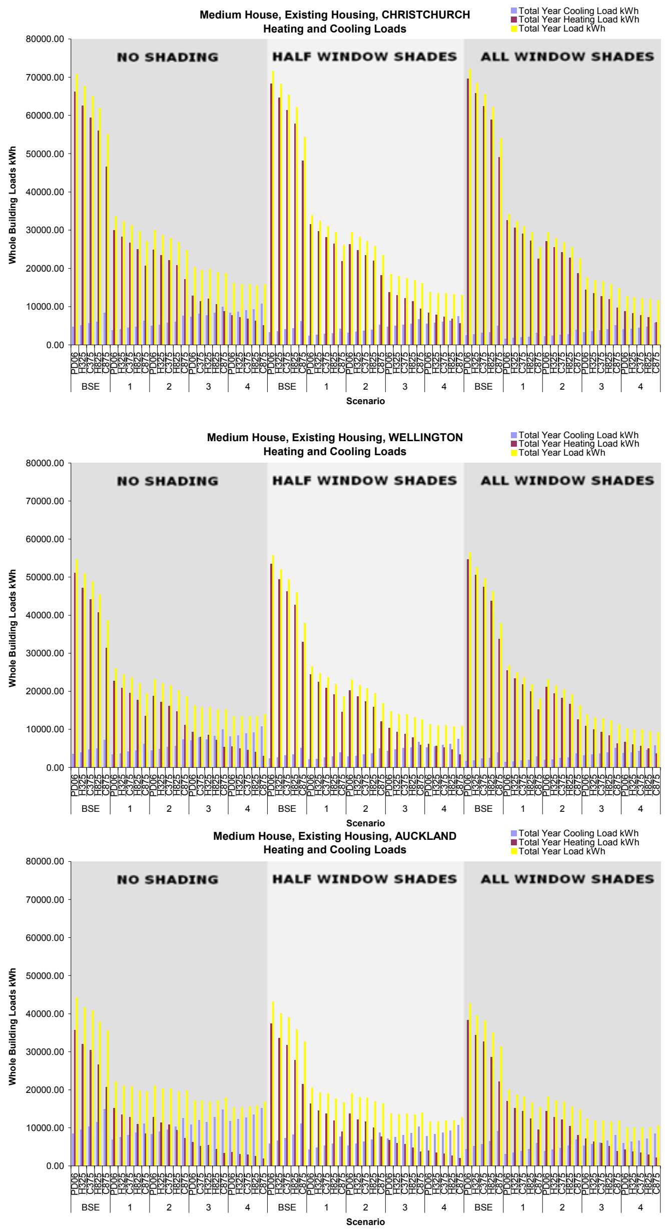


Figure 2: *Sample of simulation output for cooling and heating energy consumption for five climate scenarios, three shading options and five insulation levels (No insulation, single glazing = BSE; Ceiling Insulation only, Double Glazing = 1; Ceiling and Floor Insulation only, Double Glazing = 2; Ceiling, Wall, Floor Insulation, Double Glazing = 3; and Best Ceiling, Wall and Floor Insulation, Double glazing with LowE argon filled, thermal break aluminium frame = 4).*

Insulation has a significant impact on year-round energy consumption. The primary benefit is from reduced warming costs, and not so important for cooling energy demand.

Finally, homeowners benefit from maximising the use of natural ventilation before the use of mechanical cooling i.e. air-conditioning. This has been shown to keep average yearly temperatures within the acceptable comfort range and lower cooling energy requirements. Mechanical cooling would best be used as a fall-back in extreme temperatures.

In the following section the economic costs and benefits are analysed in order to explore economically optimal solutions for the two representative existing building types as identified in the previous section.

COSTS AND BENEFITS FROM ADAPTING TO TEMPERATURE INCREASE

The simulation results from the previous section were used to compare net benefits of selected adaptation option. The economic modelling suggests that insulation retrofitting of the existing housing stock should be done as soon as possible since the Net Present Values (NPVs) decrease over time, so the longer the delay in retrofitting, the lower the lifetime benefit (resulting in a lower NPV).

When retrofitting existing housing stock, if feasible, it is recommended that all homes have ceiling, wall and floor insulation with no awnings installed. None of the models indicate that it is best to install awnings. This is not because they do not provide significant energy savings, but because of the cost of installing them. While awnings provide good sun protection and energy savings they are quite expensive ($4,000 to $10,000 per house depending on size).

Double-glazing significantly reduces energy consumption, but in no situation modelled does it provide a greater NPV than single-glazing. Still, it is recommended that a double-glazing retrofit be considered in all regions due to superior energy performance and demonstrated strong positive NPVs. Overall it was shown that it is financially better to have single-glazing in the warmer climates if you have a small house, but if you live in a cooler climate or have a bigger house you should install double-glazing. Due to cost, in no case is it financially beneficial to install double-glazed argon-filled windows, even though these provide the greatest insulation and significant energy savings.

Due to resource constraints a wide range of situations or house types were not modelled, but rather typical house sizes by three locations to represent a sizable proportion of the stock. Ideally thousands of different homes should have been modelled and the results then averaged. Our analysis does not attempt to fine tune optimal levels of insulation; the goal is to indicate broad trends over time.

Different discount and energy price escalation rates were also modelled with the results as follows. As the discount rate increases the present values decrease, and the difference between the lowest and highest insulation present values gets smaller. The NPVs also decrease but the results (which insulation provides the highest NPV) are still the same. The opposite happens when the discount rate decreases. As the energy price escalation rises (energy prices increase at a higher rate), all the present values will go up. The present values of retrofitting the lower insulation houses increase by more than the higher insulation homes since lower insulated houses would use more electricity and therefore the present value of increased insulation goes up. With higher energy price rises the economics improve for better insulated houses. But the models still show that the economically optimal level of insulation remains the same.

CONCLUSION

Robust scientific projections show that climate change will significantly affect the New Zealand built environment. Major impacts are expected from inland and coastal flooding, building overheating, and increased occurrence of droughts and fire risk in the eastern parts of the country. It is essential that the climate-change planning process starts now, given the longevity of housing developments and infrastructure in increasingly at-risk communities. Costs to homeowners and the national economy, and social disruption and tension, can all be avoided by developing and retrofitting with consideration of increasing climate exposure and vulnerability.

The inventory of the building stock suggests that climate change adaptation should focus on residential, institutional and commercial buildings. Industrial-type buildings can largely be ignored for climate change adaptation as they are usually fairly short-lived and simple buildings.

Social impacts from climate change will be intertwined with other major social changes. A more detailed analysis of social impacts suggests these will be powerfully shaped by dynamics of social inclusion and exclusion. The prospect of increased damage means many communities may need to re-assess their futures. The social research, involving a broad range of experts from outside the building sector, warns that significant social disruption and conflict over changes in the value of land in coastal areas will occur, especially where wealthy enclaves suffer significant loss in value. The relatively mild impacts of climate change in New Zealand compared to other countries are likely to be a key driver of immigration. As climate change drives immigration, it also indirectly drives growth in the housing sector.

Building overheating from increase in frequency and severity of summer temperature extremes can be avoided by passive design and retrofit. Thermal simulations show that comfortable indoor summer temperatures can be maintained in all climate change scenarios explored by adapting to overheating with window shading and natural ventilation. The simulations also show significant year-round energy savings in all buildings using double-glazing or high-performance glazing, and improved ceiling and wall insulation.

To maximise economic benefits insulation retrofitting of the existing housing stock should be done as soon as possible. Thermal insulation comes out the most favourable as currently we under-insulate our homes by a huge amount. The second most favourable retrofit is upgrade from single-glazing to double-glazing. While awnings provide good sun protection, in no situation do they provide a greater NPV than having no awnings. It is therefore not recommended that awnings be installed if the primary objective is lower NPV.

ACKNOWLEDGEMENTS

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ESTIMATION OF ENVIRONMENTAL EFFICIENCY RELATED TO CO_2 REDUCTION FOR OFFICE BUILDINGS UP TO 2050

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Keywords: global warming, 2050, environmental efficiency, CASBEE, office buildings

Summary

In this study, the sustainability of office buildings in Japan is assessed via the indicator "environmental efficiency related to CO_2 reduction". First, the authors have developed a long-term prediction model for CO_2 emissions associated with office buildings from 1990 through 2050. The prediction via this model shows a potential 70% reduction of CO_2 emissions associated with office buildings from 1990 levels by 2050.In the second half of this report, the prediction model is extended to assess the environmental quality for office buildings by using CASBEE (Comprehensive Assessment System for Building Environmental Efficiency). As a result, it is possible to satisfy needs for both great reduction of CO_2 emissions and improvement of the level of environmental quality. The development of this model has meaning in post-Kyoto Protocol discussion.

1. Introduction

As an international trend regarding the issue of global warming, there is a high possibility that a 70% reduction of greenhouse gases from 1990 levels will be required in Japan by 2050. However the CO_2 emissions associated with office buildings have expanded rapidly in recent years in Japan, thus reduction of CO_2 emissions is an urgent issue. In this study, the authors have developed a long-term prediction model for CO_2 emissions associated with office buildings from 1990 through 2050.On the other hand, in considering sustainability, it is important to assess not only environmental load but also environmental quality. In the second half of this report, the prediction model is extended to assess the environmental quality for office buildings by using CASBEE. We report on the transition on "environmental efficiency related to CO_2 reduction" via the extended model.

2. Prediction model for environmental efficiency related to CO_2 reduction

Figure 1 shows the outline of the prediction model. The prediction model consists of three sub-models.

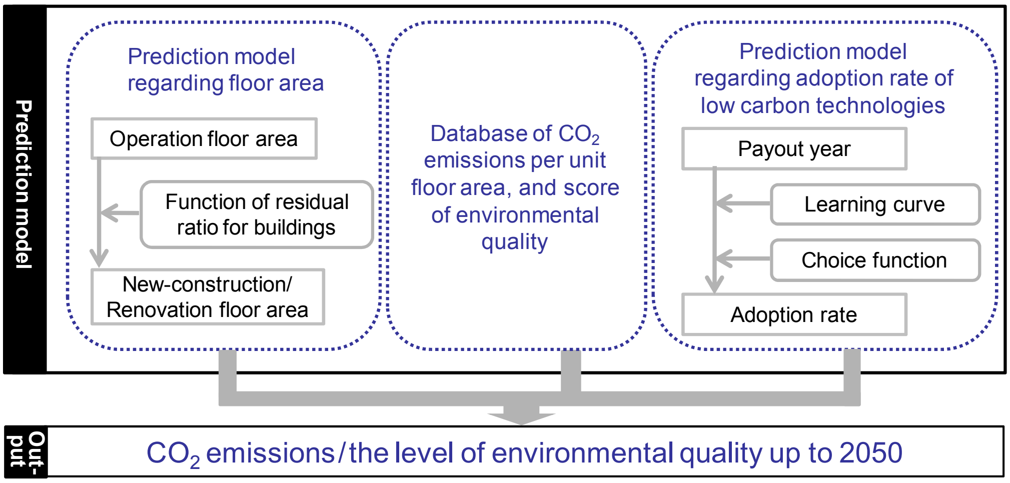

Figure 1 Prediction model for environmental efficiency related to CO_2 reduction

1) Prediction model regarding floor area: This model predicts each life stage floor area (operation/new-construction/renovation) of office buildings up to 2050.

2) Database of CO_2 emissions per unit floor, and score of environmental quality: This database concerns CO_2 emission per unit floor [kWh/m^2• year] and the environmental quality score assessed by CASBEE (Comprehensive Assessment System for Building Environmental Efficiency).

3) Prediction model regarding adoption rate of low carbon technologies: This model predicts the adoption rate of each low carbon technology, based on economic rationality.

2.1 Prediction model regarding floor area

2.1.1 Prediction of operating floor area up to 2050

In this study, operating floor area is predicted based on the estimation of future population and GDP data. Figure 2 shows the results predicted by each future scenario (urban centralization scenario: scenario A, regional dispersion scenario: scenario B).

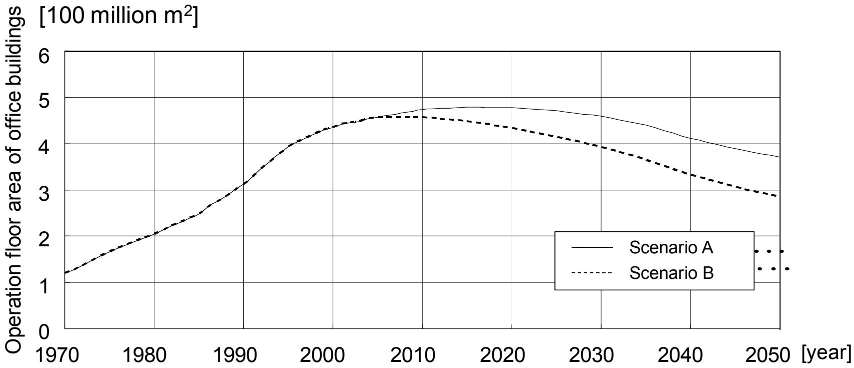

Figure 2 Prediction results of operating floor area

2.1.2 Prediction of new-construction/renovation floor area up to 2050

The new construction floor area is estimated based on the statistical data of construction up to 2005. Or later, new construction floor area is predicted that the attrition floor area which conform with residual ratio function and the demand floor area are balanced. The renovation floor area is predicted by assuming that renovation work is done in a 20-year cycle following construction.

2.2 Database of CO_2 emission per unit floor, and score of environmental quality

Figure 3 shows the flow of compiling the database of CO_2 emission per unit floor, and score of environmental quality.

a) Establishment of standard office building model

b) Selection of low carbon technologies

c) Selection of calculation/assessment tool

d) Calculation/Assessment on CO_2 emissions per unit floor area/environmental quality score

Figure 3 Flow of compiling the database

2.2.1 Calculation method for CO_2 emissions per unit floor area

a) Establishment of standard office building model
Different sized office buildings differ in energy consumption mechanisms or adopted low carbon technologies. In this study, three sizes of standard office building model are established.

b) Selection of low carbon technologies
Efficient low carbon technologies are selected based on “Guideline on environmental conservation for government offices” (table 1).

c) Selection of calculation tool for CO_2 emissions
CO_2 emissions associated with new construction or renovation are calculated by “The life cycle assessment tool for buildings”. “FACES” (Forecast of Air-conditioning System’s Energy, Environmental, and Economic Performance by Simulation) and “CEC (Co-efficient of Energy Consumption[*1]) Guideline” are used to calculate CO_2 emissions associated with operation.

d) Calculation results on CO_2 emissions per unit floor area
Calculation results are compiled in a discrete database by size, climate area, life stage, and low carbon technology. Figure 4 shows an example of calculation result in Tokyo.

Table 1 Low carbon technologies

Low carbon technologies		Building size	Performance		
			Standard	Provision when new constructed	Provision when renovated
Long-life	Leeway of story height	All	3.8m	4m	
	Leeway of ceiling height		2.6m	2.8m	
	Leeway of floor load		2900N/m^2	4500N/m^2	
Skin	Thermal insulation of	All	PAL*[1]: 300~320	PAL: 225~240	←
Heat source	High efficiency heat source	Small/ Medium	COP: 2.5	Electric engine heat pump (~2020) COP:4.5 (2021~) COP:6.0	←
		Large	COP: 0.9	Gas absorption refrigerator Replace to high performance heat	(~2020) COP:1.2 (2021~) COP:1.6
	Ice heat storage	Large	No	Yes	
	Total heat exchanger	All	No	Yes	←
Heat Fan	Control method	Large	Constant Air Volume	Variable Air Volume	←
Air conditioning	Control of outdoor air	All	No	Yes	←
	Air conditioning system	Large	Standard	Task & ambient	←
Light	High efficiency light	ALL	Standard	(~2020) Energy	←
			Standard	(2021~) Energy	
	Infant illuminance		No	Yes	←
	Daylight control		No	Yes	←
Elevator	Control method	ALL	Alternate current	VVVF*[2]	←

2.2.2 Calculation method for environmental quality score

Flow a) and b) is same as the calculation method for CO_2 emissions per unit floor area.

c) The assessment tool of score of environmental quality

The environmental quality score is assessed by "CASBEE-New Construction". The CASBEE assessment items of environmental quality are categorized by three items, "Q-1: Indoor environmental quality", "Q-2: Service performance", "Q-3:Outdoor environment (inside the compound)". In this study, the assessment coverage is limited to Q-1 and Q-2 because they are related to CO_2 emissions, and Q-3 is not assessed because it is not related to CO_2 emissions.

d) Results of environmental quality score calculation

Figure 5 shows the results of environmental quality score calculation. The reasons for the improvement of the Q-1 score by the adoption of low carbon technologies are improvement of indoor thermal comfort by the thermal insulation of the skin and improvement of indoor air quality by the control of outdoor air installation. On the other hand, the reasons for the improvement of the Q-2 score by the adoption of low carbon technologies are improvement of modifiability by the securement ceiling leeway and improvement of earthquake protection by the securement of endurance. In this way, energy saving technologies are related to Q-1, and long-lived technologies are related to Q-2. In addition, Table2 shows the detailed relationship between Q-1, Q-2 and each low carbon technology.

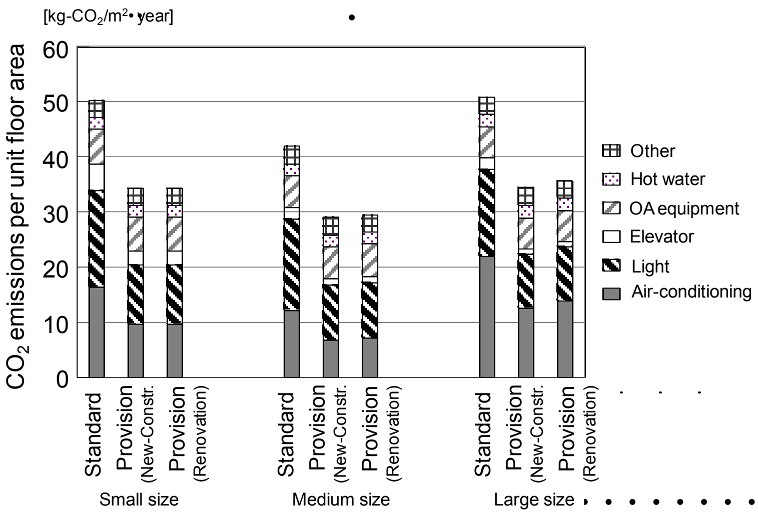

Figure 4 CO_2 emissions per unit floor area in Tokyo

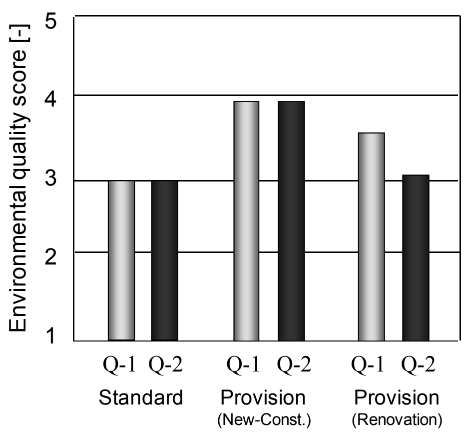

Figure 5 Environmental quality score

2.3 Prediction model regarding adoption rate of low carbon technologies

The adoption rate of each low carbon technology is predicted based on the payout year and the amount of cumulative production. Figure 6 shows the prediction results of the adoption rate.

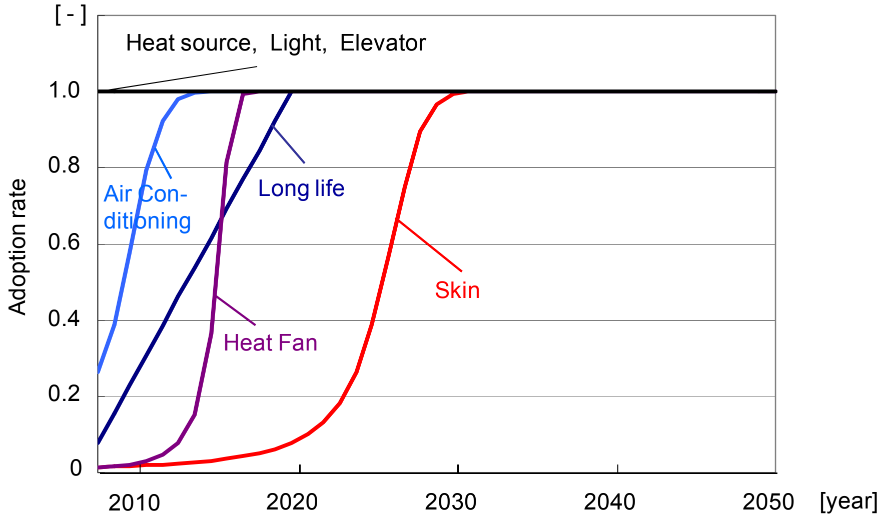

Figure 6 Prediction results of the adoption rate

3. Assumption for the prediction

3.1 Formula for the estimation of CO_2 emissions and the level of environmental quality

CO_2 emissions and the level of environmental quality are calculated with formulas (1), (2).

3.2 Definitional formula for environmental efficiency related to CO_2 reduction

In this study, environmental efficiency related to CO_2 reduction is defined with formula (3). This definitional formula is the indicator for assessing the improvement of environmental efficiency by the adoption of low carbon technologies.

CO_2 emissions associated with office buildings in Japan [kg-CO_2/year]

$$= \left\{ \sum_{size} \sum_{area} \sum_{performance} (CO_2 \text{ emissions per unit floor}_{(size,\ area,\ performance)}\ [\text{kg-}CO_2/\text{m}^2 \cdot \text{year}] \cdot \text{floor area}_{(size,\ area,\ performance)}\ [\text{m}^2]) \right\} \quad (1)$$

Level of environmental quality on office buildings in Japan [-]

$$= \left\{ \sum_{size} \sum_{performance} (\text{Environmental quality score}_{(size,\ performance)}\ [-] \cdot \text{floor area}_{(size,\ performance)}\ [\text{m}^2] \right\} / \text{Total floor area}\ [\text{m}^2] \quad (2)$$

Environmental efficiency related to CO_2 reduction [year/kg-CO_2]

$$= \frac{\text{Level of environmental efficiency on office buildings in Japan [-]}}{CO_2 \text{ emissions associated with office buildings in Japan [kg-}CO_2\text{/year]}} \quad (3)$$

3.3 Assumption for the prediction of operation floor area

For prediction of the operation floor area, adoption of the intermediate value between scenario A (urban centralization society) and scenario B (regional dispersion society) is assumed.

3.4 Assumption for the prediction of electricity CO_2 emission rate

Assumption for electricity CO_2 emission rate is estimated based on the actual achievement value up to 2005. For later dates, two scenarios are assumed for electricity CO_2 emission rate; one is to remain the same as 2005(0.425kg-CO_2/kWh), and the other is to conform to the "Ultralong-term energy technology roadmap" • 2030: 0.18kg-CO_2/kWh, 2050:0.12kg-CO_2/kWh• :

4. Results

"No provision case" means that no low carbon technologies are adopted, and "provision case" means that low carbon technologies are adopted in accordance with the adoption rate.

4.1 Prediction results for CO_2 emissions associated with office buildings

Figures 7 and 8 show the prediction results for CO_2 emissions. Assumption for the prediction of electricity CO_2 emission rate of Figure 7 is to remain the same as 2005, and Figure 8 is to conform to the "Ultralong-term energy technology roadmap". It is shown that CO_2 emissions in 2050 can be reduced by 65% in comparison to 1990 in the case of provision. On the other hand, in the case of no provision, CO_2 emissions in 2050 decreased by 42%. This is why mass construction in 1990 causes the decrement of new construction in following years. In addition, it is shown that CO_2 emissions in 2050 can be reduced by a maximum of 78% if the electricity CO_2 emission rate is improved (figure 8).

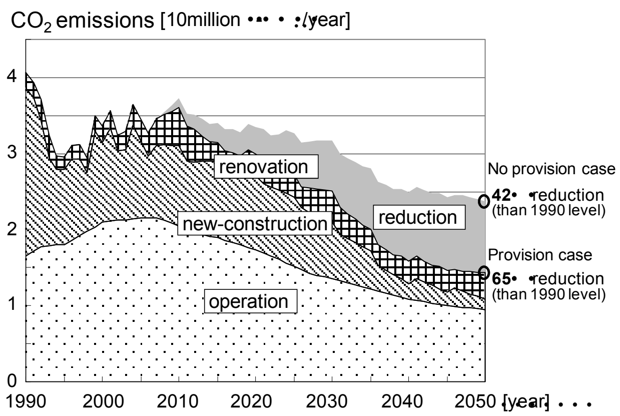

Figure 7 Results for CO_2 emissions (electricity CO_2 emission rate: fixed)

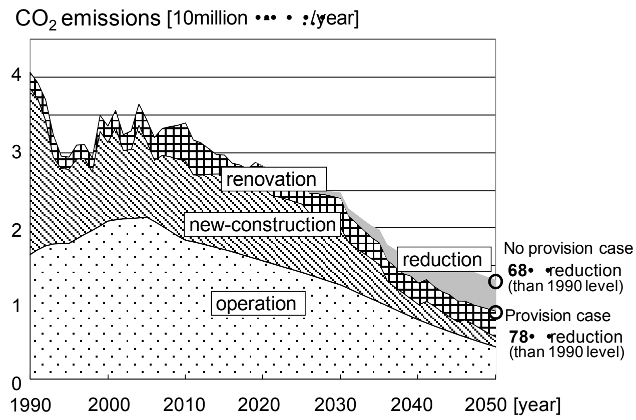

Figure 8 Results for CO_2 emissions (electricity CO_2 emission rate: improvement)

4.2 Prediction results for the level of environmental quality

Figure 9 shows the prediction results for the level of environmental quality*3. It is shown that the level of environmental quality in 2050 has improved 42% in comparison to 1990 in the provision case. Low carbon technologies are effective for not only CO_2 reduction, but also improvement of the level of environmental quality. On the other hand, the level of environmental quality has improved 4% in the no provision case. This is because the increment of floor area per capita causes the improvement of functionality.

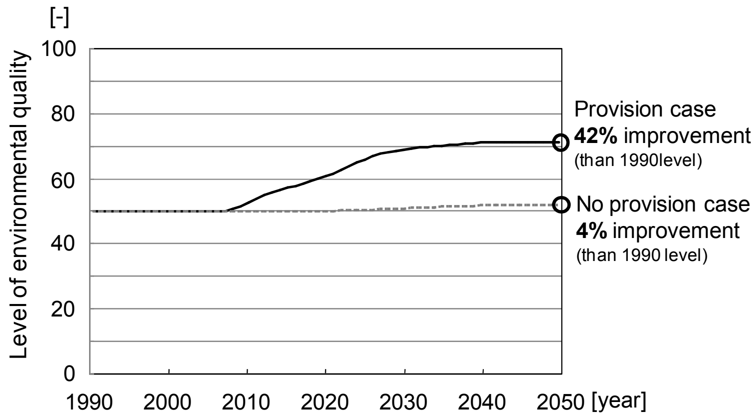

Figure 9 Result for the level of environmental quality

4.3 Transition on environmental efficiency related to CO_2 Reduction

Figure 10 shows the transition of environmental efficiency related to CO_2 Reduction. The vertical axis reflects the level of environmental quality, and the horizontal axis reflects CO_2 emissions. The Gray zone satisfies both CO_2 reduction target (70% reduction in 2050 in comparison to 1990) and improvement of the level of environmental quality. It is shown that it is possible to both achieve the CO_2 reduction target and improve the level of environmental quality by the adoption of low carbon technologies and improvement of the electricity CO_2 emission rate. In addition, the gradient of the graph depicts the environmental efficiency related to CO_2 reduction. It is shown that environmental efficiency improves 3.7~5.9 times in comparison to 1990 in the provision case.

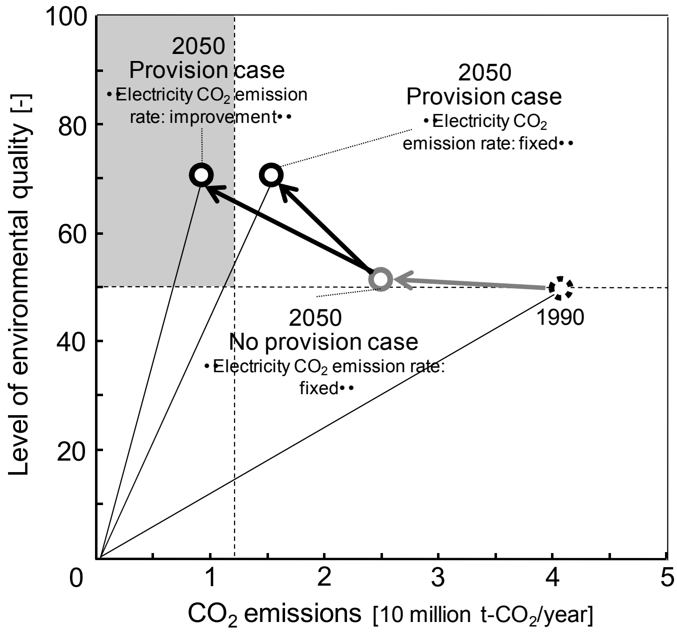

Figure 10 Transition on environmental efficiency related to CO_2 Reduction

5. Conclusion

1) We suggested a model of predicting environmental efficiency relates to CO_2 reduction for office buildings.

2) Adopting low carbon technologies are effective not only CO_2 reduction but also improvement of the environmental efficiency level.

3) It is shown that the possibility to satisfy both of, achievement of the CO_2 reduction target and improvement of the level of environmental quality.

6. Note

*1) PAL(Perimeter Annual Load) and CEC(Coefficient of energy conservation) are energy conservation standard of buildings in Japan. PAL is intended for building skin(wall, window, roof), and CEC is intended for air conditioning, ventilation, lighting, hot water supply, elevator.

*2) VVVF(Variable Voltage Variable Frequency) is a system for controlling the rotational speed of an alternating current (AC) electric motor by controlling the frequency of the electrical power supplied to the motor.

*3) The level of environmental quality is calculated following formula which is used in CASBEE.

$$\text{The level of environmental quality[-]} = \left\{ \left(\frac{S_{Q1} \times 0.4 + S_{Q2} \times 0.3}{0.7} \right) - 1 \right\} \times 25 \qquad S_{Q1} \text{ : Score of Q-1, } \; S_{Q2} \text{ : Score of Q-2}$$

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RETROFITTING MELBOURNE'S OFFICE BUILDINGS – THE SZENCORP EXPERIENCE

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Keywords: retrofit, refurbishment, office, building tune-up, upgrade, performance, Tianjin, India

Summary

This presentation outlines the substantial work on sustainable buildings undertaken by Szencorp, an Australian company specialising in the upgrade of existing commercial building stock. Its core businesses sit across property development, energy and water efficiency and clean energy technologies.

During 2004 and 2005, Szencorp became well known in the sustainable property sector for its world-leading achievements at 40 Alert Road in South Melbourne. With the maximum ratings scores for both building design and audited performance, 40 Albert Road is among Australia's greenest office buildings, setting the standards for sustainability in Australian commercial buildings. 40 Albert Road is a renovation of a 20-year-old, low-performing building. The project experience is therefore useful for the vast majority of commercial properties, and sets an example to follow. Szencorp's commitment to sharing its knowledge has created enormous interest and growth in its business activities and efforts as a sustainability advocate.

Exciting new opportunities are now opening up for Szencorp to lead the way in the delivery of other world leading sustainability retrofits both overseas and more locally. For example Szencorp is in the process of retrofitting another commercial office building to achieve maximum ratings levels. Szen2, a 2400m2 building at 124 Camberwell Road East Hawthorn, is being retrofitted in conjunction with a range of partners and building on the successes, lessons and expertise gained on earlier projects. This and other landmark projects will not only add significantly to Melbourne's and Australia's sustainable building credentials, but will prove that building refurbishments to world-leading levels provide commercial returns worthy of attracting large scale investor interest.

1. Szencorp

Szencorp has built a strong reputation as a company that walks the talk of sustainability. From a history based in property development, lighting and electrical equipment, it has grown and expanded to become a full-service engineering and property company, with expertise in water and energy efficiency, bioenergy generation and sustainable buildings. Its activities are based on a business model of "what's good for the environment is good for both the economy and enterprise value". Employing approximately 80 staff, it has offices in all states of Australia and partners in Malaysia and Thailand.

Szencorp has undertaken a range of projects and initiatives in Australia, which have created both substantial greenhouse abatement and water savings, as well as engaging the community and contributing strongly to public awareness about the need for sustainable behaviour change. Its flagship headquarters at 40 Albert Road, South Melbourne is one of Australia's best known green buildings.

The company's philosophy holds that existing building retrofitting must be the clear focus of any mitigation efforts. New buildings make up a small percentage of overall building emissions and policies that target them such as incremental improvements to building codes and standards will not provide the scale of momentum required for implementation of energy efficiency.

2. The 40 Albert Road Project

2.1 Background

Group principal Peter Szental has been a long-time advocate of energy and water efficiency in commercial buildings. His passion and enthusiasm for demonstrating leadership by "walking the talk" underpins the vision for 40 Albert Road. Relocating Szencorp's headquarters was therefore an opportunity to demonstrate sustainable development principles and practices in action.

From the outset, the project aimed for the ambitious up-front goals of zero mains water usage, grid energy usage, waste and greenhouse emissions. A detailed design options matrix was developed to look at the many potential technologies which the building might employ to help achieve these goals and ensure economic, social and environmental outcomes were considered.

An innovative partnership was formed between Szencorp, engineers and ESD consultants Connell Wagner and SJB Architects to deliver the project. The project partnership was assisted by formal plans to ensure that sustainability principles and practices were fully integrated into project delivery.

2.2 Project parameters

2.2.1 Energy

The Managed Lighting System (MLS) control system is a network of motion sensors that control lighting in offices in response to occupancy and dims lighting to compensate for natural lighting levels or lamp degradation. Energy efficiency is achieved by maintaining lighting and mechanical heating and cooling only in zones that are occupied. Lighting will switch on automatically upon entering a zone and switch off when the zone is vacated (after a delay). This functionality is designed to be adjustable to support flexibility. Similarly, the zoning can be adjusted to suit the office environment. The ventilation system is mixed mode, with natural ventilation supplied by open windows and mechanical ventilation supplied by ceiling mounted fan coil units that have a damper to close off outside air. The roof-mounted gas engine driven air conditioning units use internal combustion engine technology, rather than electric motor conditioning units, which provides several benefits. First, avoiding grid electricity use results in a lower overall contribution to global climate change emissions. Secondly, it reduces demand on the electricity grid, which cuts down on the need to upgrade the infrastructure. Thirdly, it cuts electricity demand at peak periods, thus reducing peak tariff usage.

The building also trialled the first ceramic fuel cell in commercial operation in Australia. Fuel cells use chemical reactions rather than combustion reactions to provide electrical power. Reactants are continually fed into the process to provide ongoing power output. The waste heat generated during power production has also been used to provide the building with hot water. This hot water system is supplemented by a solar hot water panel with gas boost, resulting in the building saving an estimated 12 MWh per annum by utilising solar energy to produce the majority of the domestic hot water. A 1 MWh per annum amorphous PV array plus a 4.8 MWh per annum crystalline Origin PV array, both grid connected, provides additional electricity to the building.

2.2.2 Water

Water consumption is minimised at each end use point by using the latest in controlled flow showerheads and taps throughout, some of them sensor activated only. Toilets are an award winning dual flush design using only 4.5/3 litres per flush. Urinals are waterless.

Lightly polluted water gathered from hand basins and showers (greywater) is collected, treated and reused for toilet flushing. This is complemented with a rainwater harvesting system providing 4,400 litres of rainwater storage, estimated to be enough for 3 weeks of normal flushing.

2.2.3 Indoor Environment Quality

Thermal comfort is achieved by combining natural ventilation with mechanical cooling and heating. Mechanically operated opening windows and dampers allow fresh air in and expel used air out. Natural ventilation is automated and is optimised according to inside and outside environmental conditions. Mechanical cooling or heating is supplied by ceiling mounted fan coil units. A DryKor dry conditioning unit dries and cools the office space simultaneously, using a process of natural desiccant absorption of water vapour from the air. This technology is non-toxic and non-hazardous, and the humidity is ducted outdoors, eliminating the need for condensate pumps, pipes and drainage system. This addresses "Sick Building Syndrome" problems associated with poor indoor air quality as the process removes up to 94% of microorganisms, as well 77% of particles greater than 5 microns.

Natural light is maximised by floor-to-ceiling high-performance doubleglazing and is supplemented by the atrium and glass in the central stairwell. Further, there are skylights above the boardroom. Daylight modelling shows that there will be significant natural light at desk level across one third of the office space. This will also reduce energy use on artificial lighting, since the automated lighting system dims whenever and wherever daylight levels permit, to optimise overall light levels. For the majority of the time, artificial lighting is dimmed up to eight metres away from the windows.

2.2.4 Materials

All new materials introduced into the building have been chosen with office air quality in mind. Volatile organic compounds (VOCs) emission levels are minimised in the carpets, adhesives and sealants used, and 95% of painted surfaces use low VOC paints. All composite wood used in the furniture is low in formaldehyde emissions, and a dedicated exhaust riser is provided to remove emissions from printers and photocopiers.

Most of the reinforced concrete structure and 88% of the original façade has been retained. The additional concrete required uses recycled aggregate as well as incorporating industrial waste. The material specification for the refurbishment timber (using the good wood guide) and structural concrete incorporates strict sustainability criteria.

2.2.5 Waste

An environmental management plan ensures that at least 80% of the waste used in the construction of the building is collected and sorted for recycling. During operation, onsite recycling facilities are provided to recycle paper, co-mingled plastic and glass. There are recycling facilities for organic waste and toner cartridges.

2.2.6 Education and Information

The innovations at 40 Albert Road have been extensively demonstrated to the building development and management community, and the wider public. Controlled free access to the building and its systems have been provided for educational and commercial purposes. The roof layout provides access to the PV arrays, the gas engine AC units, the DryKor de-humidifier and the ceramic fuel cell. As well, there is a comprehensive weather station and 59 individual meters monitoring the various building systems.

As a live marketing demonstration of Szencorp's business capabilities to potential clients, the publicity and marketing boost to the company has been enormous. Substantial business opportunities continue to flow as a result. Commercialisation of a range of technologies has also provided Szencorp with a business advantage by securing rights to market these Australian and international technologies through its energy and water performance contracting businesses.

2.2.7 Measuring performance

As with any investment, it is returns generated and real results that drive investment in green buildings. Szencorp believes that credible, ongoing information performance results are essential to demonstrate which green building theories work in practice and what conditions are required to make them economically viable. This is especially so because there is a lot of green building 'hype' in the market – and unsubstantiated claims, rather than growing the industry, add caution to the market's embrace of green building practices.

Monitoring, verification and public reporting is the key to accountability. The Szencorp Building has one of the most advanced and transparent building performance monitoring systems in Australia, which is publicly available at www.ourgreenoffice.com, and enables any interested party to monitor real-time building performance. Company accountability is also the key principle behind the release of public reports on building performance.

Szencorp company Energy Conservation Systems have provided many of the energy conservation measures under an Energy Performance Contract which guarantees outcomes and eliminates technical and financial risks.

2.3 Results

Table 1 40 Albert Road performance results

		Design Expectations*	First Year Results	Second Year Results
Annual Electricity Consumption (MWh)		97	92	69
Annual Gas Consumption (GJ)		321	441	308
Annual Water Consumption (kL)		157	121	76
ABGR result	Stars	5.31	5.05	5.44
	kgCO2/m2/annum	153	167	146
NABERS Water result	Stars	5.61	5.15	5.71
	kL/m2/annunm	0.167	0.299	0.101

** Connell Wagner ABGR & Energy Report, 8th Reference 6103.01 Revision 5 - March 2005*

*** Based on energy data obtained from on-site metering system and retailer supplied data*

2.4 Lessons

Performance results overall have been excellent, although some areas require further focus to achieve the intended performance. Analysing what works and what needs attention has given Szencorp a number of fresh insights into building green.

It is relevant to note that, while much has been learnt about building performance, many lessons could not be extracted because the available data was not yet detailed enough, even with the enormous emphasis placed on metering and system performance. This points to the importance of further knowledge about building management systems, monitoring and verification.

Individual technologies can provide both positives and negatives for overall environmental performance. For example fresh air ventilation provides low-energy cooling but, as we have found, it also affects indoor air quality. Choosing the right balance between low energy and clean indoor air may be a decision that can only be made on case-by-case basis in close consultation with the building owner and intended occupants.

The Building relies on a chain of many mechanical systems for successful operation. Adding to this complexity are the many variables that affect how the mechanical systems should operate, including temperature (indoor and out), solar gains, wind speed and direction, occupancy, time of day, humidity. Even though systems and related controls were specified in detail, commissioned and then independently checked for correct operation, some sequences of operation through the year were less than optimal.

Green building projects generally pay more attention to occupants, so better productivity is often expected or assumed. However, occupants may also feel pressure from this expectation, at the same time experiencing changes to individual control that influence their satisfaction with a new office.

The balance between occupant comfort and systems efficiency needs careful management. On this point Szencorp Group staff had a relatively high “forgiveness level”, given that green buildings are part of the company’s core business. However adjustment and understanding on behalf of tenants is crucial for successful implementation and if this process is not handled effectively, tenants have long memories regarding instances where they experience discomfort in occupancy.

All of this points to the fact that a twelve month post-occupancy commissioning period, incorporating a rolling review of the performance of all major systems, is essential to ensuring a green building achieves its potential.

There were many alterations and adjustments made to the building management system from opening to fine-tune performance and improve operating characteristics. The Building won’t be a static facility - tenants may change and maintenance actions can introduce new characteristics, so the need for performance review is ongoing. Automating the process by building analytical “smarts” into the building management and metering systems will be a key strategy.

Without this commitment to ongoing monitoring and verification, it is unlikely that the Szencorp Building or any green building would perform, over time, to its design intent.

3. Szen2 at 124 Camberwell Road

Szencorp has purchased a two-storey 1342m2 office block at 124 Camberwell Road, East Hawthorn with the aim of turning it into another world leadership retrofit project. Re-design of the existing 1980s building will involve a range of energy, water and environmental design measures to substantially reduce the building’s environmental footprint and financial outgoings. This new project will put into practice all of the lessons learned by the team during the course of the successful 40 Albert Road project.

The application of this team’s proven experience will allow the project to deliver a commercial rate of return, proving conclusively that investments in sustainability do not need to come at the expense of good financial sense. This integration of financial viability and world-leading environmental standards is expected to create a new financial benchmark for sustainability in the built environment.

3.1 Building Elements

Atrium: an atrium is envisaged at the front of the building. It will create a new identity and provide the opportunity for the new office to be branded as a high end, environmentally sensitive workplace. A new café/restaurant is proposed to be located within the atrium to enliven both the entry and the street life.

Façade: a new façade will be ‘clipped’ onto existing northern building façade, and designed to reduce summer heat loads.

Tenancy Floors: floors will be redesigned to connect the existing toilets & stairs with the new lift, stair & services to create a single core. A central corridor spine is provided to accommodate a multiple tenancy size/type. There is an option to exhibit some tanks & services as feature for building users, and to provide a shared meeting room.

Basement: the basement will be reconfigured to relocate the existing stair from its current central location to the southern side of existing floor plate. New bicycle parking and showering facilities will be provided, and new areas set aside for grey water treatment, rain water storage and waste processing.

NLA Extension: an extension will be built at the rear of existing building, providing additional NLA of 355 m^2. A new outdoor deck area will be located on the same level as the Ground Floor offices to take advantage of view towards adjacent park.

3.2 Building Features recognised in achievement of 6-star Green Star

Indoor Environment Quality: increased air flow rates; carbon dioxide sensors, shading to reduce heat input in summer and glare year round, daylighting on top floor

Energy: Energy efficient VRV air conditioning system, energy efficient light fittings, integrated occupancy controls, solar hot water, appropriate zoning, extensive metering, peak energy reduction facility

Transport: provision of bike parking for staff and visitors with associated showers and lockers, spaces for energy efficient small cars

Water: High water efficiency fittings and fixtures, waterless urinals, grey water recycling, rain water storage and reuse, extensive metering, water efficient landscaping

Materials: a complete re-use of the existing building, low volatile organic compound (VOC) finishes and materials, minimal use of PVC and materials containing formaldehyde, areas set aside for recycling waste

Emissions: proper selection of refrigerants, minimization of outflow of sewer and stormwater

Innovation: The following innovative approaches will be explored within the commercial circumstance that surrounds this project: gas fired absorption chiller, fresh air ventilation.

4. “Tuning Up” Melbourne’s Buildings

4.1 Background

Government is interested to improve the uptake of energy and water efficiency practices in the built environment, and integrate with existing programs to deliver more sustainable buildings. Szencorp has developed a concept whereby commercial building owners within a precinct are selected to participate in a building refurbishment program, under which their building will be a) benchmarked according to accepted energy and water performance standards; and b) upgraded to a higher standard, with the costs of upgrade recovered through the energy and water savings generated.

A pilot Building Tune Up that was run by the Szencorp group in Adelaide upgraded ten buildings at a project capital cost of $449,300, which included the delivery of sustainability audits and reports. This cost was recouped through the energy and water savings generated **within twelve months**. The cost of capital upgrade work performed is paid for over time by the ongoing energy and water savings, after which time all savings accrue to building owners.

4.2 How the “Building Tune Up” concept might work in Melbourne

In the Victorian context, project steps might include:

1) Sustainability Victoria working with DSE’s Sustainable Futures team and local government representatives to establish the project as a joint state/local initiative, under the auspices of the Victorian Local Sustainability Accord.
2) Local governments interested in participating could run the project inception phase, that is, to identify willing “building tune up” participants/commercial building owners from their municipality, and to arrange performance benchmarking on their existing sites in conjunction with industry expertise.
3) Partnerships with energy services industry providers would deliver the building upgrades, according to the specified project outcomes. Capital cost of the upgrades would be financed using either private finance from the energy services industry or sourced from Victorian Government (in either case, likely to be at lower interest rates to what could be privately sourced by building owners). This funding would also allow provision of a monitoring and verification package for each site, which would prove the upgrade results.
4) SV would work to support local government in the provision of marketing exposure/publicity and community recognition for building participants. This could be delivered through Sustainability Victoria

awards programs, or in conjunction with other similar/associated efforts e.g. ICLEI's CCP campaign, the Clinton Climate Initiative, or the 'Grow Me The Money' initiative.

5) Commercial buildings upgraded and verified savings generated by this program could be deemed eligible abatement under the Victorian Energy Efficiency Target. This is appropriate given that the initiative overcomes the stated key disadvantage of including commercial energy savings under VEET in the first round, i.e. covering the administrative costs of measurement and verification of emissions reductions achieved through different types of energy savings.

6) To close the loop, Councils could also offer to purchase (perhaps at a rate discounted to the market price) and retire the VEET certificates generated by local building owners, thereby assisting the councils in their efforts to create "zero emission" commercial precincts.

This is represented schematically in Figure 1 below.

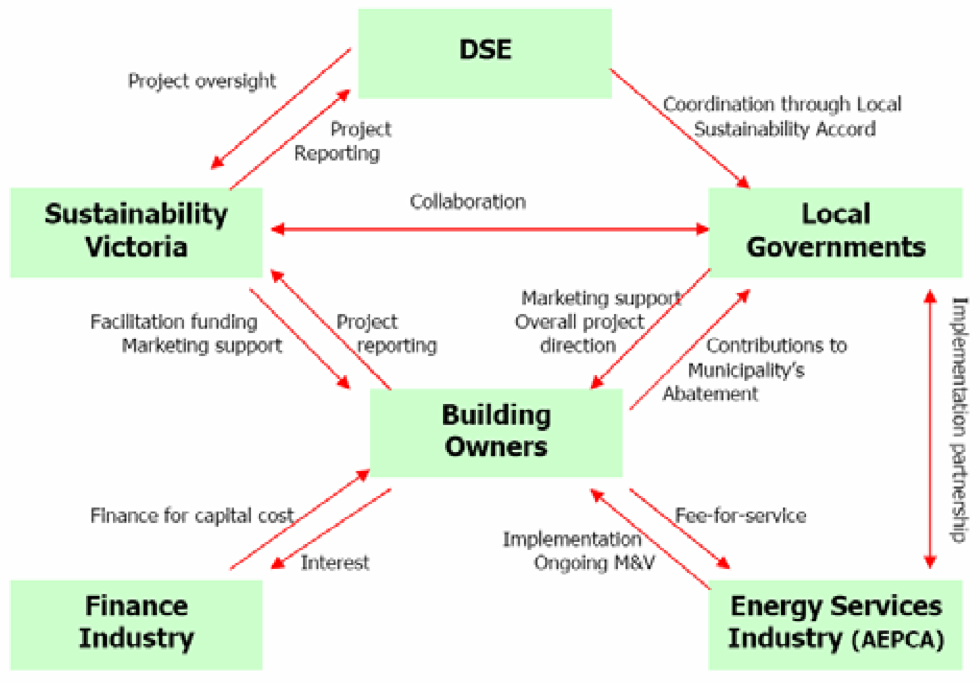

Figure 1 Project organisation – proposed Melbourne Building Tune Up

4.3 Incentives for participation

This program will encourage uptake of energy efficiency in the commercial buildings sector over and above current practice, because of incentives offered to a range of participants.

4.3.1 Building Owners

- Building owners will have part of their project involvement costs covered by Government funding.
- Building owners will have access to finance at reduced interest rates to what they may be able to attract privately
- Building owners will gain public exposure for improving the environmental performance of their assets
- Building owners will access additional income streams through VEET eligibility.

4.3.2 Local Governments

Local governments benefit from participation through

- Meeting CCP milestones (if members of the ICLEI CCP campaign)
- Extending efforts to make their municipality carbon neutral in a cost effective way
- State Government support to bolster existing programs to engage with the commercial sector on sustainability issues

4.3.3 State Government

State Government involvement is largely facilitative but, to create the appropriate incentives for participation, will involve providing funding for the project inception phase and to ensure that monitoring and verification meets requirements under the VEET scheme. It is possible that this funding be provided on a revolving basis; i.e. that it is recovered/repaid to State Government through the energy and water savings generated by the program. The extent to which this is done is proportional to the amount of incentive offered to building owners; i.e. if project inception costs are all to be recouped, then longer payback periods will result.

Amount of funding requirement varies depending on the size of each project and the difficulty of establishing benchmarks for participating buildings. A Melbourne Building Tune Up project proposal has been worked up in more detail that outlines a relatively ambitious project for Melbourne, under which a large percentage of buildings are upgraded (i.e. inception costs are high), and ongoing savings are very significant, as referred to in Table 2.

Table 2 Melbourne "Building Tune Up" Project Timeframe & Outcomes

YEAR	% of CBD Buildings Rated	% of CBD Buildings with improved to 5-Star ABGR & NABERS	Energy - reduction of existing consumption in CBD	Energy Savings (kWh)	Water - reduction of existing consumption in CBD	Water savings (kL)	Sewage discharge (kL)	GHG Emissions: reduction of total emissions*	CO2 Savings (Tonnes/CO2-e)	Predicted Cumulative Cost Savings ($)
1	10%	3%	1.20%	12,107,815	0.90%	45,404	40,864	1.20%	17,762	1,289,149
2	10%	7%	2.80%	28,251,569	2.10%	105,943	95,349	2.80%	41,445	4,297,165
3	15%	10%	4.00%	40,359,384	3.00%	151,348	136,213	4.00%	59,207	8,594,329
4	15%	10%	4.00%	100,898,460	3.00%	151,348	136,213	4.00%	148,018	18,945,401
5	15%	10%	4.00%	100,898,460	3.00%	151,348	136,213	4.00%	148,018	29,296,473
6	0%	10%	4.00%	100,898,460	3.00%	151,348	136,213	4.00%	148,018	39,647,545
TOTAL	**65%**	**50%**	**20%**	**383,414,148**	**15%**	**756,738**	**681,065**	**20%**	**562,469**	**39,647,545**

**Assuming energy composition remains the same*

5. Other Szencorp Projects

5.1 Tianjin Green Office Building, China

An Australian Consortium consisting of Maunsell, Design Inc, Bassett and Szencorp are pursuing high performance green buildings in China with the active support of the Melbourne City Council, the Victorian Government and the Federal Government. The consortium's credentials are based on Melbourne's two 6 star Green Star office buildings - CH2 and 40 Albert Rd. The Consortium has invested considerable resources in developing this opportunity and an MOU has been signed between Tianjin and the Consortium to renovate the existing Environment Protection Bureau (EPB) building with the view to expanding this throughout China and to develop a green precinct in Tianjin. The EPB have committed to a showcase leading edge building and the design team has finalised concepts. The objective of this project is to transform the existing Tianjin EPB building into a green building showcase, achieving significant energy use reduction outcomes and by ensuring that the project is delivered in a replicable manner, potentially for many other similar buildings throughout China. Expected outcomes of the project include:

- A replicable design and plan for retrofitting of similar buildings in China
- Increased comfort of occupants
- Energy and water savings and subsequent reductions in greenhouse gas emissions from the building upgrade
- Incorporation of renewable energy and embedded generation into building designs and retrofits
- Increased industry links with China

- Proof of concept that a more holistic approach to energy efficiency yields tangible results, i.e. that more sustainable buildings make economic sense
- Education and dissemination about this energy efficiency delivery model through industry and government networks and technology transfer.

The Tianjin EPB Green Office Building project will deliver the first ‘green’ retrofit of an existing building in China and will assist environmental improvements in China through design, technology, education and skills transfer. The project aligns well with the objectives of the Asia-Pacific Partnership on Clean Development and Climate and has attracted support from this initiative. It presents the capacity to act as a flagship for activities related to the Buildings and Appliances sector.

5.2 Indian Building Tune-Up

Since 1990, India has emerged as one of the fastest growing economies in the developing world. Consequently, the economic share of construction industry has grown significantly leading to increased demand of residential, commercial and institutional buildings. Building electricity consumption has more than doubled from 14% of the total electricity consumption in India in the 1970s to nearly 33% in 2005. However, the electricity supply has fallen way short of the growing demand with the peak and energy shortages in March 2007 estimated to be of the order of 14% and 9% respectively.

Recognising the demand supply mismatch, the Government of India enacted the Energy Conservation Act 2001 to promote energy efficiency and conservation in the country with an aim to reduce energy intensity of the economy. The intent of the Indian Government has yielded positive results with the energy intensity of the economy showing a downward trend for the last 3 years. The Bureau of Energy Efficiency (BEE) was created as the nodal agency to implement the Act along with its sister organisations in the states called the Designated Agencies.

Private ESCOs have recently set up the Indian Council for Energy Efficiency Business (ICPEEB), however, the ESCO industry is in infant stages. A recent report into energy efficiency improvements in India 11 concludes that a major barrier to energy efficiency uptake remains in “the absence of financial intermediation by banks and other lending institutions to promote and develop energy efficiency lending; the relative lack of private sector energy efficiency service delivery mechanisms such as ESCOs” and the fact that there is “insufficient understanding and assessment of the risks and benefits that accrue to the parties in an energy efficiency transaction. “ As a result of this lack of industry capacity, the large energy efficiency potential of India’s commercial buildings remains unrealised.

Szencorp aims to help address this barrier by working with the BEE and Indian building owners to take Australian energy efficiency service industry expertise to the Indian Commercial building market, setting up joint ventures to expand the ESCO offering in India, and delivering both know-how and tangible improvements for commercial building energy and water efficiency. The project is based on the Building Tune-Up Program delivery model, which holds that quite major improvements in energy and water efficiency can be achieved by implementing relatively straightforward and inexpensive initiatives that can also deliver excellent financial returns.

Work by Szencorp and the Indian Government has already identified a number of appropriate Indian commercial building sites for upgrade. Working in conjunction with the Indian and Australian Governments, the project proposes that Szencorp will joint venture with Indian energy service companies to upgrade the energy performance of 10 of these buildings. In the process, this will demonstrate the capacity of Energy Efficiency Audits and upgrades on Commercial Buildings to achieve significant energy savings where upgrades are paid for by future savings. The upgrades will draw on Australian ESCO Industry expertise and integrate renewable technology where applicable.

Once the buildings have been “tuned” the project will also demonstrate the Australian Government developed Green Lease Schedule’s capacity to lock in savings related to the ongoing management and maintenance of the building. As part of the Tune up, the project hopes to link in with the World Bank’s Global Environment Fund’s Chiller upgrade Program which seeks to address climate change and ozone concerns by providing financing support to upgrade the Chiller units on Commercial buildings in India.

It is hoped that this project will be able to demonstrate and document the additional major benefit of tune ups in that a tuned up building will not only use its Chiller unit more efficiently but may require a smaller chiller unit. The timing of the GEF project and ways that this project could link in are still to be finalised at the time of writing. Another major benefit could be realised through the use of solar air-conditioning units where possible. Solar is particularly suited to the Indian Climate and this would provide a demonstration of suitable renewable and embedded generation technologies within buildings.

COMPARATIVE ENVIRONMENTAL ASSESSMENT OF MASONRY WALL UNITS REGARDING MANUFACTURING PROCESS

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Summary

Sustainable building and construction with respect to environmental and economic considerations are becoming more and more important because of high energy and resource consumption in the building and construction sector. In Turkey, residential buildings are mostly built with in-situ reinforced concrete structural frame and infill external walls made of lightweight masonry such as autoclaved aerated concrete (AAC), pumice aggregate concrete hollow blocks and fired clay hollow bricks. In the paper, information gathered through field investigations on extraction of natural resources, processing of raw materials and manufacturing processes are given for AAC, pumice concrete blocks and fired clay hollow bricks and the obtained data is evaluated comparatively in terms of environmental sustainability issues such as resource depletion, greenhouse gas emissions, water use and waste generation etc.

1. Introduction

Environmental sustainability of buildings is an important matter of concern towards sustainable development, since construction and operation of buildings consume high amounts of energy and natural resources, and also are responsible for large quantities of CO_2 emissions (UNEP 2007). Environmental performance of buildings during operation period are widely studied and known whereas knowledge about the environmental performance of building products are relatively limited and also information found is differing/conflicting. This is mostly due to the fact that conditions of use, technology of manufacture, preferences, etc. are specific to country or region and these affect the assessment results. Information on energy necessary to extract raw materials, manufacture and distribution of products, which is referred as embodied energy, needs to be carefully used and national life cycle assessment (LCA) studies need to be conducted to construct a building product database in terms of embodied energy (UNEP 2007; ARUP 2006).

LCA is a general environmental assessment technique that has been widely accepted and used as a base to compare alternative materials, components and services. In building research community, as well as the studies focusing on improving and adapting the LCA methodology, research studies using LCA as a tool to assess buildings, building services or building products are found. Recent studies indicate that, product manufacturing and construction phases have also important effects on the total environmental impact as well as the use phase of buildings (Nässén *et.al*. 2007, Gerilla *et.al*. 2007, Kibert 2005). A brief survey on LCA applications at building product level and on embodied energy of building products as well is presented as follows. Koroneos and Dompros (2007) present a cradle-to-gate LCA field survey conducted to assess the brick production in Greece, and discuss the emissions to environment and their impacts. Ardente *et. al.* (2006) present a cradle-to-gate LCA field survey on kenaf-fibres insulation board, and compares its environmental performance with other insulation products in terms of energy consumption and environmental impacts when used in residential buildings. Schmidt *et. al.* (2004a, 2004b) present a comparative LCA study on roof insulation products made of stone wool, paper wool and flux, based on the inventory data collected from literature, LCA databases and suppliers. The comparison presented considers emissions to environment, energy and resource depletion, solid wastes, and their impacts. Health aspects are taken into account in the comparison as well. Reddy and Jagadish (2003) discuss the embodied energy of different types of basic building materials, masonry wall units and mortar types. Results derived from the practices in India indicate that total embodied energy of load bearing masonry buildings can be reduced by 50% when energy efficient/alternative building materials are used. Alcorn and Wood (1998) outline the embodied energy research at University of Victoria and describe the embodied energy coefficients, their background and derivation. They discuss the process-based hybrid analysis including input-output analysis. Basic approach given in the existing manual system of analysis for collecting data includes steps as: definition of product/material; major and minor players in the field; constituent ingredients and composition of product; detailed manufacturing process; energy inputs; output of a particular processing plant; prices; source, age and confidentiality of data; and other comparative data. Alcorn (2001) applies CO_2 emission factors and derives embodied CO_2 coefficients for New Zealand building materials, based on the previous embodied energy work. An example of recycled steel is also presented.

Essential requirements for sustainable building products include more efficient use of inputs such as: reduction in consumptions of non-renewable raw materials; adoption of energy efficient and clean production methods and technologies; optimum use of water; increased recycling/reuse of waste in the production; shortened distances for transportation; and the outputs such as minimized associated environmental impacts. Hence, depending on the energy efficiency during building use phase, relatively higher environmental impact of embodied energies of the building products can be anticipated.

In Turkey, in-situ reinforced concrete structural frame with masonry infill walls is the most preferred construction system in buildings. External thermal insulation systems are also used lately. Widely used infill masonry products are fired clay hollow bricks and autoclaved aerated concrete (AAC) blocks, and use of pumice aggregate concrete hollow blocks has increased recently. Studies on LCA of fired clay bricks and AAC blocks can be found in literature, since these are global products. However, research on pumice aggregate concrete blocks is limited due to its relatively local character. Additionally, as aforementioned, in each country, specific investigations are required to be done for every product in order to obtain correct information about embodied energy, gas and particulate matter emissions.

In this paper, within this context, environmental assessment of the aforementioned masonry wall products regarding the manufacturing processes is considered. The aim is to gather inventory information about these products and to develop a local comparative model that is highlighting differing characteristics of each product in terms of environmental issues such as energy and resource use, CO_2 emissions etc.

2. Methodology

LCA is a tool designed to aid in environmental evaluation and decision making at various hierarchical levels and consists of; (i) goal and scope definition, (ii) inventory analysis, (iii) impact assessment, and (iv) interpretation phases. Inventory analysis, includes the identification and quantification of all inputs and outputs of the studied system. The inputs and outputs cover items such as natural resources; energy; releases to air, water and land; co-products, etc. (ASTM 1991).

The inventory investigation of building products usually covers five main life-cycle stages, i.e. material acquisition, manufacturing, construction, use and disposal/recycling. The scope of this study on masonry wall units is, however, limited with material acquisition and manufacturing stages. Data is collected through field investigations of plants manufacturing fired clay hollow bricks, AAC, and pumice aggregate concrete hollow blocks. Following topics are studied in details:

- Raw materials acquisition
  - extracting mineral resources from quarry
  - supplying materials in processed form
  - transportation.
- Product manufacturing
  - constituent ingredients and composition of products
  - manufacturing processes – technology
  - packaging, storage and delivery.

Plant facility characteristics unique for each investigated specific building product also have some effects on environment and therefore included in the study. Plant location, plant capacity, number of workers and their transportation, electricity and water use for domestic purposes, heating of office buildings and plants, etc are relevant information considered in the case studies.

Impact assessment phase of LCA aims to evaluate the significance of potential impacts of the investigated system using the inventory data. The level of detail, choice of impacts evaluated and methodologies used depends on the scope of the study (ISO, 1997). Within the scope of this study, the following criteria are adopted for the input-output analysis in order to assess the embodied energy and the environmental impact of the investigated masonry wall units:

- Resource consumption
  - mineral use
  - water use
- Land disturbance
- Energy consumption
  - mining
  - production processes
  - transportation

- Environmental impact
  - gas emissions
  - particulate matter
- Waste management.

The interpretation of inventory analysis and impact assessment results are made on a general basis due to the fact that the field investigations were executed in limited number of manufacturing plants and therefore will not be representative of the whole masonry wall product manufacturing industry.

3. Inventory Investigations of Masonry Wall Units

Inventory investigations of pumice concrete block and AAC block were presented in detail in Kus *et. al.* (2007). In this report, only the brief information for these products are given for comparison purposes, while fired clay brick production is thoroughly explained.

3.1 Plant Facility Characteristics

The investigated plants are all located nearby the raw material sources in order to shorten the transportation distance to manufacturing units. This preference helps to save energy and in turn reduces transportation costs and environmental impacts. Final distribution distances for the delivery of manufactured products to construction sites have also an effect on the selection of plant location and the possible shortest distances to target market areas are preferred. Specific information about the investigated plants are given in Table 1.

Table 1 Some facts and figures about the investigated plants

	Pumice Concrete Block	AAC Block	Fired Clay Brick
Plant Location	Nevsehir (mid-Anatolia)	Hereke-Kocaeli (Marmara)	Isiklar-Istanbul (Marmara)
Plant Capacity / year	30,000,000 blocks	100,000 m^3	~175,500,000 bricks
Plant Operation Duration/day	24 hours – 3 Shift	24 hours – 3 Shift	24 hours – 3 Shift
Number of Production Lines	2	1	3 (extrusion and drying)
Electricity – supplied from / annual consumption (if available)	City supply network 1.8 million kWh	Private power plant using natural gas	Private power plant using natural gas
Water – supplied from	Wells in plant area	Wells in plant area + city supply network	Two artificial lake on former clay pits
Energy used in space heating / annual consumption (if available)	Coal 250-300 tons	Natural gas	Natural gas
Number of Workers (Total)	148	31	270
Office / Other	15 / 49	11 / -	41 / -
Production / Loading	60 / 12	20	89 / 140
Raw Material Acquisition	12	Outsourced (from sister company)	Outsourced
Transportation of workers			
Shuttles (number and type / travel distance per day)	1 minibus / ~240 km 1 bus / ~80 km	1 minibus / ~270 km	1 minibus / ~180 km 1 bus / ~100 km
Number of Private Cars	8 (for office workers)	-	8-10 (for office workers)

3.2 Materials Acquisition

Material acquisition phase includes all activities and processes required for obtaining all raw materials, energies and other material requirements for the product system (ASTM 1991). In the investigated plants raw materials are supplied either by extracting from the quarry or by purchasing in the processed form.

3.2.1 Raw Materials Acquisition of Pumice Concrete Blocks

Pumice aggregate, cement, water and iron oxide are constituent materials of pumice concrete block production. Auxiliary materials required in association with block production are timber pallet, steel and plastic strip, and kraft paper protection corner pieces for packaging. Information relevant to inventory analysis is summarised in Table 2.

Pumice aggregate preparation for block production is consisted of (i) excavation and loading of pumice, (ii) transportation to cleaning/sorting bunker, (iii) cleaning and sorting of pumice, and (iv) transportation to production bunker processes. Pumice is excavated from three different areas, one located at the factory site and the others located 4 and 10 km far from the factory. Pumice is usually found close to the surface and as 4-5 metres thick bands (Figure 1). Cleaned and washed pumice aggregate is screened into 0-3 mm, 3-8 mm, 8-16 mm and over 16 mm. Aggregates in 3-8 mm and 8-16 mm sizes, used in the block manufacturing, are filled into bunkers through band conveyors and are ready to be used in the production mix. Water, in addition to block production, is used for cleaning and sorting of pumice aggregate (Figure 2), and after re-used.

Table 2 Figures for Material Acquisition in Pumice Concrete Block Production (after Kus *et. al.* 2007)

Purchased basic materials	Annual consumption*	Supplied from (distance)	Transportation method/capacity	Transportation energy
Cement	30,000 t	65 km	Truck / 40 t	Diesel fuel
Iron oxide	84 t	797 km	Truck / Vary	Diesel fuel
		~8000 km	Ship / Vary	Diesel fuel
Timber pallet	150,000 pieces	70 km	Truck/ 40 t	Diesel fuel
Steel strip	150 t	797 km	Truck / 40 t	Diesel fuel
Plastic strip	70 t	797 km	Truck / 40 t	Diesel fuel
Kraft protection	35 t	Vary	Vary	Vary
Extracted material	**Annual consumption***	**Extraction processes**	**Machine used in processes**	**Energy input**
Pumice	300,000 t	Excavation	Wheel loader	Diesel fuel
		Transportation (~4.5 km)	Truck / 32 m^3	Diesel fuel
		Cleaning / Sorting	Sieve	Electricity
		Loading	Wheel loader	Diesel fuel
		Transportation (~0.5 km)	Truck	Diesel fuel
Water for block production	95,000 t	Pumping	Water pump	Diesel fuel

* Consumption amounts are based on annual production of 30 million blocks having dimensions 19 x 33 x 24 cm and weight 7346 g/block.

Figure 1 Pumice excavation in the main quarry

Figure 2 Cleaning / sorting machine

3.2.2 Raw Materials Acquisition of AAC Blocks

Sand (quartz), cement, lime, gypsum, water and aluminium powder are constituents of AAC block production. Timber pallets and polyethylene wraps for packaging are the other materials used in the investigated plant in association with the block production. All materials required for production are purchased from outside sources. However lime and cement are supplied from sister companies located at the same site, therefore classified as in-house supplied material. Lime plant employs two 250 tonnes/day Maerz type parallel flow regenerative (PFR) shaft lime kilns. Information relevant to inventory analysis is summarised in Table 3.

Table 3 Figures for Material Acquisition in AAC Block Production (after Kus *et. al.* 2007)

Purchased Material	Annual Consumption	Supplied from (distance)	Transportation Method /Capacity	Transportation Energy
Sand	35,000 t **	~100 km	Truck / 16 t	Diesel fuel
Gypsum	1,500 t **	453 km	Truck / 16 t	Diesel fuel
		250 km	Truck / 16 t	Diesel fuel
Aluminium powder	400 t **	~2,000 km	Long vehicle / 20 t	Diesel fuel
			Ship / vary	Diesel fuel
Water*	25,000 m^3 **	-	-	-
Timber pallet	92,600 pieces	~30 km	Truck / 16 t	Diesel fuel
Polyethylene wrap	92,600 pieces	~80	Truck / 16 t	Diesel fuel
In-house Supplied Material	**Annual Consumption**	**Supplied from (distance)**	**Machine used in processes**	**Energy input**
Lime	7,000 t **	0 km	Air compressor	Electricity
Cement	7,000 t **	3 km	Truck / 16 t	Diesel fuel

* includes water supplied from wells at the factory site.
** Calculated consumptions based on annual production of the factory (100,000 m^3) and AAC recipe obtained from product literature (Masa-Henke, 2003). Aerated concrete paste recipe is for a density of 500 kg/m^3.

3.2.3 Raw Materials Acquisition of Fired Clay Bricks

Inner materials used in fired clay brick production are clay and water. In the investigated factory three different types of clay are used in the brick recipe. Clay pits of type 1 and 2 are about 1.5 km, and type 3 is about 2 km far from manufacturing facilities, and all pits are factory's own property.

In clay extraction excavators, front-end or backhoe wheel loaders, and in transporting clay to brick manufacturing storage area trucks are used. Trucks operating between pits and manufacturing plant are returning back to pit empty, and this situation doubles the energy consumption per a truck of clay.

Water required for brick production is supplied from in-house sources, i.e. two artificial lakes. One lake is about 0.5 km and the other is about 1 km far from the brick production facilities and water is transported to production area through pipelines.

Information relevant for inventory analysis of the investigated factory's material acquisition phase is summarised in Table 4.

Table 4 Figures for Material Acquisition in Fired Clay Brick Production

Extracted / In-house Material	Annual consumption	Extraction / Supply processes	Machine used in Processes / Capacity	Energy input
Clay	~381,489 t*	Excavation / Loading	Excavator	Diesel fuel
		Front-end of backhoe loader		Diesel fuel
		Transportation (~1.5 km)	Truck / 25 t	Diesel fuel
Water for block production	~15,895 t	Piping (~0.5-1 km)	Water pump	Electricity

* Calculated consumption figures based on annual production of 175,348,800 bricks (19 x 19 x 8.5 cm and weight 1850 g/brick) and assuming that moisture content of extracted clay is 20 % during whole year.

3.3 Manufacturing of Masonry Wall Units

Product fabrication, intermediate manufacture, raw material conversions excluded in material acquisition stage, packaging, storing and internal transportations either outdoors or indoors are processes included in the inventory investigations of the plants.

3.3.1 Pumice Concrete Block Manufacture

Pumice concrete block manufacturing processes in the investigated factory are mainly (i) mixing, (ii) moulding, (iii) drying, (iv) packaging, and (v) storing. Sometimes an additional crushing process prior to mixing process is included when pumice aggregates are stored in production bunker without a sorting process. Blocks are formed by injection and pressing through steel mould and subsequent vibration processes. Wet blocks are air-dried in a chamber for 72 hours. During production process, handling, placing and transport of pumice concrete blocks are made by the help of a robot arm and automatic controlled transport tower while the removal of faulty blocks and packaging are made only manually. In this respect, it can be said that highly mechanised technology is adopted by the plant. Information about sub processes of main phases, and machines and equipments used in these processes are summarised in Figure 3.

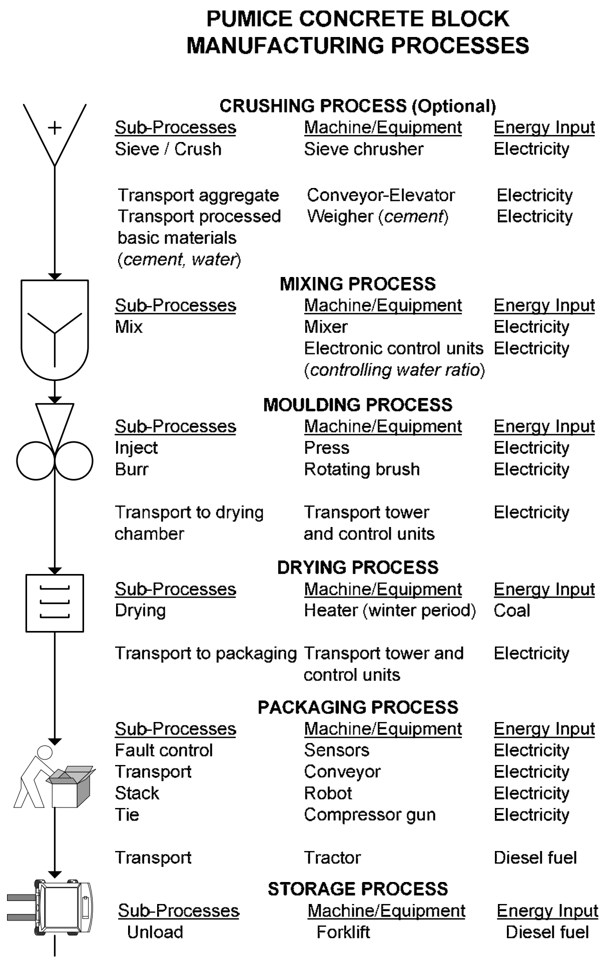
3.3.2 AAC Block Manufacture

AAC block manufacturing processes in the investigated factory are mainly (i) crushing, (ii) mixing, (iii) moulding, (iv) cutting, (v) steam curing, (vi) packaging and (vii) storing.

After crushing of silica sand with gypsum and then mixing all materials, aluminium powder is added and the paste is poured into the moulds. The expanded and hardened green cake is then wire-cut to desired size and steam-cured at 200 °C and 12 bar for about 10 hours for gaining its final strength and stiffness. The finished product is packaged and is usually delivered directly to the construction site.

The chemical reaction caused by addition of aluminium makes the mixture expand to about twice its volume, resulting in a highly porous structure. Approximately 80% of the volume of the hardened material is made up of pores, 50% being air pores and 30% being micropores. The microstructure of the solid matrix is mainly made up of microcrystalline platelets of tobermorite, calcium silicate hydrate, forming the pore walls (Aroni et.al. 1993). The quality of end product is highly influenced by the quality and mix design of raw materials, and the design of production technique among the other factors.

Information about sub processes of main phases, and machines and equipments used in these processes are summarised in Figure 4.



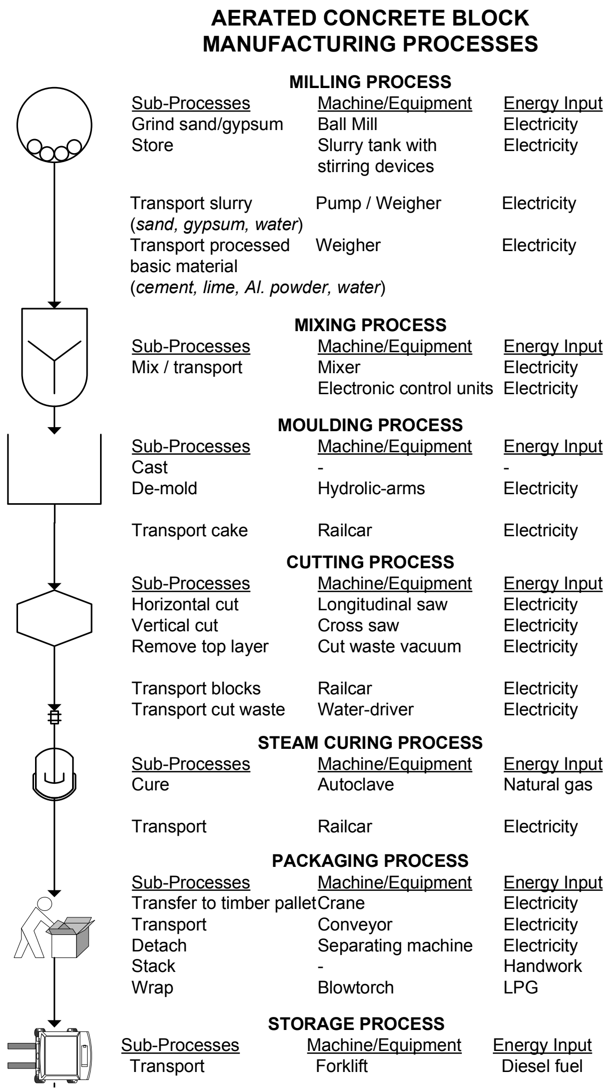


Figure 3 Pumice concrete block manufacturing processes   *Figure 4 AAC block manufacturing processes*

3.3.3 Fired Clay Brick Manufacture

Fired clay brick manufacturing processes in the investigated factory are mainly (i) clay / mud preparation, (ii) forming, (iii) drying, (iv) firing and (v) storing.

In the clay / mud preparation process, clay mixture of three different clay types taken from storage area is crushed and watered in the edge mil. Clay mud then transported to Vals machine for being compacted to eliminate air pockets. Later, it is transported to double shafts mixer for proper mixing and watering if moisture content is not adequate. For a proper forming, moisture content of clay needs to be 23-25 % by weight. During winter time, moisture content of extracted clay is about 18 % and less watering is required. However in summer time additional watering to obtain adequate moisture content is always required. Finally clay mud is transported to interim silos for resting.

In the forming process, clay mud taken from silos are compacted in the Vals machine and then transported to extrusion press. A long piece of paste is extruded through the die and is cut into smaller pieces with an initial cut and then into individual brick size with a second cut by means of a wired saw. The cut waste of the second cut is transferred back to extruder. Formed bricks are either transferred to pallettes for being transported to tunnel or chamber drying units, or directly transported to rapid drying unit by roller conveyor.

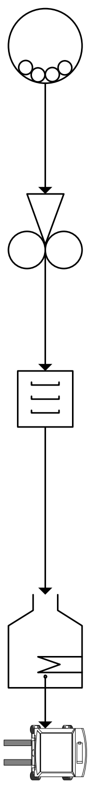
In the drying process, three different types of drying techniques are used. The first one is “chamber drying technique” in which shelved pallettes are filled into the chamber and the temperature of the chamber is increased to about 200 ℃ and left for a certain time, then the temperature is slowly decreased and the shelved pallettes are taken out. The drying continues approximately for 17 hours. The second one is “tunnel drying technique”, in which shelved pallettes move in the tunnel where the temperature increases slowly and remains in about 200 ℃ for 8 hours then slowly decreases. It takes approximately 10 hours for drying. The last one is “rapid drying technique” in which bricks move on conveyors and the air temperature in rapid drying unit gradually increased up to 200 °C and remains for certain time then decreased along the unit. It takes ~4 hours to complete drying. Following the drying, dry bricks are transferred to and loaded on trams by the help of conveyors and robot arms. Moisture content of dried bricks is about 1-2 % in summer time and 3-5 % in winter time.

In the firing process, trams move in the kiln having a length of 187 metres and the air temperature is gradually increasing and then decreasing along the length of the kiln. The maximum air temperature in the kiln is about 900 °C and it takes about 20 hours to complete the firing of a brick loaded tram. The temperature in the kiln is continuously monitored at several places.

Finally, the trams are transported to the outside of the manufacturing building for either being transported to storage area or for being directly distributed to construction sites.

The machines and equipments, and energy used in the manufacturing of fired clay bricks are summarised in *Figures* 5-7.

FIRED CLAY BRICK MANUFACTURING PROCESSES



CLAY / MUD PREPARATION PROCESS

Sub-Processes	Machine/Equipment	Energy Input
Grinding/watering clay	Edge Mill	Electricity
Compress/empty air	Vals	Electricity
Watering / Mixing	Double shafts mixer	Electricity
Interim storing	Silo	-
Internal transportations	Strip conveyors	Electricity

FORMING PROCESS

Sub-Processes	Machine/Equipment	Energy Input
Extruding	Extrusion press	Electricity
Initial cut	Wired saw	Electricity
Brick size cut	Wired saw	Electricity
Internal transportations	Roller conveyor	Electricity
Transport cut waste	Strip conveyor	Electricity

DRYING PROCESS

Sub-Processes	Machine/Equipment	Energy Input
Drying	Chamber dryer	Vary
	Rapid dryer	Vary
	Tunnel dryer	Vary
Internal transportations	Roller conveyor	Electricity
	Strip conveyor	Electricity
	Robot arm	Electricity
	Forklift	Diesel fuel
	Tramway	Electricity

BAKING PROCESS

Sub-Processes	Machine/Equipment	Energy Input
Baking	Kiln	Natural gas
Internal transportations	Tramway	Electricity

STORAGE PROCESS

Sub-Processes	Machine/Equipment	Energy Input
Unloading/loading	-	Manpower
Transportations	Tram	Electricity
	Truck	Diesel Fuel

Figures 5 - 7 Fired clay brick manufacturing processes (left); cutting and transportation of cut waste (right-top) and brick extruded from die and shelved bricks for being transported to drying unit (right-bottom)

4. Environmental Assessment

Resource and energy consumption, green house gas emissions and land use issues are thoroughly discussed for environmental assessment of masonry wall units regarding manufacturing phase.

4.1 Resource Consumption

Depletable resources consumed as raw materials in the manufacturing processes of clay bricks and concrete blocks can be classified as minerals and water. Considering sustainability, the amount of available reserves and the materials extracted in a year come into question. Low density of building products means lower consumption of raw materials contributing to their conservation. This is also beneficial during the use phase of the building, either by reducing the total loads of the building or providing better thermal insulating properties achieving greater energy efficiency. Despite their contribution to energy efficiency (with their low thermal conductivity) during the operation (use) phase of buildings, extended durability and service life of these products gain importance in reducing the depletion of natural resources by decreasing the need for new building construction.

Non-renewable energy resources like natural gas, fuel oil and coal are considered under the energy consumption sub-heading. Less-used raw materials and auxiliary materials used for packaging are left out of the scope of the present study.

4.1.1 Mineral Use

Pumice, quartz sand and clay are the main minerals needed to produce concrete blocks and clay bricks. In addition, limestone is used for cement and lime production. All these minerals are often obtained by surface quarrying. Use of recycled materials in the production is regarded as very important for decreasing the amount of extracted materials and thus protecting the finite mineral resources. In Table 5, annual mineral consumption amounts are given for all three plants. In cement manufacture, in average, 1.27 tonnes of limestone and 0.05 tonne gypsum are consumed per 1 tonne of cement (IPPC 2001). Regarding lime production, 1.78 tonnes of limestone is consumed to produce 1 tonne of quicklime (Hill and Mason 1997).

Table 5 Annual Mineral Consumption of the Visited Plants Manufacturing AAC, Pumice Concrete and Brick

	Density (kg/m^3)	Annual consumption	Pumice (tonne)	Clay (tonne)	Sand (tonne)	Gypsum (tonne)	Limestone (tonne)
AAC Block	500 (bulk)	100,000 m^3	-	-	35,000	1,850	21,350
Pumice Concrete Block (Hollow) 7.346 kg/block	488 (bulk)	30,000,000 block 451,598 m^3	300,000	-	-	1,500	38,100
Fired Clay Brick (Hollow) 1.85 kg/brick	602 (bulk)	175,500,000 brick 539,327 m^3	-	381,489	-	-	-

4.1.2 Water Use

Water needed for the production of block and brick is obtained in three ways: (i) by pumping underground water from the wells opened in the plant area; (ii) utilizing rainwater collected in the artificial lakes; and (iii) city water supply network. Total amount of water required for the processes and used for domestic purposes gains importance. Climate change is the biggest threat for the sustainability of water resources thus minimizing water use and recycling of waste water is important for efficient use and conservation of water.

4.2 Land Disturbance

From a sustainability point of view, the world reserves including non-renewable mineral resources are increasingly consumed in construction sector and the natural state of the landscape is destroyed leaving back a permanent change. After surface mining of minerals like pumice, clay, sand and limestone, disturbed land, i.e. the quarry and the surrounding land, needs rehabilitation. Land reclamation can be determined according to the specific characteristics of the open pits and the site. Agriculture and forestry are generally preferred land cover types.

In our case, depleted pumice pits are used as cultivation substrate to potato field. Clay extraction pits are rehabilitated as artificial lakes from which the water needed for the production is transported by pipes to the plant.

4.3 Energy Consumption

Natural gas, fuel oil and coal are the main energy resources for space heating in Turkey. These are depletable energy resources therefore need to be conserved and replaced by recycled or renewable ones as much as possible. On the other hand, energy for drilling of oil, gas and coal is indirectly covered by the embodied energy of the masonry wall units as for all other construction products. Electricity needed for space lighting and operating the machines is provided from city supply network and is mainly generated either from hydro-electric power stations or thermal power stations using natural gas. Besides, industry can also generate its own electricity using natural gas, as in our case, brick and AAC plants do. Vehicles used for transportation of either goods or people of industry mostly have diesel engine with manual gear type.

In addition, there is indirect embodied energy required for the investments like the machines, tools and all equipments used for extraction, production and transportation of construction products as well as infrastructure needed for generating electricity. Indirect energy for the production and maintenance of vehicles used in transportation can also be mentioned.

4.3.1 Energy Consumption in Mining

Equipment required for performing this process comprises front-end or backhoe wheel loaders. To power these work machines, diesel engine is used. Energy consumption greatly depends on the properties and efficiency of machines used as well as the amount (in weight and volume) of raw materials extracted and the depth of the excavation. Density of the material extracted thus play important role.

4.3.2 Energy Consumption in Production Processes

In the production process of masonry wall products, in general, (grinding, mixing and forming) machines work with electricity.

Heating and firing processes account for the highest energy use than any other processes; therefore temperature/time relationship is significant in determining energy consumption. For autoclaving and brick firing processes in the investigated plants, the required energy is supplied by natural gas. The autoclaving temperature of AAC is about 200 °C at 12 bar for about 10 hours. Waste steam generated at the power plant owned by the manufacturer is used in this process, thus no extra energy is required. Electricity is also supplied by this gas turbine and combined-cycle power plant. For brick, drying temperature is about 200 °C for about 4-17 hours depending on the type of the technique used, and the firing temperature is about 900°C for 20 hours. In the visited plant, the waste heat from the cooling zone of brick kiln is utilized in the drying process. In pumice concrete block manufacturing; on the other hand, there is no need for high temperatures in the process. The only heating needed is, in winter, for keeping the drying chamber air temperature around 15 °C. However, the production process of raw materials like cement and lime is highly energy intensive. High temperatures (about 1500 °C) are required in the cement clinker production phase. For the production of cement and lime, shaft kilns are generally used. Cement content in pumice concrete mix design, and cement and lime contents in AAC mix design constitute the total energy intensity together with the energy required for the other manufacturing processes. Indeed, embodied energies based on volumetric bulk densities of the wall units yield more practical values. Shape and hollow design of pumice concrete blocks and bricks are thus taken into account in terms of their contribution to energy efficiency and/or saving.

In Table 6, embodied energies, as found in literature are given (Elliott 2007, Hendriks *et.al.* 2004, NRC-OEE).

Table 6 Embodied Energy of Masonry Wall Products Manufacturing (excluding transportation)

	Mining & Hauling (MJ/m^3)	Screening & Sorting (MJ/m^3)	Cement production (MJ/kg)	Lime production (MJ/kg)	Embodied Energy (MJ/kg)	Embodied Energy (MJ/m^3)
AAC Block	Sand/limestone 78.79 / 78.79	Sand/limestone 78.79 / 78.79	3.5 – 5.5 (dry process)	5.0 – 7.0 (vertical kiln)	2.1 - 3.6	1050-1800*
Pumice Concrete Block	Pumice/limestone 48.14 / 78.79	Pumice/limestone 78.79 / 78.79	3.5 – 5.5 (dry process)	-	0.94 - 1.5	459-732*
Fired Clay Brick	Clay 78.79	Clay 78.79	-	-	1.2 - 2.5	722-1505*

* Calculated values in terms of bulk densities of the investigated plants' products.

4.3.3 Transportation

Internal (short distance) transportation within the plants, either indoors or outdoors, is generally provided by (horizontal, inclined or vertical) belt, roller conveyors and bucket elevators, 1-rail and/or 2-rail carriage systems, robot arm systems, crane, fluid transfer (slurry or watering) pumps and pipelines. All these transport equipments work with electricity. Furthermore, diesel tractor and forklifts are employed in moving and transporting final products within plant area. Between the quarry and the plant, diesel engine trucks are used. For the delivery of final products, dominating means of transport is road truck. Depending on the weight (and volume) of carried products (raw materials, auxiliary materials or masonry wall units) and the type/properties of vehicle, diesel consumption of rigid trucks varies between 30-45 litre/100 km. Shuttle bus or minibus, on the other hand, consumes diesel between 15-30 litre/100 km depending on the model (age) and type of engine.

In the investigated plants, annual total diesel consumption amounts needed for transportation of raw materials including transportation of plant workers and excluding final distribution of products are given in Table 7. Assumptions were made as all three plants work 330 days and offices 300 days a year. Trucks operating between pits and manufacturing plants are returning back to pit empty. This situation doubles the energy consumption per a truck of raw material transported but transportation of aluminium powder from abroad is exception. It is clearly seen that, transportation of AAC raw materials consumes significantly high energy and transportation of brick raw materials significantly less. This is probably not associated with the capacities of the plants. It is most likely related to the distances and the capacities of the vehicles employed.

Table 7 Annual Diesel/Gasoline Consumption from Transportation including Transportation of Plant Workers

	Raw Materials Truck (diesel)	Shuttle (diesel)	Car (gasoline)	Total Diesel consumption	Total Gasoline Consumption	CO_2* (Materials)	CO_2* (Workers)
AAC	174,640 l	17,820 l	-	192,460 l	-	501,216 kg	51,143 kg
Pumice concrete	71,200 l	21,120 l	6,000 l	92,320 l	6,000 l	204,344 kg	76,154 kg
Brick	14,650 l	18,480 l	7,200 l	33,130 l	7,200 l	42,045 kg	71,685 kg

*1 litre of diesel = 2.87 kg of CO_2 equivalence and 1 litre of gasoline = 2.59 kg of CO_2 equivalence (Jaques et.al. 1997).

4.4 Environmental impact

In order to provide a basis for a comparative environmental assessment of masonry wall units, it is necessary to identify the processes which require higher energy, and consequently, to determine the approximate embodied energies. Environmental impact depends principally on the amount and type of energy used in:

- extraction and processing of raw or primary materials
- manufacturing of products
- operation and maintenance of plant facilities including offices
- transportation of raw and auxiliary materials, manufactured products (delivery), and industry workers involved in the manufacturing processes.

Gas emissions and particulate matters are considered as the environmental impacts associated with the embodied energies of masonry wall units.

4.4.1 Gas Emissions

The main source of CO_2 emissions is burning fossil fuels like coal, oil and natural gas, and can be attributed to the high temperatures required in cement, lime, brick and AAC block production. In cement and lime production, the calcination process also gives out CO_2, which makes up about 50 % of the total CO_2 emission. In Table 8, gas emission factors are given as found in literature (EPA, ETS, GBC).

Table 8 Emission Factors

	SO_X kg/Mg	CO_2 kg/Mg	C_2H_4 Kg/Mg
Brick	1.22	194 - 235.5	0.07
AAC block	2.23	265 – 448	0.175
Pumice concrete hollow block	0.172	106	0.0229
Cement	0.56	710 – 970	0.0231
Lime	0.55	859 - 1210	0.0252

4.4.2 Particulate Matter

Particulate matters (PM), as coarse and fine particles, are emitted from power plants, industries, vehicles and buildings. PM quantities widely vary according to the plant characteristics and use of measures such as dry filter systems or electrostatic precipitators. Amount of PM emissions generated from cement, lime and brick production, depends mainly on the type of fuel, pre-heater, kiln (rotary, vertical shaft) and cooler used.

4.5 Waste Management

Minimizing waste generation and effective reuse/recycle through manufacturing processes are very important regarding reduced raw materials consumption and energy needed for post-processing of waste.

Waste material left over from the AAC manufacturing processes, prior to steam-curing process while it is still wet and unhydrated, are water-driven to auxiliary return tank for being used in the mix preparation. Faulty AAC blocks detected after curing process is stored in a waste area and sometimes used as pavement filler. Recycling of these blocks by grinding and adding to the mix production is planned for the near future.

In the pumice concrete block manufacturing processes, since the mixture is injected and pressed through moulds as individual units, there is no wet waste. Faulty or broken pumice concrete blocks which are already hardened after drying, are used as pavement filler material in the factory area to cover the pumice dust lying over the ground. Pumice aggregates left over after sorting and which are not used in the block manufacturing, having sizes over 16 mm, are used in the textile industry and in agriculture whereas sizes of 0-3 mm are used to produce plaster mortar.

Regarding the waste material from the brick manufacturing processes, the cut waste material is transferred back to the extruder. Faulty or broken bricks which are detected after firing, are stored at plant site for more than 30 years, and sometimes used as landfill when requested by neighbour factories. A research project is to be set up by the plant owner for utilizing this collected waste in the best way.

In all three plants, measures are taken to reduce the amount of faulty/broken products and the ratio of these remains between 1-2% of total production.

No wastewater is generated in any of the three plants except for the domestic water waste in the offices.

5. Conclusions

In this report, an attempt is made for understanding and comparatively assessing the manufacturing phase of masonry wall units regarding energy consumptions and environmental impacts. Comprehensive information on extraction of natural resources, processing of raw materials, manufacturing and transportation were collected from masonry wall products' manufacturing plants and data obtained was systematically organized. One plant for each masonry wall product, namely pumice concrete block, AAC and brick, was visited and their productions were investigated in detail. Plant facility characteristics were also considered as a factor affecting the environmental performance of factory-made building products. It should be noted that each plant has its own unique manufacturing characteristics and therefore it should not perceived as representing the general situation in Turkey. Other factories manufacturing masonry wall units may differ on certain measures. When assessing embodied energies according to the volume of the end-product the following conclusions can be drawn;

- AAC block manufacturing requires very low raw materials consumption due to the high porosity of the end-product. However, cement, lime and aluminium powder content in the production mixture are energy intensive processed materials although used in low quantities compared to the amount of end-product, and therefore product's embodied energy increases. Besides, autoclaving also requires relatively high energy.
- Fired clay brick manufacturing can be considered, relatively, energy intensive due to the high energy required for high temperatures in the kiln. However, its low bulk density (because of hollow design of brick) significantly reduces the embodied energy.
- Pumice concrete block manufacturing, although energy intensive cement is used, seems to be the most energy efficient among all, since no heating required in the processes, and because of its low bulk density due to porous structure of pumice aggregate and also hollow design of block.

Maximum efficiency is obtained in terms of consuming less depletable resources by either hollow design of bricks and blocks or porous material structure of the latter. In general, less use of raw materials according to the volume of the end-product contributes energy efficiency both in production and transportation. In addition, adopted efficient operation strategies in the investigated plants, such as use of waste heat in other energy consuming processes or reprocessing of cut wastes contributes energy and resource saving. From this point of view, all investigated products can be regarded as sustainable. Fuel consumption during transportation of raw materials and plant workers, on the other hand, seems to have considerable effects. Thus, strategies like decreasing the number of employed workers by changing and/or improving production systems and employing technology leading higher levels of automation rather than manual operations as well as shortening distances between quarries and plants would help to save energy and, in turn, minimize environmental impacts.

Briefly, profiling the environmental performance of building products in terms of aforementioned key issues according to sustainability approach, and bringing the assessment results in discussion may help;

- to encourage the use of energy efficient technologies in production,
- to develop methods for minimally processed materials,
- to recommend measures for reducing the impacts and costs,
- to select alternative products/materials on environmental performance,
- to plan production waste management,
- to rehabilitate quarry and the surrounding land.

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A CRITICAL REVIEW OF ENERGY SAVINGS AND COST PAYBACK FOR DOUBLE FACADES

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Keywords: double skin facades, costs, payback, energy, construction, orientation, optimal, HVAC

Summary

This paper presents a dynamic thermal modeling study to show estimated energy savings and projected payback periods for various double façade construction systems in different climates and orientations. It concludes that although the economic case for a double façade is marginal when considering purely the simple payback calculation of additional capital cost divided by annual energy cost savings, a thorough and integrated consideration of many other factors can justify their construction. Climate, construction type, construction cost, and energy cost significantly contribute to the feasibility of each unique case and must be assessed for each building and costs and benefits vary widely.

1. Introduction

Double facades offer an effective means of buffering and controlling heat, light, air and noise through a building envelope. They do, however, carry a premium first cost compared to conventional facade systems. Justification of their inclusion in a building design, therefore is typically on the basis of energy efficiency and associated cost savings. Qualitative benefits of solar control, moderated surface temperatures, noise reduction, reduced glare, reduced heating/cooling demand, moderated access to fresh air, aesthetic purity and increased daylighting are generally seen only as intangible 'bonus' benefits.

The principle of a double skin façade is an additional layer of glass offset from the conventional curtain wall forming an interstitial space that acts as a thermal buffer. Blinds are typically incorporated into the void space to prevent solar heat gains from entering the occupied space (Figure 1). Blinds may be automatically or manually operated. On the outer surface of glazing, operable vents are located top and bottom to prevent the void from overheating in the summer. In the winter the vents are generally closed to trap heat in the void and reduce heat loss through the interior windows. In the mid-season condition, the inner curtain wall normally has operable windows for natural ventilation. An additional benefit is that modulating outer vents can be used to control the void temperature and thus extend the period suitable for natural ventilation.

Despite this sophistication, detailed energy savings analyses rarely conclude double skin facades have affordable paybacks at current energy prices although there is growing amount research that shows they provide better overall energy efficiency with proper controls. The aim of this paper is to investigate which scenarios may approach affordable payback periods and to what extent these are influenced by different factors.

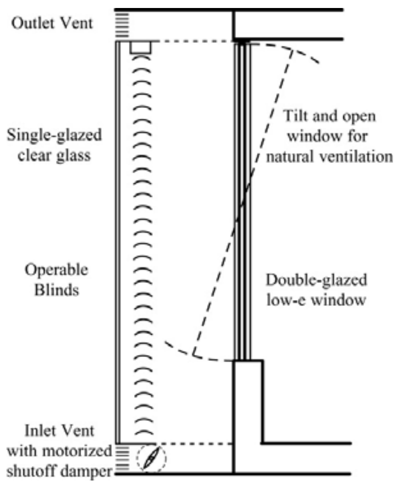

Figure 1 Typical double façade components

2. Thermal and Energy Analysis

To best understand climate conditions, dynamic thermal modeling (DTM) has been applied to the problem using the TAS software from Environmental Design Solutions Limited. DTM techniques employ a three dimensional virtual model of the building and calculate the time based thermal loads on a building based on its fabric, solar shading and historical weather data. It has been used previously in the application of double façade analysis and validated against detailed CFD analysis in this respect.

2.1 Orientation

A basic office building model was simulated with the intent of isolating the annual HVAC energy savings of a double façade over a conventional façade for various orientations. In order to do this a model of a four-storey office block was created with solid walls on three sides. The fourth side was a fully glazed façade which was rotated through eight different orientations with annual energy consumption calculated for each and for three different climates. London was selected as a mild, cloudy climate. Las Vegas was selected as a hot, dry sunny climate. Winnipeg, Canada was selected as a cold climate. Figures 2 illustrates the model geometry and the eight different orientations. Further modeling assumptions are detailed in Appendix A.

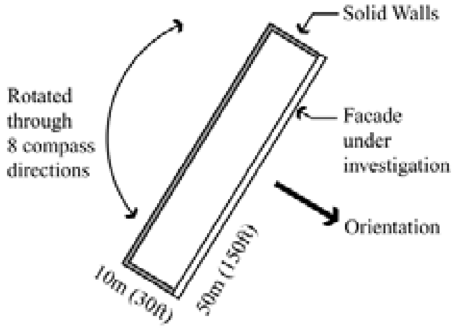

Figure 2 Plan Diagram of Simulation Model Investigating Effect of Orientation on Energy Savings of DSF

It should be noted that these results are not representative of actual office energy consumption figures due to the simplistic nature of the model. The results are intended purely as a comparison between the energy savings associated with each orientation for one design of double facade.

For London, the most significant savings in HVAC energy consumption are achieved with SW and S facades and are in the order of 23%. This is a result of the voids that are to capture solar gains in the winter providing an insulating layer and rejecting solar gain in the summer. Other orientations have less solar gain and thus heat up less in the winter and block less solar gain in the summer. Nevertheless, even the N façade shows 14% savings in energy consumption due to a greatly increased overall U-value.

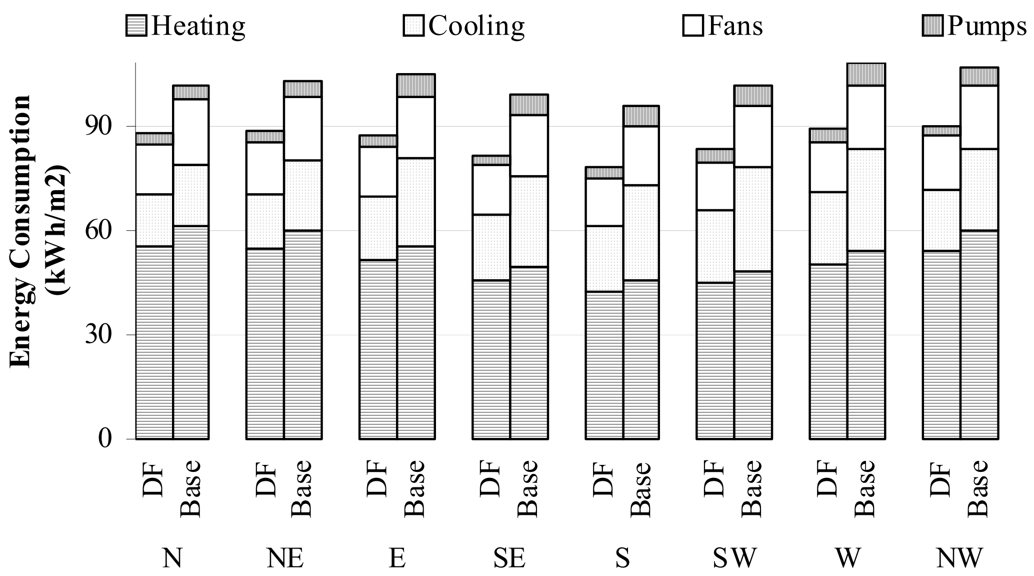

Figure 3 Energy consumption for a conventional façade and double façade (DF) for the London model

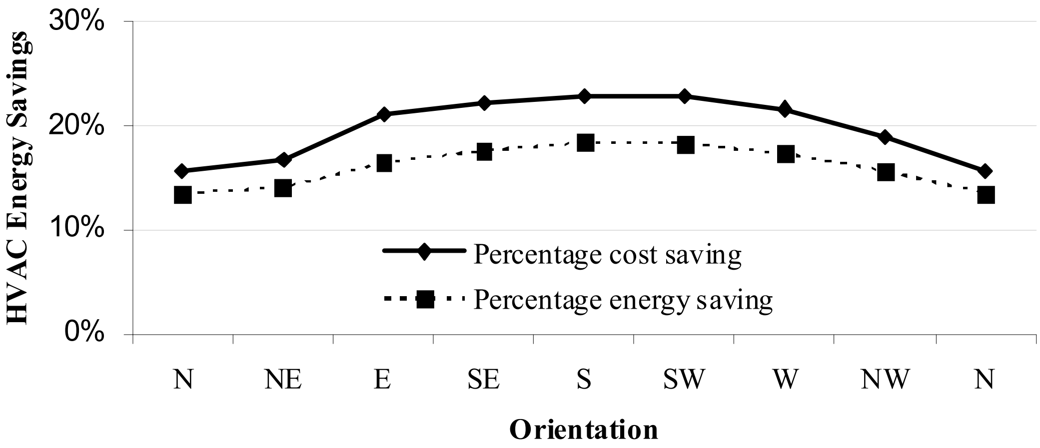

Figure 4 Percentage energy savings by orientation for the London DSF model

Las Vegas sees more energy savings from a double façade (in the region of 27%) because it is a sunny, hot climate and double facades do well to reduce cooling loads from solar gain. Other research supports the conclusion that warm climates are favorable for double facades (Cetiner and Ozkan 2005).

Winnipeg shows higher annual energy consumption than both London and Las Vegas with predominantly a heating load due to the cold climate. Energy savings shown are best on the southeastern side and are quite modest at 12%. This suggests that the design of façade selected in this analysis works more efficiently in a warm climate with high cooling load than it does in a cold climate. The solar heat gains are much less in this climate which suggests that the low-e single facade is already more efficient than it is in Las Vegas or London.

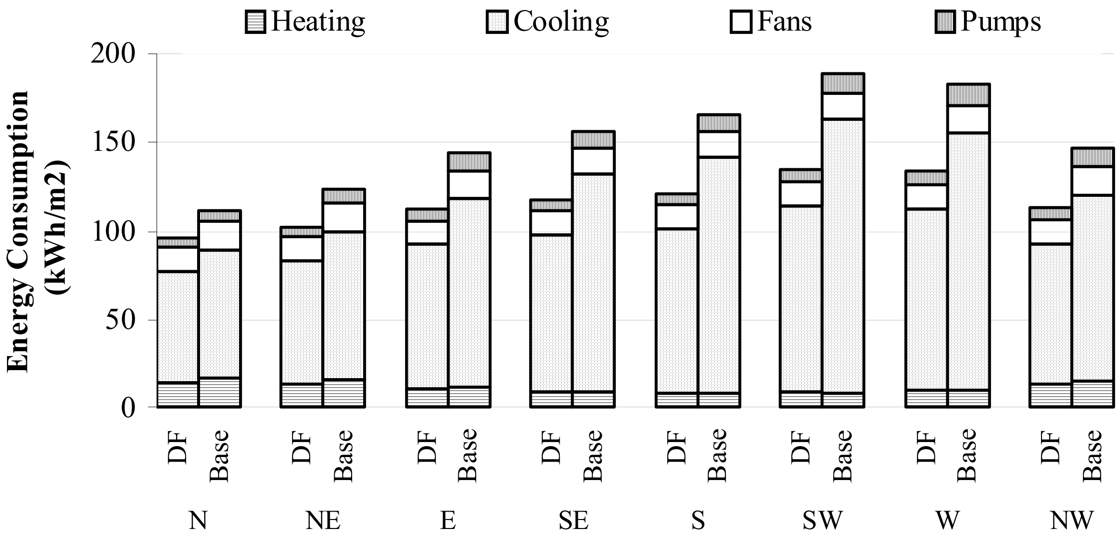

Figure 5 Energy consumption comparisons for conventional façade and double façades (DF) for Las Vegas model

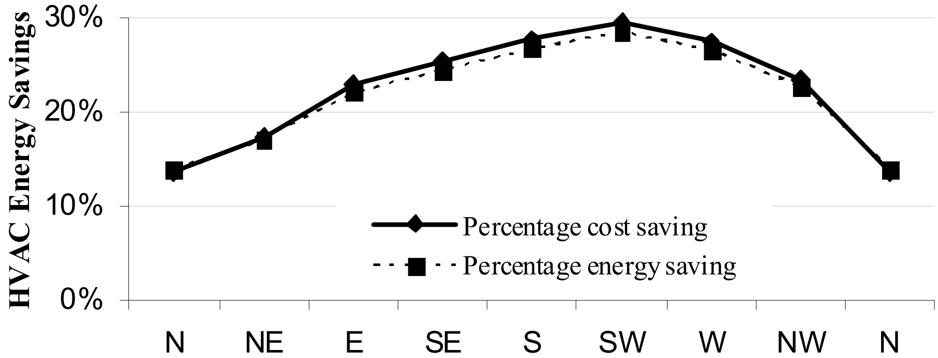

Figure 6 Percentage energy savings by orientation for the Las Vegas model

2.2 Optimal Climate

In order to determine what types of climate achieve the best energy savings through the use of double facades another model was simulated which was more representative of a typical office building. Using a southwest orientation, which was generally accepted as offering the most benefit from a double façade in the previous analysis, the building was simulated through 7 cities in different climate zones throughout the world.

The results of the analysis are shown in Figure 7 with an indication of the predicted energy consumption for the double façade versus a conventional double glazed façade for different global locations. Those generally with the greater energy consumption show the most potential for savings. It should also be noted that the same façade design has been used in all locations when in fact there may well be a different design for a warm climate as opposed to a cooler climate.

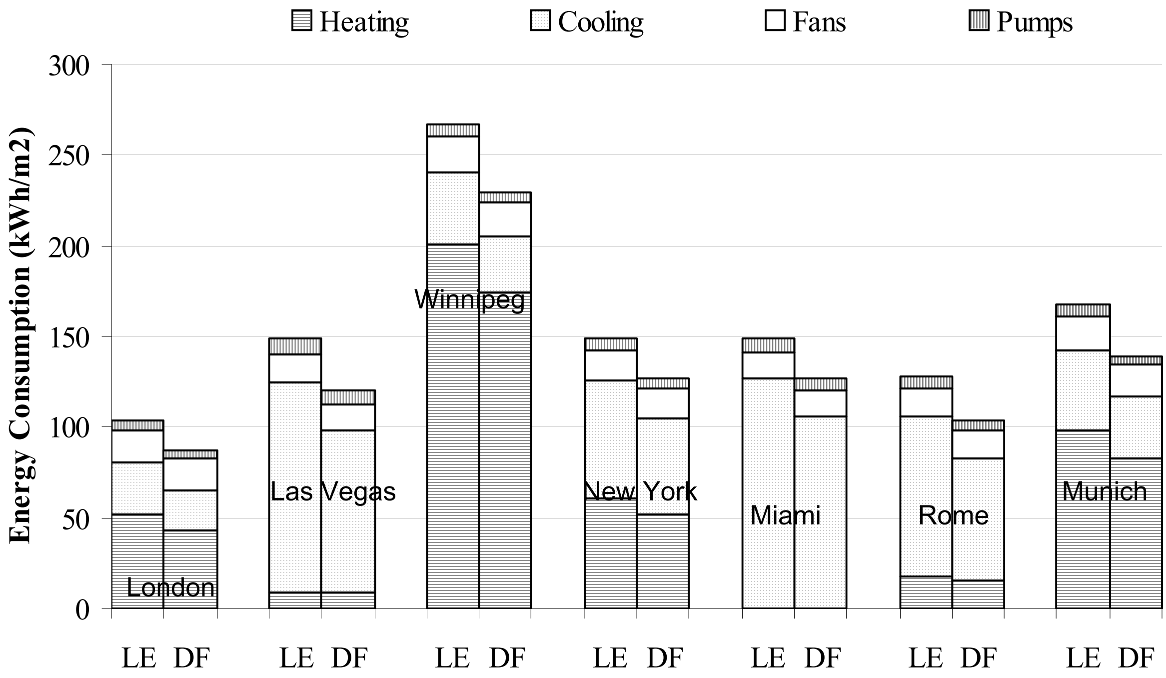

Figure 7 Energy consumption comparison for a conventional facade (LE) and double façade (DF) for different locations and climates

3.0 Economic Analysis

2.1 Façade Construction Costs

A double skin façade is a significant capital investment and an estimate of construction cost is necessary in order to make a calculation as to the likely payback period. There are wide variations depending on the level of sophistication of the façade, glass type, location, construction method and contractors experience. Many suppliers give ranges because of these factors but the figures assumed for the Las Vegas, USA analysis have been $65/ft2 for a conventional curtain wall façade with low-e glass and $180/ft2 for a simple, flat, double façade with operable vents, blinds and windows for a large building and manufactured in a factory. Europe has a wide variance of costs depending on the region. These figures are estimates rather than quotes and are based on experience and conversations with suppliers for the Europe and the US. There is some literature that has cost estimates but prices fluctuates radily and therefore much of this information is unreliable. However for comparison in 1999, double façade were approximately $585/m2 (Lee et al. 2002). The Kista Science Center in Sweden installed a double façade with venetian blinds and was estimated to cost €1000/m2 for the double façade (Streicher 2007). Table 1 lists the construction costs of facades for different locations used in this study.

Table 1 Construction Costs Assumed in Payback Analysis

	Typical Low-e	Double Facade
United kingdom	$38	$122
USA (Nevada)	$65	$180
USA (New York)	$80	$220
USA (Florida)	$65	$180
Canada	$65	$180
Italy	$145	$291
Germany	$53	$145

2.2 Energy Prices

Although double facades are meant to save energy and hence be more environmentally friendly, it usually is the payback period that determines if it is economically viable. Energy prices have an impact on the payback period. For this study, it was necessary to make assumptions on the prices of gas and electricity for each of the locations considered. Most all historical energy prices are available at the US Energy Information Administration (2008) or from the EU's Eurostat (2008).The figures used in the analysis are given in Table 2.

Table 2 Energy Prices Assumed in Payback Analysis ($/kWh)

	Electricity	Gas
United Kingdom	$0.11	$0.060
USA (Nevada)	$0.10	$0.040
USA (New York)	$0.15	$0.041
USA (Florida)	$0.10	$0.044
Canada	$0.10	$0.023
Italy	$0.16	$0.044
Germany	$0.15	$0.056

2.3 Simple Payback

The simple payback calculations in this paper are based on HVAC energy saving cost savings assuming the same type of air conditioning system for the typical and double façade.

Table 3 summarizes the energy cost payback for the 7 cities modeled and shows that the ultimate feasibility is largely dependent on energy price. The more expensive energy locations such as New York, Rome and Munich show the best paybacks with the lower energy prices of Canada extending the payback period significantly. London shows a longer payback period partly due to a lower energy price, partly due to a less extreme climate and partly due to more expensive construction costs

Table 3 Comparison of payback periods and costs for double facades

	London	Las Vegas	Winnipeg	New York	Miami	Rome	Munich
Façade area	1040m^2	1040m^2	1040m^2	1040m^2	1040m^2	1040m^2	1040m^2
Add. façade costs	$1300/m^2	$1200/m^2	$1200/m^2	$1500/m^2	$1200/m^2	$1570/m^2	$990/m^2
Add. capital investment	$1.4M	$1.3M	$1.3M	$1.6M	$1.3M	$1.6M	$1.0M
Energy cost saving	$2.46/m^2	$3.01/m^2	$2.56/m^2	$6.12/m^2	$5.41/m^2	$3.18/m^2	$5.11/m^2
Roof area	3000m^2	3000m^2	3000m^2	3000m^2	3000m^2	3000m^2	3000m^2
Annual cost saving	$7,387	$9,033	$7,688	$18,350	$9,547	$16,219	$15,319
Payback period	**185 Yrs**	**142 Yrs**	**167 Yrs**	**85 Yrs**	**135 Yrs**	**101 Yrs**	**67 Yrs**

From the results, it is possible to concluded that applies to all locations is HVAC running costs are very low compared to the capital cost of the double facade. With an expected building life of 50 to 70 years these projected paybacks would make double facades seem to be a financially poor decision. There are three things that control this, the cost of construction, the energy savings, and the energy price. The first two of these can be considered in the design and although the third is largely a factor of market forces. In the following section an analysis is carried out for double façades located in Las Vegas and London taking these factors into consideration.

2.4 Optimal Façade Design & Cost

Previous analysis has shown that the projected payback period for the considered design in Las Vegas is of the order of 142 years. Through simulation however, the baseline double façade design has been optimized to achieve 95 years. This has been achieved through optimizing the solar shading properties and control of the blinds and the temperature setpoints of the automatically opening vents and windows. The next challenge, therefore, is to reduce the construction cost of the façade and functionality to optimize the trade-off between energy savings and construction cost.

Additional features such as BMS controlled vents, BMS controlled blinds, daylight dimming, BMS controlled operable windows, shut-off dampers to air supply when windows are open, low-iron glass and an occupiable (wider) void all contribute to energy savings. However all of these additional features contribute to added construction costs. For a given climate and orientation a different set of these functionalities will produce an optimal payback period.

2.5 Payback Analysis

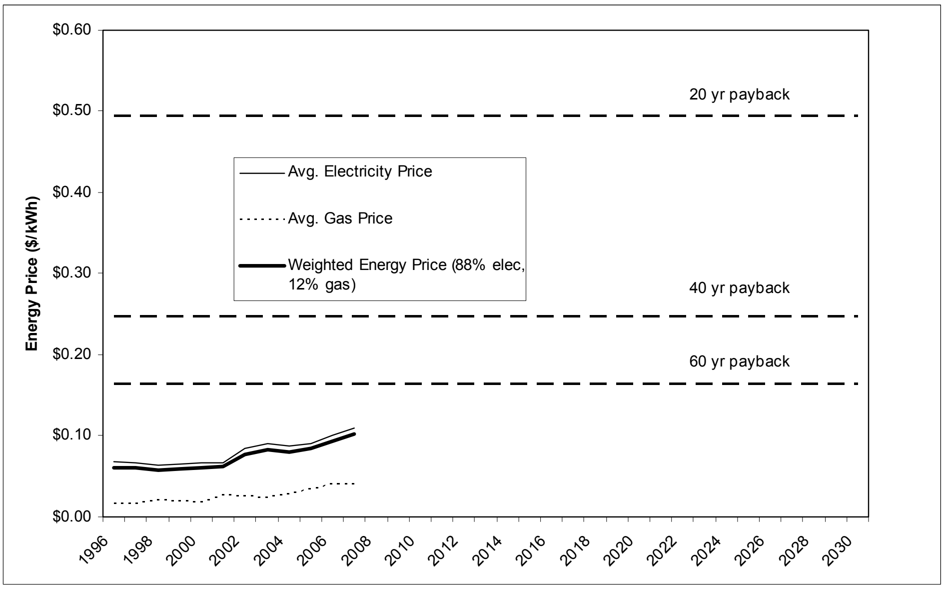

Figure 8 Energy cost for Nevada 1996-2007 (in constant 2007 dollars) compared to threshold values for target payback periods

For the optimum Las Vegas design (calculated above to have an 86 year payback at today's energy prices) the energy split is 12% gas, 88% electricity due to the predominance of cooling in this climate. A weighted average energy price for the model building has therefore been calculated and plotted on the graph in figure 19 together with threshold prices that would achieve 20, 40 and 60 year simple paybacks. This analysis shows that the historic gas and electricity prices for Las Vegas, Nevada in constant 2007 dollars would provide between 50 and 90 year simple paybacks.

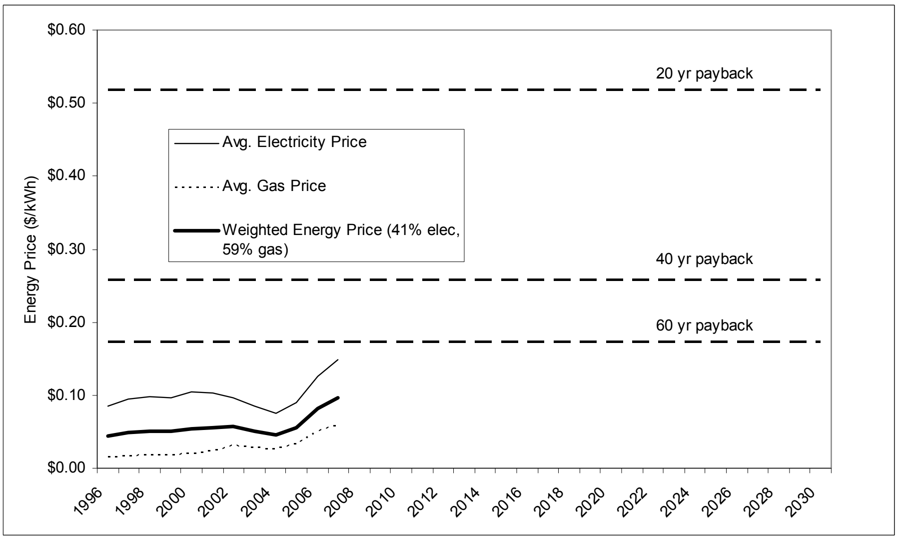

Figure 9 Energy cost for UK 1996-2007 (in constant 2007 dollars) compared to threshold values for target payback periods

If energy prices reach $0.90/kWh for electricity and $0.30/kWh for gas and the construction costs remain constant the payback would be 20 years. In the last five years energy prices have risen 20% to 75% depending on the location but are still well below a 60 year payback.

In a similar exercise, the façade design for London was optimized through simulation to give a 90 year payback at today's prices of $0.11/kWh for electricity and $.06/kWh for gas. The energy split for the modeled building in London is 59% gas, 41% electricity resulting in a weighted, current energy price of $0.096/kWh. Figure 9 shows the trend of the energy price for the UK normalised to real 2007 prices together with the thresholds for 20, 40 & 60 year paybacks.

4. Other Important Influences on Cost Payback

Other issues aside from strict energy savings and construction cost influence design decision, and a number of important factors for DSF are listed below. Many are soft issues which improve worker productivity, by far the largest portion of an office building's life-cycle cost. Little quantifiable research has been done on these topics and this is an area in great need for future research.

Additional Maintenance Costs – 4 window surfaces to clean instead of 2, motor replacement, louvre maintenance, etc.

Perimeter Zone Cooling Compared to Overall Energy – some studies have shown a significant reduction in cooling airflow but a minimum increase in the overall energy savings for a building (Doebber and McClintock 2006).

Glare Control – operable blinds block direct solar glare and accept diffuse light

Moderated Glass Surface Temperatures – blinds block direct solar rays from striking the inner glass preventing it from heating to upwards of 60°C (140°F). In the winter, the warm void heats the inner glass reducing drafts and cold radiant exchange.

Operable Windows in High-Rise Buildings –the void buffers wind pressures which otherwise make operable windows very gusty and disruptive in tall buildings.

Acoustical Buffering – the vents and void dampen noise improving acoustics near noisy roads, airports, factories or rail lines.

Increased Daylighting – operable blinds actively bounce light deeper into occupied space. Improved U-value allows larger windows.

Reduced Emissions – greenhouse gases, SOx, NOx and other particulates are reduced as energy consumption is reduced.

Aesthetic Purity – the exterior rain-screen requires no thermal breaks, structural mullions or spandrel glass providing a visually simple façade. Blocked UV, wind and rain allow a wood framed interior curtain wall. External blinds provide shading, so clear glass is acceptable.

The Air Cavity Use – it is very rare to reduce both annual cooling and heating demand. The width, type of vents, integration with mechanical systems and use of the air cavity has a significant impact on energy savings (Saelens et al. 2003).

Reduction of Rentable Square Footage – Rentable square feet (RSF) is the area for which rent is typically charged to the tenant. In major cities, the commercial office space is at a premium and a double façade reduces the RSF.

5. Conclusions

An analytical investigation has been carried out into the cost versus payback benefits of double skin facades with respect to their energy saving potential. From this work the following conclusions can be drawn.

A double façade offers the most energy saving potential on the south and south-west orientations.

Extreme climates offer more opportunity for energy savings as they require more HVAC energy and thus have greater potential for savings through improved building envelope.

Energy savings can range from 10% to 50% of HVAC energy, and cost payback can range from 30 to 200 years based on today's local energy prices. Double facades must be assessed specifically on their individual merit considering climate, orientation, detailing, construction cost and energy price.

The economic viability of double façades in a location is not only a result of the climate. Construction costs and energy price play an even more significant role in the results as there is a large global variation.

Although energy prices have risen significantly in the last five years, construction costs and material costs have also increased. Energy prices and construction costs are directly correlated and usually have the same trends. Therefore rising energy prices alone will not reduce the amount of time on return in investment for double facades.

The additional benefits of double facades have not been fully explored in this paper. Many of these attributes are unquantified. Considering their importance in making a financial case for double facades, further research is recommended in this area.

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Appendix A. Modeling Assumptions

Orientation Model:

This model was 10m (30ft) deep and 50m (150ft) wide, four stories tall with solid walls and no glazing on three faces. On the fourth face, the façade was applied as described below.

The baseline building has 70% glazing on facade side (U-value = 1.8 W/m^{2}K, R-3).

The double façade building had a double façade on the glazed side with a 1m (3ft) wide void, motorized blinds with total solar transmittance of 0.6, operable lower and upper vents 300mm (1ft) high which are open in the summer months when the void temperature reaches 24ºC (75ºF), clear 10mm single glazing on the outer facade, and insulated low-e inner glass (U-value = 1.8 W/m^{2}K, R-3) on the inner facade. The double façade model had operable windows and are open for natural ventilation when the void is between 16-22ºC (61-72ºF).

Internal Heat Gains:

Occupancy - 10W/m^2 (sensible), 6W/m^2 (latent) between 8am to 6pm, 7 days per week

Lighting – 15W/m^2

Equipment – 8W/m^2

Plant switched on 8am to 6pm heating 20ºC, cooling to 24ºC

Night setback heated to 18ºC in winter

Optimal Climate Model:

This model was 15m (45ft) deep and 50m (150ft) wide, four stories tall at the optimal orientation of SW. The baseline building has 40% glazing on all four sides (U-value = 1.8 W/m^{2}K, R-3) which does not have operable windows. The double façade building has a double façade on the southwest and southeast facades. The double façade has a 1m (3ft) wide void, motorized blinds, motorized vents at 500mm width inlet and outlet (0.5ft^2/ft), clear single glazed outer glass, and insulated low-e inner glass (U-value = 1.8 W/m^{2}K, R-3) and operable windows. All internal heat gains and plant times were the same as described above for the orientation model.

ENVIRONMENTAL CONSIDERATIONS IN CONSTRUCTION IN JAPAN, BY OBAYASHI CORPORATION

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Keywords: global warming, carbon dioxide, construction, fuel saving, industrial waste, zero emission

Summary

This paper investigates how a Japanese construction company, Obayashi Corporation, has worked to reduce environmental loads during construction.

The issue of global warming is important in the construction industry, which is responsible for 40% of total carbon dioxide emissions in Japan. During construction, diesel fuel consumption and industrial waste disposal are two major causes of carbon dioxide emissions.

Two thirds of the carbon dioxide emissions from Obayashi's construction sites are linked to diesel fuel, and more than half of these are emitted by dump trucks and construction machines. A 'fuel saving drive' method was introduced in 1999 to reduce fuel consumption.

Another factor in carbon dioxide emissions in the construction stage is the volume of industrial waste that must be disposed of. Industrial waste hauling vehicles, recycling facilities and incinerating facilities emit carbon dioxide, and about 20% of total industrial waste disposal in Japan is derived from the construction industry. A 'zero emission' method was adopted at construction sites in 1999 to reduce the volume of industrial waste.

Obayashi Corporation estimates that, as a result of various environmental actions, carbon dioxide emissions during construction in 2006 were reduced to 264,000 tons which is 30% less than those in 1990.

1. Introduction

The activities of the construction industry, from material production, material processing, and transportation to the building site, have a close relationship with environmental issues. Research on environmental loads from construction industry has shown that approximately 40% of carbon dioxide emissions in Japan are related to construction activities (Figure 1).

Although the construction industry has a potential impact on carbon dioxide emissions, carbon dioxide emissions in the transportation and building phases directly related to construction activities contributed only 6.4% of the total in 1995. However, unlike other phases such as material production, material processing and building operations, these two phases are manageable at construction sites.

In the transportation phase, the main activity relating to carbon dioxide emissions is haulage of building materials and industrial wastes. Thus, diesel fuel consumption by haulage vehicles has to be considered in reducing carbon dioxide emissions.

In the building phase, energy consumed at the construction site, such as electricity, diesel fuel and kerosene, and industrial waste disposal from the construction sites, are issues to be addressed. This paper focuses on diesel fuel consumption and industrial waste disposal in finding ways to reduce carbon dioxides emissions.

Obayashi Corporation has dealt with diesel fuel consumption and industrial waste disposal as two major causes of carbon dioxide emissions in the construction stage and applied a 'fuel saving drive' method to reduce diesel fuel consumption and a 'zero emission' method to reduce industrial waste disposal.

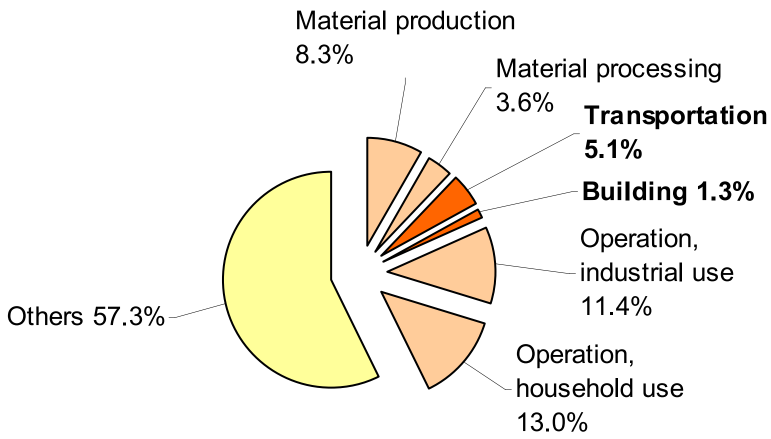

Figure 1 Carbon dioxide emissions related to construction activities estimated form inter-industry relationship table in Japan in 1995.

2. Carbon Dioxide Emissions related to Diesel Fuel Consumption

2.1 Diesel Fuel Consumption in the Construction Stage

Diesel fuel is consumed mainly by haulage vehicles in the transportation phase and by dump trucks / construction machines in the building phase.

In the transportation phase, haulage vehicles carry in building materials and carry out industrial wastes. Energy used to haul other things, like temporary materials and surplus soil, is counted in the building phase.

The main consumers of diesel fuel in the building phase are dump trucks / construction machines. Obayashi Corporation surveyed energy sources at 106 construction sites in 2006 and the results indicate that diesel fuel produces 61% of the total carbon dioxide emissions in the building phase. Dump trucks and construction machines have virtually the same impact, each consuming about 30% of the total carbon dioxide emissions. (Figure 2).

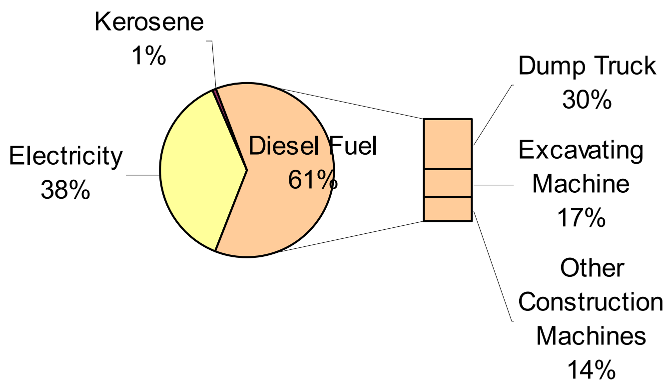

Figure 2 Carbon dioxide emissions in construction stage by energy sources at Obayashi Corporation construction sites in 2006.

2.2 Fuel Saving Drive Method

To reduce diesel fuel consumption in the construction stage, Obayashi Corporation introduced a fuel saving drive method to its construction sites in 1999.

This method, originally developed to save fuel consumption at the time of the oil shocks in the 1970s, was refined by Obayashi Corporation as a solution to reducing carbon dioxide emissions in the construction stage. Five clauses of the fuel saving drive for hauling vehicles / dump trucks are shown (Table 1). This method is more effective in city areas than in rural areas. By adapting these clauses, fuel consumption can be reduced without any initial cost.

To demonstrate the effect of the method, fuel saving drive workshops were organized with the support of haulage vehicle / dump truck / construction machine manufacturing companies. By installing precise fuel gauges to haulage vehicles / dump trucks / construction machines and driving the same route / performing the same operation, fuel consumption differences could be measured at the workshop (Figure 3 and 4).

More than 1,000 people had attended the Obayashi Corporation's fuel saving drive workshops by the end of March 2008.

To maximize the effect of the activity, Obayashi Corporation opened the fuel saving drive method to the public in 2001.

The fuel saving drive method is applicable to various haulage vehicles, dump trucks and construction machines. As shown in Table 2, since the workshops were held, fuel consumption has improved by 10 to 40% on average.

In terms of continued efficiency, the average fuel consumption of drivers who attended the workshop did not decline after they attended the workshop. The company conducted the workshop using the dump truck and started to record the fuel consumption after that. The average fuel consumption of 5 drivers who attended the workshop was nearly constant; 0.40liters/km in the next month and an average of 0.41liters/km over the following 9 months (Figure 5).

The advantages of the fuel saving drive method are not only reduction of carbon dioxide emissions but also saving of fuel cost, maintenance cost and insurance cost.

Table 1 Five Clauses of Fuel Saving Drive for Haulage Vehicle / Dump Truck

Clause 1	Avoid Sudden Start and Fast Acceleration
Clause 2	Quick Shift Up and Slow Shift Down
Clause 3	Constant Drive
Clause 4	Free Wheel Drive
Clause 5	Economical Speed Drive

Ordinary Drive
(using the actual haulage vehicle / dump truck / construction machine equipped with fuel gauge)

↓

Fuel Saving Drive Method Lecture
(lecture by haulage vehicle / dump truck / construction machine manufacturer)

↓

Fuel Saving Drive
(using the same haulage vehicle / dump truck / construction machine, drive the same route / perform the same operation)

Figure 3 Actual drive and lecture make up fuel saving drive workshop.

Figure 4 Images from fuel saving drive workshop, when a driver has completed the scheduled route, he/she changes to another driver (top left), lecture on fuel saving drive method (top right), fuel saving drive training using rough terrain crane (bottom left) and 90-ton dump truck (bottom right).

Table 2 Average Fuel Saving Ratio of Truck, Dump Truck and Construction Machines

Type	Mode	Fuel Saving Ratio (%)
Truck and Dump truck	Run	20-40
90-ton dump truck	Run	10
Crawler crane	Operation	20-30
	Run	20-30
Hydraulic shovel	Excavation/ Stowage	20
	Run	30
Rough terrain crane	Operation	20
Wheel loader	Stowage	30
	Run	10

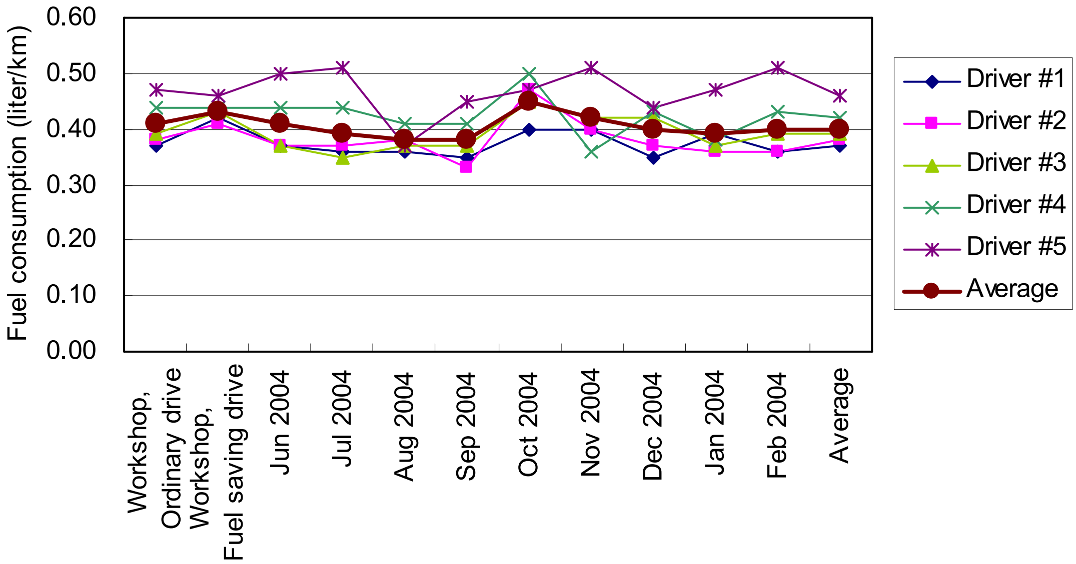

Figure 5 Fuel consumptions (liter/km) after dump truck drivers attended fuel saving drive workshop.

3. Carbon Dioxide Emissions related to Industrial Waste Disposal

3.1 Industrial Waste Disposal in Construction Stage

Industrial waste relates not only to transportation but to disposal. Carbon dioxide is emitted when industrial waste is reused, recycled, incinerated and landfilled, as well as transported.

According to the white paper put out by the Ministry of the Environment of Japan et al. in 2002, approximately 20% of both waste disposal and final landfill disposal are derived from industrial waste from the construction industry. Likewise, the construction industry produces 19% of all general and industrial wastes (Figure 6). This is because the volume of industrial waste is several times that of general waste. In 2002, the volume of general waste was 51,450,000 tons and the final landfill volume was 10,870,000.

This result shows that industrial waste produced by the construction industry must be reduced in considering carbon dioxide emissions.

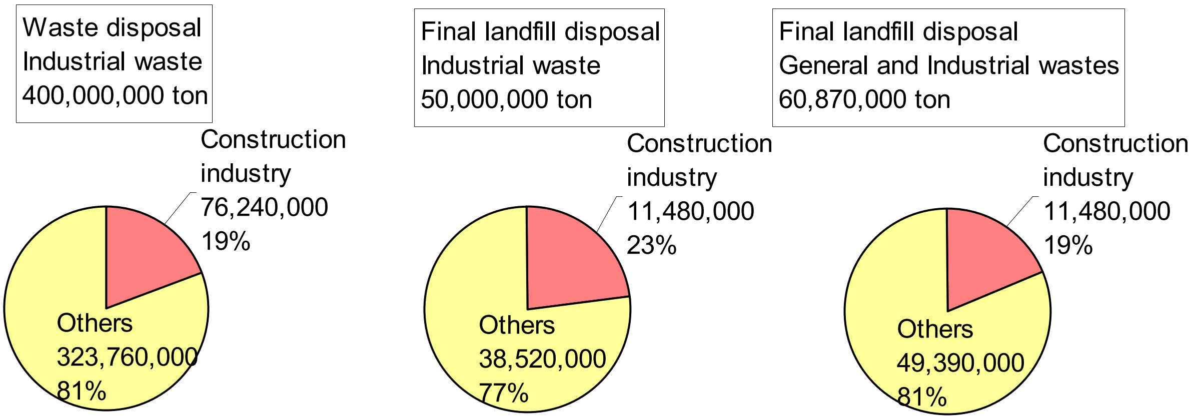

Figure 6 Proportion of waste disposal of construction industry to total waste in Japan in 2002.

3.2 Zero Emission Method

The zero emission method, originally designed to eliminate industrial waste disposal from a soap factory in Belgium, is also effective in the construction industry.

Keeping the concept of initial zero emission activity, Obayashi Corporation adapted the method and applied it to two construction sites in 1999. Successful results were achieved, and the method was then applied to all its other construction sites.

The zero emission method consists of four steps (Table 3). Firstly common awareness is shared among people involved. Then, efforts are made to produce as little waste as possible. However, some wastes are produced and they are classified to reduce the volume (Figure 7). Finally, classified wastes are recycled.

While the zero emission method is efficient in reducing industrial waste from construction site, it is impossible to achieve literally 'zero' emission in the construction industry. Obayashi Corporation set up in-house targets for zero emission; not over 5kg per unit floor area final landfill volume or not over 5% final landfill ratio.

As a result of these environmental activities, 76% of total Obayashi Corporation construction sites achieved the in-house zero emission targets, an increase of 8% from the previous year (Figure 8), and the final disposal ratio has been decreasing since 2001 and was 4.2% in 2006 (Figure 9).

Table 3 Four steps of zero emission method at construction sites

Step 1	**Common Awareness** Partnership for Zero Emission realization · Establishment of promotion body · Increase of educational activity · Organization of environmental events · Classification and reduction of general waste
Step 2	**Emission Control** Attempt to reduce emission in both design and construction stages · Improvement of construction method · Reuse of temporary materials · Reduce extra materials · Reduce packaged materials
Step 3	**Efficient Classification** Ultimate classified collection for easy recycling · Preparation of Recycle Palette and Recycle Station · Introduction of Logistic Center
Step 4	**Resource Recycling** Recycle classified waste · Establishment of resource recycling route · Positive usage of recycled materials

Figure 7 Images from Zero Emission activities, sand strainer, screen out woodchips, metals, etc. (left), magnet, pick up metals either by large magnet (center) and water, classify woodchips out from floats (right).

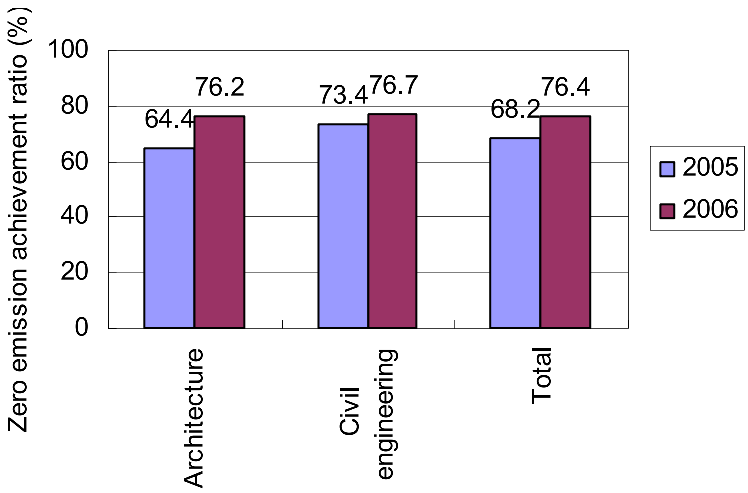

Figure 8 Zero emission achievement ratio at construction sites for Obayashi Corporation.

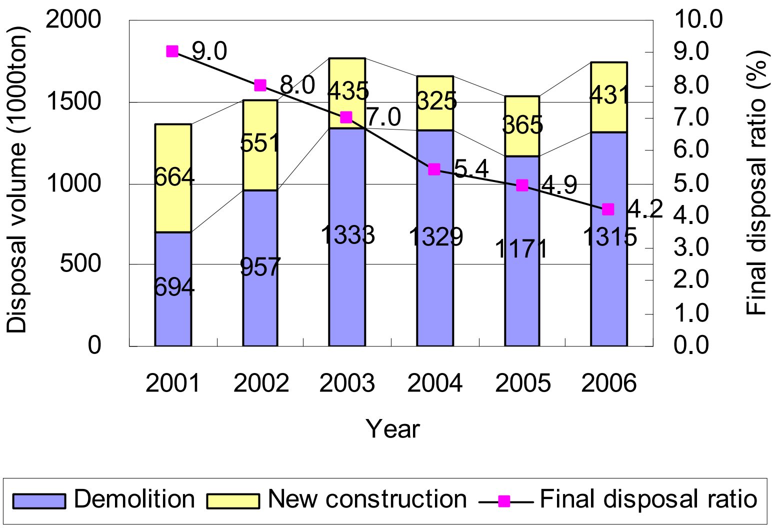

Figure 9 Industrial waste volume and final disposal ratio for Obayashi Corporation.

4. Carbon Dioxide Emissions during Building Phase

Obayashi Corporation has been surveying carbon dioxide emissions during building phase from energy consumption at its construction sites. Several construction sites of varied building types were selected and energy consumption was measured. Total carbon dioxide emissions were estimated after carbon dioxide emissions per unit sales were calculated. Measured energy consumption included electricity, kerosene and diesel fuel (Figure 10).

As a result of various environmental actions, carbon dioxide emissions during the building phase in 2006 were decreased to 264,000 tons which was 30% less than the emissions in 1990 (Figure 11).

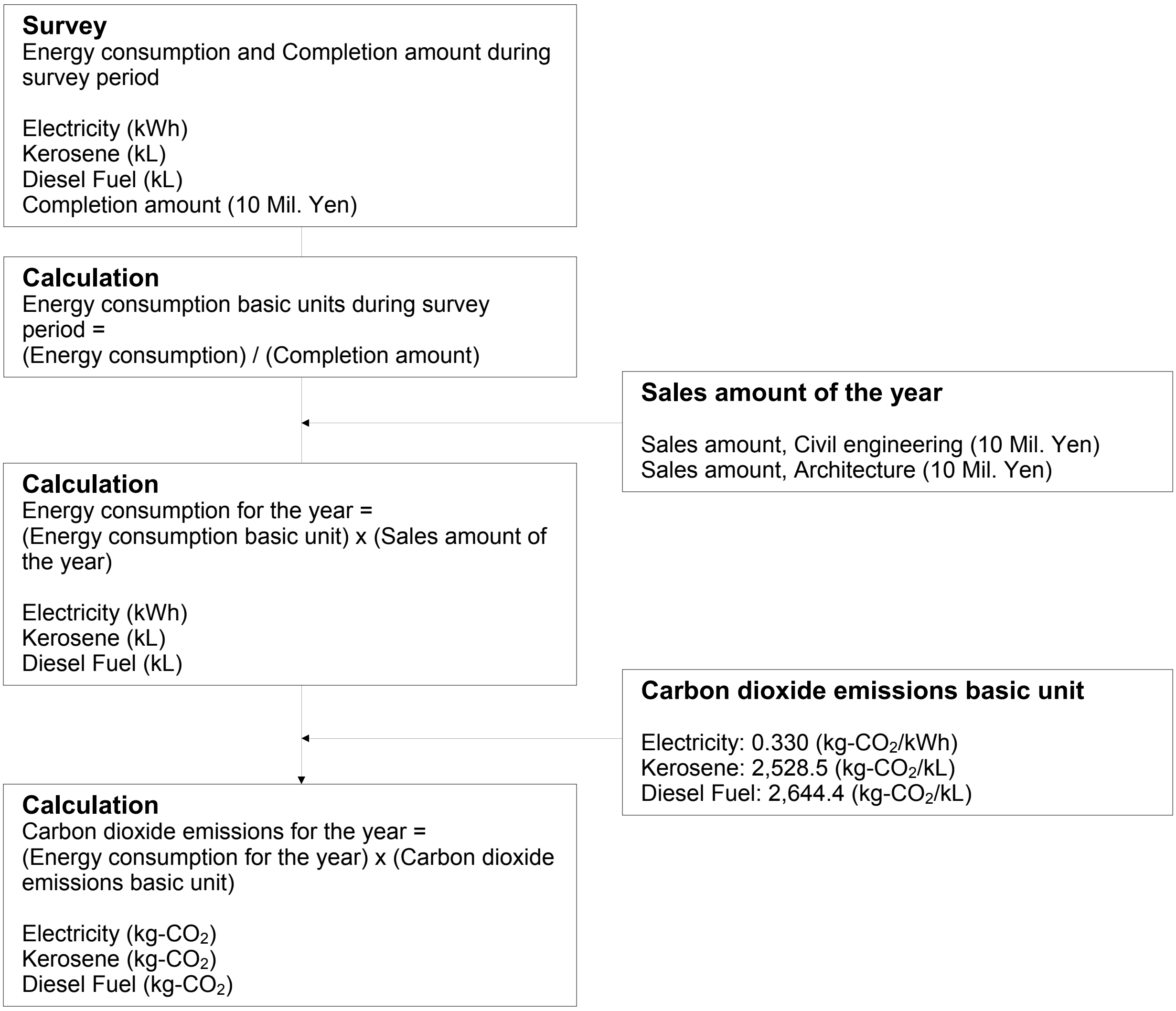

Figure 10 Estimation of carbon dioxide emissions at construction sites from energy consumption.

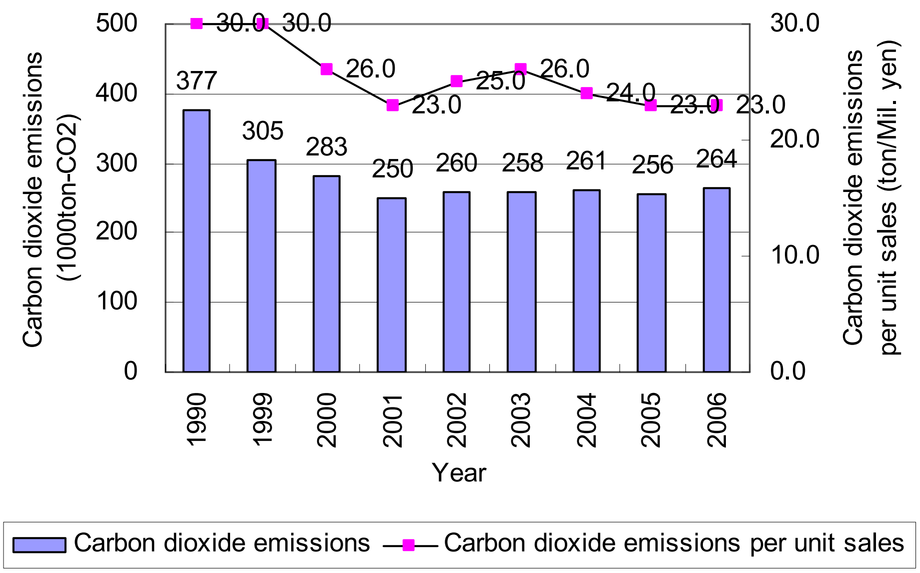

Figure 11 Carbon dioxide emissions in the building phase for Obayashi Corporation.

5. Conclusions

Although carbon dioxide emissions produced by the construction industry are more than 40% of the total in Japan, emissions during the construction stage, transportation phase and building phase, are only 6.4%. Because its environmental impact cannot be ignored and these emissions are manageable by construction companies, Obayashi Corporation started environmental activities to reduce carbon dioxide emissions from its construction sites in 1999.

There are two sources of carbon dioxide emissions in the construction stage: diesel fuel consumption and industrial waste disposal. Diesel fuel is consumed not only by haulage vehicles / dump trucks / construction machines in both the transportation and building phases, but also by industrial waste haulage vehicles. The construction industry produces about 20% of both total disposal and final landfill volume, and also relates to carbon dioxide emissions when wastes are reused, recycled, incinerated and landfilled as well as when they are transported. Obayashi Corporation introduced a fuel saving drive method and a zero emission method to mitigate this problem.

The fuel saving drive method was developed in 1999 and is used by more than 1,000 drivers / operators. Without investing any initial cost, a fuel saving ratio of 10-40% is expected for various vehicles and construction machines.

The zero emission method was also introduced to the Obayashi's construction sites in 1999. Approximately three fourths of sites cleared in-house zero emission targets in 2006. As a result of common awareness of the zero emission concept, the final disposal ratio was decreased to 4.2% in 2006, 0.7% less than the previous year.

To estimate carbon dioxide emissions in the building phase, a part of the construction stage, Obayashi Corporation surveyed electricity, kerosene and diesel fuel consumption at its construction sites. Because of the popularization of the two major methods, fuel saving drive and zero emission, carbon dioxide emissions in 2006 were estimated to be 264,000 tons-CO_2 which was decreased by 30% compared to the year 1990.

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SHADING/ENERGY GENERATING SKIN INSPIRED FROM NATURAL SYSTEMS

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Keywords: distribution, orientation, leaves, range of sun radiation, flexibility, azimuth, altitude, shading.

Summary

An adjustable shading system inspired by leaves is presented. Plants have developed unique mechanisms for specific climates and locations, where they can determine the amount of exposure for the efficient photosynthesis performance. Physiology and geometry are the most significant factors influencing light interception in plants, where leaf distribution, orientation and dynamics influence the exposure to sun radiation. Based on principles and methods extracted and abstracted from plants, a shading system was designed that has the ability to track the range of sun radiation throughout a day. Computer simulations checked the performance of the shading system through three critical days throughout the year, where azimuth and altitude angles were considered. The simulations resulted in showing different patterns of shading areas. The combination of azimuth and altitude angles determined the distribution of the shading system elements. Due to the flexibility of the system in orienting to different directions and repositioning through the day, it provides continuous shading all over the desired plane at the envelope. With the system it is possible to achieve maximum required shaded area with loose density of shade planes and avoiding self-shading, or shading with high density of shade planes for maximum energy gaining, due to their position normal to sun rays.

1. Introduction

Shading devices can be attached to building envelopes internally or externally, where they control the amount of light that permeates through the envelope. Adding shading devices to the envelope is important for reducing peak heat loads in the building, reducing cooling requirements, and improving natural lighting and more external visual contact than other standard shading devises. Energy-efficient building design is influenced significantly by the shading device. Current shading devices include solid shadings, canvas awning, roller shades, blinds and louvers. These shading technologies basically deal with extensions either vertically or horizontally, or by adding an extra cladding to protect against radiation from glazed openings, while leaving some amount of light to penetrate inside. These technologies have limited adjustability, while they are designed for the extreme situations of solar radiation and not for the whole range of solar radiation exposure (Badarnah et al. 2008).

Plants are organisms that have a significant relation with sun radiation. The relation between light and plant's leaves has been investigated and reported by numerous biologists (e.g. Ehleringer et al. 1980, Brunig 1976, and Loomis et al. 1971). Organizational features in plants offer various solutions for tracking sun radiation, either paraheliotropic or diaheliotropic. Plants have developed unique mechanics for specific climates and locations, where they can determine the amount of exposure for efficient performance. Physiology and geometry are the most important factors that influence light interception in plants (Badarnah et al. 2008). Therefore, looking at nature's solutions is a method for developing efficient technical systems for building envelopes. The structural geometry of the shade elements for *The Singapore Lyceum Theater* was inspired by nature, like sunflowers, fish scales etc. The intention of the architects (DP Architects) was, that the enveloping façade system changes pattern to suit the orientation of the sun, providing solar shading and controlling the internal environment of the pavilions (www.geocities.com). However, the individual shading devices are not adjusting themselves throughout the day or seasons according to sun-ray angles.

This paper introduces a shading system inspired by organizational features in leaves, where location and inclination were considered in the study and the developed system. The focus is on external shading elements, because of their effectiveness in blocking solar radiation before reaching the indoor environment (Olgyay 1992). Section 2 presents the background for leaves responding to sun radiation, and it is based on the work done by Badarnah et al. (2008). Based on this section, the main principles were transformed into technical solutions for a shading system (section 3). In order to evaluate the performance of the shading system throughout the day and seasons, computer simulations were carried out (section 4), and with these simulations, the different shading patterns of the same system where studied (section 5). Finally, a discussion and the conclusions are presented in section 6.

2. Background

From summarizing the techniques used in plants for reacting to sun radiation, three main categories were recognized for maximum and minimum light exposure. Leaf distribution, orientation and dynamics play a significant role in influencing the exposure to sun radiation. Principles from the different categories influence the plant to track the sun effectively. Morphological and physiological factors influence light interception in plants (Brunig 1976), where it affects photosynthesis and rate of plant productivity (Loomis et al. 1971).

2.1 Distribution

The combination of arrangement and density of leaves affects leaf distribution in plants for photosynthesis efficiency (Ehleringer et al. 1980). Therefore, there are two ways for photosynthesis efficiency: leaves distributed in a single-layer with high density or multi-layer distribution with loose density (Horn 1971). Leaf density of plants, influences the plant's projected area, which affects sunlight interception capability (Niklas 1988). Form and proportion are additional factors affecting photosynthesis efficiency (Kriegh 2003). Some plants have special arrangements that could be described mathematically, e.g. Fibonacci series, which are adopted for compact and dense packing of members.

2.2 Orientation

In plants, sun tracking is achieved in two ways: leaves move perpendicular to the direct sun rays, which are called diaheliotropic leaves, and leaves move parallel to the direct sun rays, called paraheliotropic (Ehleringer et al. 1980). Heat load, leaf temperature and transpiration rate are reduced with paraheliotropic movements (Forseth 1980). Diaheliotropic movements, fig. 1, allow a high solar irradiation and result in maximal rates of photosynthesis throughout the day (Mooney 1978). Regulation of leaf inclination is one of the mechanisms to avoid shading by neighbors (Mullen et al. 2006), fig. 1.

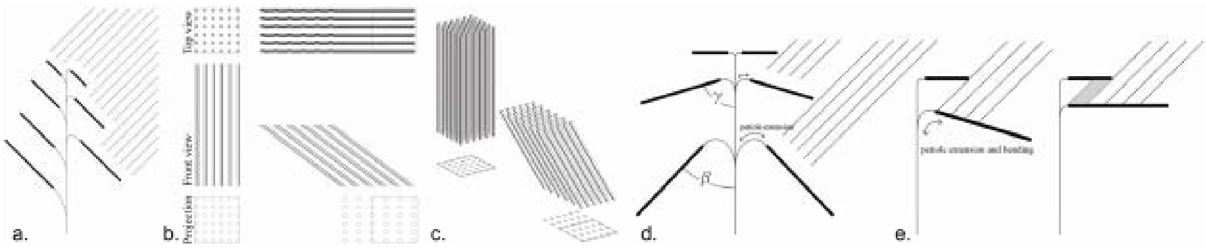

Figure 1 (a-c) The angle of incidence determines energy density.(a) leaves normal to sun rays for maximum energy gain. (b) the effect of different inclination on the projection. (c) top, front and projection view. (d,e) lower layers of leaves bend for maximum light perception. (d) lower leaves get bigger with smaller inclination (β<γ). (e) the effect of inclination, preventing self-shading.

2.3 Dynamics

Plasticity in response to sun light is one of the dominant aspects of plant architecture (Pearcy et al. 2005). This plasticity is recognized when leaflets shift from a vertical position to a horizontal position. In this process plants increase their internodes and petiole length, and leaves increase their area while reducing mass per unit area. Dynamics in plants are generated via their nastic structure (Bar-Cohen 2006); it has different functions, such as rapid bending, which is recognized at the *Venus flytrap*. Its closure is achieved through the property differences at the exterior and interior surface of the wing, fig. 2. The inner surface is able to extend 5%, while the outer surface extension is 20%. Another function is orienting horizontally or vertically, this property is adapted basically to track sun radiation. The centralization of vascular bundles in the leaf stalk allows the leaf to bend.

Figure 2 Venus flytrap. At right, a cross section showing different extensibilities for the inner and outer surfaces.

2.4 Summary of techniques used in light-responsive plants

Table 1 Summary of main organizational features in leaves for maximum light exposure.

	Distribution/position	Orientation/inclination	Dynamics
Maximum light exposure	• loose distribution at multi-layer • dense distribution at mono-layer • maximum projected area • Fibonacci series for compact pattern packing • extending stem • horizontal expansion	• perpendicular to sun-rays (Diaheliotropic) • facing east for maximum exposure at morning and afternoon • facing south/north for maximum exposure at winter noon's	• increasing internode and petiole length • increasing leaf area combined with reducing mass per unit • plasticity, nastic structure • different flexibilities of the sides of a blade • special surface properties-uncoated cell clusters (for flexibility) • convex surface shape

3. Principles Transformation

Leaves in plants have unique properties in order to track sun radiation. For maximum exposure, leaves tend to have a clear organization and distribution with an adaptive inclination and relatively high plasticity in the plant's body (Table 1). At minimum exposure, plants are less dynamic and reorient when having high exposure, e.g. at noon, also they tend to have low leaf inclinations, preventing conditions such as normal to rays. Furthermore, in order to achieve dynamics, the structural geometry is very significant. Geometry is a major aspect for determining the distribution, inclination and dynamics. Based on principles and methods extracted and abstracted from plants, a shading system was designed. For the design process we referred to the following (extracted from Table 1):

- Mono-layer at dense distribution for maximum light capture
- Plasticity, in order to adapt to different inclinations
- Different inclinations of leaves in relation to sun rays, the generated projected area could be maximized
- Leaves normal (perpendicular) to sun-rays
- Special surface properties, for flexibility
- Increasing leaf area combined with reducing mass per unit, for better photosynthesis process
- Petioles extension, in order to prevent self-shading
- Stem elongation for maximum light capture

These principles and methods are the base-line for the shading system development. The transformation of these principles and methods resulted in a shading system for building envelopes that has adjustability for different inclinations. In this complex transformation process, plant's mechanisms and building envelope's demands need to be integrated. Based on the unique shape and structure of plant's leaves, which provide them the desired flexibilities induced by sun light, it is possible to develop a system providing shading and also energy generation. The side of the sheets facing radiation has integrated cells for gaining energy and by that provides shade for underneath.

3.1 The shading system

The system consists of shading sheets, tubular members and profiles. The shading sheets are connected to the tubular supporting members via an elastic membrane for flexibility. The profiles create a grid, which allows the tubular members to roll over and control their position according to shading requirements. For sun radiation blocking, the shading sheets are flexible and can be adjusted to different inclinations, more explanation in the following sections.

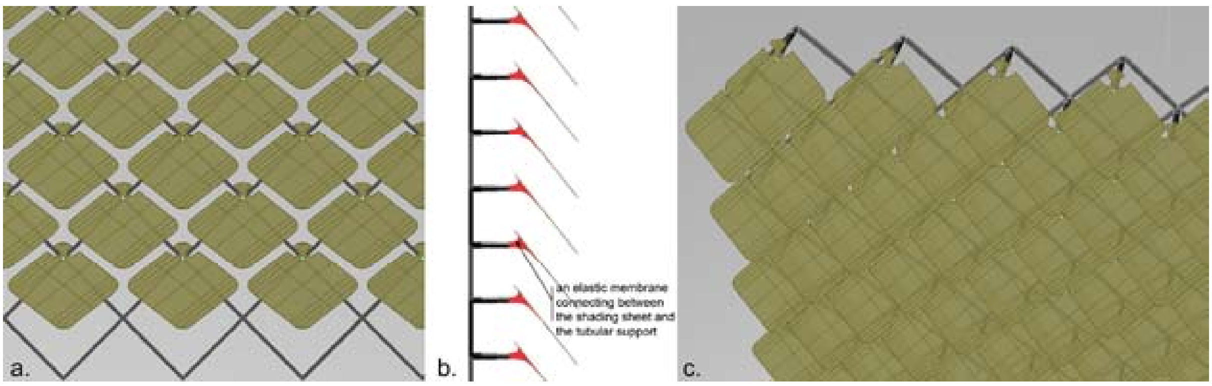

Figure 3 The shading system. (a) front view, shading sheets and profiles in the back. (b) side view, shading sheets connected to the tubular member via the elastic membrane. (c) perspective view.

This system is designed for the whole sun radiation path throughout all the days of the year, where azimuth and altitude angles are considered (Figure 4). The system blocks the sun radiation at a specific angle and allows the indirect light to penetrate between the sheets. When the sheets are normal to sun rays, their position in the depth could be different (Figure 5). In this case, indirect light reflected from the surrounding environment reaches behind the system and keeps the interior space with good quality of light. Additionally, shading sheets being normal to sun rays is the best orientation for radiation gaining, where photovoltaic cells are attached to the surface facing sun.

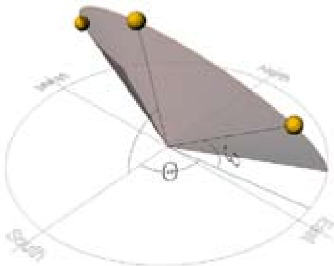

Figure 4 *Azimuth (θ) and Altitude (ω) angles determine the position of sun. The hatched surface presents the sun radiation path throughout a specific day.*

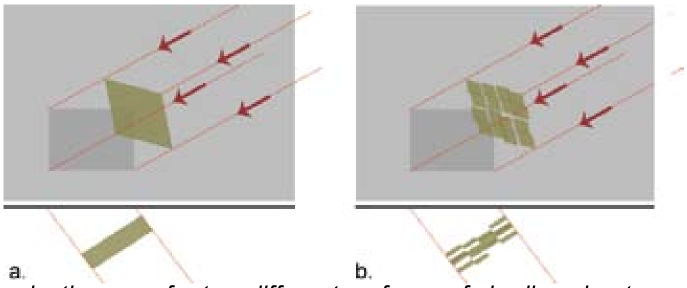

Figure 5 *The same projection area for two different surfaces of shading sheets normal to sun rays. (a) the shading sheet flat and normal to sun rays. (b) the shading sheet is divided to smaller pieces and positioned in different depths of ray direction.*

3.2 The shading component

The shading component consists of a sheet attached to a supporting tubular member with the property of elongation (Figure 6d). This elongation is important to avoid shading by neighbors. The sheet is able to have different inclinations as shown in Figure 6(a-c), where it covers and blocks the sun radiation path, which is determined by azimuth and altitude angles, throughout a day.

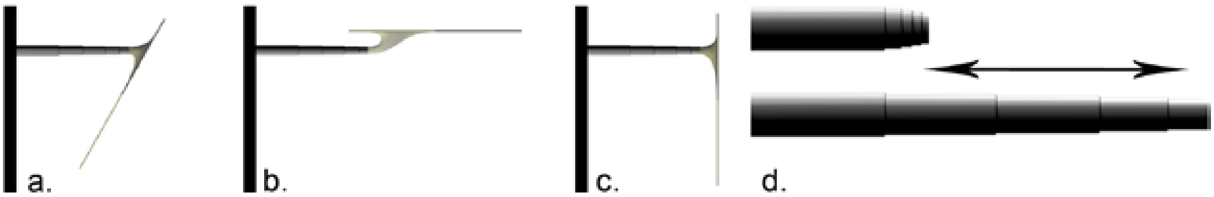

Figure 6 *The shading sheets inclination and their support elongation. (a.-c.) showing different inclinations of the sheet connected to the support member by an elastic membrane. (d) the support tubular member elongation.*

The shading component is connected to the grid of profiles allowing the components to move and change position according to users shading requirements. Four elastic wires are attached to each sheet at their corners, when one of the wires is stretched the sheet will rotate and change its inclination. The specific required inclination for a sheet is controlled via these four wires (Figure 7). The components are controlled separately with considering each other's position and inclination in order to have the maximum variation of shading patterns.

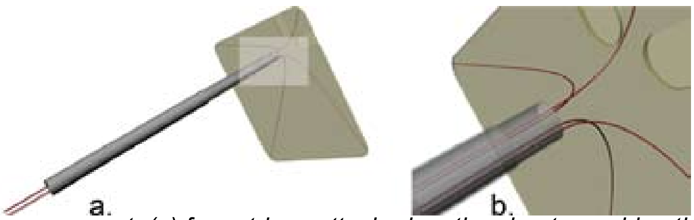

Figure 7 *The shading component. (a) four strings attached on the sheet, reaching the corners and inserted into the tubular member. (b) a close-up to the four strings interring the tubular member.*

3.3 The system implementation

The system could be applied on a flat envelope or on a freeform envelope due to its grid pattern. The scale and size of the gird depends on the specific envelope to be applied on. In cases where the envelope has a freeform layout, the grid has smaller dimensions than at a flat envelope. The shading components are controlled to move over the grid and pack under each other, in cases like cloudy days, where no shading is required and by that the visual contact to the outside is more open (Figure 8).

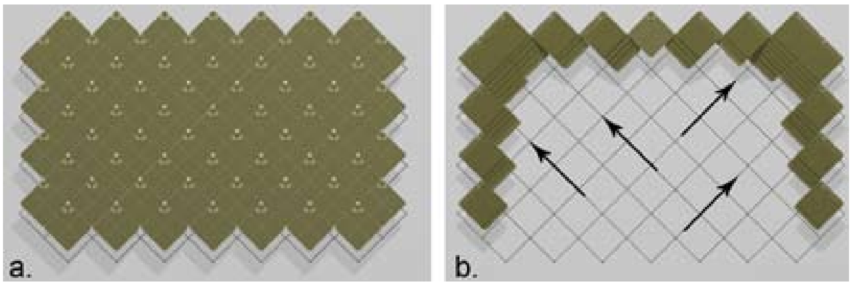

Figure 8 Shading components movement over the grid. (a) Shading components positioned to cover the radiation. (b) Shading components moved to the edges of the grid providing free visual contact and packing under each other.

4. Simulations

The main aim of the simulations is to check the ability of the shading system to track sun radiation throughout a day. These simulations refer to a specific location which is Delft at *52°0'54"N 4°21'24"E* (Figure 9), with considering three critical days throughout the year, where noon hour was determined (Table 1). The tested side of the envelope is south with 90° inclination.

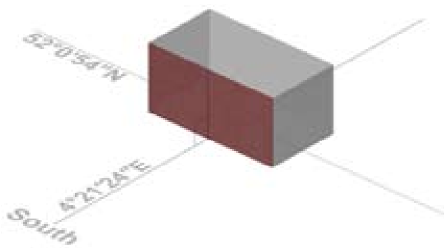

Figure 9 The shading system location, inclination and orientation.

In this paper, the focus is on the principle of the new shading system, where size of grid and amount of elements does not affect the way the shade is generated on the envelope. The dynamic projection of shading sheets, caused by sun radiation, on the envelope was studied. The values in table 1 and 2 are generated from an online calculator for sun angles (www.susdesign.com). The path of sun radiation is determined by altitude and azimuth angles. These angles change throughout the day and differ from day to day. In this paper we refer to morning and noon azimuth and altitude angles, since noon and afternoon need the same treatment but mirrored because of their similarity in relation to south (Table 2), more explanation will follow in results section.

For these simulations we refer to a system that has an initial status as in Figure 8a. It consists of 67 shading sheets distributed as a single layer all over the grid. The aim was to shade the grid with minimum shading sheets and preventing situations where two sheets shade the same spot (self-shading). In the results where sheets less than 67 are shown, means that the other sheets are moved over the rails and packed under the major shading generating sheets.

Table 2 Sun radiation period through three critical days throughout the year in Delft (day almost equal to night, shortest day and longest day).

Reference Date	Sun duration (hours)	Sunrise	Sunset	Noon
September 21	12:20	06:27	18:47	12:37
December 21	7:45	08:49	16:34	12:42
June 21	16:44	04:23	21:07	12:45

Table 3 Morning, noon and afternoon altitude and azimuth angles for three days in Delft.

	September 21			December 21			June 21		
Time	08:00	12:37	17:00	10:00	12:42	15:00	09:00	12:45	18:00
Altitude	13.16°	38.66°	15.13°	6.67°	14.56°	8.75°	38.74°	61.44°	34.40°
Azimuth	73.86°	0.03°	-70.80°	36.86°	0.01°	-31.71°	78.54°	0.36°	-84.64°

5. Results

In this section, shading simulations for three selected days (Table 3), introduced in the previous section, in Delft are presented. For each day two simulations were carried out, one at noon and the other one in the morning.

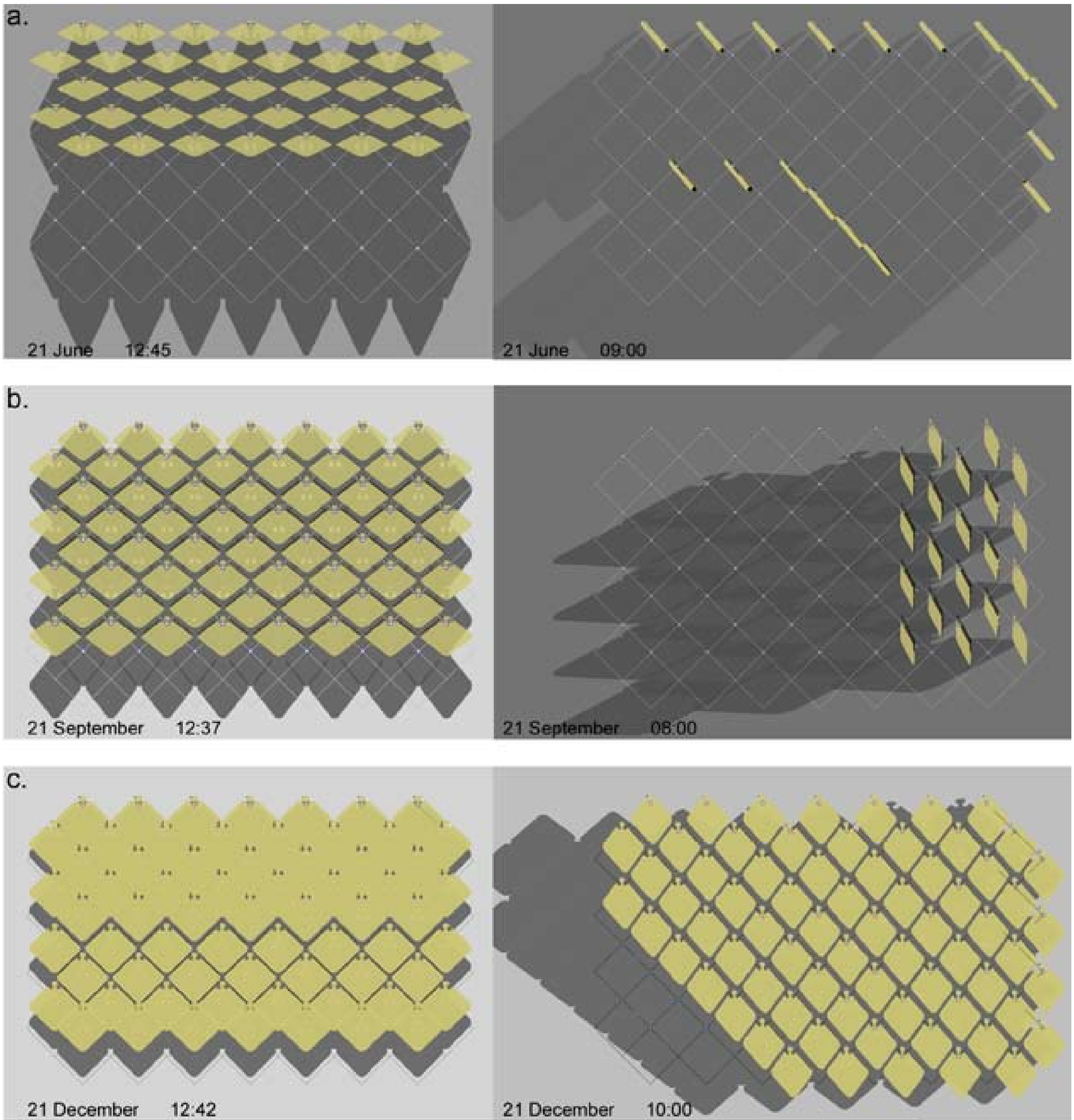

Figure 10 Shading results for the system located in Delft and facing south. (a) on the 21st of June at noon (left) and at morning (right). (b) on the 21st of September at noon (left) and at morning (right). (c) on the 21st of December at noon (left) and morning (right).

On the 21st of June, sun rays have high altitude angle at noon, which resulted in shading the surface with few shading sheets normal to sun rays (Figure 10a left). In this case the sheets have the same inclination, but the rows of shading sheets are not at the same distance from the shaded surface, this is important in order to avoid shading by neighbors. In the morning (Figure 10a right), when sun radiation reaches the southern façade then it will have already moderate altitude angle but with high azimuth, and resulted in shading with different organization and less sheets but with more surface area of shade.

On the 21st of September, sun rays have moderate altitude angle at noon, which needed more shading sheets to provide the required protection (Figure 10b left). In this case the sheets have the same inclination, but sheet rows are not at the same distance from the envelope, in order to avoid self-shading. In the morning, sun rays have high azimuth and low altitude which resulted in shading sheets concentration at east with relatively dense distribution (Figure 10b right).

And on the 21st of December, sun rays have low altitude angle at noon, where more dense distribution was needed to provide the required protection (Figure 10c left). In this case the sheets have the same inclination with different distances from the envelope, this was a way to provide a stronger visual contact with outside and lighten the perceived density of the shading system by creating the openings and division (the same principle as in Figure 5b). In the morning, sun rays have low altitude and moderate azimuth angles which resulted in having a large number of sheets, in order cover the required surface of the envelope, with high density (Figure 10c right). The same principle of distribution at noon was applied in the morning, where sheets have different distances from the envelope.

From these simulations, we notice that altitude angles, at envelopes facing south, affect significantly the density of shading sheets distribution. For low altitudes in the morning, sheets are more concentrated to the eastern side of the envelope with high or low density, depending on the azimuth angle. For different combinations of altitude and azimuth angles, different organizational patterns of the shading system are generated.

Figure 11 All shade blades have the same angle of inclination (α) when flipped. Light gray indicates the old position and dark gray the new position.

Current standard shading systems such as louver panels either vertical or horizontal, the sun radiation blocking is controlled by flipping the louvers to different angles. However, these louvers are not adapted, three-dimensionally, to track the exact sun radiation throughout the day. They tend to have the same angle of inclination when flipped, Figure 11. Venetian blinds, which consist of adjustable louvers, can be divided into separate parts, for controlling and adjusting them in different inclinations. This will control the sun radiation to get deeper in the room or reflecting it (Knaack et al. 2007). But still, this division has a limited adjustability, when the louvers are flipped they still have the same angle of inclination. The limited adjustability is due to their design principle, where louvers have their best performance at noon while facing south. This poor consideration results in cases where louvers are totally closed in order to block varied sun radiation, e.g. low altitude and high azimuth angles of radiations.

6. Conclusions

As a result of principles and methods transformation from leaves, a shading system was developed. This system is able to track sun radiation and provide shade for the desired plane of the envelope. It has flexible shading sheets that can rotate around their support. These supports are tubular members that can elongate and position the shading sheets in different distances from the envelope. The shading system is designed for the whole range of solar radiation throughout a day during the year. The simulations for performance testing refer to Delft at *52°0'54"N 4°21'24"E* (Figure 9), where different azimuth and altitude combinations influenced the shaded area on the envelope.

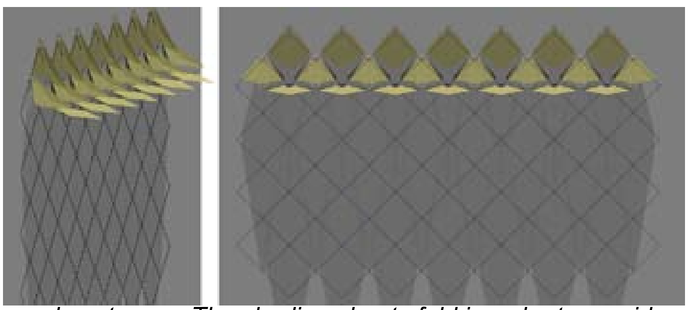

Figure 12 High altitude angles at noon. The shading sheets fold in order to provide more protection at the upper part.

From the results it is possible to conclude the high influence of altitude angles on sheets organization and their density, where azimuth angle has more influence at morning hours. The system is able to avoid self shading situation by elongating their support tubular members and by that they have different distances from the envelope, like leaves in plants elongate their petioles. If we compare it with existing shading systems, then we realize that current shading systems consider altitude angles or azimuth angles but not their combined influence (horizontal louvers for high Altitude angles or vertical louvers for low Altitudes in the morning or evening). This combination of altitude and azimuth is very important in order to cover the path radiation throughout the day, which is achieved in the designed system above. However, some improvements could be considered, the system was tested in one location for specific angles. Sometimes we have very high altitude angles and the system have some difficulties with shading the upper parts. A proper solution could be, allowing the sheets to fold and have better contact with the envelope (figure 12); in this case, the sheets don't have the same inclination, where their inclination gets higher at higher positions.

Due to the flexibility of the system in orienting to different directions and repositioning through the day, it provides continuous shading all over the desired plane at the envelope in Delft. With the system it is possible to achieve maximum required shaded area with loose density of shade planes and avoiding self-shading, or shading with high density of shade planes for maximum energy gaining, due to their position normal to sun rays. Further investigation on the flexibility possibilities of the sheets is needed in order to adopt the system to different locations with different altitude and azimuth angles.

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SUSTAINABLE HOUSING USING LIGHTWEIGHT CELLULAR CONCRETE

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Summary

Concrete is the dominant material used in the construction of many buildings, where it is used in various structural elements including external and internal walls. Depending on building type, up to 20% of the embodied energy of building materials may be attributed to the use of concrete. In the context of climate change impacts and the fact that concrete is the highest volume construction material used worldwide, there is a strong incentive to evaluate alternative technologies that may meaningfully reduce the environmental impacts of concrete use.

The use of lightweight technologies, such as precast cellular concrete wall panels, provides an opportunity to reduce the environmental footprint of construction materials, through the general reduction in materials usage, reduced transportation and lifting energy, potential improvements of in-service energy efficiency and improved recyclability.

This paper presents the results of an environmental analysis of a new load-bearing cellular concrete system and more traditional wall systems such as brick veneer, double brick and autoclaved aerated concrete. The results show that for residential buildings, the precast cellular concrete wall panel system has superior environmental performance in terms of reduced embodied energy, embodied water and greenhouse gas emissions when compared to traditional systems. This suggests that such building systems may play a crucial role in the future development of sustainable and environmentally friendly housing.

1. Introduction

Improving the energy efficiency of buildings could be a relatively effective and low-cost global greenhouse gas (GHG) abatement strategy (Enkvist et al. 2007). For instance, improving building insulation reduces the operational energy demands for heating and cooling, therefore building materials with good insulative properties will play an increasingly important role in assisting with global carbon abatement. One class of materials that may potentially play such a role is cellular concretes with densities ranging from 500 to 1500 kg/m^3. These materials may be manufactured in various elemental forms (from blocks to large precast panels) with compressive strengths of 3–25 MPa, providing a range of functional benefits, from non-load-bearing to fully structural load-bearing applications. Since the porosity of such materials increases when density decreases, low-density materials typically exhibit relatively lower thermal conductivity, and hence better insulative properties when compared to materials of relatively higher density. Therefore, products at the low-density end of the range may provide useful insulative properties in their own right, whereas materials at the higher density end need to be combined with other materials to provide adequate insulation.

Apart from the potential to provide improved building insulation, there may be a wider range of environmental benefits arising from the increased use of lightweight building materials such as cellular concrete. These may range from reduced materials usage to reduced transportation energy, both of which contribute directly to the embodied energy of a building. The lifecycle environmental impacts of using a particular material or design should not be overgeneralized on the basis of relatively rudimentary analyses of embodied energy. However, such analyses provide a useful starting point when considering alternative materials or building systems on the basis of environmental performance. In some office buildings, the embodied energy may be as high as 20 times the annual operational energy (Ballinger et al. 1995). Depending on the type of construction and design, various studies have shown that external walls contribute 10–20% of the total embodied energy of a building (Pullen 1995; Treloar 1996; Treloar & Fay 1998). Other studies have suggested that the embodied energy may be up to 60% of the overall lifecycle energy of buildings, and that materials substitution may provide up to 20% reduction in total energy over a 50-year lifecycle (Huberman & Pearlmutter 2008).

In recent years, there has been significant progress in the development of structural lightweight cellular materials for use in both commercial and residential construction. One such development is a load-bearing cellular mortar (LBCM) manufactured as large precast panels (Mak et al. 2005). Apart from direct weight reductions, which enables reduced structural member sizes and foundations, the LBCM panels may also provide further advantages in faster and cleaner construction with reduced on-site trades and waste generation. The proportional relationship between strength and density, in which strength decreases as density decreases, is well known. Therefore, the key challenge with lightweight cementitious products is to achieve the highest strength possible for a particular density. Strength not only provides load-bearing capability, but it also contributes to a wide range of other functions such as reducing breakage, and improving impact resistance and durability. Whilst strength is of primary importance, an effective lightweight technology also needs to fulfil a range of common functionalities and performance requirements. In the case of wall panel elements used in above-ground construction, these would include durability, shrinkage, impact resistance, thermal resistance and fire resistance. While the combination of a 40–50% weight reduction (compared to normal weight concrete) with structural load-bearing capacity is a compelling incentive to use such materials instead of traditional building materials, increasingly the reason for choosing them may hinge on environmental performance. This paper reports on an environmental analysis of an LBCM-based precast lightweight cellular concrete system in comparison with a conventional precast concrete and various wall systems commonly used for residential applications in Australia.

2. Defining Lightweight Cellular Concretes

Normal grade concretes typically have densities of 2300–2500 kg/m^3, while cementitious products termed ‘lightweight’ may have densities of 300–2000 kg/m^3. However, as there is no universally accepted definition of distinct classes of lightweight materials, it is important that the term ‘lightweight concrete’ is not overgeneralized, since there may by many very different materials with widely varying properties within a certain density range. Lower density products are typically used as insulation, toppings or non-load-bearing infills. Load-bearing lightweight concretes typically have densities of 1000–2000 kg/m^3. Many so-called ‘lightweight concretes’ are in fact not concrete in the traditional sense, since they do not contain aggregates, but are aerated mortars produced either by gassing reactions or the use of preformed foams. Alternatively, many such cellular concretes are cementitious mortars containing lightweight fillers such as polystyrene beads, vermiculite or pearlite, and these concretes typically have densities of 300–1200 kg/m^3. On the other hand, lightweight aggregate concretes (LWACs) normally incorporate either naturally occurring porous stones such as scoria, or artificial aggregates such as sintered fly ash or ceramics. LWACs typically have densities of 1500–2000 kg/m^3 and can be produced with compressive strength of 40–50 MPa.

3. Methodology

The use of lightweight building products has the potential to significantly reduce the environmental impacts of construction through reductions in, for example, bulk materials usage, and transportation and construction energy.

3.1 Analysis

The results discussed in this paper focus on the embodied energy, GHG emissions (in CO_2 equivalent) and embodied water in a range of commonly used wall systems compared to a new lightweight precast LBCM system. A ‘cradle-to-grave’ methodology was adopted, utilising embodied energy and GHG emission values through the Boustead modeling environment. In addition, a ‘gate-to-site’ transport value was also calculated to compare the transportation energy of different products over a distance of 40 km, based on a typical truckload of each product.

3.2 Wall Systems

The LBCM used in the analysis is a relatively high-strength cellular mortar manufactured as large precast structural panels in two density grades, i.e. 1000 kg/m^3 (H1000) and 1500 kg/m^3 (H1500). The cellular structure is created by gas aeration of a relatively high-strength cementitious mixture of Portland cement and various supplementary cementitious materials such as fly ash or silica fume. The product is precast in panel sizes up to 18 m^2 (e.g. 3 × 6 m) on steel formwork, then heat cured to achieve sufficient early-age strength before being demolded from the formwork. To improve handling, structural performance and shrinkage control, the panels are reinforced with various grades of steel mesh. The compressive strengths of the cellular material used for the H1000 and H1500 products are 8 and 20 MPa respectively. As walling systems, these cellular concrete panels can be installed with a thin concrete render, or they can be combined with insulative materials and linings to provide the required thermal insulation performance.

One of the key underlying environmental performance requirements for a wall system is its thermal rating, often expressed simply in terms of its thermal resistance or R-value. For residential construction, the recommended R-value for walls typically range between 1.5 and 2, depending on geographic location. This basic requirement provides guidance on the comparison of wall systems in this paper. The key property underpinning the R-value is the thermal conductivity of a material, which for concrete and many other materials is related to density, whereby as density reduces so does thermal conductivity. This is shown in Figure 1 where normal density concrete (NC) is compared with medium density LBCM and a relatively lower density autoclaved aerated concrete (AAC). In turn, this implies that the R-value will increase as density decreases, and thus lower density cellular concretes will exhibit relatively higher R-values compared to normal density concretes. However, when used in the normal thickness range of 100–150 mm, cellular concretes generally do not meet the thermal rating requirements for wall construction unless additional insulation is provided. For instance, the dry-state thermal conductivity of AAC ranges from 0.12–0.14 in the density range of 510–580 kg/m^3. The corresponding R-value of a 150 mm thick AAC element with a density of 550 kg/m^3 ranges 0.9–1.1, depending on the moisture content (CSR Hebel Technical Manual 2006). The dry-state thermal conductivity of the H1000 LBCM is 0.35, implying that the R-value of a 150 mm thick element is 0.45. For the same thickness of normal density concrete, the R-value would be only 0.12. However, when used as part of a wall system, the required R-value can be easily achieved by any of these concretes through, for instance, the addition or air gaps, fiberglass insulation batts, polystyrene sheets or reflective foil liners.

Therefore, it is important that environmental analyses of embodied energy be carried out for entire wall systems that meet a minimum performance requirement, rather than the primary wall material itself. From this perspective, the discussion in this paper is focused primarily on the H1000 LBCM used as 100 mm thick panels, this being the product intended for use in residential construction. Some reference will be made for comparative purposes to the H1500 LBCM and a range of wall systems commonly used in Australian residential construction. A description of the generic wall systems studied in this investigation is given in Table 1. These include brick veneer, double brick and concrete block walls, all rendered externally and lined internally with plasterboard.

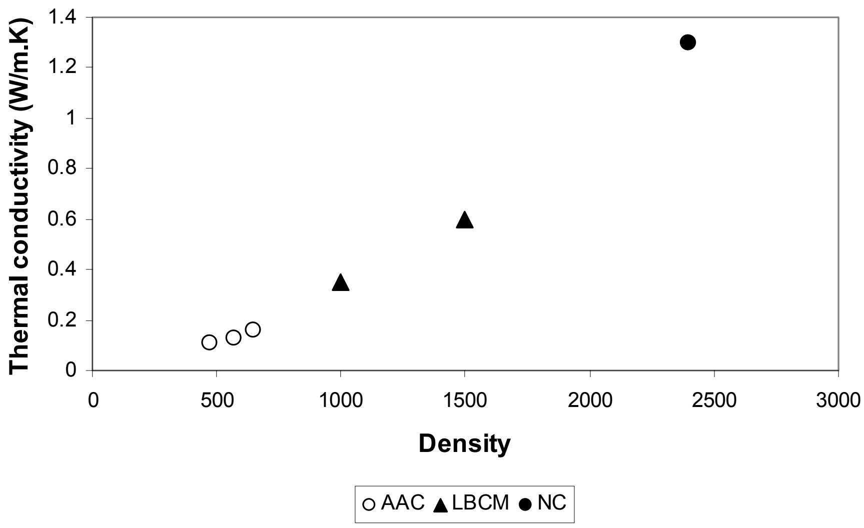

Figure 1 Thermal conductivity of normal and low-density concretes (source data for AAC, GFC Concrete Ltd *(2006)).*

Table 1 Wall systems investigated

Wall system identification	Primary material	Cladding and lining materials
PC40	40 MPa precast concrete	None
BV	Brick veneer	15 mm external concrete render, timber studs, R1.5 insulating batts and plasterboard lining
CB	Concrete block	15 mm external concrete render, timber studs, R1.5 insulating batts and plasterboard lining
DB	Double brick wall	15 mm external concrete render, timber battens and plasterboard lining
AAC	Autoclaved aerated concrete	15 mm external concrete render, timber studs and plasterboard lining
H1000/H1500	LBCM	5 mm external concrete render
H1000P/H1500P	LBCM	5 mm external concrete render, 65 mm polystyrene insulation and plasterboard lining
H1000B/H1500B	LBCM	5 mm external concrete render, timber battens, R1.5 insulating batts and plasterboard lining

4. Results and Discussion

4.1 Gross Embodied Energy

The direct relationship between bulk density and unit materials usage implies a potential to reduce embodied energy through the lower rate of materials usage in lightweight materials. However, normal density concrete is a composite material consisting of a cementitious binder and inert fillers such as sand or coarse aggregates. The relative unit contribution of these materials to the total embodied energy may vary greatly, with the gross unit energy of cement being 75–100 times higher than that of aggregates on a tonnage basis. The major volumetric constituents of cellular concrete are cement and sand, with coarse aggregates omitted. However, cellular concretes may contain more cement compared to normal grade concretes on a volumetric basis. Therefore, a lightweight cellular material may not always provide an obvious reduction in embodied energy when compared to a normal density concrete even though the amount of materials used is relatively lower. This is evident in Table 2 where two grades of LBCM (H1000 and H1500) are compared with a conventional 40 MPa precast concrete (PC40). On a volumetric basis, the gross energy of H1000 is 17% lower than that of PC40, but that of H1500 is 17% higher because of its relatively higher cement content. When the panel products are compared on a surface area basis, and including steel reinforcements, the gross energy of the 100 mm thick H1000 panel is 18% lower than for PC40. By contrast, the gross energy of the H1500 panel of similar thickness is 10% higher than that of the precast concrete. The gap in embodied energy between H1500 and PC40 has, in this case, narrowed due to the relatively lower quantity of steel mesh needed in the LBCM panel.

The results in Table 2 imply that the use of H1000 LBCM in residential construction, for example, may potentially reduce the gross energy content of a wall system by more than 15% when compared to precast concrete. However, the differences between LBCM and precast concrete are relative small, particularly when compared to other conventional wall systems. For instance, the results in Figure 2 show that the gross energy of the H1000B system is more than six times lower than that of the double brick wall and almost four times lower than that of either the brick veneer or concrete block walls. When compared to the particular AAC wall system analyzed here, the gross energy of the H1000B wall was 70% lower.

The addition of insulation to achieve the required R-values in the LBCM increases the gross embodied energy of the wall system. This is evident from Figure 2 where the addition of R1.5 insulating batts increased the gross energy from 328 to 531 MJ/m^2. However, the choice of insulation in this instance did not influence the gross embodied energy of the LBCM wall systems. The use of either R1.5 insulating batts or 65 mm polystyrene provided approximately the same amount of added insulation to the wall system, resulting in similar total R-values of about 2. However, there was very little difference in the gross energy of either wall system.

Table 2 Gross energy (MJ) of various normal and cellular concretes

Concrete	1 m^3 of product	1 m^2 of 150 mm thick panel incl. reo	1 m^2 of 100 mm thick panel incl. reo
PC40	3269	563	399
H1500 LBCM	3834	631	439
H1000 LBCM	2722	465	328

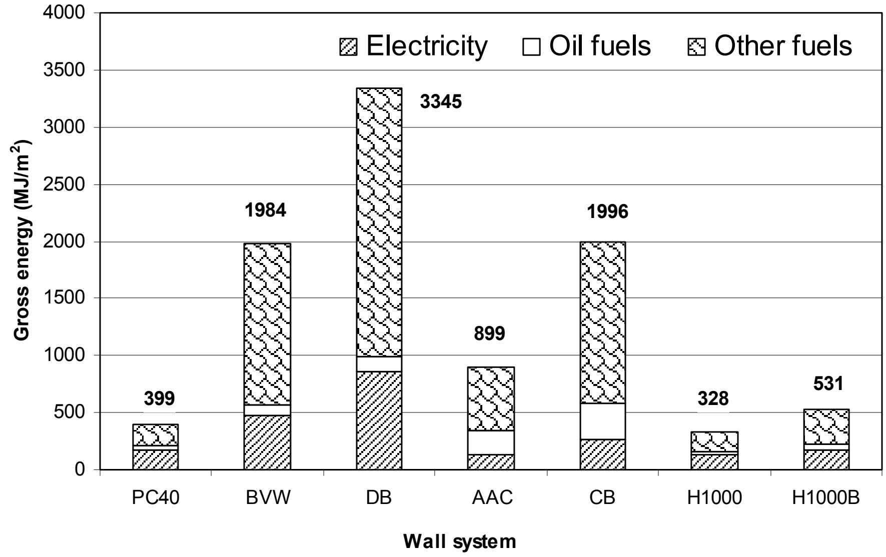

Figure 2 Gross embodied energy – comparison of 100 mm wall systems (see Table 1 for a description of wall systems).

4.2 Greenhouse gas emissions

In Australia, GHG emissions generally follow a similar profile to embodied energy values, due to the dominance of coal-fired power stations and the usually large flow of electricity use throughout manufacturing processes. However, concrete-based products can alter this profile due to the fact that CO_2 is released during the cement manufacturing process. It has been discussed previously that the cement content will dominate the gross energy of a product. This is even more so when it comes to GHG emissions.

As shown in Figure 3, in terms of GHG emissions, there was little difference between the H1000 LBCM and PC40. However, when compared to other conventional residential wall systems, the GHG emissions of the LBCM were significantly lower. Again, the double brick wall system produced the highest GHG emissions, being just under six times that of the H1000B wall system with batts. The brick veneer wall and the concrete block wall systems both benefit from a biomass credit in the GHG analysis, but still show higher GHG emissions compared to the LBCM system. The standard AAC block wall system also benefits from a biomass credit, which results in this system having the lowest GHG emissions of all systems analyzed.

4.3 Embodied Water

The consumption of water during product manufacturing processes has gained increasing interest in recent years in Australia, mainly as a result of the prolonged drought conditions being experienced here. Embodied water calculations are utilized to determine the total water consumption through a manufacturing process in much the same way as embodied energy tracks energy use through a manufacturing process.

An embodied water analysis (Figure 4) shows that the production of LBCM panels uses significantly less water than any other wall system investigated. The water consumption of a plain H1000 wall was only a quarter that of PC40, whilst that of the insulated H1000B wall system was over 60% lower than PC40, equating to a saving of more than 100 liters per square meter of panel. When compared to other wall systems such as concrete block, the use of the LBCM system produced savings of almost 160 L/m^2.

Previous discussion suggested that the choice of insulation to provide similar total R-values did not affect the gross embodied energy of the LBCM wall systems. By contrast, the embodied water content is significantly affected by the choice of added insulation material. Due to the relatively high embodied water content in manufacturing polystyrene sheets, the use of 65 mm polystyrene sheets as added insulation in the LBCM walls increased their embodied water content by more than three times when compared to a system that was insulated using fiberglass insulating batts.

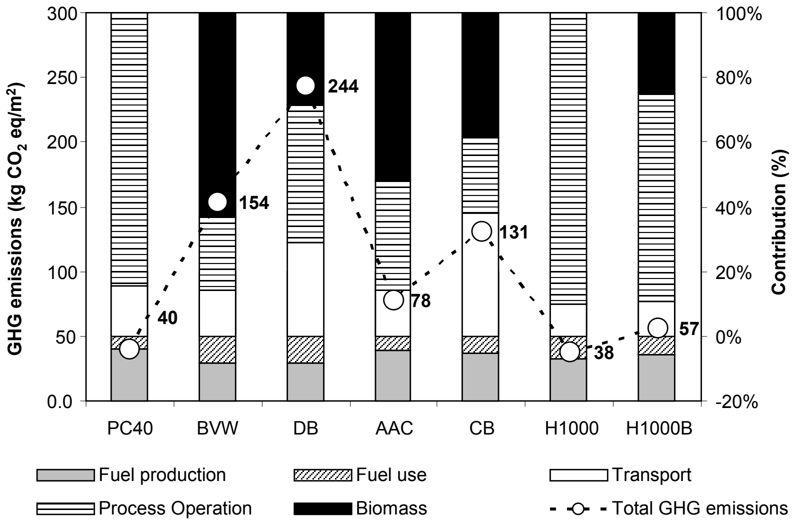

Figure 3 GHG emissions of various wall systems (see Table 1 for a description of wall systems).

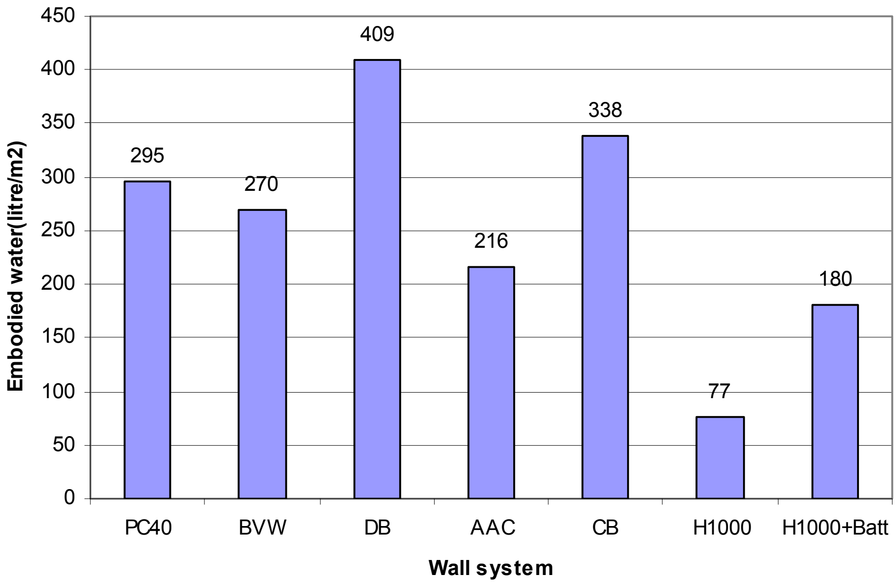

Figure 4 Embodied water used in manufacturing various wall systems (see Table 1 for a description of wall systems).

5. Implications for Sustainable Housing

This environmental analysis has shown that wall systems built with prefabricated cellular concretes have the potential to reduce the gross embodied energy, GHG emissions and embodied water content in residential construction. Based on comparisons with some conventional wall systems, the use of LBCM may result in a two- to six-fold reduction in both gross energy and GHG emissions. Adding further to potential improvements in sustainability is the reduction in embodied water used in manufacturing, and the feasibility of producing wall systems with the required thermal ratings by coupling LBCM with a range of insulation materials. However, it is important that environmental performance analyses of different wall systems be performed on the basis of some common functional requirements, such as equivalent thermal rating. Ultimately, it is necessary to obtain an objective comparison in whole building performance from either actual measurements or experimentally validated methods of calculating thermal performance (Heathcote 2008).

With Australia's housing stock increasing by an estimated 130,000 dwellings per year, the potential for reducing environmental impacts through the use of relatively low-emission materials to provide improved thermal performance, will add to the impact of other abatement strategies employed throughout the economy. The overall feasibility of using such new materials would obviously be based on a wide range of other considerations, such as unit product cost, cost of installation, fit with functional requirements, compliance with building regulations and supply chain issues associated with materials, manufacturing and transportation.

A single-storey model building with a floorspace of 25 m^2 was designed and constructed to demonstrate proof of concept for both the manufacturing process and the method of construction using LBCM panels. For construction of this demonstrator building, approximately thirty 100 mm thick panels with standard dimensions of 900 × 2700 mm were manufactured. All panels were reinforced with one layer of mesh placed centrally, and some panels included cast in conduits for electrical services. Figure 5 shows these precast panels being lifted into place and propped, as is normal practice for erecting precast concrete walls. The entire wall structure was completed in less than one working day. A number of joint preparation and surface finishing methods were used to assess the long-term weathering and shrinkage properties of the wall system. The completed building is shown in Figure 6. Further to this early demonstrator, larger precast panels of between 9 and 8 m^2 are currently being produced for application in housing.

Figure 5 Precast LBCM panels being lifted and propped.

Figure 6 The completed model building.

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Future of Bamboo? The Greenest of the Green Building Materials

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Keywords: Bamboo, Sustainable, Demand, Supply, Green, Building, Materials, Energy

Abstract:

Bamboo plays a key role in the daily lives of 1/5 of the world population even today in many countries in Asia, Latin America and Africa. In many places expensive wood, steel, concrete, glass etc.and other such materials have replaced Bamboo- labeling it as a 'poor mans' timber' a 'poor man's building material' etc.

But of late Bamboo has liberated itself from this stigma and emerged as the **'Greenest of the Green Building Materials'**. It is the most fashionable building material in Vogue today and is in great demand across the World for buildings, Interiors, landscapes, bridges, etc.

- Any talk of Sustainable Buildings today is not complete without the mention of Bamboo.
- Bamboo was/is an essential building material in the specifications of the Topmost LEED Rated and other green buildings of the world!

Lots of people want to build Bamboo Houses want bamboo furniture, bridges etc., There is a lot of **Demand** for Bamboo! There is a great market awaiting this beautiful, highly sustainable, engineering material! But somehow the **Demand-Supply** chain of this building material is not getting established. Very few Bamboo buildings are getting constructed across the world. Number of Architects, Manufactures, Govts., Policy Makers etc taking this material seriously is very low .

WHERE AND WHAT IS THE MISSING LINK?

This paper is an account of our efforts to find this missing link!

Bamboo should find its rightful and respectful place with other modern Building Materials. This will also have tremendous impact on the carbon footprints of the Building Industry as well which is the Highest Polluter (+_50%) of the **Mother Earth!** (Whole Bamboo houses use 1/7 the energy required to construct a concrete house).

SUSTAINABLE DEVELOPMENT AND BAMBOO

"Sustainability" means development that meets the current generation without undermining the ability of the future generation to meet their own needs"
(def: as per agenda 21,world climate summit in Rio de Janeiro 1992)

Development and environment are inextricably linked and must be nourished by a change in the means, the contents and the uses of growth. Three criteria's to be necessarily retained are social justice, ecological prudence, and economic efficiency.

As the repercussions and downsides of the western culture and architecture are being discovered and as the world is turning towards regional sustainable technologies – Two definite categories in the development are emerging – one based on the principles of recycling and the other on the use of natural materials capable of being used without requiring Industrial processing – Raw earth and Bamboo figure prominently in the second category of Development.

This long organic stem (a grass) wide spread in many countries of the world grows very quickly (Often up to 1.5m in the first year and acquires its ultimate structural strength some three years later.

Like wood, recycled paper and clay, Bamboo is a premier building material in the new architectural movement. Sustainability and Integrative approach are two important characteristics of this new building trend. It is Bamboo which brings together representatives of the so called third – world countries as equal partners in a fruitful exchange of ideas with architects from the industrialized countries. Bamboo is probably an enriching contribution that countries in the Southern Hemisphere can make to the architecture of the Western World. More and more advantages of using Bamboo are being discovered and the importance of Bamboo is growing everyday. A Bamboo Renaissance is taking place.

As per the 27th principles of the "Rio Declaration" which states that – "Indigenous people and their communities have a vital role in environmental management and development because of their knowledge and traditional practices. States should recognize and duly support their identity culture and interest." In this context Bamboo rich areas and communities with traditional knowledge of bamboo construction and other applications have a very big role to play in mitigating Global warming

.

The technology of construction with Bamboo could be one of the greatest contributions that the South and the Eastern world can give to sustainable Development. Only North-South and East-West complementarity will be realistic to develop a fair and global practice of sustainable development and an apt and reasonable redefinition of our future.

This paper is based on a non- linear and associative thought. It discusses bamboo's emerging diversity and significance in the context of the emerging Sustainable and Green Building movement, and not attempting to give a conclusion.

BAMBOO- AS A BUILDING MATERIAL- PRESENT DEMAND SCENARIO

To know the future – Let's peep in the history of Bamboo and analyze its current trends. Bamboo plays a key role in the daily lives of more than 1/3rd of the world population even today in many countries in Asia, Latin America and Africa. It is used to make houses and bridges, used for various articles of daily usage and crafts, eaten as a food item, and many other such applications. In many places expensive wood, steel, glass, concrete and other materials etc have replaced Bamboo, labeling it as a 'poor man's timber', poor man's building materials etc. But of late, 'Bamboo has liberated itself from this stigma and emerged as a capable contender along with other modern materials.

1. In the search for more and more sustainable and low energy or zero energy building materials.–a lot of research is being done with Bamboo as it is a renewable material. And Bamboo has emerged as an excellent material on all counts. Standard Building codes for Bamboo have been formulated in many countries across the world. This has enabled many architects and engineers to start using it with much more confidence like any other building material.

A comparison of the energy requirement for production of various building materials confirms that Bamboo is a material with the lowest embedded, grey and induced energy requirement.

Table : 1

Materials	**Energy for Production MJ/Kg**	**Weight per Volume Kg/m3**	**Energy for Production Kg/m3**	**Stress When In use**	**Energy per Unit stress**
Concrete	**0.8**	**2400**	**1920**	**8**	**240**
Steel	**30**	**7800**	**234000**	**160**	**1500**
Wood	**1**	**600**	**600**	**7.5**	**80**
Bamboo	**0.5**	**600**	**300**	**10**	**30**

Source: Prof. J.A Janssen, Eindhoven University, The Netherlands

2. The tensile strength of bamboo fibers can be up to 12 kg/cum. almost twice that of steel. The weight to strength ratio of bamboo is far better that most modern material. It also makes for excellent support because of its inherent stiffness owing to the natural subdivisions. The engineering qualities of bamboo and its intrinsic structure anticipate the principle of many high-tech materials – making it an excellent value for money ,with its attractive appearance an added bonus. Utilization of bamboo for grid matrix structures because of its flexibilities or in high – tech composite materials with high tensile strength, is a trend which can completely wipe out all other so called energy intensive high tech materials from the construction market. Since tensegrity and synergetic structures require light and high tensile basic elements, Bamboo is ideally situated for such applications. Its suitability for such structures is another feather in its cap.

Table 2 : **Mechanical properties of various woods and bamboo**

Woods	*Strength [MPa]*	*Mod. Elasticity [GPa]*	*Density [g/cm3]*
Cader	29.3-48.5	4.4-9.8	0.29-0.46
Fir	30.7-33.8	5.9-6.7	0.31-0.34
Pine	34.0-41.6	6.5-8.8	0.36-0.42
Spruce	31.0-40.0	7.3-8.5	0.38
Hickory	62.5-81.0	8.9-11.4	0.56-0.67
Oak	47.7-74.9	7.9-12.4	0.53-0.61
Bamboo [fibre]	610	46	1.16
Bamboo [matrix]	50	2	0.67
Bamboo [composite]	140-230	11-17	0.6-1.1

Source: [Bodig & Jaine,1993] in Amada et al [1996]

Table 3 : **Chemical properties of wood and bamboo**

Components	Wood	Bamboo
Cellulose[%]	40-50	45.3
Hemi-cellulose[%]	20-35	--
Lignin[%]	15-35	25.5
Olyoses[%]	--	24.3
Extractive[%]	<10	2.6
Tensile strength[MPa]	34-220	150-520

Source: Li, Zeng, Xiao, Fu, Zhou[1995]

3. Buildings of bamboo & bamboo elements can be easily recycled or dismantled and it is easy to replace individual elements. In the field of prefabricated construction elements, Bamboo will emerge as the most viable material in both the forms-whole Bamboo and Engineered bamboo as prefabrication is inherent to bamboo. Bamboo is stronger than wood in tension and compression.

4. Bamboo is replacing wood in all its applications from ply, doors and windows, shuttering ply,beams, pillars, flooring, roofing, sunshade blinds, interior furnishing, pergolas etc.All these factors will make Bamboo the most desirable building material in the 21st Century.

5. Because of the its high strength to weight ratio, bamboo has long been associated with aeronautics .Bamboo composites could become a major natural material for the Aviation industry.

6. World Green Building Council has recognized Bamboo as the most environment friendly and sustainable building material. And hence Bamboo finds a prominent place in the specifications of all the GBC-LEED rated buildings across the world as a building material and also in landscaping.

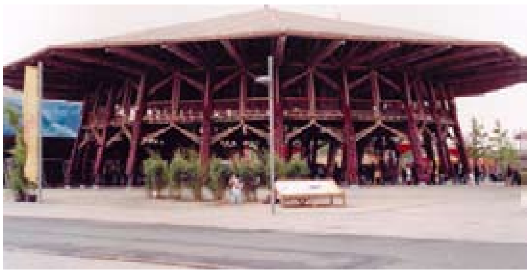
How sustainable is a Bamboo House?..

We have designed and executed a 1000 sft Bamboo House called “The Solar Hut” at the State Level Energy Park at Bangalore, India. It is a two-bedroom house with simple plan with bamboo columns, bamboo roofing understructure and bamboo composites boards for roofing, doors and interiors etc.A Comparison of the energy requirement [Embodied energy] [Ref.Table no.3,Page 4] of this building with a building with the same plan but built with conventional materials is given below.

Table 4: Bamboo House Conventional House

Materials	*Energy For production [Kg/cu.m]*	*Qty. of Material*	*Total energy requirement*	*Qty. of Materials*	*Total [Kg/cu.m]*
Concrete	1920	30	70080	175	864000
Steel	234000	0.6	140400	3	702000
Wood	600	2	1200	2	1200
Bamboo	300	30	9000	0	000
		Total	220680		1567200

The bamboo house needed 7.1.times less energy than a conventional house and hence is as many times more sustainable!



7. Simon Velez – An Architect from Columbia has designed and constructed all types of buildings from whole Bamboo- from low cost houses to high end exotic villas, large span bridges, industrial buildings, pavilions etc. He has set many precedents and his works done with Bamboo has encouraged many young Architects to experiment with this material. Simon Velez has been using bamboo since the mid 1980’s.

At the Expo 2000 at Hanover, Germany, the ZERI pavilion designed by Simon Velez made of Bamboo has proved to be a landmark in Bamboo based Architecture for its engineering qualities i.e.—strength, solidity, safety, fire-resistance, mold resistance, sustainability and aesthetics. This put into practice several principles of the "Rio Declaration" and was in perfect rhythm with the theme of the Hanover Expo –'Man, Nature and Technology'.

8. Several National and International Design Competitions have been organized for Building with Bamboo. In recent years buildings with bamboo have bagged several awards in various other Architectural Design competitions as well. This has sparked a lot of interest about this material in the architectural and engineering world - making it the most environment friendly, glamorous and fashionable building material across the world today.

Table 1.Indian Bamboo Market Potential

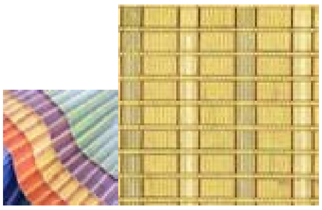
S.no	*Product/Application*	*Current Market(Rs.)*	*Expected Market(Rs.)*
1	Bamboo shoot	4.8 crores [2001]	300 crores [growing at 25]
2	Bamboo wood	10000 crores [import value]	30,000 crores [in next 20 years]
3	Bamboo plywood	200 crores	500 crores
4	Bamboo plyboard in Trucks & railways	1000 crores	3408 crores [in 2015]
5	Bamboo flooring	100 crores [Domestic]	1950 crores [2015]
		100 crores [Export]	
6	Bamboo pulp	100 crores	2088 crores [2015]
7	Bamboo furniture	380 crores	3265 crores [2015]
	Bamboo construction material		
8	Scaffolding	--	861 crores [2015]
9	Housing	--	1163 crores [2015]
10	Roads	--	274 crores
11	Bamboo grids	--	1000 crores [2015]
12	Agarbatti – Miscellaneous Industry, Pencil industry, Match-stick Industry	394 crores	600 crores [in 2004]

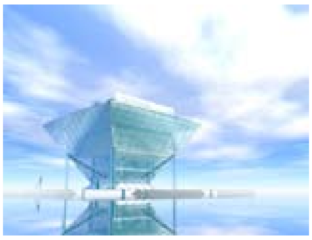
THE SUPPLY SCENARIO

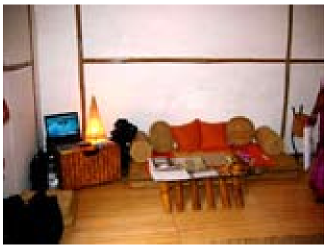
As is evident, tremendous demand for this material has been painstakingly created by several pioneers in the last several decades. A booming world market is awaiting prospective entrepreneurs and suppliers.

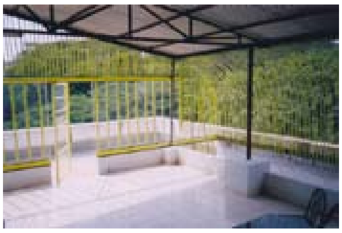
1. Bamboo is sustainable with respect to both the plant and the building material. Hence several bamboo missions have been taken up across the world to encourage bamboo plantations. Lots of farmers, horticulturists, environmentalists, architects, entrepreneur's etc. are taking up huge plantations all over the world. This will make available large quantities of this material for use in the future. And simultaneously, these plantations would mitigate the harmful effects of a global warming as Bamboo is a natural environment cleanser.
There is infact a severe shortage of quality bamboo materials. Hence, new bamboo plantations should be taken up to raise special purpose /species needed by the industry. Regulated plantation of selected species, sound management practices, proper harvest, post harvest treatments and new usages are essential for value added products.

2. Again as part of these Missions, states and countries are encouraging entrepreneurs to set up Industries for engineered bamboo product like bamboo ply, flooring, bamboo boards, roofing, wood etc. Venture capital finances and soft loans with tax incentives are being offered to prospective entrepreneurs and to number of industries have been set up. However these industries have failed to meet the growing demands of the market due to various reasons like lack of raw material availability, work force, appropriate marketing strategies etc.









Bamboo Based Products

3. All this popularity of bamboo is making it more expensive and less available for the common man. Hence, except in countries where the local labor wages are low, the cost of bamboo has gone through the roof, and lots of people have started to resorting to Imitations or plastic bamboo.

4. Architects & Engineers are slowly starting to use this material but their number is very small. Hence the number of buildings with bamboo as a building material is very very low.
Also the quality & design details and execution of these projects is very crude and amateurish. And this is hampering the propagation and popularity of the material.

5. Since the technology is new, there is a serious dearth of middle level workers like supervisors, carpenters, masons, etc absolutly essential for execution. Because of this the Architects & Contractors face lot of trouble in the execution of the projects and find it very difficult to maintain high quality standards and time schedules.

6. For the industries of engineered bamboo products, backhand industries linkages to produce the raw materials are not fully developed .This sometime cripples these industries, creating sever shortage of products in the market. The states and the countries are trying to take care of this problem but the process is very slow.

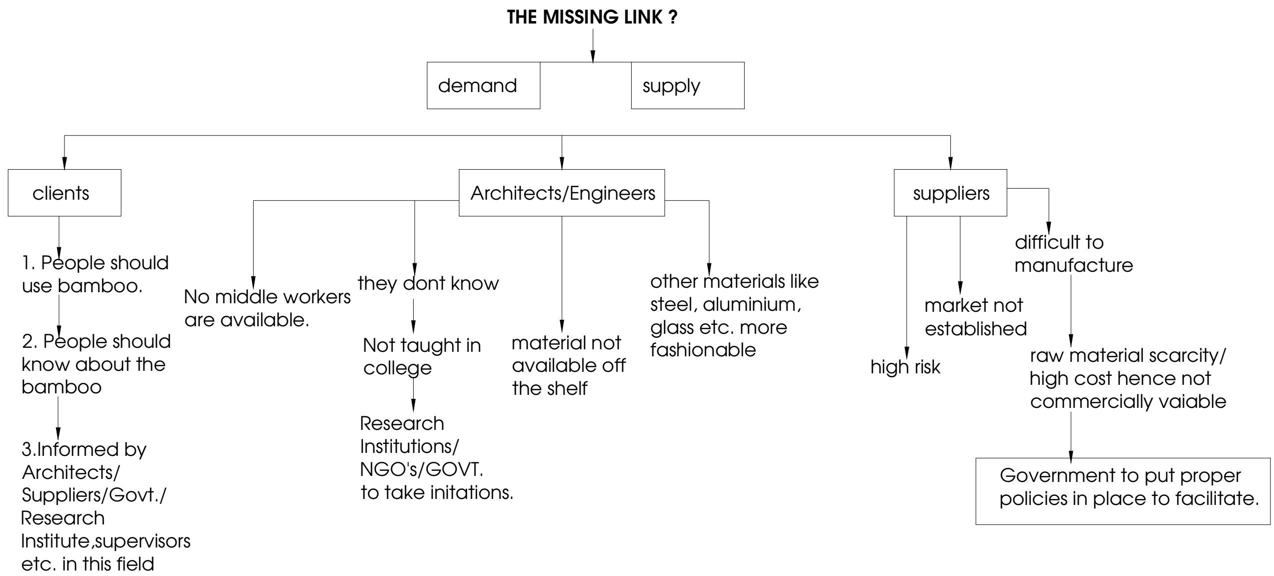
7. Since the material is unavailable all over the world, lot of export of raw bamboo and finished bamboo product is taking place, killing the very “spirit of sustainability” (by adding the energy for the transportation).On the other hand export-import of these item is making them exhorbtitantly expensive.

8. In India, National Mission for Bamboo Applications, NMBA and National Bamboo Mission,NBM is promoting the use of bamboo ply and other engineered products for disaster housing programmes. These houses provide a good solution as long as they are used as interim shelters only. But they are using it for permanent housing as well. Because of this the involvement oflocals in the reconstruction process is completely eliminated which otherwise could also provide Livilihood security to the victims. Bamboo is the most appropriate material to the used for the construction in disaster prone areas and also during disaster, only if it is used sensitively and sensibly.

9. In the mass housing sector, Bamboo is yet to make its foray as the mainstream building material. This is solely due to a seer lack of Architects and engineers with expertise in bamboo utilization and dearth of quality and quantity materials in the market.

10. Tourism sector also started with lot of enthusiasm in utilizing Bamboo in all its forms. A number of resorts has been done across the world. But since the expertise in protection of bamboo form biological hazards has not been completely standardized and generally taken very lightly, the usage is limited due to fast biological degradation of untreated Bamboo in exotic locales. And this probably further worsens the stigma attached to Bamboo as a material for Temporary structures.

11. There is no college, university or Institution as on date offering a structured course in Bamboo Technology for Building construction and Industrial Applications. Because of this the evolution, enhancement and absorption of the technicalities of Bamboo construction is not happening. There are no specialized Architects, engineers to adopt this material fully.



7

WHAT ARE WE DOING? OUR EFFORTS TO FIND SOLUTIONS.

We have been working with bamboo for several years now. This paper is the result of design, experimental works and their results by myself, proprietor Manasaram Architects, Centre for green building materials and technologies,CGBMT, and Guru Dayal, Propritor, Aditi constructions in association with various NGOs, Government, Research Institutions and Bodies and enthusiastic clients of various projects across India and abroad. We have been trying to find the panaceas for these problems- trying to establish THE MISSING LINK.

OUR ACTIONS:

• We have formed a team of Architects, contractors and R & D groups to tackle the problems of supply from every front.

• Each project that we undertake is done as a research based project with practical solutions for execution. And we always try new methods and technologies in each project to create precedents and create case studies.

• We monitor all our projects regularly and keep in touch with the clients to develop confidence. The monitoring has also resulted in a database of the performance of the material under different situations.

• We always try to use it in combination with other building materials and technologies so That it increases its workability and popularity.

• We have been conducting seminars, lectures, workshops, exhibitions etc and have also been speaking at National and International forums to spread awareness about this wonderful building material.

• We are starting a Distance Education course on 'Bamboo Technology for Building construction and Industrial Applications' in collaboration with Dayalbagh University Agra, India. It will have short term and long terms courses for Architects, Engineers, policy makers and other mid-level workers.

Epilogue

Bamboo will continue to form part of a trend in Sustainable Architecture– The return to local traditions with their enormous wealth of intelligent sustainable solutions which have stood the test of time. And man will hardly be able to survive without it in the 21stCentury.

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The Recycling of Used Tyres as an Insulation Material in Cavity Walls in a Mediterranean Climate

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Keywords: rubber tyres, recycling, insulation, cavity walls, thermal performance, building envelope, carbon emissions, sustainability.

Summary

This paper evaluates the potential of recycling used tyres in three different states: whole, shredded & pulverised. The study looks into the best use of the material as a form of insulation in cavity walls in Malta, with a typical Mediterranean marine (island) climate, where a greater concern for cooling has always exceeded that for heating - albeit until recently. The Maltese building industry still depends on a robust building technology, relying heavily on traditional quarried stone for load-bearing cavity walls.

An energy-awareness is also maturing towards curtailing carbon emissions, even if initially dominated by cost concerns, especially in view of the ever-soaring price of crude oil on international markets. Malta has also adopted the EU Directive on energy performance in buildings, thus making energy efficiency governed by national law.

In consideration of today's large amount of tyres being used and disposed of, the purpose of this study is to investigate the possibility of utilising recycled rubber as a building material, namely as insulation in cavity walls. This could replace new insulating materials, typically having a higher embodied energy content. The study evaluates the success/failure of such passive design strategies.

1. Introduction

Typical insulation-related measures in a building affect the energy consumption some 50-100 years into the future, and it is either very expensive or practically impossible to modify an existing non-optimal construction. Logically, it is still important for new buildings to be as energy-efficient as possible, since in the long term, they may become decisive for the energy consumption and possibly constitute a benchmark for what is obtainable when renovating the existing building stock of the day, whenever this materialises in future.

Innovative insulation materials are perhaps at the forefront of developments in building technology worldwide. Gaining particular attention are recycled or recyclable materials, particularly those that apart from their energy-saving measure, have an eco-friendly contribution to the environment. Given its high embodied energy and end of life disposal issues, rubber is but one of them. Rubber has aroused particular interest in its potential for recycling and re-use in different forms as safety floors, acoustic panels and thermal insulation among others. This paper focuses on thermal insulation in three forms, namely pulverised, shredded and solid sheets of opened out tyres.

2.0 Present Situation

Three problem scenarios are envisaged for Malta in the imminent future. Before presenting these an overview of the present situation is given, here outlined under traditional building technology, energy legislation and waste disposal, respectively mapping out the three scenarios.

2.1 Building Technology in Malta

The construction industry in Malta has always been heavily dependent on the local quarried material, namely globigerina limestone. This indigenous quarried material has its own unique properties perhaps giving it its almost unbeatable popularity among local folk as a standard building material used for over 5,000 years.[1] Its structural integrity, durability, weathering and thermal properties as well as its ease and low cost of quarrying combined with today's technology for cutting, planning and hoisting have all contributed greatly to its quasi-perpetual use in the construction industry in Malta.

Today, at the threshold of the 21st century, trends indicate that imported modern materials have superseded vernacular construction methods, where frame structures now replace block-on-block structural load-bearing walls, especially with an increasing demand towards high-rise development. Quarrying has also been limited both due to its exhaustion as a quality source and new quarries or extensions being curtailed by stricter environmental and land use control. The demand for quarried solid blocks of *Franka* stone (soft, lower coralline globigerina limestone) has dwindled, yet somehow complementary to this, the demand has increased for *Tal-Qawwi* (hard, upper coralline globigerina limestone) for hardcore aggregate in concrete casts and hollow core concrete blockwork, the latter now gradually replacing the quarried *Franka* stone, particularly in façades.

2.2 Energy Legislation and the EPBD

Thermal considerations have also been raised to a higher importance in view of a greater sensitivity to carbon emissions and EU legislation. The EU Directive 2002/91/EC, better known as the EPBD (Energy Performance of Buildings Directive) promotes energy efficiency in buildings both in construction and at operational stages. Conceptually a building is perceived to be energy conscious from the onset with a view to minimising energy losses through the envelope, particularly through heating and cooling, yet maintaining adequate thermal comfort standards for its occupants all year round.

In Malta this Directive was transposed to local legislation through LN 238/2006, where reference is made to the latest revised building regulations, particularly part F, where the technical guidance document sets minimum requirements for energy performance of new buildings. Although not yet enforced, it is intended to guide architects in their design schemes with appropriate construction detailing and design when applying for a building permit as from 02 January 2007. Perhaps foremost in controlling heat transfer through the building envelope is the type and thickness of insulation. Naturally this has its own energy implications. Ideally one should compare its embodied energy with the actual operational energy savings made and the pay back periods envisaged at today's energy costs. One strong potential for cutting back this embodied energy is the use of recycled materials for cavity insulation. Rubber is but one of them.

2.3 Waste Disposal & Land Use

Waste management has always posed an environmental problem worldwide. Malta is no exception. Considering a small Island State of 216sq.km, with a population in excess of 400,000 leading a more western lifestyle, waste disposal may be deemed as a very acute problem. A decision was taken some fifty year ago to collect all municipal and building industry waste in one national rubbish dump, close to a small rural community, *Maghtab*, today more known for its dump than for the original indigenous village.

In fact the problem became greater over the last two decades as the land take-up for waste disposal was having serious implications on the local residents, neighbouring towns and the tourist industry at large. Today waste management and the associated land use have gained more importance, where professionally managed engineered landfills are being meticulously planned and set up. A proper nation-wide waste separation educational programme is in place, identifying organic form inert waste, also separately collected at source. A greater emphasis on re-use and recycling is also made with a view to increasing longevity of materials and products ("cradle to the grave" life cycle) thus logically reducing disposal volumes and land-use demand. Apart from all other inert (possibly compacted) waste tyre disposal poses a serious concern, as its disposal takes up precious stockpile volume, considering a tyre's low mass per unit volume.It also poses a high helath risk when deteriorating or burnt, emitting toxic fumes.

Tyre recycling is typically considered when vehicles' tyres are beyond repair or rethreading. This is particularly the case with larger vehicles, especially when severely damaged or punctured. All but more particularly larger tyres present the most problematic sources of waste, due to the large volume required and their durability, thus having a slow rate of decay, if at all. These same characteristics that make disposed tyres generate such a waste problem can also be viewed positively, as it makes them one of the most re-used waste materials. Since rubber is very resilient it can also be reused in other forms and products. Examples include shoe soles, shock absorbers, road surfaces, noise absorption and thermal insulation.

In the U.S., approximately one tyre per person is discarded annually. In 2003 alone 290 million scrap tyres were generated, of which 45 million of these were re-used through re-threading.[2] With most landfills worldwide minimising their acceptance of whole tyres due to the health and environmental risks associated with stockpiling tyres, many new markets have emerged for recycling such a heavily disposed-of waste material. Established growing markets exist for a majority of scrap tyres produced every year; across Europe some of these plants are also being supported (or owned) by national authorities or local governments.

It is particularly worth investigating the LCA (Life Cycle Analysis) associated with the disposal of scrap tyres or their export out of Malta, as compared to the importation of synthetic rubber for use in various products such as road surfacing, safety mats for children's play areas and thermal insulation among others. The latter needs further investigation against other forms of insulation typically the more popular EPS (expanded polystyrene) or EPU (extruded polyurethane), both having a high embodied energy content.

Increase in public pressure in the field of waste management, deposition and internalization of environmental cost factors, has led to legislative measures, both National and European, which have resulted in a new scenery in the construction sector. The influence of an LCA approach is evident, when considering the environmental impact phase model of the entire building process.[3]

This paper however investigates the potential energy savings associated with achieving comfort standards through the use of three different types of rubber. These, in themselves, also encompass a different amount of embodied energy to produce; for example flattened tyres require less energy than machine-shredded crumbs, while the latter then demand less energy than pulverised rubber.

3.0 Experiment Methodology

3.1 Thermal Conductivity Theory and Codes of Practice

The ultimate aim of this paper was to determine and compare the U-values for two double skin cavity wall systems, one made of GLS (globigerina limestone) and another in HCB (hollow core concrete blockwork), both tested for three different types of rubber as cavity infill, compared to air. Independent of heating or cooling, the composite U-value is calculated theoretically assuming linear heat flow perpendicular to plane, parallel layers or skins of wall of uniform thicknesses. However in reality, all building components have irregularities, such as mortar joints, lateral cold bridges through corner bond stones, etc. These result in non-uniform transverse heat transfer, thus affecting the aggregate heat transfer through the element. Therefore this needs to be allowed for when determining the U-value of the composite element.

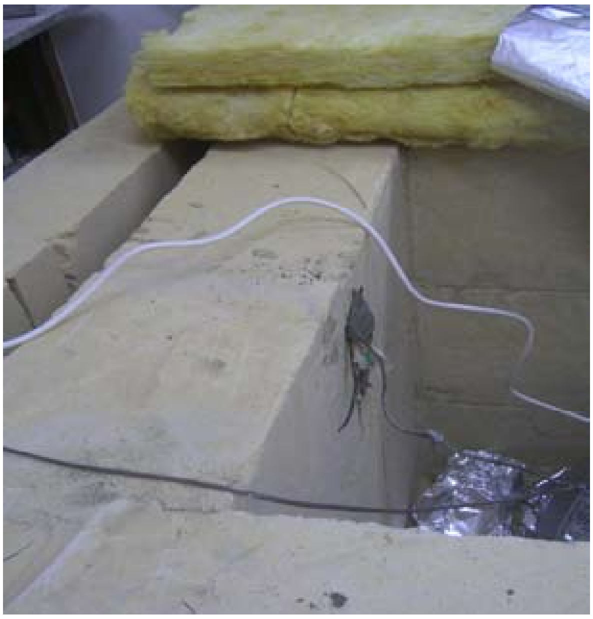
In general for such U-value calculations simplified methods are used where they are deemed appropriate for the element concerned. British Standards (BS) and other calculation methods define the scope of validity of the methods they describe. The method defined in BS EN ISO 6946 is often acceptable. This is known as the *Combined Method* since it involves the calculation of the upper and lower limits of thermal resistance of the element. Any non-uniform layer is to be treated as a bridged layer when using this method. The Standard calculates the U-value of the component from the arithmetic mean of these two limits. Hence its name, the *Combined Method*. However Anderson[4] points out that equal weighting can be an imperfect approximation when the difference is large, even though the true result always lies within the same upper and lower limits.

Finite element analysis is typically used for an accurate calculation of the thermal resistance of an element or single material in a composite part of the building envelope (wall or roof system). For routine calculations the Parallel Heat flow or Parallel Isotherm Method is used. The former overestimates the thermal resistance while the latter underestimates it hence it is for these reasons that the Combined Method takes their average. Based on empirical calculations of thermal conductivity of materials, the U-values were worked out for the different composite elements, representing wall construction in Malta, as per current practice in the building industry. These are later compared to physical testing out of similar test cells, as per current standards, namely BS EN ISO 6946. On the other hand EN ISO 8990:2003 uses the calibrated hot-box to find the steady state thermal transmission properties. This suggests using Q=UADS, but taking into account the emissivity factor, mean radiant temperature, radiant and convection coefficients.[5]

3.2 Test Cell set-up and Methodology

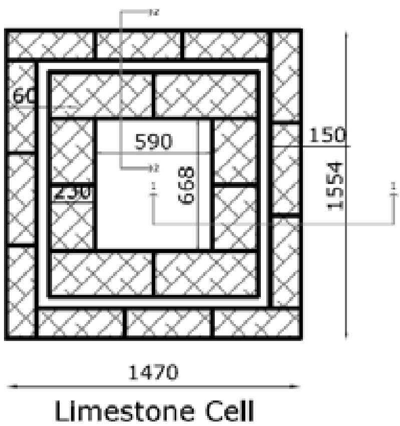
The experimental procedure involved the setting up of two test cells, as per EN ISO 8990:2000.[6] The principal difference between the cells was in their construction system. One was built using the local quarried material, *globigerina limestone*, composed of two skins of 230mm and 180mm, while the second test cell was similarly composed of two skins of 230mm and 180mm, but in HCB (hollow concrete blockwork). In both instances the thicker skin was deemed to be more effective for its thermal mass when placed on the inside.[7] A consistent cavity of 60mm was ensured throughout. The blockwork cell was plastered up to 5mm both sides, while the limestone walls were pointed both sides, both as per standard local building practice. Such cells were placed on an isolating pallet, to minimise ground cooling, yet built directly on glass wool as an insulating material. Top level capping was achieved with a similar layer of insulation, both 100mm thick; both floor and ceiling of insulation panels of the cells were lined up with aluminium foil for maximum reflectivity.

Pictures 1, 2 illustrate the experimental set up while drawings 1, 2 show the corresponding test cell dimensions and thermocouple set-up. The data logging device (not shown here) connects all thermocouples to a special card inserted in a PC, carefully navigated by moving around altogether on a trolley on castors.

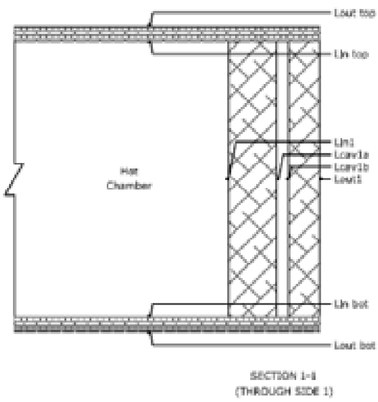


Picture 1 GLS cavity wall test cell

Picture 2 Insulation with aluminium foil lining



Drawing 1 Plan of test cell for GLS



Drawing 2 Section through test cell

Four rates of heat transfer were tested, namely with a void cavity, solid opened out tyres (sheets), shredded morsel (10-15mm) and pulverised rubber (1-3mm). The test cell facility was set up inside an environmental laboratory, behind a double door chamber to ensure a stable indoor environment. An electric heating element of a constant 1000W intensity was placed inside each test rig. A series of thermocouples were attached to the respective faces of the cell walls, interconnected to a robust data logger, previously calibrated, all set up as per MSA standards.[8] Although monitoring was initiated immediately, steady state conditions were allowed for until formal data logging was noted to be fairly stable, with a steady rate of heat transfer through the different test cells. Output results were charted and analysed for observations.

4.0 Results & Discussion

4.1 Charted Output: Building Materials comparison

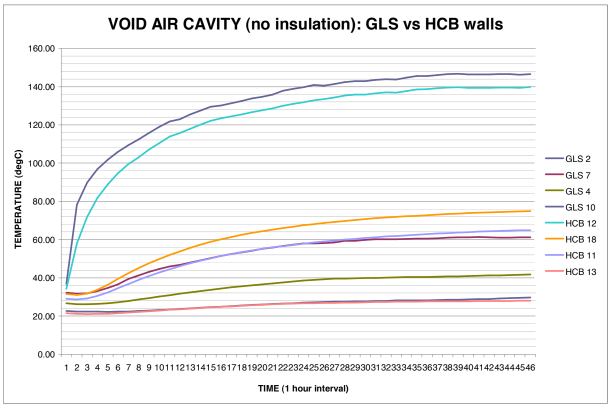


Figure 1 Void Air Cavity - GLS vs HCB

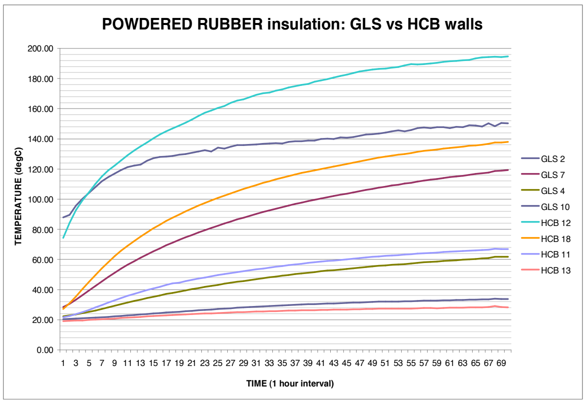


Figure 2 Powdered Rubber - GLS vs HCB

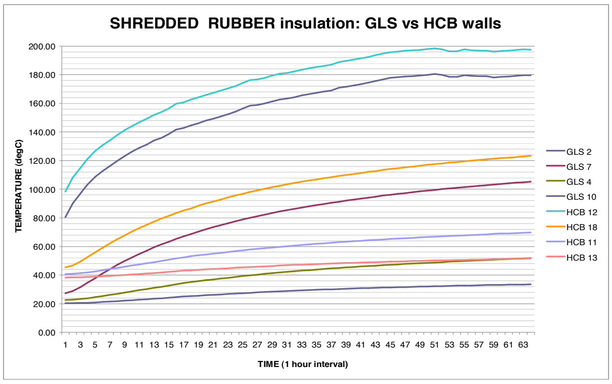


Figure 3 Shredded Rubber - GLS vs HCB

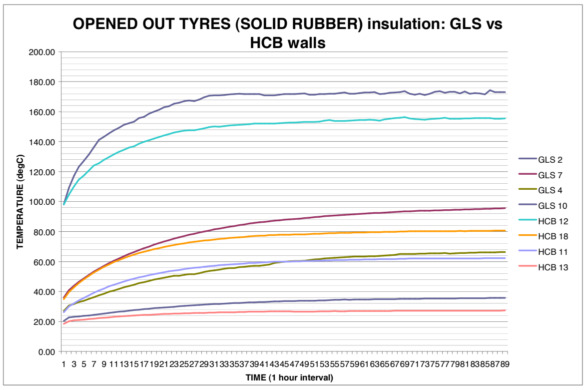


Figure 4 Solid Rubber Tyres - GLS vs HCB

From the above charts, figs 1,2,3,4 the four scenarios compare the different thermal performance of the two distinctly different building materials, GLS (Globigerina Limestone) and HCB (hollow core blockwork), the former naturally occurring and quarried, while the latter man-made, composed of hard-core aggregate, sand and cement. Both materials shave considerably high embodied energy, not calculated in this paper.

Fig.1: Void air cavity: It is noted that for both GLS & HCB heat transfer generally stabilises after 65 hourly readings. While GLS reaches 140℃ in 48 hours, HCB reaches the same temperature after 57 hours. The difference of 9 hours is attributed to the 100mm cast cavity within the HCB and possibly its lower porosity. Both GLS and HCB outer cell surface temperatures rose marginally from 26℃ to 28℃ over the same perio d.

Fig.2: Powdered rubber: Heat transfer stabilises after 60 hours for both cells. HCB inner surface temperature reaches 195℃ after 70 hours, while GLS reaches 150 ℃ over the same time frame. HCB cavity surface temperatures rose steeper than GLS from the onset. This may be due to the fact that GLS was probably still wet internally as typical for most freshly quarried stone. Although water is a better conductor of heat than air, the moisture content itself must have been cooler than capillary pores, thus lowering the kick-off temperatures. Hence the slow rise detected by the thermocouples on the GLS.

Fig.3: Shredded rubber: Both HCB and GLS rose steeply over the first 24 hours but rate of heat transfer slowed down to stabilise at 198℃ and 180℃ respect ively. Outer surface reached equilibrium after 63 hours with HCB rising to 52℃ and GLS lower by 17℃ at 35 ℃. It is also worth noting that cells' inner surfa ce temperatures experienced minor non-uniform fluctuations in temperature readings. This is possibly due to variations in the mains current supplied to the heaters since both HCB and GLS experienced consistent congruent dents in their temperature logging.

Fig.4: Solid Rubber: Inner surface temperature for both GLS and HCB rose steadily from around 96℃, possibly due to the thermal inertia of the stone from previous experiments. [This was the last test performed, and although a period of five days was allowed for cooling, the inner mass may have still been warm enough]. Its is also worth noting that both GLS and HCB temperature profiles are now experiencing more

erratic changes, yet retaining a steady flow overall. Both curves reach fairly stable values of 172℃ and 154℃ after only 33 hours of data logging. Cavity's inner surface inside the GLS cell stands at 96℃ w hile that for HCB is at 80℃. In this instance GLS cavit y temperatures are circa 14℃ warmer than the HCB c avity (unlike the former three scenarios). This is only attributed to the now dry globigerina limestone, after the earlier three experiments. Outermost surface temperatures are equally different by about 8℃ with GLS still the higher of the two cells. It is worth noting that while GLS was only pointed along its bedding joints, the HCB cell had a plastered surface composed of a sand+cement mortar of circa 5mm overall. This may have helped to dampen thermal losses overall, even if marginally. [Such surface finishes were applied to simulate current practice for typical Maltese building construction finishes].

4.2 Charted Output: Temperature Profile comparison

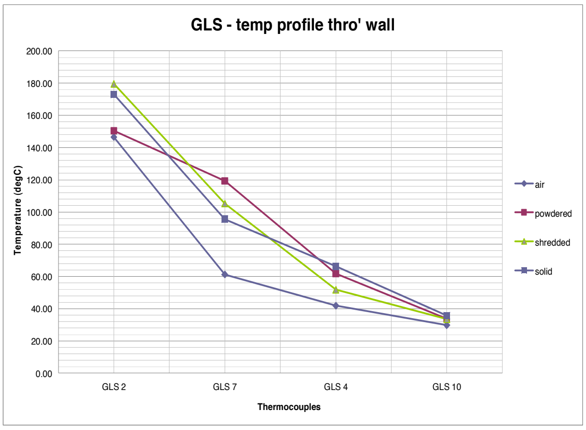


Figure 5 Temperature Profile for GLS

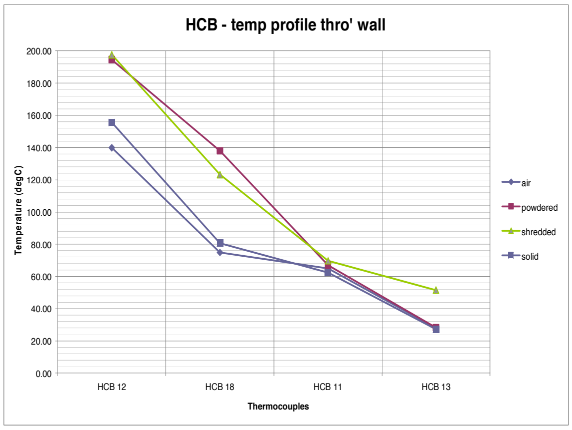


Figure 6 Temperature Profile for HCB

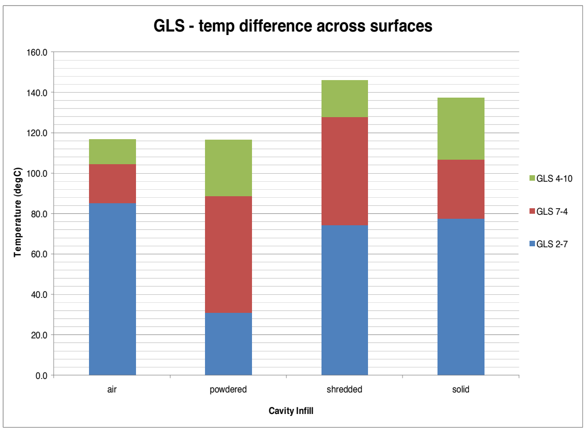


Figure 7 Four Insulation types for GLS

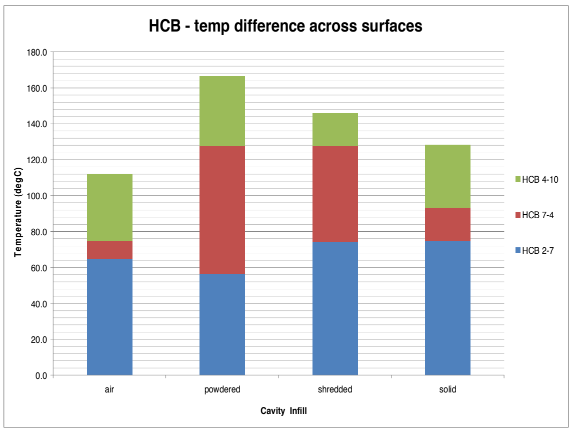


Figure 8 Four Insulation types for HCB

Figures 5 and 6 depict the 4 in 1 temperature profiles through the *two* different materials, while figures 7 and 8 represent the effect of each cavity infill (insulation type) for the same two materials, namely globigerina limestone (GLS) and hollow core blockwork (HCB).

Figures 5 and 6 indicate that while an empty (air) cavity and a solid rubber infill (opened out tyres) have a similar gradient of 72℃ and 40℃ across the inner skin and the cavity respectively, they converge to the same point at 28℃ externally. However, shredded an d pulverised rubber infill insulation behave quite differently: both GLS and HCB experience a greater resistance to heat losses through their inner skin wall of circa 30℃ and 70℃ respectively. The steeper gradi ent of the temperature profile for powdered rubber also indicates that it performs best of all three rubber types.

Figures 7 and 8 expresses temperature differences as bar charts. These further demonstrate that pulverised rubber offers the greatest resistance to the passage of heat, followed by shredded rubber.

4.2 Output Results and Discussion

After working through each cavity option case scenario for the two different materials, the following U-values were obtained, as summarised in table 1:

Table 1 U-values for different cavity insulation types

Cavity infill [60mm]	*U-value for GLS wall [w/m²K]*	*U-value for HCB wall [w/m²K]*
AIR	2.78	2.68
POWDERED rubber	2.21	1.65
SHEDDED rubber	1.91	1.77
SOLID rubber	2.03	2.19
*EPS	1.00	1.00
*EPU	0.76	0.78
*Glasswool	1.42	1.09
*Stonewool	**1.08**	**0.91**

**Note: These values were obtained through similar experiments carried out by Abela.[9]*

Comparing theoretical calculations with the experimental values inserted in Fourier's Law of thermodynamics U-values compared favourably. Table 1 illustrates all experimental values obtained. Once more it is evident that pulverised recycled rubber gives the optimum thermal performance out of the three types tested, followed by shredded rubber - both in hollow core blockwork.

However when compared with modern conventional purposely manufactured insulating materials, these performed marginally less. It is worth pointing out however that the embodied energy of both the new material, as well as the recycled rubber, did not feature in the overall energy balance equation.A holistic LCA would have been justified in this case for a true overall comparison, including embodied energy of both types.

4.3 Potential Shortcomings

To be precise, the solid rubber is actually an opened out tyre of circa 10-15mm thickness, including steel mesh. [Rim lining was deliberately stripped out to avoid steel conductivity]. The two factors that may have influenced readings are the percentage of steel content - albeit even if very low, as well as the remaining air void between the solid tyre and the cavity walls. These may have (marginally) distorted the readings for the opened out tyres. Naturally if the full 60mm cavity was packed with layers of solid tyres, the results would have been quite different for this case.

The heat source of a known intensity of 1000W was assumed to be divided between the four walls of the cell. Since the ceiling and floor of the two cells were heavily insulated with 150mm of glasswool internally lined with an aluminium foil, it was assumed that there was no absorbtion and no heat was conducted out of these two planes in theory. In reality however, the roof did warm up even if marginally. Ths may have contributed towards a margin of error when assuming the 1000W source to be divided into 250W for each side.

Initial kick-off of inner surface temperatures was slow, especially for 2nd, 3rd and 4th experiment set up with powdered, shredded and solid tyres respectively. Although a minimum period of five days in between was allowed, the thermal inertia of the GLS in particular could have remained relatively warm; this could have offset the readsings, especially when compared to the HCB, the latter having a greater porosity and a lower thermal inertia.

Globigerina limestone, when quarried is typically wet with a relatively high moisture content. Standard building practicve in Malta dictates (rule of thumb) that new buildings should be allowed to dry up for at leat one year before such walls are plasterd or decorated. In this instance, however, due to time constraints and availability of the builder, only two weeks were allowed. Hence the possibly high moisture content could have contributed to a small degree fo error, even if marginally, especially when compared with hollow core blockwork. With hindsight, this could have been measured and assessed against similar values for HCB.

5.0 Conclusions

Given that recycled tyres can be transformed into these three forms of opened out, shredded and grain size, it can be concluded that powdered rubber provides the best thermal performance of the four types tested, including an air cavity.

However it is worth noting that since the alternative four (and any other) materials compared with are purposely manufactured as insulating materials, therefore solid, shredded or pulverised rubber tyres present an added value ("win-win" situation), since they curtail waste both in terms of volume and in terms of their hazardous material decomposition.

Therefore such recycled rubber, an offshoot of used vehicle tyres, lareg or small, is here potentially put to good use. This points to the case that a full rigorous LCA (Life Cycle Analysis) needs to be worked out in order to compare the overall energy saving of the different systems against the deployment of various types of newly manufactured insulation. At this stage such a study was beyond the scope of this research paper.

5.1 Scope for Further Research

There is much potential for further research. As outlined earlier, one can focus more specifically on the embodied energy of each material in order to assess, compare and contrast different composite wall systems for their overall energy balance, including the insulating material's potential for recycling or in itself being a derivative of another material, possibly outside the building industry (e.g. tyres). This will ensure exhaustion for its embodied energy for a full LCA, with a thorough "cradle to the grave" sustainable approach.

There are numerous software packages on the market, most of which come with their own library of individual materials embodied energy.[10] Another area of research could be to compare these for similar external wall systems.

Such an approach will certainly minimise the impact of these three scenarios: the building industry's demand for new resources, reducing waste and health hazards and ultimately a reduction in carbon emissions and a lower carbon footprint of the building in question.

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BARRIERS FOR IMPLEMENTING SUSTAINABLE FACILITIES MANAGEMENT

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Keywords: Sustainability, FM, Recycling, Energy Management, Climate change

Summary

Facilities Managers are in the forefront for delivering sustainable assets management, and hence further the venture for mitigation and adaptation to climate change. This paper examines recent surveys conducting to establish the barriers and knowledge gap in applying sustainability principles and technologies in Facilities Management (FM). It describes the perceived barriers to the introduction of sustainable facilities management across the industry and reviews current analysis and understanding of sustainability and identifying the knowledge gap in its implementation. Majority of questionnaire respondents indicated the importance of sustainability to their organisation. Many of them stated that they reported on sustainability as part of their organisation annual reporting with energy efficiency, recycling, and waste reduction as the main concern to them. It is argued that the diversity of the FM role is challenging for incorporating sustainability agenda. The overwhelming barrier for implementing sound sustainable FM is the lack of consensual understanding and focus of individual and organisations for sustainability, hence appreciating the opportunities, threats and need for strategic leadership and direction in driving essential change. There is knowledge gap in having practical information on delivering sustainable FM. Skills and training provision traditionally offered to FM needs to be re-evaluated. Sustainability education and training should therefore be developed to provide effective structures and processes to apply sustainability coherently throughout FM organizations and as a common practice.

1. Introduction

Facilities managers have existed for as long as human activities have been carried out in designated buildings and sites. Wood (2006) highlights the need to address existing building stock in achieving sustainability goals and it is this emphasis on the operational phase of buildings that is indeed key to the role of FMs, since in the developed world the majority of buildings in current use will remain for the next fifty years, carrying their embodied energy and operational energy requirement into the future. Barbour (1998) identified a UK market for building maintenance and repair of £28 bn, and this easily exceeds the £10 bn new build market identified by Wood (1999). This puts into perspective our shared understanding that there has always been a need to manage the physical fabric of buildings, equipment and furniture within them, and the efficient supply of resources and removal of waste. These functions will have existed throughout history, but the complexity of modern society and its increased use of resources mean that there is now more than ever a need for facilities managers of high calibre to meet the needs of business, government and society in the 21st Century. The Barbour (2000) study indicated that over 75% of FMs had responsibility for both the routine upkeep of buildings as well as for their longer term repair and may operate at a strategic level in this activity.

According the BIFM (2007) Facilities Management is considered to be one of the fastest growing professions in the UK. The UK Facilities Management market is worth £106.3 billion Shah (2007) with an annual growth of between 2% and 3% anticipated up to 2012. The industry and its market are forecasted to develop to include non-core functions including payroll IT, activities traditionally not associated with this profession, but which are increasingly being addressed by FMs. Brown & Pitt (2001) highlight the anticipated growth in the airport sector for example, a traditionally poor performer in sustainability terms and the likely impact that sectoral growth will make in sustainability terms. The scale of growth in the built environment and the consequential growth of the FM sector is anticipated to be enormous and consequently the contribution to the environmental problems.

The concept of Sustainable Facilities Management has developed in parallel with the overarching concept of sustainable development and the growing appreciation of the scale of predicted climate change. Recent extreme weather events such as Hurricane Catrina, flooding in South East Asia and the 2005 record hurricane season in the Caribbean have illustrated the need to address the threat of global climate change. These experiences have been reinforced by scientific evidence of rising temperatures, the melting of the polar icecaps and glaciers and revised predictions of more rapid temperature increases and extreme weather conditions. The case for change has been successfully made and the need to balance the three strands of sustainable development - social, economic and environmental – is apparent. It is both fortuitous and timely that the facilities management profession has grasped the agenda for change and is aspiring to develop a practical sustainability goals within this rapidly evolving profession. Facilities managers are now at the forefront of organisational behavioural change and in a position to influence the behaviour of individuals working in business, government departments and public services within the facilities they manage. Governments at both national and international level are using regulation to bring reduce carbon emissions and manage demand. Much of the burden of regulation will need to be picked up by facilities managers at every level. Current examples of the impact of regulation are the Energy Performance Building Directive, now partly implemented, WEEE regulations from July 2007 and the changes to planning to move towards zero carbon construction.

Sustainability is becoming increasingly important for Governments, business organisations and community at large having experienced the consequences of the global warming. There is an urgent need to change the way people think and operate. The importance of sustainable development as a tool in the battle against the climate warming is well documented. The European Union as well as the UK government are designing and constantly introducing new pieces of legislation that are forcing the construction industry to achieve improved energy efficiency and to reduce the carbon emissions. Having said that, The built environment and the construction industry have a serious detrimental impact on the environment. The construction industry accounts for around 40% of all resources consumption and production of around 40% of waste including green house gases (Prasad and Hall, 2004). The built environment and especially buildings on their own use 45% of generated energy to power and maintain there in contrast only 5% is used to construct them (CIOB, 2004). The other problem of the present world is scarcity of resources and the situation is aggravating due to developing economies in China or India demanding large amounts of energy and materials. The situation is reflected through constantly rising price of energy, its limited and finite availability. The affordability and security of the supply is under a question mark. As Hodges (2004) says ‘All these lofty goals to reduce energy consumption and take better care of the environment are of clear benefit to the facility manager. Achieving these goals, however, is easier said than done’. This is due to a discrepancy between the abilities, knowledge, skills and willingness of the facilities manager to implement sustainability in their business and the fact that they are very often mandated to manage the facilities at the lowest possible present cost. The two desynchronised tendencies make another barrier that prevents the discipline of facilities management from becoming more sustainable.

In addition the social strand of sustainable development provides a focus on social justice and development, so ensuring community participation in decisions affecting wider site implications, participating in the sustainable development and possibly regeneration of the neighbourhood, embracing corporate social responsibility opportunities and possibly even buying fair trade catering supplies are all relevant. There is now an ever increasing focus on sustainable resource use as described by Barton, *et a*l (2002) advocated the concept of strategic asset management (SAM) as a guiding principle for strategic resource use that includes the principles of ecologically sustainable development for quality of life goals.

The need for sustainable facilities management, and for skilled facilities managers to carry out this function, is therefore growing and the need to develop new ways of working to meet sustainability criteria is of increasing importance. The drivers now are to meet the challenges of applying sustainable development criteria to the management of facilities. This encompasses the life cycle of facilities, from design and construction to disposal, but often with a strong focus on the operational phase. This phase provides a remit to factor sustainability into maintaining and repairing the physical fabric of the site, obtaining resources based on sustainability criteria and ensuring that this extends through the supply chain, minimising waste and disposing of it responsibly and reducing energy demand.

British Institute of Facilities Management (BIFM, 2007) reports on its website that 'although the FM profession has been presented with an opportunity to make a real and measurable difference by driving the sustainability agenda forward, it does not at present have easy access to the specialist knowledge, tools and supporting case study material necessary to make this a reality'.

The change in focus that this represents is supported by BIFM and partners in setting up a Knowledge Transfer Partnership to raise awareness of best practice in the industry and to provide an electronic knowledge portal to share information that will allow professionals to build on their skills in this area. In order to tackle the problem a project was developed. The University of Reading's School of Construction Management and Engineering in the partnership with the British Institute of Facilities Management is engaged in a project known as Knowledge Transfer Partnership (KTP). Its aim is to research the sustainability issues within the facilities management industry, design and develop investigative and diagnostic tools required to enable and facilitate the implementation of sustainability measures.

2. Complexity of the FM Industry: Definitions and Scope

The concept of Facilities Management is continuously developing. Lord et al (2002) claimed that the term 'originated in the late 1960's to describe the then growing practice of banks outsourcing responsibility for processing of credit cards transactions to specialist providers.' The British Institute of Facilities Management (2007) claimed on its website that this is one of the fastest growing professions in the UK and describes the concept as 'the integration of processes within an organisation to maintain and develop the agreed services which support and improve the effectiveness of its primary activities'. This commonly used definition of Facilities Management has been formulated first by the European Committee for Standardisation (CEN) and latter on formally adopted by the British Institute of Facilities Management. Franklin Becker, one of the Facilities Management pioneer, defines the term in the following way: 'FM refers to buildings is use, to the planning, design and management of occupied buildings and their associated building systems, equipment, and furniture to enable and (one hopes) to enhance organizations' ability to meet its business or programmatic objectives. FM thus refers to organizational effectiveness" (Becker, 1991). Chalmers FM Initiative defines yet another definition of the term which is '*the design and change of facilities and the organisation of services related to facilities, based on requirements derived from user core activities.'*

Various institutions, professionals and organisations offer different definitions but the idea that they reflect is the strong relationship and interaction between buildings, services and organisations' core activities. Organisations use buildings, services and assets to create an environment that can enhance the performance of their primary business. The remit of Facilities Management industry is very broad and is constantly growing as more activities are tend to be regarded as non-core ones and included in the facilities management sector. BIFM (2007) created the following range of ancillary services that are incorporated in the FM sector:

- Security
- Cleaning
- Catering
- Building Fabric Maintenance
- Gardening and Landscaping
- Lift and Escalators Maintenance
- Lighting
- Building Design
- Plant Replacement

- Construction Management
- Energy Management
- Voice and Data Communication
- Disposal and Acquisition of Buildings
- Relocation
- Space Planning
- Postal Services
- Secretarial Services
- M & E engineering
- IT management

Facilities management used to be perceived in an old-fashioned way as to being concerned with caretaking, cleaning, repairs and maintenance (Atkin and Brooks, 2007). Recently this view is changing as facilities management now include also such issues as real estate, finance, human resource, health and safety, change and contract management. Atkin and Brooks (2007) highlighted that the issues such as domestic services or building and engineering services maintenance are simply the most visible ones and that neither of the FM responsibilities is more important that the other one.

Atkin and Brooks (2005) discussed the issue of a various background of the facilities mangers as many of them *'are not graduates from schools or departments of facilities management'*. They are often qualified as architects, surveyors, civil engineers or accountant and often perceive the role of a facility manager as a new opportunity. Atkin and Brooks (2005) emphasise the importance of possessing certain attributes such as integrity, organisational and communication skills as these are the key to become a successful facilities manager. It is imperative, the writers point out, to be able to understand organisations, people and processes, as opposed just to the background on its own stand. Atkin and Brooks (2005) justified and gave their support to the idea of introducing specialised training and education within the FM. The professionals' background and skills are necessary but they need to understand the way people operate in buildings, the way the use them and the ways in which their performance and productivity can be maximised to the benefit of the organisation and society at large. The broadening of the scope of the FM industry, constantly changing legislation and technology pose yet further requirements in regards to training and education.

In response to the demand of the rapidly growing FM profession, more universities and colleges are offering specialist undergraduate and postgraduate facilities management courses. For those who are already in the profession there is an opportunity to undertake courses on the part-time basis which one of the benefits is application the knowledge in practice.

3. The Sustainability Debate

The term 'sustainable development' has had many interpretations and there have been numerous attempts to define it. The most oft-cited definition of the notion is derived from the report of the World Commission on Environment and Development called 'Our Common Future'. The document, also known as Brutland Report, as the event was chaired by Bro Harlem Brutland – the Prime Minister of Norway, was published in 1987. The report described the sustainable development as *'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'*.

The simplicity of the definition of such a complex issue raised an avalanche of criticism. As Manson (2008) and Norton (2003) say that the definition as lacking purpose and its meaning is empty, but on the other side, '*it can mean almost anything to almost anyone'* (Manson, 2008). The concept of sustainable development was generated over 20 years before the Brutland's Report was created. Rachel Carson in her book 'Silent Spring' (1962) brought to the international attention the devastating effects of human activity on the environment and in this way pioneered the environmental movement. The link between the economic development and environmental degradation was first expressed and put on international agenda in 1972 at the United Nations Conference on the Human Environment in Stockholm. Unfortunately, there were very little signs of implementation of the environmental concerns into practice and attempt to minimise the depletion of the ozone and natural resources or to slow down the process of global warming. In the result, the environmental situation continued to deteriorate despite the international awareness and cry out for change.

In 1992, a major success was achieved at the United Nations Conference on Environment and Development, also called Earth Summit, in Rio de Janeiro. It resulted in adoption by the Member States of the Agenda 21 which was a proposed blueprint of actions in social and economic area required to achieve sustainable development across the globe. '*Governments recognized the need to redirect international and national plans and policies to ensure that all economic decisions fully took into account any environmental impact'* where the energy efficiency had a major role to play (UN, 1992).

The UK continues to tackle the issue of sustainable development by publishing the Energy White Paper in February 2003. It puts the country on the path to reduction of the carbon dioxide emission by some 60 per cent by about 2050 with the real progress seen by 2020 (BREE, 2003; 2007). In addition, the other objectives include reliability of energy supply; promotion of competitive markets in the UK and beyond so that the rate of sustainable economic growth is rising together with productivity; and ensuring that every house is adequately and affordably heated. In March 2005 the UK Government launched a new strategy for sustainable development called 'Securing the Future'. The document presents a set of shared principles that will help to achieve the sustainable development. They were agreed by the UK Government, Scottish Executive, Welsh Assebly Government and the Northern Ireland Administration.

The publication also establishes the priority areas of action shared across the UK. These are:

Sustainable Consumption and Production

Climate Change and Energy

Natural Resources Protection and Environmental Enhancement

Sustainable Communities

3.1 Significance of Sustainable FM

The main aspect of the Sustainable Facilities Management is its contribution in the battle against climate change. It is estimated that only 5% of generated energy is used in the construction process and 45% is used in order to power and operate the buildings (CIOB, 2004). The Organisation for Economic Co-operation and Development (OECD, 2003) highlighted that buildings consume about 32% of the world's resources and that includes 12% consumption of water. The emission of CO_2 as a result of such large consumption is enormous and its contribution to the problem global warming is significant. In this respect, there is a great potential for substantial reductions of these patterns and following that, the substantial reduction of the detrimental effect that it exerts on the environment.

The other aspect of introduction sustainable measures in FM industry is the problem of rising prices of fuel and insecurity of its supply as a result of intensive economic activities of two large developing countries – China and India. The increasing demand for the resources is feared to have aggravating effect on the climate change but also could generate the 'fuel poverty' and insecurity of supply and hence exacerbate social problems.

3.2 Consequences of not practicing sustainability – the Mayans

Certainly a lesson can be learnt from the mysterious collapse of the grand Maya civilisation that occupied the areas of present-day southern Mexico, Guatemala and parts of Belize, El Salvador and Honduras. The phenomenon is very complex and there is no single, universal theory explaining the demise of the great ancient culture. Many argue that it occurred as a result of overpopulation exceeding the capacity of the environment such as overhunting outbreaks of a disease, internal wars or dangerous dependence on monocropping (Peterson and Haug, 2005).

Many also believe in and support the idea of environmental degradation and climate change (e.g. Peterson and Haug, 2005). The latter led to an intense drought lasting over 200 years (Gill, 2000). Diamond (2005) also argues that climate change was one of the factors that contributed to the destabilisation of the Maya population. On the other side, he emphasises other influence factors which could also have contributed to the decline of the society and these are hillside erosion and deforestation as signs of environmental degradation, living close to the resource limits, poor leadership and concentration on short term benefits, and increased internal warfare.

The outcome of such a sudden collapse was not only a substantial decrease of the strength of their social, economical and political system. The lessons drawn from this civilisation can act as a warning as the problems that they were experiencing are very similar to those of the present world: wars, environmental degradation, overexploiting of natural resources, overpopulation and political instability. In this respect, immediate actions are required.

The social issues as well as those economic ones are also under the consideration of the Sustainable Facilities Management. The buildings are the environment in where people work and spend 90% of their time indoors according to the OECD (2003). Creating a healthy environment and good working conditions thus are crucial as they increase the level of the productivity of the employees and therefore benefit the employers and their businesses. Clements-Croome (2004) explains that it is more expensive to employ people who work rather than it is to maintain and operate the building and for this reason *'spending money on improving the work environment may be the most cost effective way of improving productivity'*.

4. Challenges and Barriers for Sustainability

The overall aim of this study is to investigate the nature of the sustainable facilities management and provide a benefit to the industry and community in the form of best practice guidance.

The objectives of this project are as the following:

- Establish the existing level of understanding and application of sustainable knowledge and practice within the facilities management profession
- Identify the key areas of Sustainable Facilities Management where clearer practical tools, information and industry best practice are required
- Identify the benefits of sustainable facilities management
- Determine and ascertain the existing drivers for implementation of sustainable practice in the facilities management industry
- Determine and ascertain the existing barriers for implementation of sustainable practice in the facilities management industry
- Produce a best practice guide comprising case studies for the facilities management practitioners and community

The data required establishing the level of sustainable knowledge and practice within the facilities management industry will be collected through an online survey in a form of self-administered questionnaires. The survey was accessed through the British Institute of Facilities Management website and made available to subscribing members. The received data will provide information on the current state of theoretical and practical knowledge among the professionals; it will identify areas in where there is a lack of practical tools, guidance and information.

The questionnaire consisted of a set of both closed and open questions. The pilot questionnaire was tested prior the commencement of the survey on a small number of potential respondents of the same sample as the final questionnaire. The aim of the questionnaire was to obtain data on the existing level of sustainable knowledge and practice within the facilities management industry. It also aims to establish the areas of the facilities management where it is believed that more information is required on the effective implementation of sustainability. The survey takes account of the type of the respondents and attempts to indentify their level of commitment or the commitment of the organisation they represent to the sustainability. The results presented in this paper are based on the views of 93 respondents.

What does sustainability mean to you?

Figure 1 shows the classification of respondents by sector. Almost 46% of all participants of the survey were facilities management service providers, while nearly 43% of all respondents were involved in the in-house facilities management. Only 3% were product suppliers and nearly 19% were from a different background. This of last group of respondents comprised property managers, FM consultants, building maintenance managers or company directors who cannot be readily categorised otherwise.

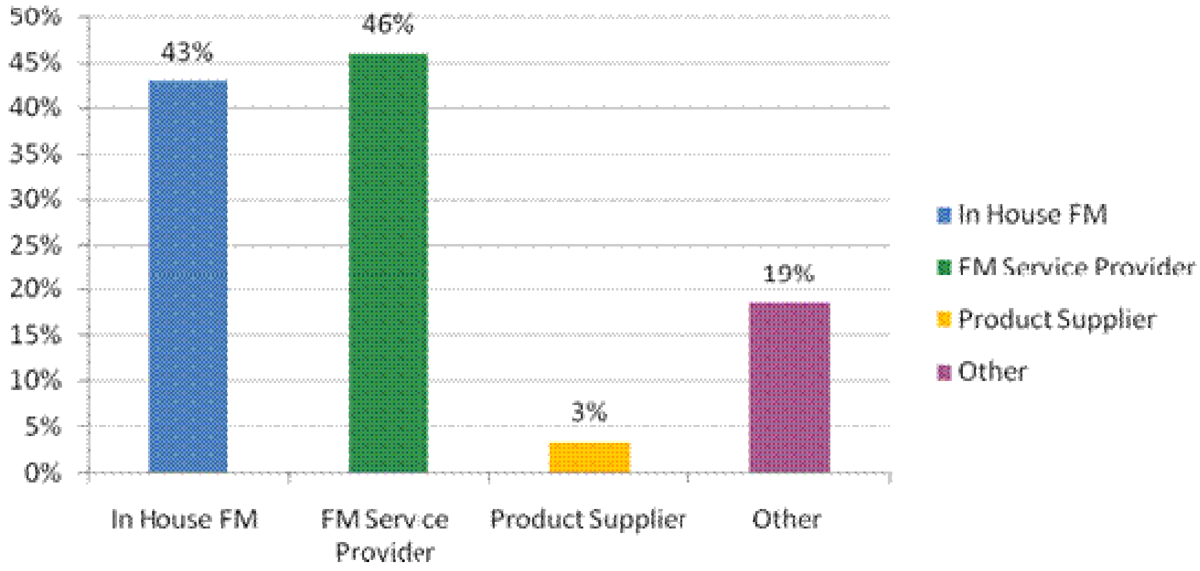

Figure 1: Respondents' classification by sector

Sustainability is characterised by three strands – environmental, economic and social and these were taken as the point of reference in assessing the level of theoretical knowledge, with respondents being required to indicate understanding in their answers. The responses were very varied as can be seen in Figure 2. Over 25% of the respondents have no understanding of the concept. 68% of the respondents recognise environmental aspects of the term (Figure 2). For instance, environmental concepts included 'protection of the environment', 'waste reduction', 'recycling' and 'limits of natural resources'. Key concepts for social issues included 'corporate social responsibility' and 'personal development'. For economic issues concepts such as 'business growth' or 'provision of goods and services' were used. Among the responses, only one individual quoted the Brutland definition of sustainable development.

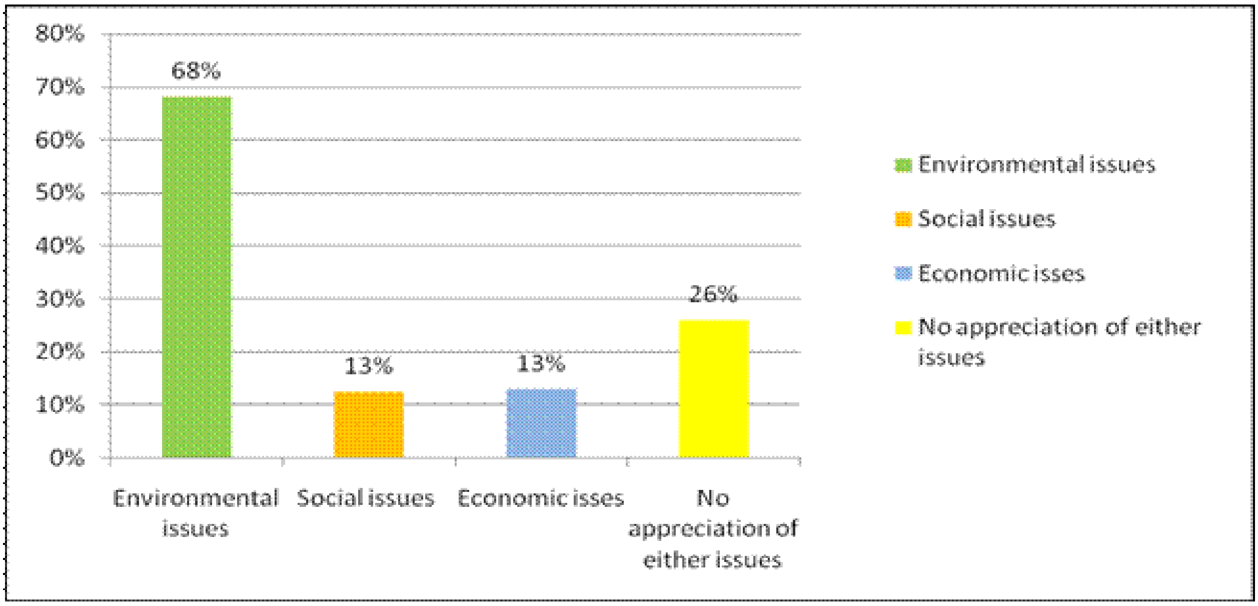

Figure 2: Breakdown of respondents' answers which encompassed the three strands of sustainability.

Below are some of the definitions of the concept provided by respondents:

"Minimising the impact of our lives on the planet and its resources. It also means a public corporate responsibility to protect the environment and its resources"

"The efficient use of finite resources involving waste minimisation, re-use, recycling and procurement"

"Sustainability is a holistic approach to development. Sustainability is about common sense in terms of the economy, environment and society, and acting responsibility"

"Acting responsibly in what we do so as to make a positive contribution to the communities in which we operate"

"To continuously provide the best services and levels of support with the minimum environmental impact"

"Providing commercial growth & business solutions, without leaving a legacy for future generations"

"Company mission and personal involvement on different levels"

Is making your organization more sustainable a key objective for you within the next 12 months?

The majority of the respondents, nearly 86%, indicated that it is important for them to make their organisation more sustainable within the next year.

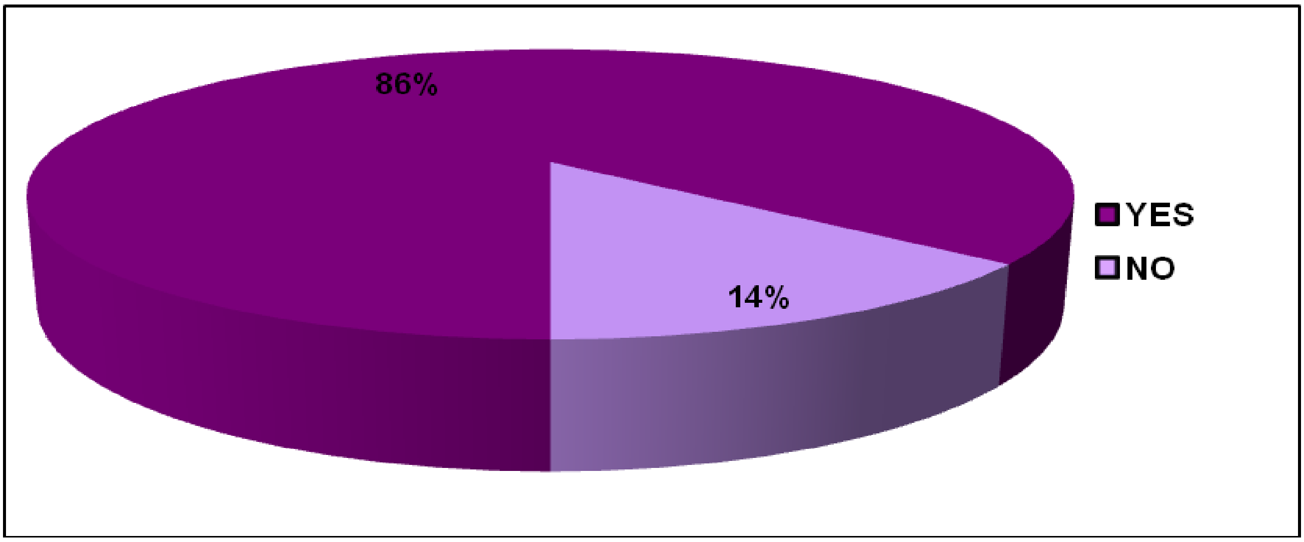

Figure 3: Proportion of respondents who indicated sustainability was a key objective for their organisations in the next 12 months.

How might you achieve this?

A wide range of responses were received in response to this question. Most of the respondents highlighted challenges such as energy efficiency, recycling, and waste reduction. These goals relate to the respondents' understanding of the environmental aspects as major part on their concept of the sustainability.

Below are some of the ideas mentioned by selected respondents to the questionnaire:

"More efficient use of energy, reduction in production of waste reviewing buying policies to ensure that we are using where possible products from renewable resources"

"Better utilities management (electric, water and gas), minimising waste and more recycling of waste, improvements in green travel alternatives"

"through the introduction of an Environmental Policy, the education of staff, focussed procurement processes and energy management"

"Selection of energy supplier with a green resource"

"We believe the best way to make our organisation sustainable is to increase our staff awareness of the issues and good practice"

"Develop travel plan
Reduce water consumption

Reduce energy consumption

Reduce-Reuse-Recycle

Raise awareness"

"There is a drive to pursue this approach to business from the main Board down to the lower grades of employee and corporate plans are in place to ensure we, and our third party service providers, do all we can to achieve both our corporate and legislative requirements"

Does sustainability feature as an objective within your organisation's corporate plan?

Nearly 80% reported that sustainability is incorporated as an objective within their organisation's corporate plan. For this reason sustainability can be assumed to be an important issue for the participating organisations and individuals within them

Was sustainability reported upon within your organisation's last annual report?

Just over 50% of all respondents confirmed that sustainability was reported as an item in the organisation's last annual report. Correspondingly, nearly 50% of the respondents confirmed that sustainability was not reported upon. When compared with responses to Question 7, it is clear that a discrepancy exists. This is discussed later in this report.

I/my organisation would find clearer, practical tools, information and industry best practice in the following areas:

- Developing a sustainability policy for my organisation
- Constructing a business proposal incorporating social, environmental and economic benefits
- Waste management and recycling
- Energy management
- Specification of sustainable products and services
- Ethical purchasing
- CO_2 footprinting
- Specification of sustainable M&E
- Occupancy satisfaction
- Biodiversity
- Community engagement
- Sustainable building and workplace design
- Sustainable travel
- Legal and statutory requirements
- Health and safety
- Flexible working
- Building disposal

5. Conclusions

Facilities Management (FM) is one of the fastet growing industry with almost 10% contribution to the UK economy. With the rising legislative requirements and targets to tackle global warming, FM are in the forefront in delivering the national and international sustainability targets.

There are challenges in the understanding and building a consensual definition of sustainability and The existence of such polarised understanding of the term together with materialised interests of various individuals and organisation is a main barrier for achieving sustainability. The lack or the limited understanding of the key concepts of sustainability and lack of practical knowledge contribute to the little implementation and effectiveness of the sustainable practice in the FM industry. The other primary problem preventing the FM sector from driving the sustainability agenda forward is the lack of expertise information and credible practical guidance. It was indicated that the energy management and the waste management and recycling were the primary areas where more information, practical tools and guidance is required. The reasons for demand of information in such areas are the result of the sustainability driving forces which the main ones are the extensive legislation, the various benefits of the sustainable solutions and their competitive advantage, the raising awareness of the global problems within the society and its demand and expectation for these practices to be implemented on a larger scale. The benefits of incorporation of sustainable practice are abundant. These comprise the economic benefits such lower energy bills or a positive revenue stream; the environmental – in the form of the reduction of the carbon emission and resources consumption and decreased amount of waste directed tot he landfill; the social benefits could be reflected in improved working conditions or a professional career training.

The questionnaire results indicated that the majority of respondents considering sustainability agenda as important to them and their organisations. Furthermore the majority stated that sustainability is incorporated as an objective within their organisation's corporate plan. Hence, sustainability is seen to be an important issue for the participating organisations and individuals within FM. The respondents indicated that information and practical guidance on wide ragne of issues will be helpful in contributing to implementing sustainable FM. Such wide range of issues included developing a sustainability policy for my organisation, constructing a business proposal incorporating social, environmental and economic benefits, waste management and recycling, energy management and specification of sustainable products and services, to mention a few.

There are numerous barriers, in addition to the lack of information and understanding of the key issue that prevents the implementation of sustainability in the FM industry. One of them is often the cost and the limited budget that the facilities management can spend on these solutions and initiatives. The other barrier is the lack of cost effectiveness of some of the technologies such as the photovoltaic systems where a large capital is to be invested and the very long payback time period is expected. Another problem is the lack of skills as well as knowledge among the professional to drive the sustainable practices. This has a great implication on education and training of FM professionals if sustainability discourse is to materialised.

6. Acknowledgment

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DEVELOPING AN INTEGRATED DECISION MODEL FOR THE ENHANCEMENT OF SUSTAINABILITY DELIVERABLES FOR AUSTRALIAN ROAD INFRASTRUCTURE PROJECTS

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Keywords: Sustainable development, road infrastructure, construction management, project delivery, performance enhancement.

Abstract

Road and highway infrastructure provides the backbone for a nation's economic growth. The versatile dispersion of population in Australia, from sparsely settled communities in remote areas to regenerated inner city suburbs with high density living in metropolitans, calls for continuing development and improvement on roads infrastructure under the current federal government policies and state governments' strategic plans. As road infrastructure projects involve large resources and mechanism, achieving sustainability not only in economic scales but also through environmental and social responsibility becomes a crucial issue. Current efforts are often impeded by different interpretation on sustainability agenda by stakeholders involved in these types of projects. As a result, sustainability deliverables at the project level is not often as transparent and measurable, compared to promises in project briefs and designs.

This paper reviews the past studies on sustainable infrastructure construction, focusing on roads and highway projects. Through literature study and consultation with the industry, key sustainability indicators specific to road infrastructure projects have been identified. Based on these findings, this paper introduces an on-going research project aimed at identifying and integrating the different perceptions and priority needs of the stakeholders, and issues that impact on the gap between sustainability foci and its actual realization at project end level. The exploration helps generate an integrated decision-making model for sustainable road infrastructure projects. The research will promote to the industry more systematic and integrated approaches to decision-making on the implementation of sustainability strategies to achieve deliverable goals throughout the development and delivery process of road infrastructure projects in Australia.

1. Introduction

Sustainability challenges are becoming part of our daily lives. Broad media coverage and breakthroughs of scientific research is raising increasing levels of public awareness in recent years. Sustainability wake-up call has permeated into practically all strata of society across the globe. Mounting environmental concerns that include climate change, greenhouse emissions, changing rainfall patterns, carbon abatement, pollution and resource scarcity threaten biodiversity, human health and lifestyles. Given the unseemly scenario, 'business as usual' must needs reconsideration and more so, efforts must be taken to make good the situation.

For road infrastructure projects that involve huge resources, large scale of works and typically long periods of development, it may cause serious implications to the environment. While environmental issues are of great concerns, such development that underpins a nation's economy is equally important and necessary. To develop the road projects as well maintaining and preserving the environment, therefore requires the sustainability approach as the ideal way forward. In this regard, governments and project stakeholders alike are under pressure to look for economically feasible, socially viable and environmentally accountable project outcomes (Figure 1).

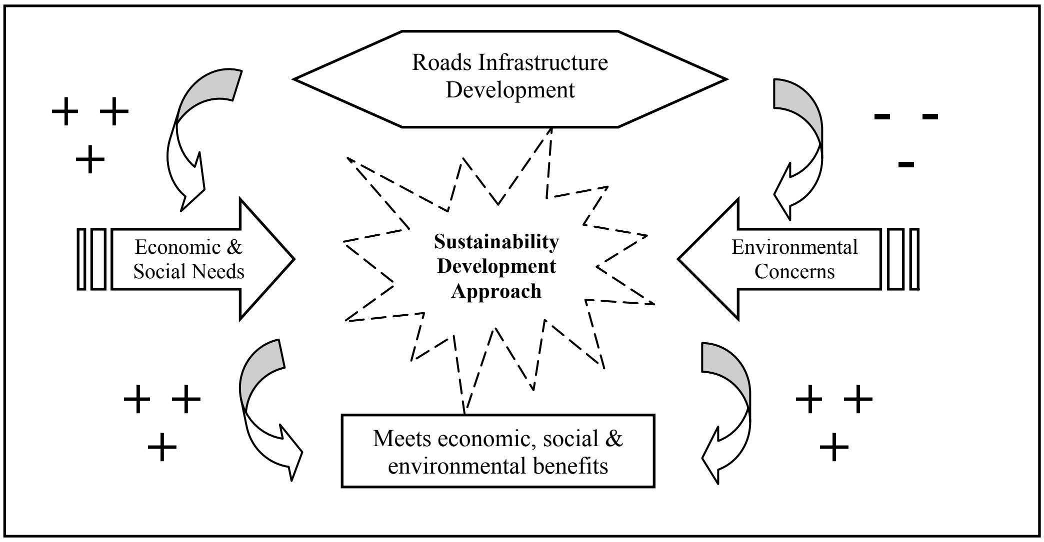

Figure 1: Sustainability Outcomes in Roads Infrastructure Development

Current efforts are often impeded by different interpretation on sustainability agenda by stakeholders involved in these types of projects. As a result, sustainability deliverables at the project level is not often as transparent and achievable, compared to promises in project briefs and designs. In the absence of common understanding among these stakeholders, achieving sustainability outcomes remains as a formidable task.

In the meantime, decision-making for sustainable development in the built environment requires new approaches that are able to integrate and synthesise all the dimensions and different point of views in a holistic matter (Mitchell, 1999; Deakin, et al., 2001). This process requires the application of a suitable operational framework, and an evaluation method or approach that is able to guide stakeholders through the decision-making. However, at the moment, such a structure for organizing the information required in decision-making is not yet available or agreed on among the different disciplines and fields of activities. The lack of an agreed structure that can help decision-making processes achieve greater sustainability is a major problem (Brandon and Lombardi, 2005).

2. A Buoyant Economy and Roads Infrastructure

Australia is currently experiencing an extraordinary economic growth and prosperity, following unprecedented resources boom. The political stability further spurs the confidence of foreign investors and thus, the economy by attracting substantial foreign investment. This has resulted ever-growing economic activities and accordingly, increased car travel and commercial vehicle movements that require greater supply of roads infrastructure. But the existing infrastructure, not only roads and highways, is well below the demand.

The Business Council of Australia has estimated the cost to the national economy due to infrastructure shortage to be about $100 billion, while the Committee for the Economic Development of Australia reported last year that the nation's economic worth could increase by 0.8% if unmet infrastructure needs were realized (Atkins, 2008). In response to the massive infrastructure needs, government has drawn up a priority list of infrastructure projects, worth billions of dollars, and regulatory reforms to speed up the planning, development and delivery of major works.

Roads and highways infrastructure that provides the backbone for Australia's economic growth is critical to this effect. Australia's roads infrastructure has been under constant scrutiny for not being able to sufficiently and efficiently cater for its rising demand. The land freight task is projected to double by 2020 and critical linkages such as the Pacific Highway between Sydney and Brisbane is under-developed, the Hume Highway in NSW is, in many sections, a two lane road (Infrastructure Partnerships Australia, 2007). Besides, Australia has a strong motorcar culture that is commonly believed to offer privacy, comfort and on-demand door to door transport. The geographical widespread and decentralized nature of development such as satellite cities, decentralized employment and housing mean more roads are needed to commute from one place to another. Additionally, many urban roads are old and in need of repair. The development bottle-necks are likely to continue until massive roads infrastructure is in place (Figure 2).

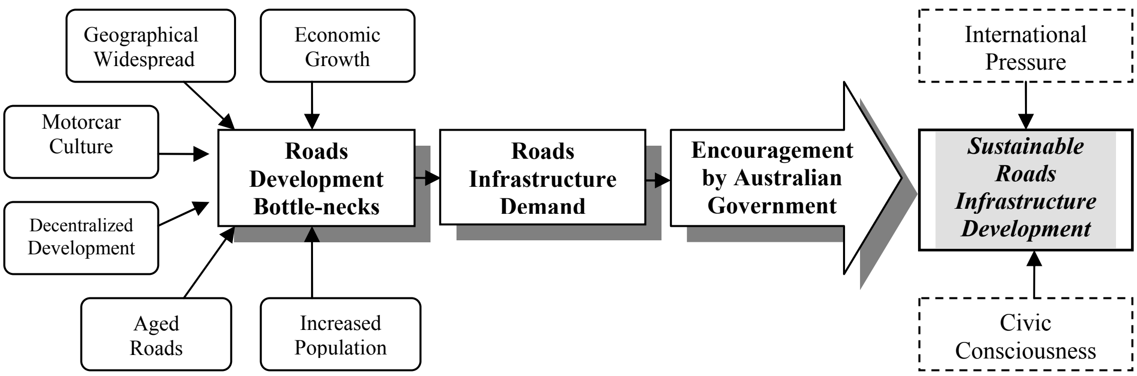

Figure 2: Roads Infrastructure Scenario in Australia

Though providing sufficient roads infrastructure will help ease the bottle-necks and bring about especially the economic benefits, this alone does not ensure a sustainable delivery. A wholesome roads infrastructure development means balance between economic, social and environmental considerations. While from time to time, one of these elements may require additional attention to ensure that balance is achieved; persistent favoring of one element over the others is not sustainable development (Engineers Australia, 2008).

3. Sustainable Road Infrastructure - The Way Forward

Indisputably, sound, well-functioning infrastructure in a country is essential for its sustained economic growth, international competitiveness, public health and overall quality of life (Mirza, 2006). No society has aspired to greatness and a capacity to endure without the ability to build, operate and maintain to a competitive standard of infrastructure required to drive its economy. However, the fact that infrastructure constitutes large built assets on earth and its demand is ever-increasing, the necessary involvement and impact towards global sustainable development efforts is critical and not to be overlooked.

Infrastructure is a key component of Australian nation's capital stock (Allen Consulting Group, 2003). The services from economic infrastructure account for more than 12% of GDP and employ 6.5% of the workforce. Infrastructure services are major intermediate inputs to Australian businesses. In turn, businesses represent some 70% of demand for power, sewerage and water, road and rail transport and postal and communication services. Economic infrastructure also accounts for some 5% of consumer expenditure.

Such facilities (eg. water supply, sanitation, urban roads) contribute to economic production and therefore are, not surprisingly, closely correlated with levels of development (Kessides, 1988). As such, the provision of physical infrastructure must be seen as a prerequisite for the achievement of sustainability of human settlements and of the meeting of basic human needs (Choguill, 1996). Roads and highways construction that often lead to other infrastructure development tops the priority list.

Though concerted efforts by Australian government in developing roads infrastructure, this crucial initiative will be more profitable and meaningful when the development is integrated with the concept of sustainable principles, since it will not only bring about economic gain, but also social and environmental benefits. This calls for a greater need of roads infrastructure sustainability in its overall delivery, especially for new projects.

Drawing from the understanding that sustainable construction can be defined as a construction process which incorporates the basic themes of sustainable development (Parkin, 2000; Chaharbaghi and Willis, 1999; Sage, 1998), sustainable roads infrastructure means the application of basic sustainable principles into roads infrastructure development. In a more concrete term, this means ensuring that our road projects are environmentally, socially and economically sustainable.

4. Sustainable Indicators and Road Infrastructure Development

To achieve sustainable roads infrastructure development, however, it is important to firstly understand how an infrastructure project relates to the principles of sustainability.

According to Dasgupta and Tam (2005), the life stages of any infrastructure project can be divided into (i) pre-project planning, which involves setting up designs, facilitating and mobilizing funds, preparing bills of materials, calculating costs and incorporating short-term and long-tem plans to implement the physical modification; (ii) project implementation, which incorporates the physical work of project implementation and could, for example, include refurbishing the existing structure wherever necessary; and (iii) ongoing operation, which includes the financial management, planning, accountability of responsible authorities, and maintenance of the structure during its design life after starting the intended operation.

Proper design, operation, and management of infrastructure must deal with every facet of its service life, ranging from conception, feasibility studies, design, construction, operation, maintenance, repair and rehabilitation, and finally decommissioning and disposal of the system after it has outlived its useful life (Mirza, 2006).

If an infrastructure project were to be sustainable, every phase of its development must be guided by the principles of sustainable development. A recent research of identifying Key Performance Indicators (KPI) for infrastructure in South Africa construction industry, Ugwu and Haupt (2005) have developed a comprehensive list of key sustainability items and its indicators. These constructs incorporate internationally accepted sustainability metrics, coupled with other performance-based indicators such as health and safety, resource utilization and aspects related to project management.

Based on Ugwu and Haupt's findings, coupled with consultation with the industry, key sustainability indicators specific to road infrastructure projects have been identified which embrace, among others, the issues of environmental concerns, social needs, and economic empowerment, along with health and safety, project management and relationship management (Figure 3). In addition, public governance and community engagement is becoming more appealing in the overall decision-making processes.

In this respect, the infrastructure development process should go through the various stages from conception, to feasibility studies, to design, to construction, to operation, to maintenance and disposal or decommissioning. These processes will be improved by the application of sustainable principles. Consideration must also be given to the differential needs of sub-criteria of each of these key sustainability items. By close monitoring of these processes and checking them against sustainable principles and its indicators, we can thereby ensure and enhance sustainability deliverables in the overall roads infrastructure development.

5. Developing Integrated Decision Model

So far, much of the focus on sustainability has concentrated on buildings and construction processes. Though there is an increased on the studies of urban sustainability in recent time, the methods and decision tools development have focused mainly on buildings; and there is noticeably poor coverage of construction and operation stages of project development (Deakin et al., 2001). Besides, less has been done on infrastructure systems, such as sanitation, transportation, and utilities, which may extend over large geographic spaces, have much wider and more varied potential impacts, and may be harder to understand from a sustainability perspective by multiple stakeholders (Dasgupta and Tam, 2005). To advance this thinking, due attention must also be given to the development of infrastructure sustainability in which this research is aspired to.

At one end, sustainable development efforts mainly remain ideological as seen in macro-level policies and broad-based concepts. They have not explained how they could be translated into practical decision-making during project delivery. The same observation holds for infrastructure projects where the current focus is largely on macro-level policy planning, with little research focusing on the micro level design and construction stage (Ugwu & Haupt, 2005). The situation exacerbates due to multiple stakeholders having different expectations and perceptions towards achieving sustainability in infrastructure projects. On the other end, there were many research initiatives attempting to develop sustainability assessment (Ugwu et al., 2006; Mirza, 2006; Sahely et al., 2005; Ugwu and Haupt, 2005; Dasgupta and Tam, 2005). In between the two, there is a perception-reality gap and mismatch, specifically on how to enhance sustainability deliverables during infrastructure project delivery.

As an exploration on ways of rectifying some of the problems discussed above, a research project is being undertaken at the Queensland University of Technology, Australia. It is aimed at identifying and integrating the different perceptions and priority needs of the stakeholders, along with identifying issues that impact on the gap between sustainability foci and its actual realization at project end level. Filling the niche found in previous studies, this research focuses on the practicality and real-world implementation of sustainability agenda in roads infrastructure projects delivery. This can be achieved based on the common understanding by various stakeholders, with individual view points shared, understood and mutual benefits supported.

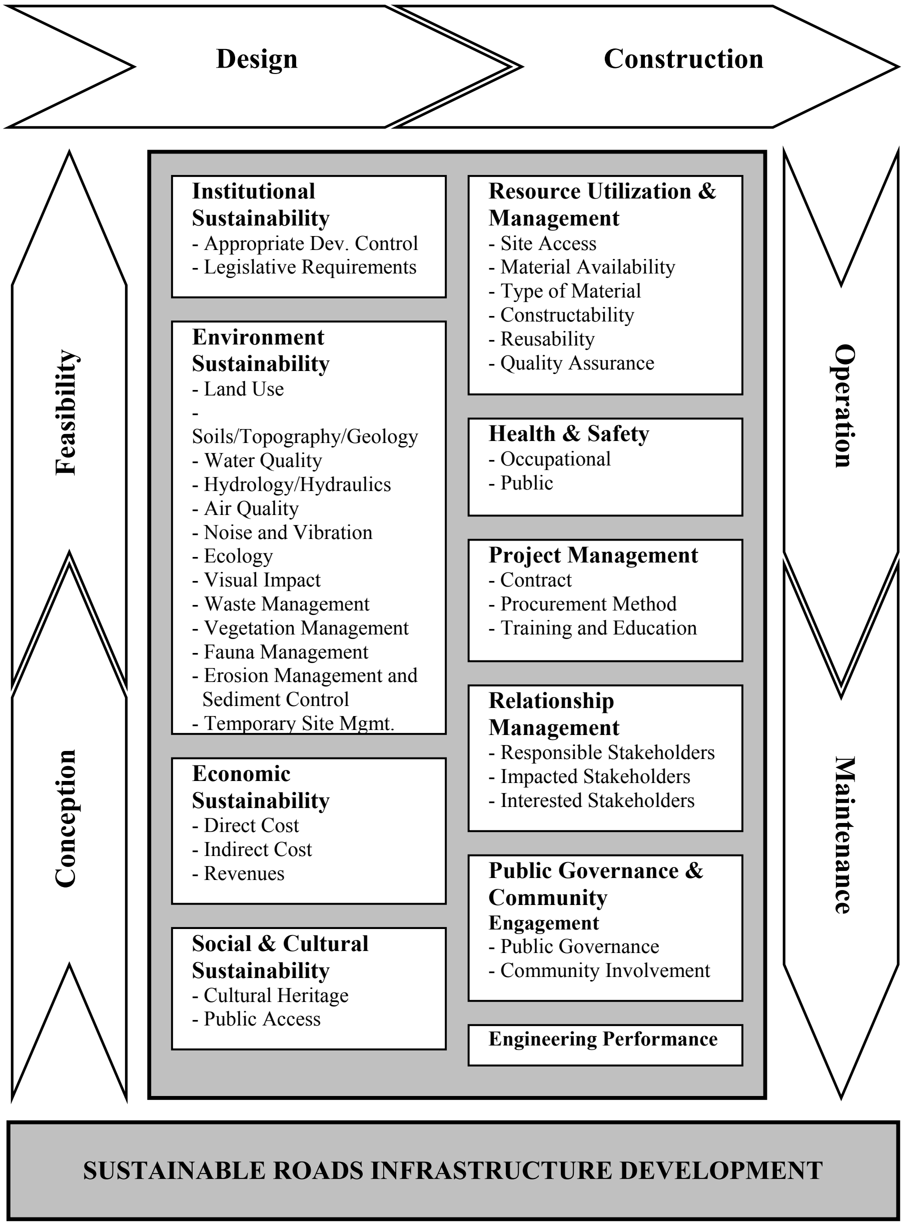

Figure 3: Sustainable Roads Infrastructure Development Processes

The on-going research project employs a combination of face-to-face interviews with industry professionals, a Delphi study among experienced practitioners and academics, and case study techniques to collect expert opinions as well as real-life project information. Figure 4 shows the overall developmental steps and information flow in this project. This acquired primary data acquired will be combined with secondary data from existing government guidelines on environment impact assessment and management, sustainable construction environment and literatures on sustainability research. Both the primary and secondary data will provide triangulation of results covering the perceptions of various stakeholders in infrastructure projects that shall underpin the basis for establishing decision-making process models for sustainable infrastructure projects.

While still at early stages of development, initial industry consultation and feedback has indicated strong interests in this research among stakeholders of road infrastructure projects. The guidelines to be formulated will help promote more integrated decision-making and actions on the implementation of sustainability strategies and foci during the construction project delivery processes. With the different perceptions and views shared, discussed, debated, and with common values and mutual benefits identified, fragmentation on the responsible roles of sustainability will be avoided. Accordingly, this helps facilitate collaboration, consultation and communication among all stakeholders involved in order to achieve consistent decision-making steps throughout roads infrastructure project development life span in Australia.

It is expected that the final framework will be formulated by October 2008 and the complete research results be disseminated to the industry by late 2009.

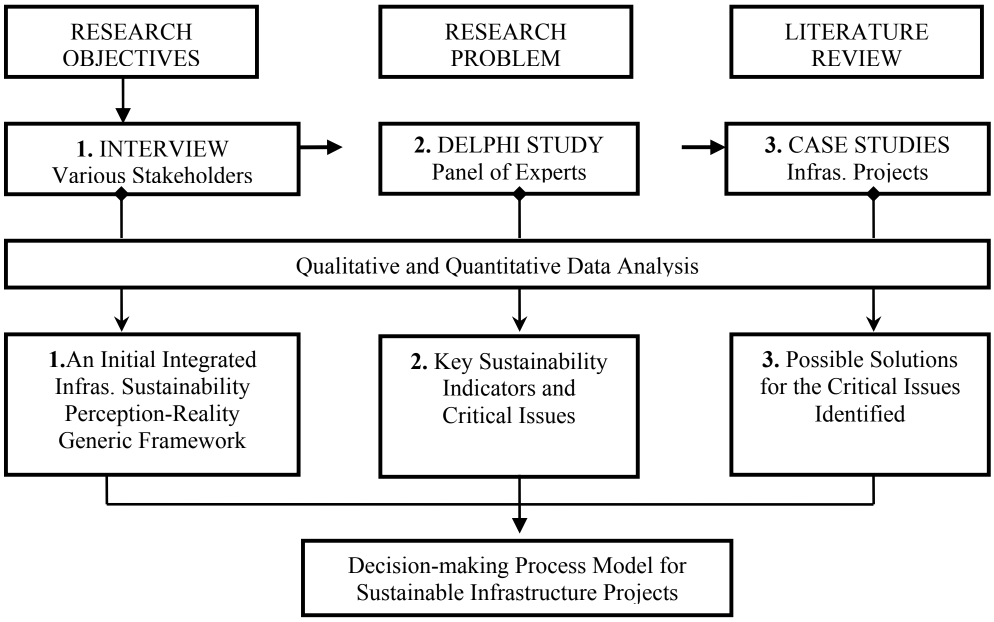

Figure 4: Research Methodology

6. Conclusion

The booming economy of Australia has caused massive bottle-necks in road infrastructure in many states over the recent years. Significant increase in infrastructure budget by three levels of governments indicates the urgency and resolve for Australia to alleviate the problems restricting its' continued growth. As road infrastructure projects requires large amount resources and can cause major environmental impact, achieving sustainability not only in terms of environment friendliness but also through economical and social responsibility becomes a crucial issue.

While sustainability is a logical link to infrastructure projects, past research for this industry sector mainly focused on policies, energy performance and overall assessment methods. As such, little has been done to promote specific applications at project implementation level which is the crux of sustainability initiatives. There is a need to find effective ways to enhance sustainability foci through project delivery, along with the development of policy and assessment methods. The gap must be filled between the industry wide recognition on the importance of sustainability and the lack of measurable sustainability deliverables and eventual realization at project ends. The on-going project, as discussed in this paper, is a positive step towards this direction by integrating different perceptions and priority needs of infrastructure stakeholders, and encapsulating critical issues affecting the sustainability delivery of road infrastructure projects through a framework of systematic approaches to decision-making on the implementation of sustainability strategies.

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ENVIRONMENTAL CONSIDERATIONS IN BUILDING LIFECYCLE MANAGEMENT OF A GENERAL CONTRACTOR IN JAPAN: OBAYASHI CORPORATION

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Keywords: contractor, organization, management, building, lifecycle, feedback, construction, operation

Summary

This paper investigates how a Japanese general contractor, Obayashi Corporation, has worked to reduce environmental loads during building lifecycles.

About 40% of total carbon dioxide emissions in Japan are produced by building-related activities. Reduction of environmental loads throughout a building's whole lifecycle is a challenge for the construction industry. Lifecycle management of a building is categorized into the following phases: Planning, Design, Material production, Construction, Operation, Repair/ Remodeling, and Demolition.

As design-phase measures, Obayashi has utilized its own integrated assessment system for energy saving, and has carried out environmentally conscious design, the results of which have been quantified as environmental protection effects. As construction-phase measures, decreases in both carbon-dioxide emission and waste generation has been achieved during construction. As operation-phase measures, a Building & Energy Management System and an Energy-Conservation Diagnosis have been introduced.

The key issue for total environmental management of buildings is to organically connect knowledge and information of the various phases of building lifecycle in order to achieve effective feedback. The organization of a Japanese general contractor is advantageous for this purpose, if information is exchanged effectively.

1. Introduction

About 40% of total carbon dioxide (CO2) emissions in Japan are produced by building-related activities including construction and operation (Figure 1). Thus, the challenge for the construction industry is to reduce environmental loads generated throughout a building's life. About half of building-related CO2 emissions occur during the building operation phase. Environmental measures taken during the design phase, such as design for energy-saving, are effective in reducing these emissions.

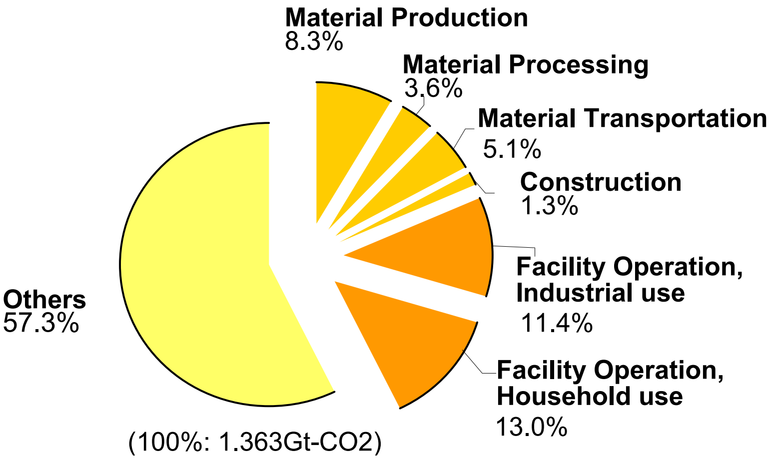

Figure 1 Carbon dioxide emissions related to construction activities estimated form inter-industry relationship in Japan in 1995.

Three organizations of construction industry in Japan, "Japan Federation of Construction Contractors", "Japan Civil Engineering Contractors' Association" and "Building Contractors Society" have established "Voluntary Action Plan on Environment" since 1996 to promote the initiative activities of the organizations' member companies. Periodically, the action plan has been revised and also its results are followed up.

The activities of Obayashi Corporation, a member company of the industry organizations, are introduced in this paper as example cases. Obayashi Corporation is one of the world's leading general contractors, being the 16th biggest global construction company in 2007 and one of the top five in Japan. Its revenue for FYE 2007/3 was ca. $132,282million. This corporation has expertise in carrying out every phase of any construction project and provides services as consultants, architects and engineers. 30% to 40% of buildings the corporation has constructed in the past 20 years or so have been designed by its in-house architects and engineers. This holistic organization is advantageous in achieving environmental goals, because, with effective feedback, lessons learnt from one phase of a building project can be easily utilized in other phases.

Since November 1997, Obayashi Corporation’s corporate activities have been based on the established “Environmental Policy” (Figure 2).

Principles

We at Obayashi Corporation regard our active involvement in environmental matters and continual improvement thereof as an integral part of our management and will take full account of the environmental impact of all our undertakings and activities, continually strive to preserve the environment and contribute to sustainable development of society.

Policies

1. We will fully observe all environmental statutes and ordinances.
2. We will reduce the burden on the environment by saving energy and resources, reducing CO2 emissions, promoting recycling, controlling the generation of waste and toxic chemicals, implementing green purchasing, and preserving natural ecosystems.
3. We will utilize environmental preservation technology and develop more effective forms of this technology.
4. Through our services, we will use our expertise, which has been acquired through our environmental preservation activities, for society.
5. We will make an effort to establish and maintain a rapport with local communities and protect the local environment.
6. Through training programs on environmental issues and publicity, we will fully inform all of our employees of this environmental policy and improve their awareness of environmental preservation.
7. We will encourage our affiliated companies, subcontractors and suppliers to take active steps toward environmental preservation and will support their efforts.

In order to promote our policy on an ongoing basis, we will establish, execute and maintain environmental preservation mechanisms.

Figure 2 “Environmental Policy” of Obayashi Corporation, 29th June, 2005

Lifecycle management of building is categorized into the following phases: Planning/Design, Construction, Operation, Repair/ Remodeling, and Demolition (Figure 3)

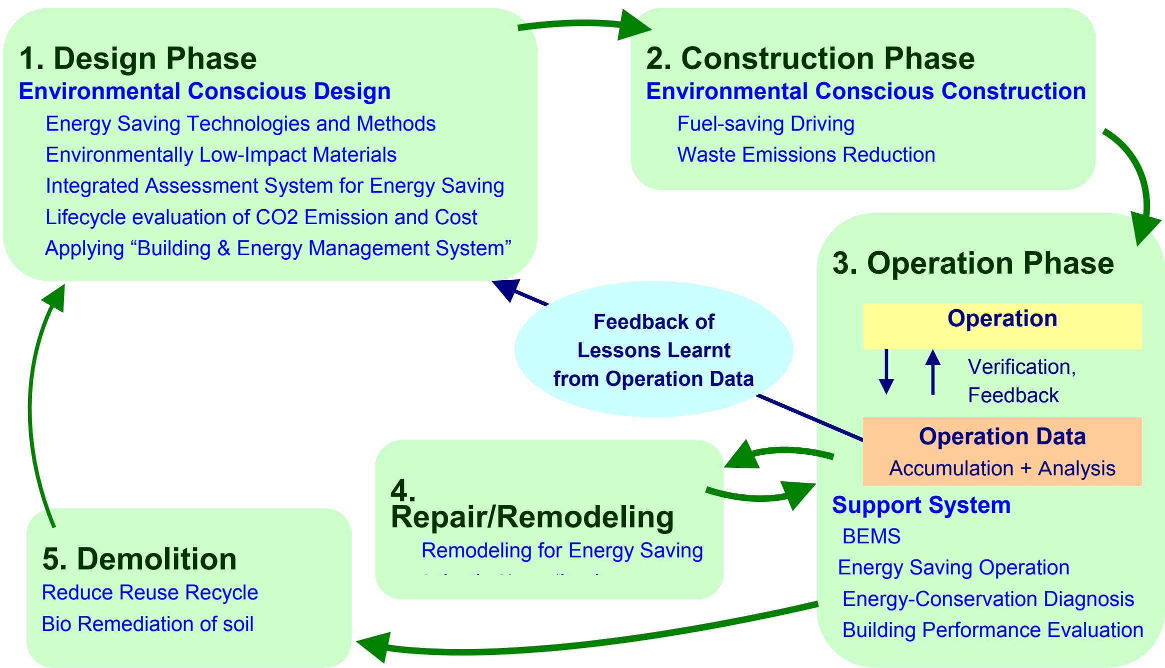

Figure 3 Measures for environmental load reduction throughout a building’s lifecycle

Some of the practices in the Design, Construction and Operation phases are introduced in the next part.

2. Countermeasures in Design Phase

A target in building design should be reduced loads and improved quality of the built-environment. For this purpose, Obayashi's design team makes its best endeavors to achieve environmental care over the building's whole lifecycle.

2.1 Integrated Assessment System for Energy Saving "Eco-navi"

Obayashi has developed and applied green technologies that are adaptable to the individual climates and characteristics of each project. Development and application of individual environmental technologies are important. However, economic and effective integration and application of those technologies are the key challenge in the design phase.

For this purpose, Obayashi utilizes its own integrated assessment system for energy saving in its decision making in the design phase. A computer program helps to check the priority of economical energy saving methods in the Pre-Design phase. Combined techniques or methods are effective in accomplishing significant energy reduction. An Integrated Vector Diagram helps architects and engineers to identify the most efficient combination of techniques and methods to satisfy clients' environmental and economical requirements. "Eco-navi" is a program that quickly shows a Vector Diagram (Figure 5). It also displays the energy saving effect as LCC (Life Cycle Cost) or LCCO2 (Life Cycle carbon-dioxide emission).

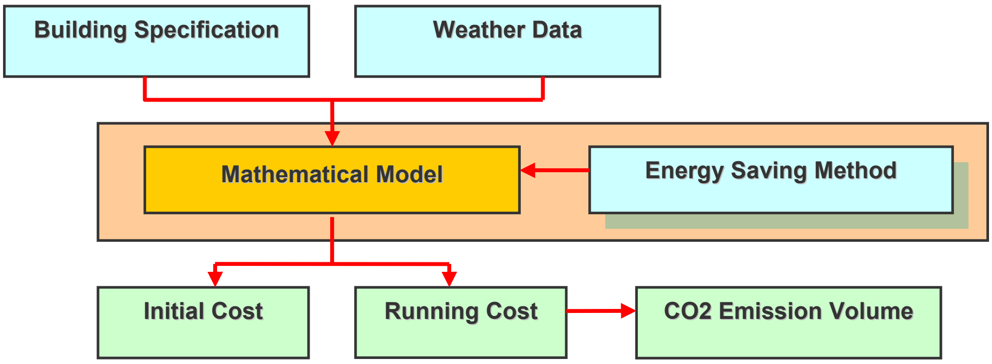

Figure 4 Information Flow of "Eco-navi"

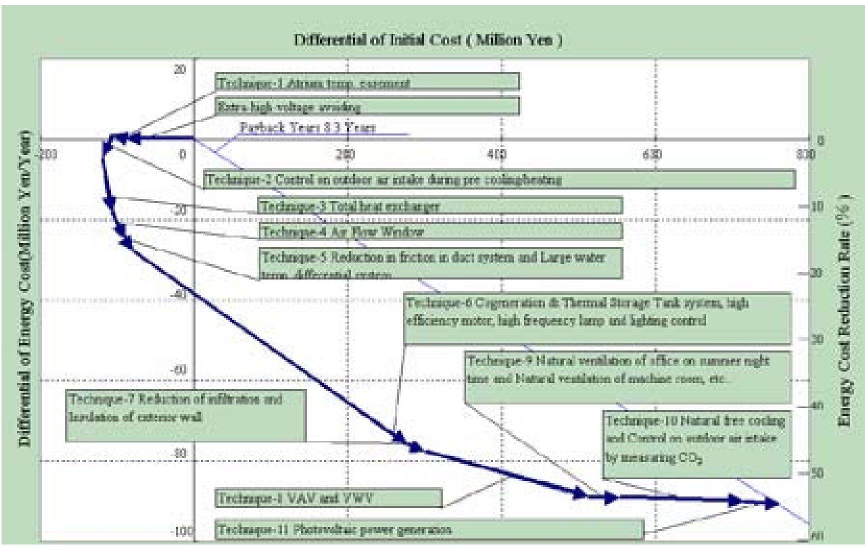

Figure 5 A Vector Diagram for Thermal Economics

2.2 Quantification of Effects by Environmentally Conscious Design

Obayashi's Design Division carries out environmentally conscious design. It also quantifies the environmental protection effects of resource-saving and energy-saving technologies. Such quantification includes low-environmental-impact materials used, energy savings, resource reduction, incremental green area, etc. For example, the amount of CO2 emissions reduced through energy saving during the operation of environmentally-conscious buildings was 19,268 t-CO2/year in 2006, down 10.2% in comparison with 1990's standard design for typical buildings. In the 2006 term, the LCCO2 reduction rate was 10.8%, assuming a 35-year lifespan for buildings utilizing environmentally-conscious-design.

Table 1 CO_2 Emission Reductions Achieved through Environmentally-Conscious Design (In comparison with 1990 standard design)

		2002	2003	2004	2005	2006
	Year	2002	2003	2004	2005	2006
Subject	No. of designs	105	111	131	127	122
	Total floor area (1,000m^2)	968	1,071	1,550	1,980	1,295
Environmental factors taken into account	**$LCCO_2$ reduction rate (%)**	**9.3**	**11.0**	**9.2**	**8.8**	**10.8**
	Reduction in CO_2 emissions achieved through					
	energy-conserving design (t-CO_2/yr)	11,314	14,808	18,493	23,178	19,268
	energy-conserving design per unit floor area (kg-CO_2/yr·m^2)	11.7	13.8	11.9	11.7	14.9
	green purchasing (t-CO_2)	10,340	26,054	38,840	29,100	31,588
	green purchasing per unit floor area (kg-CO_2/m^2)	10.7	24.3	25.1	14.7	24.4
	resource-conservation (t-CO_2)	8,267	22,939	14,028	26,654	11,000
	resource-conservation per unit floor area (kg-CO_2/m^2)	8.5	21.4	9.1	13.5	8.5

3. Countermeasures in Construction Phase

As construction-phase measures, Obayashi has been tackling the decrease in both carbon-dioxide emission and waste generation at its construction sites.

3.1 Reducing Carbon-Dioxide Emissions at Construction Sites

Obayashi successfully decreased carbon-dioxide emissions at its construction sites in 2006 by 30% compared with 1990, using fuel-saving driving techniques, etc. The main cause of carbon-dioxide emissions at construction sites is diesel fuel and electricity. The former is consumed by construction machinery and transport vehicles. The latter is for lifting materials and implementing interior work. Because the former makes up about 70% of the whole, a large part of the efforts to realize eco-friendly construction are directed towards promoting fuel saving for construction machinery/transport vehicles and stopping idling. The Carbon-Dioxide emitted in 2006 was 113,000t less than in 1990 (30% reduction). Within the next few years, Obayashi will have reached its 2010 target.

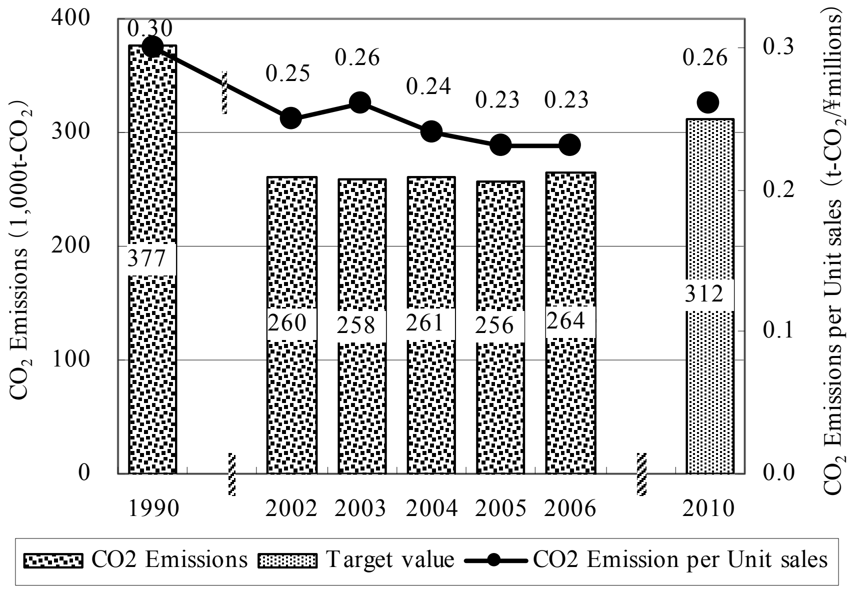

Figure 6 CO_2 Emission at Construction Site

3.2 Industrial Waste Disposal Emissions in Construction Phase

In Japan, 18% of all industrial wastes and 24% of the final disposal quantities are produced by construction activities. Since 2005, Obayashi has aimed for zero-emissions at all its construction sites by controlling waste and keeping the amount generated as close to zero as possible. Decrease in waste material and reuse of resources resulted in a reduction in the final disposal rate from 13.6% in 2000 to 4.2% in 2006.

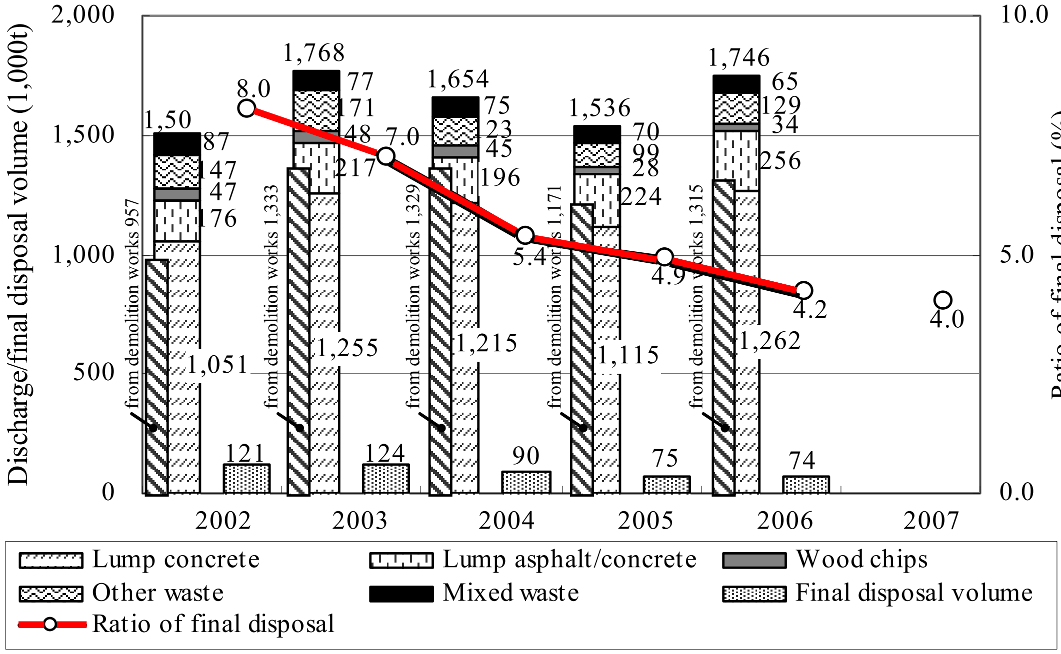

Figure 7 Changes in Construction Waste Discharge/ Final Disposal Amount (Excluding Sludge)

4. Countermeasures in Operation Phase

In the operation phase, it is important to achieve effective energy-saving performance. In addition, it is desirable that the knowledge obtained during operation is reflected in improvement of the particular building and improved design of future buildings. After delivering the building, in the building operation phase, Obayashi Corporation offers several services which are connected to environmental measures. For example, services for BEMS (Building & Energy Management System) and “Energy-saving diagnosis” are provided.

4.1 The Introduction and Application of BEMS (Building & Energy Management System)

Management for optimized building operation using only the BAS (Building Automation System) function is insufficient. Acquisition and various analyses of continuous energy data are necessary to optimize the building operation to realize effective energy-saving performance.

Obayashi Corporation has developed BEMS, named "BILCON- Σ", and has applied it to many projects. BILCON- Σ enables accumulation and analysis of operational data, in order to actualize comfort and energy conservation. “BILCON-Σ” consists of BMS (Building Management System) and CAFM (Computer Aided Facility Management). This BMS has a data acquisition system and a data analysis system. The BMS is connected directly with the BAS (Building Automation System). Using the BMS, operational data such as electricity consumption and interior temperature etc. are automatically collected over a long period from each mechanical &electrical system and accumulated in the database.

Several analysis programs calculate the collected data and evaluate the energy-saving management and efficient operation of the equipment. "BILCON-Σ" has been applied to 170 completed buildings designed by the Obayashi design division, and it is being applied to several selected projects. Obayashi not only delivers the system, but also provides building operation services using "BILCON-Σ" or operational consultancy services based on the data and analysis of "BILCON-Σ", at clients’ request. If Obayashi are entrusted with such management related services, feedback of useful information based on "BILCON-Σ" operation data can be executed effectively in its design division.

For improvement of environmental performance, the challenge is how to activate the feedback cycle from this operation phase to other building design phases.

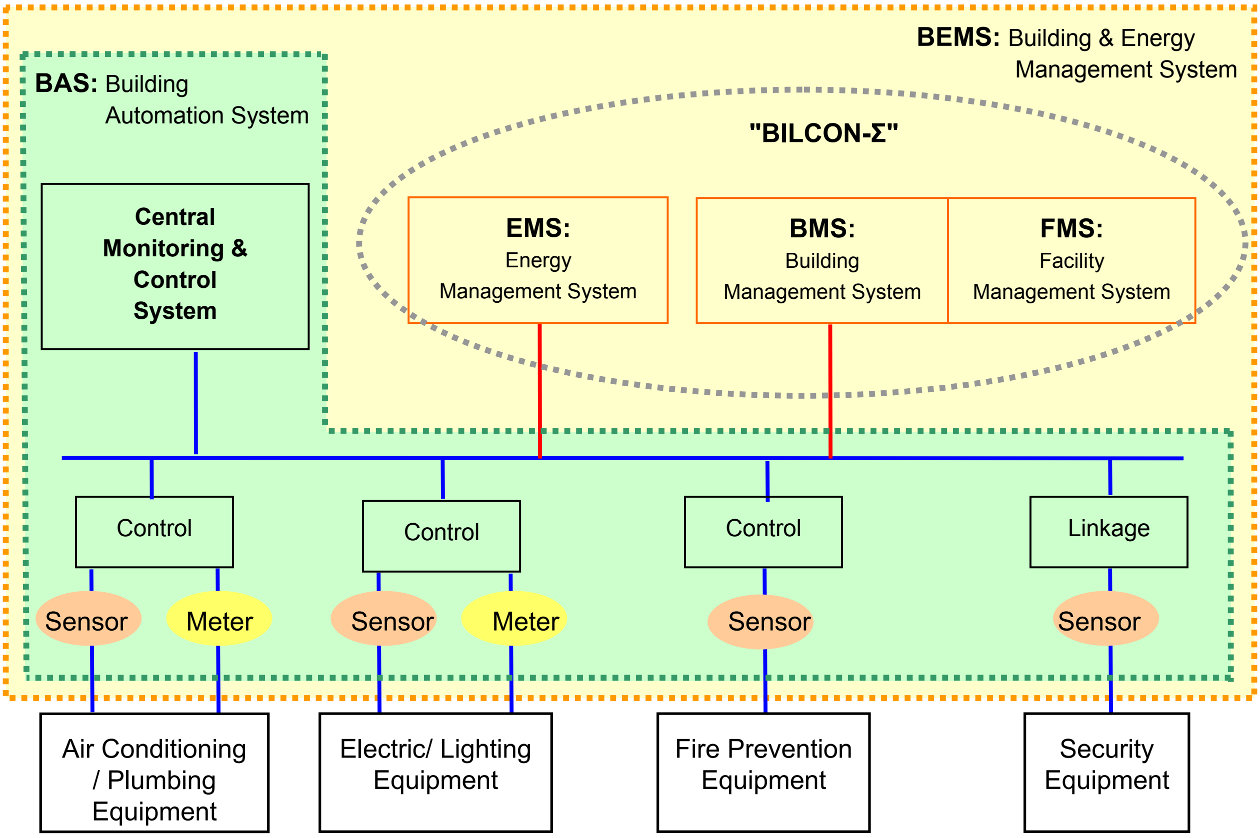

Figure 8 Diagram of BEMS (Building & Energy Management System)

4.2 Energy-Conservation Diagnosis

Obayashi has been executing services of "Energy-conservation diagnosis" and Repair/Remodeling for Energy conservation. "Energy-conservation diagnosis" enables verification and improvement of energy usage.

The service for "Energy conservation tuning," which is adjustment to the change of utilization conditions, is also provided to propel energy conservation.

5. Conclusion

Obayashi has expertise in carrying out every phase of a building project and develops feedback between phases. The most important issue at present is how to increase the acquisition of operational data for feedback to the design phase.

Because Sustainable Design is a holistic work, integrated and flexible organization is important to achieve it. Such organization can comprise not only a network of special companies or professionals, but also a single corporation. The key issue for total environmental management of buildings is that knowledge and information of the various phases of building lifecycle must be connected organically in order to execute the feedback effectively. For this purpose, an organization in which information can be exchanged easily is advantageous. Traditionally, it is characteristic of general contractors in Japan that they provide not only construction but also various building services for each phase of its lifecycle. The organization of such general contractors is advantageous in fulfilling environmental protection if the information and lessons learnt from the building phase can be utilized in other phases using effective feedback.
It is desirable for a general contractor that provides total services during building lifecycle to utilize its advantageous potential for environmental measures.

When services or works of each phase are executed by plural special companies, it is also desirable to have an organic network of environmental information exchange between professionals or companies for various phases of building lifecycle.

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COMPETITIVE COOPERATION IN SWEDISH PROJECTS FOR SUSTAINABLE BUILDING

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Keywords: cooperation, competition, increased sustainability, innovation, measurements, resilience

Summary

The notion that we are becoming more competitive and individualistic is diffused in today Sweden, argued to be a positive or negative outcome of the social, political and economical changes of the last decades. So is also in the construction sector. The call for competitive building outcomes has driven many technical innovations while the lack of cooperation is claimed to be the principal cause of non-sustainable development. Hence the dichotomy must be verified and our understanding of it must become sharper.

Challenged by the climate change societies may compete about sustainable results, but competing to be sustainable has a twofold outcome. We may compete in order to reach high performance measurable solutions in one building and we may compete to spread good enough sustainable integrated solutions throughout the environment. The both seem to be necessary, the first attracting the traditional innovation paradigm, measured in quantities, while the second risks staying in the shadow of technological progress. We have to worry about this and develop new integrated theories.

Emerging patterns of *competitive cooperation* are observed in evolving projects for sustainable buildings in a local Swedish reality, within a study (Demo-04) focused on giving guidelines for the implementation of sustainable building goals. A stakeholder participatory approach reinforces the need of a better understanding of the integrated sector-specific innovations as they all affect the design and construction processes. They are questioning the way people make decisions in everyday work and address a corporate integrated and shared responsibility. Innovations in building can be inconsistent with the concepts of sustainability when isolated from shared and clear sustainability goals. Still sustainable innovations emerge within a framework of coordinated design between stakeholders and new profiles of action in projects. Transparency is the common denominator of both cooperative and competitive behaviours and guarantees the possibility of resilience of the chosen social and technological paths.

1. Introduction

Construction work is collaborative. To undertake a construction work requires the collaboration of a number of different firms and a wide range of skills and specialists: architectural and design practices, general contractors, consultant engineers, subcontractors, fabricators, manufacturers, and suppliers. The challenges of the climate change and the global limitation of resources are changing the global rules on which modern construction work has been based, and at the same time call for increased corporate responsibility for managing the adaptive capacity of local built environments towards sustainable development.

The change emerges in Sweden as an increased awareness about the energy and matter flows in buildings and can be considered an evolution of three decades of implementation of energy efficiency in building following the ecological modernisation (Fudge et al 2002) implemented in the country during the same period. Sector-specific innovations are intertwined with sustainability goals.

1.1 Integrated sector-specific innovations towards sustainable energy efficiency

The overall technological innovation going on in Sweden is centred on energy concepts and seems to enter the sector of construction through approaching different types of innovations found within the different building activities. From the production of components to the systemic nature of the whole of the house, through the combined activities of designers, builders, construction firms, regulatory activity and construction-related research, a real technological change seems to be taking form.

For ten years ago Gann et al (1998), while addressing the impact of regulations on innovations, presented an analysis of the many factors which are influencing innovations which they noticed were becoming more and more performance-based so that regulations increasingly depended on what current practice was able to perform. Four integrated types of innovations were found in building activities: 1) *product 2) process 3) configurational and 4) system* innovations (Gann et al 1998). It is important to keep these aspects in mind when trying to understand the kind of change specifically going on in Sweden.

The *product innovation* came first, mostly conditioned by the push of the top-down managed ecological modernisation (Fudge et al, 2001; Jensen et al, 2008) which conditioned the R&D activities carried out by material and component producers. Many are the claims that these manufacturers carry out the majority of construction-related research. "They develop products aimed ultimately at improving the performance of buildings to the benefit of end-users" (Gann et al 1998). It is the case of the new window generations with low U-values, of solar heating- and energy technologies, of heat exchangers and heat pumps, of new insulating materials, just to name some.

A process innovation, such as the ways of assembling buildings or installing components, has resulted in an improvement of the way in which buildings are designed and constructed on the part of designers and builders. This may be the most diversified part of the innovation process because it is linked to local contexts of implementation. In the case of the new quite diffused performance-based requirements this is the activity which is mostly developing, as it causes an innovation of roles and responsibilities among the actors involved. As site monitoring of performances pose cost and time-limitations not affordable within current practice, pre-production energy simulation models are substituting more and more postproduction tests. The design process is very affected by this.

The configurational innovation surely depends on the abovementioned product and process innovations as it addresses the way in which "existing components are combined in new ways to provide improved performance characteristics" (Gann et al 1998). It can be observed in the long way towards healthier and more secure buildings which successfully has lead towards energy efficiency in building solutions and increased quality of requirements. The evolution from the solar house approaches of the 1970-80s to the low-energy-house concepts of the early 1990s constitutes the headlines of this configurational innovation.

Finally a *systemic innovation* is affecting the design and construction of buildings with the spreading of passive house concepts. "This occurs when change in one component or subsystem cannot be introduced without altering other parts because of the ways the whole is integrated and works together" (Gann et al 1998). The configurational and systemic aspects of the ongoing change are of interest for this study as they seem to give some guidelines about possible future directions. They affect not only the final product but also the process of becoming of the project.

1.2 What is sustainable?

We, a group of researchers from the Department of Architecture at Chalmers University of Technology in Göteborg, Sweden, have been working during the last three years on the research programme Demo-04, studying a group of six projects with declared environmental-friendly ambitions (Eden et al, 2005). All the projects were started in autumn 2004 and evolved differently in time while influencing each other (Rubino and Eden, 2007). Observing aspects of sustainable technological innovations in the specific dimension of experiences in the local context, the question about what is to be considered sustainable and what is not has often come to the fore. In the building community trust is traditionally given to studies which by means of measures are able to predict future behaviours. The belief that a unique solution will substitute all existing solutions is also rooted and the "best" solutions are experimental, demonstrative projects, driven by local "best practice" but developed independently of the normal context of current practice. The initial conditions of the projects are stated from an abstract set of ideal parameters and their results are stated from the set of these initial conditions and often self-referential.

We assume that sustainable building is a concern of the real world and that only when building projects are realized within current practice and meet the complexities of society will they be interesting as sustainable. Experimental projects are contexts for learning but become sustainable in the impact with real context. We have then been looking for a different kind of demonstration projects as contexts of change, able to implement the complex goals of sustainable building (Femenías, 2004; Eden et al 2005; Rubino and Eden, 2006; Rubino et al, 2007; Rubino, 2007). Furthermore, we are observing an unexpected innovation rate due to the new energy efficiency goals of this particular phase and wonder if the struggle for the best results constitutes a sustainable pathway. The closure around the solutions given by the *passive house* techniques seems to lock practitioners from different technical backgrounds by setting the issues of debate on sure measurable levels, in a moment of big uncertainty and disagreement. Measurements, true controllable solutions, profitability and a brave use of simulation-tools are paramount in the Swedish debate but risk to simplify the issues of a wider sustainable debate. As we are looking for sustainable pathways, we must be critical as to the sustainability of these solutions.

Are co-operational behaviours less important than optimized kWh for heating? Is the diversity of solutions not as much important for the transition to sustainable development as an isolated object with high energy efficiency performance?

1.3 Is there a measure for sustainability performance?

Long-term sustainability goals make the context of action of construction work much more complex than before. Consequently both research and practice easily renounce to follow these both qualitative and quantitative paths, and go back to the linear simplifications of predictable and measurable outcomes starting a battle of thresholds. The actual energy efficiency trends are often implementations of the energy efficiency debate from the 1970s. The same technical actors are working on them, sure of having known the true solutions leading to sustainable change. Focusing on the *environmental dimension* of sustainability the characteristics of sustainable building become an issue of *performance*. Hence, a methodological problem arises as we do not find any absolute or agreed upon measure of sustainability performance. This leads us automatically to work in the amorphous field of the many definitions of sustainability (Williams and Lindsay, 2007) forced to set up a measuring scale which goes from "slightly better than regular standards" over to "very sustainable". On this scale the "zero-emission" buildings are the "most sustainable" and the housing for, for example, climate-refugees are not regarded at all. Still the performance of the building stock has never been assessed.

In order to cope with these questions we propose an analytical framework resulting from the observations done in the Demo-04 study. It is important to underline that the many stakeholders involved are far from having reached any agreement about how the big global questions should be managed. Hence, the emerging issues of resources interdependencies lead the sustainability debate more and more towards cooperative societal problem solving mechanisms. Further, the traditional forms of the state being the sole regulator seem to be left behind. Making corporations answerable for their actions presents difficulties but networks of actors can accomplish consequences more than centralized authority. This does not mean to substitute directive-based regulations. Companies are more and more compelled to show verifiable accountability and enhanced transparency by a collective pressure and their management and performances must be evaluated within a long-term perspective. Simultaneous efforts are under way in multiple potential solutions, but the process is split among stakeholders and projects with heterogeneous background. Many current solutions have true sustainable ambitions but are not the most efficient: they are selected by small events, by the social settings of project-teams, by their access to components, and last but not least by the individual responsibility of each representative of the construction community, culturally representing the historical path taken by a local system. A feedback system for these efforts seems to be lacking.

Section 2 presents the proposed analytical and methodological framework. Section 3 addresses some inconsistencies of the traditional dichotomy between competition and cooperation. The findings of the study are presented as descriptions of emerging profiles of action along the design process in section 4 followed by a discussion about the consequences of these emerging patterns on the rationalities used in sustainable building environments.

2. The analytical framework

"We can no longer allow the attraction of having a simple, elegant, and, above all, understandable theory trump the attraction of having a theory that is difficult to understand in its entirety but better captures the workings of the real world" (Anderies et al, 2006).

The effort to be made in research is to rationalize the interplay between change and persistence, between the unpredictable and the predictable. It means that there is always an existing system where persistency is rooted but perturbed.

The adaptive capacity of a system is basically grounded on diversity, genetic diversity, biological diversity and heterogeneity of landscapes. In social systems "the existence of institutions and networks that learn and store knowledge and experience, create flexibility in problem solving and balance power among interest groups play an important role in adaptive capacity" (Walker et al 2006). Systems with high adaptive capacity are able to re-configure themselves without significant declines in crucial functions in relation to primary productivity cycles and social relations and economic prosperity.

Folke et al (2004) identify and expand on four critical factors that interact across temporal and spatial scales and that seams to be required for dealing with natural resource dynamics during periods of change and reorganisation:

1. learning to live with change and uncertainties;
2. nurturing diversity for resilience;
3. combining different types of knowledge for learning and
4. creating opportunities for self-organisation towards social-ecological sustainability.

2.1 A stakeholder approach

We assumed that the transformations of the built environment affect the resilience of the local living system as a whole in the same way that changes affect the resilience of all ecosystems (Folke et al 2004; Walker et al, 2006). The introduction of a resilience analysis of human built environments proposed a pragmatic perspective through which the wide definitions of sustainability could get meaning and gave sense to the methodological guidelines of the research study.

We proceeded then from the assumption that social and technological phenomena can be explained as the outcome of interactions among actors. Governing the built environment towards sustainability improvements is here seen as a collaborative process which involves all stakeholders, where "a stakeholder is any group or individual, who can affect or is affected by the achievements of the organization's objectives" (Kuhndt et al, 2004).

Stakeholders exist both internally and externally to the built environment. From the perspective of the building sector designers, builders, clients, employees and workers are the internal stakeholders, while end-users communities, public authorities, shareholders, financial institutions, the media can be counted among external stakeholders. The very peculiar fact in the building sector is that internal stakeholders at the same time can be external stakeholders belonging as individuals to different societal groups and networks.

2.2 Shaping a multi-actor arena for the heterogeneous engineering of SB

No study will ever be able to identify and intentionally influence the "painstaking arrangement of the myriad of human and non-human elements" interacting in technological change (Harty, 2005). Hence change is said to occur with intensification of interactions and links between elements. So we gathered a number of firms involved in six newly started projects and invited their representatives to participate in an "arena" in order to share experiences and difficulties when working with the resource and environmental performance of buildings.

A heterogeneous group of between 15 and 60 persons, representing both the "best" and the current practice of design, management, consulting and construction in town, was invited regularly, during two years, to focus-group meetings, seminars and smaller conferences. These internal stakeholders came together in order to meet academic researchers, experts, representatives from associations and stakeholder's organisations and end-users of previous completed demonstration projects. Mostly they met each other in unusual constellations and from a new perspective. During the same time the process of evolution of the projects was observed and totally 14 individuals were interviewed. It was important to know how different stakeholders use their resources and capabilities and what goals they pursue when a long-term sustainability perspective is introduced in their usual work.

3. Cooperation and competition

The chosen approach focused on human interactions and consequently on how these are affected by non-human elements (artefacts, skills, tools, pictures, measurements).

To begin with, many generalisations are in use concerning competition and cooperation. The notion that we are becoming more competitive and individualistic is diffused in today Sweden, argued to be a positive or negative outcome of the social, political and economical change of the last decades. So is the case also in the construction sector. The call for competitive building outcomes has driven management efforts at all levels and at the same time the lack of cooperation is claimed to be the principal cause of all non-sustainable development. Ideological divorces argue that competition might not admit cooperation and cooperation might not admit competition.

Hence, as sustainability is a concern for the real world, the understanding of this dichotomy must become sharper.

It can generally be assumed that the myths about competition are many and that we are not so aware of co-operative behaviours. Competition associates directly to outcomes, indeed both positive and negative as competition normally assumes winners and losers. Cooperation is a more delicate issue than competition. From the *competition point of view* cooperation is automatically interpreted as the weak characteristic of actions made by losers in order to survive. Ideologies play a fundamental role in these questions and ideological discussions often only results in sharpened initial convictions. They are usually not the way to get a better understanding of what is true and what is not.

The direct observation of ongoing change can help on the way to get a sharper picture of how competition and cooperation emerge in human action. The micro details of "human free interaction of an ordinary everyday kind" have been suspended, in terms of understanding, in order to conceptualise a macro system of generalizations approached as a natural phenomena in science. This move "encourages us to miss the essential feature of human action, namely its cooperative nature in the living present" (Shaw, 2000).

If the lack of cooperation seems to be the origin of so much non-sustainability, we have also been unused to focus on it at all. It can be difficult to accept its dynamic role showing up with thousand different faces. Project-teams are what we are interested of within a sector that has characterized its managerial trends by competitive attributes. Cooperation becomes competitive by its outcome for the local community and strengthens the bound in new contents and ever new sustainability solutions.

4. Pathways towards sustainable energy

Energy efficiency still must demonstrate its cost efficiency before it is implemented. This never happens to this level of precision for other innovations to be implemented in building enterprises. In fact while implementing innovative processes or innovative components do not require more than normal managerial spirit of competition parallel with normal paradoxes of presumed control over the predicted outcomes, resource and energy efficiency must demonstrate its profitability in detail. The complexity of the issues introduced in the projects goals cannot still be summarized in a few innovative moves easy to calculate in comparison with previous technologies. The issues introduced are concerned with a *systemic innovation* as well as a *design process innovation*, integrating a series of new components which substitute the core of the current technical support for heating/cooling and warm water supply as well as the traditional building materials used in the external walls and the type of windows used. A c*onfigurational innovation* follows and affects the process of shaping the building which is then more emerging from the interactions of the multitude of parameters involved than from "human intentionality".

4.1 Messages about new processes.

From the interviews we received messages about the elements of a new process:

- The awareness about energy and material flows in building activities give *legitimacy* for the overall sense of environmental and social responsibility of individuals.
- Working with energy efficiency goals is equal with working with environmental goals. "There is much *environment* in the *energy* we use today" (interview, march 2005)
- They adapt existing capabilities.
- The new projects present the necessity of new structures of co-operation
- Transparency during the whole design and construction process is fundamental.
- Competition is necessary, at a certain point, to spread and optimize the new solutions.

Energy efficiency has in Sweden continuity with the past. Many of the older informants talked about a change of perspective: *"There is much more environment in working with energy today. But it is easier to calculate on energy than on environment. You can both minimize it and directly control the results. All the rest, the choice of materials, upstream materials, emissions, the material-flows in future refurbishment as possibility to renew, recycle or deposit components are too difficult. A client assumes not to be able to calculate the costs for this over 40-50 years. So it is also more complex. When we began to work with energy efficiency during the 1970s (at the time of the first oil-crisis) it was very much a question of making existing technical services more efficient. We had under a period of ten years filled new buildings (think that one million apartments were built during that decade) with over-dimensioned installations. We were only looking at the service effect trusting in a never ending access to Swedish energy sources (water power plants, some new nuclear power plants)"* (Interview march 2005)

"Today we answer personally for the new we introduce in projects. At that time (1980s) research was financed directly from the BFR (Byggforsknings Rådet, i.e. the national building research trust) and the office received a 10-20 % research subvention only for the energy side of a project. Each project was later published into very simple reports which gave reference objects to be developed and knowledge transfer in the sector. Each report was further sent to all firms and consultants. Today we learn about the new only directly working in projects. In projects we meet lots of people; we get knowings about what and how others do, and what is going on even outside the local context. At least we engineers we work very locally. It is different for architects. They have the possibility to win a competition somewhere else. But then they have to trust a local consulting firm if they want the building to be built" (ibid 2005).

As a consultant you are alone in your choices. "We work with Environmental Control Program. We have to check all components as to project requirements. Then you access the homepage of the manufacturers and you control by yourself, but indeed you do not have the means to control these issues and you just follow some guidelines. At the end you just put together pieces, while you should work at least with assemblies of pieces, with connected solutions, where pieces are already put together" (interview 2005).

"When nobody knows better about how to solve the problem, you begin to play with open card and the goal is reached together, like sharing a cake which cannot be bigger than that and is made of each single kWh/m2 yr. We discovered lots of energy thieves we never thought about before. In large extreme low energy buildings, the part of energy going to the artificial lighting of the common vertical communication, elevators, common services and garages constitutes the largest part of the bought primary energy in the building. You suddenly realize that many efforts have been centred on heating and warm water production issues and that there is so much that can be done for reducing the need of primary energy" (interview 2005).

They also tell us about:

- a different co-operative behaviour searching for common solutions. A new stimulating sense of co-discovery and learning. The need of integrating specialists early in the design process
- the need of precision, exactness and correctness during the design of the details

- the need of follow-ups on the construction phase. Details are important on paper and in reality
- an unusual openness in spreading knowing of problems and practical solutions encountered already during the design process, diffusing temporary results and networking across specialist groups
- a competitive behaviour between companies increases after a first period of co-discovery. Each single organisation is maturing own internal demo-projects in order to learn, adapt the new to existing organizational capabilities and even in order to reach better solutions and stress the thresholds

4.2 Transformed energy balance calculation. Different energy efficiency solutions

The use of the energy-balance-calculation tool is finally diffused among Building Services Engineers. For just two years ago many told us about the requirement written in the project programme for the use of this tool but nobody saw the meaning of using it.

The projects object of this study where in almost all cases started with energy efficiency goals among other goals concerning the total environmental performance or a sustainable future vision.

Even if the process of innovation of buildings in Sweden shows a clear tendency to energy efficiency solutions, arrived at by the use of new materials and components, what is new in the new energy efficiency trend is a changed use of the energy balance calculation. 2005 some of the interviewees told about projects where they had been told to calculate the energy balance but they did not see any meaning in doing that. Currently three years later the energy balance calculation is paramount. The use of this tool showed a need for a clear definition of the energy goal of the project.

The EBC is the real interactive core of the new projects, able from a very beginning to connect most of the part of the building to each other towards a declared minimal amount of energy needed to heat interiors and to supply warm water. It integrates the U-values of different components of the climate shell with the degree of tightness and with the dimensions of the ventilation system along with the speed of the air exchange. The architect’s layout changes continuously, adjusting the size of windows, of balconies, of sunshades and also of solar heating or floor heating. A clear tendency to a paramount optimization of building functions has astonished more than one of the agents involved in the projects. Efficiency becomes more when it proposes a synergy of effects just within the single building.

4.3 LCC-calculations

Life Cycle Cost calculation tools have been basic in some of the first demonstration-projects of this kind. Taking the first steps inside the new energy efficiency concepts LCC-calculations have been used by some companies or consultants in order to control and compare investments with long-term costs and profitability. The difference they demonstrate is important for current practice. The LCC-calculations permit somehow current practice to look at different solutions at the same time and manage the change. This has been related to the necessity of adopting many innovations at once which has not been usual for clients and for specialists.

LCC-calculations have been used in the largest projects. The use of them is quite particular as they often are implemented in order to show long term profitability in comparison to one or two or, in one case, even six different more current solutions or even with more expensive/advanced solutions.

Optimal solutions are weight both against the prefixed energy goals and against the cost efficiency of the project. It is not unusual to state a goal (as a defined quantity of kWh/m2 yr) and an investment (as it uses to in all projects) and then state a limit as a percentage (6%, 10%) of possible overdue of costs. Moreover, many engaged practitioners have been publishing, both on the national and the international arena, detailed reports of LCC-calculations comparing costs and benefits in time for different scenarios in order to show the economical feasibility of extreme energy efficiency solutions in buildings of different kind.

4.4 End-users and current practice

Energy efficient buildings do not necessarily look different than old buildings. Walls may be thicker and windows are not cold during winter.

The optimal solutions of early demos are translated in current, context dependent, practice solutions. The “good enough” plays a usual role this time “optimized” in relation to the goals and to the quantities of innovations the cultural and social base of the project permit. It means the technological context in which the building is inserted (access to components, sub-components and so on; access to handcraft capability to support the precision needed; integration of the built solution in an existing built environment; just to name some). It also means the kind of end-user the building is built for. For just one year ago the building companies totally agreed about the opinion that consumers were not mature for energy buildings and less for eco-buildings, as they were called then. During the last few years eco-green-buildings have been transformed into a new but more current urban typology with embedded modern environmentally friendly and resource-efficient performances (Jensen et al, 2008).

The difference today may be described by the publicity campaign made by COOP in Norway: “Do it for your sake. Forget the old bad conscience”

Hence, solutions discard the expensive details offering some decimals of the average total U-value of the climate shell and of the final energy performance in change of some more freedom in shaping the building.

What is remarkable is the apparently overdue of learning in each project. The iterative process normal for a building project (Rubino, 2007) allows for the production of a redundancy of proposed solutions and continuous trade-offs until the final design is defined. Learning and practitioner-research are paramount within an environment of shared responsibility and competitive cooperation co-discovering the new possibilities lying within the new goals of energy and resource efficiency.

4.5 Responsible governance of the project

One more trend emerging from the investigation of these cases is the very common as well as unexpected need for a change of management of the design-process of the project. Generally it can be said that a tendency to “half-partnering” management solution are chosen. This means that in some way in all phases of the process agents share the responsibility for the outcomes and the transaction cost for the innovation. Learning seems at the same time to be spread on all levels.

Hence, in practice, the goal of for example 45 kWh/m2 yr can be reached in different ways. This may become possible by

- 1) using features of integrated design where the social and physical contexts determine the need of energy per person along with the amount of m2 each person has at disposal;
- 2) the design team sharing the limited quantity of kWh at disposal gives each consultant the responsibility of reducing as much as possible the quantities embedded in the functions and services s/he proposes, showing the capability of co-discovering alternative possibilities during the process;
- 3) changing the role of the architect’s pre-figurative layout which is adapting to new more dynamic rules at play;
- 4) as a consequence of the previous point, transforming the vision, that strong vision of modernity, into a dynamic, loose and adaptable “picture” (still clear and inspiring) into which the whole project team co-operates, adjusting needs, details, masses, flows. Not only functions and services for minimal costs and maximal yield are delivered but original solutions for high energy efficiency as the new competitive quality of buildings.

4.6 Profiles of action within a non-linear process/project.

A new awareness for processes which allows for the possibility of multiple outcomes is emerging. These processes are typically non-linear, path-depending and submitted to historical events.

What these projects are telling us is that small events can lock a project into different structures and that this happens at all scales.

The design-process emerges from these evolving projects for energy efficiency performances as in need of a redefinition. Open participative processes are aligned to cooperative behaviours within the boundaries of the project. Design is crossing the boundaries of different disciplines and the function of traditional actors and especially the function and responsibility of the architect is changing. The profiles of action are chosen along the process according to the specific character of the project and the agents involved, therefore allowing a wide platform for open cooperation. Different actors act next to each other in the design process, the architect’s pre-figurations being a hindrance as it wants to produce the entire process in detail and too early. The traditional total pre-figuration of the architect, responding to the linear project management, is experienced by many as a barrier. There is a general call for a figurative work able to evolve as a processing of the whole range of parameters, human and non human agents, changing economic conditions and required performances (Bono, 2007).

The process could be open-ended but it always comes to a point of return where the project begins to become a building. At that point when the general concept has been developed the design process does not stop. It is at this point that the enormous job of detailing and specialized engineering begins. Only if the expert actors have been present during all the precedent phases of the project and have been influencing the design process as to its choice of principles and temporary assembling, the continuity of processing into projecting will succeed. There will not be a break.

5. Conclusions

Emerging patterns of co-operational behaviours in a number of observed projects and in the spreading of information in this phase of change have highlighted the importance of the learning processes for sustainability, placing the evolution of knowledge and of novel solutions in the core of all building activity, i.e. the project. A new definition of the project is the ultimate context of the change caused by the integrated implementation of the four sector-specific innovations. In fact, the innovative components (*product innovation)*, the improved way in which they are assembled and installed (*process innovation)* in new combinations in order to achieve new performance-requirements (*configurational innovation*) result in a wide *systemic innovation* emerging and managed within the collaborative structure of the building sector. In everyday work thousands of people manage the transformations of the built environment often relying on individual responsibility continuously adapting solutions and sometimes inventing novel solutions (Arthur, 2004; Rubino, 2007). The freedom to choose among possible solutions is on play in this phase of change challenged by the societal goal about the management of a common good, the built environment, no longer envisioned by someone staying outside but emerging from an heterogeneous engineering (Harty, 2005). The goals of sustainability development for buildings have to be developed within new conceptual frameworks. Previously isolated dimensions (the social, economical and environmental) are intertwined and new kinds of arenas for the management of local resilience are needed to challenge the different goals and the diversity of views of the different stakeholders towards a common desirable sustainable future. The different stakeholders play different roles at different stages of the long decisional process that characterizes every building enterprise. Different visions and practices come to a confrontation and are challenged to cooperation. Building projects can no longer be isolated from the context of local sustainable goal settings for the environment as a whole. The contrary becomes obsolete and the action of isolated, uncoordinated loners is no longer competitive. Co-operative behaviour is in itself competitive as it is the sophisticated human base of learning. In further development of sustainability framework for building four concepts may resume the results emerging from this study: 1) coordinated design between stakeholders; 2) CTS (Certified Technology Specialist) action profile within projects; 3) transparency, through the whole of the building process from briefing to construction; 4) competitive cooperation, which gives feedback to cooperative behaviour and moves the limits of measurable performances within shared common visions.

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BARRIERS TO RENOVATION FOR HOUSING SUSTAINABILITY IN TASMANIA

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Summary

Australian building legislation now incorporates significant environmental performance requirements for new housing and major housing renovations. These regulations are likely to be tightened over the coming decade, especially as policies for climate change mitigation and adaptation take effect. Yet most urban and suburban landscapes in Australia are dominated by existing housing which falls well short of current standards. This observation is particularly pertinent in Tasmania, the coldest, most economically marginal state in Australia, with one of the nation's highest proportions of old housing stock. This existing housing will deliver unacceptable environmental impacts and unsustainable living conditions for decades to come unless retrofitted or renovated to improve resource use efficiency, ecological appropriateness and liveability. In this paper, we describe and analyse a range of individual, institutional and organisational barriers to renovation for housing sustainability in Tasmania. We draw upon interviews and focus groups conducted in three interrelated studies, with stakeholders from all tiers of government, and from private and non-government sectors. Our analysis of the data suggests that a number of complex narratives exist to explain the barriers to sustainable retrofitting. These are related to social values, socio-economic forces, physical constraints, deficits in capacity and deficits in governance.

1. Introduction

During the winter of 2002, monitoring of the indoor climate of an 80 year old weatherboard house in a riverside suburb of Tasmania's capital city, Hobart, recorded unheated daytime temperatures as low as 6 degrees Celsius. At the start of the following winter, Hobart City Council, the owner of the property, made available $3000 in funds for researchers to purchase and have installed draft proofing, floor and ceiling insulation, and window pelmets and curtains. Within a week after the completion of that retrofit the unheated temperature, under equivalent conditions, was recorded at 18 degrees Celsius. More significantly, the low-income tenants reported that, for the first time in a year, their children seemed free of any cold symptoms (Weaver 2005).

This example hints at the potential to improve housing in Australia by renovating or retrofitting existing stock in ways specifically oriented to the principles of sustainability – now well-established as a conceptual framework for how to live. Among those principles are intra- and inter-generational equity of opportunity; environmental protection and management; economic resilience and effectiveness; and ethical governance. Typically, these principles are expected to be fulfilled via myriad tools and mechanisms of sustainable development, which Berke and Conroy (2000, p.23) define as 'a dynamic process in which communities anticipate and accommodate the needs of current generations in ways that reproduce and balance local social, economic, and ecological systems, and link local actions to global concerns'.

We note that sustainable development is meant (but often fails) to avoid resource, property and development conflicts in pursuit of green, profitable and fair outcomes (Campbell 1996/2003), and that is perhaps because it also remains embedded in particular understandings of human existence that are broadly neoliberal (York & Rosa 2003); in short, it is *'weakly'* defined. At the same time, while sympathetic to many critiques of sustainable development so conceived, we accept that all reasonable efforts to address current and anticipated socio-ecological problems merit consideration, including those 'inside' the paradigm of neoliberal sustainable development. Among such efforts, we count the current discourse of sustainable housing, and should make explicit a hope that the discourse will be more *'strongly'* defined in due course.

We acknowledge that discussions about how to encourage and entrench *sustainable* housing policies and practices proliferate in international research and policy circles (Alexander 1998, Bhatti 1993, 2001, Burton 2003, Goodchild 1994, Schulman 2000, Various authors 1996). However, it is the design and construction of *new* housing (Crabtree 2005, Itard & Klunder 2007, Scott et al. 2006, Tiwari 2004, Tosics 2004), rather than the sustainable *renovation* of existing stock, that has attracted most attention. Despite the existence of literature on its merits dating back 30 years (Antolini 1978, Crossley 1979, Robinson & Dubin 1978, Vale & Vale 1977), retrofitting or renovation for housing sustainability appears limited in uptake.

Our working definition of *renovation or retrofitting for housing sustainability* is the renewal and adjustment of the fabric, fixtures, fittings and landscape of any given residential dwelling in order to improve the dwelling's ability to sustain the occupants within the carrying capacity of the Earth. It may include, but is not confined to, insulating, sealing the building envelope, properly treating windows by the use of pelmets, curtains and appropriate glazing, fitting water tanks, solar panels, energy efficient light, heat and water systems, and planting native, productive and low-water gardens. Such renewal and adjustment avoids or minimises the depletion of natural, human, social, financial, physical and organisational capital, and is mindful of the scalar and temporal dimensions of our actions: it remains apposite rather than clichéd to think global, act local, and over the long-term. In an ideal world, it would also move beyond site specificity and integrate with abutting and adjacent sites to effect a 'rippling' out of transformation and change.

In this paper we document a range of barriers that limit sustainable renovation or retrofitting as we define it. We report on three interrelated studies which describe and analyse a range of individual, institutional and organisational barriers to the sustainable renovation of housing in Tasmania. In particular, we seek to understand various perceptions, attitudes and values shared with us by a number of participants who deliver or influence the delivery of housing and building services. We conclude by speculating about how the existence of these barriers is linked to limitations inherent in dominant understandings of (weak) sustainable development (Davison 2001, Davison 2008), particularly those related to the (rights of the) consumer-citizen and to notions of housing as a private rather than a public good.

2. Context and Research Design

Tasmania is reputed to be the coldest and most economically marginal state in Australia, with 40% of households on low incomes, and a quarter of those reported to be suffering housing stress outside of the social housing system; housing stress being defined by the Australian Bureau of Statistics as a condition induced by having mortgage or rental payments in excess of 30% of net household income (Housing Tasmania 2003, Tasmanian Council of Social Services 2007). Hobart also shares with Sydney the distinction of having the oldest housing stock in metropolitan Australia (Australian Bureau of Statistics 2003). This stock will provide shelter for a significant proportion of the (ageing) Tasmanian population for decades to come. Much housing is of poor quality when assessed against contemporary standards, and arguably contributes to unsustainable environmental impacts, and uncomfortable and unaffordable living conditions. Such is likely to remain the case without coordinated, broad-scale renovation such as we defined earlier. Such widespread action and innovation will need to encompass the entire socio-economic spectrum, and not just those people likely to be early adopters of 'green' housing techniques. Small-scale, relatively inexpensive and cost-recovering retrofits, such as that described in the Hobart City Council example above, will be vital in achieving significant transformation of existing stock.

The scope to encourage small-scale and inexpensive retrofits for sustainability outcomes would seem considerable, given that residential building renovation currently accounts for approximately 10% of total construction activity in Australia, or around AUD$5.7 billion per annum (Australian Bureau of Statistics 2007). Yet, while there are significant commitments to comprehensive performance requirements in construction (Australian Building Codes Board 2007), numerous barriers appear to limit renovation of existing stock for sustainability gains, despite its efficacy (Edwards & Turrent 2000, Nye & Rydin 2006, Priemus 2005). It is these barriers we have focused upon in the three interrelated studies reported here. Each study was presented to the Social Science Human Research Ethics Network (Tasmania), as required under the National Statement on Ethical Conduct in Human Research, and was approved.

The first study, whose findings form the foundation of this paper, was conducted in 2004[i] and addressed the following question: *What are the formal and informal institutional and organisational barriers to retrofitting existing public and private housing stock in Tasmania for affordable energy-efficient outcomes, and how might these barriers be overcome?* Semi-structured interviews were conducted with 24 individuals with prominent involvement in housing policy in Tasmania. Taped interviews undertaken by Stratford were transcribed and analysed using hermeneutic practices that involved the reading and rereading of interviews to distil themes according to what respondents said, a process followed by synthesis with the wider literature. Part of the study's impetus was the completion of the case study described in the introduction above (Weaver 2005) and a wider research interest in questions of sustainable development and Tasmanian settlements (Armstrong & Stratford 2004, Stratford *et al.* 2003, Stratford & Davidson 2002).

The second study was conducted in 2007[ii] and targeted Hobart-based builders in order to understand how they think existing housing might be renovated to meet the objectives of sustainable development as they understood these (Elliott 2007). A postal survey was sent to 28 builders who claimed membership of the Housing Industry Association or Master Builders' Association, and follow-up semi-structured interviews were conducted with 14 of them; these were taped, transcribed and analysed in the manner described for Study 1. Representatives of the two aforementioned industry organisations were also interviewed to gain further insights into the building industry in Tasmania.

The third study, ongoing to 2010, is informed by Studies 1 and 2, and seeks to uncover more about what drives and impedes renovation for housing sustainability in Tasmania, broadening the number and range of 'actors' participating in the study, and attempting to focus on policy innovations and solutions. Watson's project[iii] commenced in 2006 and has brought together four focus groups involving a total of 20 participants to construct a picture of current perceptions of barriers and drivers to sustainable renovation, and generate a discussion on sustainable (and especially energy efficient) renovation. Focus groups' participants were drawn from State and local governments, the private sector and peak body representatives, and non-government organisations, all recruited through purposive sampling. Four semi-structured sessions, each of two hours duration, were recorded, transcribed and analysed.

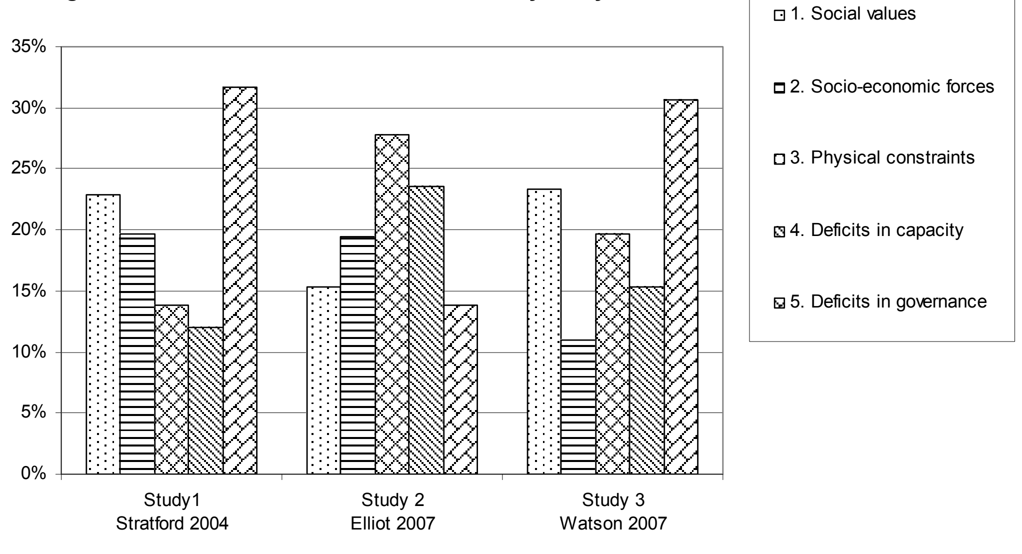
Taken together, the studies involved 72 conversations via questionnaires, interviews and focus groups. To ensure rigour (Janesick 2000), a joint thematic analysis of participants' stories describing the barriers to renovation for housing sustainability was conducted in early 2008, and was indebted to insights by Feldman *et al.* (2004) that story-lines share chronological and thematic ordering, they cement, and confine or bound.

Story-lines are sub-sets of larger narratives (for example, the narrative that retrofitting is too technically difficult or scientifically unproven). These narratives then constitute discursive orders (for example, retrofitting is too difficult, full stop, so let's not 'go there'). These orders then become routinized via our cognitive commitments to them (Hajer 1995) – in short, they become our understanding of the 'truth' and difficult to change.

3. Barriers to housing renovation for sustainability outcomes in Tasmania – key findings

In what follows, we draw on a range of participant narratives about the barriers to retrofitting existing housing for sustainability outcomes. These narratives are organised according to five categories of barriers: (a) social values; (b) socio-economic forces; (c) physical constraints; (d) deficits in capacity; and (e) deficits in governance. Figure 1 shows points of convergence and divergence among participants across the three studies in relation to these five themes. In what follows, we briefly address each in turn, focusing on one or two of the most frequently cited barriers to retrofitting.

Figure 1. Barriers to sustainable renovation by study



(a) Social values

Among the factors seen to impede renovation for housing sustainability were the following: (a) adherence to consumerist value systems; (b) inability or unwillingness of householders, industry players and governments to change behaviours, attitudes and practices; and (c) lack of motivation, apathy and/or fear of change.

Social values and practices were most frequently raised by participants from non-government organisations (NGOs) concerned to highlight intra-generational equity gaps in housing affordability, and underscore how these gaps mean that people in low income housing are often (or perceive themselves as) unable to engage in retrofitting, especially when renting. One social service provider, for example, noted that the '*primary concern for low income people is cost – most are in private rental, paying over 30% of their income but that income is in the bottom two quartiles. They have massive heating expenses and large upfront costs to get the power on … Landlords are reluctant to retrofit, for example by adding insulation, because they want a profit'.* NGO staff also tended to emphasise cognitive barriers to value-shifts such as people's lack of will to change, and the frustration of '*having the same converts around the table all the time, people without the real power to force change*'.

In marked contrast, some participants from the private sector cited the pressure they feel to respond to client demands that their renovations include 'the latest' fixtures and fitting. We were told that people in middle to upper income brackets prefer to prioritise the marble benchtop over the installation of appropriate R-rating insulation or energy efficient lighting and heating, for example. Yet, as one industry participant noted '*builders [also] have an aversion to providing too much advice to clients; it's not inside their comfort zone and they see it as a liability issue if they get it wrong – and there's not much training out there*'.

(b) Socio-economic forces

Among the socio-economic forces participants identified as barriers to retrofitting are: (a) cost as the primary basis of decision-making by householders; (b) pressures to meet client budgets; and (c) limited evidence of return on investment from retrofitting. We were also told that '*larger considerations*' beyond the socio-economics of individual households included (d) pricing, taxation and hidden subsidisation mechanisms that foster unsustainable practices and outcomes; (e) a widespread focus on economic growth and profit; (f) compliance costs; and (g) lack of market incentives for retrofitting innovations.

A number of builders informed us that their clients saw cost as the bottom line, but that this consideration was often muddied by other influences upon them, and especially by a desire to keep up with fashion trends in housing and interior decoration. In short, particular preference hierarchies influenced some people's choice of what was affordable [read desirable] – and we were told that clients would often privilege visible icons of affluence over less visible fixtures and fittings that are crucial to, for example, thermal comfort or energy efficiency.

The relationship between cost and the efficacy of any given renovation choice was a key issue for builders; most simply felt that they had insufficient information or expertise to tell clients that X action (for example, increasing the amount of insulation in a property) would result in Y savings or Y comfort gains over Z periods of time. Most also suggested that sustainable development was not a priority for many clients. One builder told us that at '*the lower end of the market … the customers I see don't even understand what sustainability is; [they] have no idea and just want to know "can I afford [the building work and] will the bank pay for it?" They're not interested in how much energy they can save as an end save; they're looking at the fixed costs of getting in.*' In passing we note that a participant from the scientific community working for an Australian Government organisation suggested that, apart from anecdotal information or one-off cases such as reported by Weaver (2005), there was insufficient data on the cumulative effects of retrofitting. He maintained that it was thus difficult to make a convincing *economic* case for retrofitting, since how much can be saved and at what cost has not been widely established (but see Howden-Chapman *et al.* 2007). We can only speculate here about whether recent changes in public perceptions of the need for climate change adaptation and mitigation may see householders come to grips with rising energy costs by taking the 'risk' to complete sustainable retrofits in any case.

In the public housing sector, Tasmanian Government stakeholders voiced an interest in the benefits of renovation for sustainability, yet highlighted the financial and policy difficulties they face. Economic pressures on their political masters have produced what one asset manager described as demand for increases in the number of dwellings rather than for quality dividends: he termed this getting '*bang for the buck*'. Given both the present extent of housing stress in Tasmania and highly publicised shortages in public housing (Flanagan 2007), this focus on the size of the public housing estate is not unreasonable in and of itself. Nevertheless, implementing well-established environmental design measures in public housing appears to have been secondary[iv]. As one government stakeholder noted, '*A significant number of properties are over 30 years old, located in broadacre housing areas, constructed mostly of concrete blocks with basic insulation and [are] not well aspected [positioned for passive solar advantage]. There has been no significant focus on energy efficiency in the construction or maintenance of these properties. This observation refers to a large amount of stock*'.

It is also noteworthy that recent intensification of action on climate change under the Rudd Australian Labor Government has also translated into – or at least coincided with – a shift in Tasmania in the *rhetoric* of sustainable and not just affordable housing (Lennon The Hon 2008). However, as one policy professional suggested, the move from rhetoric to practice is always challenging. '*Formal barriers to the uptake of retrofitting include shifting from current thoughts and operations to new ones; making energy efficiency and retrofitting emerge on the agenda as something possible to do; being able to do things cost-effectively and get a good return, capable of enhancing the asset; health and well-being not always linked to infrastructure; and change management process – it takes a while to get people to think differently*'.

(c) Physical constraints

Participants expressed a range of views on how the uptake of sustainable renovations is constrained by a range of physical conditions, most notably a sense of (a) the inappropriate planning, design and construction of housing and the perception of retrofitting as technically difficult, of limited benefit or unaffordable; (b) a settlement history based on northern hemisphere practices; (c) past investments in particular forms of subdivision and construction; (d) poor standards applied to retrofitting; (e) lack of skilled trades; (f) poor quality housing to work from; and (g) Tasmania's topography, climate, population, and isolation.

Many of those we spoke to across various sectors understood and emphasised the point that retrofitting means coming to terms with existing housing and subdivision or land-use arrangements, and revisiting and revaluing established knowledge about planning settlements and using quality building materials for thermal comfort, that we note have been in circulation, in one guise or another, for over a century (see, for example, Howard 1898/1998, Stevenson & Murray 1892). Participants thus acknowledged a need to come to grips with poor-quality housing that is inappropriately sited on individual parcels of land that are collectively unsuitably organised, the cumulative effects of which are unsustainable suburbs.

Many participants also saw retrofitting as technically difficult and, in this respect, insulation is an interesting case in point. In 2004, one industry representative told us that '*In Tasmania, 70% of all insulation sold goes to residential buildings. To fully insulate a standard new house ceiling (150-160 squares) would cost approximately $850 in materials, and approximately $300 in labour … and the payback is around 4 years … but we need people to move from R3.5 to R7 and R10*'[v]. A leader in insulation product supply noted that '*To insulate efficiently, material must be installed in a way to allow it to go back to full manufacturing thickness e.g. R3.5/185mm thick. It must be installed to fill all gaps and retains thickness or R rating drops. Batts are often manufactured to fit the spacing of traditional building frameworks. So 430mm of batts into frames of 450mm fits snug, but 600mm frames and 450mm batts equals gaps*'.

Study 2 work established that significant controversy surrounds the installation of wool, combination or fibreglass insulation and sisalation[vi] (Elliot 2007). We were told that to ensure that insulation is applied correctly for maximum energy efficiency gains, it is important that the insulation manufacturer has advised building professionals correctly; that insulation is reasonably affordable; that residential designers have properly detailed drawings; that builders store and install it correctly; that correctly sized timber is available to frame it; and that everyone has the information they need to complete their part of the task at hand. There is also the challenge of appropriate insulation being available from suppliers, which may serve to illustrate larger challenges related to supply chain management and Tasmania's isolation as an island – removed by 256km of the Bass Strait from the Victorian coast on the mainland of Australia, and thus from supplies more readily available there. In summary, unless clients have particular expectations that builders will provide constructions that have high levels of thermal comfort, these challenges are sometimes seen by builders as beyond their scope or domain.

Several builders were also concerned about the oversupply of materials – a particular problem on renovation work where only small quantities of materials are required. Some explained how they ordered more timber and other materials than necessary because the cost of transporting extra to a building site was more than the cost of 'wasted' materials and materials could only be purchased in standard bulk lots. Others explained how there was no way for them to recycle materials and said it was easier, cheaper and more time-effective to dump used materials into a rubbish skip or bin once a job had been completed. Tasmania's small industry and lack of entrepreneurial recyclers were also noted in interviews and focus groups in Study 3.

Representatives of the Master Plumbers Association who participated in our 2004 study were also keen to explain the range of difficulties facing them in doing retrofits. We were advised that plumbing and heating jobs were generally not done with a view to achieve energy gains and were often prohibitively expensive. In addition, few plumbers were familiar with workplace health and safety legislation that may pertain to retrofits, and were struggling with the enormity of detail in the Building Code of Australia (Australian Building Codes Board 2007). In the final analysis, plumbers may not be persuaded that X or Y new energy efficient option is the best for a client given cost, novelty of installation requirements and related higher labour costs or structural integrity issues. In study 3, however, we were told that there is now a water and energy efficient scheme for Tasmanian plumbers, which included an Association-backed training course on the subject.

(d) Deficits in capacity

A number of the issues raised thus far were associated by participants with (a) a lack of appropriate general education and training, and of specific skills training; and (b) a lack of good quality practice/demonstration projects. Less frequently cited but allied comments related to concerns about (c) the insufficient availability of good quality information and tools on retrofitting; (d) inability to upskill capacities; (e) limited capacity for quality assurance of skills in practice; (f) lack of access to facilities and products supportive of retrofitting; (g) lack of collaboration and integration among specialist and professionals; and (h) confusing or incomplete information on what 'sustainable' is in the context of building and renovation.

Solving these deficiencies requires significant investments in interdisciplinary and multilateral collaboration (see, for example, Després *et al.* 2004). Nevertheless, in a chicken-and-egg conundrum, such collaboration is unlikely to have effect without major investments in general and specific education and training to improve the capacity of professional to support sustainable change in existing housing.

It was generally believed that changes in education and training happen slower in Tasmania than on the mainland. Yet, Tasmania is also a source of significant innovation across a range of economic, social and environmental spheres and has been for well over a century (Green Sir 2003), and such patterns of conduct and behaviour exist now and are considered important by participants. For example, the Tasmanian Government's Building and Construction Industry Council's commitment to sustainability seems clear: an industry that (i) 'makes a genuine contribution to sustainable development by building or refurbishing facilities and infrastructure that make more efficient use of resources, protect ecological systems and account for community needs' (Tasmanian Department of Economic Development 2008), and (ii) makes available a $10,000 innovation award, including scholarship for education and training. But this initiative is itself relatively new, and its effects are yet to be fully tested.

Those most concerned with the need for training and skills-development in sustainable renovation techniques were builders, although we underscore the point that information, education and communication were universally noted as crucial in all three studies. Some had noticed improvements in the level of knowledge about sustainable renovations. Others indicated that lack of capacity and insufficient value-shifts arising from more general education about sustainable development are still barriers to the better uptake of retrofitting. One architectural professional suggested that the '*groundwork for such a shift in awareness may take many years. Education, policy and demonstration projects must be made more available. It's not so much genuine resistance but apathy*'.

Certainly, builders who participated in Study 2 were in agreement about the type of training and knowledge they would find beneficial: clear, unambiguous information both easy to access and affordable to implement. As one builder commented, as soon as information on a technique appears vague or unclear, builders and clients alike have a fear that it is too difficult to apply or could have unforeseen and risky effects. Builders also noted significant dissatisfaction with the Building Code of Australia (BCA), observing that it was financially and practically inaccessible. Although some understood why performance requirements are used in the BCA, they said that it takes them too long to find the relevant regulations and then the instructions are too ambiguous. Finally, builders also wanted to see significantly more invested by governments, Research and Development (R&D) groups, and the private sector in demonstration projects that would allow them to see, first hand, the effects of retrofits. Presently, such projects are largely oriented to new builds rather than retrofits[vii].

(e) Deficits in governance

Concerns about deficits in governance were pronounced in Study 1 and Study 3. Among these deficits, (a) lack of coherent and connected leadership and political will and example; and (b) non-aligned, complex and disjointed legislation were most often cited. But an extensive range of other interrelated observations were made about (c) the collective inability to manage or understand demand and need; (d) lack of rewards and incentives to encourage retrofitting; (e) a focus on managerialism and risk aversion; (f) ambiguous regulations and poor enforcement of same; (g) the proliferation (or lack) of performance benchmarks, standards and accreditation; (h) the lack of appropriate human resources; (i) non-aligned legislative tools; (j) tensions over mandatory and voluntary arrangements, and confusion over roles and responsibilities; and (k) capture of the State by private or union interests and a related short-term 'bang for the buck' mentality.

Lack of leadership and a deficit of political will and example were seen by participants to be evident across all tiers of government and all sectors of industry. For instance, we were told that there were significant opportunities for local government to be better involved in encouraging retrofitting in Tasmania. Two municipal officers informed us that, to '*purchase a 2,000L tank costs $600 on a small urban block. [Council X] provides the council plumbing permit ($120), and a further $170 rates rebate or $220 if the tank is connected to a toilet. This saves bulk water, especially through peak summer usage, and for water restrictions that affect gardens; and it reduces the volume and velocity of stormwater reaching waterways, thereby reducing pollution. But encouraging people [through leadership] to install water tanks is hard because they are more likely to spend money on improving the look of their house*'. Another participant, associated with local government, suggested that '*rebates may be useful but savings would need to be provided back to local governments whose rate bases are very low in many cases, particularly in Tasmania. Even sums of $5,000 or $10,000 are a significant impost'*.

Participants in local government recognise their capacity to effect change at that level via a range of voluntary activities, such as involvement in the Cities for Climate Protection protocol[viii], and regulatory mechanisms such as the BCA and planning schemes. But they also suggest the need for greater integration in policy, greater and more consistent leadership from State Government, and better (constitutional) recognition of local government. At the beginning of 2004, we were told that the '*State Greenhouse Strategy does not engage local government and it should do so – currently it impedes intergovernmental relations. Most effort now goes into dialogue about adaptation not reduction*'. In 2008, it is clear that the Tasmanian Government is now taking significant steps to address the impacts of climate change (Lennon The Hon 2008) but whether, how and to what extent that leadership gives effect to sustainable renovations is unclear. Certainly, a number of participants suggested there was a general reluctance on the part of governments to further regulate industries considered important to economic growth.

Participants also suggested that there were opportunities for all actors in the housing arena to show leadership: that householders could be more proactively engaged in adjusting their preferences; peak industry associations could better pressure their members to adopt and conform to best practice sustainability innovations in sustainable renovation; and housing professionals and trades people might be less risk averse and seek to provide well-rounded advice to clients and lobby suppliers to actively source and advertise the capacity to supply materials for sustainable housing outcomes.

4. Summary and conclusions

We now know with some confidence that, for the cases under study, there are numerous and complex narratives about the barriers impeding more widespread and effective uptake of retrofitting or renovation of housing for sustainability outcomes – narratives from which we have distilled five larger themes: social values, socio-economic forces, physical constraints, deficits in capacity and deficits in governance.

We also know that differences were evident in how stakeholder groups understood and gave relative importance to various barriers. For instance, participants from all tiers of government placed most stress on deficits in governance, while building professionals placed least emphasis on that theme and most weight on physical constraints to retrofitting for housing sustainability. In general, such differences reflect the area of focus or expertise of stakeholders, and suggest the existence of stable (even durable) discourses or 'truths' that are continuously reinscribed via particular narratives.

We have also established that there is, among different groups, some significant commonality and shared understanding of the underlying reasons for the barriers identified; that finding, too, bodes well for possible and productive collaboration for reforms to housing renovation for sustainability outcomes.

Furthermore, in general terms participants displayed well-developed appreciation of the long-term need for housing to be sustainable and, in itself, this finding is encouraging. However, it was also clear that many participants thought that this need would be met in practice *only* if renovation or retrofitting for sustainability outcomes was linked to fundamental and powerful agendas for change.

In light of the insights we have gained from working with participants, and from engaging in the analysis of the literature and its synthesis with the narratives we were provided, as a research team, we have also reflected upon what to distil – in preliminary fashion – from the three studies described here. A number of opportunities or potential drivers present themselves in the stories participants shared with us or are canvassed in scholarly and policy documents.

First among these potential drivers is the power of visionary political leadership; political in this sense including elected representatives of all three tiers of government as well as of peak professional organisations; leadership including both authoritative forms (given by constitutional or other formal fiat) and facilitative forms (charisma, influence, 'response-ability').

Second, such visionary political leadership is supported by – and in turn supports – the exercise of active citizenship. In other words, leaders will be empowered to lead to the extent that citizens question their own constitution as mere consumers, embrace their responsibilities as well as claim their rights, and have high expectations of those representing them.

Third, in terms of housing, leadership and active citizenship might mean prioritising renovation activities that extend consideration beyond individuals and their property rights to include (indeed mandate) actions that benefit non-human nature and the common good. A concrete example of that may be cited in relation to one of the authors of this paper, who has recently made a decision to sell an investment block and redirect the funds to the renovation of a main residence, prioritising over a remodelled kitchen and dining room the purchase and fitting of solar panels, solar hot water, rain water tanks, gas heating, energy efficient lighting, and an increase in insulation. Acknowledging that the author is in a position of privilege relative to many householders it remains the case that many gains appear to be possible from minor retrofits.

Fourth, opportunities for the better uptake of renovations of sustainability outcomes are likely to be enhanced by significant commitments to education and training such that innovations in retrofitting are shared across organisations and sectors and rapidly and effectively communicated and applied. In this sense, information flows need to be multidirectional: those in R&D learning as much from those in the trades as they disseminate to them.

Fifth, fiscal and financial incentives and attention to regulatory context are imperative and, at the same time, more modelling is needed to persuade householders, the building industries, housing professionals and allied groups of the effectiveness of retrofits across a range of price thresholds and in relation to a range of desired environmental, social and economic outcomes.

Finally, we are persuaded that significantly more research is needed to establish the determinants of what drives – rather than what impedes – the uptake of renovations for sustainability outcomes, but caution that such research might be most productively advanced by stakeholders having significant and joint say in its design, conduct, dissemination and implementation. The collaborative learning experiences that we think would flow from such collectively agreed investigations could be substantial and may also serve to enhance a robustly integrative approach to a common challenge.

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[iv] An the exception to this general rule has been the application of eco-building principles in a redevelopment known as Walford Terraces (Tasmanian Department of Health and Human Services (2005) Projects and Initiatives. Walford Terraces, <http://www.dhhs.tas.gov.au/agency/pro/walfordterraces/index.php> Accessed 16 March 2008). The redevelopment involved the razing of an existing cluster of units and a significant rebuild and, as such, is outside the remit of this present study.

[v] "R-value is a term predominantly used in the building industry to describe the insulation properties of certain building insulation materials. Its use is limited to situations where thermal insulation is achieved by retarding the flow of heat through the material itself rather than reflecting radiant heat away. The higher the R-value, the greater the insulation" (http://en.wikipedia.org/wiki/R-value_(insulation)).

[vi] Aluminium foil laminations attached to kraft paper and reinforced with fibreglass and a flame retardant adhesive.

[vii] See, for example, the No Bills experimental houses described at http://oak.arch.utas.edu.au/nobills/

[viii] See http://www.iclei.org/index.php?id=800

LIFE HOMES - MOVING BEYOND GREEN DESIGN TO ENHANCE OCCUPANT LIFESTYLE

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Keywords: homes, wellbeing, quality of life, sustainable, regenerative architecture, assessment, biomaterials

"A house is a machine for living." - *Le Corbusier.*

Summary

Information and trends across many aspects relate to housing sustainability. The ability to implement sustainability into housing forms goes beyond the physical environmental properties of water, energy, waste, materials and indoor environmental quality. Sustainable housing also requires solutions that facilitate comfort, affordability, a changing household structure, and lifestyle needs.

This paper outlines an initiative to provide building systems from novel materials that are designed specifically to facilitate the type of living that New Zealanders want and expect from their houses. In response to a growing global demand for materials that can be used as an alternative to synthetic products, Scion is now focused on creating plant-based biomaterials and new manufacturing processes as a basis for sustaining the consumer markets of the future.

Previous assessment of housing system needs in terms of householder behaviour (how do people use their homes, and how do some of these aspects affect the use (and needs) of the home) has allowed the main criteria for housing to be identified (Bayne et al., 2006, Bayne et al., 2002). A better understanding of the lifestyle requirements of NZ household provides more defined criteria for future materials, systems and supply chain infrastructure.

The development of a process to facilitate materials research, systems design, and building solutions that focus on and address sustainable housing criteria from a lifestyle needs perspective is the key outcome of this initiative. Four projects which address various aspects of lifestyle requirements have been identified and are outlined. The developed framework will be used to create novel systems that use bio-based materials, better facilitating transition to housing solutions that are not only environmentally sustainable, but socially sustainable also.

1. Background

1.1 Housing Sustainability

The links between a nation's housing and sustainability are numerous. Housing both impacts on the environment (in terms of e.g. materials and energy resourcing, waste and effluent, water supplies, land use) and is impacted in turn by the environment (through e.g. climate, neighbouring vegetation, dust and pollutants, human and animal populations, etc.). For most New Zealanders, housing will be the largest purchase ever made, and mortgage and rent payments impact significantly on a household budget. Keeping housing at affordable levels while maintaining a profitable construction sector is therefore an economic sustainability challenge. Housing also contributes much to a person's social wellbeing, and the building and expression of culture. Where we live, the design and character of the home environment, materials used, access to amenities and the community spirit that is present and support that is received impact greatly on ones' satisfaction from their personal housing locality and situation.

1.2 Current New Zealand situation

Housing in New Zealand has a number of sustainability challenges, including cost, performance and people's acceptance of, and adaptation to, changed urban living conditions. New Zealand housing is the least affordable in the world, with Tauranga the most expensive city to live in, and Auckland housing costs outstripping most of Australia's large centres (Gibson, 2008; Needham, 2008). Whereas the international standard for affordable housing has a ratio of median house prices to median income of 3.0 or below, New Zealand has a ratio of 6.3. A recent report by Demographia (2008) states Auckland, Wellington and Christchurch are 'severely unaffordable', with median Auckland house prices at seven times the median household income. Not only is our housing unaffordable, but our average housing debt is conservatively 129% of income (Needham, 2008).

Urban housing subdivision within individual housing lots, to provide a capital return or rental opportunity, has resulted in significant suburban infill. While intensification is welcomed by city councils and policies are in place to restrict further sprawl (such as the Auckland Regional Council policy to restrict the city expanding) subdividing puts added pressures on the existing infrastructure and surrounding house prices. It also impacts on residential lifestyle values, particularly in relation to reduced privacy and views, and increased noise. By restricting further urban expansion, housing affordability tightens also. As Property Council national director Connal Towsend states "if people can't afford to live in the city, what's the point of the [Auckland Regional Growth] policy?" (Gibson, 2008).

New Zealand indoor temperatures are also below World Health Organisation recommendations for a healthy indoor environment, with cold and damp living spaces (An estimated 30% are still not insulated in either the floors or ceiling, with many more having no wall insulation). This combined with overcrowding levels contributes markedly to respiratory and severe infectious disease (Baker et al., 2006). Recent studies by University of Otago's Wellington School of Medicine (Howden-Chapman et al., 2007) have shown a clear and demonstrable link between poor housing conditions (low indoor temperature and high relative humidity) and poor children's health. Their health and insulation studies (Howden-Chapman, 2007; Howden-Chapman et al., 2007) also show insulating the home can improve not only the health of the occupants, but also household finances due to reduced energy costs and less doctor visits. This allows lower-income families more disposable income with which to better prevent illness occurring

The New Zealand housing situation is therefore less than sustainable on a number of facets. Recent progress has begun to address the housing situation and bring it to a more sustainable level. The Leaky Homes scare during 2001 received much media attention resulting in a report ("The Hunn report") outlining a number of unsustainable building practices (BIA, 2002). This heightening of public awareness of building sustainability issues led to higher levels of building performance demand from consumers, and legislation to bring about higher building performance standards.

More environmentally sustainable technologies (e.g. heat pumps and double-glazing) are becoming increasingly standardized features in new (and some remodelled) residential dwellings. The revisions to the New Zealand Building Code (DBH, 2007) increasing thermal performance and energy efficiency (including a proposed new acceptable solution for solar water heaters) have been significant drivers for this uptake. Also contributing are the government endorsement and subsidies available to aid homeowners in installation of energy saving, clean heat and insulating technologies (including solar water-heating devices, insulation, hot water cylinder wraps and low-energy lightbulbs). The Energy Efficiency and Conservation Authority Energywise scheme (http://www.energywise.co.nz/) recently announced a government fund of $23 million for assisting residential energy efficiency and heating upgrades. The adoption of these technologies have been primarily promoted and installed to reduce household energy use, but insulation has also been promoted on health benefits due to recent studies conducted by the Wellington School of Medicine showing the links between uninsulated houses and childhood respiratory illnesses, particularly asthma (University of Otago, 2007). Similarly, reduced energy use at the sustainably designed NOW home (www.nowhome.co.nz) shows that building a well-designed home with commonly available green technologies such as passive vents, solar water heating, double glazing and thoughtful house layout can result not only in improved energy efficiency, but improved wellbeing for the occupants from reduced heating expenses, and more satisfaction with their living environment (Beacon Pathway Ltd, 2007). A biannual social research study "Quality of Life in Twelve of New Zealand's Cities" (www.bigcities.govt.nz) shows improvements across a range of indicators from previous studies (increased GDP, reduced crime, increasing access to kerbside recycling schemes).

1.3 Forward-thinking Housing Scenarios

Due to these recent initiatives, and growing concern of climate change impacts, greater awareness of the unsustainable issues surrounding housing supply in New Zealand, coupled with a growing adoption of sustainable products and government assistance is leading to strategies for homes that give positive lifestyle as well as environmental benefits. One recent initiative proposes a national regenerative built environment 'test-bed' be developed (Gomm et al., 2008), which takes into account the intricate links between human and ecological wellbeing, and the complex relationship that humans have with their buildings.

Regenerative architecture recognizes that the future of sustainable buildings will need to go beyond a 'less environmental impact' model, towards a model of both positive environmental benefit and promoting meaningful and enduring relationships between people and place (Reed, 2007). The emphasis of this regenerative model is on meeting the needs of the human populace from a lifestyle perspective – after all, buildings are primarily designed for people's use. Regenerative architecture is the participation of humans as part of the living system for the mutual benefit of both. It therefore recognizes that the most environmentally friendly and affordable 'box' of a house, while addressing certain key future sustainability needs is not very enjoyable to live in, and not mutually beneficial.

The following quote from the Joseph Rowntree Foundation (2005) sums up the present movement to reflect societal lifestyle requirements within sustainable community developments:

> *"A sustainable community is one where residents are satisfied and in which they are happy to continue living."*

Similar quotes can be found from the New Zealand Government which reflects this growing sentiment:

> *"Sustainability is sometimes defined as ensuring we can meet our needs now without compromising the needs of future generations. It is about more than protecting the environment and using resources efficiently. Sustainability also relates to ensuring continued social and economic wellbeing. It means that buildings in New Zealand must meet the needs of New Zealanders now and into the future."* Department of Building 2007, pg 13.

> *"Being sustainable involves improving the quality of life for current generations without compromising the wellbeing of future generations."* Nanaia Mahuta - speech at the launch of the Quality of Life report 2007.

Are we compromising the housing needs of future generations, what are their needs likely to be, and how can we prepare for these needs?

Scenarios can be useful indicators of how trends will impact on future society, to begin to look at future societal needs. In 2001, Scion created three scenarios of the Australasian built environment (Bates et. al, 2001) and used these scenarios to identify a number of building criteria for housing required by 2010 -2015. Future building needs were investigated by evaluating how each scenario in turn would impact upon a building's form and function, as well as the change in materials and building practices that might result due to these future trends. From this analysis, a set of future criteria for various buildings were derived (Bayne et. al, 2001). Those derived for residential buildings influenced the development of a housing design brief and sustainability footprint for affordable, environmentally friendly and desirable future housing (Bayne, 2003). Using a similar approach, Scion recently examined the Centre for Housing Research Aotearoa New Zealand's (CHRANZ) recent future housing scenarios for New Zealand in 2030 (Bates and Kane, 2005) , to investigate how these trends would change housing needs over time. Overlaying this analysis with known emerging consumer and building industry behaviour determined sixteen criteria for modern timber housing (Bayne et al., 2006; Bates et al., 2007).

These studies represent a forward-thinking approach to housing research and residential design, which aims to propel the sustainable housing research beyond environmentally friendly and 'green' design principles into housing that also improves residents' quality of living experience, and 'future proofs' housing supply.

2. The Life Home Initiative

2.1 Concept

International research on green building design recognises that sustainable buildings need to be designed for people (e.g. Storey and Pederson, 2007). There is significant thinking on how to integrate the design process such that buildings are designed to deliver healthy, desirable and productive living spaces. This indicates a movement away from focussing on technical (particularly environmental) issues alone, and towards thinking about increased social, functional and wellbeing outcomes for the building occupants through improving the design, and the technical elements that are used to create the building and its surrounds.

The concept of a 'Life Home' is one that allows future trends and consumer needs in the building sector to be applied to materials science (refer figure 1), delivering improved building systems. The 'Life Home' concept builds off two past initiatives undertaken by Scion:

A) The post-Kyoto house (Bayne, 2003) : During 2001, built environment researchers in New Zealand recognised that in order to meet Kyoto commitments, the Government's directions in terms of energy, transport, waste and urban design would require current building performance to be significantly enhanced. Scion established the 'post-Kyoto vision' that showed the residential building stock being brought up to this requirement, and 'future-proofed' to account for changing consumer needs. This vision was "the environmentally friendly home that people want to, and can afford to, live in" and consisted of :

Now homes – showing what could be done to meet future needs using currently available, advanced building systems and design thinking. This led to a collaborative design charette approach and ultimately the building of the Waitakere NOW Home® and forming of the Beacon Pathway Ltd. research consortia (www.beaconpathway.co.nz).

Then homes – a retrofitting programme for existing homes to meet future needs through using current technologies, in recognition that the vast majority of homes in New Zealand were already built.

Future homes – designing new homes using advanced (i.e. not even out of the lab yet) timber-based building systems, to reduce the carbon footprint of residential building materials.

B) Future Housing Criteria: 'The Future of Housing in NZ in 2030' (Bates and Kane, 2005) was a scenario planning report undertaken for CHRANZ in 2005. Using these scenarios, Scion extended the study to explore criteria that would be required to meet the future housing needs that were outlined in the scenarios (Bayne et al., 2006; Bates et al., 2007). These criteria were identified as:

- affordability;
- customised services;
- health and safety;
- comfort and energy efficiency;
- social responsibility;
- quality — fit for purpose and high performance;
- compatibility with denser living requirements;
- ease of maintenance;
- environmental performance;
- adaptability/flexibility of design;
- ease of (dis)assembly;
- desirability;
- self sufficiency in terms of water and energy;
- resilience to the impacts of climate change;
- smart technologies.

Life Homes continues research in this field, and by marrying past knowledge with our biomaterials research and life cycle capabilities, the project is very much in the 'future home' space. The Life Home programme complements investigation into physical elements of home, and is concerned with improving functionality and social wellbeing for the occupants through the design of the building system elements, and the materials these are built from.

2.2 Approach

The Life Home approach was established to enhance the ability of Scion (a leader of biomaterials research) to respond to the changing market needs of material users. The built environment is a large end user of timber and plant-based materials. To ensure science relevance to this end-market, especially given materials development lead times, the established future criteria for housing were used as a basis to explore technical implications for materials science.

One of the goals of the research programme is to create a Wellbeing Assessment Framework. While building assessment frameworks exist that account for environmental and economic aspects of a home environment, social elements are less easy to quantify. The assessment framework aims to establish a framework that can account for the social and cultural requirements of a home, thereby establishing a truly sustainable assessment framework.

Another of the main goals is to identify how the impacts of future housing criteria affect various areas of a home environment, and identify key indicators to achieve a more sociable and functional home environment. We are using a series of open discussion forums to aid us in this process.

The criteria were clustered into six key themes which were then explored using Strategic Conversations (refer Figure 1). Strategic Conversations involve a presentation by an expert in the field, followed by a facilitated discussion with the expert to further explore themes and questions arising out of the presentation material. These conversations were used as a basis of more in-depth idea generation, to interpret the criteria themes in terms of how the ideas and issues raised in the Strategic Conversation might impact on five key aspects of the home environment:

- *Shelter/Barrier* - The building envelope consisting of the structural walls, floor and roof, and the linings and detailing which make these elements internally weatherproof.
- *Functional elements* – Those systems which make a home workable (plumbing, lighting, telecommunications, ventilation etc)
- *Living space* – The interior areas of a home [building(s)]where home life occurs
- *The big outdoors* – The outside areas of a home environment, which includes a wider area than the housing lot. It is recognized that a person feels a sense of belonging (calls 'home') to more than the housing lot, but also the street and nearby amenities, and the community/ neighbourhood which they live with.
- *Soul* – the features and design elements which define the character of a home.

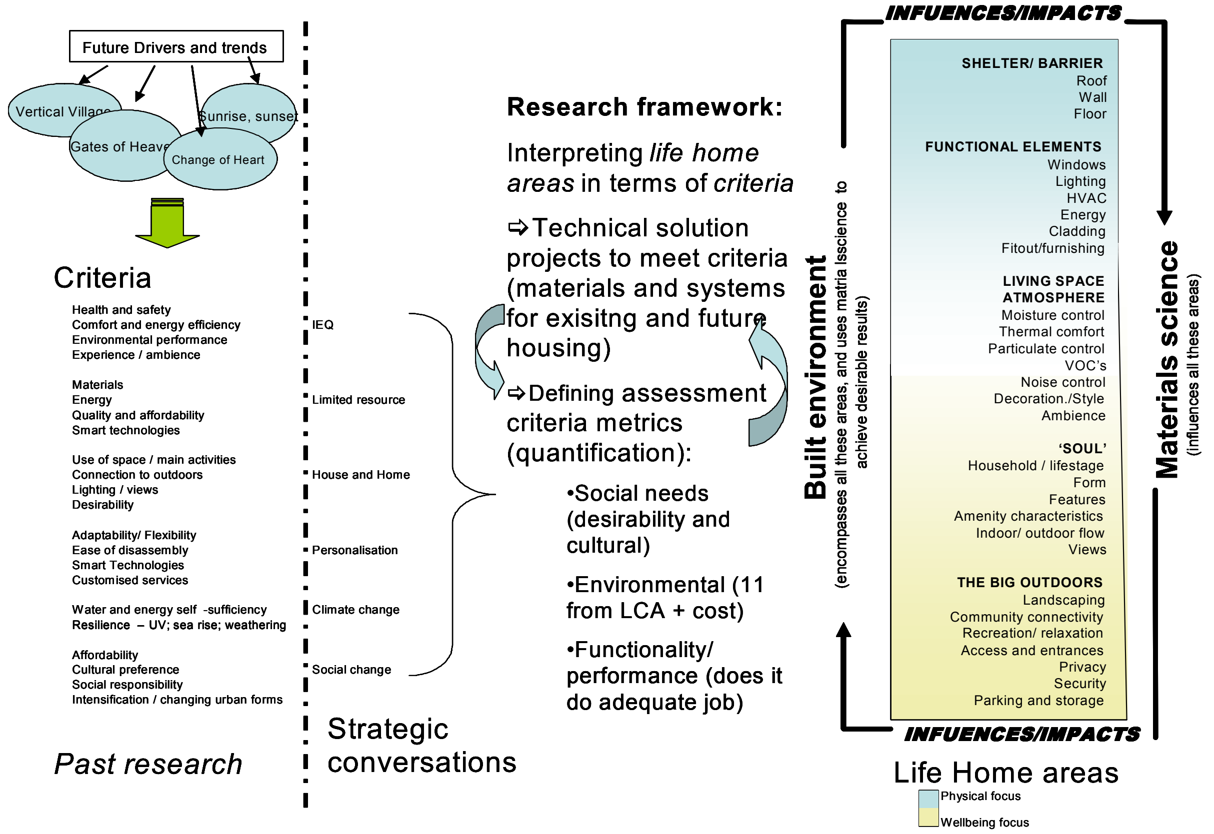

Fig 1: Life Home Conceptual Framework

These discussions also identified potential technical projects which could be undertaken as part of the technical research programme. The ability to enhance the delivery capacity of relevant science at Scion was the major driver in determining the structure of the technical programme. Additionally, the ability to enable cross-functional science thinking through a multi-disciplinary science Steering Committee allowed for the original technical projects which were put forward to be enhanced. Although creditable projects were proposed originally, merging and refining the project ideas that arose by this multi-disciplinary team resulted in a set of projects which were far more robust and encompassed a wider scope of research than had originally been envisaged. Using the criteria and Strategic Conversations as a basis for directing the technical programme, in contrast to brainstorming ideas from scratch or selecting 'plausible' proposed projects saw the establishment of some exciting programmes – none of which would have arrived without going through this process. This selection criteria was a strong one and impacted a lot on the shape of projects proposed. It was so strong that no proposal not addressing the criteria proceeded.

2.3 Outcomes

The initiative to date has identified through the process of Strategic Conversations, and multi-disciplinary refining of ideas, four main technical projects for the initial research programme:

2.3.1 Establishing a Wellbeing Assessment Framework

One of the main goals of the Life Home programme is to create an assessment criteria framework to help develop biobased materials, products or system solutions for the Built Environment, and can aid in project decision-making. This assessment framework needs to incorporate environmental, social and economic indicators. The indicators for environmental and economic aspects are well established through existing tools such as Life Cycle Assessment and Economic modelling. Social indicators, however, are usually subjective, and often due to the intangible nature, are left unquantified.

This project will use LCA methodologies, including the current research involving social components of LCA, to establish a set of criteria and metrics for social aspects of wellbeing in the home environment.
The outcomes will be a novel design framework to increase well being in the home, and at least one new material or build solution to validate the tool. Competency will be enhanced also through increased interaction and learning between the cross functional physical materials science capabilities in Scion, with social science and life cycle capability.

2.3.2 Eliminating mould from houses using natural biocides

Potential health risks caused by mould growth in residential houses is of major concern for home owners and insurance companies. Apart from physical health, significant mental health suffering is caused by mould growth in houses. Wilson et al. (2007) found the incremental health cost of leaky buildings, primarily affecting respiratory and mental health conditions through increased mould, are around $NZ474 million in present day terms.

Based on literature, moisture management remains the most critical factor for controlling mould growth in houses. However, it is unknown if other factors such as cleaning have an impact in inhibiting or promoting mould growth. Chemical fungicides commonly used to control the growth of mould are not often appropriate for indoor applications. Natural alternatives that are user friendly and have no toxicity to humans are therefore desirable for this application. Essential oils are known for their natural components, and are an ancient technology which have long been recognized for their antimicrobial activity. However, little work has been done on the use of essential oils as an anti-*mould* agent.

This project will evaluate the anti-mould activity of essential oil based products and the potential to develop anti-mould treatments for interior wall panel products, or interior surface sprays. The objective of this proposed study is to know the targeted critical measures for certain mould growth and then evaluate the ability of commercially available essential oil for mould inhibition. The project aims to exploit known natural products chemistry (essential oils) in a novel application - to control the incidence and extent of mould growth in housing in New Zealand - and includes testing on a new biomaterials panel to be developed by Scion.

2.3.3 Concepts of Modern Urban Pa

In contrast to the movement towards individual property ownership and separate housing spaces, some Western nations are experiencing a trend of increased communal living and shared use of recreational, food-growing and some living quarters. In many cases, persons of multiple generations, or multi-family groups are sharing the same housing unit or areas of a housing block. This is being driven by affordability; aging of elder generations; younger generations both working and requiring familial help in child raising; and a sense of wanting to belong to a community.

Similar to early settler communities and European villages, traditional Maori housing and village structures were communally based rather than nuclear-family modelled. Traditional Maori society was based on communal living in every respect with the wider iwi and hapu being the primary social reference point (as opposed to the nuclear family). Village location, outlay, functions, and buildings were designed to enhance this communal living pattern.

Maori papakainga developments aim to return the younger generations of mana whenua to reside back within their traditional home areas. However, many papakainga are rurally located, while 80% of Maori are urban-dwelling. It is reasonable to assume that many Maori may wish to remain in the city or urban area within or outside of their rohe, or traditional papakainga sites.

This project proposes to address issues of low Maori buy-in and meaningful ownership of housing, neighbourhood and community by creating a housing model for Maori-appropriate urban neighbourhoods. The model will draw strongly from traditional Maori communal life and marry this with the requirements of modern urban / suburban living including intensified living arrangements. Such a model offers significant potential to help address a raft of social and economic issues Maori face in urban areas, by creating a strengthened urban-Maori community soul based on desirable housing that builds esteem and personal mana, and enhancing the participation of Maori within the urban environment. The urban pa concept is likely to support improved social and economic wellbeing as it is not uncommon to visit Maori neighbourhoods and see poor nuclear family style housing right alongside a communal marae that is impeccably groomed. A similar occurrence is seen with Pacific Island neighbourhoods and their churches.

This project will establish the criteria and generic design brief for an ‘Urban Pa’ development, one that accounts for New Zealand cultural requirements as well as the growing demand for more intensified and multi-family housing design options. The outcomes of this project are expected to offer significant value to non-Maori urban communities, due to efficiencies now being demanded on all types of urban resource consumption, and the ability of more communal living to enhance individual safety.

2.3.4 Sustainable wooden furniture

Over the past 5 years or so, many countries (including NZ) have witnessed a major increase in furniture imports from China (and now Vietnam) with a corresponding downsizing of local furniture manufacturing. The economic sustainability of New Zealand’s furniture industry is threatened by the emergence of these Asian low-cost furniture factories. New Zealand’s balance of trade in furniture has deteriorated by $NZ 200m with steadily increasing imports and little or no growth in exports (Refer Figure 2).

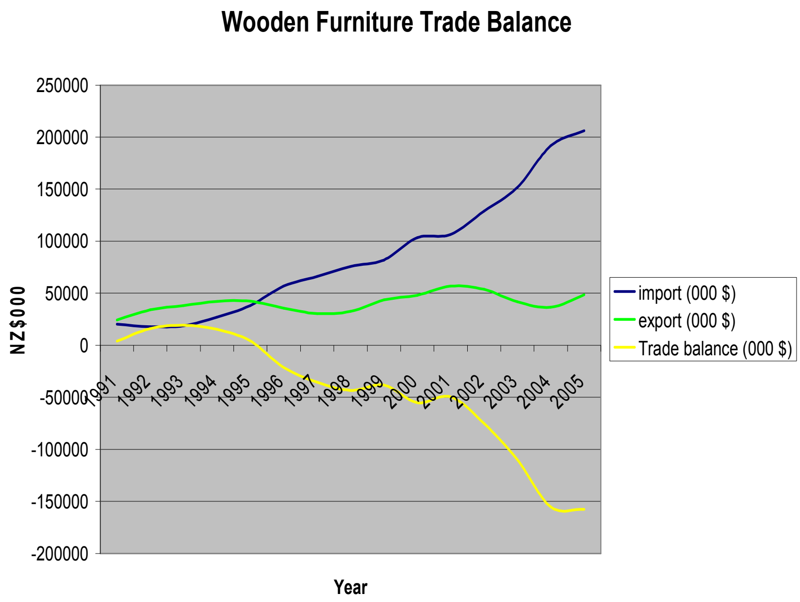

Figure 2: New Zealand Wooden Furniture Trade Balance

The huge environmental cost of furnishing (which may be replaced many times over during the life of a building) over and above the environmental cost of the building structure itself has been recognised by the Green Building Council and Green Star (in Australia) through office furniture rating systems. From an environmental perspective, furniture is coming to be viewed as a growing source of environmental impact. The reasons for this are several fold:

- There is a trend toward more frequent furniture replacement which leads to greater consumption of materials AND increasing levels of end-of-life waste.
- The growth in imports from developing countries is at the expense of use of cheap labour and production techniques which do not require the more rigorous environmental performance of New Zealand's counterpart manufacturing sector (i.e. in low formaldehyde emission control of panel products, and adherence to the Resource Management Act.)
- The use of low-cost materials which have high environmental costs of production (e.g. vinyl) and/or present hazards to the consumer (e.g. coating products).

At a time when "sustainable furniture design" is becoming a point of product/ market differentiation, how is the New Zealand furniture industry best placed to respond?

We aim to investigate the size and nature of the New Zealand furniture industry, drivers of New Zealand furniture ownership, and assess the sustainability impacts of current furniture ownership practices to identify areas that NZ furniture manufacturing industries could exploit to further the use of wood and other biomaterials as a "sustainable design" advantage. The research will provide the furniture industry the tools with which to allow the production of more sustainable (i.e. desirable to consumer lifestyle and environmentally advantageous) furniture products, and in doing so, a more sustainable home environment.

Conclusion

Sustainability is a strong part of New Zealand's current policy arena, which has an emphasis on ensuring sustainable community development occurs and quality of life is enhanced for all New Zealanders. In relation to housing, revisions to the Building Code to include wellbeing aspects, and a cross-governmental push towards social and economic wellbeing in urban developments (including regenerative architecture) supports a 'Life Homes' approach.

This initiative aims to explore in more depth the lifestyle needs of future generations, and to develop through a technical programme, a framework for building system solutions that incorporate bio-based materials to better provide for these requirements. The approach of holding Strategic Conversations around core topic areas, combined with a multidisciplinary steering committee has been central to the technical programme development, and the authors believe this process is responsible for the resultant technical programme being more rigorous and forward-thinking than a brainstorming or symposium approach would achieve alone.

An assessment framework for wellbeing will also allow the social and quality of life aspects of sustainability to be translated into the design of these systems. This will continue our ability to respond to the changing market needs of material users within the built environment.

Glossary of Maori terms

Pa – Maori village community; settlement
Papakainga - homeland, homestead
Marae – meeting grounds
Rohe – regional area
Mana – personal esteem, prestige, authority
Mana Whenua – people with authority over land, local tribal estate

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A PATTERN LANGUAGE FOR A NATIVE INDIAN VILLAGE IN BRAZIL

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Summary

Proposal: It is known that traditional communities strive for living in a land that fulfils the characteristics of their original territory. Such communities are considered very knowledgeable regarding sustainable strategies for the environment they inhabit as they are strongly connected with it. However, according to the literature, the areas usually allocated to indigenous settlements are far from having the carrying capacity required by their traditional way of living. The present work performs an analysis on the behavior of a Mbyá Guarani indigenous community, living in the municipality of Palmares do Sul, Brazil, more specifically on its construction and its space occupancy patterns. **Method of research:** The study was directed towards pragmatic questions and empirical studies in which observation, graphical expression and interviews were the main sources of evidence. The research strategy employed was an action research, aiming at identifying the community real needs and also tried to evaluate the community learning and behavioral changes resulting from the research process. **Results:** Part of the research problem included the approach adopted by the community in the development of projects and constructions for their village. Christopher Alexander´s Pattern Language (ALEXANDER *et. al,* 1977) instructed the construction of a specific pattern language for the community. **Contributions** / **Originality:** It is expected that this study enables a better understanding of the configuration of the Mbyá Guarani villages, built according to their own language.

1. Introduction

The struggle for social justice and cultural autonomy of traditional peoples has constituted one of the greatest research challenges, including practices aiming at the social welfare and the development of such communities. However, through this study, we want to show the existing interdependence conception between the Indians and nature, exploiting the cultural traces nowadays found within the villages. The studied literature indicates that for the Indians the space is based on their relationship with the different geographical and natural elements. The indigenous communities aim at living in lands contemplating all the requirements of their territory, but the inter-ethnic contact brought them to the re-elaboration of many aspects of their culture. The territory configuration of those communities was changed, as the areas where they were located became part of the settlers' demands.

Nowadays, the Indigenous lands are demarcated by the Government according to what is established in the Federal Laws dated of 1988. However, the choices that respond to their spatial preferences are exhausted, driving them to marginalized areas, far from having capacity of giving support to their cultural traits and their subsistence needs. However it is known that those communities have a deep knowledge of sustainability strategies and adaptation to the environment they are used to live, being strongly connected to the natural environment, and, consequently, to the resources found in such places. To characterize the fact, a reflection was made that specifically related to an Indigenous community, Mbyá Guarani, located in the southernmost Brazilian state and its construction and space occupation patterns. The community was chosen for being located in an area where many cultural activities are developed, being strongly influenced by the local ecological conditions.

Part of the survey problem considered the evaluation of the community participation in the plans and construction development in the village. Due to the survey approach, this study adopted Christopher Alexander´s A Pattern Language (ALEXANDER et. al, 1977), as a guide to establish an Indigenous Pattern Language. However, considering that this survey involves the analysis of only one village, it is believed that the patterns, which were found, enable just the definition of a preliminary language. It should be stressed that this article presents a speculative study, an attempt to formulate a list of ideas, and suggests how they could be developed and tested. We hope that other Indigenous ethnics could be analyzed , even with different characteristics from the one evaluated in this survey, making easier more creative plan solutions arise, adjusted to specific and different realities and taking into account their cultural needs.

1.1. Objective

The objective of this article is to define an Indigenous Patterns Language for the Mbyá Guarani community from the village *Yryapú*, aiming at identifying the elements characterizing the environment they live in.

Furthermore, this study is intended to supply elements to demarcate new Indigenous territories and enrich possible plans to be developed within those areas, contributing to the cultural sustainability of Indigenous peoples.

1.2. Building a Language

The idea of a "language" for planning and design is not a new concept. The studies developed by Christopher Alexander have been contributing to this concept along the years. According to Hanson (2005), in 1964 Alexander published "*Notes on the Synthesis of Form*" where he proposes a binary methodology, derived from fledgling computer science to develop a rational basis for the design process (HANSON, 2005). In the following years, he published the article "*A city is not a tree*", in which he considers the urban form mathematically, concluding that the structure of a healthy city is configured by a "semi-lattice" (containing multiple nodes and connections) (HANSON, 2005). In these works, Alexander continued to explore the nature of order, arguing that the majority of designers would equate order with elegance and simplicity, instead of trying to read and understand the more complex structures found in the world. In 1977, Alexander *et. al.* founded the "*Center for Environmental Structures*" and began the work that resulted in the book "*A Pattern Language*" and a series of interrelated volumes (HANSON, 2005).

"*A Pattern Language*" presents 253 patterns, extracted from different traditional cultures, which, combined, admit infinite language possibilities for the development of a plan. The elements of a language are called patterns. Each pattern describes a problem occurring repetitively within the environment, and, finally, it describes the kernel of the solution for the problem, so as to enable the utilization of this solution in different circumstances (ALEXANDER, 1977). Salingaros (2003) shows, in a simple way, that a "pattern" is a recurring solution, which can be a solution for an architectural or urbanistic problem, although also being able to solve other kinds of social or technical problems. The aim of developing a pattern language is to supply a vocabulary of design strategies which allow the efficient communication among architects, designers and customers.

The Alexandrine Patterns, as named by Salingaros (2003), begin with the language defining the city or the community. Those patterns cannot be quickly drawn or built, but they grow gradually, drawn in such a way that each individual action is always helping generate a global pattern and then build a community contemplating those patterns. After that, the part of the language giving form to groups of constructions or individual constructions and the spaces among them is described. Those patterns can be drawn or built. At this stage, the design of a construction is configured. Hence, the site plan is defined, marked on the soil with piles or drawn on the paper, as well as the heights of the rooms, with the exact size and place of windows and doors, the roof inclinations and the garden position. The last part of the language refers to the details, deciding how to make a building from a plan conceived for the site and how to construct it.

It is important to mention that the objective for the utilization of a pattern language consists on the idea that any individual can build, draw, and plan his/her own house, streets or community. However, this idea might be radical, implying in a change in architecture as seen by professionals (ALEXANDER, 1977). Alexander argues that the future depends on those who can learn to apply a pattern language within a holistic structure (HANSON, 2005). According to Capra (2006), the new understanding of life is considered as the scientific front line for the change in paradigm from a mechanicist view of the world to a holistic and ecological view. This change involves a "constellation of conceptions, values, perceptions and practices shared by a community, giving a particular view of the reality, constituting the basis of the way the community organizes itself." (CAPRA, 2006).

"Traditional cultures are far more attuned than ours to the larger wholes to which their buildings contribute. In recovering this sensibility architects must re-learn respect for the entirety of building culture (not just designers), and help those outside the building professions to participate too" (HANSON, 2005). According to Agenda 21 (PLESSIS, 2002), traditions offer examples of well-succeeded constructive patterns, besides the processes of social sustainability for the creation of the built environment based on principles of the proper utilization of materials, communitarian methods of construction and practices of environmental handling. The capacity of communicating patterns, inherent to human beings, enables the creation of an arsenal of knowledge reusable through the drawing. Then, a pattern language is connected to culture and tradition (SALINGAROS, 2003).

Novaes (1983) observes that evaluating the Indigenous house and the perception the members of a determined society have of the space they inhabit is extremely important. First of all, because it reveals the different possible ways of space conception, involving not only the ecological adaptation to the environment, but, especially, because it's possible to prove different ways of appropriation and hierarchization of the inhabited space. Latin America has a great diversity of flora and fauna as well as peoples inhabiting ancestral territories in equilibrium with their surroundings. Rescuing their constructive technologies, village and dwellings patterns may constitute a valuable support for their recognition.

2. Research Method

This article is part of a wider survey aiming at creating a tool to ease the understanding the importance of reconnecting the Indigenous communities with the land they previously inhabited. The present reflection is related with the Indigenous communities Mbyá Guarani under a current perspective. It aims at rescuing patterns of the Indians' interdependence with the environment in order to help in the discussion on the theme of sustainable development and contribute for its recognition. Nonetheless, the objective of this survey is neither to interfere on this people's culture, nor to alter the way they identify and design their territory and site. In this sense, the method was chosen because it is adequate when one intends to work with current subjects, collective and active in character.

Part of this survey is composed by the method of drawing in the practice as presented by Salingaros (2003). To give support to the survey, interviews were performed with anthropologists, EMATER[1] and FUNAI[2] technicians, and other agents working with indigenous communities, aiming at validating the collected data. Furthermore, the data collected empirically were analyzed with multiple evidence sources. However the dialogue constituted a great challenge, due to Guarani´s official language. Some of them, born in Argentina, speak Spanish and Portuguese, but without the same fluency in both languages. This difficulty resulted in strategies to make the communication easier. Interviews made with technicians from EMATER, revealed that the Indians express themselves very well through drawings. Thus, the graphical expression was the main tool of the study. Drawings, panels and texts were worked out in order to register visually what was being treated.

The work was developed in four steps. The **first one** involved activities proposed to the community in order to know more about the local characteristics and they were asked to: draw the VILLAGE TODAY and the DREAM VILLAGE. The **following step** consisted on examining in the literature twelve patterns found in the drawings developed by the Indians, besides other patterns that were verified empirically by the researcher and registered on a notebook. These patterns were shown and discussed with the community, containing adaptations to contemplate specifically the Mbyá Guarani cultural traces. The **third step** discussed new patterns not found within the existing pattern language. The **final step** proposed to put into practice a newly defined pattern language, not performed yet.

3. Analysis of the results

The survey presented in this article shows a network of patterns able to constitute a primary language for the Indigenous community Mbyá Guarani. Instead of describing in details all the patterns, the intention is to synthesize the various patterns found in *Tekoá* (village) *Yryapú*, through the description of the constructed environment observed and presented by the Indians along the drawing activities. Afterwards, the identified indigenous patterns will be described, presenting its name, the problem and the solution.

3.1. *Tekoá Yryapú*

TEKOÁ *Yryapú*, a Guarani name meaning Sound of the Sea, was homologated[3] as Indigenous Land by FUNAI in 2001. The allocated land makes border with private properties where rice is cultivated, pine tree reforested areas, and lagoons next to the coastal region of the State of Rio Grande do Sul. The village has a total 43 ha and is occupied by 26 Indians; eight of them are adults, eight adolescents and ten children. During the study, there were some visits from relatives coming from indigenous lands in the State; a whole family went to another *tekoá* and other family joined the "Cacique Duarte's" family nucleus always present in the *tekoá Yryapú*. The number of the members of an Indigenous Land varies according to its **SPATIAL MOBILITY.** The first Indians established in the region in 1993. In 2000, the first public policies were enforced in the village through the RS Rural Program[4]. In 2002, the Project called "the Indian House" (Figure 1), was put into practice, being developed by the Rio Grande do Sul State Planning Office together with Indians representatives.

Figure 1: Indian's house

Figure 2: Traditional House

Zanin (2006) presented a comparative analysis of the housing alternatives to the indigenous population made by the Brazilian government and their traditional construction. The author states that "the traditional HOUSE is symbolic, being a product of culture and social relations" (ZANIN 2006). According to Alexander *et. al.* (1977), in all cities, regions, neighborhoods or even communities, there are special places symbolizing those zones and the roots people have with such places. The indigenous community recognizes the importance of these SACRED SITES (24), and they valorize places and practices taking into account their cultural trace. Such fact can be observed through the construction of new dwellings and the ***OPỸ*** (praying house) in the *tekoá Yryapú*, made according to the traditional typology (figure 2), respecting the physical characteristics as **SHAPE AND DIMENSION, CONSTRUCTION TECHNIQUE** tuned to the **MATERIAL** available on site and **SOLAR ORIENTATION**. The location of the door is defined by the Indians in relation to the divinity. In general, they are used to making a LOW DOORWAY (224) representing a reverence act and permission request to enter the rooms (PRUDENTE, 2007). The houses built in the *tekoá Yryapú* fulfill the patterns considered traditional by the Mbyá Guarani, taking into account the **WOODEN STRUCTURE**; the roof made of witchgrass; **WALLS** made of hand-made mud, fastening made of vines, and the floor sitting on firm ground.

The constructions built through a **COLLECTIVE SYSTEM** (***potirõ***) reinforce the traditional collective dynamic, including the participation of the community in different construction steps. Looking at this dynamic, it was noticed the participation of children together with their parents, where the knowledge of traditional construction techniques is transmitted orally (**ORAL TRANSMISSION**). In their DREAM VILLAGE, the community members wish to build traditional houses for the elderly, while the youngsters keep on living in the Indian's House, already built in the *tekoá.* The present structure of the village includes ten dwellings, a communitarian center (Figure 3) and a Health Unit (Figure 4), built by the State Government, besides the two houses and *Opỹ* built according to traditional procedures.

According to Ladeira and Matta (2004) *Tekoá Yryapú* presents different elements representing the Mbyá Guarani culture. The authors identify the dwelling nucleus: *Monde* (Mundéo – hunting trap); *kokue* (field); fishing; hunting animals (armadillo); *Kurupika'y* (Bark); *Poã* (Medicinal Herbs); *Yvyra* (wood); *Takua* (bamboo); besides rivers and lakes. Furthermore, the community proposes to food growing large areas, as proposed by the government officials. The community grows witchgrass, abundant raw-material in the region, hence making the *tekoá Yryapú* an important source for many other Indian villages. There is also a support for growing fruits, mainly the native species. The tribal leader, Cacique Duarte observes the importance of orchards. The place near the *Opỹ* is indicated by the gods, according to his statement: "...the gods say this place is good for cultivating our orchards; here the plants will grow". On the same way the *pindó* (palm) is planted by the community along the lagoons. According to the tribal leader, the site that was chosen as determined by the gods and it is very adequate due to the proximity of the water.

The space distribution is made according to the **FAMILIAR NUCLEUS**, as shown in figure 5. In the path leading into the *tekoá* the prominent presence of eucalyptus and pine trees is noticeable. The access occurs through a small sandy path, without clearly defining a proper road. On the way one crosses a brook, where wooden boards, placed side by side, act as a bridge. Passing through two gates it will be possible to see some bee hives, indicating the involvement of the community in honey production.

The main access occurs from a **COURTYARD** that has many functions. It was observed that the spatial planning of the *tekoá* is characterized by the presence of this access courtyard (number 15), directly linked to the communitarian center and another courtyard next to the tribal leader house (number 14). This access courtyard is closely connected to constructions like the Indian's House and the Health Center, made of brick and fenced with metallic bars. Prudente (2007) points out this construction, made by FUNASA, as having a different style from those of Mbyá Guarani' constructions, including the space arrangement patterns, since it uses expensive materials and modifies the village image. Another element also built by FUNASA is the water tank, also fenced and looked after by the daughter of the tribal chief, who is responsible for the addition of chlorine to maintain the water potable and for distributing it to the community through a tap installed in front of the Indian's House. The ACCESS TO WATER (25) indicates that the water comes from the subsoil, from where the water is drawn by manual water pump located next to the lagoon. Alexander *et. al.* (1977) outstand the ocean beaches, lakes and the river margins as sacred places, as they are unchangeable and they advise that their proper use and conservation require a special pattern. Water has symbolic meanings which can be reduced to three main topics: source of life, means of purification, center of regeneration (CHAVALIE, 2007). For the Indians, water is linked to the sound *u*, to emotion (JECUPÉ, 1999). According to Jecupé (1999), the Guaranis say they have the *nhanderekó* (way of being) related to all the aspects of the being. The *nhanderekó* has tempers, linked to four elements, manifesting the humor and determining his personality: earth, water, fire and air. Then, the proximity to water is directly related to symbolic aspects of the indigenous culture which go beyond the water meaning, supplying the body needs.

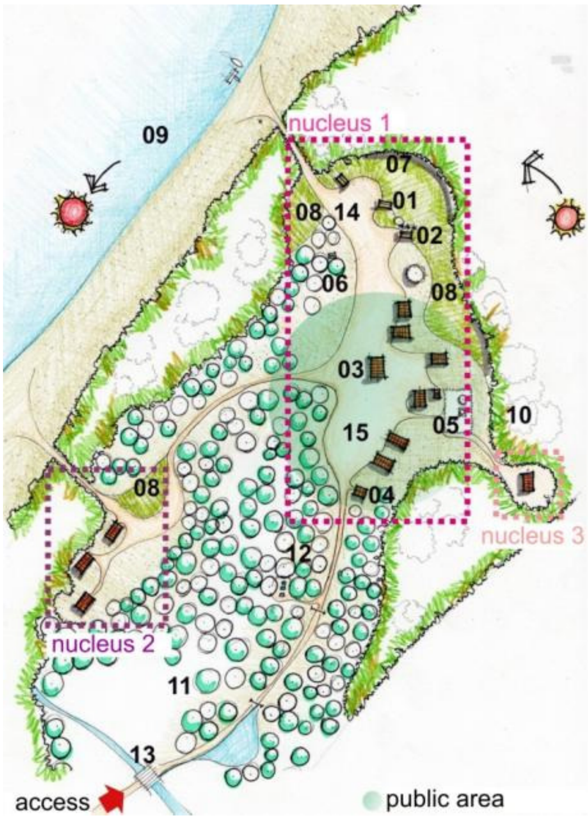
The access courtyard is frequently used for activities as: visitors' reception; children playground; parking area for the visitors; ground fire; a place where they can after lunch continue the tradition of sitting on trunks, benches and chairs distributed in the area. On rainy days, the visitors are invited to enter into the Communitarian Center, where the fire is located with benches around it. The courtyard in front of the tribal leader house is used in different ways: MEN AND WOMEN (27) have distinct tasks. At home, there is always the presence of the woman, who moves between the house and the FIRE (181). The women stay there, preparing the food on a wooden table or sitting around the fire, while the men prefer to stay nearby, mainly in the courtyard, under the trees, where they receive their friends or brothers-in-law, sitting around the fire only at the sunset. Going to the forest for collection or hunting is a male task (LARRICQ, 1993 *apud* ZANIN, 2006).

Figure3: Communitarian Center

It is possible to verify, on the village site, the DEGREES OF PUBLICNESS (36), defined through a more protected area for the community – the courtyard of the tribal leader house, and another one that is less private – the access courtyard. However, Sylvia Novaes (1983) observes that the house is not the reference point to be taken for the construction of the indigenous identity. This is identified by a wider space, the village, or the traditional territorial space of the group occupation. Thus, the house can be considered part of this dominium, being it a more intimate, stricter and more reserved area" (RAPOPORT, 1972), although being place where it is very common for them to sleep together (COMUNAL SLEEPING, 186). Considering that the indigenous house is not limited to the building itself, it is observed that there is an INTIMACY GRADIENT (127), defined by the arrangement of public and private areas, starting from the main access.

Figure 4: Health Unit

There are three familiar nucleus defined in the *tekoá,* (see figure 5), each one with a HOUSE CLUSTER (37) interlinked by PATHS AND GOALS (120), being the PATHS SHAPE (121) marked on the ground according to the Mbyá "tread", crossing forests and corn fields, widened on the section with houses and yards (ZANIN, 2006). The main nucleus next to the access to the village is defined by the presence of the tribal leader and his family. The nucleus number 2, occupied by another family is configured by the presence of three Indian's house type. The nucleus 4 has an available building, built according to the Indian's house type. Each nucleus has its production area, but the food cultivation process is made collectively.



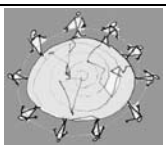
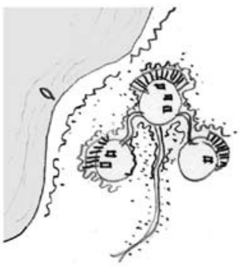
01 – *Opỹ*
02 - Tribal Leader' House
03 - Communitarian Center
04 - Health Unit
05 - Kitchen garden
06 - Poultry yard
07 - Manioc field
08 - Corn field
09 – Lagoon
10 – Wood
11 – Eucalyptus
12 - Honey Production
13 – Bridge
14 - *Opỹ* courtyard and tribal chief house
15 - Access courtyard

Figure 5: Sketch of Indian Village, Tekoá Yryapú

Planting is one of the most important activities for the Mbyá Guarani subsistence and they give priority to the traditional plants cultivation to maintain the species which have been cultivated for centuries, being called the "true" plants. Other important activities for the community *Yryapú* are hunting, fishing, harvesting and craftsmanship. These activities are conditioned to raw-material availability. In the *tekoá Yryapú,* craftsmanship is nowadays one of the main sources of income, being sold in the cities and coastal cities next to the village. However, according to tribal leader Augusto Duarte "... it is dangerous to go out of the village to sell craftsmanship due to assaults, the prejudice we suffer, waste of money for the bus and sometimes we sell not even a small animal craft". Besides selling craftsmanship, the community wishes to welcome tourists in the *tekoá* to share the Mbyá Guarani culture. There is a proposition for the definitions of tracks, crossing the forest, where they can show the traps and the existing vegetation. For the reception of tourists in the village and to make easy the selling of craftsmanship, they intend to build a big turtle-shaped house (*oga guassú karumbé*). At last, they dream of changing the village into a Mbyá Guarani model *Tekoá*,

3.2. An approach to an Indigenous Brazilian pattern language:

Tabela 1: A Mbyá Guarani Pattern Language

	**SPATIAL MOBILITY** It is common the number of individuals in the indigenous communities to vary, due to the cyclic displacements caused by religious, social and political reasons. **Ease the Mbyá mobility through policies favoring free circulation.**
	***TEKOÁ*** *Tekoá* is the place where the Guarani culture can be performed– *Teko*. **Configure villages in forested areas with a water spring, where the *Opỹ* becomes the main element, together with the jungle magnificence, surrounded by several dwellings, built according to traditional practices; verify the sun geometry and implement the *tekoá* according to the preference of the spiritual leader; occupy the woods clearings with the familiar nucleus, where the fire must be present; surround the constructions with squares and field areas; connect them through tracks or roads.**

FAMILIAR NUCLEUS

Besides defining the social and cultural characteristics, the familiar nucleus defines the layout of tekoá, according to its distribution on the local environment. Each familiar nucleus must contribute towards the Mbyá's daily social and cultural activities.

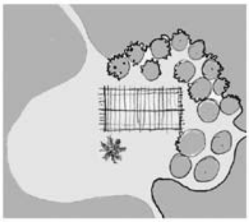
Define the *tekoá* access according to the location of the tribal chief's familiar nucleus which must provide a courtyard to receive the visitors; in the spiritual leader's familiar nucleus, establish the *Opỹ*, with the larger courtyard attached to it; each familiar nucleus shall have an area for houses, courtyard, field, vegetable garden, orchards and animals pits; all of them must be surrounded by woods and connected by paths. It is essential to the Indians' definition of orientation and location of the nucleus.

THE HOUSE

The traditional house is the place for the meals, rest, protection against heat, cold and storms. Most of the time, the house is used only as a bedroom, where all the family sleeps together.

Build houses to reflect the Mbyá Guarani cultural specificities; ease the presence of the fire through the use of natural materials, extracted from the forest surrounding the *tekoá*; supply an adequate thermal, light and ventilation comfort: it must have a rectangular shape with its dimensions varying according to the familiar nucleus that will live in the house; its use, preferably, must be during the night; respect the Mbyá definitions of priorities in the house, such as the solar orientation.

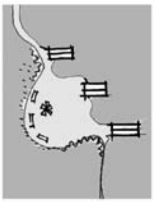
THE *OPỸ*



The existence of *Opỹ* - Praying House allows the practice of dancing and singing, elementary exercises devoted to obtaining the religious fervor and essential conditions to acquire spiritual fortitude and value.

Build the *Opỹ* being the center of *tekoá*, not geometric, next to a *pindó* (palm tree), in a place with privacy, surrounded by fruit trees; across from it, put a square; the solar orientation must be with the door to the setting (or according to the determination of the spiritual leader); protect the building with a rectangular traditional-wooden fence using the stud and mud technique for the joints and witchgrass or bamboo for the gabled roof.

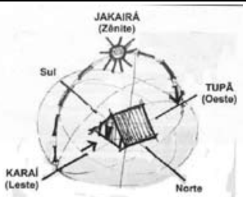
THE COURTYARD



The courtyard is a semipublic place of each family; it is the transition from the public communitarian space to the private space, inside the building.

Delimit the area of each familiar nucleus and, consequently, the space of the courtyard will be defined surrounding the houses. The courtyard must be defined to enable the contact among the householders. Define a courtyard around the *Opỹ*. Distribute benches and wooden trunks to receive the visitors.

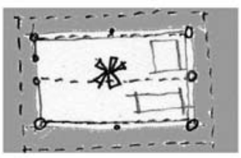
SOLAR ORIENTATION

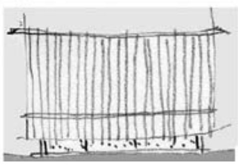


The sun is the cosmologic divinity, called *Nhamandú.* The house represents the *tekoá* life, fed and protected by the sun.

From the position of the door, orientate the house taking into account its relation with *Nhamandú*, varying between east and west. Let the decision of the adequate orientation to the *karaí* (spiritual leader).

DIMENSION AND SHAPE





Considering the climatic conditions, the availability of certain materials and appropriate technolgy, the factor contributing to the origin of a dwelling shape, that also models its spaces; its dimensions are a representation of the vision the people has of ideal life.

Build houses taking into account socio-cultural factors, climatic conditions, constructive methods, available materials and technologies. The traditional house has reduced dimensions and the shape is configured by walls covered by a gable roof, with the eaves almost touching the soil.

The dimensions of the house can vary:

- **3x4 m (12 sq.m.), lodging small nuclear families.**
- **4x5 m (20 sq. m) or 4x6 m (24 sq.m.), ideal to shelter bigger nuclear families.**

Build the *Opỹ* following the shape of the traditional house, but with larger dimensions sufficient to lodge all the community in its interior.

COLLECTIVE SYSTEM

The collective activities, known as *potirõ* – collective work dynamic – correspond to a celebration and collective event of mutual action.

Call a big group of relatives who will live in the house. Call an expert in construction to manage the construction process; the invitation can include the other dwellers of the tekoá, even dwellers from other indigenous communities; the dwellers of the house shall make food and lodging available to the participants. Stimulate the changes and knowledge transmission among the people involved.

ORAL TRANSMISSION

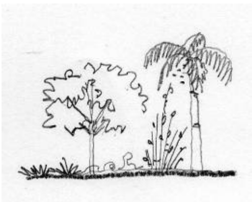
The knowledge of transmission is transmitted through practices and histories told by the elderly around the fire.

With the construction of dwellings, stimulate the transfer of traditional constructive knowledge to children and youngsters; enable the awakening of their aptitudes.

CONSTRUCTION TECHNIQUE

Technology is a resource to adjust to the environmental conditions, enabling the adaptive diversification.

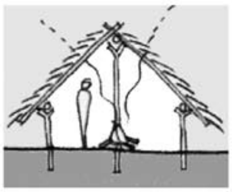
Make possible technologies demanding collective processes and consequently reinforcing the social rituals, make use of techniques adapted to the constructive materials available in the area.



MATERIAL

All the constructive materials are natural resources available in the Atlantic Forest's biome associated with symbolic and cultural values.

Use vegetal species and clay. In the *Opỹ,* choose sacred species preferably, such as: cedar (*yary*), the queenpalm (*pindó*) and the patagonula americana (*guajauyui*). Other materials which can be used are: the sweetwood (*ajuy*), mabola persimon , piptadenia (*kurupá pitá*), bamboo (*taquaraçú*), muskwood (*yywata'y*), cinnamon (*yvyra ovi*), vine (*yxypó eté*), witchgrass (*capi*), eugenia (*yva viju*), myrtaceous tree (*guavira*), philodendron - vine (*wembe'pi*), Brazil cherry (*anhangapiry*), stink insect (*takua ete i*) and dicksonia fern (*xaxim*).



WOODEN STRUCTURE

Wooden structure in Guarani is *oó ita*, *oó* meaning house and *ita,* base. *Itá* is the foundation stone sustaining the basis of the 'second earth' (*Avy Apy*) – the world they live today. *Itá* is related to solidity, stability and solid basis to the house (*oó*).

Pick arboreal species in the nearby forest, between 10 and 15cm in diameter, 2 and 3.5m in length, considering 1m more for the foundation. For the columns, choose trunks with one of the extremities in a fork shape to support the beams. Strip the bark from the trunks.

Build a rigid frame system with beams and columns, composed of three elements symmetrically arranged, using the bigger ones for the central portico and the smaller for the side porticos.

For the roofing, make available wooden rafters arranged perpendicular to the porticos. Tie the parts to the porticos with vine fastenings. When necessary, make grooves to fix the elements better and support the bamboo lathes longitudinally.

WALLS

The walls (*oó korá*) are very heavy, made of stud and mud, allowing the visual contact from the inside to the outside, hiding the dwelling interior spaces. The constant ventilation brings noise and smells with it.

Coat the building with round wooden trunks or bamboo. Dig a ditch 15cm deep and 10cm wide, approximately where the parts must be embedded and fixed vertically. Tie the parts with vine and apply a clay layer using the hand-made mud or coat with palm leaves.

4. Final considerations

The Mbyá Guarani indigenous community manifests the experience of its cultural trace through its interdependence relation with nature. It has the consciousness it is a part of the whole universe, fact mainly revealed by its spirituality. It values its symbolic and cultural elements using the oral tradition, aiming at transmitting to the future generations the elementary aspects of *nhanderekó* (way of being), thus, maintaining its culture alive. However, the non-indigenous society doesn't recognize this cultural trace. In this sense, this work tries to show in a summarized way some of their characteristics and their built environment, as a contribution on the discussion of sustainable development.

Some ideas of patterns of construction and space occupation are also presented, as dictated by the Mbyá Guarani's cultural trace. This work does not intend to clarify the deep and complex relation network existing between the Indians and the environment where they live, but it aims at trying to configure them as patterns. The experience is far from reaching the proposal presented by Alexander *et. al.* (1977), but, starting from this initial step, the work can develops, it is possible to consider and dream with more advanced results, reflecting the Mbyá Guarani's cultural sustainability and, hence, contribute to the re-evaluation of unsustainable patterns found in the current non-indigenous society.

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1 EMATER is the Rio Grande do Sul State Association on Technical Assistance and Rural Extension. (www.emater.tche.br).

2 The Indigenous National Foundation – is a Brazilian Government department which establishes and executes the Indigenous Policy in Brazil.

3 Source: Center of Indigenous Work – CT - I in 2004 – Guarani Lands at the Sea Coast – the area of tekoá Yryapú was homologated according to Decree without number, dated of 04/18/2001.

4 Program aiming at improving the natural resources management and preservation, through an integrated strategy for the adoption of sustainable practices on soil and water.

ARCHITECTURE IN THE WILDERNESS: RECONCEPTUALISING PLACE THROUGH INTERPRETIVE ENVIRONMENTS

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Summary

Ecotourism is a burgeoning sector of the tourism industry and has been hailed as the fastest growing tourism sector at the end of the twentieth century and into the new millennium. One of the four criteria that differentiate ecotourism from the broader field of nature tourism is the objective of interpretation and education. Primarily this objective is concerned with the provision of information through a variety of textual, pictorial and verbal means. However, the opportunity also exists to consider a more active and reflexive form of interpretation through the design of the built infrastructure that supports and frames the tourist experience. The relationship between architecture and interpretation is implicitly recognised within ecotourism design guidelines but remains constrained by a dominant framework that views culture and nature as ontologically distinct realms. Nowhere is this relationship more pertinent or problematic than in the design of infrastructure within national park boundaries. This paper explores the complex question of the insertion of cultural artefacts within perceived 'wilderness' environments through a case study of the Overland Track located within the Tasmania World Heritage Area. Employing a visual-based methodology, the research shows how the built environment contributes to the interpretive experience of place and how this can result in a questioning of human/environment relations.

1. Introduction

Ecotourism is a burgeoning sector of the tourism industry and has been hailed as the fastest growing tourism sector at the end of the twentieth century and into the new millennium (Honey et al 2002). It is generally associated with pristine, remote places that exhibit cultural and, most particularly, ecological difference and it offers a relatively guilt-free environment in which to satisfy the desire for travel and adventure. The discourse is firmly entrenched within the dominant conception of sustainability, where nature is seen as a privileged 'other', untouched by humans, or at least by industrialised society (Hovardas et al 2006). Images of ecotourism destinations celebrate this ideology through the promotion of 'pristine' environments; however, a more complex question arises in relation to the facilities that support the tourist encounter with the natural environment.

Inevitably, the construction and operation of any facility results in impacts on the natural environment. Thus, the goal of the various ecolodge guidelines is to follow well-established sustainability principles that aim to minimise these impacts (Crabtree et al 2004, Mehta et al 2002, Hawkins et al 1995, Drumm 2004, Hyde et al 2005, Andersen 1993). This ideology of minimal impact and of nature and humans as ontologically distinct realms is also evident in the various references to the preferred aesthetic in the design of ecotourism facilities. For example, the International Ecotourism Standard states "Architectural and landscape plans shall ensure that ecotourism buildings and infrastructure are compatible with the physical and cultural landscape" (Crabtree et al 2004:9). Although there is a general lack of clarity on the intention behind such statements, there is an evident preference for a regional vernacular approach and a desire to 'blend-in' with the surroundings.

The lack of information on the issue of image and identity in the design of ecotourism facilities is not surprising since the primary focus of ecotourism is the external 'natural' environment and not the cultural artefacts of those who wish to visit. As Ceballos-Lascurain argues, "the most important thing about an ecolodge is that the ecolodge is not the most important thing" (quoted in Beyer 2003: 4). Thus, a common image within the niche ecotourism market is architecture that is minimal, temporary and insignificant. Nevertheless, the design of built infrastructure in ecotourism destinations still maintains a high degree of importance. For example, as Peace (2005: 321) argues:

> The promotion of ecotourism demands a higher degree of creativity than most other tourist sectors because the particularities of place have to be presumed to play a pronounced part in the choice of

destination. Ecotourists, it has to be assumed, are more concerned than most about the physical and aesthetic properties of locations in which they will spend their leisure time.

This low-impact approach to design is not problematic in itself, but it misses the opportunity to engage in a more 'regenerative' relationship with place. The term 'regenerative design' has emerged in recent years to challenge the perceived inadequacies and stasis inherent in the concept of sustainability (Lyle 1994, Moore 2001). Although sustainability is not tantamount to efficiency, the use, misuse and consequent renegotiation of this term has resulted in a reduction of its potency. Regenerative design diverges from this perception of sustainability in three key ways (Owen 2007). Firstly, it shifts the frame of reference from minimal to positive impact. Secondly, it questions human/environment relations based on the Cartesian separation of subject and object. Thirdly, it attempts to reconnect environmentalism with a socio-political dimension, which has been lacking in much sustainability discourse.

Thus, a regenerative approach to the design of ecotourism facilities should be focused on more that minimising impacts. Although these will inevitably form part of the pragmatic considerations such as siting, passive solar design and the use of renewable energy technologies, there are other opportunities for architecture to engage in a more productive engagement with place. One key opportunity is the relationship between architecture and the construction of meaning of place and identity (Owen 2007).

Interpretation and education is one of the core tenets of ecotourism that distinguishes it from the broader field of nature tourism. Primarily this is focused on a didactic form of interpretation based on brochures, signage, exhibitions and tour guides. However, the built environment offers other opportunities to engage in a more reflexive form of environmental awareness. The role of architecture in contributing to this imperative is implicit in the Design and Construct Standard within the premier global tourism benchmarking and certification program Green Globe, which promotes the goal of "Enhancement of the user's understanding and integration with the natural and social environments" before identifying the design of the 'architectural style' as a one of the key strategies to achieve this aim (Hyde et al 2005: 45).

There is a danger that such an agenda can be read as promoting a direct and universal experience of the world. Indeed Andersen (1993: 131) alludes to such grand aspirations by positing that "Properly designed, the ecotourism facility can become the window for human awakening to the world". I do not want to suggest that buildings can be 'read' like texts. As Leach (2006) argues, they are necessarily 'prelinguistic'. Nevertheless, architecture is inevitably part of any tourist experience and its role in the construction of meaning of place and identity cannot be dismissed (Lasansky et al 2004, Urry 1990). It does not simply address societal visions, but its very manifestation also serves to limit and structure the forms that these visions may take (Dutton 1996). This occurs not only through the visual realm, but also through other senses such as smell and sound, as well as the ritual activities and social relationships that the buildings support.

This dynamic and dialectical relationship between architecture and society is frequently debated within literature on place (for example Casey 1993, Malpas 1999). However, within sustainability discourse in general, and ecotourism discourse in particular, it is commonly ignored. Although certain theorists and designers have attempted to negotiate the culture-nature divide that is endemic within environmental and ecotourism discourse (for example Owen 2008), the uncritical ecological naturalism is a position that persists in the design of ecotourism facilities.

Nowhere is this culture-nature divide more strongly represented than in the design and construction of built infrastructure in wilderness environments. The term 'wilderness' is a highly contested term (Callicott 2003, Callicott et al 1998, Proctor 1998). It is generally conceived as a place that exists beyond the borders of civilisation and which remains free of human intervention. This notion is critiqued both from the practical perspective as to whether any such places actually exist, and from the theoretical perspective that challenges the ontological separation of humans and nature. A full review of these arguments is beyond the scope of this paper. Various definitions are possible to distinguish areas in which land, waters, flora and fauna remain relatively intact and 'untrammelled' by humans. Nevertheless, rather than the physical identification of wilderness zones, of greater significance for this paper is the emotional connection with the concept and experience of wilderness environments which can vary from person to person.

This paper explores these perceptions in relation to the design of built infrastructure in 'wilderness' environments through a case study of the Overland Track in Tasmania. The paper firstly addresses the background to the Overland Track and the visual-based methodological approach before discussing preliminary findings from the field research.

2. Overland Track

The Overland Track is Tasmania's most iconic and popular walking track with a significant profile both nationally and internationally (Whight et al 2006: 1). It is located within the Tasmanian Wilderness World Heritage Area, which comprises approximately 20 percent of the total land area in Tasmania and extends across a large area of the central-west and south-west of the State from Cradle Valley in the north to Cockle Creek in the south (Parks and Wildlife Services 1999).

The Overland Track itself connects the two ends of the Cradle Mountain-Lake St Clair National Park over 62.5 kilometres of walking trail. Although the area is now protected as a National Park, it was used extensively for trapping, logging and mining activities prior to its current use for recreational tourism. Tourism in the area first focused on Lake St Clair after it was 'discovered' by Frankland in 1835. Subsequently, in the early 1900s, tourism extended to Cradle Mountain with the establishment of the Waldheim Chalet by the pioneering tourist operators the Weindorfers (Byers 1996). Commercial interests in the region perpetuated well into the 1900s; however, increasing protection measures were enforced from the establishment of the area as a Scenic Reserve in 1922 and a wildlife sanctuary in 1927 (Byers 1996).

For some time, the two 'ends' of the park at Cradle Valley and Lake St Clair remained distinct and were administered separately. While several pioneers made crossings between the two ends, it was not until 1937 that the official linking of the two reserves via the newly named 'Overland Track' was completed via a marked walking trail. Administration for the park as a whole passed into the control of the Cradle Mountain-Lake St Clair National Park Board in the mid 1900s (Byers 1996). However, the division of the north and south zones perpetuated in the administration of the track itself by two separate field centres and it was not until 2003 that the Overland Track was managed as a single operation (Whight et al 2006).

The Overland Track is extremely popular, particularly during the summer months, attracting approximately 8,800 walkers annually (Whight et al 2006 based on 2004-05 data). Of these approximately 90 percent are independent walkers with the remaining 10 percent comprising guided walking groups. The popularity of the walk has led to the implementation of controls on the number of walkers from November to April. During these months, numbers are restricted to 60 people departing per day and all walkers must travel from north to south. The majority of the walkers are Australians from interstate (57 percent), followed by international visitors (35 percent) and Tasmanians (8 percent) (Whight et al 2006 based on 2004-05 data). The walk attracts visitors who have low levels of prior bushwalking experience, the majority of whom are aged in their 30s and come from professional backgrounds (*ibid*).

The length and popularity of the walk has seen the construction of a large quantity of infrastructure to support the tourist experience and to limit damage to the natural environment. In recognition of the intensity of occupation and consequent impact on the environment, the Overland Track is designated as a 'recreational zone' along a 1km wide corridor as distinct from the adjacent 'wilderness' and 'self-reliant recreation' zones. All Overland Track infrastructure is contained within this narrow corridor. Most significant built interventions are established at five key overnight nodes comprising Waterfall Valley, Windermere, Pelion, Kia Ora and Windy Ridge. An additional overnight node is available at Narcissus Hut for those who choose to walk the last section of the track rather than catch the boat across Lake St Clair to the Visitor Centre at Cynthia Bay.

At overnight nodes, huts, tent platforms and toilet facilities are provided for visitors. 'Free' camping is not permitted and in several cases raised boardwalks connect all key facilities at overnight nodes to minimise environmental impact. In addition, all waste, including toilet waste, is flown out by helicopter. Other forms of infrastructure along the Overland Track include various forms of track construction such as timber and stone steps, walkways in local and imported timber, treated pine boardwalks, hardened track junctions, raised earth causeways and a variety of bridges from simple bush timber logs to steel suspension bridges (Whight et al 2006). Limited signage and track markers are also located along the route including directional signage, locational signage and revegetation signs and snow markers. Where possible this signage is limited with further orientation and interpretive signage being restricted to overnight node locations.

Much of the track infrastructure has been implemented in a haphazard fashion and much of the current infrastructure is deemed 'unsympathetic' to the environmental context (Whight et al 2006). Major upgrades of huts and tracks were undertaken in 1986 and in 2005-6. However, the inconsistencies in approaches to infrastructure, particularly between the north and south ends of the track, are deemed to be problematic. As a response to this situation, the Tasmanian Parks and Wildlife Service produced a Draft Recreation Zone Plan in 2006 that outlines the strategic direction for planning and management of the Overland Track over the next ten years (Whight et al 2006: 2). One of the key aims of the vision for the track is that it will be a "distinct product that can be differentiated from other walking opportunities in Tasmania" (*ibid*: 6). To fulfil this aim, it is proposed that the track infrastructure, including huts, tent platforms, signage, and the track route, format and construction, be designed around consistent and recognisable themes based on the unique patterns of landscape, weather and historical occupation (*ibid*: 35).

The plan recognises the significance of the design of infrastructure on the quality of the aesthetic experience for the visitor. Although the report is replete with objectives of engaging with a 'sense of place' the specific guidelines for the design of the track infrastructure are more prosaic, promoting the popular minimal impact approach. This is emblematic of the limitations of design guidelines to describe such complex phenomena. Therefore, this research was undertaken with the support of the Tasmanian Parks and Wildlife Service to provide an alternative insight into the perceptions of place in relation to the design of built infrastructure in wilderness environments.

3. Methodology: Visual-based Research

The broad epistemological framework for this research is interpretivism, which is concerned with role of the agent in the construction of knowledge and meaning. This perspective acknowledges that there is no universal experience of an event or place and aims to give voice to different points of view that may otherwise not be heard (Bijoux et al 2006: 47). While this is a common position within the social sciences, there are numerous conceptual frameworks and research methods that are employed in order to interrogate the relationship between agent, experience and meaning.

This research employs a visual-based method as a means to extend interpretations commonly gleaned from language-based approaches such as interviews. While visual-based research has a relatively long history in anthropology, sociology, psychology and action research, it remains marginal to more conventional approaches (Bijoux et al 2006). It has also received very little attention within the field of tourism (Tussyadiah et al 2007, Balomenou et al 2007). Nevertheless, it is gaining in popularity in recognition of the benefits that it offers in a field that is dominated by the power of the visual image (Jenkins 2003).

Visual-based research comprises a series of methods including video and film, photography, drawing and mapping, and design as research. The majority of methods have focused on the researcher as the primary generator of the image (for example Prosser 1998). An alternative approach, in which the participant takes a more central role in the research, is self-directed photography, otherwise known as auto-photography, volunteer-employed photography, and reflexive photography.

This research method offers several advantages including the possibility of involving participants more closely in the research task, giving greater power and control to the participant, promoting participation through this empowerment, sharpening observation of the participant and overcoming the inadequacies of language (Bijoux et al 2006, Dodman 2003, Aitken et al 1993, Moore et al, Noland 2006, Balomenou et al 2007, Tussyadiah et al 2007). It is particularly appropriate for situations that involve the description of abstract concepts – such as the perception of place – since it provides an alternative to the verbal description of such complex phenomena.

There are also several potential disadvantages that must be considered. Since primary control is handed over to the research participant, results can be highly varied and not necessarily align with researcher expectations and interests (Bijoux et al 2006: 51). Thus the results can be highly subjective and differentiated, although this can also be an advantage when investigating people’s perceptions, particularly for initial exploratory studies (Balomenou et al 2007). The research method also involves a substantial amount of commitment of time and effort from research participants restricting sample group size (Bijoux et al 2006). Finally, although the use of cameras involves a minimum of training in most situations, the technology can be restricting and intimidating (Balomenou et al 2007).

The photographic images can be seen as a form of ‘text’ to be read and thus their meaning is constructed by both maker and viewer (Dodman 2003, Aitken et al 1993, Jenkins 2003). This can place increasing bias and power back in the hands of the researcher. To counter this tendency, self-directed photography is commonly combined with a verbal-based research method such as interviews and focus groups (Kerstetter et al 2007). However, in the tourism context such approaches are rarely feasible given the geographic diversity of the research participants. Nevertheless, further insight into the construction of meaning can be obtained by the use of solicited diaries in combination with self-directed photography (Bijoux et al 2006). In these diaries, participants are asked to provide further reflection on the content of the photograph and the reason for taking it.

For both content of photographs and diary reflections, directions are frequently open rather than prescriptive, but are directed along particular themes of interest (Bijoux et al 2006: 49). For the purposes of this research, participants were asked to document their perception of infrastructure on the Overland Track using a disposable camera by taking photographs of built interventions that provoked some kind of response. They were advised that built interventions could include examples of any type or scale that they liked or disliked or that they thought promoted either a connection or a disconnection with the environment. They were also asked to provide further reflective commentary in a booklet with approximately one A5 page per photograph.

Since this is a preliminary exploratory study, participant numbers were limited to ten visitors and four rangers. All tourists were selected from independent walkers over a period of two days in the peak summer season. This constitutes approximately 10 percent of all independent tourists departing over this period. Where possible, preference was given to the inclusion of a diverse mix of international, national and local tourists, of various ages and of both genders. Similarly, the rangers were selected as a representation of both genders from the north and the south ends of the Overland Track.

4. Perceptions of Place: Preliminary Findings

At the time of writing, data collection and analysis are still being undertaken. Thus far, 60 percent of tourists and 50 percent of rangers have returned the cameras and diaries. Of the tourists, three are male and three female, five are from overseas and undertaking their first walk on the Overland Track, with one being an inter-state regular bushwalker on the track. Most are professionals in the age range of 20 to 40 reflecting the general demographic of tourists on the track, with one participant over 60. The rangers are both male and are located at the north and south ends of the track.

A total of 130 photographs have been received with each participant taking between 6 and 24 pictures apiece. Of these, the majority explored a positive relationship with place (56 percent), with only 15 percent negative and the remainder representing mixed feelings. The main area of interest appears to be related to the track surfaces themselves (27 percent), closely followed by huts (23 percent) and signage (22 percent). The remainder are concerned primarily with tents and general infrastructure including toilets, waste and water collection.

The track represents perhaps the most direct relationship with built infrastructure on the walk, engaging the visual as well as acoustic and tactile senses. The varied and uneven surfaces draw the focus of attention from the ‘world out there’ to a more immediate and extremely localised frame of reference:

> *“It seems strange when there are so many stunning views that I need to look at my feet so much of the time. This scale of experience is often not thought about alongside wilderness.”* 9:3

This intimate 'scale' of experience provoked a range of comments from participants, from recognising the love, care and 'artistic' personality that has been put into the design and construction of the track, to an awareness of water flows, weather patterns, the impact of human occupation, the power and omnipotence of nature and the relationship between body and space (Fig. 1). Primarily these experiences were positive, promoting a stronger connection with the environment. However, there were also instances of disconnection, for example the connotation of highways through the use of bitumen-coated planks and the raised boardwalks that construct a direct physical separation from the landscape.

Figure 1 Intimate scale of experience on the track: body and space

Features such as boardwalks, bitumen planks and bridges prompted a mixed response from walkers, representing a conflict between a desire for safety and convenience versus a desire for adventure, as well as a desire for minimum intervention and a simultaneous recognition of the need for intervention to maintain the bushwalkers code of minimal impact.

A similar ambivalence featured in discussions surrounding the toilets, which are one of the more iconic and recognisable built features on the track (Fig. 2). The toilets are raised composting toilet structures, similar to those found in many National Parks in Australia. As a low-tech and familiar sustainable technology, these are seen as being appropriate in remote environments. However, the plastic 'sputnik' containers, which are used to remove the liquid waste by helicopter, present a more confronting image. For one participant, they provoked debate about social versus environmental priorities:

> *"Should we have to take ALL our waste with us??... How far do we take the pristine wilderness thing until we start excluding everyone?"* 9:9

Figure 2 Composting toilets and 'sputnik' waste containers, Pelion

Conversely, for this same participant, they also drew attention to the "*reality of the remoteness*." Thus, such 'alien structures', as another participant described them, also have the potential to reinforce the idea of a 'wilderness' experience. Discussing the ranger's quarters at Windy Ridge (Fig. 3), this participant stated:

"This pod is just cool…. I would say my sense of place at Windy Ridge hut has been increased because I will remember the "escape pod"…. Although it may not seem very rustic in terms of accommodation, it is still a unique aspect to the trail." 8:10

Figure 3 Rangers 'escape pod', Windy Ridge

The participant recognises that the accommodation departs from the accepted 'rustic' image of infrastructure in the wilderness. Nevertheless, it is still seen to reinforce the experience of place by providing a point of differentiation. The idea of the 'escape pod' also connects with other even more remote 'wilderness' worlds such as the deep ocean, polar regions or outer space.

Although the Overland Track is situated in a relatively remote region of Tasmania and surrounded by an expansive area classified as 'wilderness' the popularity of the walk led several participants to question the idea of a wilderness experience, with one participant arguing that it should instead be promoted as adventure tourism. While this participant was frustrated by the quantity of people on the track she also advocated improved facilities such as more huts, cooking shelters and even picnic tables at campsites.

Generally, overnight nodes prompted less criticism concerning the extent of human intervention. Aesthetic preferences remained framed in a desire for 'rustic simplicity', however this was contrasted with a desire for comfort and a tolerance or even welcoming of social interaction. Rather than the wilderness experience of the 'world out there', here photographs and comments focused on cultural metaphors of place. Participants appreciated the 'creature comforts' of the bench and the verandah as a point of mediation between 'home' and 'away'. For one international visitor, visually appealing huts reminded her of 'Swiss chalets' and 'neo-colonial African buildings' although her ultimate quest was to find 'Australian architecture'. For locals, huts and their associated infrastructure were more readily recognised as being grounded culturally in place. The 'Swiss chalet' is in fact Du Cane hut, an early example of pioneer building on the track and an icon of history for one of the rangers (Fig. 4).

Figure 4 Du Cane Hut

The meaning of the built environment is inevitably open to multiple interpretations in response to cultural norms and individual experience. Such ambiguity is not always desirable and more didactic forms of communication are also employed, particularly in the form of track markers, locational signage and environmental management information. The provision of such information is a balancing act between minimal intervention and effective communication. While the balance was generally seen as appropriate, in some instances communication was seen to be compromised. For example, a tin can on a stick provoked a positive response from one participant as 'rubbish' turned into 'wilderness way-finding infrastructure', while for another the same device was seen to provide insufficient security for a solo traveller.

5. Conclusion

The aim of this research was to explore how the built environment contributes to the interpretive experience of place. As these preliminary findings demonstrate, although more direct forms of communication are inevitably required, the built environment does provide an additional layer of interpretation that facilitates a more personal and reflexive engagement with place.

In particular, the experience of walking on the track itself prompted quite wide-ranging interpretations of place that extended far beyond the immediate frame of reference. The visual image remains the most powerful device drawing on both direct as well as symbolic connections (the tarmac road, 'artistic' personalities'). However, the interpretive experience is also enhanced by engaging the other senses, in particular the relationship between body and environment, which forces the more intimate and localised engagement with place while walking on the track.

At a more abstract level, the research demonstrates how the built environment can support the regenerative agenda of questioning human/environment relations. Rather than the 'low impact' approach to place, it was often the more confronting images, such as the scale of the toilets and the waste containers that prompted such consideration. These images do not necessarily provoke a negative response, but reveal complexities and ambiguities over the extent to which intervention is seen as necessary and desirable and the value of social versus environmental priorities. Furthermore, the insertion of 'alien technologies', such as the 'sputniks' and the ranger's 'escape pod', are not necessarily divorced from the experience of 'wilderness' but also reinforce images of isolation and unfamiliar worlds 'out there'.

These preliminary findings suggest that further investigation is required into the interpretive experience of place through the built environment. They also suggest that the dominant objective within ecotourism guidelines to produce a 'compatible architectural style' is limiting both for the interpretive potential of more confronting images as well as for the contribution of senses beyond the visual.

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USE OF STEEL-MAKING CO-PRODUCTS AND ORNAMENTAL STONE-CUTTING WASTE IN THE PRODUCTION OF LOW IMPACT MASONRY COMPONENTS

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Keywords: Sustainable building; steel, co-products; components; LCA.

Summary

In order to intensify the use of industrial and mining wastes in the building sector as an environment friendly strategy, a research project was carried out to explore the possibilities of using different alternatives as raw materials to produce low impact construction components.

This paper refers to the segment of such research dedicated to development of pressed bricks containing different types of co-products and wastes from steel-making and marble and granite industries. The piloted mixes originated four experimental mixes that used wastes as binders, activators and different aggregates grading fractions.

Obtained physical, mechanical, durability and environmental characterization results for the bricks showed the potential for application as non-load bearing masonry components, with several possibilities for pigmentation and architectural composition. Simplified LCA analysis compared the environmental impacts associated to the production of the three types of bricks, making the superior performance of the proposed components evident. Industrial property protection applications were submitted concerning mixes, components and production processes.

1. Introduction

The awareness that the economic activities in the planet cause environmental problems deriving from waste generation, not always adequately disposed off, motivates the need of public policies so as to direct its use potential to decrease the consumption of non-renewable raw materials.

An adequate approach to the problem lies in the development of technologies and products aiming to reduce wastage generated in the whole productive chain, resulting in economically competitive solutions which also perform efficiently technical and environmental perspectives.

In this sense, the construction industry is an excellent ally, for being responsible for the production of assets and services with significant economic and social contributions, since it participates with 14.5% in the Brazilian GDP. At the same time, the huge housing deficit existing in the country, coupled to the high costs of basic inputs, incentive studies viewing new technologies, directing different researches in the quest for more economic products.

The establishment of new environmental paradigms propels the civil construction industry towards the integration of technology, economic and environmental performances, considering the whole life-cycle. Life-cycle analysis (LCA) is an internationally accepted methodology for environmental assessment, and aims to define an structured and holistic picture of production systems, allowing for a concrete and measurable visualization of potential impacts that each and every stage of a product's, process's or system's life-cycle may pose on human activities, the environment and natural resources.

In order to intensify the use of steel making co-products and marble and granite waste in the building sector as an environment friendly strategy, a research project was carried out to explore the possibilities of using such alternatives as raw materials to produce low impact construction components. This paper refers to the segment of such research dedicated to development of solid bricks.

The advantage of being able to incorporate steel-making co-products, such as blast furnace slag and different types of fines, positions the production of this brick as a potentially important contribution for reducing the consumption of non-renewable raw materials, while providing a more adequate destination for such wastes and allowing the implementation of public policies aiming at greater social inclusion.

For different reasons, both soil-cement bricks and solid ceramic bricks populate common sense imaginary as ecological products. Authors conducted simplified LCA analysis to compare the environmental impacts associated to the production of solid ceramic bricks, stabilized soil (soil-cement) pressed bricks and co-products pressed bricks.

2. Materials and methods

2.1. Materials

The materials used in this study are wastes originated at steel-making and marble and granite industries located in the metropolitan region of Vitória, ES, Brazil, as well as Portland cement blast furnace CP III-32-RS, gypsum, CH I lime, sodium silicate, and pigments. These materials were either applied as activators, fines to improve mix grading and compacity, or eliminated from the experimental mixes after pilot laboratorial testing.

2.2. Methods: physical and mechanical performance evaluation

As from an initial inventory, wastes with potential for use in the experimental mixes were preliminarily selected based on generation and storage data; on the chemical composition supplied by the company, with attention to the presence of harmful compounds and to the existence of potentially agglomerating compounds; on the information on environmental classification supplied by the company; on the visual analysis for the observation of qualitative requirements such as fineness, granulometry, color and humidity and on the company interest in recycling the wastes generated in function of the amount stored; monthly generation or of the environmental classification (Souza Filho, 2005).

Based on this assessment, seven types of co-products and wastes were selected and initially used in the study (Table 1).

Table 1 Source and average generation of the pre-selected wastes (NEXES, 2005).

Co-products and wastes	Source	Average generation (t/month)
Pre-calcitic lime stage	Calcination	1 700
Fine calcitic lime	Calcination	2 700
Blast furnace slag	Blast furnace	125 000
Dry-pit slag (gross)	Blast furnace	435
Sludge from the water treatment plant (WTP)	WTP	1 500
Marble and granite waste	Rock processing	10 000 (estimated)

Next, waste sampling was conducted, based on NBR 10007/1984. Waste characterization prioritized those with highest potential to succeed, such as ground granulated blast furnace slag (ggbfs) and dry-pit slag, which came from a known origin and showed promising results. Materials (Table 2) and wastes (Table 3) characterization encompassed physical and chemical tests, as well as micro structural analysis and environmental characterization (leaching and solubilization).

Table 2 List of materials studied and characterization tests conducted (Souza Filho, 2005).

Materials	Physical tests	Chemical tests
CH I lime Gypsum Portland cement CP III-32RS Sodium silicate Pigments	Fineness #200 (NBR 11579/1991) Fineness (NBR 9289/1986) Specific mass (NBR NM23/1998)	Chemical analysis

Table 3 List of wastes studied and characterization tests conducted (Souza Filho, 2005).

Wastes	Physical tests	Chemical tests	Microstructure
Dry-pit slag WTP sludge Ggbfs Ground marble and granite waste	Fineness #325(NBR 9202/1985) Fineness #200(NBR 11579/1991) Blaine surface area (NBR NM 76/1998) Humidity Bulk density (NBR NM 23/1998) Bulk density (NBR 9776/1987) Unit weight (NBR 7251/1982) Particle size distribution (NBR 7217/1987). Clay content (NBR 7218/1987) Clay and other fine material content (NBR 7219/1987)	Chemical analysis Qualitative chemical analysis by EDS	SEM Glass content Refraction index Particle size distribution (laser) X-ray diffraction

2.3. Methods: life-cycle analysis

LCA analysis was conducted using SimaPRO as a platform for data input and output interpretation aid. SimaPRO is a robust computer tool that includes a broad LCI database, which includes a diversity of raw-materials, energy scenarios, transport modes, production processes and waste management and treatment alternatives. This database was scrutinized for detection of commonalities with the Brazilian industry. All disparities were identified and local data was gathered and inserted in the platform. The boundaries set for the analysis encompassed, whenever possible, raw material extraction and semi-industrial transformation for manufacturing the bricks, excluding storage, distribution and post-manufacturing phases (use, reuse and maintenance, wastes recycling and destination) (SILVA, 2005).

Ecoindicator 99 is one of the possible environmental impacts evaluation methods to be used with SimaPRO. Such method considers in environmental impact valuation the influence of cultural values – and therefore personal preferences – on the results and the correspondent impact hierarchy. Based on distinct sociological, philosophical and psychological fundaments, criteria and weighting, individualist (I), equalitarian (E) and hierarchical (H) can be selected. In this work, the hierarchy perspective (H/A) was adopted, in accordance to GOEDKOOP; SPRIENSMA (2001) recommendations. Sensitivity analyses were carried out to investigate if and how the adoption of other cultural perspectives would interfere in the final results obtained. Scenarios with different types of cements available in the Brazilian market were also built, to allow for a more accurate evaluation of soil-cement bricks. For the complete analysis and discussion, see Silva (2005).

3. Production Process

Given current depletion levels of proper clay natural reserves, the search for alternative solutions for brick production has speculated on the suitability of different types of industrial and mining processes wastes (Malhotra and Theri, 1995; Ferreira et al., 2003).

For the production of the presented low environmental impact bricks, the same manufacturing technology used for soil-cement pressed bricks was used, according to NBR 8194/1984 specifications for the Type II brick class (23 x 11 x 5 cm). The co-products bricks however essentially incorporate wastes such as ggbfs (binder), sodium silicate (chemical activator) and dry-pit slag and different types of fines, such as rock cutting waste, WTP sludge (aggregates), contributing for reducing non-renewable raw material consumption, an efficient way of environmental preservation. Moreover, as burning is not necessary, there is an expressive reduction in energy consumption and, as a consequence, of environmental damages resulting from the manufacturing process (Silva, 2005).

Besides avoiding stockpiling or land filling of steel-making co-products, the proposed brick production dispenses both the soil and cement demanded for manufacturing soil-cement components, contributing for mitigation of environmental impacts inherent to excavation from natural deposits and reduction of energy consumption and CO_2 emission to the atmosphere. Furthermore, if damaged or broken, the bricks may be crushed and re-pressed, minimizing solid waste generation (Silva, 2005).

The bricks development and production phases encompassed waste sampling, reception control, identification and characterization of wastes and materials with potential for use, mixes piloting and selection of the experimental mixes, brick pressing and curing.

After the pilot mixes were tested, four experimental mixes were selected, using as components ggbfs, CH I lime, WTP sludge and a dry-pit slag and marble and granite waste. One of the mixes was formulated aiming at the use of as many types of waste as possible and, in this sense, CH I lime was replaced by rock cutting waste, without employing sodium silicate activator. The materials used in each mix are listed in Table 4.

Table 4 List of mixes tested.

Designed mixes	Materials
T-1	ggbfs, rock cutting waste and dry-pit slag
T-2	ggbfs, CH I lime, WTP sludge and dry-pit slag
T-3	ggbfs, sodium silicate and dry-pit slag
T-4	ggbfs, rock cutting waste, WTP sludge and dry-pit slag

According to Grande (2003), there is a relation between mechanical resistance and mix homogenization. A horizontal axis mixer was the most efficient alternative available and therefore chosen for this study (Figure 1) (Souza Filho, 2005).

Figure 1 Horizontal axis mixer (Souza Filho, 2005).

The bricks were pressed in a hydraulic press (Figure 2), resulting in excellent resistance and quality products. In real cases, such equipment would allow larger production scales, though presenting the inconvenient of being expensive and heavy (Grande, 2003; Souza Filho, 2005).

Figure 2 Hydraulic press (Souza Filho, 2005).

After being pressed, the bricks were stockpiled, respecting a maximum height of 10 bricks to guarantee the stability of the set. As a subsequent phase, the components were cured in wet chamber for 7 days (Figure 3).

Figure 3 Curing of the pressed bricks (Souza Filho, 2005).

The lab tests used for assessing components' properties were determination of compression resistance and water absorption (NBR 8492/1984), durability tests (dimensional variation and mass loss) adapted from NBR 13554/1996 and environmental characterization of the bricks (leaching, in accordance with NBR 10005/1987, and solubilization, in accordance with NBR 10006/1987).

4. Architectural possibilities

The pressed bricks, as a function of their production process, usually have the prismatic shape provided by NBR 8491/1984 of ABNT shown in Table 5.

Table 5 Types and nominal size of the soil-cement pressed bricks (ABNT, 1984).

Denomination	Dimensions (cm)		
	Length	Width	Height
Type I	20	9,5	5
Type II	23	11	5

The pressed bricks followed the specifications NBR 8194/1984 of the Brazilian Association of Technical Standards (ABNT) provides for the type II class of bricks, as can be observed in Figure 4a. The same standard requires that, when used, recesses on the brick's top and bottom surfaces must be 1.3 cm deep and placed at least 2.5 cm from the parallel edges.

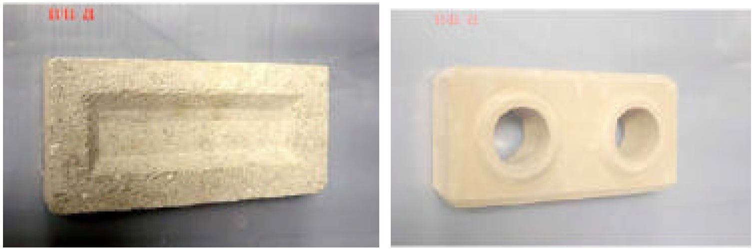

Figure 4(a) Prismatic brick with reentrance and (b) hollowed brick (Souza Filho, 2005).

Bricks with holes were also produced, with built-in fitting system (Figure 4b). Even though this system is not standardized, for the same mixes used for the solid components, the hollowed bricks reached good results concerning the production, handling and aesthetics. Satisfactory results were achieved for addition of 1% of pigment (dry materials weight). Brick configuration is variable to fit design needs and designer's creativity (Souza Filho, 2005).

Partitions and even facades walls using the co-products brick do not require plastering, as long as they are protected by the roof and waterproofed. Components' reduced weight, dovetails, and larger size further reinforce economic feasibility and execution easiness of the proposed masonry systems.

5. Presentation and discussion of obtained results

5.1. Physical and mechanical performance

Compression resistance and absorption results for the final mixes are shown in Table 6.

Table 6 Compression resistance and absorption results (Souza Filho, 2005).

Trace	Average compression resistance, at 7 days (MPa)	Average absorption, at 7 days (%)
T-1	11.25	17.58
T-2	15.38	15.90
T-3	12.34	16.43
T-4	14.50	15.63

When tested according to NBR 8492/1984, the bricks not only complied with the requirements, but attained compression resistance values at 7 days much superior than the 1.7 MPa, minimum individual value prescribed. Water absorption, an aspect that usually threatens most pressed bricks, was also analyzed and as well complied with the standardized limits.

Results measured according to a methodology adapted from NBR 13554/1996 Soil–cement: Durability test using wetting and drying cycles, when analyzed by descriptive statistics, showed no significant (lower than 1%) dimensional variation of the bricks.

Concerning weight loss, the results were again below 1%, by far complying with NBR 13553/1996 specification (Materials to be employed in monolitical non-load bearing soil-cement wall), which sets 10% as the maximum acceptable weight loss value for a granular soil.

Environmental characterization through analysis of the leached extracts showed that, for most parameters considered, concentrations were lower for bricks than for the original wastes, and that such results were extremely inferior to the maximum limits prescribed by NBR 10004:2004. As to the solubilization results, it was verified that the transformation process of co-products into pressed bricks was again beneficial, suggesting efficient encapsulation of most of the analyzed elements (Lorenzoni, 2005).

From the economic point of view, pressed bricks containing steel-making co-products and marble and granite waste would be economically viable and competitive (R$ 0.23, or USD 0.10, no subsidies included) for transportation radius of up to 20 km from the supplying industries. In same conditions, solid ceramic bricks would be priced around R$ 0.43 (or USD 0.20) (Souza Filho, 2005).

5.2. Life-cycle analysis

Ceramic solid bricks are perceived as ecologically-friendly in the south of Brazil, under the argument of using renewable fuel (firewood) for burning components. On their turn, soil-cement bricks are usually marketed in Brazil as ecological as well, under the argument of not needing to be burned at all.
When developing the Life-Cycle Analysis (LCA) of the production processes of solid ceramic bricks, soil-cement pressed bricks and steel-making co-products pressed bricks, Silva (2005) concluded that the latter masonry components presented the best environmental performance (Figure 5), independently of the cultural perspective adopted for environmental impacts inclusion, valuation and hierarchy, and of the type of Portland cement considered (either Portland Cement type CPI (95% of clinker) or type CP III (up to 70% of blast furnace slag as clinker replacement).
Aggregated impact for ceramic and soil-cement bricks showed to be similar, though the distribution among human health, and resource consumption impact clearly varied. The combustion of firewood constitutes the most significant impact flow of the ceramic brick production process. As well as other biomass elements, it is understood as "neutral" energy as the CO_2 emitted in the combustion is assumed as equivalent to the CO_2 absorbed during plant growth. It should not be forgotten, however, that the combustion of firewood generates other emissions that are not equally neutralized (methane, N_2O, NO_x and volatile mixtures except for methane, among other emissions).

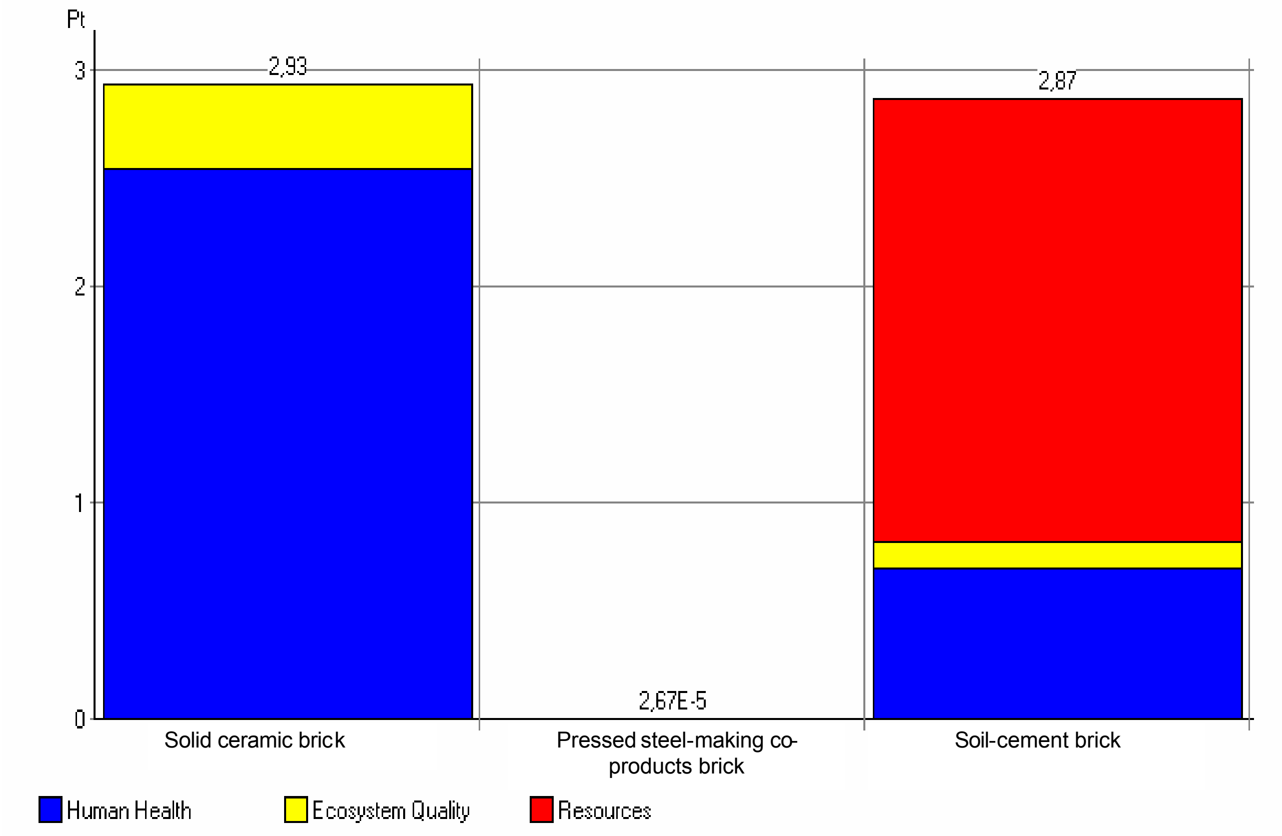

Figure 6 LCA results comparison for solid ceramic bricks, pressed steel-making co-products and soil-cement bricks (Silva, 2005).

6. Conclusions

The production of bricks containing steel-making and marble and granite waste showed to be viable under the economic, technical and environmental points of view, proving that finely crushed granulated blast furnace slag, dry-pit slag, rock cutting waste and WTP sludge are co-products with adequate characteristics for the production of pressed bricks.

The pressed bricks dispense burning, considerably reducing energy consumption for their production. Another advantage lies in the production process, which can be manual and easily assimilated, thus being suitable to several ongoing social housing programs. The components also offer costs benefits, excellent technical results for use as non-load bearing masonry components, and several aesthetic possibilities for pigmentation and differentiated architectural composition. The excellent physical and mechanical properties results obtained for the bricks suggest the viability of a large number of applications as other civil construction components, such as pre-cast flooring and paving blocks for bikeways and sidewalks.

As from the environmental characterization, it was observed that the transformation process of co-products into pressed bricks was beneficial, since most of the elements analyzed in the lixiviated and solubilized extracts were encapsulated and the pH of the samples analyzed.

Obtained LCA results objectively elucidated some interesting facts. First, because soil-cement bricks are frequently found in the literature as “ecological” bricks, as if having no environmental impact at all. However, the cement parcel in their composition should not fail to be considered, since it has important environmental consequences. Second, because ceramic bricks are equally advocated as environmentally more reasonable for using a renewable source of energy for baking the components. Nevertheless, they use non-renewable raw materials, are characterized by high energy consumption and/or high gaseous emission to the atmosphere (Silva, 2005).

This work, though not yet representative of the production practices co-existing within the Brazilian territory, contributes to overcome the initial inertia and trigger the construction of a national environmental database for building materials.

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THE DEMAND AND RECYCLING APPROACHES OF CONSTRUCTION MATERIAL IN CHINA

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Keywords: aggregate, concrete, C&D waste, recycling

Summary

With the rapid economic development and urbanization, the demand for construction material is increasing vastly in China. Meanwhile，a large amount of construction and demolition waste (C&D waste) is produced in the process of construction and reconstruction. It is popularly recognized that it is a sustainable way to recycle C&D waste to meet the demand for construction material. Considering the present special phase of development in China, it is very important to develop a sustainable way to protect natural resources and reduce environmental pollution. Based on the statistic data on construction in China, the aggregate amount used in concrete will be demanded about 6400 million tons in 2010 and the amount of aggregate only used for hollow concrete block, concrete paving units, concrete porous bricks, solid concrete brick, concrete curbs is estimated about 74 million tons in 2005. And in same time, the amount of various wastes such as C&D waste, decorating waste is estimated about 812 million tons in 2005. So it has great opportunity to recycle the C&D waste in China. Considering the various recycling approaches it is possible method to used C&D waste to replace the aggregate in various concrete precast blocks.

1. Introduction

Nowadays resources, environment and development have become the subjects of sustainable development [1]. Facing the decrease of natural resources, environmental pollution and economic development，people hope to get to know the relationship between material consumption and social development especially population development and their mutual influencing factors from the past[2，3]，then obtain the approaches to sustainable development. We can't take it for granted that the environmental pollution will gradually decrease when the social economy has developed to some extent [1].The conflict between the decrease of natural material and the augmentation of environmental pollution is very conspicuous in the rapid development of social economy. Architecture has a great impact on resources and environment. It's effective to adopt the technology of reuse、recycling、and reduction which are named as "3Rs" to achieve sustainable development[4]. But the realization of technology sometimes depends on social economic condition. It needs social economic policies which can fit sustainable development [5]. Just like in China，a developing country which is developing very fast and whose industrialization, urbanization and modernization are still on the way, the resources can't satisfy the demand of development according to the present material-consumption model[6]. A quantitative calculation of resource consumption and the amount of reused resources is needed to make and carry out sustainable economic policies because it can provide foundation for the adjustive force of economic policies and choice of technology. From this point of view this, the demand of concrete and quantity of reused resource is estimated in this paper.

2. Analysis of the demand for construction material

2.1 Analysis of the demand for cement

The demand for construction material is increasing with the development of social economy and the enhancement of people's living standard. However, in different steps of social economic development, the demand for construction material is also in different levels. At the initial period of social economic development, we aim at meeting the basic demand of living, thus the demand for construction material is comparatively low; then at the middle period, we aim at meeting the demand of residence and activities, so the demand blooms; finally at the mature period, we aim at meeting the demand of mental life, so the demand scales down. The relationship between the construction material and social economic level can be demonstrated by the relationship between cement-consumption and Gross National Product (GDP) [7]. When the national income hasn't reached 10,000 dollars, the per capita cement-consumption is increasing. And when the national income is over 10,000 dollars, the per capita cement-consumption is decreasing. According to Chinese[8] and American[9，10] statistics, China's per capita cement yield and America's per capita cement-consumption since 1950 is figured out(Fig.1). From fig.1，we know that near China's per capita cement yield was less than 200kg in almost 30 years before 1990 and the demand for construction material developed slowly, for China was still in the initial period of development before 1990.Then after 1990,as the social economic development getting into metaphase, the demand increased quickly, by nearly three times in ten years. Looking at American per capita cement wastage, we can see that the per capita cement wastage didn't decrease but remain 300kg during its mature period. Furthermore, the consumption has increased continuously in the past ten years.

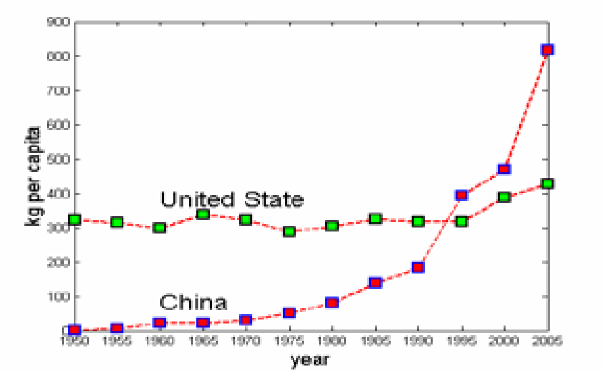

Figure 1 The Chinese and American per capita cement

If using the cement consumption of per 10,000 GDP (CCOPG) to estimate the demand for cement [12,13], we can figure out both China's and America's CCOPG, which is shown in fig.2. We can see that in America, CCOPG reduced gradually in the last 50 years, then it kept stable (about 895~810kg) since 1990.But in China CCOPG reached the maximum in 1980, then also kept stable as 4573~4418kg which was much higher than that of America since 2000.And this accords with the fact that China is a developing country while America is a developed country.

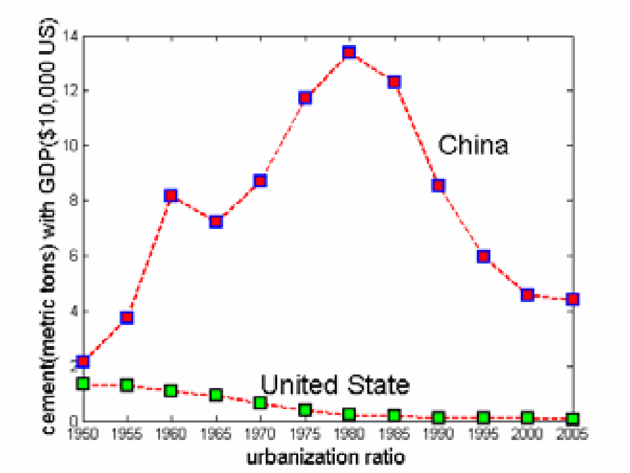

Figure 2　CCOPG in China and America

There is some kind of contact between the social economic development level or people's living standard and the degree of urbanization. Urbanization ratio reflects a country's economic development. So we could use urbanization ratio to reflect the demand for cement or its consumption [6]. As the Fig.3 showed, the connection between cement yield or wastage and urbanization rate is figured out in China and America from 1950 to 2005. We can see that it's difficult to establish a direct connection between cement yield or wastage and urbanization ratio. But it can also been seen that when the urbanization ratio is comparatively low (less than 50%), the cement consumption increases as urbanization ratio increases; while urbanization ratio is comparatively high (more than 50%),the cement increases slowly. But even if urbanization ratio reaches more than 80%, the cement wastage still increases.

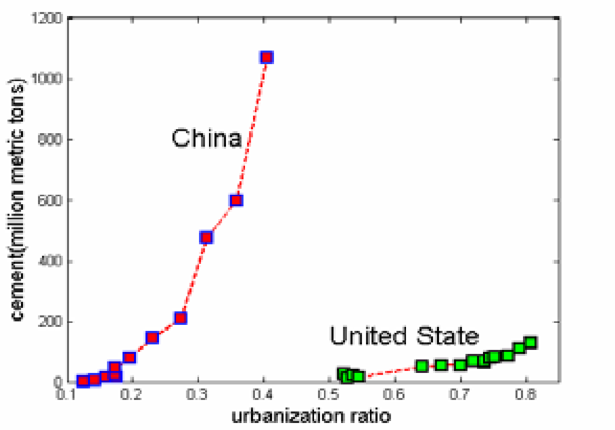

Figure 3　The cement yield or wastage and urbanization rate in China and America

As the law of the world urbanization proceeding step said: urbanization is in the elementary period when the ratio is under 30%, in the rapidly developing period when the ratio is between 30%-70% and in the mature period when the ratio is more than 70%. China and America are in different developing steps respectively. Urbanization ratio could reflect a country's economic development level, while CCOPG could also reflect it. The change of urbanization ratio and CCOPG both in China（1950~ 2005）and America（1930~ 2005）can be figured out ,as is shown in Fig.4, from which we could see a good continuous tendency. We proceed a polynomial fitting by the least square method with the data of China after 1980 and of America from 1930 to 2005.And a evaluator which reflects the connection between urbanization ratio and CCOPG is figured out, as is shown in Eqs(1). And urbanization ratio and CCOPG which are calculated with Eqs (1) are shown in Fig.5.

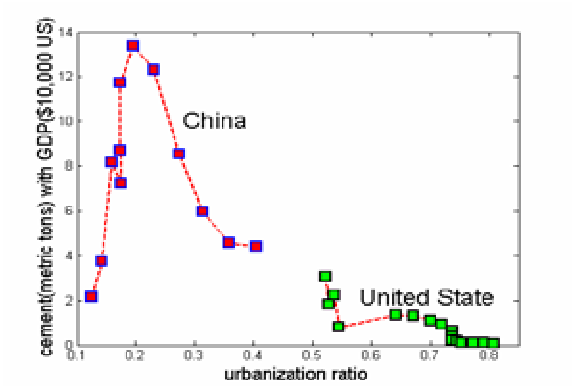

Figure 4 CCOPG and urbanization ratio in China and America

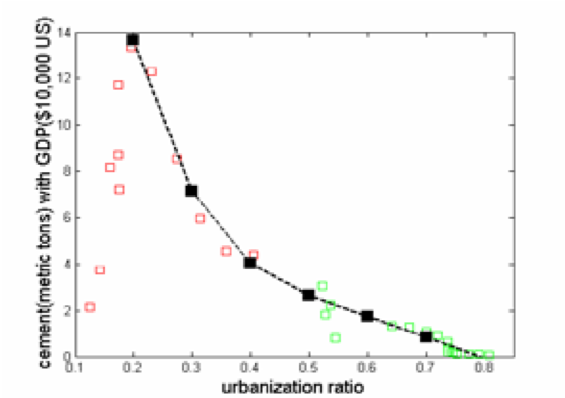

Figure 5 CCOPG and urbanization ratio

$$Y = 245.7X^4 - 633.3X^3 + 605.5X^2 - 263.4X + 46.8 \quad (1)$$

Where Y represents CCOPG（tons），X represents the urbanization ratio.

Substitute the predicted value of China's urbanization ratio [10] into Eqs(1) to calculate the future CCOPG. Based on the Chinese GDP of 2005, the Chinese GDP of 2010~2030 can be forecasted according to the economic growth rate, which is forecasted according to Chinese macroeconomic [15]. According to the CCOPG and GDP, China's demand for cement from 2010 to 2030 can be forecasted as Table (1) shows. In fact, China's cement yield of 2005 has already reached 1.069 billions tons. What are shown in Table (1) is comparatively conservative. But we can see that the demand for cement will increase continually in the recent 20 years.

Table 1 The Chinese demand of cement from 2010 to 2030

Year	urbanization ratio（%）	CCOPG（tonnes）	The rise ratio of GDP in5 years（%）	GDP (billion dollars）	The quantity of cement (billions tonnes）
2005	40.5	3.9475	8.1	2419.31	0.960
2010	45.1	3.2021	6.4	3571.25	1.211
2015	49.5	3.0167	6.4	4870.00	1.469
2020	53.6	2.7611	5.4	6641.05	1.833
2025	57.2	2.5064	5.4	8638.53	2.165

2030	60.5	1.4571	—	11236.80	1.636

Whether from national income or the period of urbanization point of view，China is still in the acceleratedly developing phase. Due to the large population，the demand for cement will increase quickly in the recent years [16] .

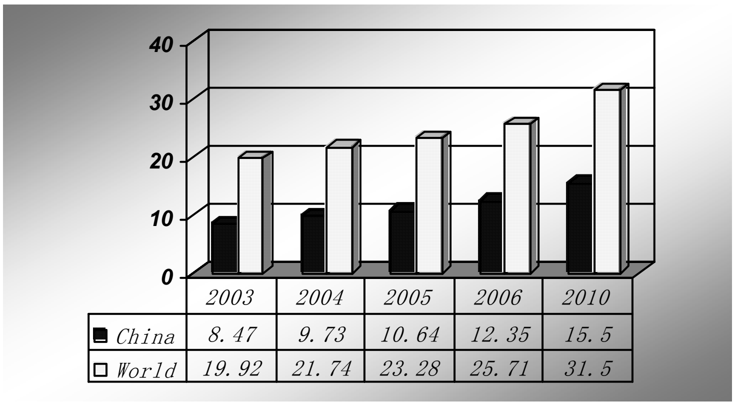

Figure 6　The cement yield in China and in the world(hundred million tons)

2.2　Analysis of the demand for the dinas

Dinas is the main body of the concrete, so the demand for it is increasing quickly as the cement-consumption increases. But owing to the decentralization and randomness of the dinas production, it's hard to make a precise calculation on true dinas production and dinas consumption. According to the assessment of dinas production from 2001 to 2003[17-19], the demand for dinas of each year and in the future could be estimated based on the ratio(1:4) of cement and dinas in concrete(Fig.7).The demand will reach 6.4 billion tons in 2010 in China.

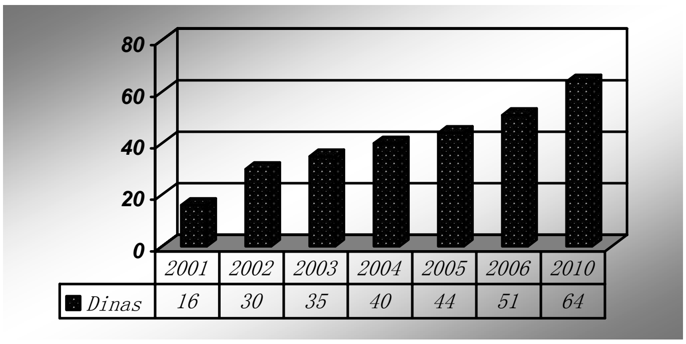

Figure 7　The dinas production statistics(2001~2006) and the forecasted quantity in 2010 (10 million tons) [17]

2.3　Analysis of the demand for the concrete products

The concrete products include concrete hollow block、concrete cork brick、concrete solid brick、concrete pavement brick and concrete curb stone, and so on. The demand for these products and their production are increasing quickly with the fast development of China's fundamental construction. From the yield from 2000 to 2006 shown in Fig.8, we can see that every kind of concrete products is on the rise. The consumption of concrete was about 74.41 million tons based on the yields of different kinds of concrete products in 2005.And the consumption of dinas was about 59.53 million tons based on the ratio 1:4 of cement and dinas.

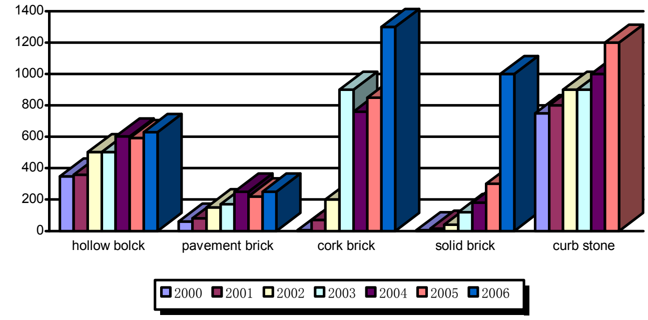

Figure 8 The yields of different kinds of concrete product (2000~2006) in China
concrete hollow block (hundred thousand m³) concrete pavement brick (million m²) concrete cork brick (ten thousand m³) concrete solid brick (ten thousand m³) concrete curb stone(ten thousand m)

3. Estimation and forecast of the quantity of C&D waste

It's inevitable to adopt reuse、recycle and reduction namely "3Rs" to meet the continuously increasing demand for construction material. The waste which is generated during the whole lifecycle of construction, decoration, maintenance and ultimate dismantlement is the best resources for reuse and recycle. There're different recycling technologies for different components in C&D[21].And using the C&D as main ingredient to produce concrete products is a way of recycling technology, based on the feasibility of economy and quality control.
The C&D includes constructing waste(CW)、construction decorating waste(CDW) and construction demolition waste(CDEW),which is generated during the period of building, using and demolishing. Because of the present mass construction and urban renewal in China, the quantity of C&D increases quickly. It provides a solving way for the large demand for construction material.

3.1 Analysis of the quantity of CW

The quantity of CW can be estimated via building area.30m^3 waste is produced in the process of constructing 1000m^2 building areas. The density of the CW is 1.5 metric tons/m^3, that is to say, 45 tons' waste is produced in building every 1000m^2 building areas. In China the total building area is 2275.88 million m^2 in 2005, so the quantity of CW is 102.41 million tons in 2005.

3.2 Analysis of the quantity of CDW

The construction waste of Shanghai in 1997 is calculated as 12.70 million tons. The residents in Shanghai have to pay 200~300 Yuan per family for the C&D in the decoration. Then we can estimate that about two cars of C&D are generated during decoration for every family. It means 4 tons of C&D are generated in each family, if a car of C&D is considered to weigh 2 tons [22].As is shown in the《Town building general statistics bulletin(2003)》promulgated by the construction ministry, per capita housing area of Shanghai has reached 29.4m^2, while the average number of family members of Shanghai in 2003 is 2.654 persons per family, namely, the average building area is 78m^2 per family. If we replace 78m^2 with 80m^2, we will get the result that the decoration of a 80 square meters' building will make 4 tons of waste. Meanwhile, referring to the data in Finland which are made by monitoring many construction scenes, they adopt 15~ 45 kg per m2 when estimating the CDW, which is similar to the estimation of Shanghai mentioned above. Considering the economic development degree of Finland and shanghai, the decoration of a 1000 square meters' building will make 35 tons of CDW.

In addition, data show that 10% of residents in shanghai decorate their houses, it means 10% of old buildings is decorated in Shanghai. Considering the economic development degree in Shanghai, I take 8% as the old building decorating ratio (OBDR) when estimating CDW all over the country in this paper.

The building area of countryside houses is neglected in the above estimation. On the one hand, the OBDR of countryside is much smaller than that of town, on the other hand, the quantity of CDW produced during decoration in countryside is also much smaller than that in town. So the town building area is taken as the radices of old building decorating area. The total building area in town is 16.451 billion m^2 till 2005, so old building area for decoration is 131.608 m^2 million. Thus the quantity of CDW is 4.606 million tons in 2005.

3.3 Analysis of the quantity of CDEW

The CDEW of every building relates closely to its structure. Generally 50~100m^3 or more CDEW is produced while demolishing 100m^2 building areas. As statistics show, a building with 7 layers and 49 households in Japan [22] makes 1.86 tons CDEW per m^3 .This paper takes 1.8 tons per m^3. RDC is defined as the ratio of demolition areas and building areas at the same time. According to the statistical data from 1996 to 2003 in China, the RDC was about 0.16[12]. The building area is 2275.88 million m^2 in 2005. The demolition area in 2005 can be estimated to be 368.69 million m^2. Thereby, the CDEW in 2005 is 663.64 million tons.

Add CW、CDW and CDEW to obtain the quantity of C&D. The C&D is 812.11 million tons in 2005 in China, and per capita C&D is 0.59 tons.

4. Analysis of recycle

The C&D is 812.11 million tons, while the consumption of dinas in concrete products is 59.53 million tons in 2005 in China. If the recycle utilization ratio of C&D can reach 8%, it could meet the demand for the dinas. Generally it costs 50 Yuan for a ton's dinas, so the output value of recycling dinas for producing concrete products could reach nearly 3 billion Yuan, while the value of the whole C&D could reach 40 billion Yuan.

Now 70% of Chinese building construction material is walling material, in which clay brick takes up predominance. We have to consume more than 1 billion m^3 of clay resources and 70 million tons of standard coals [23] to produce clay brick each year, which means to destroy field of 500 thousand mou. If the clays are substituted by C&D, we need a billion tons' C&D. At the same time we avoid destroying 500 thousand mou's field and save more than 70 million tons of standard coals.

Through the analysis, it is possible to realize material supply, production capacity and benefit when using C&D to produce concrete products. Meanwhile it has much developmental space and potential to recycle C&D for producing walling material, and has positive effect on saving resources, protecting land, reducing dissipation of energy, and so on.

5. Conclusion

Now China is on the way to industrialization, urbanization and modernization. In this special developmental period, a mass of different kinds of materials is demanded and simultaneously lots of waste and debris are generated because of China's large population. Carrying out the strategy of sustainable development and realizing the mode of recycling economy have become an urgent mission for China. The large demand for materials determines the importance of achieving recycle in construction field. According to the statistics both in China and America, the cement consumption of every 10,000 GDP has been related much to urbanization ratio. The analysis and estimation of the demand for construction material and the generation of C&D shows that it's possible to use C&D to produce concrete products whether from the point of material supply, production capacity or benefit. It has much developmental space and possibility to produce walling material with C&D, and it will bring positive effect to saving resources, protecting land and reducing dissipation of energy, and so on.

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TITLE: BEST PRACTICE WASTE MANAGEMENT IN RESIDENTIAL CONSTRUCTION

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Keywords: waste management, on-site grinding, recycling, sustainable, residential

Summary

Residential construction sites present a number of opportunities for improvement in the management of waste.

This paper presents solutions for the management and minimisation of waste that were explored as a part of Australand's 'Best Practice in Waste Management' project. Australand, supported by the Victorian State Government Sustainability Fund, partnered with Sustainability Victoria to improve waste management practices on our residential construction sites around Australia.

Waste management practices are rapidly evolving in Australia. The management of construction and demolition waste is changing from the single activity of sending rubbish to landfill, to a more sustainable process involving reducing, reusing and recycling potentially valuable waste streams. This evolution is being driven by a number of business, social and environmental factors including: increasing cost of fuels; rapidly increasing landfill levies; legislative change; and increased community environmental awareness.

Australand adopted a comparative analysis of two development projects to trial a series of new initiatives and procedures to assess the effectiveness of current practices against the potential to be gained from improved waste management practices.

Sustainable waste management initiatives that were trialled and refined included:

Site waste management plans: As part of Australand's new Environmental Management Plan policy, construction sites are required to draft a waste management plan outlining recycling targets for the sites and methods for achieving these targets.

Waste separation: Many sites can now use a simple "one bin" solution where waste is sorted and recycled off site. Where regional recycling facilities are not available waste separation will still be required to achieve recycling targets

Waste Grinding: Australand has undertaken successful waste grinding trials in Victoria. Envirogrind Recycling was able to grind waste bricks, tiles, concrete and timber into valuable aggregate and wood chips which can then be reused on site.

These waste management practices have a number of environmental, social and financial benefits, which include:

- Preventing valuable resources from being disposed to landfill;
- The reuse of materials on site, which reduces the need to purchase virgin products where the reprocessed material is appropriate;
- Reducing the burning of fossil fuels and generation of greenhouse gases associated with decreased transportation of materials to and from the site

Australand is committed to demonstrating environmental leadership and continues to be proactively addressing sustainable waste management in all operations.

1. Project Introduction

Australand Residential recently conducted a waste management project, "Best Practice in Waste Management", which received funding support through the Victorian Government's Sustainability Fund. The aim of the project was to explore a number of options focussed on improving our performance in managing waste on site. Two similar medium density residential developments sites were selected as part of this project to provide a comparison. Each project had a similar number and nature of lots being developed and both were being developed on a similar construction timeframe.

Legend Hill is a medium density residential development on a green field site in Epping, on the northern fringe of metropolitan Melbourne. La Perouse is a medium density residential infill development on former golf course land at Bonbeach, in south east Melbourne.

Legend Hill provided the 'business as usual' site, while La Perouse was used to trial some waste minimisation initiatives. Both sites provided opportunity for innovation which could support improved waste minimisation performance for Australand Residential developments in the future.

Australand has previously trialled waste minimisation initiatives on residential development projects, including source separation, supplier take-back of packaging, pre-fabrication of components etc., and, where successful, has included some of these practices within day to day operations.

Figure 1 The two storey dwellings under construction at La Perouse, Stage 3, Bon Beach, Victoria.

2. Project Aims

With the support of the Sustainability Fund, Australand's "Best Practice in Waste Management" project, aimed to address objectives that included.

- Seeking a long term reduction in waste generation and in the volume of waste going to landfill;
- Gaining a better understanding of upstream drivers of waste generation and the most useful management levers to influence a reduction in waste to landfill;
- Trialling practical new concepts, technology and practices as appropriate;
- Promoting sustainability throughout operations through education and training of subcontractors and employees; and
- Developing a platform of understanding and experimentation for future work and improvement in Australand's waste management practices.

Australand acknowledged that this was an ambitious project, but sought to noticeably improve waste management performance through mechanisms such as its Sustainability Strategy and site specific Environmental Management Plans (EMPs),. The support of the Sustainability Fund provided a rare opportunity to review and evaluate some of the more challenging aspects of managing residential construction waste. The focus included data collection, performance monitoring, and capturing practical site based innovations, with the learning to be shared within Australand, and more broadly disseminated across the residential construction sector.

Australand's waste goal for the project was to reduce total waste generation and reduce volume of waste going to landfill by 50-80%. Australand has achieved this goal and exceeded it in some instances. The nominal recycling rate of material leaving the site was between 45% and 90%.

3. Site Waste Management Plans

It was determined that each site should have a site specific waste management plan that would be created as part of the site Environmental Management Plan (EMP). This has now been introduced as standard practice and has been included as a requirement of Australand's new site EMP policy.

This new requirement resulted in changes being introduced to our site establishment planning, daily site management practices and communications with site personnel. Both projects included in the trial were very busy and challenges included ensuring that sufficient area was set aside for collecting waste and managing the segregation of waste at the source where possible. The process also accounts for issues of site operations, signage, collection vehicle access etc.

Initially, our waste contractors did not process or recycle soil and many bins were being rejected for recycling and sent to landfill due to soil contamination. Australand was able to source a new waste contractor with soil screening facilities that enable soil to be recycled. This boosts our recycling rate by an additional 30%.

Australand had learned from previous waste management trials that the understanding and committment of all staff involved in the project would be required for any of the initiatives to be successful. To this end, a series of tools were developed to promote sustainability throughout our operations and to educate and train sub-contractors and employees including: subcontractor site inductions, regular discussions, posters, site signage and information handouts.

Ongoing reinforcement of the importance of waste management is critical and this involves promoting the value of recycling through site inductions and tool box sessions where on-site practices are discussed and personnel are kept abreast of changes occurring on the site.

A site induction handout 'Managing Waste at La Perouse, Your Responsibility as a Subcontractor' was developed for the site supervisor for issue during staff and subcontractor inductions. It outlines all the waste management systems and practices on the site, including requesting that subcontractors support the separation of discarded materials such as bricks, tiles and plasterboard, and that they place these materials in designated "drop zones" or on pallets for collection by the bobcat contractor for later recycling. The subcontractor information sheet was posted in the site office and staff lunch room together with the site's Environmental Management Plan.

An Australand Occupational Health, Safety and Environment (OHS&E) Induction DVD has been developed for use in the site induction process which involves all site staff and subcontractors. The 15 minute DVD addresses a range of site OHS+E issues including site cleanliness and waste management.

Australand also worked with waste management contractors to improve signage, data collection and provide regular performance reporting on waste management.

Australand Residential division conducts regular site audits to review OHS&E performance. The audit program has been modified to include the review of a range of waste management systems and supporting site based waste minimisation practices, ensuring compliance with resource efficiency initiatives.

4. Waste Separation and Supplier Take-back

Many sites in Melbourne can now adopt a simple "one bin" for waste recycling. This provides for waste to be collected in a mixed bin which is then sorted and recycled off-site, giving up to 95% recycling rates. These facilities were trialled for residual waste including concrete, plastic and metals, and are now being used as standard in Australand sites in Melbourne and Sydney. Reports for two Victorian sites that have had off-site recycling in place achieved 80% and 93% recycling rates in May 2008.

This system removes the very onerous requirement for ensuring that waste is separated into individual bins and is kept clean of contaminates. Previous trials undertaken by Australand Residential determined that the multiple bin solution was unsuitable for our sites due to space limitations, monitoring the content of bins and ensuring that all bins were close to the work area.

The recycling rates achieved were also enhanced by supplier take-back schemes for plasterboard, packaging, polystyrene from waffle pods as well as concrete recycling. Australand prefers to establish long term supply agreements with suppliers and these agreements include clauses pertaining to improved waste management practices including take-back, pre-fabrication etc.

Figure 2 *Plasterboard off-cut stockpiling awaiting collection.*

5. Waste Grinding

One of the key initiatives to be trialled in this project was the potential to adopt material recycling and re-use on site. Envirogrind Recycling Australia Pty Ltd was contracted by Australand to undertake waste material grinding during Stage 3 of construction.

The LaPerouse project offered opportunity for this trial as it was being developed in stages and areas of land in future stages was available for collecting and stockpiling waste materials for re-processing. This undeveloped area also had access to water for dust suppression during the grinding process.

Figure 3 *The Envirogrind Packer 750 mobile grinder & the 6m^3 tip truck.*

Initially bricks and tiles were stockpiled for reprocessing however, the Packer 750 mobile grinder used by Envirogrind can process timber as well as brick and tile materials. The grinder has the ability to capture and separate out gang nails and other miscellaneous metals from timber and on this basis, the range of materials for reprocessing was later extended to include discarded timber. The intention of the Envirogrind works was to reprocess this range of discarded materials into products that could be reused on site.

Envirogrind was also able to process plasterboard to produce a gypsum soil improver for clay soils, however Australands' take-back arrangement for the collection and processing of plasterboard was considered a better option resulting in a better use of the recycled material.

The bricks and tiles processed on site were reused in applications including the base aggregate for footpaths (prior to concreting) and also weather proofing surfaces for temporary paths and car parking areas. Any remaining crushed brick and tile material will was to be used as aggregate under driveways in Stage 4 of the development. The chipped timber material was used in broad area landscaping applications including mulch around large advanced trees planted in public areas throughout the site. The chipped timber was too coarse for mulching residential gardens however Envirogrind has indicated that processing the timber into finer grades will be possible in the future.

This was the first time that recycling and reprocessing of materials for reuse had been trialled on an Australand site in Victoria. Accurate data on the likely quantities of brick, tile and timber that may be generated during construction was not available from previous residential developments which complicated the programming of visits to the site by the Envirogrind equipment. As a result, the stockpiles of material were monitored by the site supervisor who contacted Envirogrind when it was considered there was enough material for reprocessing.

Three grinding sessions were conducted during Stage 3 of construction, which were over a two day periods due to the extensive stockpiles of material. Envirogrind has recommended that in future we should increase the frequency of grinding to regular intervals of every two to three weeks during the peak construction period.

5.1. First Grinding Session

The first grinding session was conducted about four months into the construction program. Only bricks and tiles were being stockpiled at this time. Envirogrind crushed the approximately $45m^3$ of material and deposited it directly into a $6m^3$ tip truck. This also enabled Envirogrind to transport the aggregate material to a preferred location on site for re-use and provide a measure the volume of material processed.

The final quantity of aggregate created for reuse was $39m^3$ which equates to the recovery of six and a half x $6m^3$ waste bin loads of brick and tile material for reuse and the saving of the purchase costs of new aggregate for use on the site.

5.2 Second Grinding Session

The second grind followed approximately five weeks after the first. Timber was introduced to the process this time, along with the bricks and tiles. The same process that was employed in the first session was followed. Bricks and tiles were ground and approximately $60m^3$ of crushed aggregate was produced. Approximately $30m^3$ of timber was chipped, producing approximately $18m^3$ of woodchips for reuse. In total this saved over fifteen x $6m^3$ waste bin loads of material leaving the site.

Figure 5 Wood and processed wood chips from grinding for landscaping use.

5.3 Third Grinding session

During this visit, Envirogrind Recycling processed 60 cubic metres of brick and soil resulting in 51 cubic metres of finished product of crushed rock supplied to Australand for re-use on site.

Australand contractors, in their enthusiasm to recycle all wood waste, inadvertently contributed treated wood to the pile. Envirogrind Recycling employees pulled this out and it was not recycled. The total wood ground on site resulted in roughly 25 cubic metres of wood chips being supplied to Australand.

5.4 Grinding Concrete Bricks

In the second grind there were a higher proportion of concrete bricks and pavers in the stockpile of materials.

The grinding had to be stopped part way through the process due to the teeth of the grinder being both worn and breaking off. It is believed that the concrete bricks, which are harder than clay bricks, may have contributed to the abnormal wear and tear on the teeth of the grinder.

Envirogrind is investigating a coating process which should help to reinforce the teeth of the grinder to improve the ability to grind these concrete bricks and pavers in the future. They are also looking at alternative crushers that are able to process harder materials, including basalt rocks commonly littering land in northern Melbourne.

As a result of all three grinding visits, a total waste diversion of 207 cubic metres, equivalent to 35 x 6 cubic metre bin loads, of waste was diverted from landfill. This waste was converted to a total of roughly 25 cubic metres of wood chips and 141 cubic metres of aggregate. This equates to approximately 30% of the waste stream being re-used on the site.

The on-site grinding initiative has a number of environmental, social and financial benefits, which include:

- Preventing valuable resources from being disposed to landfill;
- The reuse of materials on site, which reduces the need to purchase virgin products for the applications where the reprocessed material is appropriate;
- Reducing the burning of fossil fuels and generation of greenhouse gases associated with decreased transportation of materials to and from the site.
- Improved neighbourhood amenity and safety by reducing the amount of large truck traffic on local roads.

Figure 6 Left: Crushed tile and brick aggregate Right Concrete bricks which caused more wear and tear on the grinder.

6. Waste Collection

The site supervisors and bobcat contractors were observed to be key ‘enablers’ for improved waste management on site. It was evident that it was critical to involve them in the development, implementation, promotion and monitoring of waste management initiatives from the outset. It was important to ensure that this involvement did not add to their workload or distract from the core process of developing the project, and was able to be simply incorporated into the daily aspects of their roles.

At both the La Perouse and Legend Hill sites, the bobcat contractor was identified as a key person in supporting good site waste management practices. Consistently the bobcat contractor had a good working relationship with the Australand staff and other subcontractors on the site. One of the key roles of the bobcat driver is to maintain site cleanliness including keeping roads clean of mud, removing waste piles etc. The bobcat contractor is experienced with managing the materials discarded on site and, because of this, had a range of practical solutions to support better waste separation and collection. Methods of material separation and on-site collection practices are critical in improving the diversion of waste materials into recycling streams and these practices, if acknowledged and encouraged, will improve our waste management performance.

At Legend Hill, the bobcat contractor used a series of mini-skips, which could be carried by the bobcat, for the collection of materials. These mini-skips were placed in the front ‘drop zone’ of a house under construction enabling material to be placed directly into them. The mini-skips also helped by reducing the amount of soil contaminating the waste because discarded materials were not being scraped off the ground when collected and by frequently emptying and moving the bins as required. In addition, reducing the amount of soil that goes into the bins reduces the rate at which the bins fill, reducing the overall cost of collections and associated costs.

Figure7 Mini skip

The 1 m^3 mini-skips can contain about one tonne of material, which is the equivalent of four bobcat buckets, therefore the use of the skips reduces bobcat movements on the site.

At La Perouse the bobcat contractor sought to address similar issues of material placement and separation, which supported the recovery of bricks, tiles and timber for reprocessing on site and also plasterboard, which was collected by Clipstar Melbourne for recycling. Without the benefit of the mini-skip system, the bobcat driver sought to clearly designate ‘drop-zones’ for subcontractors. By using existing materials on site like old pallets, small areas were cordoned off on each house lot to define the “drop-zones” for the stockpiling of discarded materials. Waste materials were deposited directly onto the ground within the designated “drop zones”, so there was some soil loss associated with collection of this material. As with the use of the mini-skips, the practice of having designated “drop zones” helps to improve site cleanliness and reduce health and safety hazards.

The Legend Hill bobcat driver contracted the manufacturing of 12 mini-skips for use on construction sites. On the basis of the manufacturing costs of the skips, and the hire rate that Australand pay for their use, the period for cost recovery on the skips was 15 months each. Approximately six to eight skips are required for a 30 house development site.

Considering that the use of the mini-skips helps to improve site cleanliness, improve the quality of waste collected and also reduce bobcat movements on site, there are obvious environmental as well as occupational health and safety benefits associated with the use of the mini-skip system which must be considered for future projects.

7. Improving Recycling Rates

Australand staff and subcontractors worked well to divert a significant amount of brick, tile and timber material out of the waste stream and into the stockpiles for reprocessing. That said, over the course of the development these materials were still observed to be going into the general construction waste bins in small quantities. Ongoing reinforcement of the importance of separating out these valuable materials will be critical.

Promoting the value of recycling through site inductions and tool box sessions; reinforcing site practices such as placing these materials in designated 'drop zones' on each house lot for collection by the bobcat contractor; and staff seeing first hand the onsite reuse of these materials, will help to reinforce this waste minimisation initiative.

If Australand were to use soil screening products such as the innovative Australian product FlipScreen™ waste leaving the site would be further reduced by about 30%. Flipscreen is a soil screening attachment for a standard bobcat.

The collection of data relating to our volumes of waste has also highlighted the need to review our materials ordering processes, wastage allowances etc. This process will commence shortly.

8. Conclusion

Australand's "Best Practice in Waste Management" project has resulted in a number of changes to our waste management practices, especially in the areas of fomalising our approach to the issue though site specific EMPs, communication with site personnel and on-going collection of waste data. The project also resulted in us focussing on our waste management supplier agreement, seeking alternate waste management contractors who were more able to meet our needs and ultimately establishing an agreement with a new contractor. We have also paved the way for the introduction of new technologies including the mini-skip system, on-site waste grinding and a number of simple initiatives like the creation of "drop zones".

The grinding technology provides a sustainable approach to waste management, cutting waste to landfill by 30% or more and reducing resource depletion by using recycled materials on site. The technology also greatly reduces carbon emissions from transporting large amounts of waste off site. The trial diverted 130m^3 or almost twenty two 6m^3 bin loads of brick, tile and timber material into the on----site recycling and reuse program. There were issues with the amount of soil that was processed with the bricks and tiles and remained in the crushed rock aggregate. It is estimated that soil makes up to 30% of all construction waste as significant volumes topsoil are collected during site scraping and clean-up activities. On-site screening of wastes to remove and reuse soil could significantly increase recycling rates of the site.

The embedment of the lessons learned into our operational processes and the communication of the findings of this project in relation to the new technologies explored, will ensure that our waste management performance will continually improve into the future.

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NATIONAL ACTION PLAN FOR CONSTRUCTION AND DEMOLITION WASTE AS FORMULATED BY THE INDUSTRY ITSELF

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Keywords: Construction and demolition waste, PCB, national action plan, cooperation, volunteer work, regulations, construction sector

Summary

In 2001 the Norwegian construction industry introduced its own National Action Plan for Construction and Demolition Waste in alliance with the waste and recovery industry. The plan was formulated and effectuated by people working in different parts of the industry: Producers of building materials, builders' merchants, property developers, contractors, architects, consulting engineers, demolition contractors, along with the waste and recovery industry. The work was coordinated by the Federation of the Norwegian Construction Industry.

Our main goals were:

- All hazardous waste shall be handled in a proper and safe manner
- No waste should be disposed in illegal ways
- 70 % recovery by the end of 2005

In 2004 recovery of construction and demolition waste had increased from under 20 % (1998) to over 60 %. By then collecting hazardous waste from demolition and refurbishment had become the object of much focus. PCB was regarded as one of the most important substances to keep out from landfills. The project introduced a new collection system for old windows containing PCBs. This system has been extremely effective.

The project had extensive contact with the national pollution control authorities. The main objective was to make the politicians agree that there was a need for national rules for handling construction and demolition waste. In particular there was need for a means of detecting hazardous substances in constructions that were going to be refurbished or demolished. 1. January 2008 we succeeded. New national rules on C&D-waste were introduced.

The National Action plan was evaluated in 2006 and a new plan for 2007-2012 was formulated. The cooperation between the actors in the construction and waste sector is continuing as is the cooperation with the authorities, but the construction sector is still in the driver’s seat when it comes to this Action Plan.

1. Introduction

In 1997 the major organisation for building material manufacturers, craftsman's enterprises and civil engineering enterprises in Norway decided to join forces. They established The Federation of Norwegian Construction Industries (BNL). The main issue was to provide services and deal with commercial policy, employer issues and internationalisation for member companies and associations. More focus on research and development was a part of this policy.

At the same time there was a new awakening due to environmental impacts from the building sector in Norway. More and more development projects were related to environmental issues. A group of persons from the construction industries established EcoBuild (ØkoBygg) in cooperation with the government authorities. EcoBuild carried out different reports which showed the environmental situation for the building sector. Amongst these there was a report that showed that probably 80 to 90 % of the construction and demolition waste (C&D-waste) in Norway were sent to landfills. Only about 10 to 15 % were reused or recovered. The data were in fact very insecure. Nobody had exact figures for the quantities.

It was also said in the EcoBuild report that about 40 % of the waste in the world was generated in the building sector. These facts were quite new to many of us in 1998. People who had worked in the construction industry all their life were not aware of the situation. In fact, the most frightening information in the report was that the construction waste contained a lot of dangerous substances, and that these substances obviously were spread all over due to lack of control with the general waste stream from the sector.

These facts, combined with an offer of help from the Green Warriors of Norway, made us decide to try to do something serious about the waste situation. In cooperation with the most important organisations in the building sector and the recovering industry, BNL carried out a status report on C&D-waste in Norway in detail (as far as it was possible at that time). The project was financed by EcoBuild and the participants themselves.

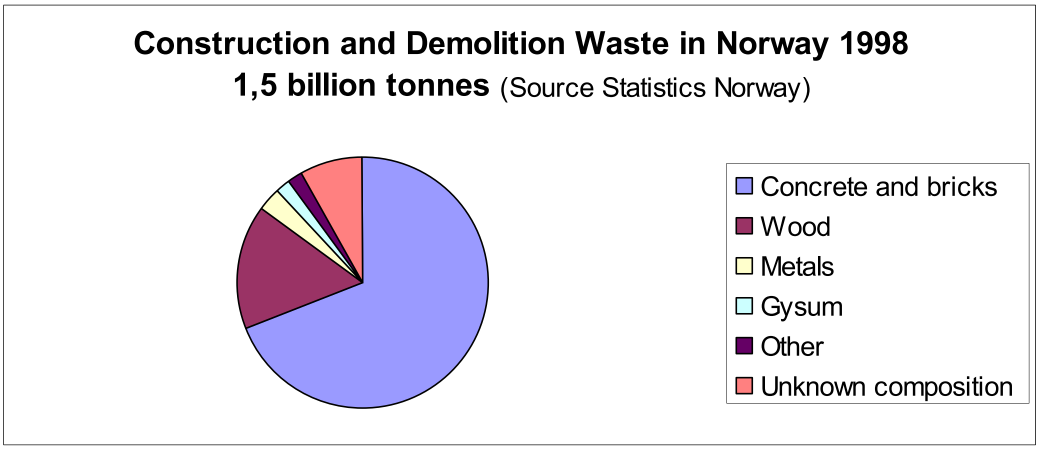
2. Results from the first Status Report

Our initiative was welcomed also by Statistics Norway. A reference group from the construction and the recovering industries was established to help the institution make better statistics for C&D-waste. Our status report contained the first generation statistics for this kind of waste in Norway, carried out by Statistics Norway in cooperation with us for the year 1998. Generated amounts were estimated on the basis of waste factors because no measurements were to be found. The figures are therefore uncertain.

The results showed that about 1.5 billion tonnes C&D-waste were generated in Norway in 1998 (the population of Norway was 4.4 million people). This does not include refurbishment waste from private households and excavations (clean soil and stone). The amount of C&D-waste was at that time about the same level as household waste in Norway.

The major part of the waste was generated from demolition (62 % of total weight), refurbishment generated 24 % and waste from new building projects 14 %.

About 70 % of the C&D-waste were concrete, bricks and other heavy materials. Then came (in decreasing order) wood, metals, gypsum, paper and cardboards, plastics, hazardous waste, insulations and glass. Unknown waste accounted for about 8 %.



Disposal (treatment) of the waste was not a part of the statistics due to lack of information, but it was believed that probably a minimum of 80 % of the C&D-waste was sent to landfills. There was more or less no control with the C&D-waste at the landfills, and it was assumed that quite a lot of it went to illegal landfills. This was known both by the state and local authorities, but, except for the capital of Norway (Oslo) and a few neighbouring municipalities –hardly anybody did anything to avoid the illegal filling.

Serious contractors that had an environmental policy and wanted to do a good job by sorting materials for recovery, had problems by getting contracts for demolition and refurbishment. They could not compete with companies that had “no costs” for sorting hazardous waste and “getting rid of it”. The customers, both from the private sector and public authorities, were not conscious of the environmental impact of C&D-waste (at least they did not want to acknowledge it). This lead to that the serious part of the construction sector was not able to demonstrate their environmental ambitions and take responsibility for the environment in building projects.

3. Working out a National Action Plan for C&D-waste

The first status report made it clear to BNL and our cooperating organisations from our own sector and the recovering industry that we had to act and take responsibility for what was going on. We had to stop further pollution from C&D-waste and recover more of the clean waste.

We gathered people from all parts of the sector for a work shop. This included producers of building materials, builders' merchants, property developers, contractors, architects, consulting engineers, demolition contractors, along with the waste and recovery industry.
A project manager was engaged. She reported to a core group which was lead by BNL.

More than 70 people from different companies took part in this effort. They were divided into 11 groups that worked with different fractions of C&D-waste, laws and regulations and others. After a period when the groups were working on their own with some help from our project leader, we had a last, joint work shop. The core group collected the information and developed it into a National Action Plan for C&D-Waste.

The whole effort lasted for about six months. The project manager was the only one who was paid. All other participants attended on a voluntary basis on behalf of their employees.

The National Action Plan for C&D-Waste was presented on the 15 February in 2001 and handed over to the Minister of the Environment. It had then already been approved by BNL's Executive Committee.

4. The main Topics of the Action Plan for C&D-Waste

Our vision: The building industry should have a reputation as responsible and offensive both as regards managing waste and environmental issues in general.

Our main goals:
1. All hazardous waste should be collected and disposed in a proper manner
2. Prevent illegal landfills
3. Maximum 30 % landfill within the end of 2005 (or: 70 % recovery)
4. Within the end of 2005 all new projects should be planned for generating less waste (minimizing) and more source segregation

To reach the main goals 27 action points were implemented. The most central point was to get new national regulations for C&D-waste and mapping before refurbishing. This was considered most urgent and would impact almost all other actions in the action plan, especially in relation to controlling the hazardous waste from demolition and refurbishment.

The construction industry had no instrument to force customers to take environmental issues into consideration before selecting a contractor. Of course they could do their best if they won the bid, but then there is the risk of loosing money on their projects. As everybody knows; only the winner gets the job. The serious tenders are therefore likely not to demonstrate their skills for handling C&D-waste. Unfair competition could only be avoided through legislation.

5. Implementing the Action Plan

5.1 Organisation of our Efforts

As for the implementation phase, this was based on volunteer work from the firms and people in the whole value chain of the construction industry and the waste and recovery industry. A networking group containing the 13 most important federations, organisations and government agency (Public Roads) was established to coordinate projects and take joint initiatives. This group was lead by a networking leader from BNL. A written collaboration proclamation of was signed by all parties. However, all participants were free to do as they wanted. There were also a lot of initiatives from different parts of the sector that worked separately to fulfil our common action plan.

To BNL it became most important to show that the serious part of the construction sector take responsibility for the environment, and the more we worked and showed results, the more positive attention we received.

5.2 Hazardous waste

The attention was however not always positive. After just at short time it became clear to us that our central goal had to be goal no 1: All hazardous waste should be collected and disposed in a proper manner. This included mapping dangerous substances in existing constructions, conditions that were not known to neither the construction industry, nor to the public at that time. This lead to one of our most important endeavours: to get control of PCBs in buildings.

We found that that the dangerous environmental pollutant PCB had been used in Norwegian constructions in sealants, floorings, paints, mortars, double-glazed windows, capacitors in light fittings, other capacitors and cable outlets in power supply units. Because the property owners and people in the construction sector had no ideas of this, most of the PCBs from refurbishment and demolition went to landfills (and maybe also as unknown pollution in recovered materials). This information (brought into light by us) was put on the front pages of the newspapers: “Glaziers are dumping poisonous windows at landfills” and related articles. This negative public focus is perhaps the price that you have to pay for bringing to light facts about dangerous substances in buildings.

In fact we did a lot to get control over PCB in buildings. In 1980 PCB was forbidden to use in Norway, but we still had a lot in existing constructions. At the time we started our work most of the remaining PCB in Norway was supposed to be in buildings. The Norwegian Pollution Control Authority assumed that there were about 450 pure tonnes. About 44 % of this, 200 tonnes came from double-glazed windows and 100 tonnes from capacitors in light fittings.

In the project period the authorities forbid PCB-capacitors in light fittings to be used in buildings, and existing capacitors had to be substituted by January 2008.

This is in short what we did regarding PCB:

- Mapping of PCB in buildings in Norway
- Developed and distributed the folder “Identifying of PCB in Norwegian Buildings”
- Established a return company for PCB polluted double-glazed windows. The return company, Ruteretur, should ensure that it would be no more expensive for the property owner to deliver their polluted windows to a recovery plant than to deliver a clean window
- In cooperation with the environmental authorities, made new regulations that forces property owners to participate in a return scheme for polluted windows.
- Campaign (including information brochure) to eliminate capacitors in light fittings from buildings in cooperation with the Norwegian Pollution Control Authority (who was responsible for inspections)
- Arranged a Nordic seminar on Demolition and PCB in buildings
- Developing courses in PCB refurbishing
- Speaking about PCB in different seminars and work shops for the construction sector

For people who do not know about PCB in windows we have to add that the PCB is found in the sealant behind the metal spacer between the two glasses, and not in the glass itself. These kinds of windows were much used in Norway during the period from 1965 to 1979 because they were insulating much better than the windows used earlier.

The action plan also dealt with other hazardous waste as e.g. CCA-polluted wood, asbestos, mercury, lead and others, but our main focus were on PCB because of the risks and the large quantities that were present in existing buildings.

5.2 Regulations of Construction and Demolition Waste (C&D-Waste)

As mentioned before, the construction industry had no instrument to force customers to take environmental issues into consideration before choosing a contractor. The lowest tender gets the contract. The price charged for mapping hazardous waste, refurbishment of this, source segregation and safe waste handling were not part of the most common contracts, including public sector contracts. Only through legislation could unfair competition be avoided.

This statement became vital trough our work with the National Acton Plan for C&D-waste. To implement a new practice concerning the handling of C&D-waste we had to argue with the environmental authorities and the politicians and request new regulations.

The Municipality of Oslo already had such a regulation which had been adopted the late 90s, and they were very satisfied with their results, but almost none of other of the 433 municipalities in Norway had any focus on this. They were not aware of the hazards in the C&D-waste either.

In 2002 the authorities introduced guidelines for handling C&D-waste, but they made it voluntary for the municipalities to implement the rules. This had almost no effect. Only some 30 municipalities adopted the regulations, and only a few maintained them. Our network had a hopeless job of encouraging all 433 municipalities to adopt the regulations.

5.3 Recycling

Recycling of different materials was a part of our action plan. The materials we gave priority were concrete and bricks, gypsum, plastics and cardboard, wood, glass, insulation materials, roof coverings, metals and electronics in buildings in addition to hazardous waste. For the two last ones there are regulations that state that you have to deliver these kinds of waste to certain plants, but as long as you don't know what materials are hazardous, they are not handled correctly. Skills for the right persons are key here.

With regard to concrete and bricks there were some ongoing projects where especially the Public Roads Administration, some major contractors (mainly Veidekke) and the recovery industry were participants. A lot of very important know how and reports have come out of these projects. These actors joined forces with our project.

The asphalt industry also had an ongoing project which was coordinated into our action plan. Because of a voluntary agreement within the sector they soon gained impressing recycling results. The agreement included a fee on bitumen.

5.4 Competence

The competence about C&D-waste was rather low in the construction sector when we started our effort. It was therefore of the utmost importance to increase the skills. In short this was done by:

- Developing guidelines for handling C&D-waste and spreading these
- Developing guidelines for handling of hazardous waste
- Developing a new Norwegian standard for removal of hazardous substances, disassembly and demolition
- Developing and holding pilot courses
- Giving lectures in different settings and sectors (many!)

All material developed in the project is free of charge. Our main goal in this respect has been to get as many as possible to make use of our guidelines and material.

6. Results: Did we reach our Goals?

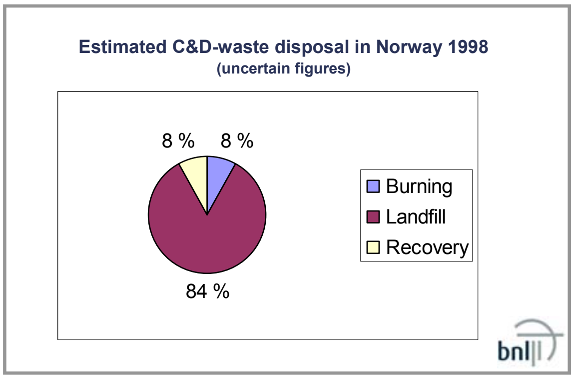
6.1 In general

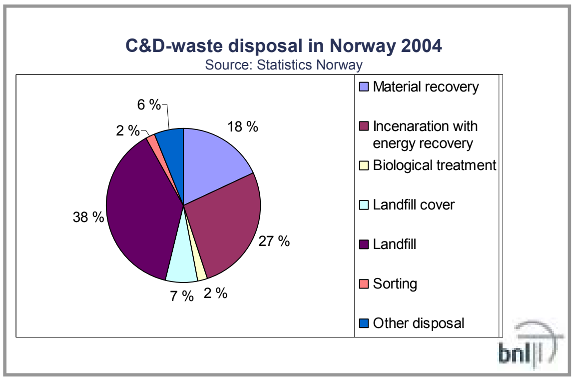
Only the most important results are reported in this paper. The full report is found on our common web site for environmental issues in the construction sector: www.byggemiljo.no (for the time being only in

Norwegian).

6.2 Recovery

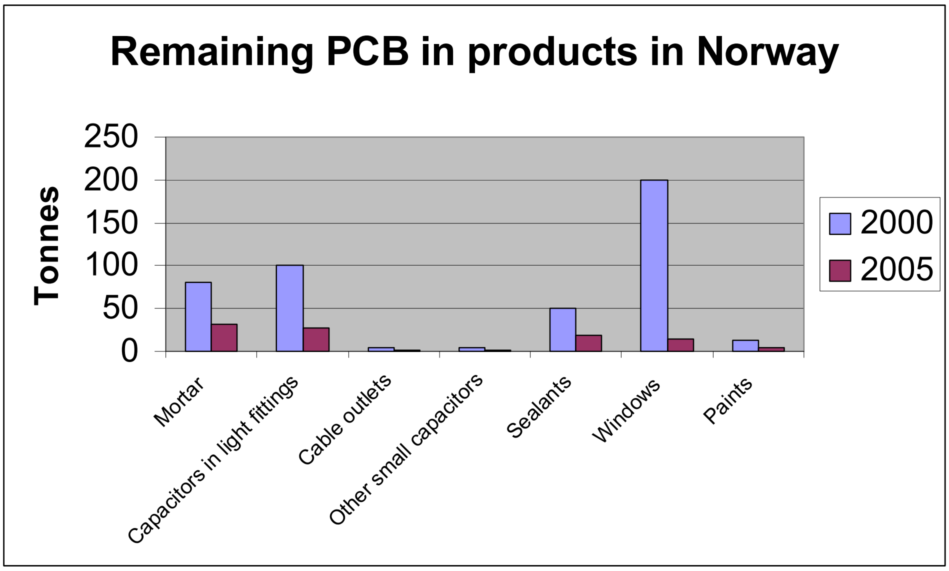
Our action plan was very ambitious at the time of implementation, 70 % recovery at the end of 2005 seemed unattainable when we started. Unfortunately Statistics Norway does not have statistics for the year 2005. Figures are shown below for the situation in 1998 and in 2004, one year before our first plan came to an end. (The situation in 2001, when our work started, is likely to be about the same as in 1998, but the data are very uncertain). It shows that in 2004 38 % went to landfills. It is therefore impossible to say whether or not we reached our goal; maximum 30 % landfill at the end of 2005. The fact is nevertheless that the recovery percentage has more than tripled in the period.





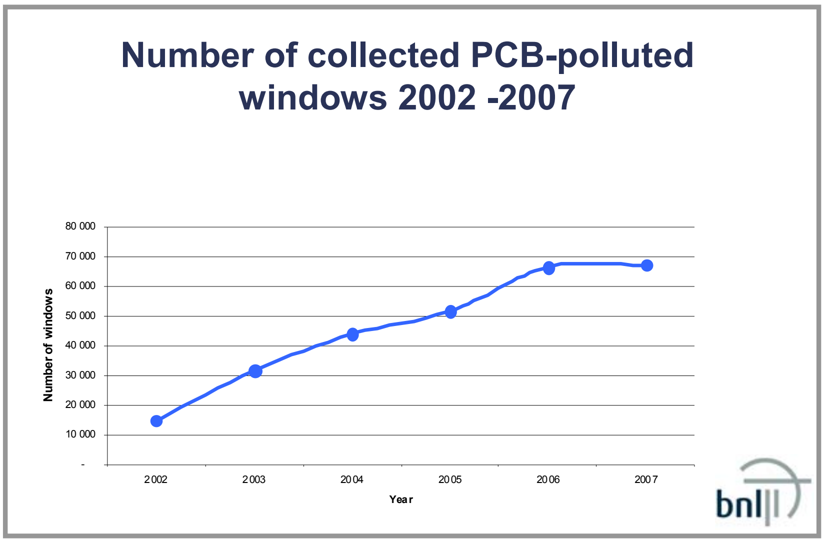
6.3 Hazardous Waste

In respect to hazardous waste we have statistics for collection of PCB from the Norwegian Pollution Control Authority. Remaining PCB in products has decreased from 453 tonnes in 2000 to 155 tonnes in 2005. The largest reduction in PCB was in windows and capacitors.



Source: Norwegian Pollution Control Authority

From 2002 to 2007 the collection of windows have increased from 15 000 to 70 000 pr year. This is approximately 100 % of what was expected to be the rate of yearly generated quantity of windows for condemnation. The effect of establishing of the return company Ruteretur has been remarkable, so has the effect of the campaign (and regulations) to end the use of capacitors in light fittings



Source: Ruteretur AS (www.ruteretur.no)

6.4 Breakthrough for National Regulations on C&D-Waste

At last, 1 January 2008, we could reap the results of our lobbying with regard to the political system. New regulations for mapping hazardous waste, refurbishment of this, source segregation and safe waste handling were introduced for the entire country. Our network in the construction industry is of course very satisfied, but if these national regulations had come in 2002, we could have been 6 years ahead with regard to practicing safe waste handling in the construction sector.

The new regulations give us great opportunities to get hold of all hazardous waste in refurbishment and demolition projects. The property owner has to carry out and show the local authority a list of all hazardous waste in the construction that is going to be refurbished or demolished. He also has to report how he is going to handle/deliver the waste. This means that the development firm will have to get the job priced, and the contractors will have information of what kind of waste he is going to handle. It is unnecessary to say that this is of the highest interest for the workers and their safety.

7. Further Efforts

In 2006 our network evaluated The National Action Plan for C&D-Waste of 2001. A new plan was implemented for 2007 to 2012[1]. This time as well all the work was done for free, on voluntary basis, except for the manager. You can find the report on www.byggemiljo.no (in Norwegian).

The cooperation between the actors in the construction and waste sector is continuing as is the cooperation with the authorities, but the construction sector is still in the driver's seat when it comes to this Action Plan.

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TAIWAN GREEN BUILDING MATERIAL LABELING SYSTEM AND ITS APPLICATIONS TO SUSTAINABLE BUILDING IN SUBTROPICAL ZONE

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Keywords: Green Building Material, Sustainable Building, Life Cycle Assessment

Summary

The Green Building Material (GBM) Labeling System of Taiwan proposed by the Architecture and Building Research Institute was officially launched in 2004 to systematically and effectively evaluate the performance of green building materials (Chiang 2004). The connotation of the GBM Label is mainly to enhance the built environment and to provide the actual benefit toward the concept of human health and earth sustainability. The system carries out quantitative assessments and laboratory tests based on a variety of measures in different stages of the life cycle of a building. Its criteria and standards are established accommodating with the subtropical climatic condition. In addition, the regulation of at least 5% mandatory green building material utilization has also been involved into Taiwan's Building Code and become effective since 2006.

The GBM system covers four major aspects, including Health, Ecology, Recycling, and High-performance (ABRI, 2007a). The Healthy GBM for improving the indoor environmental quality requires low emission, odor free, and no asbestos. The Ecological GBM typically includes low toxicity processing and natural materials without shortage crisis. The Recycling GBM aims to reduce wastes and to reuse abandoned materials and recycling aggregates. As for High-performance, it basically refers to the materials with high permeability and high noise insulation. By the end of June 2008, 131 Labels have been conferred covering 1,032 green products. Among these products, the healthy material occupies 74%, and followed by the high-performance category 16%, recycling 9.2%, and ecological 0.8%. The percentage distribution indicates the health issue has been highly emphasized and points out the development trend of the building material market in Taiwan. The latest statistics and relevant studies also show that the GBM Labeling System is well coordinated with the current local sustainable building evaluation practices and can be further applied to the development of the eco-community and eco-city in subtropical zone.

1. Introduction

Green building material is one of the basic elements of a sustainable building. The serious energy and natural resources shortage that our living environment is currently facing shows an imperious demand on developing a better building material certification and management mechanism. Followed by the promotion of green building evaluation and labeling more than a decade, the Architecture and Building Research Institute (ABRI) of Taiwan proposed the Green Building Material (GBM) Labeling system in 2003 and officially launched in 2004, shown in figure 1. The system aimed to promote a sustainable built environment for the earth and a healthier living quality for human beings. It was established based on ISO15686 series, ISO21930 series, ISO14040 series, as well as the Integrated Building Performance (IBP) system proposed by the EU, to ensure the evaluation criteria and standards meeting the current development trend of the world. Both of the global and local environmental issues, such as anticipated exhaustion of fossil fuels, increasing and fluctuated energy prices (Meadows et al., 2006), environmental pollution problems, high dependency on imported resources, high temperature and high humidity, a large amount of CO_2 emission from the building industry, as well as over 10 million-ton construction wastes generated annually, must also be taken into consideration to develop a comprehensive assessment tool for green building materials. In general, the assessment of green building materials begins with establishing criteria for evaluating the environmental performance of building materials. The criteria may incorporate low toxicity, minimal emissions, low-VOC assembly, recycled content, resource efficiency, recyclable and reusable materials, energy efficiency, water conservation, IAQ improvement, locally products, etc (Froeschle, 1999). The GBM evaluation system of Taiwan systematically comprises of four categories, including health, ecology, recycling, and high-performance. Its assessment mainly adopts the life cycle assessment approach, covering four stages of the life cycle of a building: resource exploitation, production, usage, and disposal and recycling.

Figure 1 Taiwan green building material label

Among the above categories, healthy green building material is the major promotional emphasis in the system. With extensive material usage of indoor decoration and remodeling for housing, the formaldehyde (HCHO) in building materials and volatile organic compounds(VOCs) emitted in a warm environment can result in fairly high risk to be harmful to health (Shao et al,2003). According to relevant research results (Wu et al., 2003), the risk values of carcinogens such as the formaldehyde in building materials and VOCs in office spaces in Taiwan are 100 to 1,000 folds over the WHO standard, causing people to suffer from respiratory and skin diseases. With respect to the relationship between the GBM labeling system and the current EEWH green building evaluation system in Taiwan, analyzed as table 1, the GBM system can typically contribute to a healthier indoor environmental quality. The issues of indoor air quality (IAQ) (Wolkoff••1998), indoor environmental quality (IEQ), and indoor environmental health (IEH) have been addressed and being further studied. From the perspective of the “Architecture Doctor (AD)” concept, now researchers and experts would diagnose causes of IEQ problems and prescribe recipes, for instance, strategies of green building and green building material application. The GBM labeling system can thus provide for architects or designers with proper measures that are capable of accommodating local climatic conditions and meeting people’s health needs. For ecology, recycling, and high-performance, the GBM evaluation items can also effectively correspond to green building evaluation indicators and feed back to green building design.

Table 1 Relationship between Taiwan’s Green Building Evaluation and Green Building Material Application

Green Building Rating System EEWH		Green Building Material
Category	Evaluation Indicators	Applications
Ecology	Bio-diversity	--
	Greenery	--
	Water Soil Content (Water infiltration and retention)	High-performance GBM (permeability), Ecological GBM, Recycled GBM
Energy Saving	Energy conservation	High-performance GBM (energy saving)
Waste Reduction	CO_2 emission reduction	Ecological GBM, Recycled GBM
	Construction waste reduction	Ecological GBM, Recycled GBM
Health	Indoor environment	Healthy GBM, Ecological GBM, Recycled GBM, High-performance GBM (sound insulation)
	Water conservation	High-performance GBM
	Sewage and garbage improvement	--

Since July 2006, the mandatory green building material utilization has been involved into Taiwan’s building code. For indoor decoration and floor materials in buildings, green building materials shall cover at least 5% of the total indoor decoration and floor material uses. Fulfilling the requirements of ecological, recycling, healthy, and high-performance attributes, the green building material regulation may effectively reduce environmental impacts and improve the IEQ, so as to gradually achieve “human health and global sustainability.”

2. Evaluation system, implementation and management

The major purposes of the GBM labeling system can be described in three aspects: 1) promotion of high-quality and healthy life; 2) protection of ecological environment; and 3) enhancement of industry competition ability. The system focuses on the entire building quality and effective management and control of human health risk factors. Its general requirement includes basic environmental protection aspects, such as no asbestos, no heavy metal, no radioactivity, etc. The evaluation system consisting of four categories is illustrated as figure 2 and described as follows:

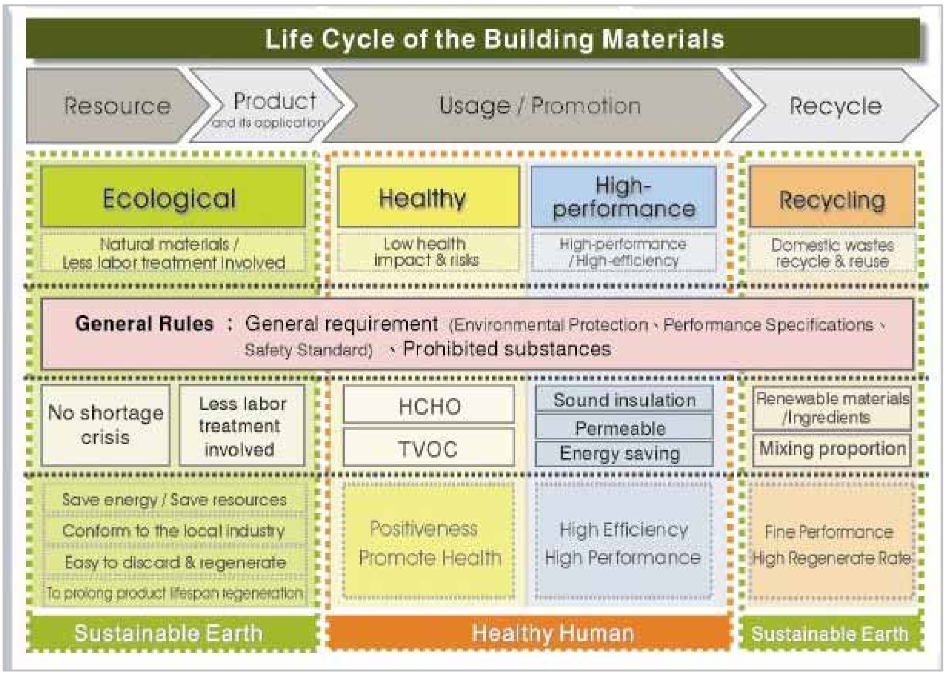

Figure 2 Framework of Taiwan green building material evaluation system

Ecological GBM:

What is taken from nature shall be used in nature. The Ecological GBM is that, during its life cycle, the building material fulfills general requirements, uses natural materials (Berge 2001) without shortage crisis, consumes minimal resources and energy, requires less labor treatment, or possesses recycled characteristics after disposal. The goal is to promote the natural building material that is good for both the environment and human health. For example, ecological wooden structure materials shall come from the forest with sustainable management. The assessment includes the certificate of FSC (Forest Stewardship Council), PEFC (Programme for the Endorsement of Forest Certification schemes), or other certificates of origin, shown as figure 3.

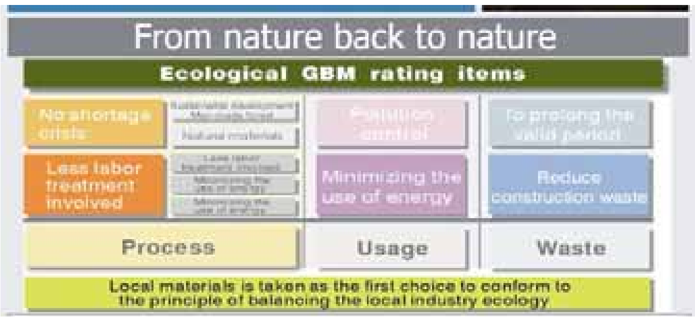

Figure 3 Evaluation of ecological green building material

Healthy GBM:

Since formaldehyde contained in building materials, and VOC_S added during the production of indoor construction materials, application and glue preparation, under the climate condition of high temperature and humidity, harmful chemical substances may be emitted in the air and directly affect human health and indoor environmental quality (Chen et al. 2006). Thus, the system focuses on the management and control of the relevant hazards. The test is based on ISO16000, and the standard is HCHO is less than 0.08 mg / $m^2 \cdot$hr and TVOC less than 0.19 mg / $m^2 \cdot$hr, shown as figure 4.

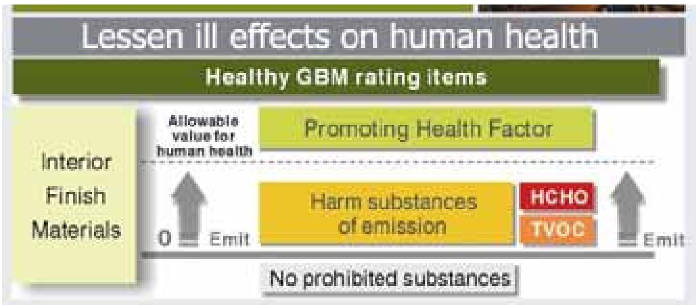

Figure 4 Evaluation of healthy green building material

High-performance GBM:

In response to the green building design issues, such as building environment noise, poor ground water retention, glazed curtain wall causing energy consumption, and the problem of dazzling sunlight, the environmental performance of a building material should be concerned and involved. By improving building materials to resolve the problems and increase efficiency, the system intends to promote building quality and standard of the living environment (noise insulation, permeability, etc), and also reduce entire energy consumption, which is in the scope of high performance green building material. The assessment includes ISO717-1, ISO717-2, ISO11654, and the test follows ISO140-3, ISO140-8, ISO354, and ISO9050, shown as figure 5. The approach also presents the harmonization with the ISO standards in Taiwan's GBM system.

Figure 5 Evaluation of high-performance green building material

Recycled GBM:

In order to reduce construction waste, and to reuse and recycle the materials, the system focuses on the regeneration of green building materials, in order to ensure basic functional demand, and improve reuse rate of waste materials, in order to achieve a sustainable society, which is in the scope of recycled green building materials. The assessment includes the types of recycled materials, their sources, and recycled content percentage, and its test is based on the ISO and Taiwan's CNS standards, shown as figure 6.

Figure 6 Evaluation of recycling green building material

For the practical operation of the GBM labeling system, the testing departments are national grade laboratories passing TAF accreditation. The factory owners of building materials can file the application and supply test data with TAF certification, proofs of production, ingredient and quality control, and registration document of its legality. Through the review by the Green Building Material Labeling Review Committee, suggestions of approval or rejection are given. For those who pass and obtain the green building material label conferred by the Architecture and Building Research Institute, the label is valid for 2 years and renewable. In terms of post-market management mechanism of green building material labeling, non-scheduled spot checks are implemented to ensure the use of the GBM label and the quality of green building materials.

3. Evaluation results and market trend analysis

By the end of June, 2008, 131 Labels have been conferred covering 1,032 green products. Among these products, the healthy material occupies 74%, and followed by the high-performance category16%, recycling 9.2%, and ecological 0.8%, shown in figure 7. The percentage distribution indicates the health issue has been highly emphasized and points out the development trend of the building material market in Taiwan. For a non-toxic and healthy architectural environment, as well as sound-proof and permeable function of building materials, there are 1,032 green building material products, including 379 building decoration paints, 56 wooden floors, 63 wooden boards, 92 gypsum wallboards, 71 inorganic boards, 2 organic boards, 1 rug, 3 glue preparations, 2 crack fillings, 11 soundproof door, window and wall systems, 3 floor coverings, 28 high pressure concrete ground bricks, 2 absorbent material systems, 194 permeable bricks, 73 ceramic face bricks, and 52 healthy PVC products. Mostly, paints ranked the highest, followed by permeable bricks, as well as wooden boards and gypsum wallboards.

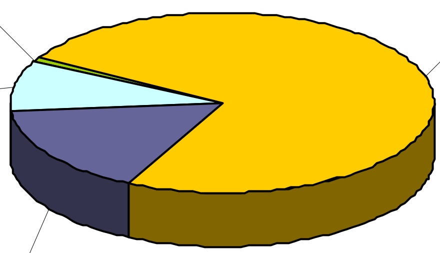

Figure 7 Percentage of four categories of GBM labeling promotion

Currently, the ratio of new and existing buildings is 3% to 97% in Taiwan. Using green building materials and green technology to improve indoor environmental quality and architectural environment, people can renew, reuse and prolong the life cycle and value of old buildings. Meanwhile, interdisciplinary integration of architecture, medicine, ecology, interior design and material technology transform traditional construction into a sustainable and circulating industry. Starting from energy saving and resource efficiency by combining an ecological circulatory system, corresponding local environment, community civilization, as well as historic and regional features, the GBM system creates a core concept of sustainable built environment in Taiwan.

4. Applications on sustainable building in the subtropical zone

Long-term research results indicated that the green building material evaluation standard should be based on its local environmental condition in the subtropical and tropical zone, which is applicable to the climate of high temperature and humidity. The GBM system also should be able to be applied to green building design and IEQ improvement. Building materials that meet the standards of the GBM labeling system may be used in various green building evaluation indicators. For example, indoor building material construction evaluation and sound environment evaluation among indoor environment indicators encourage the use of all of healthy green building material, ecological green building material, recycled green building material, and high performance soundproof green building materials. Specifically, preferential credits are adopted in the green building rating system to reward ecological green building material uses. In addition, soil water content indicators may choose high performance permeable green building pavement materials to increase water retention and storage. It is to alleviate the effect of urban heat island effect and reduce the capacity of a public drainage facility, as well as the occurrence of city flooding. The recycled green building materials meet the demand of CO_2 and waste reduction indicators. It can reduce the environmental burden caused by waste accumulation and the expenditure resulting from new resource development. High performance energy-saving glasses may respond to the daily energy-saving indicator for reducing energy consumption.

The application of Taiwan's GBM Labeling System on sustainable buildings in the subtropical zone focuses on the evaluation of chemical and physical building material evaluation. In response to the climate of high temperature and humidity, biological factors are added into items of evaluation (Wu et al, 2005). In a continuing effort of research and national policy, emphasis is on the ecological city in tropical zone. From green building materials, green construction, eco-community, and, furthermore, eco-city, a complete circle has been constructed to build a healthy and efficient sustainable homeland. The promotion experiences of green building materials and green building technology can be expanded to the living environment of countries in the subtropical/tropical zone and responded to the theme of SB08: "Connected, Viable, and Liveable."

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EFFECTS OF ENERGY SAVING MEASURES AT RENOVATION

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Keywords: energy saving measures, dwellings, multi-dwellings buildings, renovation

Summary

This study focuses on the necessity of having knowledge about different energy saving measures when renovations and reconstructions are planned and designed. It is also of great importance to have routines to follow up what effects the actions taken have had on the energy consumption as well as on the indoor climate when the renovation is completed. A big part of the existing buildings in Sweden are built during a ten-year period between 1965 and 1974. When these buildings are to be renovated there is a great potential for energy saving.

1. Introduction

The Swedish government attaches great importance on energy saving. The goal for the government is to reduce the total energy consumption per sq. meter heated floor space in dwellings and non-residential premises with 20% until 2020 and with 50% until 2050, compared with the energy consumption 1995. The use of energy for heating and ventilation can be minimized if the houses are well-insulated and have a controlled air-exchange.

Many dwellings in Sweden were built during a ten-year period between 1965 and 1974. During this period, there were no requirements on low energy consumption in buildings, so there when these buildings are to be renovated there is a great potential for energy saving. Common energy saving actions are:

- replacing the windows with windows having a low U-value or adding one more pane of glass
- supplementary insulation in the attic
- supplementary insulation of the outer walls
- sealing of windows and doors
- adjusting the heating- and ventilation system
- use of heat recovery system

According to SABO (The Swedish association of municipal housing companies) the interval between façade renovations, change of roof-material or change of windows is 30-40 year. For adjusting heating system the interval is 10 year. Energy saving measures in connection with renovation of facades and roofs are supplementary insulation and changes to more energy efficient windows. Buildings that will be affected by such measures are built from about 1961 to 1980. During this period a large number of dwellings were built in Sweden, about 996 000, which corresponds to about 41% of all dwellings in multi-dwelling buildings in Sweden 2006.

About 30% of all dwellings in multi-dwelling buildings existing the year 2006 have been reconstructed between 1976 and 2006 SCB (2006). Of the dwellings built 1961-80 about 15% have been reconstructed between 1990 and 2006. According to Boverekt (2003), about 50% of the dwellings renovated between 1975 and 2002 have been subject to façade renovations, and on about 56% of the dwellings actions have been taken on the roofs. These measures can be change or repair of the facing, possibly combined with supplementary insulation.

Energy saving measures on the ventilation system consist of adjustments of the existing system and installation of heat recovery system. About 60% of all multi-dwelling buildings in Sweden built before 1975 had natural ventilation in the year 1980, which corresponds to more than 1 million apartments. About 700 000 apartments built before 1975 had in 1980 original mechanical exhaust ventilation. During the 1950´s balanced ventilation was introduced and at 1980 this kind system was used in about 100 000 apartments. When the buildings were modernized in the period 1975 to 2002 about 400 000 apartments have changed ventilation system, totally or partly. 54% of the renovated apartments in multi-dwelling buildings have a changed ventilation system in 2006 Boverket (2003).

When reconstruction/renovating buildings it is important that the actions taken result in buildings with both low energy consumption and a good indoor climate. To obtain knowledge about the effects it is necessary to follow up the energy consumption and to evaluate the indoor climate. Experiences in form of successful solutions and how to avoid bad solutions must be transferred to future building projects. It is necessary that the developer demands low energy consumption and a good indoor climate early in the planning and design phase both when houses are constructed and renovated.

The selection of methods used in renovations are in many cases based on recommendations obtained from computer programs. After renovation very little feedback is received on how effective the energy measures were, whether the energy goal has been reached or if the computer program has given reliable results.

2. Energy efficiency buildings with a good indoor climate

2.1 Energy efficiency in planning and design phase

One example of means for assistance in the planning and design phase for energy efficiency buildings is the so callad “Energilotsen” produced by the companies Skanska Teknik, Cementa, Strusoft and Lunds institute of technology, www.energilotsen.nu. The city of Stockholm have produced a written report called “A program for environmentally adapted construction (miljöanpassat byggande vid nybyggnad)” to help the client to specify his demands in order to obtain energy efficient and sound buildings when constructing multi-dwelling buildings Stockholm Stad (2006).

The project “Teknik för hållbarhet I 50-60-70 talens bostadsområden” has compiled good experiences and facts about measures that enhances the environmental aspects at renovation. The research group has not evaluated the measures Vidén (2004-).

2.2 Evaluation of indoor environment

Today there are many different methods for evaluating the indoor environment. One example of a method to estimate both the indoor and outdoor environment for buildings is the so called “Ecoeffectmetoden”. This method shows the effects concerning energy consumption, use of material, indoor environment, outdoor environment and lifecycle costs. The indoor environment is evaluated by questionnaires, technical measurements and by looking at critical details. Glaumann (1999). One other method is the so called “P-märkning” where the indoor environment is evaluated by inspection and measurements. Defects are measured SP (1995). Evaluating the buildings environmental status and assessing the environment of the building are other methods to study the indoor environment. MIBB (2001). Investigation of indoor environment problems can be carried out by using check-lists Swesiaq (2006) or by using questionnaires Andersson et al.(1990) and Stockholm Stad (1990). Requirements and specifications for the indoor environment are presented in different reports Boverket (1998) and VVS-tekniska föreningen (2006). There is also a method for planning for a good indoor environment Hult (2002).

3 Evaluation of energy saving measures in reconstructed buildings

Two examples on studies involving evaluations of energy saving measures at reconstruction of multi-dwellings buildings in Sweden are the so called “Energisparkvarteren” Anderlind et.al.(1986) and the so called “Högskoleprojektet Elmroth et al. (1989). By realizing energy saving measures in existing buildings all around Sweden and then evaluating them carefully, owner of buildings may be convinced that the energy saving actions are profitable. At the project “Energisparkvarteren” about 1800 apartments built during the 1950´s were evaluated. The measures taken were:

- replacing the windows with windows having low U-value or adding one more pane of glass
- supplementary insulation in the attic
- supplementary insulation of the outer walls
- sealing of windows and doors
- adjusting the heating- and ventilation system
- use of heat recovery system

In these projects no evaluations of the indoor climate have been carried out. The table 1 below shows some examples on the energy savings from different energy saving actions

Table 1 Energy savings from different energy saving actions

Measure	Number of buildings	Energy saving
Adjusting the heating- and ventilation system	5	8%
Adjusting the heating- and ventilation system+ supplementary insulation in the attic (120 mm)+replacing the windows	5	15%
Adjusting the heating- and ventilation system+ supplementary insulation in the attic (120mm)+ supplementary insulation of the outer walls (120mm)	5	18%
Adjusting the heating- and ventilation system+ supplementary insulation in the attic (200mm)+ sealing of windows	9	18%

In the other project "Högskoleprojektet" a number of multi-dwelling buildings been have investigated in order to show the results of different energy saving measures. 36% of the buildings were built before 1940, 37% were built between 1941 and 1969 and 27% were built between 1961 and 1975. Results from the actions taken are shown in table 2.

Table 2 Energy savings from different energy saving actions

Measure	Number of buildings	Energy saving
Replacing the windows	27	9%
Supplementary insulation in the attic	29	5%
Adjusting the heating- and ventilation system+ replacing the windows	6	11%
Adjusting the heating- and ventilation system+ supplementary insulation in the attic or façade	16	11%
Adjusting the heating- and ventilation system+ sealing of windows	10	8%

An important result from the investigation was the knowledge about how different energy saving measures co-operate and how they have influence of each other. The conclusion from "Energisparkvarteren" was that every building must be treated individually when selecting energy saving measures. Measures that give god results in one building can give bad results in another building. Combination of different energy saving measures showed the best results when the combination was made especially for the building in question.

4. Energy saving measures at reconstruction and evaluation after reconstruction

A research project at the University of Halmstad describes the actions taken when renovating buildings constructed between 1966 and 1970 in Halmstad Sweden, Borgström (2006). The purpose of the renovation was to lower the energy consumption and to renew the exterior of the buildings. The actions taken have been evaluated both before and after the reconstruction in order to find out if the right actions have been taken with regard to the energy consumption and the indoor climate. This was done by comparing the measured energy consumption before and after the reconstruction, by measuring the indoor temperature before and after reconstruction and by analyzing some parts of the building where no actions were taken.

Students from Halmstad University have in their degree project compared different actions taken to decrease energy consumption in some of these buildings, Jörgensen, Olsson (2002). This study was made before the renovation. The computer software, Enorm 1000, has been used for the calculations. Calculated measures are replacement of existing windows with triple-glazed windows, supplementary insulation in the attic, supplementary insulation on the facades and all measures used together. Results from the calculation are shown in table 3.

Table 3 Calculated energy savings

Measure	Energy saving
Replacing the windows	8%
Supplementary insulation in the attic (500mm)	2%
Supplementary insulation of the façade (50mm)	28%
All measurements	38%

When the buildings were renovated the actions taken were:

- 100mm supplementary insulation on the attic
- 50mm supplementary insulation of the facades
- The windows in the facades have been replaced by triple-glazed windows
- Adjusting the heating system

- Sealing of balcony door
- New inlet terminal

No actions were taken to neither the external wall nor the windows at the insert balcony. When analyzing the indoor climate it is of interest to look at both those parts where actions have been taken and those parts where nothing was changed. The part of the building that is of special interest is the section composed of the walls and windows at the inset balcony. Measurements have been made of the indoor temperature close this part of the building.

Through this renovation the use of energy have decreased with 19% which is lower than the estimated value. This is due to that the thickness of the insulation used in the attic was 100mm compared to the estimated 500mm. In addition, not all windows were replaced with triple-glazed windows.

The indoor temperature does not exceed the limits for temperatures indoor set by the National Swedish Board of Health and Welfare (2005). When the outdoor temperature is below zero, the surface temperature on the windows at the inset balcony is low. This can result in cold downdraughts and cold radiation and an uncomfortable indoor climate.

5 Conclusions

Following conclusions can be drawn:

- Many dwellings in Sweden were built during a ten-year period between 1965 and 1974. When these buildings are to be renovated there is a great potential for energy saving.
- It is important that all parties in the construction process are joined in aim for low energy consumption and a comfortable indoor climate. It is also important that they are all aware of the close relationship between the use of energy in buildings and the indoor climate.
- It is also important to evaluate the outcome of actions taken at renovation. A good indoor climate should be an important target in the planning and design phase even at renovation.
- It is necessary to increase the knowledge about different energy saving measures that can be used at renovation/reconstruction, and also to establish routines to follow up both the effects on energy consumption and to evaluate the indoor climate after renovation/reconstruction.

6 Further research

Give an overview of the methods some real estate company's uses and describe disadvantages and advantages of the methods.

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THE BIG INDOOR AIR EMISSIONS THREAT – SECONDARY EMISSIONS

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Summary

Substantial progress has been made understanding volatile organic chemical (VOC) emissions from indoor sources including building materials, furnishing, and some cleaning and maintenance products. During the past two decades, emissions from building materials and other sources have declined significantly in many developed countries. Researchers have begun to understand the potentially larger health threat posed by secondary emission, the chemicals formed by the interactions between oxidants in indoor air and chemicals on surfaces, and by hydrolysis. Many of the by-products of these interactions are more irritating, odorous, or toxic and may pose a far greater health hazard than the chemicals from which they are formed. Building materials, cleaning products, and many consumer products contain chemicals that react with oxidants to form formaldehyde and other, higher molecular weight aldehydes, acidic aerosols, and fine or ultrafine particles. Researchers have identified some of the most important indoor sources that combine with ozone (O_3) at common indoor concentrations to form these secondary products. The fundamental processes and critical building material and cleaning products have been identified along with recommendations for minimizing occupant exposure to hazardous chemicals resulting from indoor air chemistry and secondary emissions. Exposure to harmful secondary emissions can be reduced to improve indoor air quality

Key words: Indoor air quality, secondary emissions, volatile organic chemicals, ozone.

Background

Contaminants found in indoor air come from either indoor or outdoor sources. Among the most important of the indoor sources are building materials and furnishings, especially when they are new. Surfaces exposed to the interior are important, especially if they are periodically cleaned, re-finished, or renewed with wet-applied products that emit many of their constituents while drying or curing. The quantity of such materials can be very large over the lifetime of a building, and for some regularly-applied cleaning and maintenance products, large over even short periods of time. For example, the total mass of floor wax applied to a resilient floor product following manufacturer's instructions for regularly renewal can equal the mass of the flooring itself in a period of one or two years (Levin, 1999). Other indoor air pollutants enter a building from the outdoors and are carried in by ventilation air from mechanical or natural ventilation or through infiltration. Finally, occupant activities such as food preparation, cleaning, and personal hygiene, or from equipment and appliances can be sources of indoor air pollutants. Among the most well-known and important of these pollutants are volatile organic chemicals ((VOCs), chemicals that are found in air at normal indoor conditions of temperature and pressure.

Volatile organic chemicals in indoor air

Substantial progress has been made understanding VOC emissions from primary sources indoors including building materials, furnishing, and even some cleaning and maintenance products. As early as the late 1970s, researchers in Denmark were measuring emissions of formaldehyde from building materials and furnishings (Mølhave, 1981). By the mid-1980s, emissions testing of formaldehyde from composite wood products (particle board, plywood, fiberboard) used in federally-subsidized or insured housing and mobile homes in the U.S. was required. Apart from the formaldehyde emissions, early reports of emissions testing from building materials were primarily from research projects and were not generally reflected in guidelines and standards for building materials and finishes. In the mid-80s and onward, emissions testing began being applied to buildings in design (Levin, 1985; 1986; 1989; Tucker, 1990; Levin and Hodgson, 1996). And in the 1990s, emissions testing of many building products began to become increasingly common, at least in "green" building design processes (Tichenor, 1996; 2007). A comprehensive review of emissions testing became available in 2007 (Tichenor).

During the past two decades, concentrations of VOCs emitted from building materials and other sources have declined significantly in many developed countries. The decline is partly attributable to emissions testing and increased awareness of the importance of emission in determining indoor air quality. According to one review, a large fraction may also be attributable to regulation of emissions into ambient air where many VOCs are precursors of photochemical smog (Hodgson and Levin, 2003a; Levin and Hodgson, 2006).

Figures 1 and 2 (from Hodgson and Levin, 2003a) present results of VOC measurements from several studies. Figure 1 compares survey results from offices and residences reported between 1990 and 2001. Figure 2 compares Figure 1 residential results to surveys done prior to 1990. From the results it is clear that with several exceptions, the concentrations of most of these VOCs generally found indoors had decreased significantly from the levels found prior to 1990.

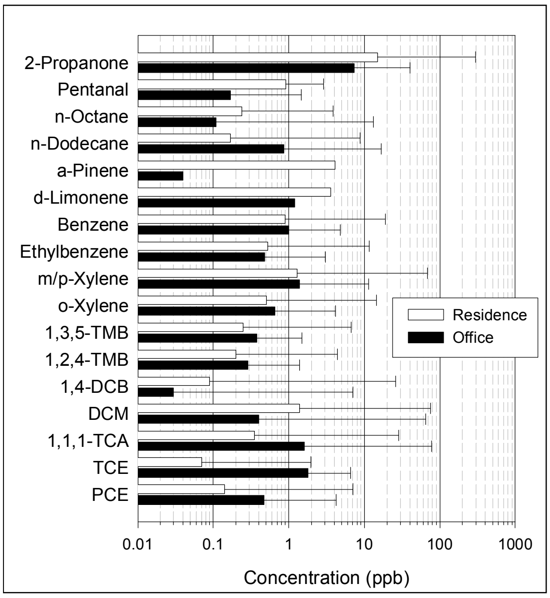

Figure1: Residential vs Office buildings: Comparison of central tendency and maximum concentrations (whiskers) of selected VOCs (1990-2001 studies). TMB = trimethylbenzene, DCB = dichlorobenzene, DCM = dichloromethane, TCA = trichloroethane, TCE = trichloroethene, PCE = tetrachloroethene.

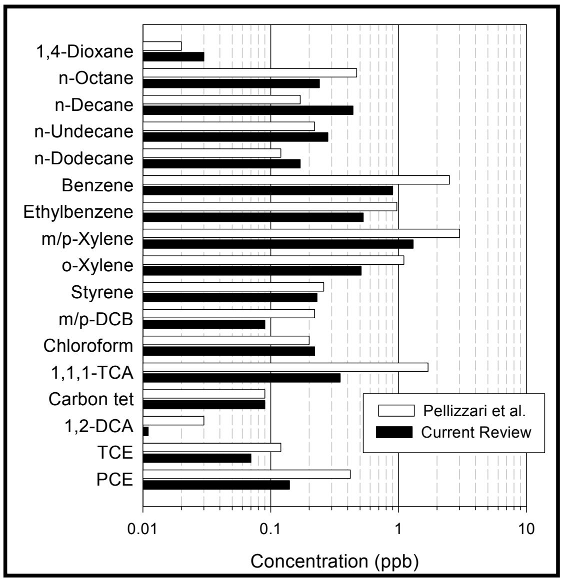

Figure 2: Residential buildings: Comparison of geometric mean (GM) concentrations of 17 VOCs (U.S. EPA TEAM studies prior to 1990 as reported by Pellizzari et al.1986 vs 1990-2001 studies). DCA = dichloroethane.

Formaldehyde

Not shown in these two figures is formaldehyde, probably the most well-characterized of indoor air pollutants in terms of health effects which include nose, eye, and skin irritation, upper respiratory tract irritation, and cancer. In the late 1970s and into the 1980s in the United States (U.S.), formaldehyde concentrations in indoor air often were found exceeding one part per million (ppm). The U.S. Occupational Safety and Health Administration's guideline value for protection of workers exposed to formaldehyde was 3 ppm, and this concentration was occasionally approached in indoor air where large quantities of plywood, particleboard, and hardwood veneer plywood were used, especially in mobile homes and manufactured housing where these materials dominated interiors. More commonly, in new homes and offices, concentrations often reach several hundred parts per billion (ppb).

Today, the OSHA regulations require that employers whose workers are exposed to more than 300 ppb inform the workers of their exposures, and formaldehyde measurements in new buildings in the U.S. are more commonly in the 10 to 30 ppb range, a decrease of roughly a factor of 10 generally and as much as a factor of 100 in extreme cases. It was not unusual to find concentrations exceeding 100 ppb throughout the 1980s and even into the 1990s. Formaldehyde has once again become a pollutant of major concern indoors because a lot of composite wood products entering the U.S. and Europe from Asia have very high formaldehyde emissions. So designers and builders need to continue verifying that the products they are specifying and using are low emitting products. The State of California has recently passed regulations that would limit the emissions of composite wood products to the 100 ppb range.

Emissions testing and product labeling

Other volatile organic chemicals also continue to be a concern, and emissions testing and certification programs are becoming common means of screening products for green or sustainable buildings. However, these screening programs are often driven by the product manufacturers rather than public health agencies or population concerns, so there continues to be much to do to limit occupant exposure to emissions from building materials and furnishings (Tichenor, 2007).

Early concern about secondary emissions

While there is still substantial and appropriate concern regarding VOC emissions from new building materials as well as from cleaning and maintenance products and occupant activities, recent interest among many of the pioneers of emissions testing and indoor air research has shifted to "secondary emissions." In the last 15 years researchers have begun to recognize the potential importance including the large health threat posed by secondary emissions, the chemicals formed by the interactions between oxidants in indoor air and chemicals on surfaces. Many of the by-products of these interactions are more irritating, odorous, or toxic than the chemicals from which they are formed.

Nazaroff, Cass, and other early indoor air chemistry researchers

One of the earliest to document the importance of these chemical reactions in indoor air reactions was William W Nazaroff of UC Berkeley. Nazaroff studied chemical reactions indoors both in air and on surfaces in southern California museums. His 1986 paper written together with Glen Cass of Cal Tech, "Mathematical Modeling of Chemically Reactive Pollutants in Indoor Air," described some of the basic processes that form the background of indoor air chemistry research since that time. Their work was funded to investigate the impact of polluted air on art works, and what better place to study this than in Los Angeles of the early 1980s? Their article's abstract reads, in part: "A general mathematical model is presented for predicting the concentrations of chemically reactive compounds in indoor air. The model accounts for the effects of ventilation, filtration, heterogeneous removal, direct emission, and photolytic and thermal chemical reactions." Near the end of the paper, it states: "The model is formulated to be a general tool for studying chemically reactive air pollution systems." In other words, their work could be used to estimate the effects of increasing or decreasing outdoor air ventilation rates as well as the use of filtration but also to predict the impact of airborne chemical reactions on building and other indoor material surfaces and on airborne concentrations of various pollutants.

Several researchers prior to Nazaroff and Cass had looked at indoor air chemistry; a very early publication was by MG Wilson in 1968 (Wilson, 1968).) An early paper on by-product formation from surface reactions was by James Pitts (1985). But nobody really pursued the topic of secondary emissions vigorously, and it did not gain much attention from the indoor air research community until the early 1990s.

Charles J. Weschler, Ozone, and Indoor Air Chemistry

Among the most important of those who took up the challenge and opportunity highlighted by the Nazaroff and Cass paper and the earlier work by Wilson, Pitt, and others is Charles J. Weschler. Much of the present awareness of indoor air chemistry is due to Weschler's work. First he called attention to the significant ozone concentrations indoors at a time when it was widely believed that concentrations indoors were inconsequential due to ozone's reactivity (Weschler et al, 1989). He reported that indoor concentrations of ozone were inversely related to the outdoor air ventilation rate and directly related to the outdoor ozone concentration. A typical office ventilation rate of just under 1 air change per hour (h^{-1}) results in an indoor-outdoor (I-O) ozone ratio of approximately 0.2. A school or assembly space with an air change rate of ~3 h^{-1} will have an I-O O_3 ratio of ~0.5. and a laboratory or other space with approximately 6 air changes per hour has an I-O O_3 ratio of about 0.7. To this day there are still many building, health, and chemical scientists who hold to the myth that ozone is not present in significant concentrations or important in indoor air.

Weschler raised awareness of ozone reactions indoors and the resulting secondary emissions in his 1992 paper reporting experiments with ozone and carpets (Weschler et al, 1992). He showed that the emissions from carpet of styrene and of 4-phenylcyclohexene (4-PCH), a by-product of the styrene butadiene rubber (SBR) latex manufacturing process, would rapidly react with ozone indoors to form formaldehyde, acetaldehyde, and other, higher molecular weight aldehydes. SBR latex backings were the most common on commercial carpet in that era and represented about 85% of the commercial carpet market. Weschler reported that the concentrations of VOCs that were markedly reduced "…in the presence of O_3 are those that contain unsaturated carbon-carbon bonds (4-phenylcyclohexene, styrene, and 4-ethenylcyclohexene)."

Not long after Weschler presented his findings described in the 1992 *Environmental Science and Technology* article, the present author received a call from an architect whose client, a law firm, had just moved into a newly renovated office space. All the secretaries were complaining of eye and skin irritation among other symptoms by the end of the first week in the office. Each secretary had their own laser printer at their work station, and laser printers emit ozone. The firm had called an industrial hygienist to measure the 4-PCH in the air, but the hygienist found very low concentrations. The apparent reason was that the ozone from the printers was reacting with the 4-PCH so that there was no 4-PCH left in the air to measure. As a result of the reaction, formaldehyde and other aldehydes were formed, and these are known irritants. Thus, the lessons of the researchers began to inform the design of buildings, and laser printers were recommended to be isolated in rooms equipped with exhaust directly to the outdoors. This kind of finding led Weschler to the title of a talk on his ozone and carpet research titled "Indoor VOCs: Is What You Measure on

Tuesday Night the Same as What You Measure on Wednesday Afternoon?" The title conveyed dramatically the problems indoor air chemistry causes for investigators of indoor air complaints and illustrates the importance of understanding indoor air chemistry processes.

Weschler has since published many papers on the subject of indoor air chemistry and especially reactions of materials commonly found indoors with ozone, and he has collaborated with others in experiments in Europe and America, in the lab, in buildings, and in simulated aircraft cabins. These experiments have shown that the ozone concentrations are lower indoors than outdoors because the ozone was reacting with indoor surfaces. He (and many others as well) reported that the products of these reactions included formaldehyde, higher molecular weight aldehydes, acidic aerosols, and ultrafine particles. The outcome, as Weschler has often said, is that the ozone is removed but the reaction products are more hazardous than the chemicals from which they are formed. Two of his most important and useful overview papers are "Ozone in Indoor Environments: Concentration and Chemistry" (Weschler, 2000) and "Ozone's Impact on Public Health: Contributions from Indoor Exposures to Ozone and Products of Ozone-Initiated Chemistry" (Weschler, 2006).

Fundamentals of ozone chemistry in air and on surfaces

Ozone is very reactive and easily reacts with unsaturated compounds that are commonly found in typical buildings. These compounds include citrus based solvents, the so-called "green" solvents (containing d-Limonene and other citrus oils) that have gained popularity as replacements for the toxic traditional solvents formerly found in many products. They also include chemicals found in many softwoods, the terpenes like alpha-pinene. Pine oil cleaner is an example of such products. Ozone also reacts with the oils found in linseed oil resulting in the very strong and persistent odor of linoleum floor covering. These oils, composed primarily of esters of linolenic, linoleic, and oleic acids, have also been found by other researchers to form the aldehydes and odorous compounds emitted from linoleum and other products using linseed oil in their formulation (Morrison and Nazaroff, 2002). What these chemicals have in common is unsaturated double carbon bonds that react very quickly with ozone.

Researchers have begun to understand the processes involved in the generation of secondary emissions and have identified some of the most important indoor sources that combine with ozone at common indoor concentrations to form these secondary products. In 2007 at UC Berkeley, some of the leading researchers gathered to discuss "interfacial chemistry in indoor environments" at a workshop sponsored by the National Science Foundation and the California Air Resources Board and organized by Glenn Morrison of the University of Missouri, Rolla. The following section summarizes some of the presentations and discussions at that workshop based largely on Morrison's report of the workshop to the sponsoring agencies (Morrison, 2007) and his article in the journal *Environmental Science and Technology* (Morrison, 2008).

The fundamentals of indoor air chemistry are illustrated in Figure 3 provided by Glenn Morrison from his presentation at Healthy Buildings 2006 in Lisbon, Portugal.

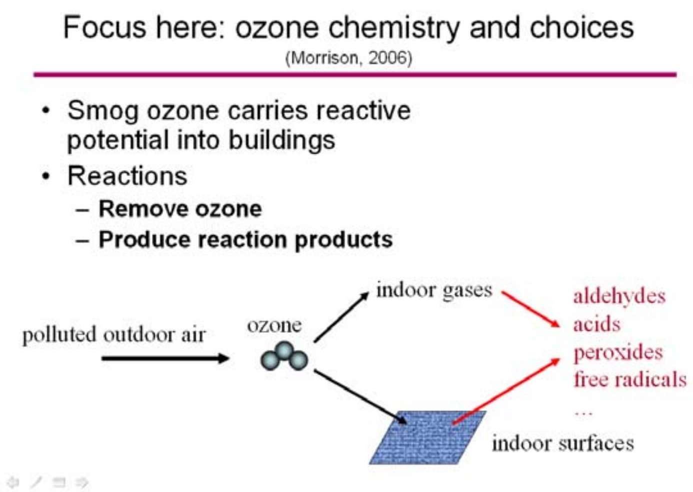

Figure 3. Fundamentals of Indoor Air Ozone Chemistry (source: Morrison, 2006)

Ozone Reactions with Surfaces

Many of the most widely-used building materials, cleaning products, and consumer products are made from chemicals that react with ozone and other oxidants to form formaldehyde and other, higher molecular weight aldehydes, acidic aerosols, and fine or ultrafine particles (Weschler 2000; Nazaroff and Weschler, 2004;

Nazaroff et al, 2006). Thus, as indoor air researchers probed deeper into the sources of the chemicals found in indoor air as well as the disappearance of some that enter the air but are not found in the expected concentrations, they discovered the importance of chemical reactions for explaining the presence of (and determining the fate of) some of the more important chemicals.

One of the active and most productive research areas has been the study of ozone reactions with various indoor surfaces and compounds found on these surfaces. The basic schematic relationships are shown in Figure 3 below from a 2006 presentation by Glenn Morrison. Ozone readily reacts with an ample supply of unsaturated compounds that generally exist in typical buildings at concentrations many times greater than observed outdoors. Products of this chemistry include carcinogens (formaldehyde, acrolein), irritants (carbonyls, dicarbonyls, acids), free radicals, and other oxidation products of concern (e.g. pesticide oxidation products). The volatile products have been coined “secondary emissions”, and the resulting concentrations of chemical reaction products are large enough to have health and comfort consequences at typical indoor ozone levels.

Perhaps the most important overall finding is that reactions between ozone and indoor surfaces strongly influence human exposure to ozone, the chemicals and surfaces with which ozone reacts, and to the chemical by-products. As illustrated by Weschler and Shields (1989) and later by Lee et al (1999), the reactions of O_3 on indoor surfaces reduce occupant exposure by factors ranging from 2 to 10. The surface area available for such reactions is extremely large, far larger than the planar surface area because the reactions take place at the molecular level and the surface area available is large compared to the building volume. The reaction products can be attached to surfaces by sorption thus extending the average length of time the products are indoors and increases the probability that conversions will occur, and unique compositions and morphologies at indoor surfaces can promote some reactions or promote selectivity in reaction pathways.

Chemicals in Products Applied to Surfaces

One of the major concerns emerging from the interfacial chemistry research is that many of the O_3 reactions occur with chemicals commonly found and unintentionally applied to indoor surfaces. Ozone reacts with the common pesticide cypermethrin (Segal-Rosenheimer and Dubowski, 2007). It also reacts with the terpenes used as the active ingredient in cleaning or other scented products (Singer et al, 2007). Researchers have now found that cleaning products and air fresheners increase the ozone deposition on surfaces (Singer et al, 2007). Compounds that had sorbed to the surfaces made up as much as half of the ozone reactions.

Two examples, orange oil cleaner and pine oil cleaner, are presented in Figure 4. The concentration of ozone introduced in these experiments, 40 ppb, is not uncommon in indoor environments. In residences without air conditioning or mechanical ventilation, open windows can easily result in such concentrations on a summer day in most cities in North America. What is most impressive here is how long the concentration of formaldehyde formed by the reaction lingers in the air after application on an apparently “dry” cleaned surface.

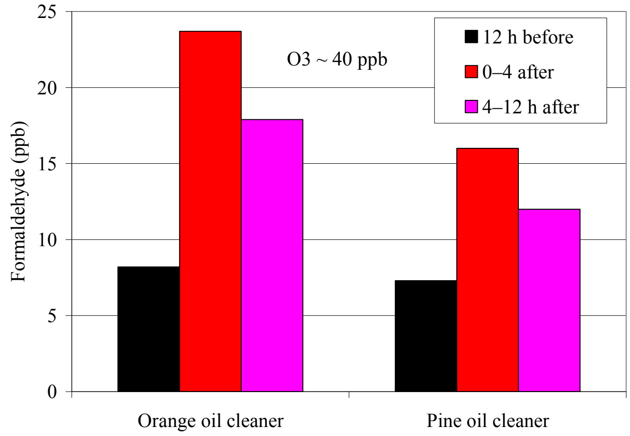

Figure 4. Cleaning products exposed to O_3 and formaldehyde formation (Singer et al, 2007)

Reactions of ozone with people

An extremely interesting and potentially very important finding is that the interfacial chemistry is taking place at the “human surface”. This became apparent in simulated aircraft cabin experiments, densely occupied with human subjects (Weschler et al, 2007; Wisthaler et al, 2006) and in studies of the “personal cloud,” (Corsi et al, 2008). Ozone delivered by the fresh air system in aircraft cabins forms compounds somewhat unique to its reaction with human skin oils or sebum. The researchers also concluded that in aircraft cabins, people are major O_3 sinks – larger than carpet, seats and dirty HEPA filters combined, and that O_3 and its oxidation products adversely affected 12 of 29 self-reported symptoms based on questionnaires from occupants. Evaluation of individual aircraft surfaces, in small-chamber experiments, confirmed these findings (Coleman et al, 2007). Coleman also found ozone chemistry formation far higher with soiled human clothing than with laundered clothing, suggesting that the skin oils, perhaps among other accumulated chemicals on soiled clothing, were reacting with the ozone to form formaldehyde, acetaldehydes, and other typical ozone reaction products (see Figure 5).

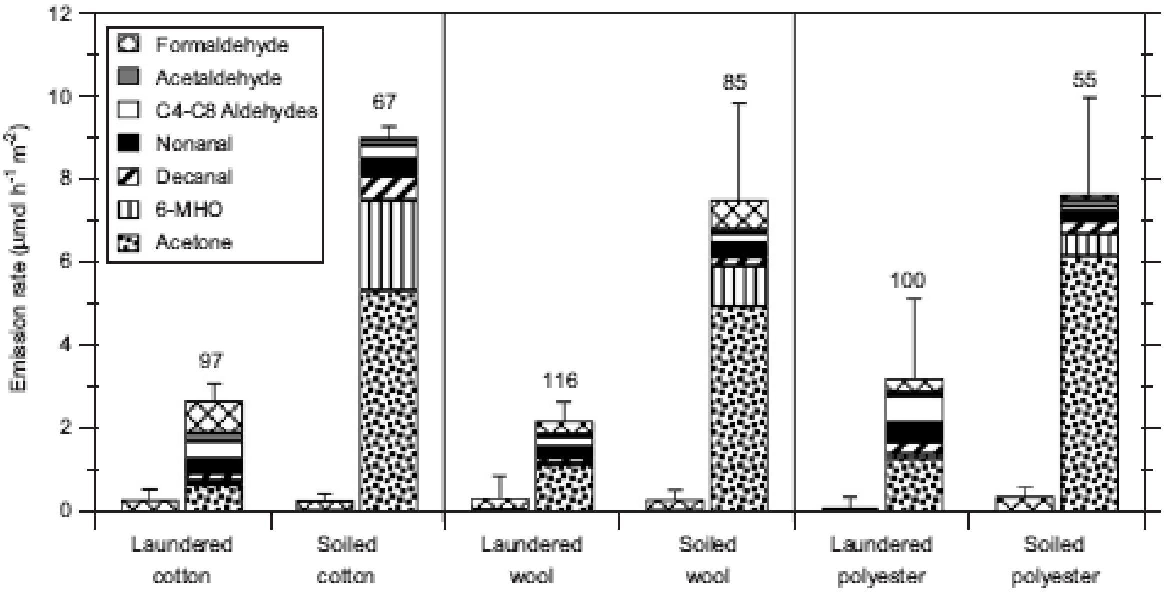

Figure 5. Clean and soiled clothing exposed to O_3 and chemical by-product formation (Coleman et al, 2008). For each material presented, the left bar represents the average emissions without ozone during a 180-min conditioning period (no ozone), and the right bar represents the average emissions during the initial 90-min ozone exposure period. The number above the right bar is the 90-min average residual ozone concentration in ppb; the supply air concentration was always 160 ppb. Error bar indicates plus one standard deviation from analysis of replicate integrated samples

Corsi et al (2008) investigated the presence of personal reactive clouds that result from ozone reactions with terpenes and terpenoids emitted from personal care products. “Screening experiments were performed with three perfumes and two hairsprays to determine the extent of secondary organic aerosol formation in the breathing zone of a subject who had applied these products. The results of screening calculations and preliminary experiments confirm that chemistry occurs in the “near-head region” of individuals who apply scented personal care products to their hair or facial skin.”

Even human hair reacts with ozone. Studies showed a very high probability of ozone reacting with hair follicles (Pandrangi and Morrison, 2007). When humans are in densely occupied environments such as classrooms, theatres, or airplanes, their aggregated reactivity will reduce their exposure to ozone but increase their exposure to the products of ozone-sebum reactions.

Reactions of other outdoor air pollutants with indoor surfaces

Reactions of other components of smog such as nitrous oxides (NOx) (Sakamaki et al, 1983) have also been studied on indoor surface; Pitts et al. (1989) showed that this chemistry also occurs on indoor surfaces and can generate nitrous acid (HONO) levels that exceed outdoor levels when NOx is released from indoor sources such as improperly vented gas burners.

Hydrolysis

Some important chemical reactions and physical processes indoors do not involve pollutants that are part of photochemical smog. The importance of hydrolysis (the decomposition of a chemical compound by reaction with water, such as the dissociation of a dissolved salt or the catalytic conversion of starch to glucose) is now recognized as an important source of indoor air pollutants as well as the potential deterioration of building materials. These processes in indoor environments are known to cause toxic and odorous chemical emissions.

One of the more important of these breakdown processes is the hydrolysis of plasticizer (e.g., di-ethylhexylphthalate -DEHP) generates mono-ethylhexylphthalate (EHP) (Lundgren et al, 1999) which may be associated with asthma (Norback et al, 2000). Plasticizers are often used in vinyl flooring and in adhesives to improve their functional properties. When vinyl flooring is applied to insufficiently cured concrete (high moisture content), hydrolysis will occur. Concrete flooring and gypsum board which are both highly basic can help catalyze this hydrolysis. (Corsi et al, 2007). Hydrolysis reactions depend on local pH and moisture conditions, but these parameters are rarely quantified accurately or sufficiently, and their influence on hydrolysis is poorly understood.

Indoor Chemistry and Occupant Health

“Secondary emissions”, the reaction products of ozone chemistry, include carcinogens (formaldehyde and acrolein), many irritants (including carbonyls, dicarbonyls, and acidic aerosols), free radicals, as well as other products of the oxidation process (e.g. pesticide oxidation products). It is apparent that the concentrations of these chemicals produced by such reactions have potentially important occupant health and comfort implications at ozone concentrations typically found indoors (Weschler, 2004).

Exposure to these secondary emissions may pose a far greater health hazard than the chemicals from which they are formed (Weschler, 2004; 2006). Weschler has also suggested that since a significant fraction of people’s exposure to ozone does occur indoors due to the far larger fraction of a typical person’s day spent indoors and since when ozone is removed from indoor air through indoor air chemistry, many of the reaction products are toxic, that some significant fraction of the morbidity and mortality reported by epidemiologists during periods of high outdoor ozone may be attributed at least in part to pollutant exposures that occur indoors (Weschler, 2006).

Some provocative recent findings

Ozone is nearly always present in sufficient concentrations in outdoor air to present concern for the health of building occupants. A recent analysis of the U.S. EPA’s BASE study data showed that outdoor ozone concentrations were associated with increased SBS symptoms (Apte et al, 2008). Additional analysis of the same data showed that a combination of higher outdoor ozone and synthetic fiber filters resulted in very large increases in the risk of SBS symptoms (Buchanan et al, 2008).

Summary of health implications

As is the case for most indoor pollutants, little is known about the health outcomes of exposure to most of the reaction products of indoor chemistry. Weschler’s analysis (2006) suggests that the reported epidemiological correlations between outdoor levels of ozone and morbidity or mortality are due, in large part, to indoor exposures to ozone and the byproducts of its reaction with other species indoors. His estimate is that indoor exposure to ozone transported indoors from outdoors is conservatively 2/3 to 3 times that of outdoor exposure to ozone. Meanwhile, indoor exposure to ozone oxidation products is often many times greater than outdoor ozone exposure. It can be anticipated that indoor levels of reaction products may correlate with outdoor levels of ozone, but this hypothesis still needs to be fully evaluated in field settings. Many human and animal experiments have shown adverse reactions to homogeneous ozone chemistry (see references in Tamás, G. et al, 2006). It appears, therefore, that real toxins, irritants, sensitizers and so forth are generated, and seemingly generated at levels of concern.

Controlling Indoor Chemistry

“Controlling indoor chemistry means controlling sources, reactants and conditions that promote that chemistry…. Indoor air and outdoor air are part of the same continuum. Yet scientific, legislative, and philosophical separation of these domains has adversely affected our ability to target efficient solutions for reducing exposure to smog and its consequences. We now see that smog chemistry does not stop at the door, but churns away in the indoor spaces where we spend most of our time. Thus indoor air and its chemistry need the same attention given to ambient air for the past 50 years” (Morrison, 2008).

What can be done?

There is a general agreement in the indoor air research and professional communities that source control is the alternative of choice. Then, after eliminating indoor pollution sources, authorities recommend dilution and removal by ventilation for indoor source pollutants. But ozone and its reaction products indoors present a dilemma in terms of the ventilation strategy. Where outdoor air contains any significant quantity of ozone, it may be important to limit the amount of outdoor air intentionally introduced into a building.

One of the ways to address the problems presented by indoor ozone reactions is to select materials that are less likely to react with ozone or to form harmful reaction products. It would clearly be wise to avoid introducing products that contain many of the chemicals that are especially reactive such as citrus-based solvents and cleaning products and terpenes (e.g., pine oil cleaners) that have been shown to react strongly with ozone to form undesirable products. Glenn Morrison has illustrated the processes and provided some preliminary data on ozone and formaldehyde formation with common indoor materials as shown in Figures 6. Extension of his work with more materials and application of the results can reduce occupant exposure to formaldehyde and other important indoor air pollutants from the ozone that is almost always present in sufficient concentrations to cause the reactions.

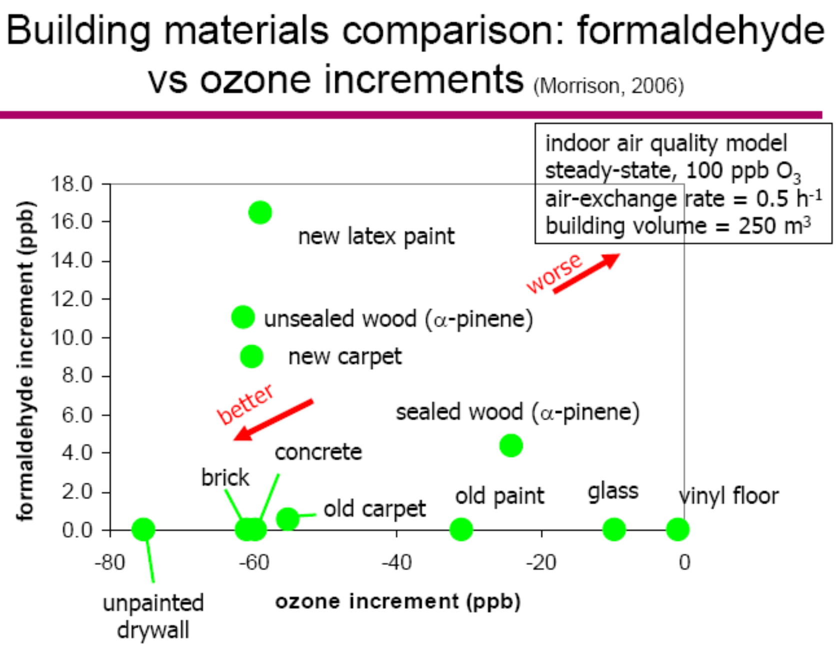

Figure 6. Building materials comparison: Formaldehyde vs Ozone increments (source: Morrison, 2006)

An alternative to attempting to address the ozone indoors by careful selection of materials is to remove the ozone by air cleaning when mechanical ventilation systems are used. Controlling indoor chemistry means controlling sources, reactants and conditions that promote that chemistry. Ozone is a clear target and its removal from buildings is anticipated to lower indoor concentrations of aldehydes, ketones, organic acids, free radicals and secondary organic aerosols. Activated carbon (AC) filtration is available for commercial buildings and is effective at removing ozone, and some VOCs, from supply air. Standard 62.1 from the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) requires AC filtration for high ozone areas, but the standard is rarely implemented and is not enforceable unless adopted or incorporated by reference by the jurisdiction having code authority. ASHRAE is currently revising Standard 62.1 to make intentional ozone removal (e.g., activated carbon filters) more widespread in commercial buildings. No standards exist for AC filtration in residential buildings and its use is negligible (Siegel, 2007). A proprietary catalytic agent available from BASF is used in aircraft cabin air systems to remove ozone when aircraft fly at high altitudes or latitudes where stratospheric ozone concentrations can result in ozone entry into aircraft cabins. Without removal, ozone concentrations can reach 200 ppb in aircraft cabins, and that is after the removal that occurs by interfacial chemistry.

Charles Weschler has written: “Reducing ozone levels in urban areas has proven to be a difficult and costly problem. It is easier to remove ozone from indoor air than from outdoor air. Filters are available to accomplish this with only small energy penalties. At present, the health consequences of exposure to the products of ozone initiated indoor chemistry are poorly characterized; adverse effects are inferred from several loosely connected studies. However, further examination of the hypothesis expressed in this article [The associations between ozone concentrations measured outdoors and both morbidity and mortality may be partially due to indoor exposures to ozone and ozone-initiated oxidation products].is warranted since it affects overall mitigation strategies. For example, if even partially true, it would be beneficial to remove ozone from the supply air of mechanically ventilated buildings, especially schools, hospitals and daycare centers located in regions that continue to experience elevated outdoor ozone concentrations.” (Weschler, 2006).

Acknowledgments

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A STUDY ON THE MEASUREMENT OF THERMAL ENVIRONMENT IN LARGE ENCLOSURE

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Keywords: Large enclosures, Thermal stratification, Vertical temperature distribution, Thermal comfort

Summary

The purpose of this study is to analyse the characteristic of an indoor thermal environment in large enclosures under heating and cooling conditions. This study measured the indoor thermal environment in winter and summer seasons. We examined the indoor thermal environment of large enclosures, namely, the vertical, horizontal temperature distribution and the thermal comfort environment.

1. Preface

1.1 Background and Purpose

Recently, the construction of large enclosure buildings such as an international airport, sport facility, atrium, convention center have been increasing. And the discussion on attracting of dome stadium and large enclosure, which meet the purpose to use, such as popular sports, events and meeting spreading the interests of representative landmark and lucrative business at the competitiveness securing level in each country.

But a large enclosure building has a general characteristic of frequent thermal movement toward to indoor/outdoor due to its great height, large volume, small residential area for total volume, and lightweight outer shell of the building directly exposed to open air. In addition to the normal residential and office buildings, large enclosure buildings can to customized to meet various requirements, such as the indoor environment, the number of persons, purpose of use, and residential area. Because of such requirements, a large enclosure building has difficulty in securing thermal comfort in the indoor area, an issue that needs to be solved for proper control of the indoor environment.

This study I analyzes the characteristics of the indoor thermal environment by actual measurements of the indoor thermal environment of a large enclosure building and provides basic data for planning a reasonable cooling & heating and air conditioning system of a large enclosure building in the future.

1.2 Scope and Method

The indoor stadium located in the Seoul Olympic Athletic Park of Seoul, Korea was chosen as the representative large enclosure building for this study. The analysis method uses 1/2 of the total area as the measurement area because of the symmetry of the total area for analysis of the summer and winter characteristics of the building. The outdoor weather conditions were measured(:) thermal environment index(MRT, PMV), wind velocity, and ventilation quantity.

The outdoor weather data were measured and stored in the installed, real time weather instrumentation, such as the Anemometer, Pyranometer and Relative humidity transmitter and Weather Station of DAVIS Co.Ltd. Many Thermistor sensors were installed to measure the temperature in the stadium, and the data provided by these sensors were stored automatically by the Data logger. The relative humidity of the supply & exhaust port was measured by a potable digital temperature-humidity meter(SK-L200Ⅱａ).

2. Measurement Method

2.1 Summary of the building to measure

The indoor stadium, which is located in the Seoul Olympic Athletic Park of Seoul, Korea, was selected as the test building, whose specification is summarized in Table 1. This building has capacity to hold 6 858 persons with changeable guest seats (1 635 seats) and fixed guest seats (5 223 seats) on the 1st and the 2nd level, and offices are posted by the corridor of the building. The heating system is divided into the stadium zone where central supply in the park supplies the steam and the office zone where Korea District Heating Corporation supplies medium temperature hot water. The heat source from each zone will be supplied to air conditioning system of the building through the basement common duct. The air conditioning system has 1 unit for cooling/heating and 1 unit for ventilation of each zone and supplies cooling & heating to the blow down system of wall sides and the 2nd floor guest floor.

Figure 1 Exterior view of the measured building

Table 1 Summary of measuring building

Completion	April.1986
Scale	B1F, 3F (diameter : 97 m, height : 22.35 m)
Structure	Reinforced concrete
Roof structure	Cable
Building area	8 658 ㎡
Floor area	16 358 ㎡

2.2 Measuring condition and Method

The measurement was executed for non-air conditioning, intermittent air conditioning and air conditioning (considering the body load) in the summer/winter season for 3 days on Feb 7 ~ 8 and Feb 24, 2007 in the winter season and 3 days on Aug 22 and Aug 24 ~ 25, 2007 in the summer season for the indoor gymnasium to evaluate the thermal environment of large enclosures.

The measurements for the non-air conditioning condition are shown in Table 2 and those for intermittent air conditioning were measured by 1st, 2nd and 3rd in real time. The measurements for the air conditioning condition were conducted during a match or an event. The indoor thermal environment was measured at selected points located at regular intervals, with the starting point being the center of the indoor gymnasium. The circular indoor total area was divided in half as shown in Fig. 2 and all of opening & shutting parts in the building were closed because they were expected to influence the temperature distribution.

The weather station of DAVIS Co., Ltd was installed adjacent to the building to measure the outdoor weather and to store the temperature, humidity and solar light quantity data. The temperature and humidity of the supply/exhaust port were measured at 10 second intervals by a potable digital temperature-humidity meter(SK-L200Ⅱａ), and the velocity of air at the supply/exhaust port by Hot-wire wind velocity meter. Vertical temperature was measured at V2 ~ V5 points at 0.5m interval up to 3m high and 1.5m interval over 3m high with the installed Thermistor sensor, and horizontal temperature was measured at A1 ~ A7, B1 ~ B7 and C1 ~ C7 points with the starting point being the guest seat floor with the installed temperature sensor at 1.0m and 1.1m high and stored at 10 second intervals by Monitoring Device.

The air stream velocity for guest seat was the average value of velocities measured 12 times at 5 second intervals measured by a Hot-wire wind velocity meter, and the globe temperature was stored at 10 second intervals by the installed temperature sensor in the globe. PMV was measured by a thermal comfort meter at 20 minute intervals according to the ISO 7730 setting of 1.2clo of wear test and 1 met of activity test in the winter season, and 0.5clo of wear test and 1 met of activity test in the summer season. The equipment and measurements are listed in Table 3.

Table 2 Measurement schedule and condition

Division	Measuring schedule		Measuring condition		
Winter season	Non heating condition	Feb 7. 2007	Heating off		
	Intermittent heating condition	Feb 8. 2007	1th	09:00 ~ 11:00	Heating on (293K)
				11:00 ~ 11:50	Heating off (294K)
			2th	11:50 ~ 13:30	Heating on (294K)
				13:30 ~ 14:00	Heating off (297K)
			3th	14:00 ~ 15:30	Heating on (294K)
				15:30 ~	Heating off (297K)
	Heating condition (With heat loads from occupant)	Feb 24. 2007	08:00 ~ 12:00		Heating on
			14:00 ~ 18:00		Volleyball game
Summer season	Non cooling condition	Agu 24. 2007	cooling off		
	Intermittent cooling condition	Agu 22. 2007	1th	09:00 ~ 11:00	Cooling on
				11:00 ~ 12:00	Cooling off
			2th	12:00 ~ 14:00	Cooling on
				14:00 ~ 15:00	Cooling off
			3th	15:00 ~ 17:00	Cooling on
				17:00 ~	Cooling off
	cooling condition (With heat loads from occupant)	Agu 25. 2007	10:00 ~ 17:00		Cooling on
			12:00 ~ 18:00		High school festival

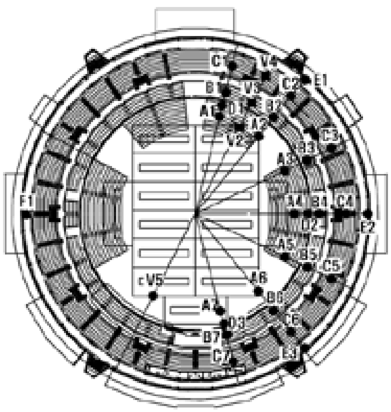


Figure 2 Measuring point of the measured building

Table 3 Measuring contents and equipments

Measuring Items	Measuring points			Measuring equipment
Atmospheric phenomena	Outdoor of measuring building		1	DAVIS/ sechang Instrument
Temperature & Humidity	Air supplying opening	D1,D2,D3, C2, C4, C6	6	DAVIS/ sechang Instrument
	Exhaust opening	E1, E3	2	
Wind velocity	Air supplying opening	D1,D3,C2, C4, C6	5	Hotwire Anemometer /8570
	Exhaust opening	E1, E3	2	
Vertical temperature	V2 ~ V5		76	SOAM-TLS Monitoring Device(TLS)
Horizontal temperature	0.1m 1.1m	A1 ~ A7, B1 ~ B7, C1 ~ C7	42	
Indoor surface temperature	F1		1	THERMO TRACER/ TH5104R
Seat Wind velocity	1F seats	B1 ~ B7	7	Hotwire Anemometer /8570
	2F seats	C1 ~ C7	7	
Globe temperature	1F seats	B2,B4,B6	3	SOAM-TLS Monitoring Device
	2F seats	C2,C4,C6	3	
PMV (Predicted Mean Vote)	B4		1	Hermal Comfort Meter /AM-101

3. Result and Analysis

3.1 Analysis of vertical temperature distribution

3.1.1 Vertical temperature distribution and changes in the winter season

As shown in Fig. 3(a), the indoor temperature under the non- air conditioning condition was the lowest temperature of the day, indicating an even temperature distribution just after sunrise, regardless of the location and height, and the highest indoor temperature of the day with the outdoor temperature before & after 16:00 pm. It is concluded that the greater vertical temperature rise in the upper area than in the lower area is due to the difference of the lighting load and sunlight quantity with time at 9m above the upper floor part of the arena under the non-air conditioning condition.

The difference of temperature stratification and build up occurred for the heating condition set by time under the intermittent air conditioning condition. The vertical temperature by height was uniform before the operation of the heating system, was 279K of the high/low temperature difference in the arena 2 hours after operation of the heating system as Fig. 3 (b) and was 276K high/low temperature difference at the guest seat on the 1st and 2nd level due to the relative low height of the building.

It is estimated that there would be air space by moving low temperature air to the lower space as blow down air stream with high temperature risen by buoyancy positioning to the upper space. High/low temperature difference was generally reduced 11 hours after heating, showing 276.5K high/low temperature difference 50 minutes after the end of the heating supply, as shown in Fig. 3 (c). In the case of heating condition (considering the body load), the temperature rose rapidly and air space occurred by the 279 ~ 280.5K vertical temperature differences by location, as shown in Fig. 3 (d) after heating, and the temperature stratification formed during heating was slowly relieved, showing 274.5K ~ 275.5K vertical temperature differences 2 hours after the end of the heating supply, as shown in Fig. 3 (e), when the volleyball game started.

Relieved air space has been maintained until the end of the game at 293 ~ 295.5K indoor temperature in the residential area. However, the actual temperature decreased rapidly after the game. The body heat of the guests of the volleyball game acted to maintain the actual temperature to 293 ~ 294K, the 1st heating setting temperature of the intermittent air conditioning condition. This resulted in the exchange of indoor thermal energy with low temperature air removing body heat by opening/closing the exits after the game.

The indoor vertical temperature for heating and non-heating times is compared in Fig. 3 (f). The high/low temperature difference upon heating was 279.7K, and that upon non-heating was 274.2K. The temperature at 3m height increased rapidly upon heating. This is the reason why the blow down air upon heating to a high temperature moves toward the upper space by buoyancy to form temperature stratification.

3.1.2 Vertical temperature distribution and changes in the summer season

Due to data error and loss of non-cooling and cooling (considering the body load) condition in the summer season, the vertical temperature distribution was analyzed only for the intermittent cooling condition. Air space with high temperature on the upper space was formed at 9 ~ 11 am upon the 1st heating, unlike what was done for the intermittent cooling of Fig. 4 (b). It is considered that low temperature blow-down stream with big density moves to the residential area to keep the indoor temperature 297.5K, but temperature stratification was formed by the buildup of high temperature air that rose from the upper space of the roof. In the case of Fig. 4 (b) in which the cooling supply was ceased, the temperature in the lower space by location influences the residential area by continuous heat transfer between the high temperature formed from in the upper space of the indoor area to show higher temperature distribution than 299K cooling setting temperature by higher 275K than that of Fig. 4 (a).

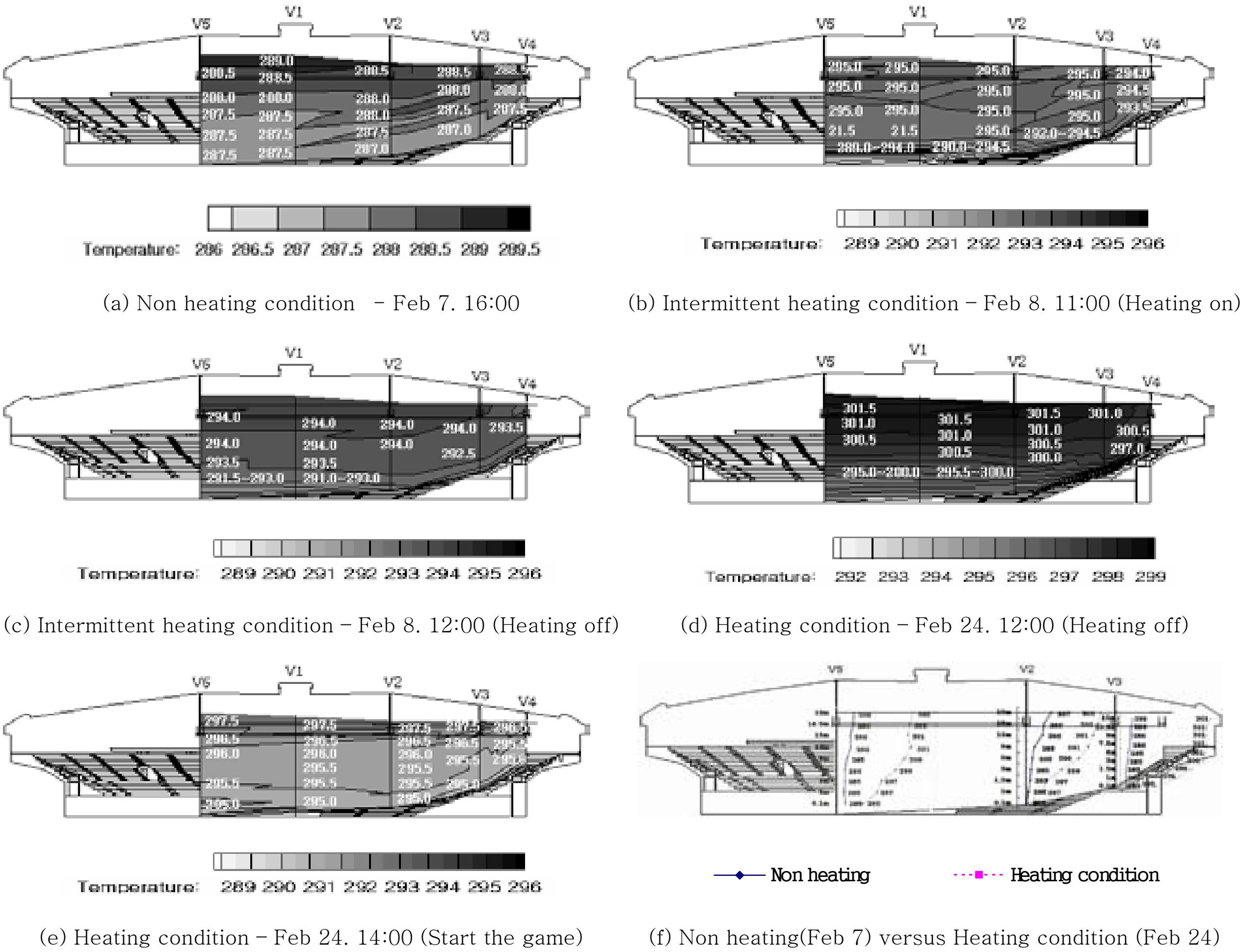
3.2 Analysis of horizontal temperature distribution

3.2.1 Horizontal temperature distribution and changes in the winter season

Horizontal temperature at 1.1m high on the guest seat at the 1st level in the winter season is shown in Fig. 5. The maximum horizontal temperature difference was 273.8K at each measurement location because the outdoor air from the exits at the guest seat of 1st level on non-heating condition, and the horizontal temperature changed slightly until 9 ~ 15pm during intermittent heating in the intermittent heating condition. During the volleyball game in the heating condition (considering the body load) from 13:30 ~ 18:00, the horizontal temperature distribution by measurement location was 294 ~ 294.5K, which was maintained until the end of the game; this temperature range was higher than 293 ~ 294K range of the1st heating temperature condition of intermittent air conditioning condition.

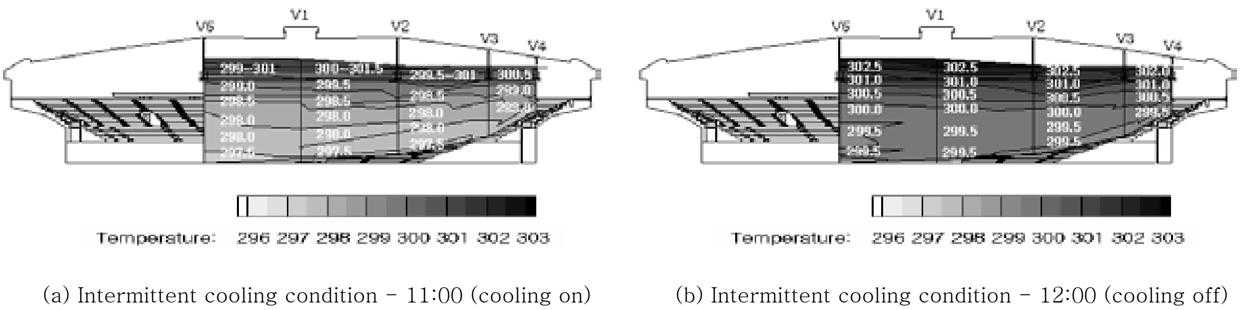
3.2.2 Horizontal temperature distribution and changes in the summer season

The horizontal temperature at 1.1m height on the guest seat at the 1st level in the summer season is shown in the Fig. 6. The horizontal temperature is similar to that of the non-cooling condition and is slightly different from that of the intermittent cooling condition, except in the B1 area , but is greatly different from that of the cooling condition (considering the body load).In spite of continuous cooling during



(a) Non heating condition – Feb 7. 16:00
(b) Intermittent heating condition – Feb 8. 11:00 (Heating on)
(c) Intermittent heating condition – Feb 8. 12:00 (Heating off)
(d) Heating condition – Feb 24. 12:00 (Heating off)
(e) Heating condition – Feb 24. 14:00 (Start the game)
(f) Non heating(Feb 7) versus Heating condition (Feb 24)

Figure 3 Vertical temperature in winter season.



(a) Intermittent cooling condition – 11:00 (cooling on)
(b) Intermittent cooling condition – 12:00 (cooling off)

Figure 4 Vertical temperature in summer season.

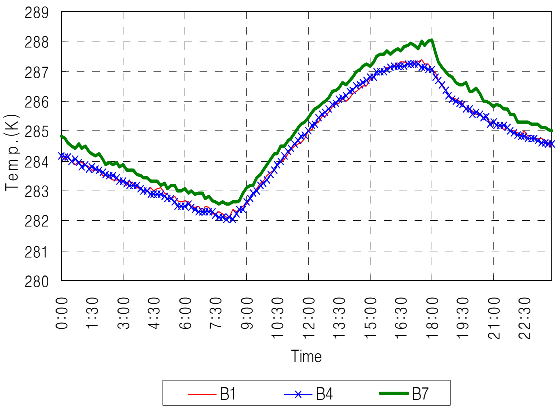
10:00~17:00, the horizontal temperature rose slowly by the body heat of students and their parents during the 12:00~18:00.

3.3 Indoor Thermal Comfortableness

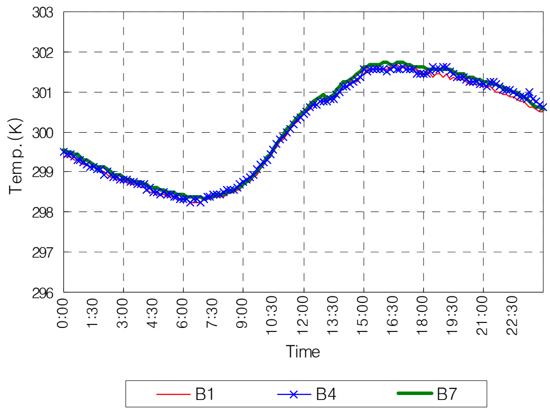
3.3.1 Indoor thermal comfortableness in winter season

The result from PMV with the measurements of the indoor thermal environment in the winter season is shown in Fig. 7. PMV in the non-heating condition is -1.89 ~ -2.99, which indicates discomfort due to low temperature, as shown in Fig. 7 (a), but the PMV value decreased rapidly after heating and there was a small change of the PMV value due to the movement of the guests during thestart and end of the 2nd volleyball game, but indoor thermal environment satisfied the comfort standard of ISO-7730, showing -0.46 ~ -0.12 PMV value during the game for 15:00~17:00.

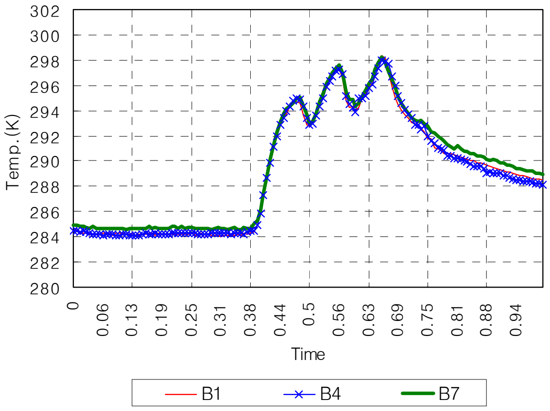
In the heating condition (considering the body load) of Fig. 7 (b), the PMV value at all of 6 measuring area was -0.12 ~ +0.15, 2 hours after the start of heating at 10:00, representing the improved indoor thermal environment according to the ISO-7730 comfort standard. PMV values from 5 measurement locations, except 1 PMV - 0.5 value, satisfied the ISO-7730 comfort standard -0.5 ~ +0.5 at 14:00, 2 hours after 12:00, the duration of 4 hours of continuous heating.



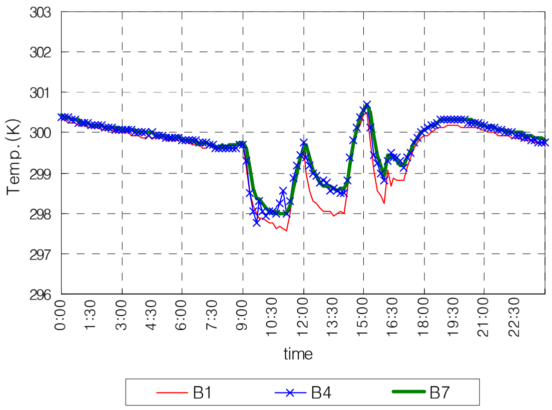
(a) Non heating condition – 1F seats



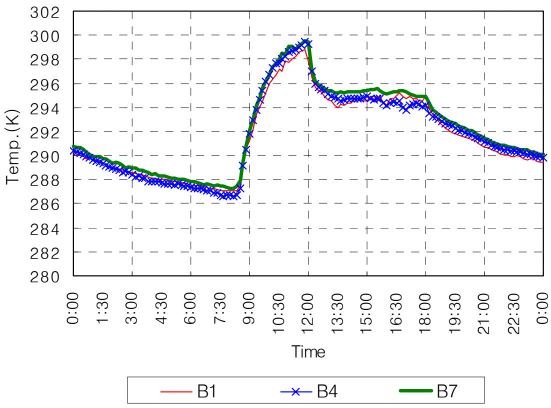
(a) Non cooling condition – 1F seats



(b) Intermittent heating condition – 1F seats

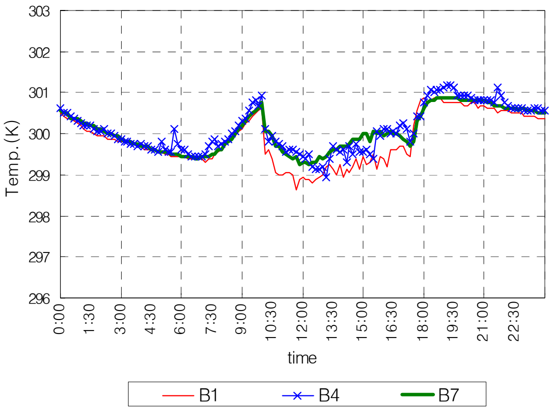


(b) Intermittent cooling condition – 1F seats



(c) Heating condition – 1F seats

Figure 5 Horizontal temperature in winter season

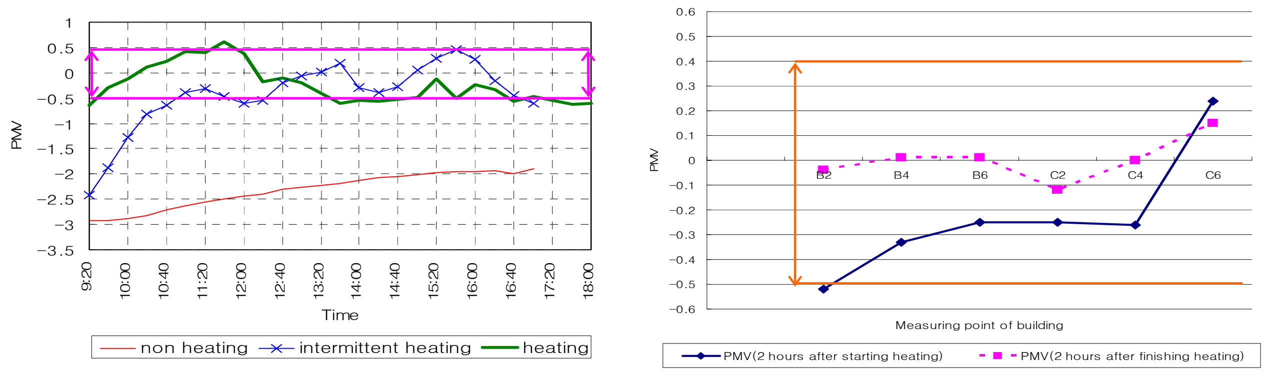


(c) Cooling condition – 1F seats

Figure 6 Horizontal temperature in summer season

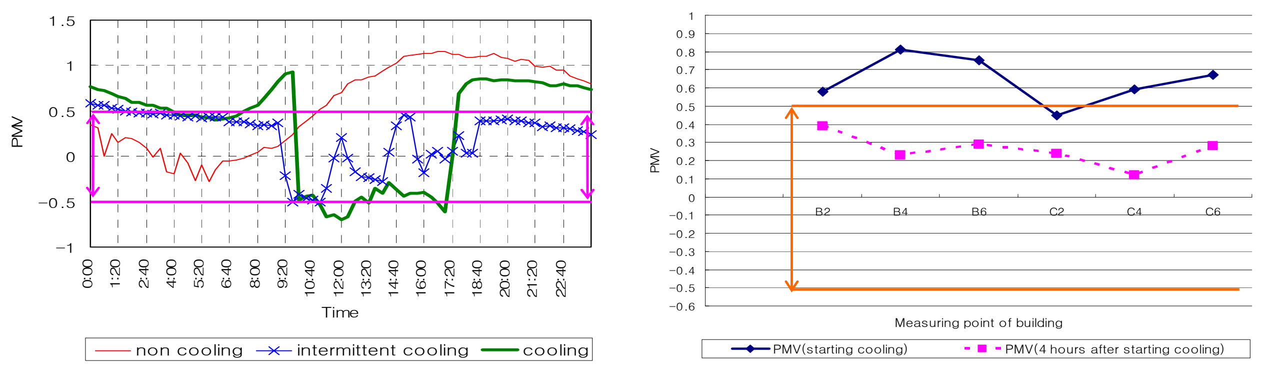
3.3.2 Indoor thermal comfortableness in the summer season

PMV result with the measurements of the indoor thermal environment in the summer season is shown in Fig. 8. As the non-cooling condition of Fig. 8 (a) shows, the PMV value is 0.52 ~ 1.16 , which indicates discomfort due to high temperature after 11:00am, resulting from the rise in the indoor temperature due to the influence from the outdoor temperature. In the intermittent cooling condition, the PMV value varied according to the cooling condition set with time and satisfies the ISO-7730 comfort standard, except during the period of dawn. PMV values measured from 6 areas at 10:00am, the starting time of cooling in the cooling condition (considering the body load), are +0.58 ~ +0.81, exceeding the ISO-7730 comfort standard and PMV values at the time of 4 hours passed from the cooling start are +0.12 ~ +0.39 to maintain the indoor thermal environment satisfying the improvement of PMV value and ISO-7730 comfortableness standard on starting cooling.



(a) Heating condition – B4 (b) Heating condition – B2, B4, B6, C2, C4, C6

Figure 7 PMV in the Winter season



(a) Cooling condition – B4 (b) Cooling condition – B2, B4, B6, C2, C4, C6

Figure 8 PMV in the Summer season

4. Conclusion

The indoor thermal environment of a large enclosure during the summer and winter seasons was investigated. An indoor stadium was selected to obtain indoor vertical & horizontal temperature distributions and evaluate indoor thermal comfort. The results of this study are summarized as follows.

(1) The vertical temperature distribution showed a large high/low temperature difference of the arena by about 279K. The vertical temperature difference in the guest seat at 1st and 2nd levels was reduced greatly by the influence of the relatively low height of the building in the intermittent heating and heating conditions in the winter season. The temperature stratification, which reduced after stopping the heating in the heating condition (considering the body load) until the end of the game, was believed to have been maintained by the body heat from the guests at the volleyball game. In the summer season, the low blowdown stream with big density moved to the lower space and 297.5K indoor temperature was maintained in the lower space by location but the temperature stratification was formed by the buildup of high temperature air that rose in the upper space of the roof. The high temperature stratification formed in the upper space did not influence the residential area upon operation of the exhaust fan, which was installed in the upper space.

(2) The horizontal temperature distribution by location during the volleyball game for 13:30~18:00 in the winter season was 294 ~ 294.5K , which was until the end of the volleyball game by the influence of the body heat from the guests at the volleyball game. This temperature distribution was higher than 293 ~ 294K of the 1st heating temperature condition, by 273.5 ~ 274K. In the cooling condition (considering the body load) in the summer season, in spite of continuous cooling for 10:00~17:00, the horizontal temperature rose during the school festival for 12:00~18:00 by the body heat from students at the event and from the guests.

(3) With respect to the indoor thermal comfortableness, the ISO-7730 comfort standard was satisfied by the -0.46 ~ -0.12 PMV value for 15:00~17:00pm after the heating was stopped in the winter heating condition (considering the body load) because of the body heat from the guests at the game. In the summer cooling

condition (considering the body load), -0.35 ~ -0.49 PMV value with 53.1~59.2% humidity and 0.43 ~ 0.86 ㎧ air stream from 12:40 ~ 16:20 during the event maintained the indoor thermal environment that satisfied the ISO-7730 comfortableness standard.

Before planning a reasonable cooling and heating air conditioning system of a large enclosure building, several items must be considered such as large enclosure problems and indoor thermal characteristics.

First of all, an air-conditioning system supplying jets flow velocity from seats at air current rate of within 0.5m/s must be adopted no produce cold draft heating load in residential area. Secondly, an air current induction fan assuring swirl in the residential area must be adopted to achieve thermal comfort although set up higher the temperature of a room.

It is decided that the result of this study could be used as basic data to plan a reasonable cooling/heating air conditioning system of a large enclosure building and in the future, studies of various outdoor environment conditions of middle and rainy periods are needed.

Acknowledgement

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FROM ENERGY CERTIFICATE TO SUSTAINABILITY REPORT – SUSTAINABLE BUILDING IN GERMANY – OBJECTIVES, RESULTS, LESSIONS LEARNED

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Keywords: sustainable building, policy making, energy certificate, assessment method, labeling

Summary

The introduction of compulsory energy certificates for existing and future buildings as well as the development, testing and implementation of schemes for the description, assessment and certification of the sustainability of buildings are linked to a number of prerequisites. Drawing on examples from German experience, this contribution aims to demonstrate how a broad-based social consensus can be reached by making use of the “Round Table” instrument - a consensus which at the same time is based on the current state of research and standardisation and is integrated into the strategies of the European Union. In particular the transition to an assessment and certification scheme which is mainly based on quantitative assessments represents a major challenge. A substantial effort will have to be made to develop methodologies, to make data available for the environmental and economic assessment and to establish assessment criteria. At the same time, investors and planners must be provided with suitable tools to formulate objectives, to examine different options and to exchange information. This paper will demonstrate how a certification scheme can be integrated into a package of complementary and supporting planning and assessment tools. Finally, the development of a manageable solution for investors acting at international level to assess the sustainability performance of buildings at very different locations is suggested.

1 Framework and trends in Europe

1.1 Selected directives and research projects of the EU

The Federal Republic of Germany as a member of the European Union is an active player in shaping the process of a stronger orientation of the European building, housing and real estate industries towards the principles of sustainable development. Germany transposes regulations of the European Union and the European Commission into national legislation and supplements these provisions by national initiatives and programmes.
The role and responsibility of the building sector in shaping the built environment to be socially equitable and environment-friendly, in maintaining and creating employment and conserving resources, on one hand, as well as the importance of modernising the existing building stock to save energy, conserve resources and protect the environment, on the other hand, has been recognised in Europe. Concerning the update of the European Construction Products Directive [EU 1989] for example, which already contains requirements on hygiene, health and environmental protection in the production and use of construction products, there is currently a debate on if and what kind of supplementary requirements to combat climate change and achieve sustainability (in this field particularly the sustainable use of resources) should be included in the directive.
The EU’s Energy Performance of Buildings Directive [EU 2002] which entered into force in 2002 sets out requirements for the evolution of the description and assessment of the energy efficiency of buildings, the large-scale introduction of energy certificates for existing and future building as well as for the systematic maintenance and repair of the heating, ventilation and air conditioning systems of buildings.
Existing methods and instruments to evaluate the environmental compatibility and sustainability of buildings – cf. information available on PRESCO at http://www.etn-presco.net - are analysed and compared in concluded and current EU funded research programmes under German participation, and elaborated by means of the LEnSE principles for the development of a uniform European label for sustainable residential buildings (cf. information available at http://www.lensebuildings.com) and put up for discussion.

1.2 Selected strategies and standardisation projects

In view of the importance of the building, housing and real estate industry, the EU aims to develop "sustainable construction" into a lead market [EU 2007] over the course of the next years. In this endeavour, the EU is pursuing the Thematic Strategy on the Urban Environment [EU 2004] which was established as early as in 2004. The strategy includes a stronger emphasis on sustainable settlement development and sustainable construction as well as the further development of the energy certificate into a document which describes and assesses the sustainability of buildings. This involves integrating additional aspects such as indoor air quality, accessibility, noise levels, comfort, environmental quality of the materials, the life-cycle cost of the building and the ability of the building to resist environmental risks, such as flooding, storms or earthquakes into the methods to assess the sustainability of buildings.

The development of harmonised methodologies for sustainability assessment in Europe takes place within the framework of the standardising activities of CEN TC 350 taking into account the results of international standardisation according to ISO TC 59 SC17. The state of discussion reached within CEN TC 350 in early 2008 can be described as follows:

- The assessment of the sustainability of buildings is to be carried out on the basis of the description and assessment of economic, ecological and social aspects while at the same time taking account of the technical and functional quality of the building.
- The object of assessment is the building including the land on which it is build. It shall be assumed that a prior decision-making and assessment process regarding the building's location has taken place.
- The assessment is to be based mainly on quantitative methods, which means that the assessment of the environmental impact of the building should be based, amongst others, on the results of the life-cycle assessment and the assessment of the economic aspects mainly on the results of a life-cycle cost calculation.
- The issue of the health, comfort and safety of the users, visitors and neighbours should be taken into consideration when assessing the social quality of a building.
- Issues of defining assessment criteria (reference, limit and target values) and assessment processes should be settled at national level.

Germany is actively participating in the international and European standardisation process and makes use of the achieved results as a basis for developments at national level.

2 Starting positions and first experiences made in Germany

2.1 Actors and activities

For more than a decade, Germany has been working towards implementing sustainability principles in all spheres of daily life and economy. In this effort, the building, housing and real estate sector or rather the need area of "building and housing" in connection with sustainable settlement development have been identified as key action areas. Considerable efforts have since then been undertaken by the construction materials industry, the building, housing and real estate sector, the scientific community, the financial and insurance sector, policymakers and public administration as well as by associations and representatives of all stakeholders. These efforts aim at developing and implementing strategies to save energy, conserve resources, consider environmental and health aspects as well as to achieve cost efficiency and profitability when planning, building and operating buildings while at the same time taking account of quality aspects in terms of functionality, technology, design and urban planning. Activities focus on the development, testing and implementation of new products, technologies and construction methods, refined design and planning principles as well as of planning, assessment and optimisation tools and methodologies for the assessment of economic, environmental and social adequacy of buildings as well as of further education and training schemes for professionals in this field.

The explanations in subsequent Section 2.2 are mainly based on the perspective of the public sector in its different roles of legislator, client and owner, funding body and coordinator and elaborated by means of examples of activities of the Federal Ministry of Transport, Building and Urban Affairs.

2.2 National legislation on energy efficiency in the building sector

The transposition of the EC Directive 2002/91/EC on the Energy Performance of Buildings into national law brought about comprehensive amendments to the German legislation on energy conservation (Energy Conservation Act, Energy Conservation Regulations). On this basis, the Federal Government adopted the Energy Conservation Regulations in 2007 which entered into force on 1 October 2007. They provide, amongst others, for a phased introduction of energy certificates for the entire building stock. In the future, an energy certificate must be presented for any transaction (in this case: sale or letting) in connection with buildings or apartments. This certificate will contain an assessment of the energy performance of the building as well as voluntary information on its CO_2 emissions.
Experiences made in Germany have shown that any reservations that may exist concerning the introduction of energy certificates can be overcome by a preceding trial period, the involvement of all stakeholders in a dialogue as well as by making necessary data and calculation tools available. While for example energy billing services, craftsmen and chimney sweeper focus on issuing relatively inexpensive energy certificates which are based on the assessment of energy consumption, architects, engineers and energy consultants offer energy certificates which require a calculation of the energy demand and can easily be expanded to represent an entire energy concept. In Germany, both types of energy certificates are considered acceptable (more information at www.dena.de/en/). The certificates are meant to provide information on the energy efficiency of buildings, on one hand, and suggestions for upgrading the building shell and the heating, ventilation and air conditioning systems, on the other hand. In doing so, they can serve as an instrument for increasing transparency in the real estate market.

The EU council adopted comprehensive strategic objectives in the field of combating climate change and conserving resources. Key issues are
- reducing CO_2 emissions in relation to the initial basis of 1990 by at least 20 % by 2020.
- increasing the share of renewables in the total energy mix to 20 % by 2020.
- reducing end-use energy consumption by 20 % compared with the forecasts for 2020.

Against this background, Germany intends to tighten the legal requirements regarding the energy efficiency of buildings by around 30 % and to adopt additional provisions – the Renewable Energy Heating Act – which specify mandatory quota for the use of renewables to heat buildings and hot water in new buildings. The Renewable Energy Heating Act and the amended Energy Conservation Regulations will both enter into force on 1 January 2009. In the medium term, Germany is aiming to achieve a passive house level for new buildings.

2.3 Round table and Sustainable Construction Guide

In 2001, the Round Table on Sustainable Building at the Federal Ministry of Building, Transport and Urban Affairs was established as a result of a joint initiative by the building industry and the Federal Ministry of Building. The tasks of this Round Table are, amongst others, counselling the Federal Government and the Federal Ministry of Building, Transport and Urban Affairs in all matters of sustainable building, establishing a platform for discussion for all relevant stakeholder groups, preparing statements on international and European legislation and standards, developing bases for a national certification scheme as well as presenting and debating the latest research findings. Information on these issues can be found at www.nachhaltigesbauen.de. At present, the work of the Round Table is focused on establishing concrete criteria and requirements for the assessment of the sustainability of buildings. These topics were incorporated into the initial version of the Sustainable Construction Guide of 2001 [BMVBS 2001] which has been revised and expanded to cover the topics of planning and construction in the existing building stock.
Germany has made positive experiences concerning the work of the Round Table. It became clear that an instrument serving to form and exchange opinions has been and still is urgently needed in order to find out more about the different motives and interests of the stakeholder groups and to take them into account. In the meantime, a considerable development has taken place. Originally, mainly the construction materials industry and the building industry were actively involved. It was in the construction materials industry's interests, to identify the impacts of sustainable construction for the production and distribution of construction products and to participate in this process at an early stage. The building industry, supported by the Federal Ministry for Building, pursued a strategy of integrating the sustainability issue into a general debate and campaign to improve building quality. For about one year now, funders, insurers, rating agencies and renowned companies from the consulting sector have also been putting forward their viewpoints and interests. These interests are mainly orientated towards developing and shaping a uniform scheme to describe, assess and certify the sustainability of buildings – see section 4.

3 System of complementary planning and assessment tools

In addition to the development, testing and implementation of a certification scheme on building sustainability, further measures will be required. It is true that a credible label will contribute to marketing and market penetration as well as to the establishment of compact requirements on the part of the public sector and investors to be met by sustainable buildings. Planners and building companies, however, further need bases and tools to achieve the objectives required by the certificate, by means of planning and structural measures. In addition a quantitative approach for the assessment and certification of buildings will require data for establishing life cycle assessments of construction products, construction processes and buildings, for the life-cycle cost determination as well as for the estimation of the useful life of building components and the time period they remain part of the building.

Therefore, the scheme of complementary planning and assessment tools explained in **Figure 1** and **Table 1** was developed and realised. Different tools for optimising building parts and buildings as well as for certification are drawing on an identical basis of data (qualitative information - such as health risks in the handling and use of material- on construction products, life cycle assessment data, service lives, cost characteristics) and can exchange data via defined interfaces. In the course of the design development, it is thus possible to replace product and vendor neutral data from the planning phase gradually by product-specific information from the bidding phase.

The integration of key certification requirements into the planning process shall ensure that essential information is already produced in the planning phase instead of having to be collected within the context of the actual certification process – which would, in general, involve additional costs. The building passport will be an important basis for information in the certification of existing buildings.

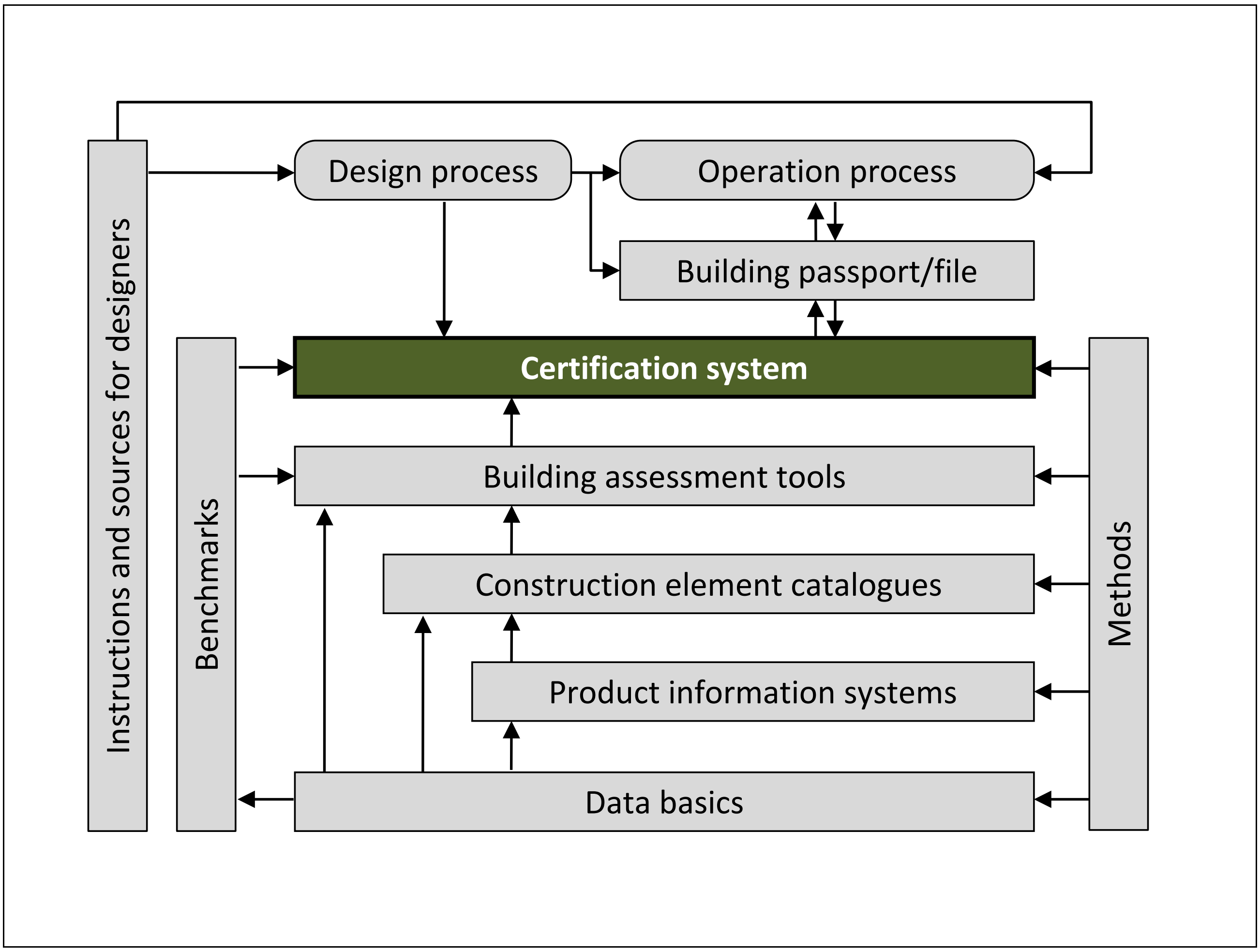

Figure 1 The place of certification in the system as a whole

Table 1 – overall system - overview

Basic data	**Data for the life-cycle assessment of construction products and processes** A national database with data regarding the life-cycle assessment of relevant construction products is established, continuously updated and enlarged, serving as a basis for life-cycle assessment of buildings and structural works. Current efforts focus on the life-cycle assessment of the heating, ventilation and air conditioning systems of buildings.
	Data regarding the useful life of construction parts Data regarding the useful life of construction parts are a prerequisite for life-cycle assessment and life-cycle costing. A database is established on the basis of research findings.
Methodologies	**Method development** Methodical bases for the following aspects, amongst others, were developed as a basis for the assessment of the overall performance of buildings. - an assessment of the resource and land use - the assessment of the quality of planning, construction and management - assessment of the stability of the building's value - inclusion of external costs in profitability assessments
Benchmarks	**Establishment of reference, limit and target values** Benchmarks are established and applied, amongst others, for the development of assessment criteria for the following areas: - data on the life cycle assessment of (reference) buildings - operating costs / life-cycle costs - data for the assessment of efficient land use - data for the assessment of the overall energy consumption in operation
Planning and evaluation tools	**Building products and hazardous materials information systems** Building product systems make environment and health relevant information on building product categories available on the network and thus contribute to decision making in planning processes. Hazardous materials information systems draw attention to environmental and health risks in connection with the handling and use of construction products (German examples of such systems: WECOBIS, WINGIS)
	Element catalogues and design optimisation tools For building components (such as walls with their complete layer structure), the findings of life-cycle assessments and costing are made available, applying the element method which is commonly used for cost calculation in Germany. The tools which are used for drawing up element catalogues can also be used for design optimization under economic and ecological aspects (German examples: SIRADOS; bauloop)
	Complex planning and assessment tools & construction optimisation As a means to support planning and at the same time as a basis for certification, complex tools are used which, based upon a one-time description of the building structure, establish construction costs, operating costs, energy consumption in the operation phase as well as the life-cycle assessment for the entire life-cycle and serve as a basis for building optimisation (German example: LEGEP).
	National scheme for the assessment and certification of sustainable buildings The scheme describes and assesses the sustainability of buildings, including the results obtained by means of other tools – see section 4.
Tools for the tendering process	**Supplementary environmental requirements for calls for tender** Supplementary environmental requirements to be integrated into the specifications are prepared and made available in the form of text modules.
Tools for planners	**Guidance and recommendations for action** In a network-based guide, planners are made aware of sub-steps in the planning process which are of enormous importance for sustainability aspects. They are then provided with target oriented and problem specific information by means of references to standards, guidelines, literature and case studies.
Documents	**Building passport / building dossier** Throughout the building's life cycle, relevant information on the building is described, managed and updated in the building passport or building dossier.

4 National scheme for the assessment and certification of sustainable buildings

The multitude of methods and tools which are already available for the assessment and certification of the environmental and health compatibility and the sustainability of buildings has been described and analysed repeatedly. Looking at them more closely, it becomes clear that so far the larger part of them have focused on applying criteria from the fields of locational quality, energy efficiency, climate change prevention, conservation of resources and health and thus contribute to describe the environmental and health compatibility of green buildings. Mainly qualitative assessments which are expressed in point systems, but which are also frequently based on the results of the preceding calculations of the energy efficiency of the object are widespread. Schemes which additionally take economic aspects into account and which also consider the results of life cycle assessment and life-cycle costing, however, are not very common yet.

In its current work on the development, testing and implementation of a national system to describe, evaluate and certify sustainable buildings (German Sustainability Assessment Method – GeSAM), Germany is focussed on the current state of international and European standardisation in ISO TC 59 SC 14, ISO SC TC 59 SC 17 as well as CEN TC 350. The aim is to assess the sustainability of buildings by including ecological, economic and social aspects in all their dimensions. This assessment should be based on quantitative methods of life cycle assessment and life-cycle costing and thus on scientifically recognized methods. The actual draft national certification scheme is based on a concept [Graubner 2007] developed by the Technical University of Darmstadt and the University of Karlsruhe which was commissioned by the Federal Ministry of Transport, Building and Urban Affairs. The scheme was the object of intensive discussions with all interested stakeholders and the German Sustainable Building Council which took place amongst others at the Round Table on Sustainable Building and at the Congress on “Sustainable Planning, Construction and Operation of Buildings” in December 2007.

The “GeSAM - German Sustainability Assessment Method“ envisages including economic aspects in addition to the environmental und social performance of the building and thus expands the “green building approach” towards a “sustainable building approach”. The method gives equal importance to ecological, economic and social aspects and takes account of this fact in the weighting of the three dimensions of sustainability assessment. In addition to the evaluation of the building’s sustainability, the quality of the building’s location and the quality of the planning, construction and management is described. **Table 2** provides an overview of the criteria applied by the scheme. Only selected examples are given for the criteria. The entire list of criteria currently contains around 70 criteria.

Table 2 German Assessment and Certification System – overview and examples (as at 03/2008)

Criteria category	*Partial aspects*	*Examples*
Ecological Quality	Global environmental impacts	Global warming potential
	Local environmental impacts	Particulate emissions from heating systems
	Use of resource	Use of primary energy
Economic Quality	Life cycle costs	Operating costs
	Value stability	Forecast development of the building’s value
Social and functional quality	Health and comfort	Indoor air quality
	Functionality	Barrier-free access
	Design and urban quality	Art in architecture
Technical Quality	Compliance with technical standards	Compliance with thermal insulation standard
	Quality of building facilities	Quality of heating system
	Durability, resistance	Hail resistance
	Aspects of conversion and demolition	Recycling potential
Process Quality	Planning quality	Stakeholder involvement
	Quality of construction activities	Low-noise construction site
	Management quality during operation	Operative cost controlling
Quality of Location	Conditions and risks of the microlocation	Risk of flooding
	Access to transport links and media	Public transport links
	Possibilities of expansion	Reserved space

In establishing criteria and developing measuring procedures and assessment standards, Germany is oriented towards its national objectives which however at the same time based on the commitments made at European and international level. These are, inter alia:

- limiting the land take per day for traffic and settlement areas to 30 hectares per day in Germany, for example by giving priority to the inner development of settlements rather than to their expansion – to be taken into account in the evaluation of land use due to the type and size of the land plot.
- improving energy efficiency by tightening the requirements on the permissible primary energy consumption of new buildings of 30 per cent from 2007 to 2009 and additional 30 % by 2012 – to be taken into account in the evaluation of non-renewable resources consumption.
- increasing the share of renewable energy for heating in buildings from around 6 % in 2006 to 14 % in 2020 - to be taken into account in the evaluation of renewable resources use.
- giving more weight to life cycle costs when making investment and procurement decisions with the objective of reducing these costs – to be taken into account in the evaluation of economic performance.
- improving indoor air quality - to be taken into account in the evaluation of the environmental compatibility in terms of social performance.

The Sustainable Construction Guide of the Federal Ministry of Transport, Building and Urban Affairs contains a comprehensive presentation of objectives and possible approaches in connection with the planning, construction and management of sustainable buildings. An updated version which includes additional provisions for the existing building stock will be published in the course of 2008.

The following preparatory measures for the introduction of the certification scheme are currently undertaken in Germany:

- Development of training and examination programmes for certifiers
- Completion of the basic data for the life-cycle assessment of buildings
- Revision of the basic principles for estimating the actual time during which a component will remain part of a building (estimated service life period)
- Further development of methodologies for the calculation of external costs
- Trial of the certification approach by applying it to selected objects

First results of the trial of the certification approach will be included in the presentation of national example objects at the SB Challenge 2008.

5 Summary and perspective

Against the background of the experiences made in Germany, it can be said that the establishment of a Round Table on Sustainable Building involving all relevant stakeholder groups is a key prerequisite for developing a national consensus on issues concerning the integration of sustainability aspects into the building, housing and real estate industry. Hereby it is possible to initiate and coordinate preparatory work in the form of research projects, on one hand, and to formulate joint positions on the development of a national assessment and certification scheme, on the other hand This scheme, however, is embedded in a package of complementary information, planning and assessment tools which is based on a uniform basis of data and oriented towards the current state of international and European standardisation.

For the investors acting at European or international level, however, the problem of having to deal with a multitude of different national assessment and certification schemes persists. For this reason, Germany will take part in initiatives which aim towards a mutual recognition of certificates or a joint assessment approach while applying the individual national target values and weighting factors. Intensive discussions with neighbouring states on this issue are planned to take place in late 2008.

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SPACE FRAME WALLS: FACILITATING POSITIVE DEVELOPMENT

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Keywords: Positive Development, sustainable development, Green Scaffolding, Green Space Wall, living walls, ecological design, virtual modelling, building information modelling, ecosystem goods and services

Summary

This paper reports on progress in developing new design and measurement concepts, and translating these concepts into practical applications. This research addresses gaps in 'best practice' green building, and is aimed ultimately at replacing green buildings with *sustainable* urban environments. Building on the author's previously articulated concepts of Design for Eco-services and Positive Development, this research will demonstrate how to eco-retrofit cities so that they reverse the negative impacts of past design and generate net positive ecological impacts, at no extra cost. In contrast to 'restorative' design, this means increasing ecological carrying capacity and natural and social capital through built environment design. Some exemplars for facilitating Positive Development will be presented in this talk, such as Green Scaffolding for retrofits, and Green Space Walls for new construction. These structures have been designed to grow and change over time, be easily deconstructed, and entail little waste. The frames support mini-ecospheres that provide a wide range of ecosystem services and biodiversity habitats, as well as heating, cooling and ventilating. In combination, the modules serve to improve human and environmental health. Current work is focused on developing a range of such space frame walls, optimised through an innovative marriage of eco-logical design and virtual modelling.

1. Innovations in Design and Measurement

1.1 New Design Concepts

The talk will present a range of eco-logical design concepts that are currently being developed and digitally modelled. These new design modules can create urban 'eco-services', mitigate climate change and address other sustainability issues on virtually any site, at a net resource savings. The term 'eco-services' is used here to encompass ecological health and resilience for its own sake, as well as the essential functions provided by the natural environment. With Professors Robin Drogemuller and John Frazer, and students from the Queensland University of Technology, the prototypes are being 'virtually' modelled in 3D CAD systems to optimise the modules for different applications, sites and contexts through generative feedback loops. The research will show that simple software tools can support the uptake of sustainable design within professional decision making and design processes. This digitally-supported Design for Eco-services process will facilitate further in-depth peer review and collaboration with 'green' building firms and organisations.

1.2 New Measurement Methods

New kinds of benchmarking and measurement concepts are being developed to facilitate Positive Development. These are necessary for assessing urban eco-services, and the 'positive' ecological impacts generated by the new design concept. This research aims to correct biases against sustainability that are now embedded in existing assessment tools (below). The project applies a new 'sustainability standard', where the building leaves the ecology healthier after construction than before (Birkeland 2003). With PhD students, a prototype computer-aided tool is being created to aid both the design and assessment of Positive Development projects in different urban contexts and micro-climates. User-friendly, illustrated guidelines will explain the logic underlying the new form of assessment.

2. Beyond best practice

'Best practice' green buildings are not sustainable. There are, however, already many isolated examples of technologies that reduce the *rate* of future resource consumption, compared to standard buildings - at a good return on investment (Katz 2003, Lucuik 2005, RICS 2005, GBCA 2006). There are, for example:

- Resource autonomous developments that generate their own energy and treat their own waste (Vale 2000 and 2002, Mobbs 1989)
- Building retrofits that increase worker health and productivity while saving resources (Romm 1998)
- Appliances that operate on direct solar energy, and so on (Poole 2006)

Green approaches reduce impacts, but still increase total resource flows and externalize impacts. For example, most green buildings increase the 'urban heat island' effect, where cities are much hotter than their regions. The 2003 European heat waves resulted in up to 35,000 deaths (IFRC 2004). To be sustainable, then, buildings must ultimately generate net positive impacts and create surplus eco-services. The foundation of the proposed research is the author's 'Positive Development', whereby new construction would have net positive impacts, and compensate for embodied energy and waste. A 'Positive Development' is defined as that which *adds* social and ecological (as well as environmental) value to the urban environment by expanding both the:

- 'Ecological base', which encompasses natural capital, biodiversity and habitats, ecological health, and bio-security (ie the life support system)
- 'Public estate', as substantive democracy ultimately depends on equitable access to the means of survival

3. A pre-requisite to sustainability

As we have already exceeded the Earth's carrying capacity, urban development that supports the ecology, as well as improving the human environment, is essential to sustainability. Ecological restoration is not enough. Sustainability cannot occur without a new kind of built environment design that generates surplus eco-services, habitats and ecosystems. Currently, built environment design drives excessive demand for materials and energy in other industries, shapes resource consumption into the future, and closes off future development options and social choices. While the built environment is central to social and ecological problems, this research will show how development can be converted into a sustainability solution (Birkeland 2002). Therefore. this research addresses the essential pre-requisites of a sustainable built environment, as follows.

3.1 A fundamental paradigm shift in green building theory and practice.

A fundamental paradigm shift in green building theory and practice is required. The concept of re-designing development to reverse prior impacts and generate net positive gains represents the next stage in the evolution of environmental management paradigms (Birkeland 2003). The theoretical stages have thus far progressed from: (a) 'compliance' or end-of-pipe design, through (b) 'eco-efficiency' or front-of-pipe design (Weizsacker, Lovins and Lovins 1997), to (c) 'zero-waste' or closed loop design, where waste is designed completely out of production and consumption systems (McDonough and Braungart 2002). Natural systems can replace or reduce most capital and energy intensive mechanical systems (see Beattie and Ehrlich 2004, Benyus 1997). However, the proposed paradigm will enable us to aim beyond zero waste and/or carbon neutrality to net Positive Development through (d) Design *for* Eco-services.

3.2 An approach that can address the scale of the problem.

Any solution must contemplate the scale of the problem. Current management approaches (eg incentives and trading) cannot address the sustainability imperative in time. Several international bodies, such as the OECD, have warned that material and energy flows need to be reduced by 90 percent within a few decades (Hasegawa 2002). Overall, the built environment generates about half of those resource flows (Roodman and Lenssen 1995). 'Green' buildings increase total material and energy flows. Also, only 2-4 per cent of the building stock is new each year, and half of building energy is embodied in construction itself. So even if *all* new buildings were 'green', they would only address 2 percent of 20 percent energy flows (ie .04), and would still have other negative impacts. Due to the material and energy flows in existing buildings then, 'eco-retrofitting' of cities is a pre-requisite to sustainability. The proposed retrofitting concepts support this imperative, as they can be adopted and replicated virtually anywhere on a large scale. They can also be applied in new buildings.

3.3 A practical strategy for implementing eco-retrofitting.

The research offers a practical strategy for implementing eco-retrofitting as well. Eco-retrofitting has already proven to pay for itself in human and natural resource savings, while generating employment and low-risk investments (Romm 1998). Any extra R&D and construction costs can be recovered from the net resources savings and capital gains in a short period of time (Edwards 1998, Katz 2003). Retrofits of commercial buildings bring substantial savings and increased worker health and productivity, while reducing externality costs as a whole (Hargroves and Smith 2005, Esty and Wilston 2006). For example, the market value of a retrofitted home, on average, instantly increases more than the cost of the retrofit (US EPA 1998). Indeed, investments in greening buildings compare favourably with investments in stock and bonds (Romm 1998). The savings from water, energy and material efficiencies will increase as their true costs are eventually reflected in their price (see Meyers and Kent 2001). While the contemporary approach is to rely on indirect and hence unpredictable incentives, this project will harness market forces towards 'direct action'.

3.4 New design and measurement concepts for the conversion to Positive Development.

New design and measurement concepts are required to support the shift to Positive Development. Although eco-retrofitting would cost society less than doing nothing, 'best practice' exemplars and tools will *not* drive the fundamental systems change in the construction industry that is needed. Current environmental management and assessment tools are biased against eco-retrofitting (Drogemuller 1999), as well as ecological sustainability (Birkeland 1993). In fact, sustainability is deemed to be 'addressed' by tools that simply predict, measure and trade off negative economic, social and environmental impacts to reduce relative future harm. Because our computational tools focus on negative inputs and outputs, they encourage change at the margins. Further, they do not take into account the unique nature and intrinsic value of living things. They reduce complex, location-dependent, living ecosystems to generalized resources and impacts. The focus has been on impacts (ie measuring symptoms) rather than design (ie identifying causes and solutions). The proposed approach would address significant systemic biases in building design and assessment tools (below).

3.5 New methods for increasing positive impacts at the building and urban scale.

This research aims to develop new methods for increasing net positive impacts at the building and urban scale. There are myriad measurement methods for buildings, but they largely ignore eco-services and ecosystems. Ecosystem goods and services refer to natural systems that, for example: support biodiversity and productive ecosystems; treat organic wastes; sequester carbon; control pests; produce food, fibers, and pharmaceuticals; help regulate the local (and global) climate; develop fertile soils and prevent erosion; purify air; store and recycle water; and alleviate floods, drought and storm water runoff (Daily and Ellison 2002). The term has been used to refer to human benefit only. Thus we need a term that includes ecosystem health, resilience and integrity, or 'eco-services' (ie not just 'good and services'). Existing methods indirectly encourage the substitution of ecosystems by built and manufactured capital. The proposed approach would replace fossil fuel driven machines with natural systems.

3.6 Contribution to building information modeling ('BIM').

Finally, this research will contribute to building information modeling ('BIM'). The construction industry is rapidly moving towards BIM. It provides a single information model for 'real time' information exchange between participants in the building design and construction process. At present, however, BIM cannot deal with crucial sustainability issues like embodied energy, greenhouse gas emissions, biodiversity and health. The project is contributing to, and benefiting from, current work at QUT, led by Professors Robin Drogemuller and John Frazer, toward better integration of BIM and virtual modelling to support more sustainable design and construction. This research project is essential to ensuring that such technical advances in the building industry integrate deep sustainability principles and criteria.

4. Sample space frame modules

The primary advances provided by this project are: a) design for eco-service concepts and prototypes and b) eco-service measurement concepts and tools. This project will show that net contributions to the ecology, as well as society, are possible through development itself, despite unavoidable 'ecological waste' (Birkeland 2007b). Two generic prototypes are illustrated here: a) Green Scaffolding for eco-retrofitting, and b) Green Space Wall for new buildings. These generic types are briefly presented before the discussion about how they address sustainability issues and represent an advance over what is now called 'green building' design.

4.1 Green Space Wall

The Green Space Wall is an ecosphere that doubles as an exterior wall or mixed interior/exterior spaces in new development. Despite the unavoidable resource flows embodied in new construction, there will always need to be new buildings, which currently have significant embodied waste. New building can, however, reduce the impacts of the urban areas by *substantial* positive on-site and off-site ecological gains. These walls can create multiple, synergistic uses of space. For example, they can generate clean energy, air, water, food and soil - while providing social space. This approach contrasts with many 'green buildings' which minimize space to reduce the *additional* resource flows and negative impacts created by conventional materials and forms.

This Green Space Wall may be applied in a national sustainability (education, exhibition and collaboration centre. The proponents are a coalition of NGOs known as the ANSI that has garnered significant national community, public sector and professional involvement and support for the proposal.

A range of functions are included within an expanded double-skin building that redefines the human-nature barrier. Some modules support ecospheres for biodiversity protection or food production. The building acts like an integrated space frame sitting above a flood plane (with footings that do not require concrete). The solar stacks and light weight mini-wind generators are fully integrated with the vertical triangular structural trusses.

Figure 1 Example of new building using a Green Space Wall

4.2 Green Scaffolding

Green Scaffolding applies mainly to eco-retrofitting. It essentially wraps a light weight structure around the exterior of *existing* buildings to provide the full range of climatic and ecosystem functions. Such ecospheres are low in embodied energy and waste, adaptable, demountable and portable. Similar modules can also be installed in public spaces, or over some streets and parking structures, to contribute aesthetic and social values while increasing urban eco-productivity.

Virtually any building can be retrofitted to reduce its heating, cooling, lighting and ventilating bill, while cleaning air and water, reducing the urban heat island effect, producing soil and food, and adding environmental and social amenity. Such modules can be supported by horizontal or vertical triangular trusses that also support environmental controls like air ducts, solar stacks or shading devices.

Figure 2 Example of eco-retrofit using Green Scaffolding

5. Advances in design

These design innovations address basic omissions in 'best practice' green building design, by providing for the expansion of: (a) natural functions in urban systems to improve the ecology and eco-productivity of cities, (b) the integration of infrastructure and 'ecological space' for ecosystem re-generation with less net land cover, (c) the provision of eco-services to reduce mechanical equipment, fossil fuels, the urban heat island effect, etc, described below.

5.1 Improving eco-productivity and urban ecology

Green Space Wall and Green Scaffolding can increase the eco-productivity and ecology of cities. Design has largely ignored the need to design *for* nature, in addition to design for people. At best, green design aims to design *with* nature or *like* nature, and generally adds passive or active environmental controls onto a non-sustainable building archetype. This is partly because, in the name of 'efficiency', architectural spaces have sometimes been segregated and minimized. For example, contemporary best practice, 'double-skin' buildings reduce energy consumption, but create 'dead' spaces, adds costs, and increase the urban heat island effect. Design for Eco-services, in contrast, increases and optimises space for *both* social and natural functions.

5.2 Integration of infrastructure and ecological space

Green Space Wall and Green Scaffolding integrate infrastructure with ecological space to support ecosystem regeneration and productivity. Integrated 'whole systems' design approaches are understood to provide more efficiency gains per dollar because they create positive synergies, rather than trade-offs (Hawken, Lovins and Lovins 1999). However, conventional eco-retrofitting concepts have not been fully integrated with the structure, so they can add to construction costs even though saving resources. In the proposed prototypes for retrofitted and new buildings, the structure and eco-services themselves replace many high maintenance and fossil-fuelled mechanical systems. Being integral with the structure, they can prolong the functional and structural life of buildings. More importantly, this approach can improve ecosystem and human health, and universal access to the means of survival (eg food, heat and water).

5.3 Provision of multiple eco-services

Green Space Wall and Green Scaffolding aim to *demonstrate* means to overcome certain common deficiencies in green building. These are reflected in the proposed design of the Australian National Sustainability Initiative (Figure 1). The proposed sustainability learning centre will demonstrate a whole new typology of architecture that creates net positive ecological and social impacts. A lightweight, demountable space frame structure supports a Green Space Wall, composed of double-skin ecospheres. These modules create a variety of ecosystem goods and services ('eco-services') as well as providing environmental control functions. The modules not only heat, cool and ventilate the building, but produce clean energy, air, water and soil. Depending on the orientation and other functions, the exterior Green Space Wall would contain, for example:

- Vertical landscapes for water and air purification
- Habitats for small animals (eg frogs, beetles, lizards) that can be viewed from inside
- Sail and shade cloths designed for circulating cool air as well as providing shade
- Solar stacks and shower towers integrated into the vertical truss structure
- Bird and possum nests, fish ponds and butterfly breeding areas
- Pipes for exterior mists (cooling and fire prevention) integrated in the vertical truss
- Internal Trombe walls (from local construction rubble) for thermal rock storage
- Vertical composters and worm farms that are visible to building users
- Living machines to treat grey water and even sewage (in sealed modules)
- Light weight vertical wind turbines integrated with vertical structural truss
- Corridors, external walkways and/or decks that move through some modules

The next stage is to quantify and test the positive contributions to social and ecological sustainability made possible through this new design approach.

6. Biases in measurement

The project will apply new measurement concepts, to the design of a new computer-aided tool to quantify and assess Design for Eco-services. Just some of the problems with existing methods that the tool will address are listed below (Birkeland 2008):

- Traditionally, environmental planning and management has only tried to measure negative impacts, even though this is - by definition - impossible in a 'complex system' (Birkeland 1993). Predicting negative impacts requires an understanding of bioaccumulation and the interactions of toxins with immune systems. In contrast, development that did no harm would only need to be a good investment. Yet most assessment tools do not even count positive ecological impacts. The new tool will put net positive ecological and social gains on an equal footing with the relative reduction of future negative impacts and risks.

- The economic costs of environmental damage that conventional development will have in the future are downplayed in assessments, due to the inherent difficulties of predicting and measuring open systems. Yet many assessment methods do not even count the economic benefits of an *undisturbed* natural environment. They apply a meaningless relative standard, comparing green building to 'typical' buildings of the same kind, rather than to ecological conditions existing prior to any development (the author's 'sustainability standard'). The new tool will put the economic benefits of a healthy environment on an equal footing with the economic costs of green development.
- Most assessment methods favour existing, fossil-fuel driven, industrial processes and non-sustainable building types, in that their impacts are treated as 'normal'. An eco-retrofit or innovation is expected to pay back its costs (and sometimes even its embodied energy) whereas standard building equipment usually does not. That is, mechanical equipment is *not* seen as costing 'extra', even though they require regular maintenance, repair, spare parts and specialist mechanics. The new tool will put passive systems on an equal footing with fossil fuel equipment.
- Because our measurement methods treat current urban conditions as a neutral baseline, rather than negative, we usually only count the costs that will be incurred from this point on. Thus, our tools not only count the 'sunk cost' in existing systems, they exclude the 'opportunity cost' of poor design. To overcome this bias against eco-retrofitting, the benchmark should be the pre-development ecological conditions on the site. Thus we would compare *both* the original building - and the proposed retrofit - to pre-development conditions (ie sustainability standard). The new tool will put eco-retrofitting on an equal footing with new construction.
- As ecosystem services cannot be directly measured, 'surrogates' have always been used to enable quantification, such as the area of wetlands or volume of biomass (Heal 2000). However, such surrogates usually only look at one or two values of natural systems, such as carbon sequestration or water purification. Even holistic concepts like 'ecological footprints' can really only measure a reduction in relative negative impacts. Therefore designers do not try for multiple and surplus eco-services (Birkeland 2007a). The new tool will put the expansion of ecosystems on an equal footing with resource conservation and efficiency measures.
- Our conventional building assessment and rating tools do not assist in design as a creative process. Most, if not all, so-called 'design tools' only measure pre-conceived designs. Further, their measurement concepts are based on, and thus perpetuate, conventional building typologies. This project will provide means to help designers to create something that does not yet exist. That is, to 'design'. The new tool will put creative design processes on an equal footing with reductionist analyses.
- Because assessment methods treat complex living ecosystems as mere resources, this 'legitimizes' the substitution of natural for built and manufactured capital. Reducing the ecology to mere inputs and outputs conceals the need to increase ecosystem integrity and environmental flows - not just reduce consumption. Our current tools also discount the future by, among other things, not counting the time and cost of replacing living ecosystems or 'ecological waste' (Birkeland 2007b). The new tool will put ecological time on an equal footing with financial time.
- Our assessment methods do not consider how conventional development can transfer resources and increase disparities of wealth over time. Equitable concepts like 'environmental space' (ie the available renewable resources divided by the relevant population) are not yet applied to built environments. New concepts are also needed like 'negative space' to reflect the distributional impacts resulting from the conversion of (public) land and natural capital to private development. The new tool will put the distribution of resources, including space and access to the means of survival, on an equal footing with the distribution of negative impacts.

7. Biases in assessment

The 'DNA' of current assessment and rating tools - based on input-output accounting rather than design - encourage marginal improvements to an unsustainable archetype. They act as a barrier to Positive Development. Design tools needs to be very different than current approaches. The design concepts and measurement tools will help us move beyond green buildings to sustainable ones. Some biases to be overcome include (Birkeland 2008):

- From retrospective analysis to future-oriented design. The analysis of the predicted impacts of a proposed design can reinforce old forms and patterns of development at the expense of forward-looking processes that seek to value add and create new synergies.
- From impact reduction to impact reversal. The emphasis on mitigating negative impacts can be at the expense of eco-innovations that seek to improve social and ecological conditions through positive off-site and on-site impacts and health improvement.
- From building on templates to changing underlying concepts. Tools that encourage incremental modifications to conventional building templates can delay or prevent the re-design of basic infrastructure, spaces and forms that would increase the ecological base.
- From universal engineering to natural systems solutions. The perceived need to reduce everything to numbers can lead to mechanistic approaches that exclude the ecology, because natural systems defy simplistic measures (being complex systems).
- From aggregating impacts to mapping flows. Analyses that aggregate measurements to get a point value can obscure the potential for whole systems efficiencies to positively affect total resource flows by creating synergies among systems on different scales or levels.
- From sequential and segmented processes to integrated ones. The focus of LCA-based analyses on inputs and outputs of processes at separate stages during the construction process can encourage sub-optimal changes at the expense of rationalizing the whole supply chain.
- From data-driven indicators to implementing change. Overvaluing factors that we have data for can come at the expense of mapping systems dynamics to find better means of meeting needs or better 'leverage points' for generating positive ripple effects throughout the system.
- From an individual project to a contextual perspective. The focus on the efficiency of individual buildings and their components can be at the expense of rethinking buildings in relation to their context to improve social, structural and ecological deficiencies of the urban area.
- From fossil fuel reduction to a shift to solar resources. The emphasis on energy reduction through efficient use of fossil fuels distracts attention from means to convert to healthier *sources* of energy, and tends to lead to 'under-design' of passive solar systems.
- From reducing space to value adding space. Pseudo-efficiency and cost reduction through zoning and minimizing spaces in buildings can come at the expense of optimizing spatial resources by simultaneously accommodating human activity in viable ecosystems.
- From reductionist accounting to design reporting. Reductionist analyses can lead to tradeoffs between positive and negative factors at the expense of holistic design processes that explore wider options with the aim of increasing social, natural and economic capital.

Processes which frontload ecological design can help to overcome the inherent biases in our current assessment and measurement tools.

Conclusion

The transition to development that increases sustainability (rather than reducing negative future impacts relative to standard buildings) will require radically different design and assessment concepts and tools. The paper has provided a brief overview of progress toward new design and measurement processes presaged in *Positive Development* (Birkeland 2008). The talk focuses on *design* concepts and eco-technologies that can facilitate Design for Eco-services.

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A FRAMEWORK FOR UNDERSTANDING THE ENVIRONMENTAL IMPACT OF BUILDINGS IN AUSTRALIA

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Keywords: environmental impact, life cycle assessment, building materials, assemblies

Summary

A major barrier to realising dramatic improvements in the environmental performance of buildings' structures is the inability to accurately quantify the environmental impacts of design alternatives. This paper presents a framework for determining the environmental performance of building materials and assemblies in Australia.

Presently being developed under the working title of "Building Assemblies and Materials Scorecard (BAMS)", this project aims to establish a method and reporting format to assess the environmental performance of building materials and assemblies. Learning from international initiatives, BAMS uses life cycle assessment (LCA) to ensure consistent and science-based evaluation of construction options. The underlying LCA framework of BAMS is unique in that it combines a number of essential LCA ideas in one scheme. It is intended that in the short term BAMS will provide a common basis for materials assessment in a number of existing environmental building rating tools in Australia such as Green Star. The potential applications as a long term goal however, may be far more extensive.

1. Introduction

The relationship between global climate change and energy use is well documented (Garnaut 2008, IPCC 2007, OECD, 2002, 2003). Building construction, maintenance and operation is responsible for the bulk of energy consumption in the developed world, and increasingly so for the developing world (Bressand et al, 2007, Farrell et al 2008). In keeping with worldwide trends (World energy demand is expected to jump by 71% by 2030 (Huberman et al 2008), total energy consumed by Australian buildings is expected to grow, further contributing to greenhouse gas emissions and other environmental impacts (CSIRO 2008).

The environmental impacts of buildings can be divided into three life cycle stages: i) 'construction'; ii) 'operation'; and iii) 'deconstruction'. Construction being those impacts associated with producing the materials, transporting them to the site and the assembly of the building; operation being those impacts associated with energy use, water use and other activities such as maintenance over the building's life; and deconstruction being those impacts associated with disposal of the building at the end of its life, which may include some recycling. Traditionally, the operational impacts have tended to dominate the total environmental impact of a building over its life cycle.

This paper centres on the Building Assemblies and Materials Scorecard (BAMS) Project. Drawing from international experiences, this project aims to understand the environmental impacts of building assemblies and materials. The project received funding from the Victorian Sustainability Fund. The deliverable at the end of the first phase was to develop a proof of concept for the BAMS project. The founding partners included Victorian local and state government organisations and a national peak industry organisation. As the founding partners are many, the project brings together key tool-developing organisations and potential users to jointly develop and implement a common methodology.

This paper presents the development to date for the first stage of the BAMS project, addressing base building materials for residential and commercial applications. The focus is on the broader concept and the approach, rather than the technical detail in the development of the scorecards. The long term future includes setting up an operational BAMS governance and accreditation system, refinement of LCA data, increasing the number of assemblies, including branded products and integration with other developments as appropriate.

2. Aim of Building Assemblies and Materials Scorecard

The Building Assemblies and Materials Scorecard project was initiated and developed to:

- Provide a common basis for assessment and comparison of building materials environmental performance across a growing range of tools and approvals processes;
- Provide a basis for minimising the impacts and optimising the environmental performance of building products and materials over their life cycles through incorporation of an agreed method in a range of relevant tools and systems; and
- Generate increased awareness about the potential for the appropriate use of building materials to reduce the total environmental impact of the construction sector.

Specific deliverables were to:

- Prepare a State of Knowledge report outlining key issues and opportunities;
- Undertake stakeholder workshops as part of a needs analysis and stakeholder consultation process;
- Develop an LCA-based scoring methodology for a range of common building assemblies incorporating generic building products;
- Use the developed methodology to score a number of generic building assemblies; and
- Assist partners in implementing the scorecard in their respective contexts through training and workshops outlining the scorecard's approach.

Strengths of the BAMS approach include:

- It is based on scientific life cycle data rather than qualitative estimates and is designed to support the National Life Cycle Inventory Initiative (auslci);
- It considers the whole of life performance, including construction, operation and deconstruction;
- It looks at environmental performance based on the application - where and how building products are used such as in a wall, or floor, or roof;
- It brings together key tool-developing organisations to jointly develop and implement a common methodology, offering for the first time a single reporting format for materials performance assessment;
- It helps manufacturers, suppliers and design teams respond proactively to growing interest in the environmental performance of building products and materials.

The stakeholders directly benefiting from BAMS include:

- Building rating tool users and industry professionals;
- Building rating tool owners and developers;
- Building materials and product manufacturers and representative organisations;
- LCA practitioners;
- Building and materials policy development professionals.

3. Research Design

A literature review provided an understanding of the state or play with regards to sustainable building material use in Australia and internationally. The literature review identified the following:

- Data on environmental impacts is currently generally insufficiently available or accessible.
- There is insufficient interoperability between existing tools and systems.

- Capabilities such as the Australian Life Cycle Inventory are still in development while others do not exist, such as an Australian damage indicator including effective biodiversity metrics.
- The high level of tool development (particularly at a local government level) has led to the multiplicity of overlapping approaches that are generating confusion and 'measurement fatigue'.
- International developments, in particular the development of ISO 21930 for Type III standards, have the potential to streamline the standardisation of environmental considerations into the Australian context and into Australian Standards.
- While Type III labelling provides a basis for reporting of environmental information, the standard was established on the basis that comparisons would not be made between products except on the basis of whole-of-life considerations. An additional step will be required to operationalise Type III results for decision-makers including specifiers, through an approach that takes an assemblage life cycle perspective.

To provide the capacity to address these issues, the BAMS project framework needed to enable a life cycle and assembly (rather than individual materials) approach to be taken, and create an effective platform for standardisation of approaches and growing interoperability in the Australian context. The framework also needed to allow for investigation of the possibilities and limitations of single-score weighting. Accordingly, Figure 1 illustrates the framework for activities and staging of the BAMS project.

The BAMS project considers the inputs into building construction, as well as operation and deconstruction scenarios. Building operational energy requirements (major drivers of operational environmental impacts) are addressed through a set of performance levels for energy efficiency as appropriate for the assemblage. For example, operational performance is critical for assessing the life cycle performance of cladding systems, however it is a less important consideration in cladding systems currently.

A range of environmental impact indicators were used, determined by the project partners. Generic building assemblies have been designed to be benchmarked on the basis of their life cycle performance, so that assessments can be made of relative performance against generic measures, such as standard performance and leading performance. Following the benchmarking exercise, a method of rating performance was devised, using a range of factors such as uptake, performance range and potential for future market transformation.

Consultation with stakeholders and the building industry as a whole indicated a strong preference for a single score output for BAMS. To achieve this single score, environmental impact indicators needed to be weighted. The project partners worked with the research team to build a shared understanding of opportunities and effective approach for weightings.

4. Development of the scorecards

The main phases that comprised the development of the scorecards were:

- data collection;
- method development;
- weighting process;
- life cycle impact assessment (LCIA);
- scoring process (develop scoring methodology, producing scorecards);
- peer review and stakeholder review.

The stipulations set out in ISO 14040:2006 were followed for data collection. The data categories used in the various life cycle stages included resource use, energy use, water use, land use, emissions to air, water and soil, and final waste. The quality of data complied with the data quality assessment method currently under development in the AusLCI project.

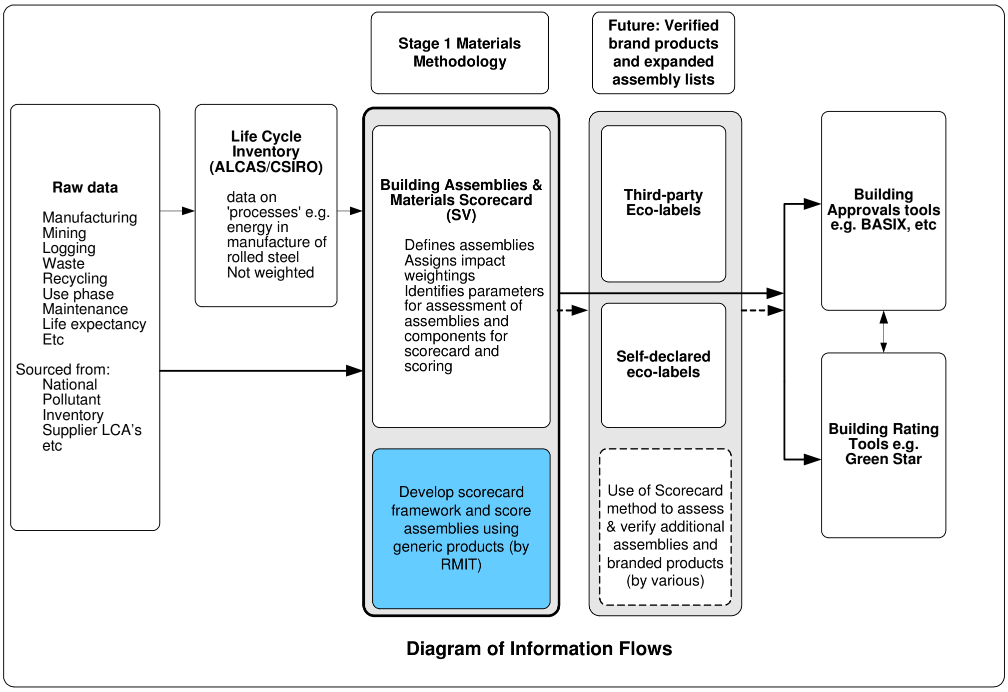

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Figure 1 BAMS Framework: Activities and information flows for the Building Assemblies and Materials Scorecard

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The methodology followed close parallels with the AusLCI project. However, since the method for BAMS was developed prior to the AusLCI project, it was agreed that the allocation rules follow the Dutch NEN 8006:2004 standards. Figure 2 shows the initial drafts of these scorecards.

The life cycle stages included in the BAMS project were:

1. Construction: extraction of raw materials; production of intermediate products; manufacture of assemblies; transport to the building site; building assembly on site .
2. Operation: energy consumption; maintenance and replacements.
3. Deconstruction: disassembly and waste treatment at the end of life cycle.

Transport between each of the stages is included in the LCA.

The five main indicators used for the BAMS project were:

- Resource use – measured as the additional energy required to extract future resources including fossil fuels and mineral resources.
- Water use – direct water extraction from the environment noting the water supply stresses in the location of the water extraction.
- Climate change – greenhouse effect based on fossil carbon dioxide equivalent emissions.
- Human health damage from pollution (excluding human health damage from climate change) – measure in WHO measure of death and morbidity (Disability Adjusted Life Years – DALYS).
- Land Use – measure of land occupation measured in area and time.

The environmental profile was calculated for each of the impact categories. Environmental impacts were checked to see if they were characterised. Normalisation and weighting followed next, leading to the scoring.

When the LCA of an assembly is completed, the result is expressed as a single indicator. It was anticipated that the user of the BAMS scorecard would like to make informed decisions regarding the sustainability of an assembly, when compared to its direct alternatives. The “BAMS score”, has been created to facilitate this decision by providing a relative environmental performance score of an assembly that is the result of directly comparing the performance of products providing similar functionality.

The scoring system was based on the BREEAM’s A-B-C system, where “A” represents best practice and “C” represents the worst. Therefore, “A” represents the most sustainable assemblies and “C” the least sustainable assemblies in their functional group. A separate set of BAMS-scores is determined for each group of assemblies. It is envisaged that for the Australian system, as “A” represents industry best practice, it may be incorporated into the leading best practice sustainability rating tool: the Green Star suite of tools, developed by the Green Building Council of Australia (GBCA). It is also envisaged that as “C” types of assemblies would represent minimum requirements, they would be equivalent to minimum standards set up by the Building Code of Australia (BCA).

It is important to note that the BAMS scores need to change over time. As new products are added to the group of assemblies and/or the environmental performance of existing products (assemblies) changes, the benchmark will change accordingly.

At every stage of the process, the project partners had opportunities to provide feedback. A peer review of the methodology was undertaken to ensure that the approach used for the BAMS project was robust and credible.

5. Conclusions

There is a rapidly expanding range of evidence demonstrating that environmental impacts are real and that significant steps are required to address them. The significant contribution of buildings to global environmental impacts, makes them an appropriate area for focus. Across the building life cycle, materials and assemblies can be significant contributors to total building performance, hence there is a need to optimise the selection of materials and assemblies in new designs to minimise environmental impact.

Furthermore, provided accurate and reliable information is available to decision makers regarding the environmental implications of different assemblages, and there is appropriate motivation to drive optimal environmental choices, significant reductions in the environmental impacts of buildings can be expected through the optimal use of materials and assemblies.

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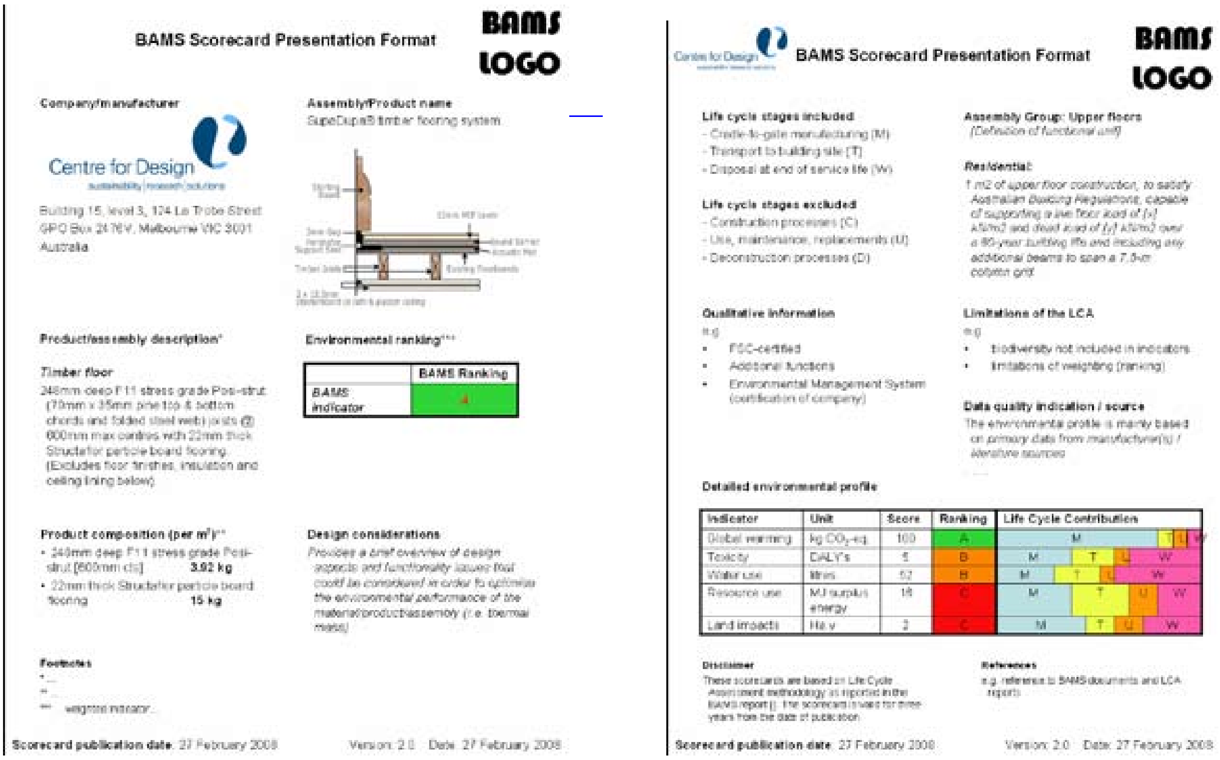

BAMS Scorecard Presentation Format

BAMS LOGO

Company/manufacturer

Centre for Design
sustainability | research | solutions

Building 15, level 3, 124 La Trobe Street
GPO Box 2476V, Melbourne VIC 3001
Australia

Assembly/Product name

SupaDupa® timber flooring system

Product/assembly description*

Timber floor

240mm deep F11 stress grade Posi-strut (70mm x 35mm pine top & bottom chords and folded steel web) joists @ 600mm max centres with 22mm thick Structaflor particle board flooring. (Excludes floor finishes, insulation and ceiling lining below)

Environmental ranking***

	BAMS Ranking
BAMS indicator	A

Product composition (per m²)**

- 240mm deep F11 stress grade Posi-strut [600mm c/c] **3.92 kg**
- 22mm thick Structaflor particle board flooring **15 kg**

Design considerations

Provides a brief overview of design aspects and functionality issues that could be considered in order to optimise the environmental performance of the material/product/assembly (i.e. thermal mass)

Footnotes

* ...
** ...
*** weighted indicator...

Scorecard publication date: 27 February 2008 Version: 2.0 Date: 27 February 2008

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Life cycle stages included

- Cradle-to-gate manufacturing (M)
- Transport to building site (T)
- Disposal at end of service life (W)

Life cycle stages excluded

- Construction processes (C)
- Use, maintenance, replacements (U)
- Deconstruction processes (D)

Assembly Group: Upper floors
(Definition of functional unit)

Residential:
1 m2 of upper floor construction, to satisfy Australian Building Regulations, capable of supporting a live floor load of [x] kN/m2 and dead load of [y] kN/m2 over a 60-year building life and including any additional beams to span a 7.5-m column grid

Qualitative information

e.g.

- FSC-certified
- Additional functions
- Environmental Management System (certification of company)

Limitations of the LCA

e.g.

- biodiversity not included in indicators
- limitations of weighting (ranking)

Data quality indication / source

The environmental profile is mainly based on *primary data from manufacturer(s) / literature sources*

Detailed environmental profile

Indicator	Unit	Score	Ranking	Life Cycle Contribution
Global warming	kg CO_2-eq.	100	A	M T U W
Toxicity	DALY's	5	B	M T U W
Water use	litres	52	B	M T U W
Resource use	MJ surplus energy	18	C	M T U W
Land impacts	Ha.y	2	C	M T U W

Disclaimer

These scorecards are based on Life Cycle Assessment methodology as reported in the BAMS report []. The scorecard is valid for three years from the date of publication.

References

e.g. reference to BAMS documents and LCA reports

Scorecard publication date: 27 February 2008 Version: 2.0 Date: 27 February 2008

Figure 2 Draft concept of the presentation of the BAMS scorecards

Currently, the operational impacts of buildings are expected to dominate total environmental impacts over the building life cycle. However, as regulations dealing with energy efficiency, technical advancement in this area, rating tools and policies are developed to reduce energy consumption, the balance between operational and embodied (construction and deconstruction related) impacts is expected to shift. This shift in emphasis toward the embodied impacts of buildings will be expected to make projects like BAMS, which focus on materials and assemblies, even more important.

An initial analysis of barriers and opportunities showed that a broad range of stakeholders will benefit from the BAMS project, through provision of a valid, tested, publicly available method and protocol for building materials assessment. Stakeholder engagement is essential in ownership of the project and its process. Moreover, adoption and use, in concert with policy and market drivers, will lead to the significant environmental outcomes required as outlined above. The role of stakeholders in the project and in this endeavour is critical. It will ultimately assist in the uptake of BAMS and its sustainability outcomes.

6. Future Developments

The first phase of the BAMS project that has been described in this paper has concentrated on developing a proof of concept for Australia. Obviously, further work needs to be undertaken to move from the generic scorecards, to that of specific assemblies and materials from information provided by manufacturers.

Beyond this, however, there are a range of future developments that could flow from the development of the scorecard and methodology. These include:

- Development of a procedural manual for the method to allow certification of assessments to it by third parties (e.g. by Good Environmental Choice Australia (GECA) or others) or producing companies;
- Development of a procedural manual to allow peer-reviewing of scored assemblies and potentially products; and/or
- Lists of assemblages incorporating brand-specific products assessed either by third-party certifiers (e.g. GECA or other) or by supplying companies. Such lists could be used and facilitated by interested parties e.g. local governments and/or responsible authorities.

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ZERO ENERGY HOUSE: AN INTEGRATED DESIGN PROCESS FOR AN INTELLIGENT SUSTAINABLE BUILDING

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Summary

The Gruppo Polo – Le Ville Plus building firm from Cassacco (Udine-Italy) and the University of Trento (Italy) are developing a prototype of a smart green building where a family of four people will live and that will be monitored for one year to check the correspondence to the project purposes.

The total cost of the research project, included the construction, has been financed by the Friuli Venezia Giulia Region and by the Gruppo Polo – Le Ville Plus.

The building is called "casa energy zero" referring to the fact that it does not use energy coming from conventional nets or from nonrenewable sources mainly of fossil origin. In addition the building is classifiable as autonomus house because the consumed energy is produced in situ by alternative and clean sources.

The main features of this smart green building are:

- carbon neutral;

- built with renewable materials and innovative building elements producing clean energy (sunspace, LVP intelligent window® , etc.);

- low energy consumption and with bioclimatic characteristic;

- integration between energy systems using alternative and clean sources;

- use of intelligent systems to manage clean energy sources in order to guarantee both inner environmental comfort and energy saving.

In order to test and validate the research expected results, the theoretic behavior of the prototype hypothesized during the design phase will be compared with the continuous on site monitoring of the functioning and performance of the active and passive systems, paying attention to the energy saving and the users' comfort conditions.

The building is now under construction. It will be completed in Autumn 2008 when the monitoring and evaluation phase will start.

1. Introduction

This paper deals with a research activity carried out at the Laboratory of Building Design of the University of Trento (Italy) aimed at the development of an integrated design process of a prototype building, whose performance will be monitored and evaluated on a real scale model. The main features of the design process are:

a. use of natural materials both for the bearing elements, made of wood, and for the finishing realized with dry systems;

b. attention to the energy performance of the envelope both in winter and in summer period, working especially on their structure and composition as well as on the inner joints (between the base-elements) and the outer ones (between the sub-elements);

c. integration with energy systems using alternative and clean sources: passive solar systems (sun space, Trombe wall, natural ventilation), thermal and photovoltaic solar systems, biomass and geothermal systems;

d. installation of an intelligent system for the managing of both the active and passive solar devices in order to minimize the total energy consumption but assuring in the meantime the best inner users' comfort conditions, even through self learning procedures;

e. development of innovative building elements as the so called "LVP intelligent window®" that will generate low speed air draught in order to contribute to the cooling and warning of the rooms together with an intelligent system for the draught modulation and optimization.

The prototype will be monitored to check the correspondence to the project purposes. Comparative analysis with simulation model will be performed.

In the following chapters, the most relevant aspects of the project mentioned above will be deeply analyzed and explained.

2. The Bioclimatic Concept

For what concerns the bioclimatic strategies, the building (design by arch. Arnaldo Savorelli – Solarch Studio in Bussolengo – Italy) presents both passive elements for winter heating and for summer ventilation and cooling (Figure 1 and 2).

First of all, it must be noticed the particular position of the construction inside the building site, situated at the northern side in order to let the widest part of the garden and the livable spaces directed to the South. The whole shape is interesting and studied in accordance with the local climate. The main body of the house, in fact, has a compact rectangular plant with an unique roof pitch facing the North with a double result: to protect the house from the northern cold winter winds and, in the meantime, to expose the widest part of the southern façade to the warm sun radiation during the cold season. Moreover, there is a little difference in altitude from the main roof and the secondary one on a lower level: it allows the presence of several little windows at the top of the building that, being inaccessible from the outside, can be left completely opened even during the night in order to guarantee a proper ventilation of the inner spaces during the warm season.

The southern façade, facing the garden and the pool, is a wide glass surface that takes advantage of the sun irradiation and let it enter the house till the back of the space during winter, while in summertime it is shaded by overhangs and provided with brise-soleil in order to avoid over irradiation and glare phenomena. In addition, a sun space and a Trombe wall are present. The northern façade, on the contrary, has little windows most of which are used just for summer night ventilation and to allow a proper views to the north side of the landscape.

Figure 1 Rendering of Casa Zero Energy – South-East view

Figure 2 The building under construction – North-West view

The façades facing East and West have themselves bioclimatic features, presenting low windows but large enough to let the user be delighted of the outer space without causing discomfort coming from the apparent daily sun path. Moreover, adequate shadows are provided.

3. The Building Technique

The prototype is a timber framed building with external and internal timber walls.

The building is built with natural and renewable materials excepted the hardware of the carpentry that is in steel. For this reason the building is classifiable also as natural building.

Actually in Italy there are few timber buildings, but their construction is increasing for the raising consciousness of users in relation with environmental issues and green buildings. In Italy, the majority of timber buildings are built with panel systems borrowed from the close Austria. Only few systems are planed and made in Italy, most of all with handmade systems.

For this research we chose to experiment a framed system that could be produced with industrialized techniques and that is completely designed in Italy by the Gruppo Polo – Le Ville Plus with the support of the University of Trento. The choice of this building system instead of a panel one is due to the greater building tradition in framed construction, also if limited to the Italian Alpine Region. In addition, it allows an higher constructive flexibility and it is easier to adapt to different configurations, even if the various building components are made with industrialized processes. The expected time for the construction of the prototype was 10 months, but the real time for the end of the works will be presumably 14 months. The delay is due to the experimental feature of the building site and to the necessity to modify some building details during the construction phases in order to improve their performance.

The pillars have a square cross-section 16x16 cm, they are connected to the basement by steel structure and steel plug. A knee wall connects together all the posts and it closes the frame. The main beams and the secondary beams (used sometimes as wall plates) are in glue-lam with a square cross-section 16x16/24 cm. The intermediate floor and the roof are built with glue-lam beams with a square cross-section 8x24 cm and a step of 50-80 cm. In both cases, the floor is built with board and insulation materials. In particular, the roof floor has a U value (thermal transmittance) of 0,197 W/m^2K. The external walls are made up by thermally insulated elements and by timber panels. With this kind of wall it is possible to reach a value of thermal transmittance of U=0,192 W/m^2K (Figure 3 and 4). The basement is a crawl space finished on the extrados by a reinforced-concrete slab. In this way concrete volume, which has a great heat capacity, can accumulate energy to help the heating system in the winter season.

The inner walls have a timber framework and plasterboard cladding. Wood fiber, a natural insulation material, is positioned in the free space between the frame grid. Nowadays, in Italy the most diffused type of inner wall is built by steel section and plasterboard cladding. This solution is in contrast with the natural house concept because the steel section set can determinate a Faraday cage that can reduce the inner environmental quality for the presence of electric charges that can not be disperse. In the prototype, a new type of inner wall will be tested that has not this problem because the frame is in timber and the elements are made by industrialized processes. The horizontal elements are lists 40x60 mm, the posts are two coupled lists 30x 50 mm. The system planned in this research is patented by the Gruppo Polo – Le Ville Plus and the University of Trento .

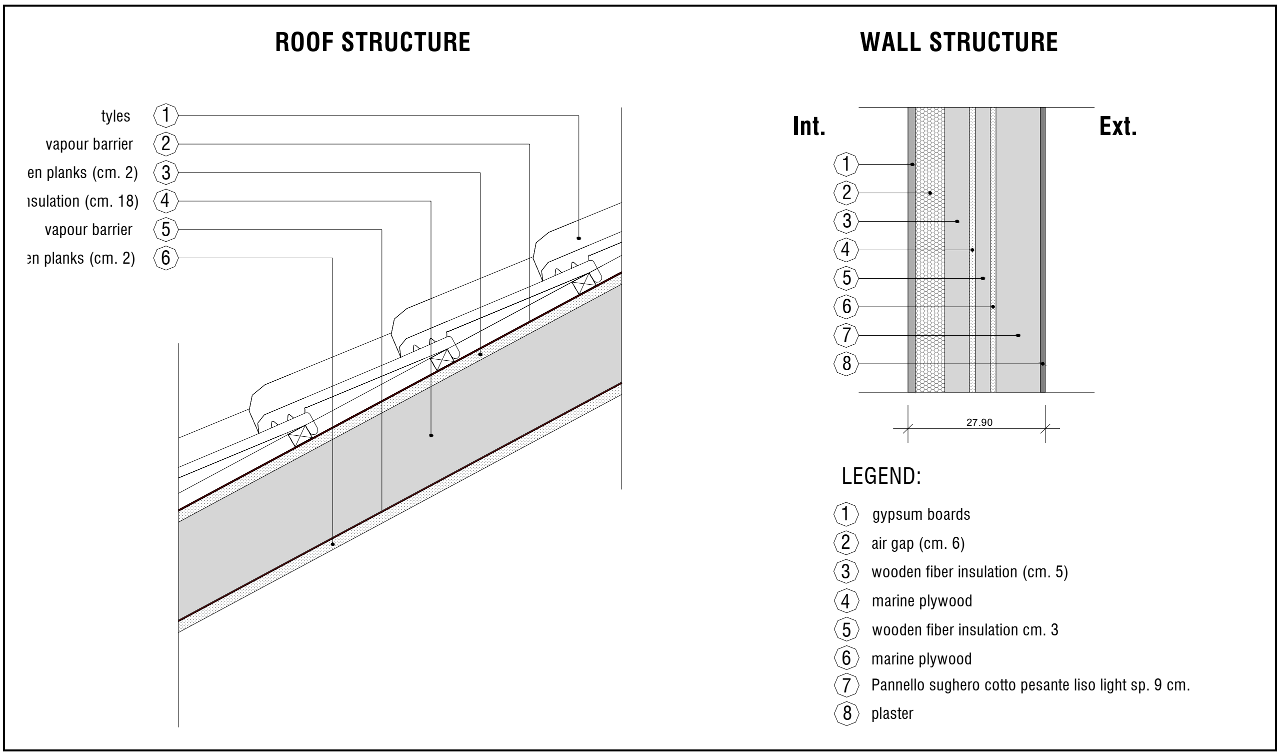

Figure 3 Detail of the roof and external wall structure

Figure 4 Picture of the inner part (main wooden frame) of the external wall under construction

Another innovative element planned in this research, is the LVP intelligent window®. It is built by two glazed panels with an interspace of 30-45 cm (depending on different solutions). Each panel has two openings with a flap putted on the top and on the bottom. In order to improve the air circulation in the interspace, a small fan is positioned in the lower part. The fan is operated by a small electric motor powered by a small photovoltaic system. The opening and the closing of the flaps manages the circulation of the air inside the interspace. In this way it is possible to run warm air into the house during winter, taking advantage of the greenhouse effect. In the same way, opening the opposite flaps it is possible to extract warm air from the inner space incrementing natural ventilation. The flaps are managed by the intelligent supervision system of the house and the opening/ closing is totally automatic depending on inner and outer environmental conditions (especially temperature values).

The building is now under construction. It will be completed in Autumn 2008 when the monitoring and evaluation phase will start.

4. The Intelligent System

The smart solutions implemented in the prototype building focus on the followings main goals:

- to test and verify the utility and the effective use of scenarios for the flexible utilization of automated passive solar systems;

- to quantify the contribution of automated control for the lighting, shading and conditioning systems;

- to experiment the possibility to guarantee both safety and security to the house users.

The devices and the correspondent functionalities of the smart system have been specifically established, in order to manage the interactions of all the technological system components in compliance with the peculiar issues of the prototype. In particular the following input devices have been included in the smart system design: temperature and humidity sensors, magnetic contacts to check the opening or closing state of the windows, occupancy and movement detectors, illuminance sensors (IEA, 2000).

Each device will be connected with a weather station in order to monitor the outside climate conditions (temperature, illuminance level, wind speed, rain) and with supervision touch screens in order to visualized and control the parameters available on the bus.

The design of the automation system has been developed in collaboration with the *bpt group*, in order to define both technical characteristics and programming possibilities of each device. Moreover in this phase the wiring structure, the topology of the bus system and the position of the smart elements have been identified.

The sunspace of the building is completely automated. It is a passive solar system, used mainly to heat the indoor spaces in the winter season. The automation system gives a specific signal about the proper functionality mode based on the outside weather conditions specifically connected with the proper use of the sunspace in winter season and with its complete opening in summer time.

The implementation of its functionality program has been previewed in two specific temporal modalities: seasonally and daily running function.

The functionalities of the smart system for the sunspace are:

- automated control of the opening/closing system of the windows, in order to optimize the convective fluxes of the air and the temperature level not only inside the sunspace but also in the adjacent rooms (automated control and priority of the manual operation);

- local and remote visualization of the windows opening/closing state and of the sunspace shading system according with the best position dynamically calculated;

- detection of the temperature values in the sun space.

The cooling system of the building is based on natural ventilation strategies. The functionality of the automation system for the natural ventilation improvement in the inner space is focused on the activation and the trigger action of the windows automated opening system. The main input parameter of this regulation function is the local detection of the inside temperature in order to support the air fluxes. The opening modalities of the opening systems are the same described above for the sunspace.

The building is equipped with shading systems. Their automated control is applied in different complexity levels: from the simple motorized action of the shading system to the complex control of smart shading systems, able to change properly the brise-soleil position according to indoor and outdoor environmental conditions (temperature and illuminance level). In this way, by means of the automation control system, it is possible to adjust both the slope level (angle of descent) of the brise-soleil elements and their movement speed (step by step or up and down).

The heating system of the building is controlled by the automation system. It is previewed, indeed, the integrated control of the heating system by means of the simultaneous use of radiant heating, solar panels and pellets boiler with height efficiency (the so called “integrated fireplace”). The whole system is regulated using a supervision system with seasonal mode. It is based on the subdivision in thermal zones of the radiant heating system.

The smart functionalities of the control system for this specific application involves the integration of the radiant heating with the solar panel, the proportional opening in continuous of the thermal valves of each single zone, the separate and differentiated activation of each defined thermal zone and, at least, in addition, the possibility to get, a remote control of the whole heating system.

The photovoltaic panels are connected to the automation system only for what concerns the data related to the hourly production of photovoltaic energy. It is indeed useful a comparison of these data in relation with the weather parameters values recorded by the outdoor weather station, correlated with the sun position and the sky conditions.

The smart system has been included as tool to guarantee the users’ safety in the experimental house, because it is able to monitor the domestic environment for what concerns faults and malfunctions of the systems or fire dangers. Moreover the automation system could help the normal manage of the domestic environment, for example by the automated opening of heavy shading systems.

With smart systems it is possible to have, as well by remote position, a constant security control of the building, through outside and boundary alarm and detection systems. At the same time it is possible to visualize the visitors’ identity using the connection with video-phone or mobile-phone. For this issue, the same magnetic contacts on the windows and occupancy detectors installed for the energy saving management could be used.

Significant data about the daily use of the building elements are controlled and monitored by the bus net of the devices installed. The supervision system allows indeed not only the recording of environments parameters but also the users’ behavior analysis. With these data it will be possible to improve the theoretic model of the building analyzed in relation with both weather conditions/building constructions characteristics and the user’ action in real use situation (Reinhart, 2004).

5. The on Site Monitoring

Even in Italy, summer average temperature are slowly increasing causing brief but very intensive muggy periods. The design and the construction of a light envelope building in a temperate Mediterranean climate is therefore a challenge directed towards the investigation of two main aspects: the possibility to guarantee adequate summer comfort conditions in bioclimatic free-running buildings, that is design with great attention to the local climate (most of all with reference to the sun position and prevailing winds direction); the necessity to provide building elements with an high thermal capacity in order to diminish temperature rises. This second aspect has been recently faced by the Italian regulation (Legislative Decree 311/06) providing a minimum mass value of the elements of the envelope of 230 kg/m^2 if the average daily solar global irradiation of the site in July is over 290 W/m^2. The mass, however, is not the only parameter to be taken into consideration speaking of thermal inertia and, most of all, it is also important *where* massive elements are positioned, even considering the building inner spaces.

In order to prove and to verify that this approach guarantees an high quality result, better users comfort conditions (following the recent adaptive comfort theory - Nicol and Humphrey 2002), an higher energy saving and the possibility to built using wood even in temperate climates, the research approach is based on to main activities:

1. the continuous thermal survey of the building;
2. an energy simulation in dynamic state conditions.

5.1 Continuous Thermal Survey

It will be carried on by recording data of the temporal courses of some specific environmental parameters (air temperature, relative humidity, air velocity, globe temperature, walls surface temperature) related to the most used thermal comfort indices (PMV and PPD – Fanger 1970) and to the adaptive comfort theory (Figure 5). Probes will be positioned in a certain number of rooms chosen for their exposure, their level and their different use. In addition surface temperature probes will be position both inside and outside the outer wall of the building together with fluxmeters, in order to reconstruct, during real life conditions, the thermal profile of the walls and their thermal behaviour in terms of thermal inertia (phase shift and temperature decrease).

In a second time, a new approach (already experimented by the authors) concerning the measurement on site of the thermal transmittance of the opaque elements of the envelope will be deepened by means of

Figure 5 The probes used for the assessment of the inner thermal comfort conditions

thermal fluxmeters and thermovision technique, both in a quasi steady state condition (winner period) and in thermal transitory one (spring and autumn).

The results of the research will increase a data bank concerning several thermal survey campaigns of real buildings that have been carried on by the Building Design Laboratory since 2002. In this particular experience, the surplus value (besides the possibility to monitor a building with mixed-mode systems, both passive and active, put all together one near the other in the same climatic context, with the same boundary conditions and so contemporarily assessable) is that, as far as the research goes on, some parts of the building can be modified in order to improve the thermal performance and the comfort conditions according to the output of the research itself.

5.2 Energy Simulation in Dynamic State Conditions

Once the building has been monitored, a virtual model of will be realized using specific software (EnergyPlus and its pre-processor DesignBuilder for the thermal simulation, Flovent for the fluid dynamic one) in order to determine the virtual temporal courses of indoor temperature and of the heat transfer through the building envelope as well as the circulation of the air flow in the indoor spaces and its capability to cool down the space and the structure. In a second time, a critical calibration of the model will be made in order to take into account the real behaviour of the inhabitants and their use of the building components (by means of specific questionnaires as well as a careful analysis of the recorded data), with particular reference to the bioclimatic strategies (shading elements, natural ventilation, sunspace, Trombe wall). When the annual recorded temperature trend is comparable to the virtual one (concerning both the temporal courses and the absolute values), the model can be assumed to be the “perfect virtual copy” of the building during the real life conditions for the duration of the study. Finally, it is possible to modify some building elements characteristics on the virtual model, in particular the mass value of the structure materials (but being careful to leave unchanged their thermal transmittance in order to verify only the influence of one parameter -in this case mass- on the building thermal performance), the shape and positions of the windows used for the ventilation, the disposition of the inner spaces and so on.

Following this methodology, it is possible:

- to compare the inner temperature trend in the base situation, that is the real one, and in the different versions analysed in order to evaluate the maximum, minimum and mean differences during the day when the mass of the building envelope is changed;

- to analyse the influence of an heavy envelope on indoor comfort conditions;
- to evaluate the influence of the building shape on a proper passive ventilation and cooling strategy.

The final goal is to propose guidelines useful in order to design proper bioclimatic and light weight buildings even in a Mediterranean temperate climate.

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TITLE: ENVIRONMENTAL ASSESSMENT OF RESIDENTIAL BUILDINGS IN CHINA

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Keywords: residential development, green buildings, sustainability, environmental assessment methods

Summary

China is the fourth largest country and has the largest population in the world. With its economic growth since the economic reforms starting from 1978 the government has struggled to contain environmental damage and social strife related to the economy's rapid transformation. The environmental degradation in China has been accelerated with the rapid growth in population and urbanization and the foremost problem that has challenged the government is the insufficient supply of housings. The growth in residential development has increased the demand for energy and natural resources for the manufacturing of building materials. Any improvement in the sustainable performance of residential developments in China will have significant impacts on environmental deterioration on a global scale. The concept of sustainable residential development is adopted in many countries and rating tools have been developed to guide and assess environmental performance of buildings. The purpose of the paper is to analyze the tools that are available in China to assess the environmental performance of sustainable housings and to present the results of an on-line survey and interviews in Beijing.

1. Introduction

According to the Department of Communities and Local Government (CLG) in the UK in 2004, approximately a quarter of the CO^2 emissions came from the energy consumption of homes (CLG, 2006). Sustainable residential development is about considering possible design options and to evaluate their life cycle impact. The information available during the design stage is limited and requires tools that can guide designers with default data and intelligence. Environmental building performance assessment tools for residential developments are designed to improve the overall building performance, minimize environmental impacts and costs. Most of these tools have been developed to transform the design goal into specific performance objectives and to provide a framework to assess the overall design. However most of the tools are voluntary only and are undertaken at the discretion of developers.

The purposes of this paper are (1) to examine the main issues and problems in relation to sustainable residential development; (2) to analyze the methods/tools that are available in China in assessing environmental performance of residential developments; (3) to present results of an on-line survey and semi-structured interviews in Beijing to explore the impact of environmental performance assessment tools for residential development in China.

2. An overview of sustainability assessment of residential developments

In recent years, a growing number of sustainable housing projects have been completed and sustainable housing is increasingly becoming part of common building practice. Sustainable residential development was one of the issues addressed in the United Nations Conference on Environment and Development at the Earth Summit in Rio de Janeiro in 1992 (Bhatti, 2001; Li & Shen, 2002). Bhatti (2001) states that sustainable residential development can make major contribution towards an environmental future. The method by which residential development is produced, consumed and managed, and the way it contributes to social and cultural life has major impacts on the environment.

IEA (2006) suggests that sustainable residential development can be achieved through preservation of the global environment, harmony between house and environment, and promoting health and pleasant living. From this viewpoint, a sustainable residential development is characterized by futurity and equity issues which aim to ensure that everyone today and the generations to come have a decent place to live which uses less resources to run than most existing homes. In addition to considering land use, orientation, shadow and light, concerns need to focus on the long-term costs - social, environmental and economic. Sustainable housing will be a growing part of the housing industry, making it a business opportunity waiting to be explored.

The purpose of sustainable housing is to raise the standard of living and to offer an opportunity for people to have a decent house to enhance social unity, well-being, economic growth and social improvement. Sustainable housing concerns not only the fabric of buildings but also the social and environmental context of construction practices. In sustainable housing construction, the concept of eco-efficiency is important and implies that a reduction in the environmental impact of housing construction can be undone by trends such as an increase in the average size of houses, and a decrease in the average number of persons per house (Klunder 2004). Sustainability is not just about low energy; it also means that people are happy to live where they live and that they live in a healthy environment.

Conventional residential developments are designed and constructed in accordance with the building codes, whereas green residential developments are designed, constructed and operated to consider environmental performance and minimize environmental impact. Most of the assessment tools have been used for planning and design development with specific performance objectives and provide a framework to assess the overall design using either rating system or assessment criteria.

3. The green challenge of sustainable housing in China

China is the fourth largest country in the world and accommodates more than 20% of the world's population (CIA, 2006). With its economic growth since the economic reform in 1978 China's GDP has increased more than tenfold while the environment has been deteriorating at an alarming rate (Cai, 2004; Ho, 2006). In 2005 China stood as the second largest economy in the world after the United States (CIA, 2006) and the second largest greenhouse gas emitter in the world and will be the leading emitter within the next couple of decades (Rousseau & Chen, 2001; Cai, 2004, Ho, 2006).

With economic development the government has struggled to contain environmental damage and social strife related to the economy's rapid transformation. According to the United Nations seven of the ten most polluted cities in the world are in China (EIA, 2005, Glicksman & Lin, 2006). The ongoing environmental deterioration such as air pollution, soil erosion and loss of arable land poses serious threats to economic growth in the long term if the Chinese government fails to control the environmental problems as a matter of urgency.

The environmental degradation in China has been accelerated with the rapid growth in population and urbanization and the foremost problem that has challenged the government is the insufficient supply of housing. According to the United Nations (2004) China has 1.56 million households still in need of housing and 350,000 households are still living in situation where they have less than $8m^2$ of gross floor area per capita and there is an increasing demand for residential housing needed to house the ever increasing population. As such any improvement in the design, construction and operation of residential housings will have significant impact on the rest of the world. The residential sector has already developed rapidly since the economic reform and is also the fastest growing sector in terms of energy and materials demands. Environmental pollution and insufficient housing are the two obstacles for achieving the goal of sustainable development in China (Ho, 2006).

Housing development in China is detrimental to the environment in many ways. Housing development is the main cause of loss of arable land for agriculture. The rapid growth in residential development has increased the demand for energy and natural resources for the manufacturing of building materials. In 2000 the total energy consumption in China had already exceeded total energy production by 17% of the same year (Ho, 2006).

In 1996 the Chinese government adopted housing reform to advance quality design standards and high quality construction methods and materials. However sustainability was not addressed to include energy conservation standards, healthy building features, durability and low maintenance features, water conservation standards, or recycling building materials (Rousseau & Chen, 2001). In 2006 the Central Committee of the Chinese Communist Party approved the 11th Five-Year Plan with the aim of reducing energy consumption by 20% per unit of GDP by 2010. The plan states that conserving resources and protecting the environment are basic goals, but it lacks details on the policies and reforms necessary to achieve these goals (CIA, 2006).

4. Toward sustainable housing

4.1 Laws and regulations

According to Rousseau and Chen (2001) China's rapid housing development was partly caused by the changes in the economic structure from a planned economy to market-driven economy which has led to the rapid expansion of the property market. The changes have led to the conversion of home ownership from government assigned to private ownership and the introduction of mortgage banking. The rapid economic development has stimulated serious migration of people from the rural areas to seek work and better living environment in the cities. The rapid modernization and industrialization in urban areas have escalated the demand for residential spaces.

Faced with the problems of insufficient housing especially for the low income people, affordable and appropriate housing has become a main focus of the Chinese government. In the series of Five-Year Plans for National Economic and Social Development, the government set goals to satisfy four key principles of housing development, namely affordability, livability, sustainability and adaptability. In recent years the government has established codes and standards to guide sustainable residential development. As Zhu and Lin (2004) state environmental building assessment systems developed by others will not be useful in China due to cultural and regional differences.

The Technical Assessment Handbook for Ecological Residence was introduced in 2001. This was the first rating assessment system for assessing sustainable housing which aims at improving environmental quality of residential buildings (Zhu and Lin, 2004). The handbook clarifies the concept of ecologically sustainable development as well as provides guidance in the planning, design, construction and management of residential buildings. It is constantly updated and the latest edition was published in 2006. The handbook is developed based on a list of performance standards and a set of design guidelines which are stringent requirements for pre-requisites. The handbook is only a simple rating system without explicit weighting. The usefulness of the handbook may be restricted as it only relates to residential projects and is voluntary only without clear consequences for non-compliance. The Technical Essential for Construction of Healthy Housing was introduced by the China National Engineering Research Centre for Human Settlement in 2004. It is very similar to the Technical Assessment Handbook for Ecological Residence. It also provides a standard for the design and construction of sustainable housing and emphases that green housing will need to concern environmental health as well as community welfare.

The development of the Green Olympic Building Assessment System (GOBAS) has impact on the development of environmental assessment tools in China. In order to integrate the goal of ESD into the development of Beijing Olympic 2008, the GOBAS was developed in 2002 and launched in 2003 supported by the Ministry of Science and Technology. The GOBAS gives a clear introduction on the design, assessment criteria and methodology of green building for the Olympic buildings. It lays down guidelines and principles for improving quality of buildings as well as reducing resource consumption and impact on the environment. It is Olympic buildings only. The assessment system was developed based on the concept of building environmental efficiency as in the CASBEE and LEED on a whole of life approach (Lin et al., 2005). Beijing Municipal Construction Committee has issued official document to adopt GOBAS as the Beijing local green building standard.

Following the launch of GOBAS, the Evaluation System for Green Buildings in China was developed as one of the 10th five-year national research plan. This system is an extension of GOBAS to be more regional specific and overcome the weakness of GOBAS to be a national standard for the evaluation of green buildings. It can be used to assess different types of construction in different climate zones (Qin & Lin, 2005).

In addition to sustainable housing assessment tools there are codes and standards issued by the government as a mean to improve building performance and to promote green buildings construction. The Outlines and Technical Principles for Green Ecological Residential Quarter Construction was introduced in May 2001 and it outlines the principles and targets on saving water and energy, ecological land use and pollution abatement. The Assessment Criteria for Green Building was issued in June of 2006 and it was the first nation-wide criteria on project construction in China to assess the green building from multiple objectives and criteria based on the whole of life approach for residential buildings. The assessment criteria clarifies the concept of green building and set up a legitimate assessment approach to assess housing performance. According to the assessment criteria, a green building should save resources (energy, land, water and materials), protect the environment and reduce pollution maximally, provide healthy, applicable and high-efficient space, and harmonize with nature during its life cycle.

Laws and regulations on energy conservation in China can be dated back as early as 1998 and the Design Standard for Energy Efficiency Building was issued in July 2005 as the first national wide criteria in China for energy saving design of public buildings. It is applicable to the design for energy efficiency of new and existing buildings. With improvement to the building structure and insulation, the standard aims at reducing the total energy consumption to 50% of that in 1980s. In 2006 the Regulations for the Administration of Energy Conservation in Civil Buildings came into force with the aim to develop household-based heat metering technique and equipments. It aims at enforcing the administration of energy conservation to improve the efficiency of energy use, and promote indoor environmental quality. It was applicable to residential but not applicable to low-rise residences built by peasants.

4.2 Research method

The introduction of the Technical Assessment Handbook for Ecological Residence in 2001 has marked an important era of sustainable housing in China. The Handbook has no doubt raised environmental awareness among construction professionals and guidelines that they can follow in the design and construction of sustainable housing. In order to examine the extent of impact an on-line survey was designed and conducted among construction professional in Beijing in December/January 2008. The questionnaire survey was designed and distributed online for a wider coverage and provided a quick and easy platform to return the completed survey. The purposes of the survey were to examine construction professional perception on green buildings and to explore the role of these assessment systems in the construction industry in enhancing sustainability in residential developments. Following the survey two semi-structured interviews were undertaken with representatives from the Beijing Institute of Architectural Design and Beijing Urban Engineering Design & Research Institute Co. Ltd. in January 2008.

The questionnaire was divided into three parts. The first part was intended to obtain general details of the respondents. Part two was intended to obtain the views of respondents in respect to their understanding and acceptance of green buildings in construction. It contains twelve questions. Part three was designed to identify the level of expertise the respondents have on the criteria for assessing sustainable housing and how familiar were they in using the Assessment Handbook for Ecological Residence for sustainable housing in China. This part contains eight questions. In addition to choice-based questions the questionnaire also contained several open ended questions whereby the respondents were asked to provide written opinions and have received tremendous replies.

The survey was undertaken in conjunction with Tianjin University of Technology (TJUT) and assisted by the China Engineering Cost Association (CECA) in distributing the online survey as well as organizing personal interviews for the research. The anonymous questionnaire was sent to practitioners in the construction industry in Beijing via email with a URL containing the online survey in December/January 2008. Many of the participants also forwarded the URL to other practitioners in the industry. Therefore it was difficult to determine the exact response rate. At mid February, 59 completed questionnaires had been received via online.

4.3 General information

Of the 59 returned survey 66% were from male respondents whilst 34% were from female respondents. Respondents came from a variety of background. The cost engineers and engineers have contributed the majority of the returned survey of 39% and 34% respectively. Architects and contractors have only contributed 10% and 9% respectively whilst the remaining 8% of the respondents were developers, project managers and academics.

Approximately 91% of the participants have less than 16 years of work experience and 65% were 26 to 35 years of age. The survey result reflects the keenness of younger professionals to take part in the survey and to provide personal opinions. Of the 59 returned survey 78% have provided written responses on the government regulations on environmental issues and their opinions on what the government could do to protect the environment. The responses will be summarized and reported later.

The respondents were asked to express their concern about the environment, 32% claimed that they were concerned about the environment a great deal, 59% were only concern a fair amount whereas 9% responded only little concern. The feedback indicated that they are quite skeptical about environmental protection and this may reflect the level of environmental awareness among the professionals. It is further reflected through their experience in working with environmentally related projects. About 23%% have less than 1 year work experience on environmentally related project whilst 69% have between 1 to 5 years and 8% have between 16 to 20 years working experience with environmental design, construction, maintenance and assessment. However with the respondents having work experience in environmental projects about 78% have done less than 5 projects whilst only 22% have done from 5 and up to 16 projects so far. The outcomes indicate that the respondents have insufficient exposure for dealing with environmental issues in construction and experience in relation to environmental projects. However considering that the first environmental assessment handbook was published in 2001 the result is quite encouraging.

In addition to the limited years of work experience in environmentally related project, based on the survey returns work experience of practitioners in construction industry in environmental project had been immature and at an early stage. Overall the respondents were rather young and inexperience. The outcome may be due to the majority of respondents (approximately 91%) having less than 15 years of work experience. It demonstrated that practitioners in the construction industry have very limited experience in environmentally related construction projects.

The survey also discovered that only 10% of the respondents with work experience in environmentally related project have received training in order to perform the work such as post-graduate studies, energy saving courses, clean technology courses or attended environmental CPD seminaries. Environmental training should be an area that the construction industry supports in order to equip professionals to improve their competence in environmental projects.

4.4 Observations and discussions

Part II was designed to obtain opinions and feedback on greening the construction industry. The questions were designed as a standard Likert scale where respondents were asked to rate each question from strongly disagree to strongly agree. The results are summarized in Table 1. Based on the returned survey the majority of the professionals agree that environmental issues are important for the construction industry and should be incorporated in construction projects. Approximately 95% agree that the demand for green buildings will increase and 90% believe that green buildings will increase in importance and increase in workload in the next few years.

About 84% believe that adherence to environmental practices can help the industry to grow further. This indicates that people are gradually realizing the benefits of green buildings to the well-being of humankind. This result was in line with the opinions from the two semi-structured interviews as they experience an increase in demand for sustainable housing in Beijing and people tend to prefer staying in green buildings as opposed to conventional buildings. The table also indicates the opinion from the survey respondents that laws and regulations will become more demanding and it was also confirmed in the semi-structured interviews. This is particularly serious for the energy conservation laws passed in October 2007 and in place in April 2008. In addition in December 2007 the government issued the Government Procurement List of Energy Saving Products which was the first mandatory energy law to enforce the use of energy saving products to reduce impact on the environment.

With regards to whether the construction industry has done enough to protect the environment the respondents had diverse opinions and only 28% agree, 34% disagree and 38% are not sure. About 70% disagree that research and development of green building is sufficient and further development is crucial in this area. However about 55% believe that the construction professionals are well aware of the importance of green buildings to the environment as opposed to the 21% that disagree. In relation to the level of expertise of construction professional in the design and construction of green buildings only 47% agree but 36% disagree that professionals have the expertise in the design and construction of green buildings.

Table 1 - Summary of opinions on greening the construction industry in China

Proposition	Responses (%)				
	Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
Environmental issues are important for the construction industry	2	0	5	55	38
Environmental issues should be incorporated in construction projects	2	2	3	59	34
The demand for green buildings will increase	2	0	3	54	41
Green buildings will increase in importance in the construction industry	2	0	8	53	37
The workload in the design and construction of green buildings will increase in the next few years	2	0	8	63	27
Adherence to environmental practices helps the industry to grow	2	2	12	71	13
The law and regulations on green buildings will become tougher	2	0	25	49	24
The construction industry has done enough to protect the environment	5	29	38	23	5
Research and development of green buildings is sufficient	24	46	12	13	5
Construction professional are well aware of the importance of green buildings to the environment	2	19	24	50	5
Construction professionals have the expertise in the design and construction of green building	2	34	17	30	17

The survey results only provide a rough indication of the current situation of environmental awareness among construction professionals. However the survey results provide insight into the areas that may require attention. The overall result indicates that the construction professional's environmental commitment in Beijing is immature and lacks exposure. The situation will change dramatically when government environmental protection rules and regulations will be more and tougher.

Table 2 - Impact of Technical Assessment Handbook for Ecological Residence in the construction industry

Proposition	Responses (%)				
	Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
The handbook is user friendly	6	6	35	53	0
The handbook is useful in assessing environmental performance of residential developments	0	6	35	59	0
The handbook is a useful guide in the design of green residential developments	0	6	53	41	0
The criteria set in the handbook are achievable	6	6	59	29	0
The handbook will help to provide better sustainability outcomes in residential developments	0	12	35	53	0
The assessment criteria are sufficient to cover the environmental aspects of promoting green residential developments	6	18	29	47	0
The cost of building green residential developments will be more expensive than traditional developments	6	6	35	47	6
Green residential building will take longer to complete	6	12	23	47	12
The handbook should be improved and applied to other types of construction	0	6	23	65	6

Part III of the survey was designed to examine the impact of the environmental assessment tools for residential building performance. The survey chose particularly the Technical Assessment Handbook for Ecological Residence as an example as this was the first assessment tool introduced in China. These questions were also designed as a standard Likert scale and questions were rated from strongly disagree through to strongly agree. Based on the returned surveys about 8% have used the assessment handbook before whilst about 20% only knew about it but had not actually uses it. This indicates that environmental assessment tools for sustainable housing in China were not very well accepted as compared with other countries. The use of the Handbook is voluntary and it is up to the developers to decide whether to adopt the guidelines set in the Handbook or not. For the performance tools to be more effective in enhancing housing sustainability they may need to be mandatory such as BASIX in Australia. Summary of survey results are included in Table 2 above.

As summarized in Table 2 about 53% agreed that the Handbook is user friendly. About 59% agree that the handbook is useful in assessing sustainable housing performance and 53% believe that the use of the handbook will help to enhance housing sustainability. However only 41% believe that the handbook is useful in guiding design and construction for residential projects. With regards to the assessment criteria set in the Handbook only 29% agree that the criteria set in the handbook are achievable whilst a majority (59%) is not sure. This indicates insufficient exposure to the Handbook and lack of environmentally related work experience of respondents. There are also not enough details about the area that they believe to be unachievable.

In general the respondents agree green buildings will cost more and will take longer to complete as compare to the traditional approach. Finally about 71% agree that the Handbook should be applied to other types of construction. However some respondents believe that the handbook is only a concept and lacks practical structure for implementation. With regards to improvement that can be made to the handbook, some respondents suggest to comprise statistical data to exhibit the usefulness and potential of the tool in promoting housing sustainability in addition to use case studies for demonstration. Some recommend a more detailed investigation to ascertain the usage and impact of the tool. Others suggest that an environmental assessment tool cannot be single dimensional and environmental aspects should be taken into account at the same time with economic considerations. On the other hand both environmental and economic appraisals need to be considered in the assessment framework on a whole-of-life approach. Due to lack of experience from the respondents in the tool the survey can only provide a superficial reflection on the impact of the tool and further research will be required.

Two semi-structured interviews were undertaken in January in Beijing. Representatives from Beijing Institute of Architectural Design and the Beijing Urban Engineering Design & Research Institute have experiences in both design and construction of green buildings in Beijing. At the interview they stated that green residential development is still at an early stage in China. Firstly, most developers still place financial return at high priority because green designs generally cost more. They prefer the traditional construction in the design and construction of residential buildings. They believe sustainability can only be put into practice if it becomes mandatory. Secondly, the existing sustainability assessment systems need further development. The existing system is either insufficient or incomplete in guiding design and construction. In addition the system is not appropriately known or understood by most professional in the construction industry. Thirdly, there is a lack of financial incentives by the government to encourage green development. This is particularly important as green construction is generally costly. Unless green construction cost is reduced, developers will not have the motivation to build green. Fourthly, the general public is commonly fond of living in green residential buildings as they all accept that these buildings can provide with healthier and better living environment. However since the supply of these building is generally insufficient and expensive they are inclined to stick to traditional residential buildings.

5. Conclusion

Sustainable housing has profound effects on human beings' daily lives and well-being. In China with a huge population and rapid urbanization, housing shortages has become an important task confronting the government. More effort needs to be made to provide sufficient accommodations to the people as well as minimizing load to the environment. The task needs a more systematic and holistic approach to assess and promote housing sustainability. There is no doubt that environmental assessment tools contribute significantly to achieve the goal of sustainable development within construction. On one hand, it provides a methodological framework to measure and monitor environmental performance of residential development, whilst on the other it alerts the building profession to the importance of sustainable development.

Sustainable housing is multidimensional and the evaluation of sustainable housing cannot be achieved using a single criterion and single objective function. The decision-making process for sustainable housing uses multiple criteria and objectives and needs to be considered on a whole-of-life approach as it is not just considering economic and environmental problems. It also needs to include social and economic evaluations during the service life of the building. Therefore a set of multiple goals and criteria needs to be considered simultaneously. The sustainable housing industry needs to appreciate the affordability for home buyers especially those issues relating to design and cost. The reality is that home buyers will respond to environmental issues providing it is affordable and does not come at a cost penalty. Professional designers should maximize the environmental performance and concentrate more on achieving lower costs. If additional cost items are to be included, developers, builders and governments will need to consider introducing innovative financial incentives.

The questionnaire survey and interviews have provided a preliminary insight into the current situation of sustainable assessment of housing development in Beijing. Beijing is the capital of the country and any conclusions drawn will provide an indication of the condition of environmental awareness among construction professionals in the country. However China is a huge country with regional variations, therefore further research may be required in other regions of China in order to obtain a better understanding of the situation. In order for housing sustainability to be made more important, environmental awareness should be made in a more radical way to promote sustainable housing for the sake of creating market demand and stimulating business interest in developing sustainable housing. The government by developing and coordinating sustainable housing polices in a more systematic way as well as providing financial incentives to encourage more sustainable housing. On the other hand supporting and providing further education and training to construction professionals, researchers and academia will contribute to the design and technology advancement of sustainable housing.

Acknowledgement

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QUANTIFICATION OF BUILDING/ENVIRONMENT SYSTEM PERFORMANCE

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Keywords: building performance, risk, reliability, probability, environment, climate

Summary

The paper points out the role of risk analysis methods in applications for sustainable development. The method for quantification of system performance in terms of probability of failure and reliability, referring to this kind of methods is presented. It is proposed to support urban, architectural and structural design of buildings in the context of comfort, healthy living conditions, and sustainability. The results of applications of the proposed methodology to evaluate the probability of excessive heat loss through the two types of building envelope are presented.

1. Introduction

Building design has to ensure structural stability and well-being of people both indoors and outdoors under limited negative impact on environment for example in the form of excessive energy use. It includes urban, building (form, façade and material) and installations design in relation to the environmental and climatic conditions of the place where the building is constructed. Climatic conditions, human activities inside a building and criteria for human comfort are random in nature. Even the properties of structures are comparatively uncertain. Probabilistic analysis appears as the appropriate approach to account for those uncertainties when evaluating building performance. Eventually, probability of poor-performance (failure) or reliability, which is a complement to the probability of failure, can be calculated.

The application of probabilistic methods of analysis in building design reaches back to the sixties and mostly concerns safety of structures (Ditlevsen 1996). In the fields of building design including human health, comfort and well being, some attempts to adopt probabilistic methods to support design have been introduced. The concept of evaluating the hazard of improper moisture conditions was introduced by (Nielsen A. 1987, Nevander et al 1991). This work has been continued by (Harderup 2000) (Monte Carlo Simulations), and (Pietrzyk et al 2004, Kurkinen et al 2004) (FORM, First Order Reliability Method). The risk of radon concentration in a building enclosure was analysed by (Ljungquist & Lagerqvist 2005). The probabilistic model PROMO has been developed and validated by (Pietrzyk 2000) to estimate the probability of insufficient air exchange or excessive heat loss. The limit state approach based on a random variable model and FORM techniques for applications in building physics is presented in (Pietrzyk & Hagentoft 2008). This enables quantitative comparisons of different design options, and hence the reliability-oriented (probability-based) analysis (Pietrzyk 2005).

Probabilistic model for evaluation (quantification) of building/environment system performance based on load-resistance (demand-capacity) random variable model (Kottegoda 1997) is referred to in this paper. It gives opportunity to take into account a random character of system load and also random character of system capacity expressed in the form of performance criteria stated for human health, human comfort, to meet economic standards or in order to prioritise the sustainable solutions. It offers estimation of the probability of performance failure using mathematical relationship between probability density functions (pdf) of the load parameters.

2. Risk analysis for sustainable development

2.1 General

Risk analysis has become a very important tool in assessment and governance of environmental and societal risks to sustainability. Figure 1 illustrates designing for sustainable urban development. The goal is stated to ensure well being for individuals (space of acceptable solutions is represented by the shaded area) under limitations introduced to prevent or mitigate the high risks (see bounds drawn with dashed lines – models 2). The bounds cut off and diminish the space of the satisfying solutions. The high risks (of great importance to mankind, societies or human beings, usually with catastrophic consequences) are identified by risk analysis methods and if not ignored, result in various decisions towards sustainability. Risk analysis methods are also used in order to ensure people well being (see models 1) for example in built environment or inside the buildings. In this case the appropriate design can be perceived in terms of reliability as the focus is put more on ensuring acceptable performance of the building rather than on defeating high risks.

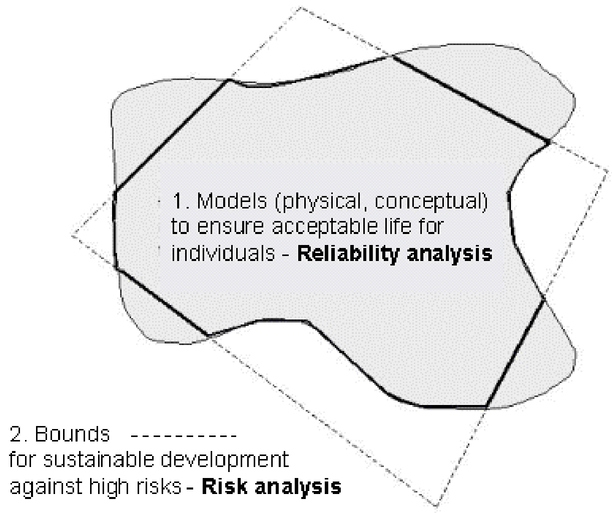

Figure 1 Designing for sustainable development

2.2 Towards quantitative risk assessment

Qualitative risk assessment describes a nature and source of the hazard, identifies alternative scenarios for the risk outcome and the severity of the consequences (McDaniels & Small M.J., 2003). There is a trend for completing the qualitative risk assessment with quantitative evaluation of probability of failure. Likelihood of occurrence of failure events multiplied by their consequences results in quantitative risk assessment. This allows more rigorous comparisons of alternatives. Probabilistic risk assessment offers estimation of the probabilities assigned to the outcome of the model representing variability and/or uncertainty in the model and its inputs.

3. Reliability of building/environment system performance

3.1 Definition of (considerations about) building/environment system

Building performance depends on the structure and the way that it is used, but also on the environmental conditions of the site and the microclimate in a vicinity of structure, which is influenced by the building itself. It supports the idea of using the concept of building/environment system performance. Generally microclimatic conditions outside the structure act as a boundary layer for processes inside the structure and in the building enclosure. But, there is also a reverse influence of the structure on the nearest environment, for example on the wind field in its neighborhood. It can encompass pedestrian discomfort or excessive heat loss through a building envelope, followed by consequences against sustainability in the form of increased energy consumption to warm up buildings or excessive use of motorized transport.

Figure 2 shows interdependence of the processes inside a building enclosure, in a building structure, and outside of a building. Focus is put on the measures important for humans' health, comfort, and energy performance of a building. Quantitative analysis may be used to examine such factors like ventilation, heat loss, moisture performance of building components etc. Many of them are listed within the gray boxes.

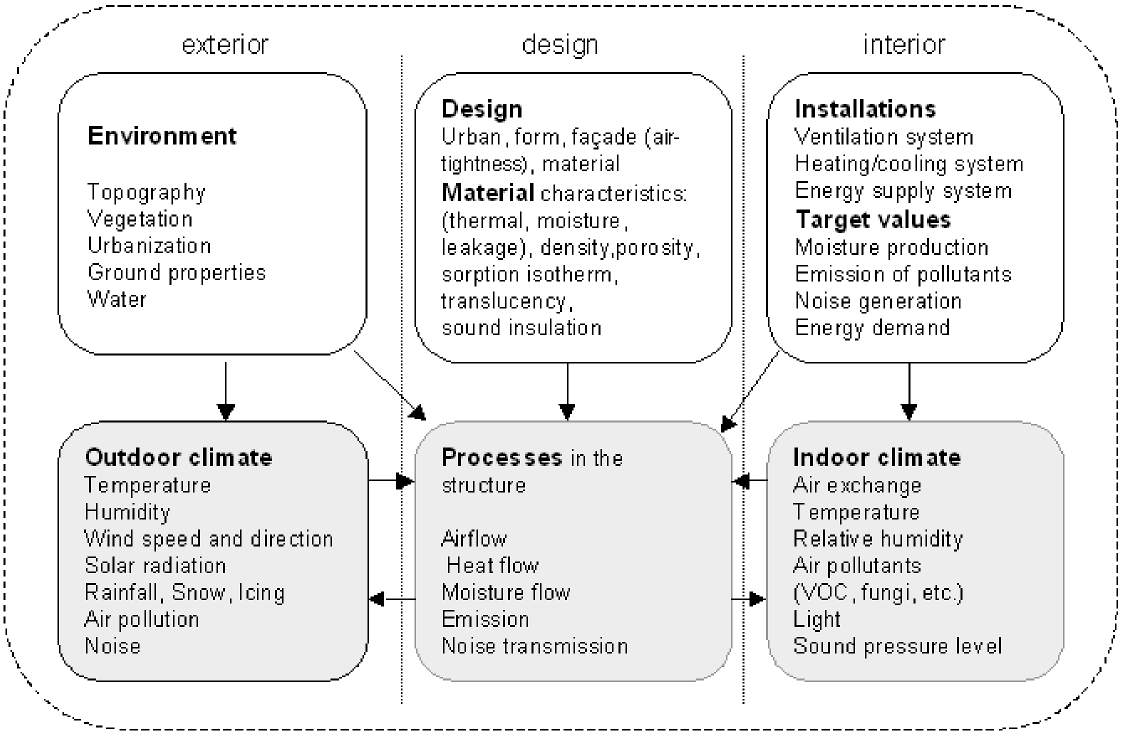

Figure 2 Interdependence of the processes inside a building enclosure, in a building structure, and outside of a building.

3.2 Evaluation of building/environment system performance – methodology

In carrying out a reliability analysis of building/environment system performance, a list of all hazards should be compiled. Those hazards are associated to failure events characterized by some sort of unacceptable serviceability (for example: insufficient air exchange, excessive energy loss, too high sound pressure level). Failure events are usually the consequences of the physical state of the building characterised by the parameters (performance aspects) S not meeting prescribed limits (performance criteria) R as presented in Figure 3. Unacceptable performance caused by air-, heat- and moisture flow through a structure, the illumination conditions, noise transmission, wind/structure interaction etc, can appear in the form of unhealthy conditions (mould growth, emission of irritating compounds from the material), discomfort (insufficient air exchange, esthetical changes of the surfaces, odour, draught, mites propagation, high level sound propagation, insufficient illumination, pedestrian discomfort), damage of the material (changes of physical or chemical properties of the material), and excessive energy loss (for example caused by high wind speed and turbulence around buildings).

In the probabilistic modelling the design variables and parameters are explicitly identified, as well as, load (demand) S and resistance (capacity) R probability distributions are determined (see Figure 3). Probability density function of load S is approximated, taking into account uncertainties of input parameters describing external and internal load and the structure (see fields within dashed rings in Figures: 2 and 3). Fundamentally, two common types of uncertainties may be present in any calculation: uncertainty resulting from the lack of information or uncertainty caused by the natural variability in a parameter. Uncertainties that arise from the lack of knowledge about parameters can be modelled with the help of expert judgement that can lead to assignment of probability distribution. Uncertainties that arise from variability can be modelled with the help of statistical approach if enough data is available (experiments, simulations).

Requirements for the system are specified in the form of performance criteria. The performance criterion R indicating the conditions favourable for a performance failure can be treated as a random variable with the probability distribution function evaluated from the probabilistic approximations based on deterministic function of input random variables, from experiment or by expert judgment. Generally, performance criteria result from the analysis of economic and social costs and benefits. Some of them are defined in the Code of Practice or in the international standards elaborated by International Organization for Standardization (ISO) or European Committee for Standardization (CEN). Minimum air exchange rate, minimum or maximum internal temperature, maximum speed of airflow inside the building, maximum relative humidity, the maximum overall average U-value of a building envelope or the minimum air tightness are examples of type minimum and type maximum limits for building performance parameters.

Reliability of the design is estimated by comparing if the system can carry effect of applied loads without jeopardizing well-being of people. It can be carried out with the help of performance function $Z = R - S$. The state $Z = R_2 - S = 0$ (for maximum type with threshold R_2) or $Z = S - R_1 = 0$ (for minimum type with threshold R_1) divides the response space into safe (positive Z) and unsafe (failure) (negative Z) regions characterized by reliability or probability of failure P_f.

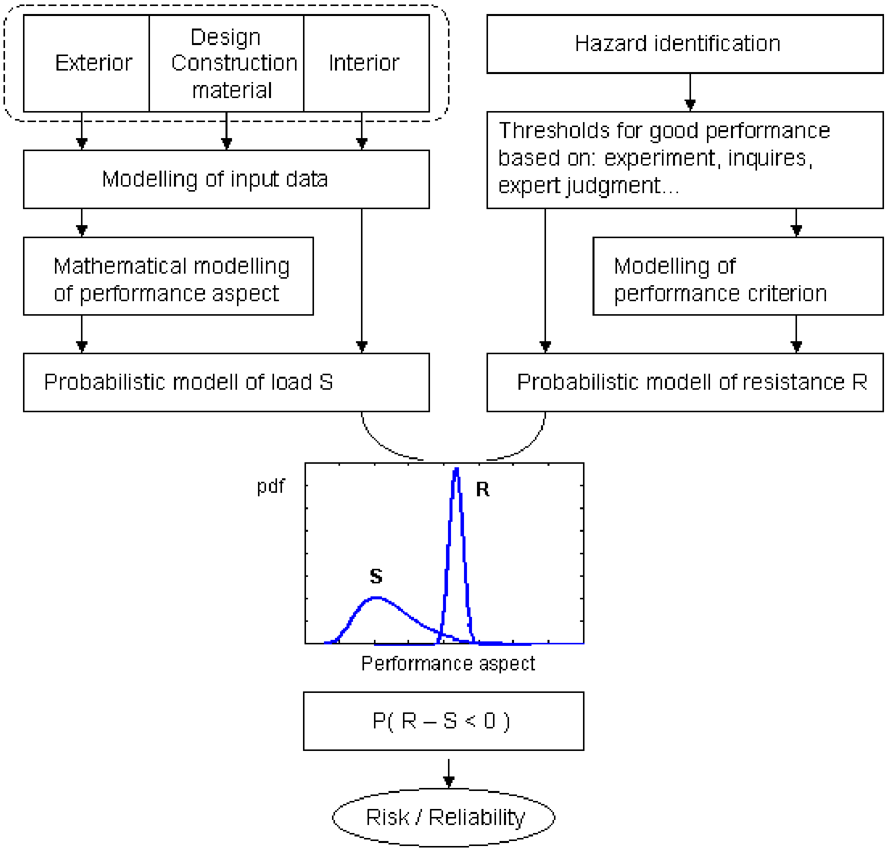

Figure 3 Methodology of quantification of building/environment system performance. Concept of load-resistance model applied (extended) to the problems of unhealthy conditions, discomfort, and excessive energy use

The process of reliability analysis does start with the hazard identification and description of the physical relationships between all influencing parameters. Analysis of the parameters leads to the conclusions about the importance of their variability or/and uncertainty to the investigated response of the system and the decision if they should be treated as deterministic parameters or random variables in the model. The time dependence of the random variables should be examined to choose an appropriate model for the system. The following steps should be performed:

- Description of the hazard of building/environment system performance
- Choice of the performance aspect
- Statement of the performance criterion ensuring that the system meets performance requirement R
- Specification of the mathematical models describing the performance
- Identification of the parameters important in the modelling of the performance
- Description of the uncertainties associated to the parameters
- Sensitivity analysis of the influence of the parameters on the model response
- Specification of the character of the time dependence
- Model formulation (performance functions) on the basis of the physical relationships, input data and time dependence analysis
- Decision on the reliability measures to be used
- Application of the reliability method in order to estimate the reliability measure for the stated hazard

4. Examples

Two examples of estimation of probability density functions (pdf) of heat loss (performance aspect S is presented by power loss (kW)) for two buildings of the same size with different properties of the envelopes and different ventilation strategies are presented. Performance requirement in the form of threshold power loss for heating can be introduced at the deterministic level of R (kW) (see Figure 6). The input parameters, which should be treated as random variables, are selected. They include temperature difference across the building envelope ΔT, thermal transmittance U and air change rate ACH. Probability density function of ACH is estimated in air infiltration model with wind and temperature input variables (Pietrzyk 2005). The modelling flow is shown in Figure 4. Performance function for heat loss Φ is proposed. Final results for the chosen examples are presented in terms of probability density function of power loss. It depends upon the interaction among the envelope construction, the local climate at the site and the chosen ventilation system.

The modelling details can be found in (Pietrzyk 2000). Two cases are considered (see Table 1). The first one for the building envelope working according to the dynamic wall principle with the thermal properties depending on the air infiltration rate when natural ventilation is assumed. The second case includes a tight envelope and balanced ventilation causing the constant (deterministic) air change rate equal to the mean value of the air change rate noted for the case 1: ACH = 0.7. For this case thermal transmittance depends only on the temperature of the material, hence indirectly on ΔT. The examples are calculated for the period when $T_{int}>T_{ext}$ (T_{int}=const) for the house situated in northern Sweden.

Table 1 Description of the calculated examples

Case	Envelope	Ventilation	Air exchange		$\Delta T = T_{int} - T_{ext}$	
			Mean / St.dev.	distribution	Mean / St.dev.	distribution
1	dynamic wall	natural	0.7 / 0.3	lognormal	15.3 / 9.5	truncated
2	tight	balanced	0.7 / 0.0	(deterministic)		normal

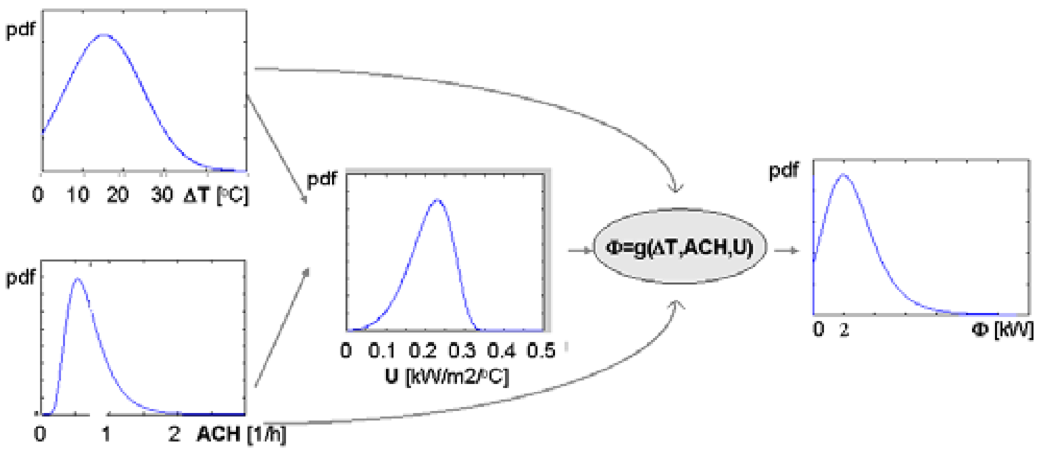

Figure 4 Modelling flow of random variables for estimation of probability distribution function of heat loss (case 1).

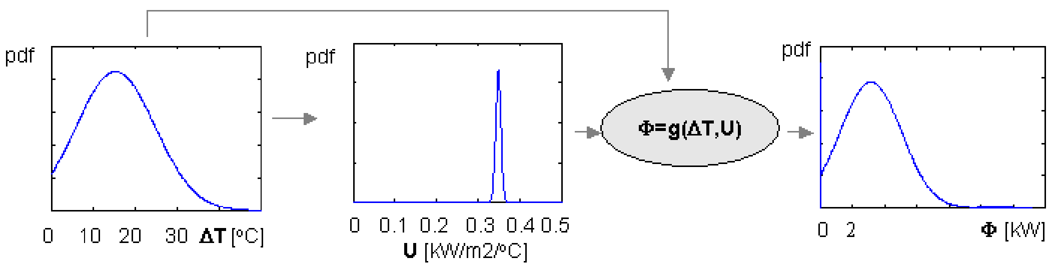

Figure 5 Modelling flow of random variables for estimation of probability distribution function of heat loss (case 2).

The power needed to compensate for heat and ventilation losses is presented in Figure 6 in the form of probability density functions for both cases. Threshold R can refer to the assumed maximum effective power of heating device. If other heating sources are absent, the probability of failure P_f defined as T_{int} decreasing below assumed constant value is equal to the area below the pdf to the right from the threshold. Probability of failure can be translated into the total time during which the prescribed performance criteria are not met.

Case	Reliability	P_f
1	0.91	0.09
2	0.86	0.14

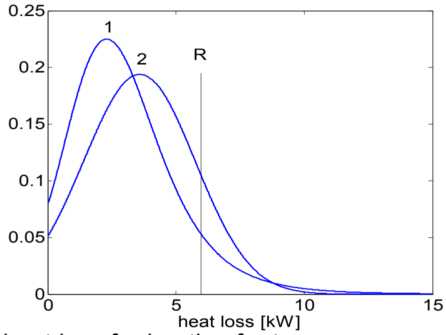

Figure 6 Results of probabilistic approximations of heat loss for heating for two cases: case 1 – naturally ventilated building with dynamic wall, case 2 – mechanically ventilated building (balanced ventilation) with tight envelope.

Comparison of these two options can be carried out in terms of probability of failure or in terms of reliability = 1- P_f. For R = 6.0 kW the results are given in Figure 6. For the assumed sufficient power of heating system, the conclusions about the uncertainty of the energy consumption for heating can be drawn.

5. Conclusions

Risk analysis methods can be used in order to ensure people well being in built environment or inside the buildings. In this context the appropriateness of a design can be better expressed in terms of reliability as the focus is put more on ensuring acceptable performance of the building rather than on defeating high risks.

Quantification of building/environment system performance in the form of probability of satisfying performance is proposed. It gives opportunity to probability-based approach in the design process relying on estimation of the reliability of a building performance for the alternative designs. It also allows obtaining the reliability-based assessment of existing buildings exposed to the changed conditions (climate change, local climate change due to urbanisation etc.) in order to promote the sustainable solutions.

A probability-based evaluation of building/environment system performance delivers an input to the risk-management models. The risk-management models prioritising different requirements should be developed.

6. Acknowledgment

Financial support of The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning FORMAS is gratefully acknowledged.

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SEMI-SCALE HYGROTHERMAL EXPERIMENTS AND THEIR ROLE IN SUSTAINABLE DESIGN OF BUILDING ENVELOPES

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Keywords: sustainable design, building materials, building envelopes, energy savings, semi-scale testing, interior thermal insulation system

Summary

Advanced semi-scale device is introduced as an effective tool for the sustainable design of new building materials and structures in the paper. At first, the requirements of building designers on the development and production of new materials with reference to the sustainable development principles are formulated. The main attention is paid especially to the savings of energy for heating and air conditioning of buildings. Then, the procedure of semi-scale testing is described which is aimed at the assessment of hygrothermal performance of building structures and materials. Since the energy expenses of buildings are mostly consumed by heating systems, in the final part of the paper an application of semi-scale device for the analysis of hygrothermal function of newly designed interior thermal insulation system on hydrophilic mineral wool basis is presented. Within the experiment, the insulation system is exposed to the difference climate conditions corresponding to the typical winter period which is the most critical part of year for buildings and their energy consumption. On the basis of the experiment it can be concluded that the analyzed system performs in satisfactory way from both thermal and hygric points of view.

1. Introduction

Continuous decrease of fossil fuels supplies, an increase in their prices and last but not least impact of their consumption on the living environment is reflected in the operating expenses of buildings. Another serious problem represents an increase in building materials production. The building materials are manufactured mainly on natural basis, what has harmful effect on the living environment quality. For example among all construction materials, around 65% is concrete, produced in the world at an approximate rate of 4600 millions of m^3 per year. In concrete production, around 90% of all energy consumed is used to obtain cement, which is also a major source of CO_2 emissions. Within the production of 1 t of Portland cement, 1 t of CO_2 is evolved in the atmosphere.

Therefore, development of new, advanced building materials having higher utility quality is necessary in the sense of the sustainable progress of building industry. However, not only the final advanced properties of materials should be considered. Also the energy and natural materials consumption should be taken into account. Hence, the secondary raw materials (i.e. waste materials) find widespread use in building materials production.

In this work, we have focused on the reduction of operating expanses of older buildings, where the heating costs represent almost 80% of the total energy costs. With reference to the sustainable development principles, especially the passive and low energy buildings should be constructed. In Table 1, there are given specific energy consumptions dividing buildings into several categories according to the European technical standard CSN EN 730540-2:2007 – Thermal Protection of Buildings. Since the most of existing buildings do not meet the requirements of the current strict thermal technical standards, there is need to improve the existing structures in order to eliminate thermal bridges and decrease the heat losses.

The improvement of thermal performance of existing buildings can be simply done by additional thermal insulation systems that can be applied on exterior or interior surface of the building envelopes. Exterior thermal insulation systems are quite simple and popular solution. In this manner, the thermal bridges are fully eliminated and standard thermal insulation materials can be applied. There were developed many thermal insulation systems taking advantages of assorted types of thermal insulation materials as on organic basis (expanded plastics, wood wool, cork, straw, technical hemp) as well as on inorganic basis (foamed glass, glass and mineral fibers). Particular products differ in thermal resistance, heat capacity, shape, flammability, specific composition of their structure, etc., what in the relation to the designers' requirements assigns the possibilities of their application in building practice. For example, application of 10 cm of mineral wool on exterior surface of residential house having floor space 120 m^2 leads to the 60% decrease of natural gas consumption for heating systems. However, the exterior insulation systems can not be applied universally. The typical example represent historical buildings, where the preservation of original architectonical view of facades is one of the top interests of conservationists. Also in case of too complex facade surfaces, the exterior systems fail. In these cases, the interior thermal insulation systems find use.

Table 1 Specific Energy Consumptions of Residential Houses

Energetic type of building	Unit	Energy consumption of residential houses	
		Heating systems	Total
Passive house	[$kWh.m^{-2}.h^{-1}$]	15	42
Low energy house	[$kWh.m^{-2}.h^{-1}$]	50	130
Standard new building	[$kWh.m^{-2}.h^{-1}$]	115	170
Old building	[$kWh.m^{-2}.h^{-1}$]	220	280

Since the interior thermal insulation systems are not natural solution, they represent particular problems for proper hygrothermal performance of improved buildings. The main problem is risk of water vapor condensation in thermal insulation layer transported from the interior air. A common solution to this problem consists in placing a vapor barrier just under the internal plaster on the surface of the insulation layer, so that both the insulation layer and the load bearing structure are protected against water vapor. This solution assumes that no mechanical damage of water vapor barrier will appear during the service life of building. However, this assumption can perform on the theoretical level only. In the practice, it is very difficult to avoid mechanical damage of the water vapor barrier placed in such an inappropriate way.

In the insulation system, which functionality is verified in this paper, a water vapor retarder is used instead of the water vapor barrier and placed between the wall and the thermal insulation layer. Since this solution is quite new and innovative, new types of materials for water vapor retarder as well as for thermal insulation layer were designed and manufactured.

The materials were designed and manufactured according to the directed design principles. We will not go into the details but a short description of the directed design methods is necessary. At first, there is essential to perform computational analysis of the studied problem with the special attention to the optimization of material properties. Especially the thermal and hygric material properties should be closely investigated. Within the computational design of material properties, the requirements of thermal technical standards have to be taken into account. Using the computational simulations, the information for design and production of required materials is obtained. The second step of the directed design represents materials' manufacturing. In our case, the thermal insulation material was produced by Rockwool, Inc., the water vapor retarder was developed in a cooperation with Mamut-Therm, Ltd..

After that, the developed materials have to be tested in laboratory in order to check whether the requirements on materials properties were met or not.

The last step in the development of new materials involves the verification of their functionality in the real conditions of buildings. This can be done basically in two ways. The first possibility is to build special test house were the developed materials will be applied in the insulation system layers and exposed to the real climatic and service conditions of structure. The performance of inbuilt materials is then continuously monitored. This procedure is very popular and gives probably the most predicative information on materials' performance. On the other hand, it is highly time consuming and rather expensive.

In this paper we present relatively new approach to the evaluation of the functionality of newly designed building materials and structures which is markedly cheaper and less time consuming. Hence, it could find widespread use in the sustainable planning and design of effective and environment friendly buildings. Laboratory character of the proposed method allows also testing of smaller building components as window frames, transitional details of roofs, insulation materials, plasters etc..

2. Semi-scale experiment

The effective design of new materials according to the exact requirements of building designers requires development of sophisticated and precise enough method for the verification of the materials performance during their climatic loading. On this account we have focused on the design and development of new testing method that will allow predicting of hygrothermal behavior of building structures and components in the conditions very close to reality. Design of such testing method represents certain substitution of full-scale test house measurement of field variables of heat and moisture transport and requires development of new testing device.

The presented experiment uses the sophisticated testing device that enables simulation of climatic conditions that are as close as possible to the real climatic conditions on building site. Nevertheless, it still maintains laboratory character, so that the expenses can be kept considerably lower compared to the test house testing. That is why we denote it semi-scale experiment.

For the realization of semi-scale experiment, climatic chamber system that enables simulation of difference climate conditions of a building envelope samples with the real thickness of all its components was developed. The climatic chamber system consists of two climatic chambers, connected by a specially developed tunnel for placing the studied specimens. The test space is water and vapor proof and thermally insulated. The climatic conditions in the system are controlled by programmable microprocessor that makes possible to simulate relative humidity and temperature corresponding to the real climatic data of the test reference year. To the climatic chamber system, there is possible to connect accessory water drench system for rain simulation. The scheme of the climatic chamber system is shown in Figure 1.

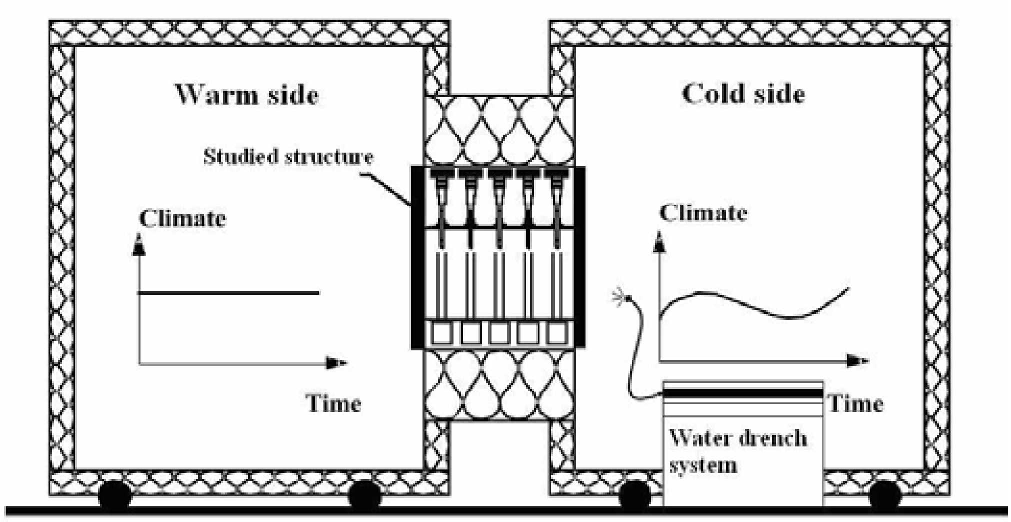


Figure 1 Scheme of the climatic chamber system.

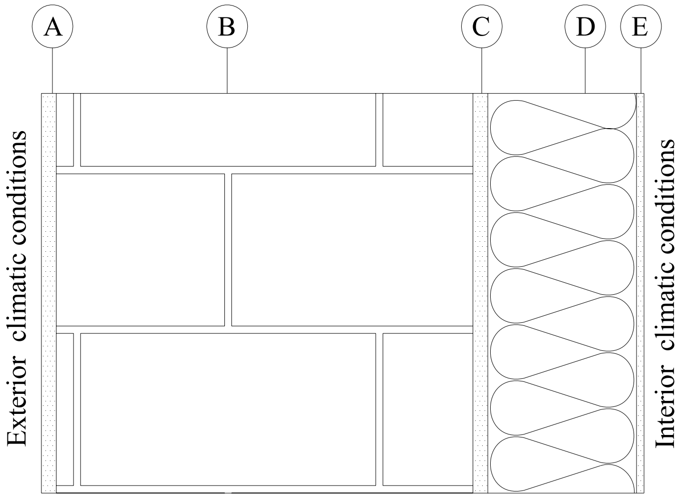
In the tested structure, monitoring of moisture content, relative humidity, salinity, capillary pressure, temperature, air velocity and heat flux, is possible. Since the system has laboratory character, modified advanced laboratory meters are used. The details on the particular sensors and meters can be found in (Pavlík and Černý, 2002, Pavlík et. al, 2002). The sensors that were used within the experiment presented in this paper will be described in the following section.

The sensors are installed in the structure into prepared bore holes and the upper part of the bore opening is water and vapor proof insulated by silicon sealing. Only the thermal flux sensors having plate shape are spot glued on the front sides of the investigated structure. In the installation of the specimen into the connecting tunnel, its thermal and hygric insulation from the tunnel walls performed for the sake of simulation of one-dimensional heat and moisture transport in the envelope belongs to the main tasks. We employ extruded polystyrene boards in a combination with mineral wool, the front sides of insulation materials are covered by polyurethane foam.

After installation of all sensors and insulation of the investigated structure in the tunnel, the tunnel is connected with the climatic chambers and the experiment can be started. The measuring system should simulate the hygrothermal processes in building envelopes in the conditions close to the reality. Therefore, the external and internal conditions simulated in the particular climatic chambers have to be realistic. We employ hourly reference-year based data for temperatures and relative humidities in the chamber simulating external climate and proper constant temperature and relative humidity data in the chamber simulating the internal conditions. Because our water drench system does not allow simulation of controlled water drops, only total amount of rain water for every day is simulated. The rainfall data are also taken from the test reference year. The measured data of field variables are processed and evaluated by measuring control units that are continuously controlled by external computer.

3. Experimental

In the experimental part of the paper we present the application of semi-scale testing approach for the verification of functionality of newly designed interior thermal insulation system which basic principles were given above. On the basis of laboratory tests of material properties, following new materials were chosen as an optimum solution for interior thermal insulation system: hydrophilic mineral wool Dachrock (Rockwool, Inc.), water vapor retarder SM-T FLT – a material on flexible cement glue basis (Mamut-Therm, Ltd.), and interior plaster SM-TJ VJ (Mamut-Therm, Ltd.) on lime basis. The insulation system was applied on fragment of brick wall 300 mm thick. The arrangement of the studied structure is given in Figure 2.



A lime plaster SM - T VJ, Mamutherm, 10 mm
B brick wall 300 mm
C retarder - cement glue SM - T FLT, Mamutherm, 3 - 10 mm
D mineral wool Dachrock, Rockwool, 100 mm
E lime plaster SM - T VJ, Mamutherm, 5 mm reinforcing plastic net

Figure 2 Arrangement of the studied structure.

Since we did not apply the rain simulation within the experiment, the brick wall was before beginning of the climatic loading partially wetted by water. In this way, the building-site conditions of real brick wall were roughly simulated.

The tested structure was exposed to the difference climatic conditions corresponding to the typical winter period, which is the most critical part of the year from the point of view of water condensation in building structures and their hygrothermal performance. On the exterior side, climatic data corresponding to the time interval of November 1 to March 27 were simulated. As climatic data, the test reference year (TRY) for Prague was used. On the interior side, constant climatic conditions were applied which were chosen according to the standard computational values for residential houses (relative humidity 50%, temperature 21°C).

In the tested structure, continuous monitoring of liquid moisture content, relative humidity and temperature was performed. For monitoring moisture content special device from Polish company Easy Test working on TDR (Time Domain Reflectometry) principle was used. The accuracy of moisture content measurement given by producer is ± 2% in volumetric moisture range 0-100%. Details on the TDR method, measuring technology, calibration and applied two rod sensors are given e.g. in Pavlík and Černý (2006), Jiřičková (2004). For monitoring relative humidity and temperature, commercially produced combined sensors by Ahlborn were employed. The accuracy is as follows: capacity humidity sensors are applicable in the humidity range 5-98% with accuracy ± 2%, resistance thermometers have accuracy ± 0.4°C in the temperature range from -20°C to 0°C, and in the temperature range from 0°C to 70°C is the accuracy in temperature measurement ± 0,1°C.

4. Results and discussion

The measured experimental results are presented in Figs. 3-5. Figure 3 presents the temperature profiles in the investigated brick wall provided by the interior thermal insulation system. We can see that the interior surface temperatures are typically higher than 20°C. This finding clearly demonstrates the proper thermal function of the designed interior system. Since the interior surface temperature is high enough, the quality of indoor climate from the point of view of well-being of building occupants is achieved. This temperature also reduces the risk of biological pollution of indoor climate as well as of the interior surface.

Regarding the thermal loading of the brick wall, the temperatures only rarely decreased deeper under the water freezing point. This finding which reflects the relatively mild weather conditions in Middle Europe is very positive, particularly regarding the durability of exterior surface layers.

The relative humidity profiles are given in Figure 4. We can observe increased relative humidity values in the brick masonry what corresponds with the measured liquid moisture profiles. The measured content of liquid moisture was typically between 3 and 5% (see Figure 5). Since the accuracy of TDR moisture sensors is ±

2%, we can conclude that the liquid moisture was evenly distributed. This moisture is a result of partial wetting of the studied structure within the specimen preparation which within the experiment was not evaporated because of applied winter climatic conditions. Nevertheless we can estimate, the liquid water will be within the summer period evaporated what was proved by the results of computational simulations.

In the whole thickness of thermal insulation board Dachrock, the relative humidity values were lower than maximal hygroscopic moisture content. It has proved that the application of designed insulation system does not cause water vapor condensation in insulation layer or on its surface. Hence, the thermal insulation properties are preserved and the harmful effect of mould growing is eliminated.

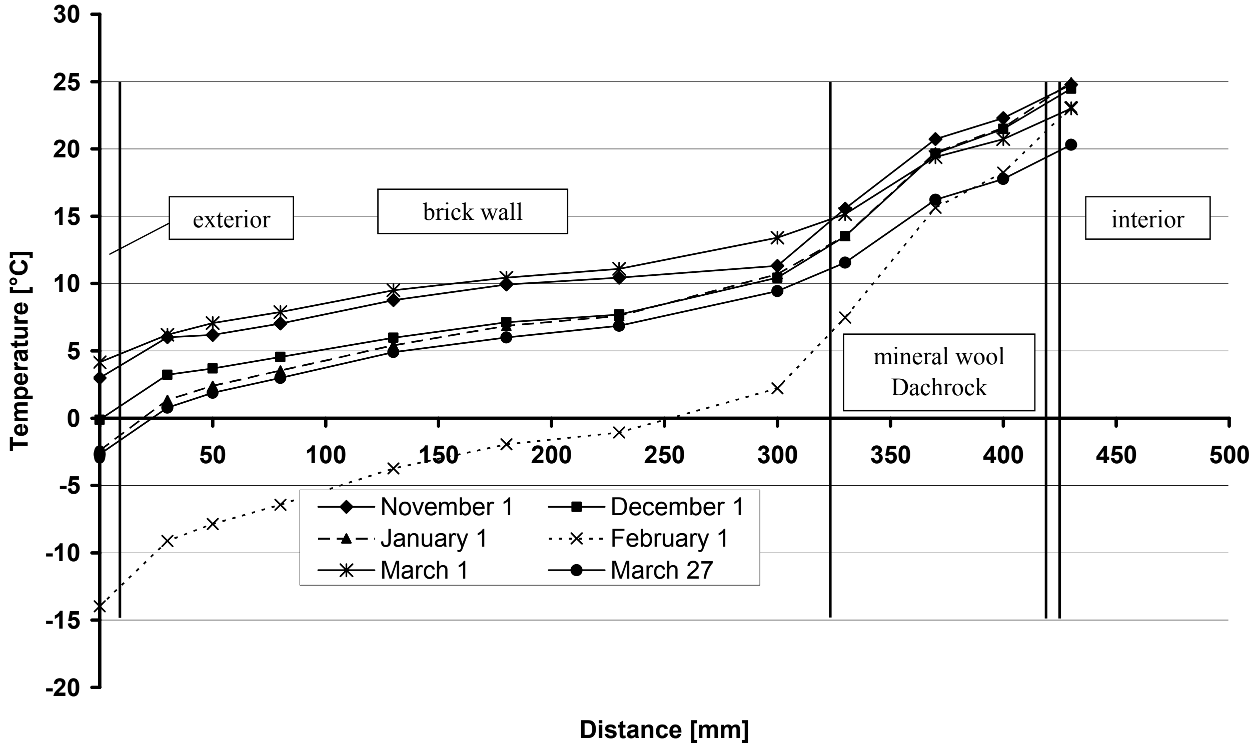


Figure 3 Temperature profiles in the insulated brick wall.

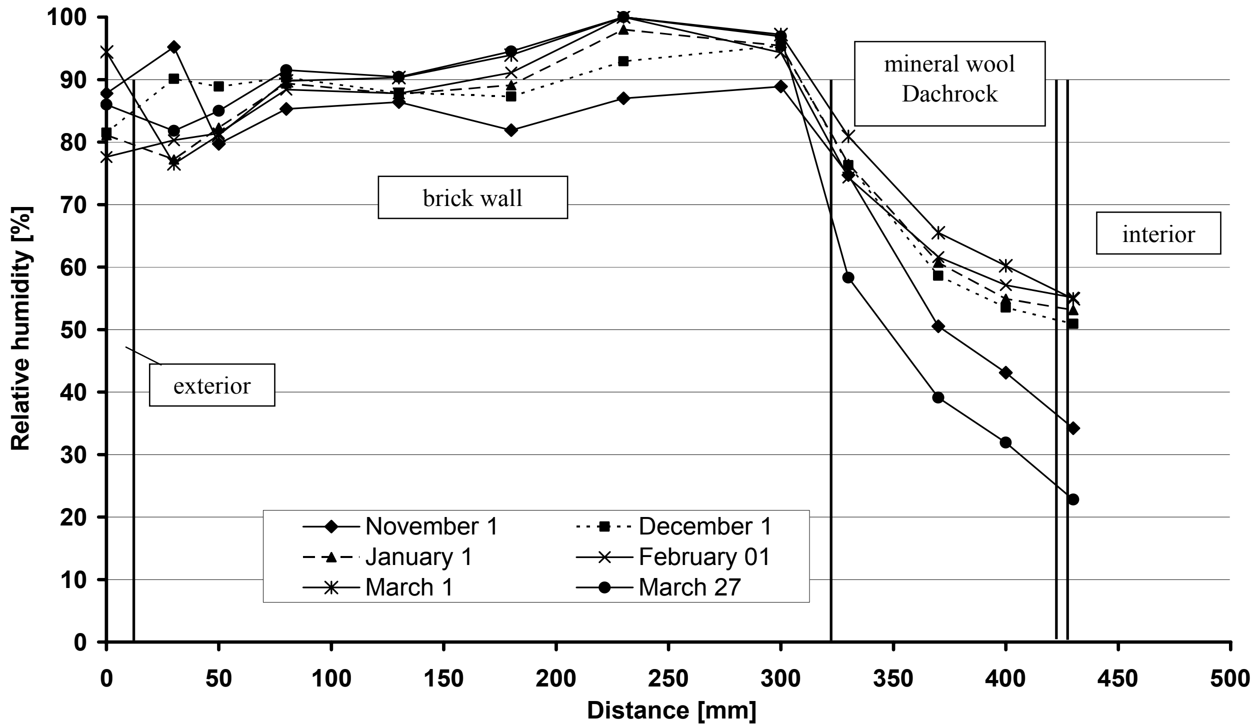


Figure 4 Relative humidity profiles in the insulated brick wall.

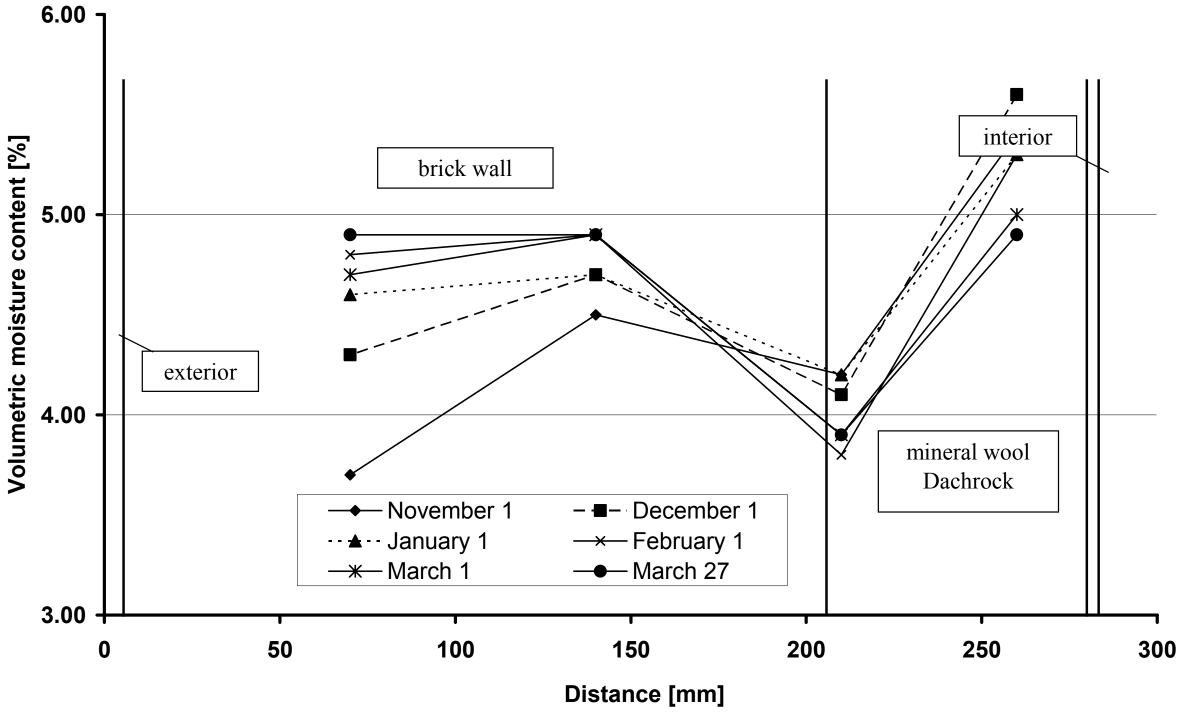


Figure 5 Liquid moisture content profiles in the insulated brick wall.

5. Conclusions

The experiment presented in this paper has proved the usability of semi-scale experiments in the process of sustainable design of building structures and components. It can be used not only for design of new materials and structures but it can find application also in verification of their functionality and behavior under almost real climatic conditions. The main benefits of the developed testing methods are as follows: lower expenses of experiments in comparison with full-scale test house testing, use of advanced laboratory meters for monitoring of field variables, possibility of controlled climatic loading.

Concerning the verification of newly developed interior thermal insulation system, the obtained results represent the valuable information that will help to the application of designed insulation system in building practice. Very positive finding is also fact that the measured relative humidity, liquid moisture and temperature fields are in a good agreement with the computational simulation of the studied problem. Hence, the semi-scale experiments can be also applied for calibration and validation tests of computer codes solving the problem of coupled moisture and heat transport in porous materials.

Acknowledgement

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ENERGY EFFICIENT DESIGN & PLANNING OF SMALL SETTLEMENTS AS A SUSTAINABLE BUILDING APPROACH

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Keywords: planning patterns, orientation, simulation, shadow pattern, density of population

Summary

In the present day context energy play an important role in every pursuit of life. In a country like India, where economy is rising at a rate of more than 8 percent per annum, the need of energy is also increasing manifold, particularly with the coming up of MNCs & Real Estate developments. Design & planning of buildings and settlements can play a major role to curtail the energy demand and thus can help in achieving the global objective of sustainable development.

In India the majority of the areas come under composite climate and our buildings are often designed without taking enough consideration of climate. If we can place our built areas under shade for majority of times by virtue of design & planning, we can save lot on energy bills. From the studies, it is shown that 40% of energy needs can be reduced by only designing the buildings with proper specifications & placing them in a best orientation. In a study for Delhi region, the orientation of buildings if kept with longer axis as East –West i.e. major façade facing North & South and shorter facades on East & West, the building performs best for thermal comport. If it is tilted 15 to 20 degree north then it also gets the advantage of air movements. Further having higher building blocks on south side rows, we get the advantage of the shadow on north side blocks by the movement of sun from east to west. This pattern of planning give the maximum advantage of energy saving. In the paper, the design & planning approach to save energy for a small settlement for a 5000 population has been discussed as a strategy for sustainable building development.

1. Introduction

Energy in all forms is vital to sustain life. In housing it is used for cooking, heating, cooling, illumination and to run various gadgets. In the light of large demand of energy over the last 10-15 years and its short supply,, building industry in India has become quite energy conscious. Further the program on Global security and sustainability has given priority to the areas like conservation and sustainable development. Here we are more concern with conservation of energy in built environments. It is also necessary for sustainable development as the sources of non-renewable energy are limited and getting depleted day by day. The alternative sources of energy could be biogas, biomass, solar energy, wind energy, hydropower etc. For sustainability we have to depend on renewable sources of energy which are available in abundance and non-depletable in nature.

Now a days every country is very much conscious about the use of energy. As per a study in USA the energy consumption in buildings accounts for 36% of country's energy supply and energy use is growing at a rate of 3.3% a year. Heating and cooling equipment consumes 42% of all building energy use at a cost of $ 81 billion. A passive solar design can save as much as 50% on heating bills for only 1% more construction cost. These facts illustrate the capability and importance of passive solar building design with respect to conservation of both energy and money. Apart from general lack of norms and regulations, one reason that buildings are poorly adapted to the climate is lack of knowledge among building designers, whether an architect or engineer or town planner.

In the field of passive solar architecture related to individual buildings many research works have been done. Some studies have been carried out on tree shade effects on residential energy use at California using different type of trees (e.g. shape, size) and location around buildings. Tree shade reduces summer air conditioning demand and increases winter heating load by intercepting solar energy that would otherwise heat the shade area. Similarly studies are available on shading of windows, their designs etc. In all studies the effects have been limited to single building only. In this paper the impact of energy conservation has been studied at a settlement level with different planning patterns through design of buildings, their orientation and distances among the buildings of different heights for shading effect.

In India two solar houses have been constructed in Ladakh. A NGO, Ladakh Environment and Health Organization (LEHO) has taken the first step at 3500 m above sea level for designing a building using passive system of heating. They introduced solar buildings in Ladakh with the help of a France based NGO, Geres. Similarly few buildings with passive features have been constructed in the plains of North India at Delhi & Gurgaon etc. to save the energy loads. The seminars / conferences are being held by various concerned departments to reduce the transmission / distribution losses and to use low energy saving devices & equipments like fuse less systems etc. In this background a project was under taken to achieve energy conservation through design and planning of small settlement.

2. Methodology

The methodology adopted involves to finding out the physical requirements for a settlement of 5000 population for which energy requirements are to be analyzed. This includes the various types of residences, education facilities, recreation facilities and shopping facilities. Then area of the site is to be find out considering an assumed density of population.

To calculate the energy requirements of a settlement the number of residences, their design, specifications, orientation and design of other buildings like shopping, schools etc. are all important. The requirements of different buildings adopted in the study for a population of 5000 persons are :

2.1 Requirements

1. No of houses	-	1000 @ 5 persons / family
2. EWS[i]/LIG[ii] houses	-	600
3. MIG[iii] houses	-	230
4. HIG[iv] houses	-	170
5. Primary school	-	1
6. Nursery school	-	2
7. Convenient shops	-	2

i EWS Economically weaker sections
ii LIG Low income group
iii MIG Middle income group
iv HIG Higher income group

The number of low category houses has been taken as 60 per cent of the total houses as majority of the population in India belongs to this section of population and as a policy government also want that in any urban housing scheme major share of houses should be assigned to low income group people. The other building requirements are also kept as per prevailing planning norms in India. The density of population has been assumed as about 125 persons / acre or 315 persons /hectare. This comes out to about 50 houses per acre assuming 5 person per family and total requirement of land comes about 40 acres or 16 hectares approximately. Accordingly a plot of 400m x 400m has been theoretically selected for the study point of view.

2.2 Architectural Design

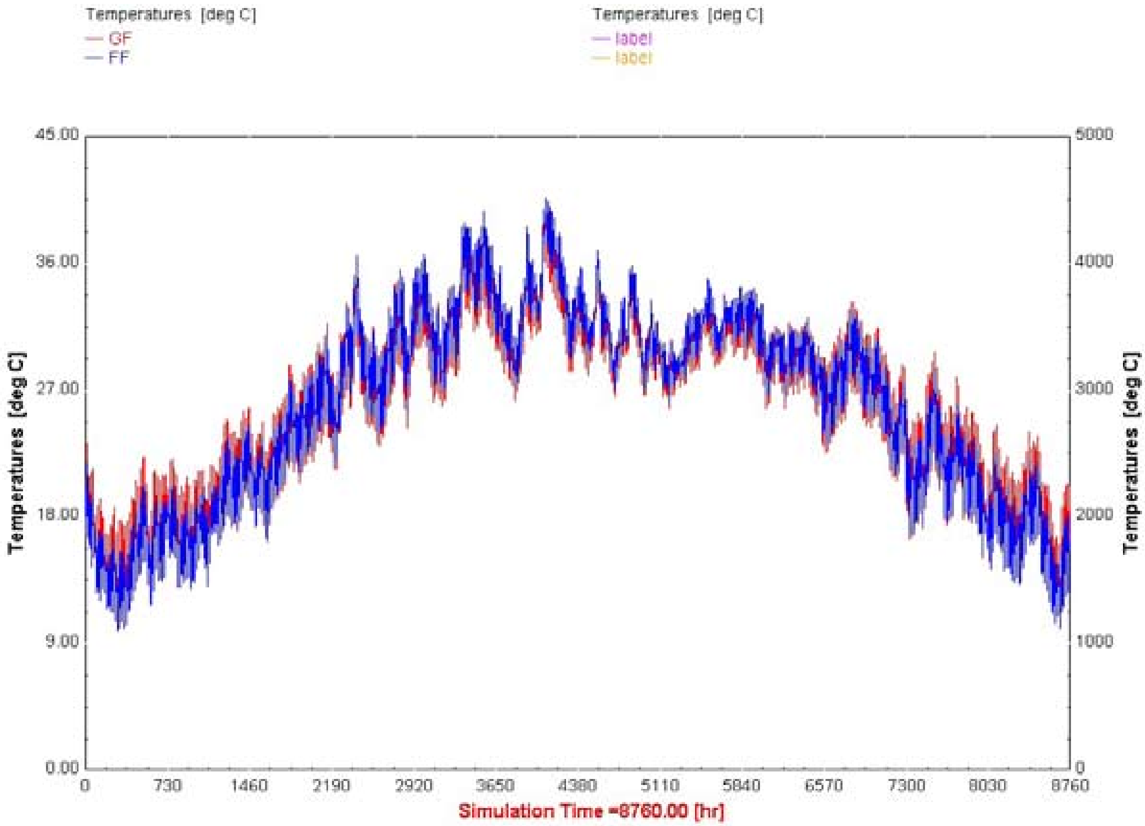
To calculate the energy load of a building their architectural design and specifications are important consideration so the designs for various categories of houses, a primary school, a nursery school and a shopping center have been developed. The areas for LIG, MIG and HIG houses have been taken as 36.00 sq.m., 72.0 sq.m. and 108.0 sq.m. respectively. The areas for primary and nursery schools are 421.65 sq.m. and 90.74 sq.m. respectively. Shopping complex with 20 Nos. of shops has been designed with area of one shop as 12.00 sq.m.

2.3 General Specifications

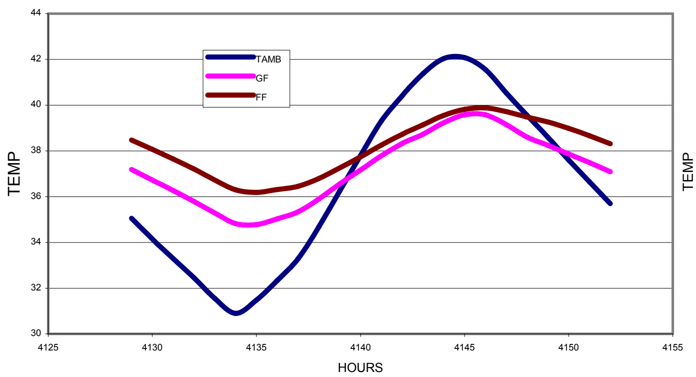
1. Brick work in cement mortar for 9” (23cm) thick brick walls and 4½ “(11.5cm) thick brick with ½ inch (10mm) thick cement plaster on both sides.
2. 4” (10 cm) RCC roof with 10cm thick mud fuska including insulating layer of tar felt, & 2” brick tiling.
3. 4 cm thick cement concrete flooring on 7.5 cm lean concrete in two room set.
4. 5 cm thick cement concrete flooring including 1.5 cm thick moisac finish and 7.5 cm thick lean concrete.
5. Windows with plane glass of 3 mm thickness with wooden frame.

2.4 Energy Considerations

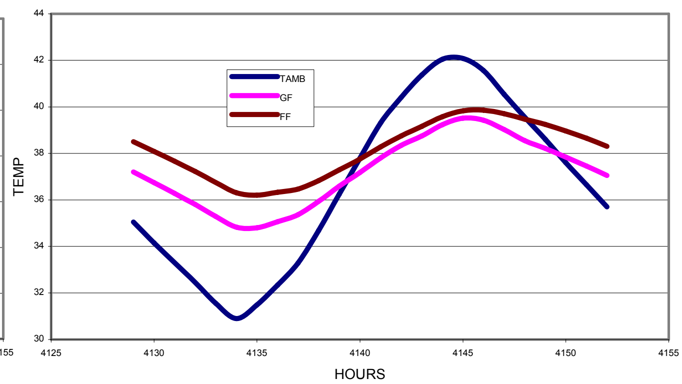
For the above designed buildings energy flow have been calculated for 22nd June temperatures putting these buildings in eight cardinal directions and having 2 and 4 Storey developments by using TRNSYS software. The energy simulation curves have been prepared for Delhi Region. Annual simulation curve and simulation curves for 22nd June for LIG two storey house buildings have been shown for four cardinal directions i.e south facing, south west facing, west facing and north west facing in graphs 1 and 2. During temperature simulation process shading factor on the building surface is also required. For this purpose, software/program has been developed using FORTRAN programming language to calculate the shadows. It calculates the height of shadows on the opposite buildings placed at a given distance at different orientations of the building for different altitudes and azimuth of the sun at different hours of the day.



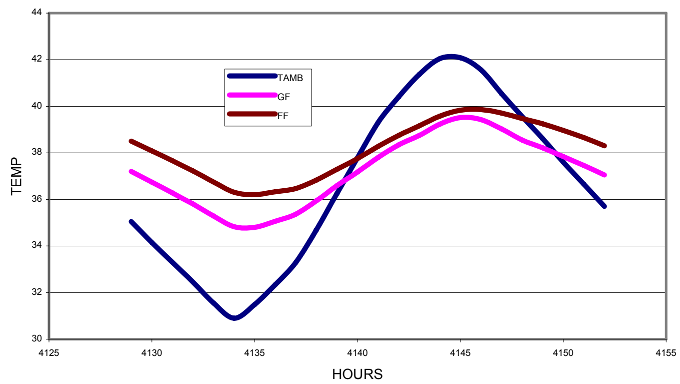
Graph 1 Annual Simulation Curve LIG 2 storey house.



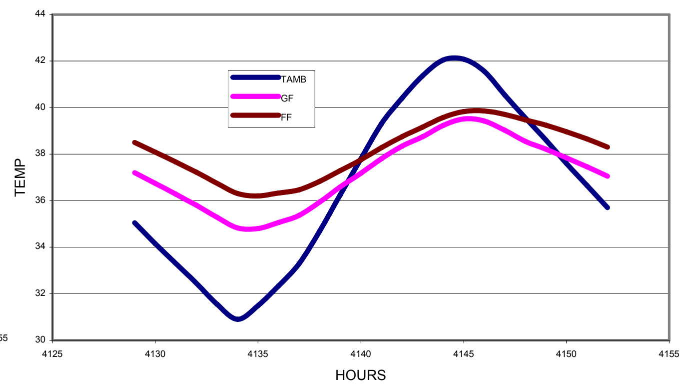
South Facing



South - West Facing



West Facing



North - West Facing

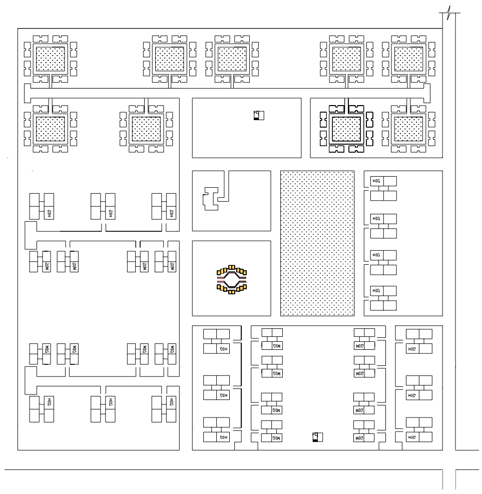
Graph 2 Simulation curve for LIG 2 storey building for 22nd June.

3. Layout Planning

Three layouts have been developed, two with normal / traditional type of clusters & road patterns having 4 storeyed walkup apartments for LIG group and 2-4 storey apartments for MIG & HIG group. Here the buildings have been placed in all the directions as depicted in FIG. 1 & 2.

The other layout has been developed considering orientation of all the buildings in E-W direction as longer side (facing north & south) because it consumes minimum energy. It is also depicted from the cooling load tables 1, 2 & 3 and corresponding histograms fig. 3, 4, 5 for LIG, MIG & HIG houses.

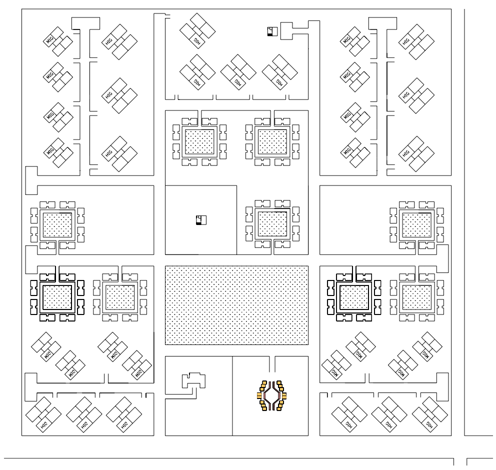
Further, while placing the blocks of buildings the height of blocks on the northern side rows have been reduced while of the blocks on the southern side has been increased to get the maximum advantage of the sun movement. It is reflected in the different design of residential clusters. Then these clusters have been grouped in a plot area of 400 m x 400m i.e. 16.00 hectare plot giving a density of 315 person / hectare or 126 persons / acre approximately. The development has been envisaged from 2 to 12 storeyed. The plantation of trees has been proposed on western side of clusters with a continuous belt of trees all round the boundary line of the site. The layout has been enclosed as Fig. 6.



Legend
- **Area of the plot**
  16 hactare/40 Acres
- **LIG Houses = 576**
- **MIG Houses= 256**
- **HIG Houses = 168**
  Total = 1000
- **Primary School – 1**
- **Nursery School – 2**
- **Shops – 16**
- **Neighbourhood Park – 1**
- **Tot lots – At cluster level**
- **Density 25 DUs/Acre**
- **Type of Development 2 to 4 Stories**

Figure 1 Settlement layout plan for a neighborhood of 5,000 population, Alternative – I

The energy conservation in a settlement is a function of so many things because a settlement comprises of houses, community buildings and services. As the study was specifically to conserve energy through planning patterns and land uses, it is important to understand the concept of planning pattern and land uses taken in the study.



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- **Shops – 16**
- **Neighbourhood Park – 1**
- **Tot lots – At cluster level**
- **Density 25 DUs/Acre**
- **Type of Development 2 to 4 Stories**

Figure 2 Settlement layout plan for a neighborhood of 5,000 population, Alternative – II

Table 1 Cooling Loads (kw) for LIG Houses in Different Directions

Direction	2 Storey Development	4 Storey Development
N	3.32	4.846
NE	3.795	5.826
E	3.686	5.618
SE	3.73	5.7
S	3.258	4.757
SW	3.811	5.858
W	3.687	5.62
NW	3.772	5.785

Table 2 Cooling Loads (kw) for MIG Houses in Different Directions

Direction	2 Storey Development	4 Storey Development
N	5.751	7.759
NE	6.282	8.845
E	6.088	8.434
SE	6.238	8.753
S	5.719	7.694
SW	6.302	8.884
W	6.089	8.437
NW	6.209	8.855

Table 3 Cooling Loads (kw) for HIG Houses in Different Directions

Direction	2 Storey Development	4 Storey Development
N	8.301	11.054
NE	8.919	12.305
E	8.598	11.652
SE	8.874	12.217
S	8.263	10.978
SW	8.933	12.342
W	8.6	11.656
NW	8.916	12.32

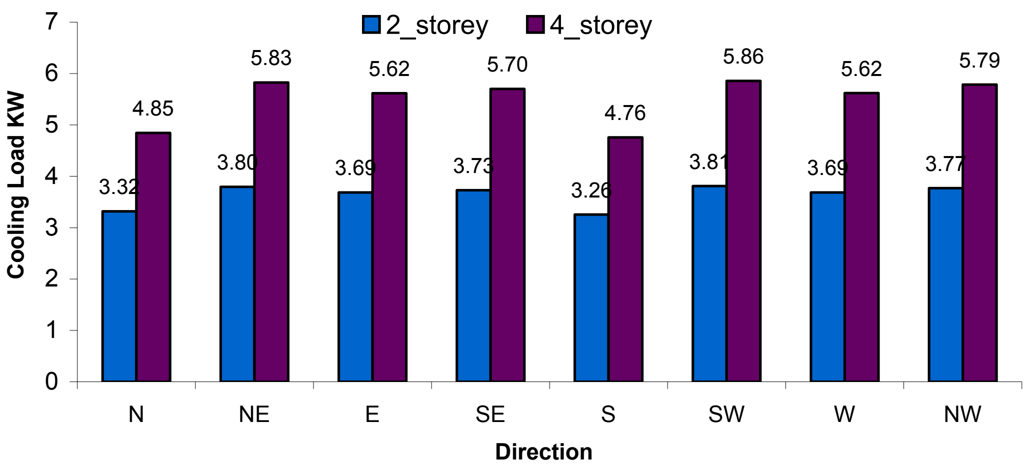

Figure 3 Histogram for cooling load (kw) for LIG houses

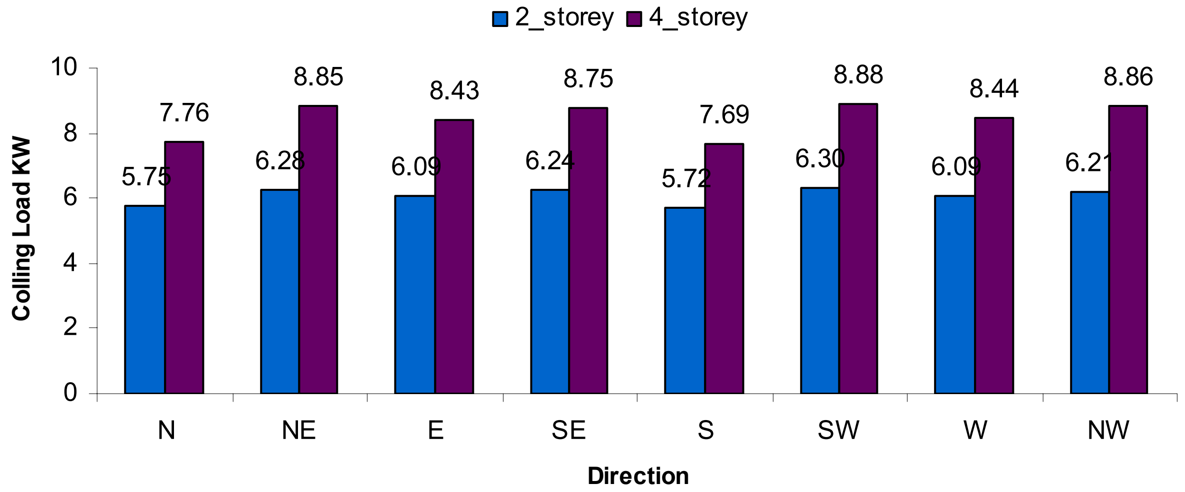

Figure 4 Histogram for cooling load(kw) for MIG houses.

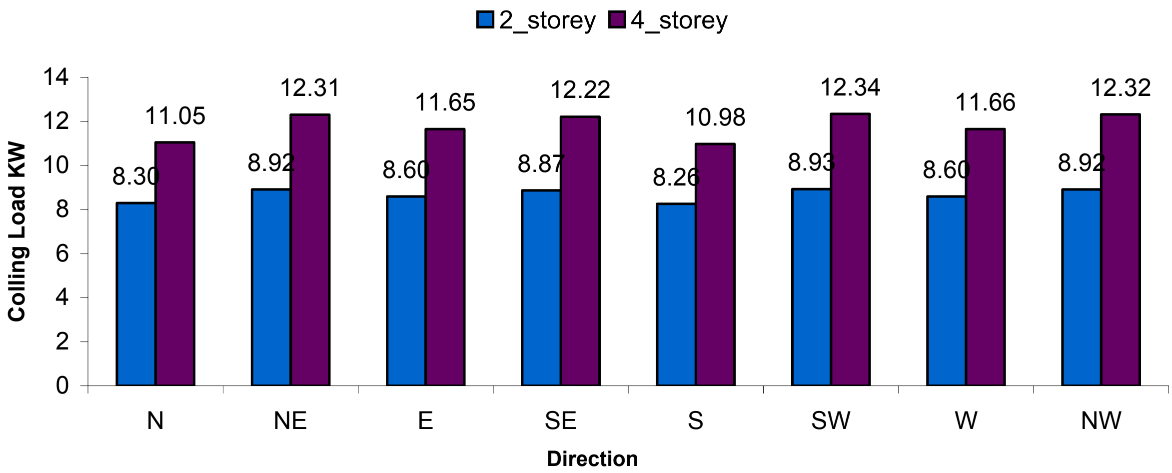

Figure 5 Histogram for cooling load(kw) for HIG houses.

4. Planning Patterns & Land Uses

Planning pattern at city level may be taken as an out come of major road patterns i.e. linear, grid, radial or a combination of these. At a small settlement level-planning pattern in general is the disposition of various buildings, in a locality in different fashion. This is the type of development in terms of height, number of storeyes and orientation of building blocks. The height or number of storeyes play an important role in conserving energy because in a multi-storeyed building more number of floors are in shade. The top floor can be provided with proper insulation. Placing the buildings with respect to each other in a space in terms of distances and directions is also very important because of various patterns of shadows displayed on the opposite or side buildings. Orientation also plays a role as north & south surfaces get negligible quantity of sunrays.

The land use is a direct result of type of development or planning pattern. As we go higher we consume less space on ground and we reduces the land area for a particular land use like residential and get more open area as a more green/open land use for recreational activities i.e. parks, playgrounds, landscaping etc. for a better environment.

The distances and direction becomes significance because in a particular direction the building consumes less energy as compared to other direction. Further the distance & direction changes the shadow pattern of the blocks and the advantage of the shadows of higher buildings can be taken on the other buildings if higher blocks are placed in a fashion giving maximum shadow on the other blocks.

1. Shops
2. Primary school
3. Nursery school
4. LIG quarters
5. MIG quarters
6. HIG quarters

Figure 6 Layout plan.

5. Discussions and Findings

The results of the studies through temperature simulation curves drawn using TRNSYS for 22nd June indicates that orientation having longer sides on E-W direction is the best for energy considerations. So the orientation of the blocks of a building should be with E-W as longer side and facing north or south. The results for cooling load calculations for a LIG cluster planned in a traditional fashion of four storeyed development having 64 houses required a load of 40.78 KW while a cluster of similar houses planned in the proposed fashion requires a cooling load of 30.05 KW only i.e. a saving of 25% of cooling load. In these calculations the impact of shading has not been considered, if it is also taken in to account a saving of 35-40% of cooling load can be achieved easily. Shadow pattern studies show that maximum shadow on the buildings can be obtained on east & west surfaces placed against each other. This indicates that the surfaces of the building facing east and west should be put closer to each other to get the maximum advantage of the shadow. On north and south faces of the buildings there is hardly any shadow of opposite buildings. The shadows on south east & south west direction of blocks are generally thrown from the side blocks placed at an angular position on south side.

Further the higher blocks of buildings / residences can be put on southern side of the other buildings so that advantage of the shadow of these blocks from movement of sun from east to west can be taken on the southern side by the blocks situated at angular position i.e. blocks which are on the E / W sides of the immediate north side blocks. For example, if we take a cluster of houses (figure.7) as described above having six blocks in two rows A & B. Blocks of row B on south side are higher then blocks of row A on north.

The block No.5 is situated on southern side of blocks No. 1&3 of row A at angular position and both the blocks will get the advantage of shadow of block No. 5 on south. Similarly, the blocks No. 2&4 on north side would get the advantage of the shadow of south side block No. 6 which is higher and placed at an angular position. Now in this cluster of 6 blocks practically every critical side having undesirable heat gains is protected except the west and south-west sides of blocks No. 1&5 which can be taken care of by providing suitable landscaping / planting of trees.

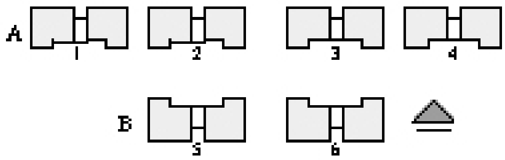

Figure 7 Block layout.

6. Conclusions

India is at a threshold of overall development including its economic and physical development. Physical developments include the design and planning of buildings and settlements where lot of energy is required as maintenance and in the process of material development. By proper planning and design energy of the order of 40 percent or more can be saved easily using proper specifications and orienting the building blocks in suitable direction. Study for Delhi region shows that if residential blocks are placed in east –west direction with 15 to 20 degree tilt on north side, the advantage of sun and air movement taken together and providing some insulation in roof finish can save the energy bill upto 35- 40 percent. This saving can further be increased if southern side blocks in the layout are taken of more height than northern side blocks which may provide shadow on northern side low height blocks with movement of sun from east to west. Thus we can contribute in achieving the broad objective of global sustainability by way of planning and design of buildings.

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APPLICATION OF ALTERNATIVE SILICATE BINDERS IN THE PRODUCTION OF HIGH PERFORMANCE MATERIALS BENEFICIAL TO THE ENVIRONMENT

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Keywords: high performance concrete, fly ash, metakaolin, ground granulated blast furnace slag

Summary

Complete sets of mechanical and durability properties of high-performance materials containing alternative silicate binders are not available even for very common types of these materials, at least not in the form that they could be directly used as input parameters of computer codes for durability analysis. As without a good knowledge of these properties it is impossible to perform any serious durability analysis of particular elements of building structures based on these materials, the determination of mechanical and durability properties of high-performance materials based on alternative silicate binders is a very actual problem. In this paper, compressive and bending strengths and moisture and heat transport and storage parameters of high performance concrete containing alternative silicate binders, namely metakaolin, fly ash and ground granulated blast furnace slag are measured.

1. Introduction

During production of Portland cement carbon dioxide which is one of the greenhouse gases is emitted to the atmosphere. Approximately 1 tone of CO_2 arises during the production process of 1 tone of Portland cement, about one-half of it originating from decomposition of limestone, which is the main raw material for Portland clinker, and the second half from fuel combustion necessary for cement production. Globally, in 1995 the amount of production of cement was about 1.4 billion tones. This means that the manufacture of Portland cement contributed about 1.4 billion tones of CO_2 to atmosphere (Malhotra, 1999). Therefore, with respect to a necessity to decrease the amount of carbon dioxide in atmosphere, alternative materials such as fly ash, ground granulated blast furnace slag, silica fume and metakaolin/calcined clay have a high potential to replace a part of Portland cement in concrete. Fly ash, ground granulated blast furnace slag and silica fume are waste materials. Metakaolin is produced by thermal decomposition of kaolin without production of CO_2. This supports the application of these materials or their combinations as environmental friendly cement substitutes.

High-performance materials based on silicate binders are characterized essentially by their compressive strength. Therefore, when the first high-performance materials (HPM) appeared, they were merely considered as high-strength materials. However, within the last several decades, this basic view has changed substantially. In the new HPM, some other properties such as water, heat and salt transport and storage parameters, freeze-thaw resistance or abrasion resistance began to gain higher importance and in some cases they even became decisive for the solutions made in the design process.

Despite the gradual shift of using alternative silicate binders in the HPM design and application philosophy towards a generally recognized necessity to measure a wider scale of HPM parameters, mechanical properties still remain the far most frequent parameters investigated. We will give only a few examples of the investigations done during the last couple of years on various types of HPM containing alternative silicate binders. An extensive review on the effect of silica fume on the mechanical properties of concrete was published by Chung (2002). Qian and Li (2001) studied the relationship between stress and strain of high-performance concrete with metakaolin. Li and Ding (2003), Khatib and Hibbert (2005) analyzed the effect of metakaolin and slag on compressive strength of concrete. Badogiannis et al. (2004) studied the strength development of metakaolin concrete. Wong and Razak (2005) compared the efficiency of calcined kaolin and silica fume for strength performance of concrete.

For water and water vapor transport and storage properties of HPM containing alternative silicate binders only very few references were found in common sources within the last years. For instance, Khan (2003) determined the sorptivity of several high-performance concretes incorporating fly ash and microsilica prepared with different water/binder ratios. Khatib and Clay (2004) studied water absorption characteristics of metakaolin concrete. Razak et al. (2004) compared water sorptivity of concrete with metakaolin and silica fume. Bai et al. (2002) measured sorptivity of concretes with pulverized fuel ash and metakaolin.

In this paper, measurements of mechanical and moisture and heat transport and storage parameters of three different HPMs containing alternative silicate binders as partial replacement of Portland cement, the first with ground granulated blast furnace slag, the second with metakaolin, and the third with fly ash are presented and compared with the results obtained for reference material containing only Portland cement as binder.

2. Materials

Four different types of high performance concrete were studied. Three of them contained alternative silicate binders, namely metakaolin (BM), ground granulated blast furnace slag (BS), and fly ash (BP). The fourth was reference HPC mixture with only Portland cement as binder (BR). Table 1 presents the composition of the studied concrete mixtures.

Table 1. The composition of concrete mixtures [kgm^{-3}]

Component	BR	BM	BS	BP
CEM I 42.5 Mokrá	484	440	440	440
aggregates 0-4 mm	812	812	812	812
aggregates 4-8 mm	910	910	910	910
plasticizer Mapei Dynamon SX	5.3	5.3	5.3	5.3
metakaolin MEFISTO	-	44	-	-
ground granulated blast furnace slag Štramberk	-	-	44	-
fly ash	-	-	-	44
water	188	188	188	188

3. Experimental methods

3.1 Basic properties

Among the basic properties, the bulk density, matrix density and open porosity were measured. Each sample was dried in a drier to remove majority of the physically bound water. After that the samples were placed into the desiccator with deaired water. During three hours air was evacuated with vacuum pump from the desiccator. The specimen was then kept under water not less than 24 hours.

From the mass of the dry sample m_d, the mass of water saturated sample m_w, and the mass of the immersed water saturated sample m_a (the so called Archimedes weight), the volume V of the sample was determined from the equation

$$V = \frac{m_w - m_a}{\rho_l}, \qquad (1)$$

where ρ_l is the density of water.

The open porosity ψ_0, the bulk density ρ and the matrix density ρ_{mat} were then calculated according to the equations

$$\psi_0 = \frac{m_w - m_d}{V\rho_l} \qquad (2)$$

$$\rho = \frac{m_d}{V} \qquad (3)$$

$$\rho_{mat} = \frac{m_s}{V(1-\Psi_0)} \qquad (4)$$

The samples for determination of basic properties were cut from the standard prisms; their sizes were 40 x 40 x 20 mm in the case of open porosity and matrix density, and 40 x 40 x 80 mm in the case of bulk density determination.

3.2 Mechanical properties

The measurement of compressive strength and bending strength was done using the hydraulic testing device VEB WPM Leipzig 3000 kN. The apparatus consists of a stiff loading frame having the capacity of 3000 kN. The 100 x 100 x 400 mm samples were used in the experiments. A constant strain rate of 0.1 – 0.2 MPa/s was imposed on the specimens.

3.3 Water and water vapor transport properties

Two versions of the common cup method were employed in the measurements of the water vapor diffusion coefficient (Roels et al. 2004). In the first one the sealed cup containing silica gel (5 % relative humidity) was placed in a controlled climatic chamber with 97 % relative humidity and weighed periodically. In the second one the cup containing the saturated solution of K_2SO_4 (97 % relative humidity) was placed in the 25 % relative humidity environment. The measurements were done at 20°C in a period of two weeks. The steady state values of mass gain or loss were determined by linear regression for the last five readings.

The water vapor diffusion coefficient D [m^2s^{-1}] defined as

$$j = -D \; grad\rho_m , \tag{5}$$

where j is the water vapor flux [$kgm^{-2}s^{-1}$] and ρ_m the partial density of water vapor in the porous body [kgm^{-3}], was calculated from the measured data using the equation of state of an ideal gas according to the equation

$$D = \frac{\Delta m \cdot d \cdot R \cdot T}{S \cdot \tau \cdot M \cdot \Delta p_p} , \tag{6}$$

where Δm the amount of water vapor diffused through the sample [kg], d the sample thickness [m], S the specimen surface [m^2], τ the period of time corresponding to the transport of mass of water vapor Δm [s], Δp_p the difference between partial water vapor pressure in the air under and above specific specimen surface [Pa], R the universal gas constant, M the molar mass of water, T the absolute temperature [K].

On the basis of the diffusion coefficient D, the water vapor diffusion resistance factor μ (which relates the diffusion in the air to the diffusion in the porous system) was determined:

$$\mu = \frac{D_a}{D} , \tag{7}$$

where D_a is the diffusion coefficient of water vapor in the air.

The water sorptivity was measured using a common experimental setup. The specimen was water and vapor-proof insulated on four lateral sides and the face side was immersed 1-2 mm in the water, constant water level in tank was achieved by a Mariotte bottle with two capillary tubes. One of them, inside diameter 2 mm, was ducked under the water level, second one, inside diameter 5 mm, was above water level. The automatic balance allowed recording the increase of mass. The water absorption coefficient *A* [$kgm^{-2}s^{-1/2}$] was then calculated using the formula

$$i = A \cdot \sqrt{t} , \tag{8}$$

where *i* is the cumulative water absorption [kg/m^2], *t* is the time from the beginning of the suction experiment. The water absorption coefficient was then employed for the calculation of the apparent moisture diffusivity κ [m^2s^{-1}] which is defined as

$$j_w = -\kappa \; grad\rho_v , \tag{9}$$

where j_w is the liquid water flux [$kgm^{-2}s^{-1}$] and ρ_v the partial density of water in the porous body [kgm^{-3}], in the form (Kumaran, 1994)

$$\kappa \approx \left(\frac{A}{w_c - w_0} \right)^2, \tag{10}$$

where w_c is the saturated moisture content [kgm^{-3}] and w_0 the initial moisture content [kgm^{-3}].

The samples for determination of water and water vapor transport properties were as follows: the specimen size was 50 x 50 x 20 mm, and samples were on four lateral sides water- and water vapor-proof insulated with epoxy resin to ensure the one-dimensional transport.

3.3 Thermal properties

Thermal conductivity and specific heat capacity were measured using the commercial device ISOMET 2104 (Applied Precision, Ltd.). ISOMET 2104 is equipped with various types of optional probes, needle probes are for porous, fibrous or soft materials, and surface probes are suitable for hard materials. The measurement is based on analysis of the temperature response of the analyzed material to heat flow impulses. The heat flow is induced by electrical heating using a resistor heater having a direct thermal contact with the surface of the sample. In the experimental work 3 cubic samples 70 x 70 x 70 mm were used.

4. Experimental results and discussion

4.1 Basic properties

The basic properties of studied HPCs are shown in Table 2. The highest value of porosity achieved the material BM containing metakaolin and the lowest value the material BS with slag admixture. The difference between these two materials was about 34 %. The bulk densities of all materials differed only up to about 2% and matrix densities up to 5 %.

Table 2 Basic physical properties of the studied concrete mixtures

Material	Bulk density [kg m^{-3}]	Matrix density [kg m^{-3}]	Open porosity [% m^3 m^{-3}]
BM	2366	2691	13.0
BS	2334	2602	9.7
BP	2356	2717	12.5
BR	2380	2715	12.3

4.2 Mechanical properties

Table 3 shows the compressive and bending strength of the studied HPCs after 28 days. The results were very similar for all materials, only the material BP with fly ash achieved about 8 % lower values. The other differences were within the error range of the experimental method.

Table 3 Mechanical properties of the studied concrete mixtures

Material	Compressive strength [MPa]	Bending strength [MPa]
BM	86.95	11.93
BS	85.30	11.10
BP	80.52	10.64
BR	87.31	11.63

4.3 Water and water vapor transport properties

The results of measurements of water and water vapor transport parameters of the studied hardened cement mixtures are presented in Tables 4 and 5.

The measured data revealed basic information that the values of water vapor diffusion coefficient corresponding to the lower values of relative humidity (5/25 %) were always lower than those for higher relative humidity values (97/25 %). This is in accordance with the previous measurements on many other materials including concrete (Kumaran 1996). The main reason for this finding is coupling of water vapor transport with liquid water transport in a material with higher relative humidity where the capillary condensation takes place in a much higher extent than in the range of lower relative humidity (Černý and Rovnaníková 2002).

Comparing the data measured for the four studied HPCs, we can see that the values of water vapor diffusion coefficient of BM and BP were in the both ranges of higher and lower relative humidity about 2-3 times lower than for BS and BR. This does not agree very well with the open porosity data in Table 2; the material BS with the lowest porosity achieved the second highest water vapor diffusion coefficient. However, the reason for this discrepancy cannot be explained with the data available at the moment. The pore distribution should be measured, to get a better insight into the problem.

Table 4 Water vapor transport properties of the studied concrete mixtures

Material	97/25 %		5/25 %	
	Water vapor diffusion coefficient [m^2s^{-1}]	Water vapor diffusion resistance factor [s]	Water vapor diffusion coefficient [m^2s^{-1}]	Water vapor diffusion resistance factor [-]
BM	1.10E-06	21.0	7.09E-07	32.4
BS	2.61E-06	8.99	1.31E-06	17.7
BP	1.34E-06	17.2	5.23E-07	44.6
BR	3.63E-06	6.60	1.50E-06	15.8

The effect of alternative silicate binders on the liquid moisture transport parameters was pronounced for materials with ground granulated blast furnace slag and metakaolin. The water sorptivity values of BM and BS were about 30-40% lower than for BR. On the other hand, water sorptivity of the material with fly ash achieved nearly the same value as the basic mixture BR. Here the results were in better agreement with the open porosity data from Table 2 than for water vapor transport parameters. The material with lowest open porosity achieved the lowest water sorptivity value. A more detailed discussion in this respect, once again, would require the pore distribution measurements.

Table 5 Water transport properties of the studied concrete mixtures

Material	Water absorption coefficient [kg $m^{-2}s^{-1/2}$]	Apparent moisture diffusivity [m^2s^{-1}]
BM	0.0070	4.09E-09
BS	0.0057	3.77E-09
BP	0.0105	6.49E-09
BR	0.0099	7.15E-09

4.4 Thermal properties

The data in Table 6 show that the thermal conductivity of all materials was very similar. The differences were in the whole analyzed moisture range rather low, up to 10%. The highest thermal conductivity in dry state achieved the material BS which is in a qualitative agreement with the open porosity data in Table 2.

Table 6 Thermal properties of the studied concrete mixtures

HPC	Moisture content [% kg kg^{-1}]	Thermal conductivity [$Wm^{-1}K^{-1}$]	Specific heat capacity [$Jkg^{-1}K^{-1}$]	Thermal diffusivity [$10^{-6}m^2s^{-1}$]
BM	0.00	1.565	728	0.908
BM	2.87	1.760	738	1.052
BM	4.00	1.952	753	1.092
BM	4.66	2.085	762	1.155
BP	0.00	1.550	692	0.951

BP	2.00	1.750	715	1.039
BP	2.40	1.780	717	1.053
BP	3.80	1.940	747	1.102
BS	0.00	1.632	705	1.001
BS	0.72	1.760	719	1.030
BS	3.40	1.978	787	1.142
BS	4.17	2.077	800	1.190
BR	0.00	1.486	672	1.040
BR	2.53	1.690	703	1.070
BR	3.92	1.915	742	1.157
BR	4.77	2.085	766	1.252

The specific heat capacity of BR was slightly lower than for other materials in the whole range of moisture content. However, the observed differences were within the error range of the measuring method of ±10%. The values of thermal diffusivity were once again very similar for all materials in whole the moisture range. This reflects the low differences in both thermal conductivity and specific heat capacity data of the investigated materials.

5. Conclusion

The investigations of mechanical and moisture and heat transport and storage properties of high performance concretes containing metakaolin, ground granulated blast furnace slag and fly ash as partial replacements of Portland cement in this paper revealed that these materials may become a viable alternative to the HPC containing only Portland cement as binder. The mechanical properties of the materials with metakaolin and ground granulated blast furnace slag were after 28 days of curing the same as of the reference HPC, for the material with fly ash an 8% decrease was observed. This is a very perspective result because the rate of pozzolana reaction with water is lower than the hydration reaction of cement (Černý and Rovnaníková 2002); thus it can be anticipated that the strength of the materials containing metakaolin, ground granulated blast furnace slag and fly ash in long-term view will be higher than of the reference material with Portland cement only. The water transport properties of three studied concretes with alternative silicate binders were found to meet reasonably the basic requirements necessary to achieve such a durability which is expected for HPC; concretes with metakaolin and ground granulated blast furnace slag transported liquid water significantly slower, concrete with fly ash exhibited approximately the same water absorption as the reference material. Heat transport and storage properties were for the alternative materials very similar as for the basic material with only Portland cement. Therefore, it can be concluded that the use of alternative silicate binders as partial replacement of Portland cement can be considered as a perspective way for the production of high performance materials beneficial to the environment.

Acknowledgement

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SUSTAINABILITY IN ROOF REHABILITATION

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Keywords: roof, rehabilitation, sustainability, mansard, green-roofs, BIPV

Summary

Sustainability and energetic performance of the buildings may be accomplished in more than one way; the process of refurbishment is a good opportunity for it. The walls, the windows, the roofs, the floor, each of them can be remodeled in order to ensure better comfort standards and to preserve energy in the same time.

In many situations the roof is subject to severe interventions, from the re-evaluation of the use of the space beneath the pitched roof (from a simple attic to dwelling) to drastic changes of the volumetry of the buildings (by creating new penthouses), in the case of the low sloped roofs, that deal ultimately with the functionality and aestetics of the building.

This paper focuses on some of the types of interventions for roof rehabilitation, carried out in Romania, taking into consideration cultural, environmental, technical and functional implications that they have on the built space or on the entire building.

Beginning with a brief presentation of the number and the state of the dwellings in Romania, the most current types of interventions on existing buildings are listed, according to what is expected to be achieved in terms of performances, after carrying out the rehabilitation work.

Abstract

The higher need of space in the urban areas led to the identification of buildings that can be refurbished, remodeled, even heightened, in order to accommodate people into the heart of the city.

The stock of existing dwellings in Romania is very important. Over 8 million dwellings. Most of them are located in blocks of flats (over 83,799 blocks). 52.5% of the dwellings are built in urban areas. Among them 15.3% were built before 1944, about 76% between 1944 and 1990, and the remaining of 8.7% after 1990 [1].

The existing stock of buildings in the cities – dwellings as well as public institutions - is subject of complicated activities of refurbishment and conversion that aim to accomplish higher comfort, efficient use of the energy resources as well as appropriate functionality of the existing space. In many countries the preoccupation to decrease the urban pollution and the urban heat island effect, to preserve and improve the environment by constructive means and to use new forms of energy has led also to the development of appropriate roof structures. Nowadays, although there are Romanian investors – home owners or institution managers – who are open to the use of non-conventional energy systems, and environmental preserving systems, we are still very much at the beginning with the implementation of the new technologies for producing green energy.

In Romania building consolidations, general repairs or refurbishment are frequent. In fact, the need of re-building after the major earthquake of 1977 (when 35.000 dwellings were destroyed, many of them in mass buildings), the aim to ensure dwellings for the population in the '80s, as well as the building activity of the past 20 years (changes of the political and economical conditions, that led to higher comfort exigencies and to the migration from collective dwellings to individual houses) shows that the building industry is very much active.

Taking advantage of the need of structural interventions over the existing buildings as well as of general repairing, the work of intervention aims not only to improve the overall hygro-thermal behavior, but also to ensure extra space for the users of the buildings.

The evaluation and the decisions for the most adequate means of overall interventions for rehabilitation are often made by bringing together specialists from different fields of activities: architects, engineers (structure, HVAC), urban designers, historians (in the case of patrimonial buildings), geologists and other experts (chemists, physicists, environmental specialists etc).

1. Types of roofs – types of interventions

The roof can be defined as a building component that fulfills the same functions as any other part of the building envelope. The traditional function of the roof is to protect the upper part of the building against weathering.

Roofs can be characterized from many points of view; in the following lines we present some possible classifications:

- by volumetry (or geometry): pitched roofs and low sloped roofs;

- by the features of the roof covering elements: continuous – watertight membranes or discontinuous – different types of shingles and tiles; obviously, the type of material dictates the roof structure and the geometric conformation of the roof;

- by the type of the materials that fulfill the protection (roof covering): “traditional” natural materials, like earth, straw, reed, wood, ceramics or metal shingles and “new” products, like all the waterproof membranes, different types of cement-based shingles, glass, PVC, metallic sheets, composite panels etc

- by the type and material of the structure of the attic, that supports roofing: wood, metal, concrete

- by the type of space that results beneath the roof (in the attic): technical or functional

- by the way the roof responds to other requests of the building envelope: hygro-thermal protection, acoustic protection, fire and wind protection, natural lighting, natural ventilation

In recent times, the demand to save the natural (and sometimes also the built) environment as well as the higher need to discover and use alternative forms of energy led to a new request that can be formulated for the roof as well as for the façade: to be an environment preserver or/and an energy generator.
The main types of approaches that can be emphasized, while deciding about the complexity of an intervention over an existing building, are presented in Table 1. Each of the actions has implications over the roof component. The structural interventions on the entire building are not to be discussed here; they may be or may not be applicable and therefore they are not mentioned in the table.

Table 1 Principles regarding the aims and means for intervention on existing buildings

	Aim	Means of interventions	Type of building on which it (generally) applies
I	Preservation of the original features of the building: volumetry, internal horizontal and vertical partitions, materials and technologies	replacement of the original building components with identical ones	• historic monument • architecture monument • traditional buildings • buildings for tourism, integrated in the local architecture • private, medium-low income owner
II	Preservation of the main original exterior features of the building while improving the comfort parameters and increasing the functions of the building envelope; some parts of the roof system changes due to the new exigencies imposed to the envelope. Internal horizontal and vertical partitions may be changed	insertion of thermal insulation structures as well as the conversion of the (technical) attic into a (functional) mansard; possible use of new systems or technologies for roofing (eco-technologies);	• private, medium income single owner • private, medium income multiple owners (mass dwellings) • historic building, • public institutions hosted in historic buildings (when applicable)
III	Accomplishment of a complex rehabilitation where, along with the structural and hygro-thermal new performances, the volumetry of the building changes significantly, by adding (a) new floor(s) on the roof top	interventions over the structure that take into account the new floor(s) that are built on the low sloped roof; possible use of new systems or technologies for the new roofing;	• private, medium income owner • mass dwellings with multiple or unique owners • public institutions

Considering the consequences of the interventions strictly in regard with the roof, some of the conclusions that can be drawn out generally link the type of approach with the type of the building and it’s functions.

2. Identical replacement of the roof system (I)

This is a main condition imposed in the case of historic buildings, cultural heritage etc, as a need to preserve the traditional building systems, materials and techniques. The replacement of the roof system with similar, identical or comparable products is currently used in the rehabilitation of traditional houses with thick earth, straw or reed roofing, with wooden shingles, or ceramic tiles.

Their performances are connected to the thickness of the roof (in the case of earth, straw or reed) and with the slope (in the case of wooden shingles, or ceramic tiles), as shown in Figure 1.

Figure 1 Traditional houses in the Village Museum in Bucharest; the original materials, structure and techniques for the roofs are preserved (as they are for the whole building)

The same principle may apply in the case of new buildings, in special locations, where the architectural style of the place dictates the integration in the landscape. It is the case of some buildings for tourism, in natural preserved areas, or where the architecture of the rest of the buildings is traditional and continuity is requested.

3. Identical volumetry of the roof (II)

In the case of an intervention that aims to improve the comfort parameters without altering the constructive features of the building, the interventions that are carried out should be compatible with the original roofing materials (ceramic tiles, metallic sheets). The structure of the roof may change, in order to accommodate the thermal protection system [2].

The overall image of the building remains the same, although interior modifications are often being made by changing the interior partitions or even by re-evaluating the position of the floors, in the case of important structural consolidation work.

In the case of the buildings with low sloped roof ("terrace roofs"), the possibilities of interventions are larger, from the simple repair or replacement of the waterproof membrane, with a similar one, having more or less the same characteristics, to the more energy saving type of waterproof system, which is the "green terrace roof".

3.1. Interventions on pitched roofs

While the rest of the building and the envelope withstand severe modifications, the roof covering remains, in general lines, the same (see Figure 2).

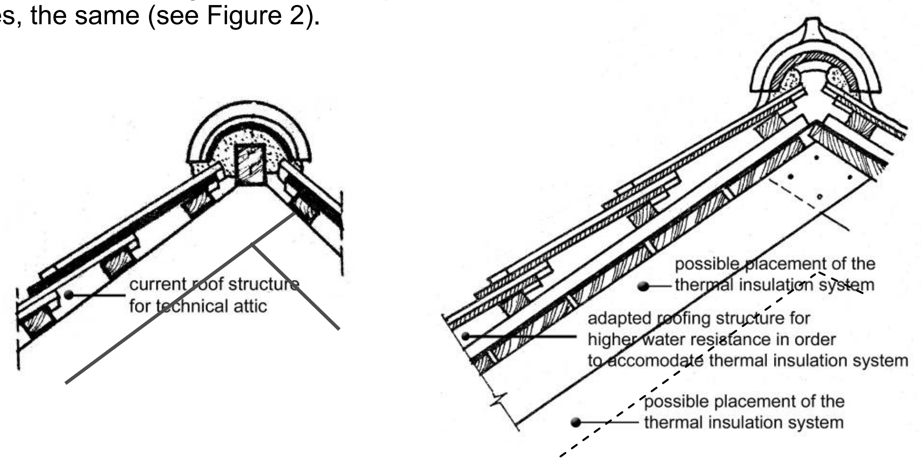

Figure 2 Roof structure with ceramic tiles for a traditional building with technical attic and the changes of the structure, for ensuring better water protection and thermal insulation, when converting the attic from technical to functional [3]

In the case of an intervention where the aim is to make a better use of the attic, the most important problems are to ensure the same hygro-thermal and functional conditions in the attic as in the rest of the building. Not the entire space beneath the roof can be used. The steeper the slope, the more space of the attic can be functional.

Providing an appropriate thermal insulated system on the roof (and walls) can be accomplished without major complications, there are structural, installation, functional and legal problems that have to be solved, in order to transform a technical space into a functional one [4].

Appropriate vertical circulation to the new functional space should be adapted. Sometimes this requests complicated interventions to be made inside or outside the building.

Also, the space conversion implies very careful evaluation of the height where the different objects are to be placed and – more than that – the relation between the user and the position of these objects so that the user may actually be able to reach to them (Figure 3)

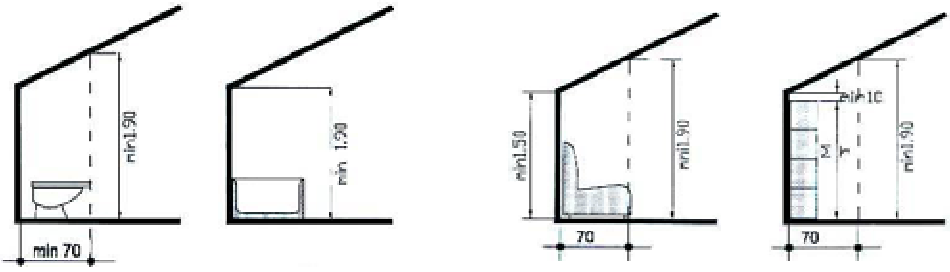

Figure 3 *recommended placement of sanitary or furniture objects, in a mansard; the height of the room at 0.70m from the mansard wall should allow an adult to stand comfortably [2]*

The heating, ventilation air conditioning and sanitation has either to be extended on the newly appeared floor, in case the system permits such an operation, or to be designed and carried out, independently only for the top floor.

In many of the cases of intervention on existing buildings that aim to convert the technical attic in a functional mansard, the replacement of the wooden structure of the attic is also required, due to the alteration of the original one.

The new structure is, usually, metallic, in order to accommodate the functional requirements (height, functional surfaces) as well as the hygro-thermal requirements (thermal insulation associated with the roof structure -rafters, roof boarding, laths – and the roof covering, while preserving the shape of the roof, the height and the type of roofing materials (see Figure 4).

Figure 4 *The attic of the School of Architecture, before the work of refurbishment and after; the volumetric and imagistic features of the building are preserved, by using the same type of roofing material (ceramic tiles), but the use of the interior space has changed, from technical to functional*

3.2 Interventions on low sloped roofs ("terrace roofs")

3.2.1 The replacement of the membrane with a new one may imply a major improvement of the performances of the roofing system as well as of the comfort conditions of the rooms beneath it.

Waterproof PVC membranes with PV coating are now available, so that the function of "energy generator" may also apply in the case of low sloped buildings, with no supplementary equipment installed on the roof (PV panels, frames, supporting structures) [6].

3.2.2 The use of green (terrace) roofs is another possibility of intervention on a low sloped roof structure, that leads to energy saving and heating costs reducing. By using these systems, the state of the exterior environment is at least preserved, if not improved. Polluted areas might even be thus rehabilitated (as we note the case of Linz in Austria where the politics of the "green roof" helped to "de-pollute" this industrial city).

Briefly, among the advantageous aspects of green (terrace) roof performance, the following should be noted:

- retention of an important quantity of the rain water (vegetation acts like an absorbent sponge), thus reducing the pressure imposed on water collectors placed on the terrace.

- reduction of the noise level felt by users who live on the top floor. This is due to the additional mass represented by the soil and the plants. In general, persons living near noisy environments such as airports, discotheques, parking structures, and industrial areas are better protected against noise with a rather non-expensive means.

- protection against electromagnetic radiations [9];

- achievement of a constant interior temperature with no heating peaks in the apartments situated on the top floor under the roof. This is due both to the additional thermal protection represented by the soil and plants as well as to the increased percentage of humidity produced by the breathing of the plants, that cool the air in the vicinity of the roof.

- preservation of the natural environment, as represented by these systems. As mentioned, in polluted industrial areas, the environment might be "healed" after the installation of green roof terraces.

3.3. Roof integrated photovoltaic systems as "clean" energy sources

In the past few years the possibility of integrating photovoltaic panels on the existing buildings – in particular, on existing roofs – gave the building envelope a new function: the energy generator [5], [6], [7]. Photovoltaic panels can be placed over the existing roof, or within the roof, acting also as skylights, with a minimum of constructive implications (the generator, represented by solar panels, the inverter, which converts the system's direct-current electricity to alternating current, batteries that provide energy storage and electrical components needed for installation).

While, in the case of new buildings, the specific aspect of a building that has a building integrated photovoltaic panel (BIPV) on the roof is acceptable, where historic buildings are concerned it is necessary to analyze whether the new envelope component is aggressing the image of the building or the neighborhood. Therefore it may be wise, in the given case, to proceed with a thorough study of the visibility of the pitched roof (and implicit, of the panels) [8] and install, for instance, BIPV on the slopes that are oriented to interior courtyards if the orientation and angle of these slopes are efficient for the performance of the panels.

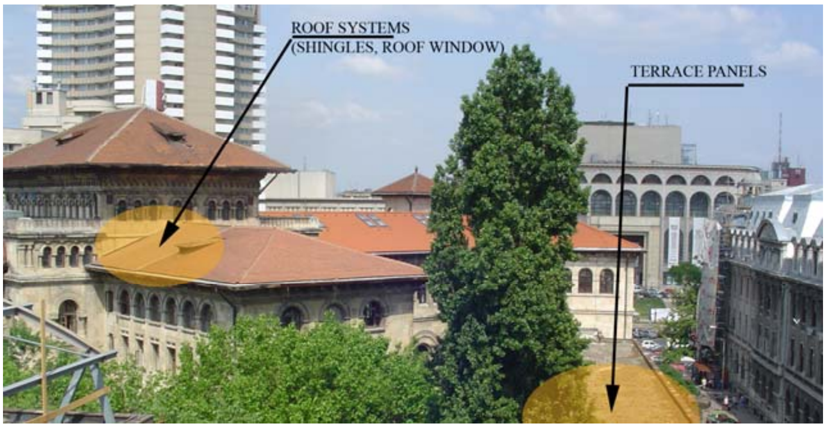

Figure 5 The roof of the School of Architecture in Bucharest, with the possible placement of PV panels on the South Western slopes of the pitched roof and on the terrace roof.

4 Overall changes of the roof – components as well as volumetry

Although the green roof system seems to be the most adequate for urban conditions, in most of the cases the possibility of adding a condominium on the roof seems to be more appealing. Like everywhere else in the world, the prices of houses in the center of the city are very high. In order to build in an expensive area, either some buildings are demolished or the existing buildings are heightened, by building condominiums (on top of the roofs of existing buildings).

The owners are presented the bright side of the problem: building a condominium, with a pitched roof, on top of a low sloped roof is an advantage, as it ensures

- better protection against water and snow (given strictly by the geometry of the traditional roof)

- a fairly rapid pay-off of the investment, once you rent the mansard that results.

The true colours are, however, not as radiant. Supposing the structure of the building allows the extra storey, there are legal problems as well as technical, design, structural, construction, economical other implications that are extremely complicated.

Some of the difficulties have been presented above (as the technical and design problems are more or less the same with the ones that appear when transforming a cold attic into a liveable place), but, due to the specific features of the mass dwelling, where each apartment is owned by a different person, legal, sociological, financial and juridical aspects rise: in multi-storey dwellings, where each apartment is owned by a different person, it is not a simple task to have everyone accept building a condominium.

The nuisance (debris, dust, noise, shocks) of demolishing the roof system (waterproof membrane, thermal insulation, slope, concrete) to reach to the reinforced concrete floor is differently felt by persons on the different floors: those who live on the floor beneath the roof are more exposed to noise; the dust and debris affects all the users of the building. Once the condominium is built, new problems appear: how and who gets the money, how is it spent, and so forth.

Last but not least, there are construction aspects that deal with the management of the site: while working on the condominium, extra costs have to be taken into account for protecting the building. Once the roofing membrane has been ripped off, it should be immediately replaced. There have been cases of buildings (at least one every year), when the rain destroyed from top to bottom all apartments and produced short-circuits, because the roof was not protected any more.

5. Conclusions

The sustainable roof system can be defined as a building component that conserves, recycles and helps renew natural resources. Where traditional materials are concerned, sustainability is given by the use of the same systems that are resulting as secondary products from other activities (straw, reed), are generally available (earth, wooden shingles) or are recyclable (ceramics).

Where waterproof membranes are concerned, the appropriate UV, IR or anti-oxidation protection can increase the service life from an average of 15 years to 25 years, provided that the system is appropriate for the specific use, well installed and accordingly protected.

In either case, the development of the roof integrated photovoltaic systems can – and should – be taken into consideration.

Building condominiums on existing roofs should be carefully considered, with all implications – constructive, technological, environmental. When it is a correct design option, the new roof system that covers the condominium can be designed as a part of the envelope of the building that, apart from the traditional characteristics, fulfills the task of environmental preserver and energy producer.

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AVOIDING OVERHEATING RISK IN TIMBER FRAME DWELLINGS IN A MEDITERRANEAN CLIMATE. THE CASE OF SANTIAGO DE CHILE

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Keywords: wood, housing, envelope, overheating

Summary

The country shows a general absence of wood as a building material in architectural works and in the realm of housing. In Chile, wood production will grow significantly within the next five years. A research project that is being held in the Wood Innovation and Development Centre of our university tries to solve different pathologies, traditionally related to the wood construction in Chile through the development of a new skin. Improvements included in this envelope have been observed in some foreigner experiences, especially in northern Europe. Simulations by means of TAS software have been made to study the thermal behaviour of three housing prototypes in different Chilean climates, which have shown a good performance in terms of heating loads. However, overheating appears as an important drawback in summer, particularly in the case of Santiago, city with a Mediterranean climate. This study explores different solutions to avoid overheating in the prototype of Santiago tested through TAS. For this city, aspects such as thermal mass, ventilated roof and ventilation strategies have shown to be effective for improving the thermal behaviour of this dwelling for cooling periods. Additionally, the impact of windows over the internal thermal behaviour related to the ventilated air cavity of the panels was studied through a series of experimental models named “summer test”. By means of these models, the positive effect of the air cavity over the thermal performance is demonstrated, since it reduces internal temperatures in comparison with a model without air cavity (buffer effect). In this context, when the models are exposed to direct radiation (north facade) without solar protected, the positive effect of the cavity is eliminated, producing overheating. However, when the windows have complete opaque solar protections, diffuse radiation does not reduce this effect, buffering internal temperatures.

1. Introduction

Wood is an abundant Chilean raw material which has not been able to position itself at a national level corresponding to the country’s present state of development. This fact accounts of the massive absence of wood as a building material in architectural works, despite that historically, there were a lot of prefabricated systems that had used wood as main material. Just in the 60’s, in Chile we can find 31 prefabricated system. Between them, 28 were based in radiate pine, oak, aspen, plywood or another kind of panel. However, since the decade of 80’s, this material has been used widely to emergency solutions (due to earthquakes and other natural disasters) and social housing, producing a scenario which wood has been directly related to this situations (or with the second house, typically placed in the coast and used in holidays). Most Latin American countries share these difficulties and have no developed research and advanced technological transfers in this area.

According to the National Statistics Institute, in Chile, while house building reaches to 120,000 per year, only 12% represents timber housing. As it was explained, in Chile there is a negative image of wood as a building material also due to a deficient quality control and inadequate design solutions that have been used mainly in social housing construction. On the other hand, according to the statistics provided by the Instituto Forestal de Chile, the production of forest industry will be twice increased within the next five years, and nowadays, there are 1.800.000 hectares of plantations and 20,000,000 m^3 of annual harvesting. This growth makes imperative the incorporation of advanced technologies and specialized design, since national wood consumption for construction is still limited. For example, if the annual sawmill wood consumption per capita (m^3) is compared between different producing countries, Chile just reach 0.11 m^3 per capita, very far way to Scandinavian countries, with values between of 0,60 in Sweden and 1.02 m^3 per capita in the case of Finland.

Concerning to timber housing advantages, such as energy savings during heating season (due to the own construction process, which incorporates an interior layer of thermal insulation), no diffusion has been made in the country. This aspect is particularly appropriate to Chilean cold climates (which have an interesting wood construction tradition), similarly to the situation to Scandinavian countries, Canada or Germany, which have even more extreme climates in the heating season. However, some Chilean climates in Mediterranean latitudes, such as Santiago, present high temperatures and solar radiation in the cooling season associated to an important thermal oscillation (Figure 1). Therefore, overheating could appears as an important drawback in summer, since it is traditionally associated with timber construction, mainly due to a low thermal mass, which is not able to buffer internal temperatures (due to the principle of thermal lag absence).

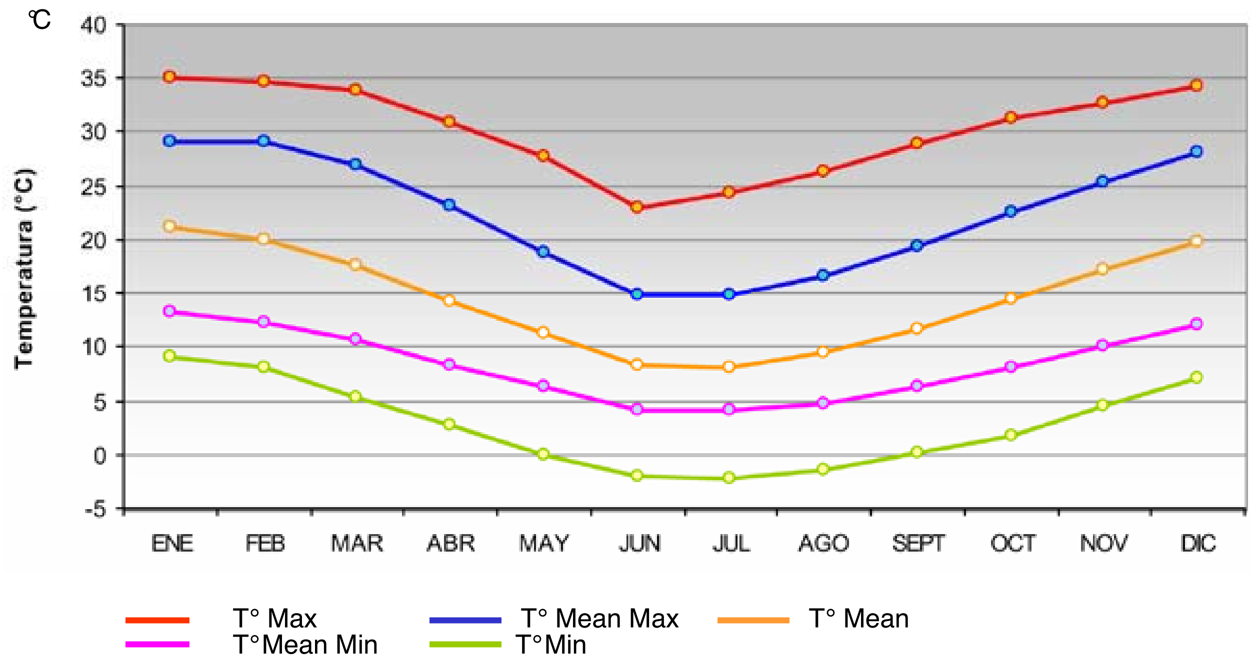

Figure 1. Mean and peaks temperatures city of Santiago

Different experiences have showed the positive effect that thermal mass may produce during cooling season in the internal conditions of a house in Mediterranean climates /1, 2, 3/. An experience carried out by the Fundación Chile in the 80's, that it was called "Viviendas Energitérmicas", showed both good thermal performance in winter and overheating in summer, this latter probably due to a inadequate orientation, lack of shading devices in eastern and western windows, limited ventilation in attics and low thermal mass to decrease thermal oscillation /4/, which affected severely the internal comfort conditions.

2. Methodology

2.1 Envelope design in timber housing

The research project FONDEF D03I1020 "Diseño por envolvente para la vivienda de madera: Innovación Tecnológica para fomentar el uso del Pino Radiata en Chile" (Envelope design for timber frame housing: technological innovation to promote Radiata Pine use in Chile) tries to solve different pathologies, traditionally related to the wood construction in Chile (humidity, acoustic, thermal insulation, termites and others). This applied research proposes to work within a Research and Development (R+D) scheme, supported by a joint effort of the State, universities, and private companies in the area of materials as well as building companies, in order to create new knowledge and open new fields for practical applications. The existent studies in Chile have rigorously searched for solutions involving specific parts and components, thus allowing for great advances in this area. Nowadays, however, it is necessary to start from that basis and develop the concept of "envelope", understood as a whole. Starting from this concept, new "skins" will be tested against the demands of the different Chilean climates.

Therefore, the mentioned project includes three different house constructions located in three different climatic zones of the country: central interior (Santiago 33º30’ S), southern coast (Puerto Montt 41º30’ S) and southern interior (Temuco 38º46’ S). These prototypes were tested before and after constructive process, in order to improve massive housing offer, increasing presence of wood housing construction in the national market. The research project produced a series of simulation to assess the thermal performance of these three prototypes, which was expressed through the heating demand and internal temperatures of the main rooms. In the two southern cases, results were completely successful for the heating season, reaching values of around 70 and 93 KWh/m^2 year in Temuco and Puerto Montt, respectively. In both of them, due to their climatic conditions, overheating does not appear as a particular critical problem, which on the contrary is one of the most important aspect to be considered as design criteria for Santiago (Figure 2). This study explores different solutions to avoid overheating in the prototype placed in this city (architects: Mario Ubilla and Rodrigo Cepeda), the most sensible location to this problem, tested through TAS software. For this latitude, aspects such as thermal mass, ventilated roof and ventilation strategies have shown to be effective for improving the thermal behaviour of this dwelling for cooling periods, which were assessed by means a series of thermal simulations.

Figure 2. Santiago Housing Prototype

The external wall framing of the house is composed by: Radiata pine studs 45x90mm every 600 mm, interior of gypsum board, vapour barrier, fibber glass of 90 mm filling the cavity, OSB and exterior envelope over a ventilated cavity of 25 mm. (Figure 3). Exterior envelope in the case of the house of Santiago is concrete stucco and OSB for exterior sheathing. The house also considers single glazing in windows and a ventilated attic with 100 mm of fiber glass over a gypsum board ceiling.

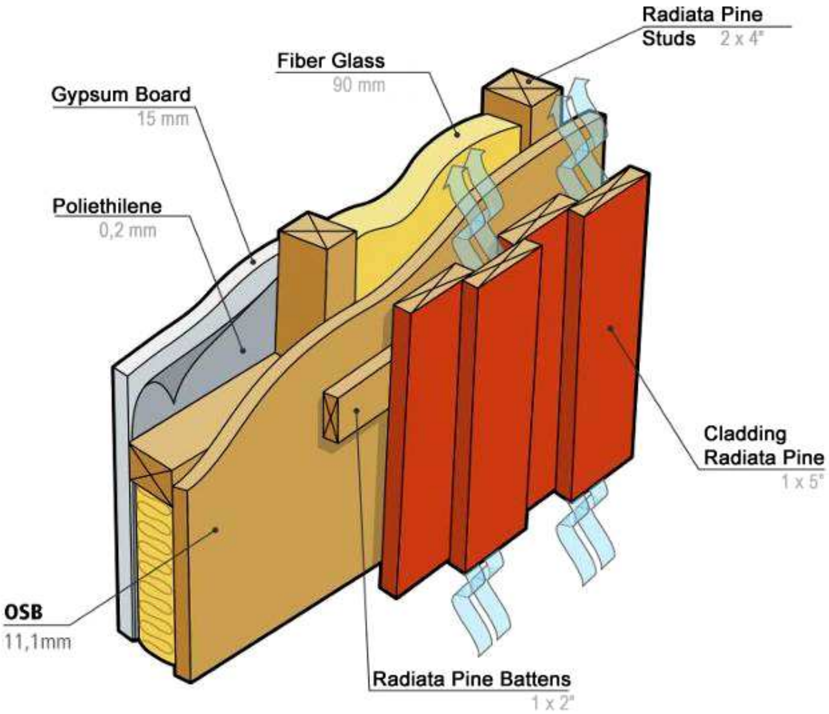

Figure 3. FONDEF D03I1020 Panel

2.1 Thermal modelling methodology

Evaluations content in this document were carried out from a modelling method of thermal performance in dynamic state. This one corresponds to a closer approach to the real behaviour of a building due to involving a great amount of variables (physical characteristics of materials, internal gains, occupation loads and other modelling settings) and complete climatic information (annual hourly values for temperature, direct and diffuse radiation, direction and velocity of winds, precipitations and cloudiness). In contrast to steady state estimations that assumes no variation between interior and exterior temperature through the time (and used mainly to specify HVAC systems from peak values).

This study was carried out by means of TAS software from the UK, and widely extended in Europe to expert environmental consultancies. TAS software lodges a series of modules, which are placed in a 3D modeller, a thermal-energetic analyzer, a climatic and control system simulator, and even a 2-dimentional module of CFD (computational fluid dynamics). Concerning environmental modelling tools, TAS has been catalogued as a tool of advanced level, in contrast to medium level ones (which are useful in architectural design owing to their fast answer and friendly interface), due to the fact that it considers greater entries of variables and delivering the necessary accuracy for an expert assessment.

Housing prototype designs have been evaluated by this software through thermal zone logic to distinguish the thermal behaviour per room and at the same time the heat transfer between them. It includes natural ventilation modelling, which is one of the most complex phenomenons to represent even with other specialized software.

2.3 Simulations of Santiago Housing Prototype

After the first simulations (made together with the southern prototypes), improved thermal models were considered, with the aim to assess the most realistic behaviour of the Santiago prototype, which finally was placed in the most unfavourable orientation from the point of view of the overheating. Therefore, this second series of TAS simulations was defined according to the following conditions:

2.3.1 The house modelled in the four orientations (N, S, W and E). It is chosen the best orientation considering the results in terms of heating and cooling loads. For these simulations, a steady ventilation of 1.0 air change rate throughout the year. Internal conditions for estimating the mentioned loads are:

Maximum temperature: 26℃

Minimum temperature: 20℃ (from 07:00 hrs to 23:00 hrs) - 18℃ (from 23:00 hrs to 07:00 hrs)

2.3.2 The chosen case of the previous simulations is assessed with variable ventilation through opened windows in the cooling season and trickle infiltration by windows and doors (with a value of 0.3 air change rate). The proposal ventilation is focused during morning and evening (after sunset). It is estimated the cooling load and the behaviour of internal temperatures in the rooms.

2.3.3 Shading external opaque devices were considered in eastern, northern and western facades (protecting windows) to assess their effect in the thermal performance of the house.

2.3.4 The effect of the thermal mass over the thermal performance was studied, considering internal partitions of concrete blocks.

Internal gains considered for all simulations reached a value of 115 Wh/m2day. These gains are mainly associated to occupancy, lighting, equipment and heat produced in kitchen and bathroom due to use of them. All simulations considered high attic ventilation (10 ach).

3. Results

3.1 Heating and cooling demand

Since heating demand was similar for the four different orientations (around 65 KWh/m^2 year), criteria for selecting the best orientation was the cooling demand. As it can be seen in Table I, the lowest cooling demand was experienced when the main façade of the house was assumed south oriented, being this one the case selected for the following simulations. Figure 4 shows plan of the first and second floor of the house with orientation considered in the following simulations.

Table I: Heating and cooling demand for the prototype for different orientations of the main facade. City of Santiago.

Orientation	Heating demand kWh/m^2 year	Cooling demand kWh/m^2 year
South	65.3	20.3
North	65.8	22.7
East	64.2	27.5
West	66.3	24.8

Figure 4. First floor (left) and second floor (right) plans for Santiago housing prototype

3.2 Temperature variation

Figure 5 shows simulated temperature variation in four different rooms of the house for a selected day in Santiago (5th January). This day shows a temperature variation which is typical of a summer day of the city. In this case light partitions and a steady ventilation of 0.7 ach and 0.3 ach for infiltrations and external opaque solar protection to avoid direct solar radiation to windows were considered.

Due to internal gains, we can observe high temperatures in bedrooms of the second floor (bedroom 1 & 2), where users concentrate their activities after 19 hrs. In order to decrease these temperatures, different simulation with different strategies were considered and the best performance obtained is shown in the graph of Figure 6.

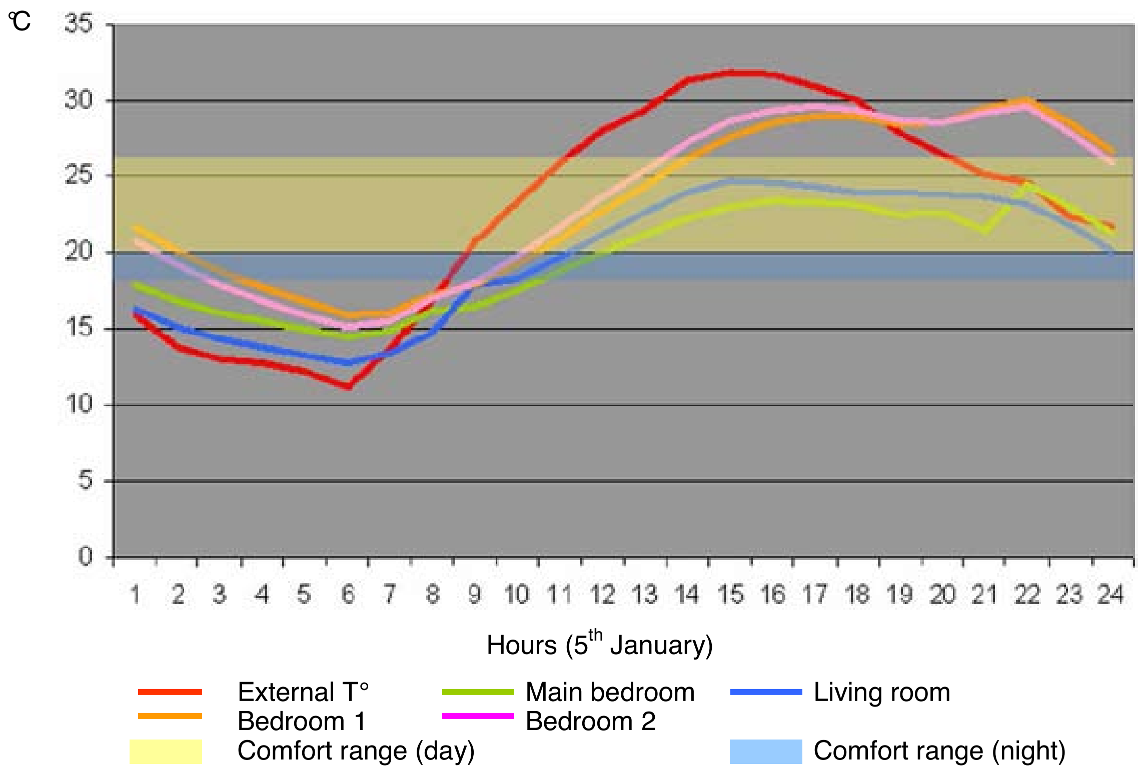

Figure 5. Temperature variation for timber frame partition walls and steady ventilation in different rooms for a summer day

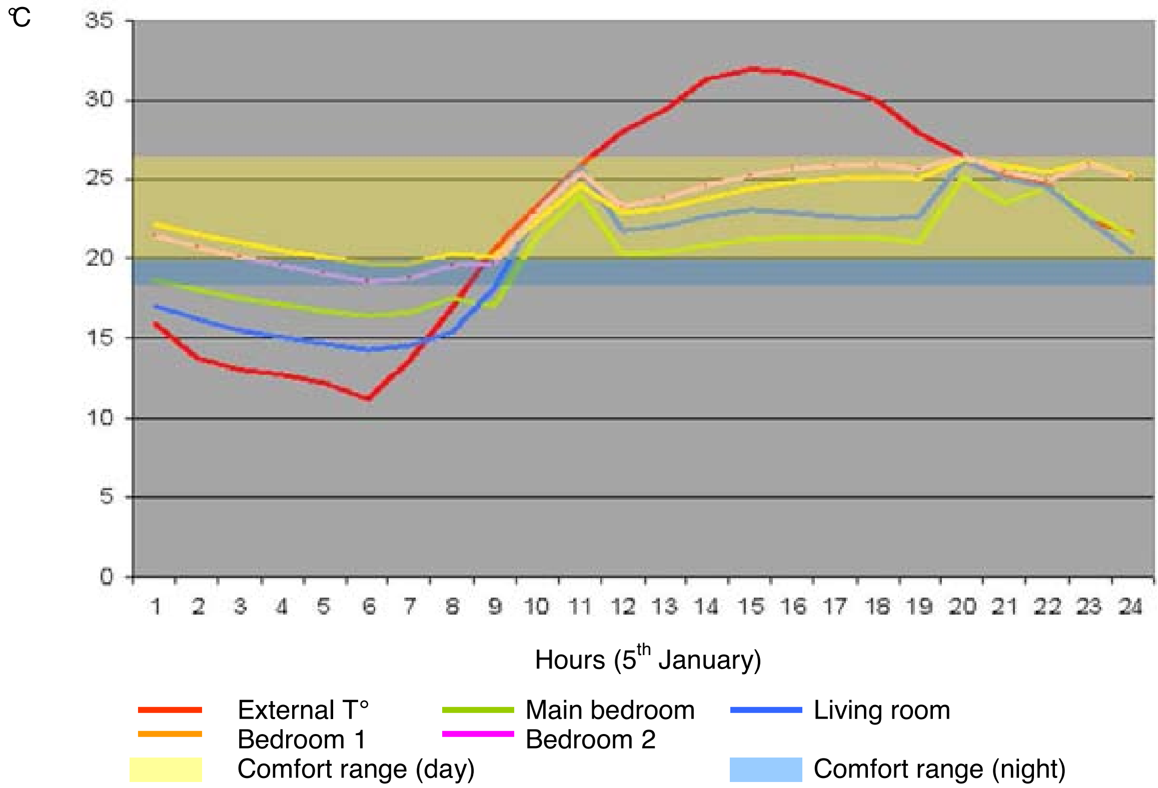

Figure 6. Temperature variation for concrete block partition walls and nocturnal ventilation in different rooms for a summer day

Figure 6 shows lower temperatures in rooms of the second floor. In this case, steady infiltration of 0,3 ach and nocturnal ventilation through partial opening of windows were considered. Solar protection was also considered.

The combination of the use of thermal mass and nocturnal ventilation permitted to decrease temperatures after 19 h and to increase temperatures during the night over 15℃ in occupied spaces during this peri od of the day, both in first and second floor.

4. Conclusions

First of all, this research shows that thermal behaviour of timber frame houses may be significantly improved for cooling for heating and cooling periods of the year.

For heating periods, the use of thermal insulation in the cavity of panels and in the ceiling of the house is effective to obtain an efficient thermal behaviour. In the case of cooling periods, for a Mediterranean climate such as the observed in Santiago, the use of external opaque solar protection in windows, high attic ventilation and strategies of thermal mass with nocturnal ventilation have showed to be effective to reach comfort in the inside.

Thermal mass combined with nocturnal ventilation allow a decrease in the internal temperature oscillation. This positive effect, that allows a temperature variation within the comfort condition in the inside, would completely disappear if no opaque solar protection in windows is used. However, this fact that was not completely demonstrate through the current simulations and by means of a series of experimental models could be tested. Indeed, a test related with the impact of the solar protection associated with the air cavity of the panel was made as part of a series of physical models with aim of assess precisely the effect of this air gap and other related variables (such as solar protection). These experimental models are presented as further research.

5. Further Research

The effect of ventilated air cavity in the panel could not be assessed by means of the thermal simulation, due to limitations of the model (the width of the gap is just 25 mm). However, the research team had the hypothesis that this cavity could improve the thermal behaviour of the prototypes during the cooling season, since the air gap could reduce the effect of solar gains over the envelope, removing the unwanted heat from the internal surface inside the cavity by means of buoyancy.

For this reason, four identical modules of 2.4 x 2.4 x 2.4 m were built, with ventilated attic, 100 mm of thermal insulation in the ceiling and external panels according to specifications (see Figure 3). All the modules have identical orientation and are placed in the courtyard of DICTUC laboratory that made the installation, calibration and collected the obtained registers. One of the four modules remained as patter during all the tests (without ventilated air cavity), with the aim to be compared with all the other modules (with ventilated air cavity), which suffer a series of changes depending on the kind of test (and the objective of the assessment). In all the modules, they were installed a series of thermocouples to register internal temperatures (in the centre of each module), exterior surface temperatures and temperature inside the cavity.

The first question to be solved therefore was about the effect that the ventilated air cavity has in the internal temperatures of the modules. Figure 7 shows the results obtained to the second test, which tried to assess the effect of different kind of envelopes in the internal temperatures. The curves have an almost identical behaviour to the three evaluated cases: radiate pine cladding, OSB for exterior sheathing and concrete stucco. However, when they are compared with the pattern (without ventilated air cavity), it was clearly demonstrated that the ventilated air cavity reduce internal temperatures of the modules by means of a buffer effect between 3℃ and 5℃.

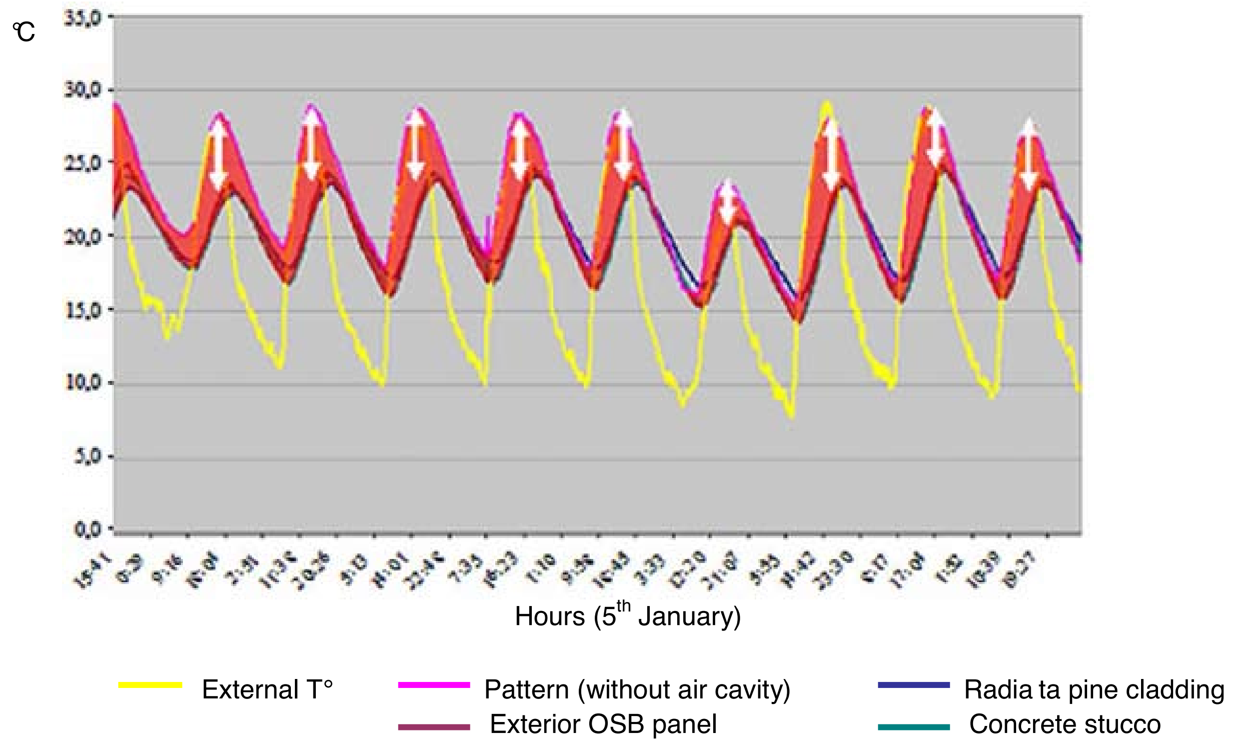

Figure 7. Temperature variation test two: different envelope materials

However, this positive effect would be reduced or even eliminated if solar radiation can penetrate inside the room through a window. In the case of the direct radiation, the result is obvious: greenhouse effect will generate overheating. Nonetheless the effect of diffuse radiation is more difficult to predict accurately from a theoretical point of view. Therefore, this problem was studied through a third test, which had the objective of assess the impact of windows and floor thermal mass over the internal temperatures of modules (and their relation with the air cavity). In consequence, they were tested:

[a] Module without air cavity (pattern)

[b] Module with air cavity (25 mm), covered window (north facade) and exposed floor (to assess the thermal mass efffect)

[c] Module with air cavity (25 mm), exposed window (north facade) without solar protection (including direct & diffuse radiation)

[d] Module with air cavity (25 mm), exposed window (north facade) with solar protection (including just diffuse radiation)

It can be observed that in the module [d] with solar protection (overhang), the positive effect of the air cavity remains, with a similar buffer that in the case without windows (second test, Figure 7). Therefore diffuse radiation does not reduce the effect of the air cavity in the thermal behaviour inside the modules. On the contrary, this one is clearly eliminated when windows do not have solar protection producing overheating (internal temperature curve is over the external one), such as in the module [3], which even shows a poor performance that in the pattern module.

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FRICTIONAL DAMPING EFFECT OF WALLS CONNECTED BY DRY CONSTRUCTION METHOD WHICH HAS POTENTIAL TO CONTRIBUTE TOWARD THE REALIZATION OF STRUCTURAL DESIGN FOR DISASSEMBLY

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Keywords: reuse, concrete, panel, masonry, wall, prestress, friction, damping

Summary

The objectives of this paper are to propose a sustainable connecting method between wall and frame of structure, and to clarify the frictional damping effect of the connection. Walls and frames are not bonded to each other at the proposed connections, making it possible to disassemble members once assembled, so that they can be easily reused or recycled. And the proposed connection absorbs the energy of external force, such as seismic force, by slip with friction between wall and frame.

High-speed horizontal loading tests were conducted on the proposed connections between walls and steel frames. Types of walls are precast concrete panel, SRB-DUP (Steel Reinforced Brick based on Distributed Unbond Prestress theory) wall, which is a kind of dry-masonry wall proposed by this authors, and reinforced concrete block wall. As a result of the experiments, it was found that precast concrete panel is the most suitable for the proposed connecting system.

The horizontal load-displacement relationship of the connection between SRB-DUP wall and steel frame was applied to static load incremental analysis and time history response analysis of the structure, revealing that the frictional damping effect of SRB-DUP wall is high, even the case where low prestress is given to the structure at each connecting point between wall and frame.

1. Introduction

Reduce, Reuse and Recycle are recognized as effective in reducing environmental impact. Especially, Reuse does not require any remanufacturing processes needed in the case of Recycle and therefore achieves a large reduction in environmental impact. However, the current system of building structural engineering is built on stress transmission mechanisms using bonds, such as adhesives (wooden structures), welding (steel structures), and rebar-concrete bonding (reinforced concrete structures). And this fact can often make it difficult to easily reuse building materials. For making Reuse of building materials easy, the different materials should not be bonded together. Frictional connection attracts attention as one of the connecting methods advantageous to Design for Disassembly, because it keeps construction element whole during removal (2006). In this paper, a disassemble-able connecting method by friction between wall and frame is proposed.

Generally, stiffness of wall is higher than that of frame. Therefore shear force loaded into the structure composed of walls and frames concentrates into walls. And it causes shear failure unless the strength of the wall is sufficient (2005a). In the country and area where an earthquake occurs frequently, if the serious damage by the earthquake occurs, great energy and cost will be spent on restoration, and environmental load will increase. The proposed connection absorbs the energy of external force, such as seismic force, by slip with friction between wall and frame.

2. Outline of the Proposed Frictional Connecting Method between Wall and Frame

As for type of wall connected by the proposed method, precast concrete panel, SRB-DUP wall, and reinforced concrete block wall, etc. are assumed. And as for type of main structure of a building connected by the method, steel frame, and wooden frame, etc. are assumed. Figure 1 shows the connection of the

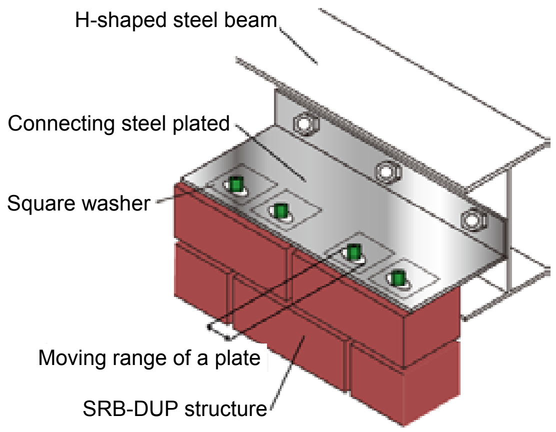


Figure 1 Overview of the Proposed Frictional Connecting Method between Wall and Frame (1)

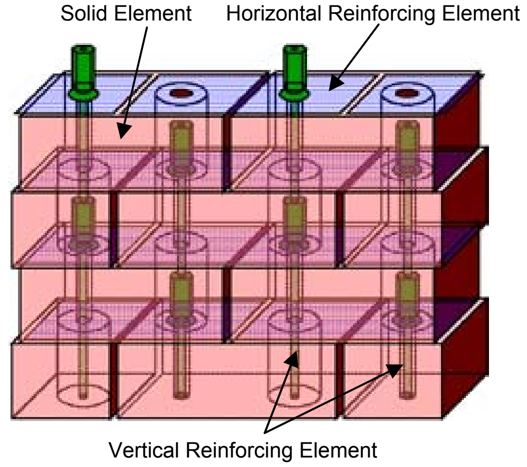


Figure 2 Overview of the SRB-DUP structure

steel frame used as the main structure of a building and the SRB-DUP structure that is used as a damping wall. Connecting steel plates are used for connecting damping walls to the main structure. They are mutually connected using bolts. The bolt hole of the connecting steel plate used for connecting the SRB-DUP damping wall takes the form of a long hole along the length of the plate. Dead load, live load, and inertia force by the earthquake, etc. are loaded into the structure composed of walls and frames. However, since rigidity of the steel frame is comparatively low, much of horizontal force is transmitted to the SRB-DUP wall panel whose rigidity is higher. When the horizontal force becomes larger than frictional resistance between the wall and the main frame, slip occurs there. After it, frictional sliding is induced at the connecting point between the SRB-DUP wall panel and the main frame to absorb external energies. And since the horizontal force exceeding the value at the time of slip occurring is not loaded into the SRB-DUP wall panel, the damage on the wall panel is controllable to the minimum.

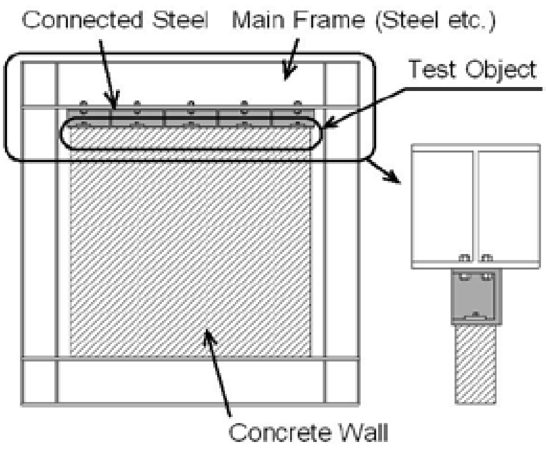


Figure 3 Overview of the Proposed Frictional Connecting Method between Wall and Frame (2)

The SRB-DUP structure is developed by the authors (2007). It is a dry-masonry structure, which has a friction-resistant type of stress transfer mechanism. Overview of the SRB-DUP structure is shown in Figure 2. By making a whole assembly where its constituting elements are not bonded with one another, assembled members can be disassembled, and later can be utilized for Reuse or Recycle. The SRB-DUP structural members demonstrate high vibrating energy absorbing capacities in their strong axes, and demonstrate resiliencies in their weak axes, using positively the voids which exist between their constituting elements. Furthermore the SRB-DUP wall can be used not only as the main load bearing structural member of a building, but also as a frictional damper for controlling vibration of the building with other main structural system as shown in Figure 1.

A damping wall panel of concrete or SRB-DUP etc. can be placed in the plane of the steel frame as shown in Figure 3. However, in order to design so that the wall may not support vertical load like general damping wall, the shape of the connecting steel needs to be devised.

3. Loading Test for the Connection of the Damping Wall and the Main Structure

3.1 Outline of Loading Test

In this research, horizontal loading tests were conducted by inducting frictional sliding between the wall and the connecting steel mounted on the wall after extracting a part of the proposed damping wall to clarify the frictional damping characteristics of the connection. Types of walls are precast concrete panel (curtain wall panel and ALC panel), reinforced concrete block wall, and SRB-DUP wall. A total of 9 types of test pieces, PCe to BCe shown in Table 1, were assembled by varying the material of wall and the type of plating for the connecting steel.

Table 1 Types of Test Pieces

Type	Material of wall	Coat type of connecting steel	Prestress (kN/bolt)
PCe	Precast concrete curtain wall panel	Electrolytic zinc-coated	4.0, 8.0, 12
PCd	Precast concrete curtain wall panel	Hot dip zinc-coated	4.0, 8.0, 12, 16, 20
ALCe10	ALC panel (thickness: 100mm)	Electrolytic zinc-coated	4.0, 6.0, 8.0
ALCe05	ALC panel (thickness: 50mm)	Electrolytic zinc-coated	2.0, 3.0, 4.0
RCBe	Reinforced concrete block wall	Electrolytic zinc-coated	4.0, 8.0, 12, 16, 20
BGd	Brick (ground)	Hot dip zinc-coated	4.0, 8.0, 16
BGe	Brick (ground)	Electrolytic zinc-coated	4.0, 8.0, 12, 16
BCd	Brick (covered with FAS mortar)	Hot dip zinc-coated	4.0, 8.0, 12
BCe	Brick (covered with FAS mortar)	Electrolytic zinc-coated	4.0, 8.0, 12

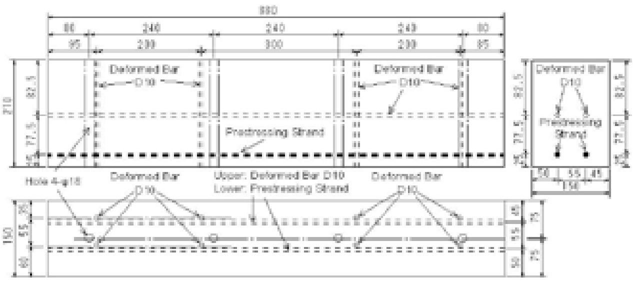


Figure 4 Test piece of PCe and PCd type

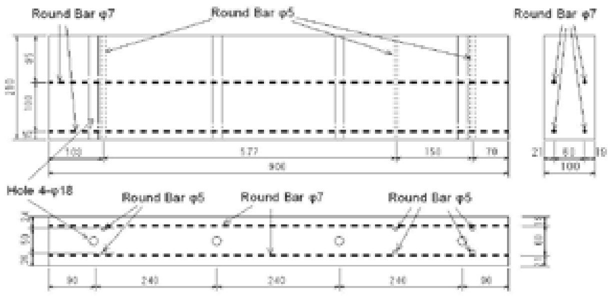


Figure 5 Test piece of ALCe10 type

PC (precast concrete) curtain wall panel, whose size was 1,000mmx1,000mmx150mm, was cut by the concrete cutter so that 2 header sides and the underside might be form, and so that its height, length and bar arrangement might become as it is shown in Figure 4. And 4 circular holes with a diameter of 18mm were opened for the loading test. The specified design strength of concrete was 50N/mm^2. The mold side of the PC curtain wall panel was used for the contact surface with the connecting steel.

ALC (autoclaved lightweight concrete) panel, whose size was 900mmx600mmx100mm, was cut by the concrete cutter so that the underside might be form, and so that its height and bar arrangement might become as it is shown in Figure 5. And 4 circular holes with a diameter of 18mm were opened for the loading test. ALC panel, whose size was 900mmx600mmx50mm, and in which the metal lath had been arranged in the center of the thickness direction instead of steel rods, was cut by the concrete cutter so that the underside might be form, and so that its height might become 210mm. And 4 circular holes with a diameter of 18mm were opened in a similar position to Figure 5. The top surface in the state where the each ALC panel was shipped from a factory was used for the contact surface with the connecting steel.

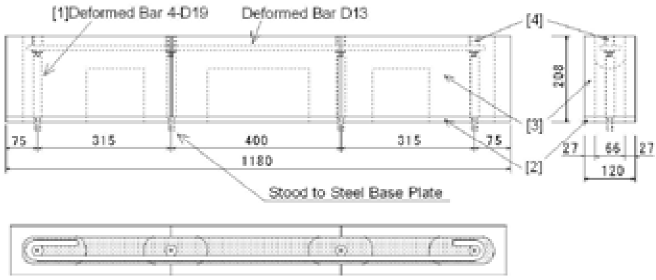


Figure 6 Test piece of RCBe type

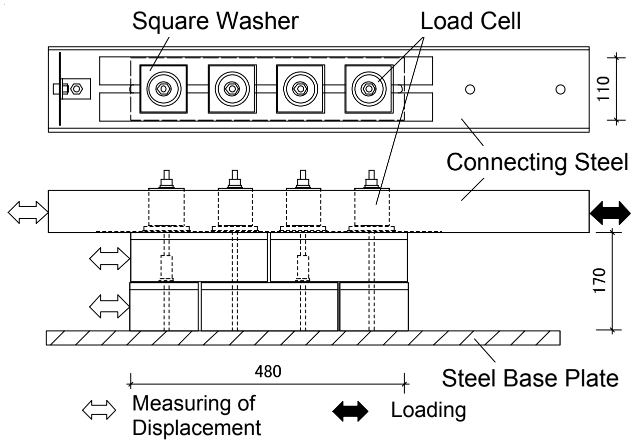


Figure 7 Test piece of BGd, BGe, BCd and BCe type

The details of a RCB (reinforced concrete block) wall test piece are shown in Figure 6. Odd-form concrete block for building, type C in JIS A 5406 was used for the loading test. The screw of M12 type (ISO metric classification) was cut at one end of deformed reinforcing bar of D19, and the screw of M16 type was cut at the other end (Figure 6 [1]). M16 side of it was stood to the steel base plate with a thickness of 25mm. Cement mortar with a thickness of 20mm (Figure 6 [2]) was laid on the steel base plate, and four blocks (Figure 6 [3]) were laid in a single row on it. A 40mm long nut (Figure 6 [4]) was stood to the M12 side of each deformed bar. Then a horizontal reinforcement was arranged at the upper part of the wall, and it filled up with cement mortar. Compressive strength of cement mortar is 40.5N/mm^2, and Young's modulus is 2.42x10^{4}N/mm^2. The about ±1mm unevenness of the top surface of the wall was finished flat and smooth with the polymer cement mortar whose compressive strength is 29N/mm^2 (catalog value).

The details of a SRB-DUP wall test piece are shown in Figure 7. The test piece was a brick wall, whose size was 480mmx170mmx110mm, and which was constructed by the SRB-DUP dry construction method. Elements of a SRB-DUP wall test piece are shown in Figure 8. Bricks with punched-out holes were 2 types of clay bricks meant for SRB-DUP method, and their top and the bottom surfaces were ground or covered with fly-ash slurry mortar to make them smooth and parallel, as well as to keep their height-dimensional precision. The standard deviation of their heights was 0.12 mm. Horizontal reinforcing plates were made of 1.0mm thick and 80mm wide steel. As the vertical reinforcing element of the SRB-DUP method, steel bolts of M12 type were used with 40mm long nuts, circular cut washers and spring washers. Both the bolt and the nut have ordinary strength.

In the loading test, channel steels of hot dip or electrolytic zinc-coated SS400, whose sectional size was H150×B75×tw6.5×tf10, fitted to the length of each tested wall was used as the connecting steel. They are shown in Figure 9. As for the PC curtain wall panel and ALC panel, steel headless bolts of M12 were stood to the steel base plate with a thickness of 25mm through the circular holes with a diameter of 18mm in the tested wall. As for the RCB wall, steel headless bolts of M12 were stood to the long nuts embedded in the wall. As for the SRB-DUP wall, steel headless bolts of M12 were protruding from the top of a tested wall. Through the headless bolts, a channel steel, a square washer, a circular cut washer, a load cell, a circular cut washer again, a spring washer and a nut were arranged in order on each tested wall and fixed as it is shown in Figure 7.

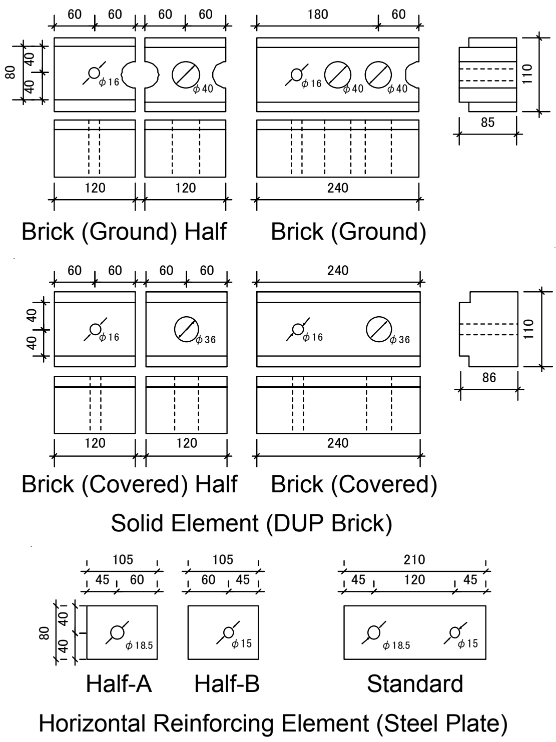


Figure 8 Elements of SRB-DUP wall

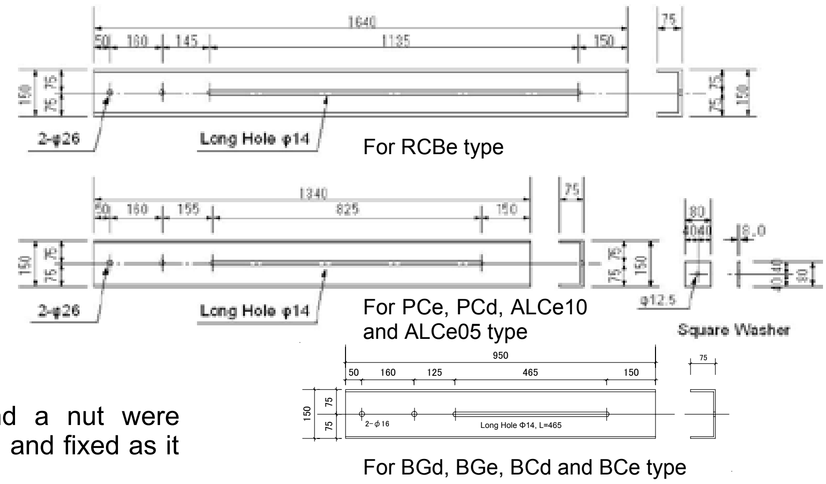


Figure 9 Channel Steel for Connecting

The magnitude of prestress (tensile force) given to the bolts of each tested wall was set as several steps shown in Table 1. First, small tensile force was given to the bolts, and the loading was conducted. After the loading, tensile force of the bolts was increased to the next setting value, and the next loading was conducted. Figure 10 shows the status of the test. Forced displacement of 10mm, 20mm, 30mm, 20mm, and 10mm in the single-sided amplitude of vibration with frequencies of 1.0Hz, 0.5Hz, 0.33Hz, 0.5Hz, and 1.0Hz were applied alternately from one end of the connecting steel in the given order for five cycles each. The total slide distance per load reached 1,800mm.

Figure 10 Test Status (PCe type)

3.2 Results of Loading Test

Figure 11 and Figure 12 show the relation between the horizontal displacement of the test piece and the horizontal load applied to the test piece. This figure shows some typical results of the loading test.

As for the test pieces of the PC curtain wall panel, the stable hysteresis characteristics near rectangular

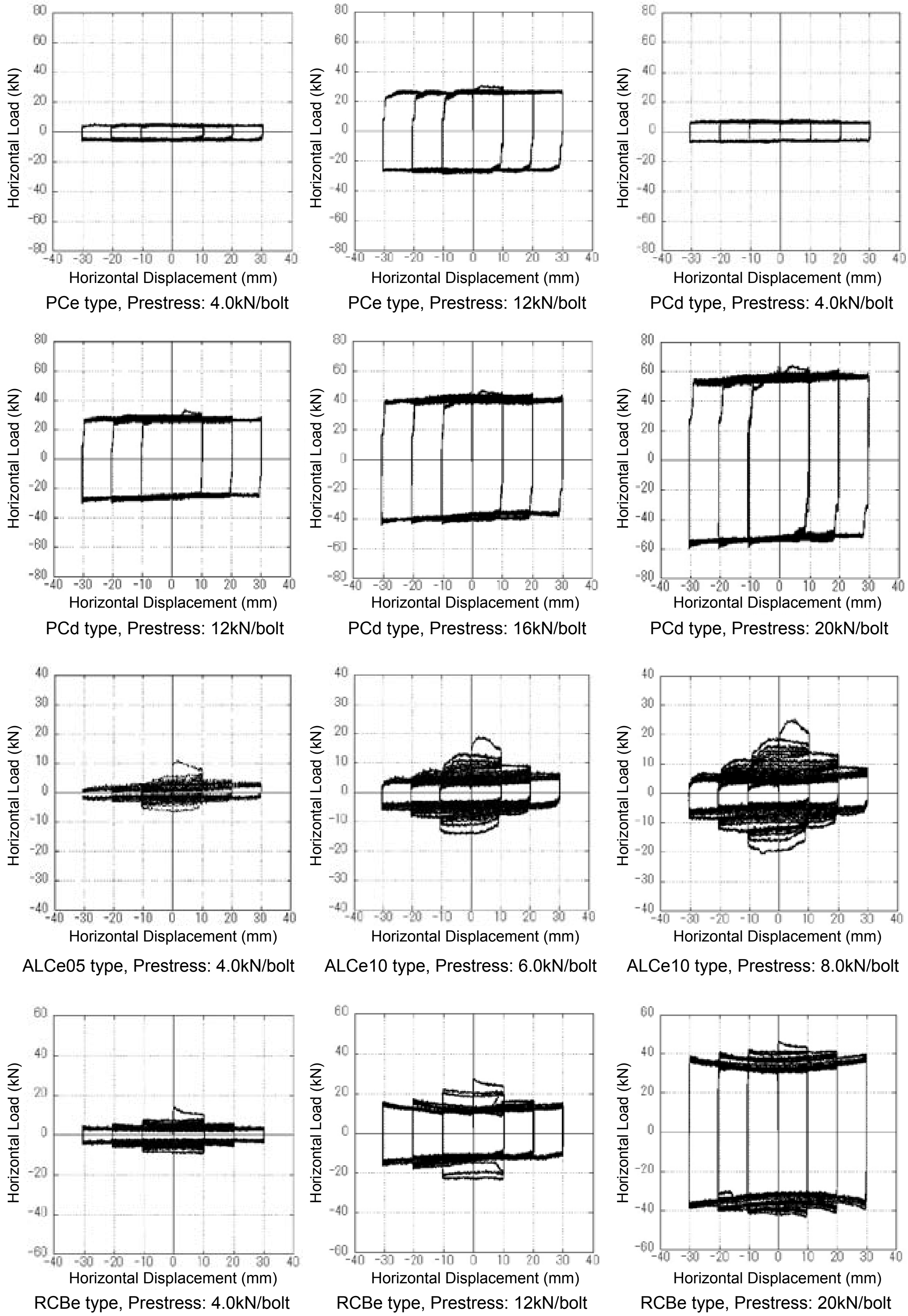
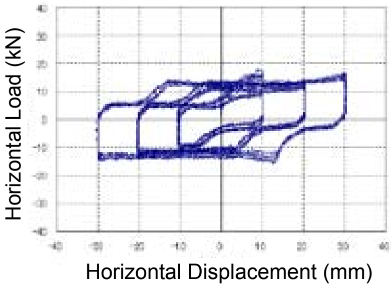
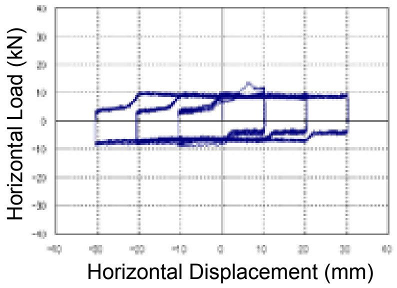


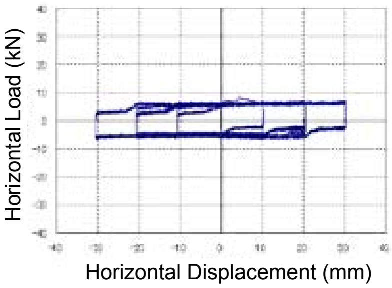
Figure 11 Relations between Horizontal Load and Horizontal Displacement (1)



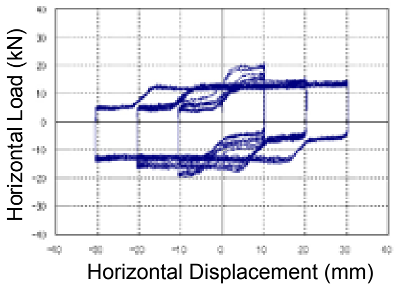
(a) BGd type, Prestress: 4.0kN/bolt



(b) BCd type, Prestress: 4.0kN/bolt



(c) BCe type, Prestress: 4.0kN/bolt



(d) BCe type, Prestress: 8.0kN/bolt

Figure 12 Relations between Horizontal Load and Horizontal Displacement (2)

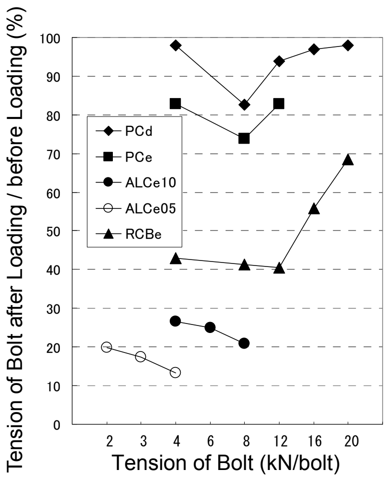


Figure 13 Relaxation of Tensile Force Given to Bolts about Test Pieces of Concrete Wall

shape were acquired. Horizontal resistance while the slide had occurred between the wall and the connecting steel was larger than the case of other test pieces. The resistances of the PCe type and PCd type did not have a conspicuous difference mutually, and the influence on the horizontal resistance by the method of zinc plating was not so large.

As for the test pieces of the ALC panel, the top surface of the panel was ground by loading, and tensile force given to the bolts and horizontal resistance decreased remarkably.

As for the test pieces of the RCB wall, when tensile force given to the bolts was low, reduction of the horizontal resistance while the slide had occurred between the wall and the connecting steel was large. However, when the tensile force of 16kN/bolt, or 20kN/bolt was given to the bolts, the rate in which level resistance decreases while the slide had occurred became small. This phenomenon has appeared also in Figure 13 having shown relaxation of tensile force given to the bolts about the test pieces of concrete wall. It is considered to be the cause that the influence of grind became small by repetition of loading although the portion of the polymer cement mortar which had finished the top surface of the wall was ground by early loading.

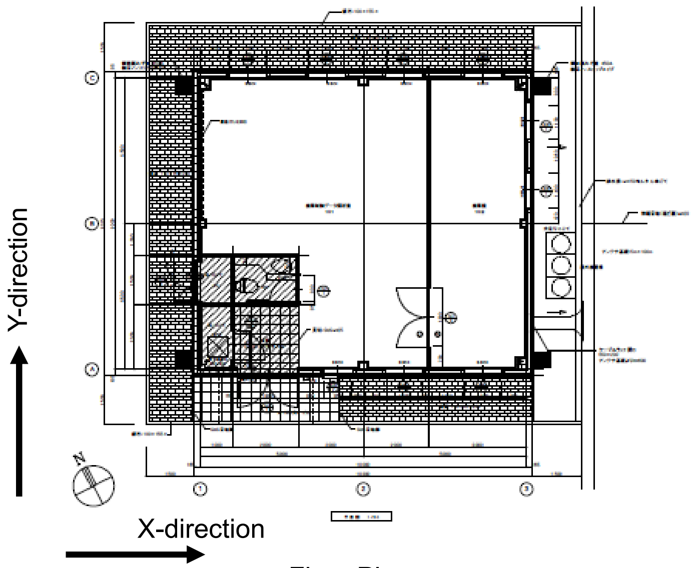
As for the test pieces of the SRB-DUP wall, in the case of Figure 12 (d), where the prestress is large, the horizontal resistance of the test piece changed stepwise, while in Figure 12 (c), where the prestress is small, an almost rectangular curve was observed as the relation between the horizontal load and horizontal displacement. It is considered to be the cause by which the horizontal resistance changed stepwise that the slide occurred also in positions other than the top surface of the SRB-DUP wall. And the influence on the horizontal resistance by the method of zinc plating or the kind of brick was not so large.

4. Vibration Analysis of a Building Using SRB-DUP Damping Walls

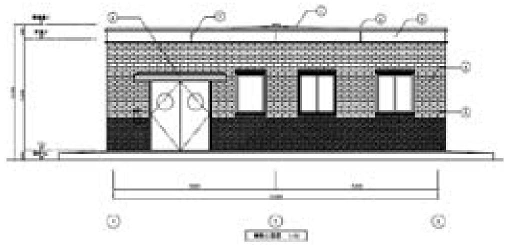
4.1 A Building Using SRB-DUP Damping Walls and Outline of Vibration Analysis

Figure 14 and Figure 15 show the Satellite Communications Laboratory (a single story structure, height: 3.97m, main structure: steel frame) of Kyushu University, Ito Campus, Fukuoka, Japan, that uses SRB-DUP damping walls. Vibration analysis was performed for this building.

For the purpose of comparison, vibration analysis was performed for the same shaped building with ALC panels used as non-structural wall instead of the SRB-DUP structure as well as with the SRB-DUP structure used as non-structural wall. The analysis procedure was as follows. A model of the connection was developed for the relation between the horizontal load and the horizontal displacement obtained by the test (shown in Figure 12 (c)). Then, a static load incremental analysis was performed by using hysteresis characteristics of the SRB-DUP wall considering the performance of the connection and the SRB-DUP beam to find the relation between the story shearing force and the story deformation angle of the building. Based on the obtained results, a model was established for the hysteresis characteristics of the building in the form



Floor Plan



South Elevation

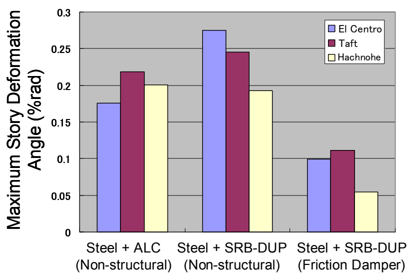
Appearance of Building

Skelton: Steel Structure

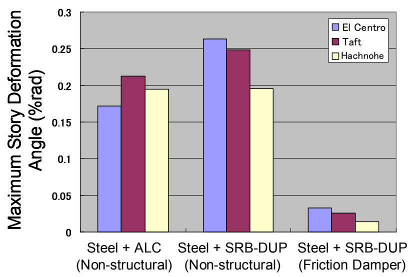
Figure 14 Satellite Communications Laboratory Kyushu University (1)

Figure 15 Satellite Communications Laboratory Kyushu University (2)

of a trilinear skeleton curve, and then time history response analysis was performed to find the building's response to the input vibrations. The earthquake waves inputted in this analysis were three waves of El Centro-NS, Taft-EW, and Hachinohe-NS. Each earthquake wave was normalized the PGV (peak ground velocity) to 25cm/s and 50cm/s, and was applied to the analysis.



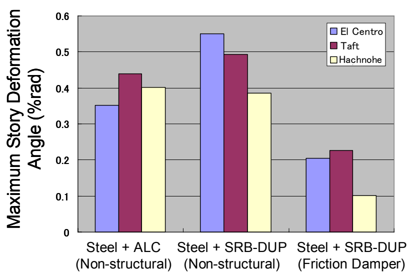
PGV: 25cm/sec, X-direction



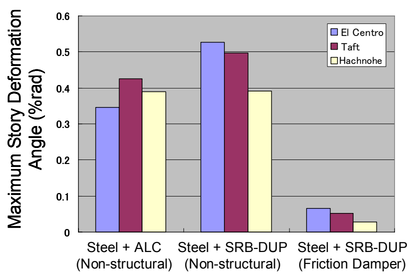
PGV: 25cm/sec, Y-direction

4.2 Results of Vibration Analysis

Figure 16 shows the results of the analysis. This analysis was based on the assumption that a relatively small prestress was applied on the connection between the SRB-DUP structure and the skeleton of the steel structure. Even in such cases, the maximum story deformation angle of the building in the case where the SRB-DUP structure was used as damping wall decreased greatly compared with the case where it was not used, and the damping effect of the SRB-DUP structure was clearly observed.



PGV: 50cm/sec, X-direction



PGV: 50cm/sec, Y-direction

Figure 16 Comparison of Maximum Story Deformation Angle

5. Conclusions

In this study, a disassemble-able connecting method by friction between wall and frame was proposed. The proposed connection absorbs the energy of external force, such as seismic force, by slip with friction between wall and frame. Horizontal loading tests were conducted by inducting frictional sliding between the wall and the connecting steel mounted on the wall to clarify the frictional damping characteristics of the connection. The horizontal load-displacement relationship of the connection between SRB-DUP wall and steel frame was applied to static load incremental analysis and time history response analysis of the structure to find the building's response to the input vibrations. The results are as follows.

(1) Precast concrete curtain wall panel is the most suitable for the proposed connecting system.

(2) It is necessary to devise the usage in consideration of the ALC panel being ground as the slide with friction between wall and frame occurs.

(3) As for the reinforced concrete block wall, the contact surface with the connecting steel must be made not to be finished later if possible. When finishing up the contact surface unavoidably, the kind of finish material must be taken into consideration.

(4) By the vibration analysis, the damping effect of the SRB-DUP structure was clearly observed, even a relatively small prestress was applied on the connection between the SRB-DUP structure and the skeleton of the steel structure.

Life cycle energy (LCE) and life cycle CO_2 ($LCCO_2$) of wooden, reinforced concrete and SRB-DUP housing were compared in a series of study on SRB-DUP structure. And it was found that the SRB-DUP structure, in which bricks are reused, is effective in reducing LCE and $LCCO_2$ (2005b). Future research will include estimating the environmental impact of changing from conventional solution to the proposed frictional damping system. This connecting method could contribute to improved earthquake-resistant capabilities in buildings as well as improved reusability of building materials.

Acknowledgements

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SWARM PLANNING: DEVELOPMENT OF A NEW PLANNING PARADIGM, WHICH IMPROVES THE CAPACITY OF REGIONAL SPATIAL SYSTEMS TO ADAPT TO CLIMATE CHANGE

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Keywords: Regional design, climate change, spatial planning, complexity, swarm planning, climate mapping

SUMMARY

Climate on earth is changing. Due to these changes mankind is forced to adapt as well as to produce energy, which minimises the effect on global warming. The question is how spatial planning is capable to contribute to realise these aims. The changes in society - which becomes increasingly complex and two-sided – may be used as a chance. In order to adapt and produce energy the potentials in a region should be used. They can found by mapping the energy and adaptation potentials of the region. Once they are mapped they can be integrated in climate proof designs, which are able to make regions more resilient. The realisation of these designs should be conducted by starting processes instead of define an end-plan. The processes are started by creating the right impulses and realise the right enduring patterns in the landscape. Both are able to influence the entire regional system. To create impulses - which are able to start a process of realising integrated climate proof designs - a new planning paradigm is required: swarm planning.

1. Climate Change

Global warming develops slowly, but continuously. The most recent 150 years show a clear, yet extreme, warming. Trying to stop this process will take a long time – decennia or more. Warming of the atmosphere enhances a slow warming of the oceans, which react – due to their large warming-capacity – very slow. The emissions of greenhouse gases of recent decennia, combined with current emissions, lead to a warming, which will continue for the next decennia. Beside the reduction of emissions, aiming to reduce climate change, mankind has to adapt to the upcoming changes in climate [IPCC, 2007a+b, Gore, 2006, Stern, 2006].

Table 1.2 Two scenarios (2050) for Groningen [Roggema, 2007a]

	Royal Dutch Meteorological Institute (KNMI) - scenario	Accelerated Melting Land Ice-scenario
Precipitation spring and autumn	+ 20%	+ 30%
Precipitation summer	- 20%	- 40%
Precipitation winter	+ 15%	+ 30%
Temperature	+ 1,5	+ 3,0
Sea level rise	+ 35 cm	+ 150 cm

The province of Groningen [Roggema, 2007a] developed two scenarios. The first scenario is based on a combination of the four KNMI-scenarios [KNMI, 2006]. For the second scenario, an accelerated

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melting of the land ice masses of Greenland and Antarctica is taken as the base. Both scenarios are defined for 2050. In table 1.2 parameters of these scenarios are summarised. Both scenarios were developed to show the broad range of possible futures. If policies are developed – which is the purpose in Groningen – future adaptation policies can be developed in a robust way, making use of the range described in these scenarios.

In every era the climate changes. The speed is mostly subject of debate. It is expected that the aim to freeze the rise of temperature on a level of +2°C by the end of the century is difficult to achieve and that a rise with 3°C is more likely to happen. The sea level might have risen by then with at least one metre and – if ice-sheets of Greenland and the Western Antarctic are melting more rapidly – even more. Furthermore, it is impossible to fixate the emissions of greenhouse gasses immediately. Even if this might be possible, temperature on earth and the sea level will continue to rise for the next decades. There is a multiple urgency: on the one hand side mankind is forced to adapt to the consequences of climate change and on the other hand mankind is obliged to produce energy in a way that minimises the effect on global warming.

2. The incorporation of adaptation in planning

The timeframe of changes in climate is spread out over a long period. Starting now, it will continue for the next century and beyond. This means that it has approximately the same time span as building houses. They are supposed to last also 100 year or more. And it certainly has the same resonance as the design of urban and other spatial structures and patterns, which will last over centuries. Theoretically it must be easy to combine long-term changes and developments with spatial planning. But in practice spatial planning mostly fixes its horizon on a period of ten years (figure 2.1). By doing so an unnecessary difficulty is introduced. Although it is rather simple to incorporate long-term changes in the spatial planning system, it is seldom done in practice. If we look at the new spatial law in the Netherlands [Staatsblad, 2006, Schoot, 2007] and the current practice of development planning, the issues can hardly be found in plans. A more anticipative planning system needs to be developed, which connects more to recent and future societal developments.

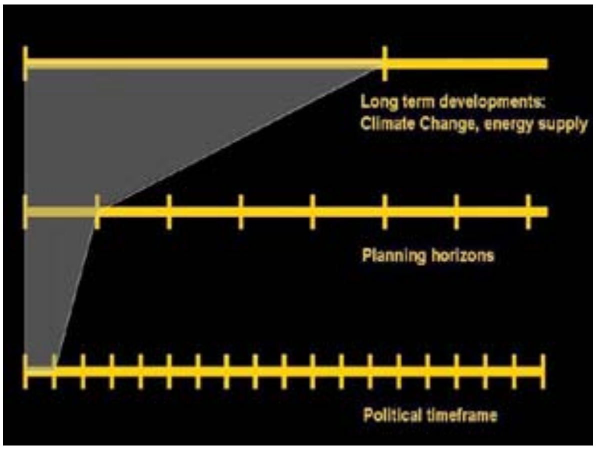

Figure 2.1 Connection of long- and short-term [Roggema, 2007c]

3. A changing society

In the Internet society, one is not only a consumer of news, adds or products, but also generator of information and able to deliver to the Internet in order to share it with others. This free space of exchange, where every consumer is also a producer, might influence the spatial design of regions. Adaptation to climate change and the sustainable supply of energy are issues, which might lead to serious problems on the long term. These changes are fundamental and irreversible. Therefore, it is important to take measures now. These measures need to encourage desired longterm developments at short notice. Existing planning methods – which try to fix the future on a term of max 10 years – and the regular political focus of four to eight years, need to be connected with a further future (see figure 2.1). This requires a new design paradigm. This paradigm needs to enclose the characteristics of the transition to the Internet society [Toffler, 2006] and Web 2.0 [Eye, 2007, NRC Next, 2007].

3.1 Serious changes

Serious changes are ahead of us. They can be summarised as follows:

- The make-ability of the world or a society is an idée fixe;
- Climate change is an illustration of how an increasing series of complex interactions lead to visible problems. The exact relations between interactions and effects are impossible to overview by individuals;
- Required measures need to encourage desired longterm developments at short notice. This requires a new design paradigm, which needs to enclose the characteristics of the transition to the internet society and Web 2.0;
- The new economy is a connection of people, ideas and information. In this new economy flexible network organisations take over. In this new world it is more important to be a contributor and connector than owner of knowledge or goods. Not the possession is the key factor, but the immaterial, virtual additions to the net and the exchange of information is;
- If we sustain the Internet development on the developments in climate change new landscapes lie in front of us. It is no longer only possible to consume, but also to deliver climate resiliency to the spatial environment.

The changes in society offer a chance to adapt more easily to climate change, because large groups of people intend to work together, not in a power based way, but by contributing values. This state of mind opens views to a stronger build society than the hierarchical one, because people are no longer only consuming energy or political messages, but they start to produce them theirselves and start contributing. Instead of a one-way society a both ends-society is emerging. The only thing is that these large groups need to be steered to start those processes, which enhance the resiliency of a region and thus make it a more adaptive one.

4 Mapping climate potentials

We know that the climate is changing and that it is hard to integrate this in regular planning systems, but that there are chances based on the emergence in a both-ends-society. If these chances are to be taken seriously, the knowledge of this fuzzy future needs to be available. To get this information available a method of mapping the potentials may be used [Dobbelsteen et al. 2006, Roggema et al. 2006]. This mapping method can be used for the energy as well as for the climate issues.

The key-factors in climate knowledge, which are crucial for spatial functions, are precipitation and sea level rise.

4.1 Precipitation

The future changes in precipitation are shown in figure 4.1. The maps show for Groningen and Drenthe provinces the possible changes in 2050 in two KNMI ’06 [KNMI, 2006] scenarios for both the winter and summer period.

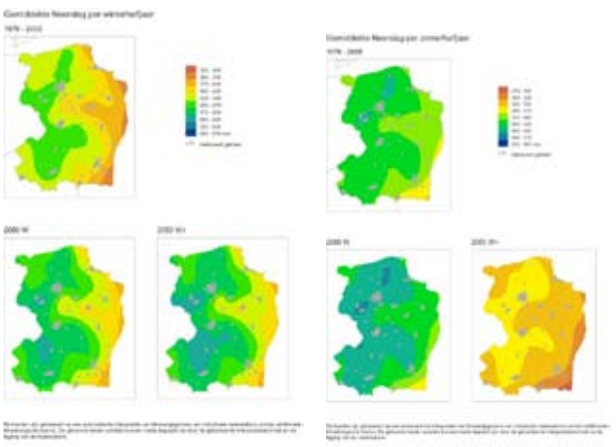

Figure 4.1 Precipitation in the winter and summer six-month period (1976-2005, W-scenario and W+-scenario) [DHV et al. 2008]

Main outcomes of the analysis of precipitation maps are:

1. In the summer period drought will probably increase. In the 'dry' scenario of the KNMI (W+) in the peat colonies the drought will become the biggest problem. In this area the water shortage is at this moment already a problem – partly solved by the inlet of IJssel lake water from outside the area - and this problem will increase. Another development, not visible on the maps, is the increasing intensity of severe rain showers.
2. According to the KNMI '06 scenarios, autumn, winter and spring become wetter. Although a dry summer will have its 'drying' effects, which will lead to average dryer autumns, the total amount of precipitation in the winter period shows an increase.

4.2 Sea level rise

The sea level rise as a result of global warming will continue the next centuries. To what extend depends on the speed of melting processes of land ice. Even if we stop today with the emissions of CO2, the melting processes will continue in this period. Therefore, we must adapt to the rise of the sea level. The maps (figure 4.2) show the impact of the rise of the sea level for Groningen in two scenarios and compared with the current altitudes (+50 and +150 centimetres) if the sea could enter the land undisturbed. In reality the landscape contains several obstacles (roads, little dikes), which prevent the sea from flooding the land without barriers.

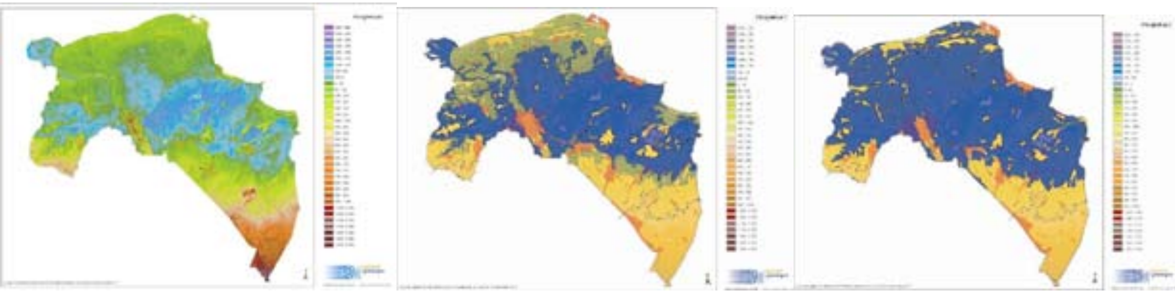

Figure 4.2 Flooding according to altitude lines (current situation (left), 50 cm sea level rise (middle) and 150 cm (right), [Roggema et al. 2007a]

The maps show an illustrative and theoretical image based on altitude lines. The maps are not taking into account the circumstances in which a breakthrough takes place, namely when the sea level is much higher than normal (spring tide) and heavy rain and wind is appearing. The map is not showing the meaning of maintenance of dikes in order to keep them strong and a breakthrough is less likely to happen. But the impact of a much faster melting land ice, leading to a sea level of maximum + 3 metres above the current level in 2100, is also not visualised in the maps.

4.4 Idea-map Climate Adapted Groningen

Climate analyses and notification of the effects on existing functions lead to an Idea Map of adaptive Groningen (figure 4.3), in which the adaptation principles are spatially translated. The map can be read as a spatial image of climate design ideas.
The Idea Map shows the spatial design of the principles. In the lower zones water is collected. This lower area plays also a major role in a main robust wet ecological connection between Dollard and Lauwers Lake. Existing brooks discharge their water towards this wet zone. A robust ecological network emerges, which offers space for existing as well as colonising species. Because these area is located at the lowest parts of the area the water can flow naturally towards this zone. The surplus of water in autumn and spring can be collected here. Nature has the best chances to survive in these areas in dry summers. The reservoirs are also functioning as the source to provide of agriculture especially in the Peat Colonies, by making use of the, partly existing, canal system under the condition that this is economically feasible. This makes it possible to continue the potato starch production. The

supply with clean water is necessary, because the groundwater level will drop and becomes saline in the 'dry' KNMI scenarios, which decreases the availability of water in summer.
In front of the Northern Coast new Wadden Islands are created to facilitate protection, nature development, living and recreation.

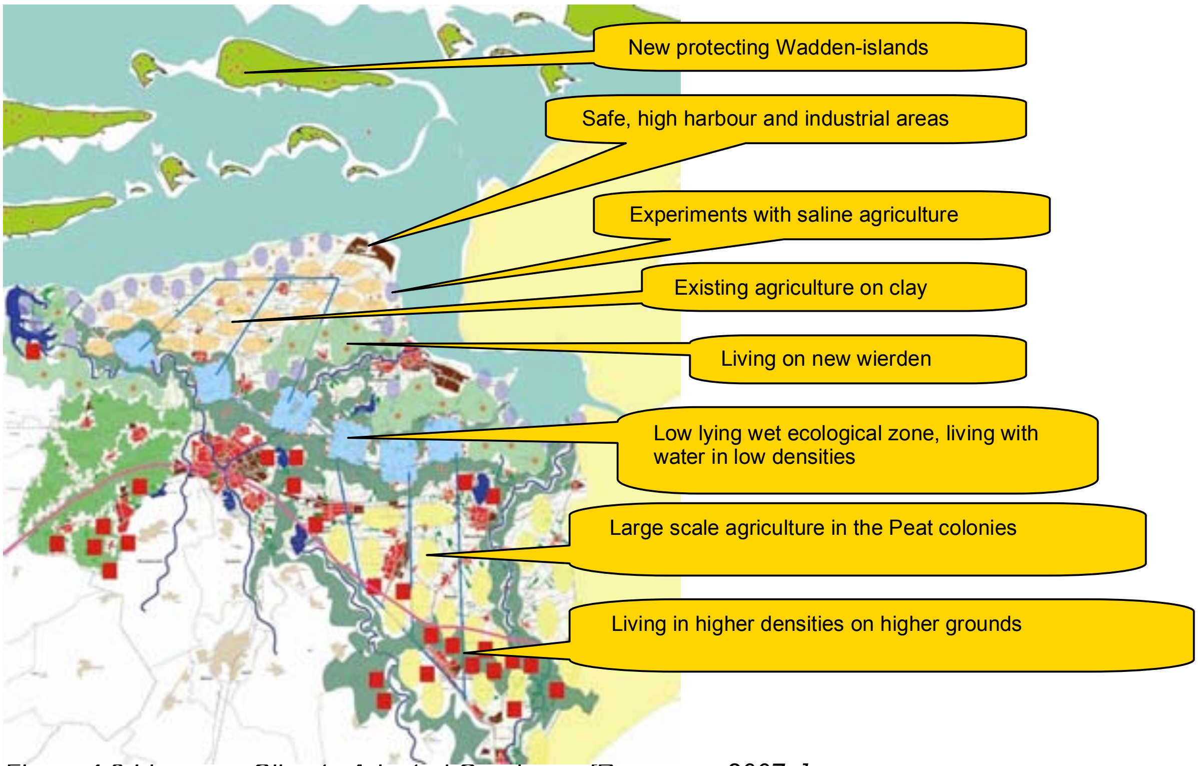

Figure 4.3 Idea-map Climate Adapted Groningen [Roggema, 2007a]

5. Swarm planning

The next step is to define those kind of measures which are coherent with the adaptation aims and fit in the future society. The way this climate-resiliency can be improved may be found by comparing the spatial system of a region with a self-organising system and the way these systems increase their overall fitness [Homan, 2005] (or become more resilient) and reaching a higher level of complexity. Tipping point offer insights in the way these kind of changes can be enhanced. The possibility of sudden change is at the centre of the idea of the tipping point. Big changes occur as a result of small events. The situation is similar to the phenomenon of an epidemic. Epidemics follow three rules [Gladwell, 2000]. By applying these rules to planning and design, the question when a design becomes a success and reaches required changes, can be understood. First of all the law of the few tells us that a successful design will originate from a small group of individuals. The design is not what the common people expect. To change things the design will be away-from-the average [Ridderstråle and Nordström, 2004, Roggema, 2005].
Secondly, the stickiness factor suggests that a successful design sticks in ones heads. Once having seen the image of the design it is not forgotten. A good example of this is the design for Almere Poort, the Wall (figure 5.1) [MVRDV et al, 2001].
Finally, the power of context in relation to design processes tells us that a design with huge impact provides the solution to a commonly felt problem. If a fundamental change is required, a widely shared context of deep trouble improves the chances of change. A sense of real urgency is required for fundamental change. If the existing system dissatisfies, a crisis is required to jump to the next level of complexity required to upgrade the system (figure 5.1) [Geldof, 2002, Timmermans, 2004]. These crises can be seen as the tipping points in design processes.

Figure 5.1 The Wall in Almere Poort, MVRDV, 1999 Crisis enforces the jump to a higher level, Geldof, 2002

5.1 A new design paradigm

In this paradigm the role of spatial design is seen as introducing essential impulses to influence the whole system, like a swarm of birds is reshaping itself constantly under external influences. Spatial design will no longer be concerned with the whole picture, but will focus on those essential design interventions that enforce the region to reshape it self. The metaphor is not any longer the blueprint, but acupuncture.

Thus, for a swarm planning approach [Roggema et al, 2006, 2008a+b] to be successful, two aspects are essential: the (spatial) characteristics of the region and the availability of extraordinary ideas. Complex systems theory suggests that the swarm paradigm will work where the following conditions are met:

- A large group of individual elements (people, buildings)
- Many connections (virtual, roads, rail, water)
- High quality of relations (fast, intense)
- High quality network (flexibility, intensity)
- Enough, but not too much, diversity (neighbourhoods, groups)
- Several co-existing patterns (patches)

If these circumstances pertain idea-mergers between different elements will lead to creative jumps, and new structures and information is created. A small group of extravagant idea creating people will enforce this and transform it into a sticky idea, which influences and shapes large parts of the region. If the sense of urgency is there -climate change for instance- a suitable trigger brings the idea to a tipping point and collective patterns emerge out of co-evolution of local systems, leading to an increased overall fitness of the system [Homan, 2005], which is able to adapt more easily to climate change.

5.2 Kwelderworks Eemsdike and blauwe stad examples

The project Building on structures [Meliefste et al, 2008] shows several interesting interventions, aiming to anticipate on future climate change. The propsed intervention is dealing with the rising sea level and the upcoming shortage of drinking water. The proposal is to store fresh water in the Lauwers Lake and adjust the water level there up to the level of the risen sea (figure 5.2). By doing so it is possible to let the water flow into the sea without pumping. But more important, the entire water system (the swarm in this example) of Groningen is forced to adapt itself. The risen water level in Lauwers Lake implies also the rise of water level in Reitdiep and other small canals and brooks. The result of this will be that the capacity to store rainwater is increased dramatically. And this helps to solve the problem of heavy rain showers and potential flooding in villages and towns. In other words, by solving the first problem and intervene in the Lauwers Lake, the entire region is challenged to adapt to the effects of climate change: the swarm reshapes. The same kind of analysis can be made for the planning process of the Blauwe stad.

Figure 5.2 Proposal for fresh water storage in Lauwers Lake [Meliefste et al, 2008] (left) and Blauwe stad (right)

5.3 Steer the Swarm

Because of the inability of traditional spatial planning to create and reinforce effective interventions, capable of changing the regional system, a new steering principle needs to be developed. In the environmental spatial plan of the Province of Groningen [Roggema et al, 2007] this issue is explored in some depth, leading to the decision to develop a range of approaches to influence the spatial system (figure 5.8). In doing so it is hoped that the best regime to realise a satisfactory outcome will emerge. The aim is to end up with a regime that is able to change the direction of the 'swarm' towards a high standard of spatial quality and resiliency. The most appropriate approaches may differ from area to area, depending on their identity, and the availability of a number of approaches to choose from in combination with the unique characteristics of the area will make it possible to retain the flexibility to make the area adaptive to uncertain future developments.

6. Conclusions and discussion

If the future society wants to deal with changes on the long term, like the adaptation to climate change, it should organise its planning system according the rules of the future society. Swarm planning, in which the contribution of large number of people are used to change the form of its spatial order and the people are steered in the direction of resiliency by the introduction of a certain well-defined impulse, makes use of the new rules in society. These rules include an increased two-sided exchange of values and collective attributions. In order to make use of these new rules, swarm planning needs to adjust the characteristics of complex adaptive systems. By doing so, swarm planning may be able to increase the overall fitness of the system, i.e. increase the resiliency. The following characteristics are important:

1. A large pool of genes (measures, inhabitants, functions), some simple rules and enlargement of trails (improving impact) is the start of changes on the long-term
2. The genes of regions, the trails and the simple rules, which may be successful in turning a region into a climate-proof one, are yet to be found. The elements, which play in the future society a major role in interconnecting, are not clear yet. In history, the sidewalks in a neighbourhood functioned like the interconnection platform, but today and in the future interconnections are made in a different way and at different places. The transport system, the sidewalk, the stranger (the away-from-the-average) and the ‘city’ of our time is yet to be discovered;
3. Swarm planning (large pool), with a well-defined (simple rule) impulse (which is able to enlarges the trail/impact) may be able to steer a region into the desired direction

If decision-makers in a region decide on the required interventions, which can be discovered by mapping the energy and adaptation potentials of a region, it is well possible to incorporate them in the spatial planning system, which is lied down in the new spatial law in the Netherlands. Far more difficult is it to realise a climate proof region by using development planning as it takes longer times and tends to be compromisional.

Several subjects and questions raised in this paper require further research:

a. The way the complexity can be used in spatial terms

b. The exact effects of interventions on the resiliency of the region and the level of adaptation and energy supply
c. The way the interventions are put together and chosen.

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POTENTIALS AND CHALLENGES FOR SUSTAINABLE RETROFITTING OF NON-DOMESTIC BUILDINGS: A UK PERSPECTIVE

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Keywords: sustainable development, retrofitting strategies, environmental, commercial buildings, urban regeneration, revaluing property, Bristol, UK

Summary

This paper presents tentative results from a study of retrofitting activities in the commercial property sector in Bristol, the UK. The study is part of on-going research on the theme 'Retrofitting the city' that explores the adaptation of existing built environments to deal with climate change and objectives for sustainable futures. From the Bristol study two concepts related to retrofitting becomes especially apparent: 'commercial' and 'community'. Results indicate that we might be experiencing a shift where the UK property sector is gaining conscience of the risk of having 'unsustainable' property as part of their portfolios. This change is induced by occupier demands, increased costs for energy and waste management etc., and a more complex process for planning permission. Environmental ambitions have to be balanced with commercial viability, but strengthened policies are to be expected. The study shows that retrofitting of single buildings often includes visions for regeneration of urban areas and the involvement of the local community. This agenda seems partly to be pushed by new planning permission procedures. The study points to a number of fields in which contributions are needed to facilitate future sustainable retrofitting activities including: the archaeology of site, rewiring of the city, and the socioeconomic and environmental benefits in a revaluation of existing property.

1. Introduction

The starting point for this research project is the increased pressure on the urban built environment related to growing urban populations, environmental protection and visions for sustainable development. In 2008, statistics show us that we have reached the tipping-point when half the world's population became city dwellers (www.un.org). From a European perspective where almost 80% of the population lives in urban areas, and cities are changing slowly there are important work to be done to existing, obsolescent and deteriorating urban structures. The UK building stock is renewed by no more than 2% per year through new construction and major renovation. As for the next 50 years the majority of the stock will be comprised of building that exists already today, it is generally perceived that initiatives to address goals for carbon reduction in new buildings will have relatively little impact on the stock as a whole.

1.1 Scope, Definitions and Limitations of the Study

The aim for this paper is to identify and understand the commercial framing of retrofitting activities of existing buildings and the mediation of these issues in current development and regeneration processes. Focus is on non-domestic buildings, an area that has been less studied than the dynamics of the domestic building sector (Bruhns *et al.*, 2000). In addition, the potential for carbon savings in the commercial building stock is seemingly large. The rate of growth of energy use in the commercial sector in the UK has since the 1970s been three times greater than in the domestic sector (Scrase, 2001). The study includes mixed use development (residential, work space and leisure) which is increasingly part of contemporary commercial property development.

As regards definitions, Flourentzou and Roulet (2002) state that the concept of ‘renovation’ can be divided in two sub-categories: retrofit and refurbishment. The concept of ‘retrofit’ identifies actions to upgrade a building to new requirements while ‘refurbishment’ refers to actions to bring back the building to its original state. We use the term retrofit as it conforms to a necessary environmental upgrading and it also highlights the act of revaluing property. Retrofitting actions will also include strategies in new design to facilitate adaptation to future demands for energy reduction etc.

1.2 Methodology

An extensive literature review has been carried out in order to understand the dynamics of the commercial property sector in a UK perspective regarding retrofitting strategies as well as its ability to respond to the sustainability agenda. This paper sums up the research field based on the literature review and tentative results from on-going empirical studies, setting out a range of issues to be examined and that might become hypotheses for the continued work. The paper has three main parts: a review of knowledge regarding environmental issues and non-domestic buildings; a review of knowledge regarding the dynamics of the British commercial property sectors; and a short presentation of the four case studies and their outcomes.

The empirical material consists on the one hand of interviews with senior representatives in the Bristol commercial property sector, and the other hand of four evolving cases of retrofitting of non-domestic buildings in Bristol city centre. At present 14 qualitative and open-ended interviews (length from 1 hour to 1 hour and a half) have been carried out with 16 actors including architects, developers, estate agents and planning officers. Additional interviews have been made for the case studies. The choice of the four cases reflects problems when addressing different categories of non-domestic buildings. This includes obsolescent 1960s and 1970s office buildings, industrial buildings and listed buildings. The choice of cases also shows varying approaches to address the sustainability agenda from basically ‘green’ projects to more commercially pragmatic approaches.

2. Addressing the Non-domestic Building Stock

During last years, major work has been done to develop a UK national database on non-domestic buildings (NDBS) (e.g. Environment and Planning B, 2000 vol. 26; Bruhns *et al*, 2000). Compared with the domestic stock, the non-domestic building stock is very diverse, complex and heterogeneous. If the housing stock can be effectively represented by 1000 dwelling types, the non-domestic stock would need maybe 100.000 building types (Pout, 2000). Many non-domestic buildings have mixed use and mixed construction, coming in a huge range of shapes, size and materials. In addition, the boundary between domestic and non-domestic is not always clear.

2.1 Age and Lifecycle

The majority of non-domestic buildings in the UK were built before the 1980s (Bruhns *et al*, 2000). Just over half of the stock is more than 30 years old. Old buildings (pre-1939) dominate in retail and offices while newer stock is found in factories and warehouses. Over 50% of all office space was built prior 1939 but only counts for 30% of the total floorspace. The old age of the UK office stock indicates a great potential for energy efficient retrofitting or refurbishment activities.

In general, non-domestic buildings have been found to have a higher replacement rate than domestic buildings, one important factor can be that they more often change ownership than domestic and in each ownership change the question of demolishing or recycling will appear (e.g. Bradley and Kohler, 2007). Non-domestic buildings are also to a higher degree exposed to changes in use and have a high rate of change of tenants/users. The service life of a building can be prolonged through regular maintenance and refurbishment and does not automatically mean the physical life of the building. The economic life is established by taxes, legal requirements and accounting standards and is not necessarily related to the likely service life or physical life. The ‘effective life’ of buildings, in general, seems to be much higher than different assumptions of service life and economic life. Some parts of buildings, like the foundation and structure, will probably have a technically longer life than other parts and longer than the assumed service life. Internal replacement cycles in for example office layout and leisure decoration, is higher than external or structural replacements (Ball, 2003). This indicates that subsystems should be controllable and replaceable and that certain design criteria such as floor heights could be provided in the perspective of a possible 'second service life' (e.g. Bradley and Kohler, 2007).

2.2 Carbon Reduction

Non-domestic buildings in the UK are responsible for almost 20 % of the UK's energy consumption and carbon emissions (Communities and Local Governments, 2008). Even if less in total numbers than domestic buildings, several categories of non-domestic buildings have the highest energy use per square meter as for example office buildings. The repatriation of energy use in UK offices is: 58% for heating, 15% for lighting, 7% for IT equipment, and 5% for water heating (Mortimer *et a*l., 2000). The remaining 15% is used for cooling, fans, small power equipment etc. The Carbon Trust (2006) claim 15% of the office electricity use to IT services a figure that is expected to rise to 30% by 2020. In addition, HVAC – heating, ventilation and air conditioning (AC) – uses 20-30% of the total space in commercial buildings (Wagner *et al*, 2005).

Last years rapid growth in commercial energy use reflects expansion in floor space where offices occupy twice as much floor space in 1994 as in 1970 (Scarse, 2001). Between the mid-eighties and mid-nineties, the use of AC increased by a factor of three in the UK. This increase has various reasons (EOF, 1995): client demand, institutional requirement and market perception; deeper plan constructions; increasing external pollution and noise; high density of occupancy; higher internal gains principally from small power loads (poor efficiency of lighting and IT equipment); excessive solar gain due to poor design but also hotter summers. The heavy dependence on electricity for AC, lighting, IT equipment etc. is one major contribution to natural deterioration from the commercial property sector as in UK, electricity production emits twice as much carbon dioxide emissions than for example gas heating due to inefficiencies in power stations (Toke and Taylor, 2007). The situation will be different with new energy efficient lighting and IT equipment. For example, the use of energy-efficient lighting can reduce the overall energy use by 4 to 10% (McAllister and Sweett, 2007). Another problem is related to occupancy and the importance of energy efficient behaviour. One architect office in our study claim that 60% of their energy use is outside office hours (this energy is used for IT services, heating and some cooling).

2.3 An Inclusive Sustainability Perspective

Several studies point to the relative environmental advantage of retrofitting existing buildings compared to demolishment and new construction. In their comparative study, the British Research Establishment BRE (Andersson and Mills, 2002) suggests that the re-construction option (based on lifecycle of 60 years) has a higher environmental impact when using the same method of ventilation or cooling, even though the uniqueness of every site could influence results. The comparative evaluation is based on: embodied impacts (including transport, maintenance and disposal), cooling and ventilation energy, heating and lightning energy, capital costs, whole-life costs, rental values (lettability and manageability), buildability (speed of construction and disruption). The higher environmental impact of the re-construction option is attributed to the demolition and materials involved in the new construction (40-50% of the environmental impact).

The BRE study points to the necessity to expand the scope of environmental considerations beyond embodied energy and energy in use. However, few studies focus on the inclusive 'ecological footprint' and the sustainability agenda regarding socio-economic aspects of building activities (e.g. Building Research & Information, 3/36 2008). For example, location, e.g. accessibility by low carbon transport means will be of importance. A few models under development include other environmental measures in commercial property valuation such as water, waste, material and biological diversity (Ellison *et al*, 2007; McAllister and Sweett, 2007).

3. Addressing the commercial property sector

Generally the 'greening' of the commercial property sector is perceived as "tense and uncertain" and the "idea of 'development' appears anonymous with environmental degradation and unsustainable development" (Guy, 2000). Different actors in the commercial building sector have differing values and wishes concerning what they want to achieve from development of property. In a 'vicious circle of blaim' (Cadman, 2007) occupiers would like sustainable buildings but there are few available; constructors can build them but are never asked; developers would ask for them but investors will not pay for them; and finally investors would found them but nobody asks for them. The circle is further reinforced by the agents that can not see any market demand. However, there are witnesses of an emerging awareness regarding the consequences on investment portfolios of neglecting social and environmental issues and a perceived risk for future or 'anticipatory' legislation (Pivo and McNamara, 2005; Lützkendorf and Lorenz, 2007; Scarse *et al*, 2007; Cadman, 2007). This development is supported by new property rating systems capable of expressing the relative advantages of sustainable measures through the treatment of 'unsustainability' as additional risk (downside risks such as environmental hazard, increased rates of obsolescence and value depreciation) and the inclusion of sustainability for the calculation of credit and mortgage. In addition, sustainable building has been acclaimed to bring countless win-win situations as they are not necessarily more expensive to build and their ownership results in financial benefits including lower operating costs, improved marketability, longer life-spans, reduced exposure to increasingly stringent legislation, and increased occupant productivity and well-being.

Other internal market drivers are for example changed conditions for occupiers with shorter leases and opportunities to negotiate space based on functional demands, and more flexible and healthy workplaces (Guy, 2000; Sayce et al, 2007). However, the strongest pressure for sustainable and energy efficient commercial property does not seem to come from occupiers. Observations made by Cadman (2007) is that developers has led the way since the late 1990s and more recently, also investors have taken a shift and started to shape good practice.

External enablers to adapt more sustainable property management comes from strengthened legislation, taxes as for example The Climate Change Levy, The Aggregate Levy and land fill taxes, as well as raised energy costs. Several political documents addressing carbon reduction has been published last years, e.g. the Climate Change programme (2006), the Climate Change Bill (2007) and the Sustainable Energy Act (2006). The government has set out a progressive tightening of Building Regulations. The 2006s revision to Part L on Conservation on Fuel and Power of the Building Regulations is set to reduce carbon emissions for new built and refurbished non-domestic buildings. Another key measure is the Energy Performance of Buildings Directive, i.e. energy labelling of buildings. Furthermore, the government supports sustainable property management through VAT reduction on renewable energies; the English Partnerships, the regeneration agency, that focus on sustainable urban regeneration; and the Carbon Trust that supports private and public organisations in reducing energy use and carbon emissions. Launched in 2007, the UK Green Building Council sustains a new partnership between government, industry and other stakeholder groups that facilitates dialogue and sets up objectives on the road to more sustainable futures.

Except from cutting-edge buildings the raised awareness for sustainable property has not led to large market transformations. Despite rapidly increasing energy prices it is difficult to create a business case on cost reduction from environmental property even when adopting a whole-life approach (Sayce *et al.*, 2007). In the hand of the occupier, energy costs only represent a fraction of total business costs. Several authors state that a market-led shift to sustainable property is unlikely to happen within the time-frame set out by the current political agendas, proposing more fiscal measures if the market fails (Scarse, 2001; Toker and Taylor, 2007; Sayce *et al.*, 2007).

4. Case studies of Retrofitting Projects in Bristol UK

In early 2007, Bristol council launched the action Bristol Green Capital. Together with Bristol Partnership they seek to establish joint public-private and voluntary actions to reach the Community Strategy target to cut carbon dioxide emissions in Bristol by 60% by 2050.

At present the local authority's possibilities to push the environmental agenda in planning permissions is weak, but strengthened policies are expected in the end of the year. Changes to planning permission procedures have through for example the introduction of the 'section 106 agreement' set restrictions on the developers for the benefit of the local communities.

4.1 Hamilton House – The Pioneering Environmental Retrofitting Project

Hamilton House project is the retrofitting of a 1970s office block in central Bristol for mixed use including residential, offices, retail and a café. New light-structure penthouse apartments are added on the roof and a new residential building to the back of the block. Built in 1974, Hamilton House is currently only partly occupied as offices for the owner, a commercial developer. The owner approached the Bristol City Council with a proposal for a redevelop to housing which was refused. Instead, the city council proposed them resubmit an environmentally focused proposal.

Bristol based architects White Design work on the project now subject for planning permission. One of the challenges is the building being set back from the street with 5 metres, a space that quickly dilapidated. In the new scheme this space is turned it into an atrium, approaching the façade to the street, creating a place for a café and art exhibitions (the building has a Banksy mural), and providing a noise screen that will enable the building to be naturally ventilated. A new façade will be set up with super-insulated panels and floor to ceiling full height glazing. The whole block is heated with a biomass boiler and there will be solar heaters for domestic hot water. The architect has experienced problems as the original structural data of the building can not be retrieved. The structure will be reinforced for wind loads to comply with contemporary regulations.

The architect is convinced that the retrofitting project is the best sustainable solution and works on convincing the developer that this project would not only increase the market value of the property but also support the regeneration of the area, a great story in which they would take part. In their negotiations with the planners, they put forward that the project would add public value in terms of environmental quality, mixed use living, the attractive atrium space and a public garden.

4.2 Lake Shore – The Commercial Green Regeneration Project

In 2004 the award winning developer Urban Splash (South West) bought the 4,5 hectare site with the former Imperial Tobacco head quarter (HQ) building in Hartcliffe, an area that suffers from problems which characterise a socially excluded community. The HQ building from 1973 is a modernist structure of Cor-ten steel sitting on an artificial lake. In 1991, the factory was closed and HQ building was left derelict. In 1997 the building was listed by English heritage.

Urban Splash has a long record of approaching difficult and run down sites and successfully regenerating them in commercial terms. Their vision for the Lake Shore project is to retrofit the listed building and add a new building to create 406 apartments, live and work space, and some commercial space. They wish to attract people offering high quality architecture in an environmentally green area to comparably low prices. The success of Urban Splash can be linked to their niche market of approaching derelict and unwanted sites that they have been able to buy to low prices (and sometimes with additional grants from governments) leaving them resources to focus on their passion for architecture and design and now recently on the green agenda.

Initially Urban Splash aimed at an excellent level of BREAM rating Eco Homes (now Sustainable Homes). They are actually on level 4 (of 6) due to changes in the assessment model. Prerequisites of the site allowed them to use geothermal heating combined with a biomass boiler, local waste water management. They have plans for solar collectors and wind turbines and the lake has been decontaminated. Their work with the local community has brought together a job initiative where 10 trainees work on site. Furthermore, a social enterprise scheme matches local skills with enterprises. The architect is Acanthus Fergusson Mann (see 4.4).

4.3 Broad Quay and A Few More Cases – The Commercial Projects

This case presents a few retrofitting project by the commercial architects Atkins Walters Webster, AWW. The main case, Broad Quay comprises the partial demolition and regeneration of a 1970s office tower in Bristol city centre and the construction of new buildings on the site. The tower which is transformed into a hotel is re-clad and the original slab slightly extended outwards to suite the new use as a hotel. The 18 story hotel will be equipped with AC. The rest of the site will be developed for residential units, leisure and retail. Issues that the project has brought up are: the importance of an intelligent assessment of the existing structure and basement in order to support recycling instead of demolishing; and the commercial value of a good basement and piling that can be reused (for example car parking). This case shows that the reuse of the original foundation, not making changes to the infrastructure can be very commercially beneficial.

The architects own offices in a 1970s office building has undergone an interim recycling, a kind of refreshment to modern standards resulting in good presentable offices but with lower rent levels than a state-of-the-art new built office. The lower floor levels have low density occupancy and are naturally ventilated. The top floor, a lightweight construction has high density occupancy and AC. The concrete slab has been left bare for thermal adjustment and purging of heat at night.

The former Dingles department store a listed 19th century building originally built as residential has undergone a major redevelopment to host shops on the ground floor and residential apartments in the upper floors. The project can be described as recycling a site as only the exterior facades are kept and all slabs are changed to fit new uses. The recycling of the listed façade has been an expensive venture resulting in some qualities but also compromises in use.

Figure 1 Case study images: Lake Shore, Broad Quay and Hamilton House.

4.4 The Greenbank Chocolate Factory – Sustainable retrofitting and the Community

After 100 years of chocolate production, Elizabeth Shaw closed the Bristol Greenbank factory in 2006, with the loss of 145 jobs. A volume house developer made a proposal to demolish the existing building and build a new residential block. The local community opposed to the development with the aim to save the historically important site. Bristol planners rejected the scheme and it was upheld that it was important to retain the site for local work space. The site was sold to Bristol based developer Squarepeg who develops a new scheme with the approval of the community to provide a mix of affordable work space, retail, leisure, and community space. The aim is to use state-of-the-art sustainable building practices to create a pioneering development. The architect George Fergusson from Acanthus Fergusson Mann has experience from similar projects. In 1995, he saved the Tobacco Factory in Bristol from demolition and redeveloped it into a successful cultural venue that is likely to have supported the regeneration of the local area.

5. Results and Discussion

The interviews with Bristol based commercial property sector actors as well as the presented case studies point to some broad issues that will be further discussed. First, the raised importance of the sustainability agenda will be discussed, and the commercial move from retrofitting towards regeneration. Second, mechanisms related to motivation, enablers but also problems in retrofitting and recycling activities will be further explored.

5.1 The Sustainability Agenda and Regeneration

The interviews reveal a shift as the sustainability agenda has gained in importance over the last 1,5 to 4 years. Including the commercial agents acclaim that sustainability is now part of their business agendas. However, barriers remain. A few respondents find that there are not yet enough reliable renewable energy technologies on the shelf. They think that this problem will be solved in the coming five years and prefer to wait before investing in these technologies.

The case studies show a bias for retrofitting in a regeneration perspective, with more or less involvement of the local community, while high ambitions for energy efficiency are less apparent. Compared to recent Swedish development with a strong single focus on energy efficient building and passive house concepts (Femenias *et al*, 2008), the UK cases seem to address a more socioeconomic then environmental agenda. From the perspective of developers and investors, regeneration is interesting as developments that address local concern easier receives planning consent and can be given subsidies (Pivo and McNamara, 2005). The 2007 IPD Regeneration Index states market advantage in investing in regeneration over the long-term. Their study shows that total returns for all property in regeneration areas has outperformed all UK property over the last five years. Regeneration is claimed to be no longer a niche market but mainstream.

5.2 Retrofitting Decision Making Mechanisms

How does the commercial property sector deal with decision making facing retrofitting and recycling of existing buildings and structures? There are a number of factors that will enable the recycling and retrofitting of existing buildings. From a commercial point of view the market is the starting point. Some of the case studies show expensive engineering and design solutions that can only be carried through when there is a strong demand. Urban Splash in their approach to commercial development shows a way to create market demand. If instead the market demand is low, it can be a business case to do only an interim refurbishment for lower costs. The application on the Part L in the building regulations on energy efficiency should be applied on all planning permissions why necessary refurbishment activities in low budget projects can be called off.

It is seldom that physical deterioration defines the timing and nature of retrofitting activities (e.g. Ball, 2003; Bradley and Kohler, 2007). Often triggered by ownership changes or in between lease contract it is generally functional or locational obsolescence that will determine if the building will be recycled or demolished. Functional obsolescence can originate from several aspects: changes in the market with new user demands, development of internal equipment technology or simply due to poor initial design. The study points to some key design criteria important in this decision process. The floor to ceiling height will determine the possibility to install raised floors and AC. Low floor to ceiling heights can be a determining factor for demolition or change of use to residential (not in need of raised floors/AC). The size and flexibility of floor space are other important factors. Modern offices often demand large open floor space for good communication and more productive working conditions. Functional obsolescent buildings in city centres are probably more often subject to demolition to reach higher density and better functionality in a new building, which is an economically more attractive solution (e.g. Bradley and Kohler, 2007).

In order to reduce energy and especially electricity use, natural ventilation and natural lighting are issues in current UK property development. The depth of the building plan will be determining for the use of natural ventilation with a maximum width about 15 metres. A shallow plan but a low floor to ceiling height can be compatible with natural ventilation depending on the location: noise and pollution levels, heat islands in city centres, occupancy rates and the height of the building (when over 14 stories windows can not normally be opened). Thermal mass is advantageous for naturally ventilated as well as air-conditioned (and night cooled/ventilated) offices.

Several respondents brings up the issues of spending 10% more initially to get better design quality, for example higher floor to ceiling heights, that will be of advantage in future retrofitting. This is often the case with head quarter buildings and buildings for other well-established institutions. It can also be argued that older buildings develop status and prestige that could justify higher rent levels and motivate recycling instead of demolishing (Ball, 2003). The intelligent assessment of the value of the existing structure is important. As expressed by one director of architect AWW: “A building that has a good frame and a good basement is a good asset”.

5.3 The Archaeology of Retrofitting and Rewiring the City

The empirical studies point to the importance of thorough initial analysis of the existing structures. One problem is that the records of the existing structure and the infrastructure are often missing. The cases show that even for rather recent buildings, from the 1970s, drawings can not always be found and not structural data. It can be very costly to analyse a structure and it can lead to just-in-case reinforcements or even demolition. The infrastructure issue is of great importance for future retrofitting of urban areas. The large costs that are related to under ground work, locating and relocating pipes and wires will be of additional commercial benefit for the recycling of structures and in particular valuable basements and piling.

6. Subjects for the Continued Research

Several broad areas for further studies can be drawn from the project at this stage. First, are the tendencies reflected in the empirical study signs of a long-term shift towards more sustainable property management? Are on-going activities the result of enlightened clients, one-off market events, or business cases: what are the real mechanisms that enable these projects? The study does indicate that once sustainability issues begin to bite there will be a switch to a market situation where failure to take this in account will lead to increased exposure to financial risk. Second, the study points to the need for further studies of the links between on the one hand retrofitting of existing buildings, or parts of the structure, and environmental impact and commercial value, and on the other hand the link between commercial regeneration and local sustainable development. Will regeneration projects as those studied actually contribute and sustain the local economy and the quality of life for the actual local population? What are the long-term effects of the projects? Third, retrofitting of cities involves a broad field of areas from infrastructure and recycling of existing material capital to the relive of degenerated areas. There is a need for further reflection on the organisation and documentation of work in the retrofitting of cities.

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THE AUTONOMOUS HOUSE: A DEMONSTRATION OF BUDDHIST ECONOMICS

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Summary

Despite increasing awareness of the need for a sustainable society to tackle the global crises mankind is confronting, the industrial-affluent-consumer society still remains mainstream. To implement ecological philosophies so as to promote the transition to a sustainable world order, demonstrations of alternative lifestyles and settlements are key, as when industrial society runs into really severe problems people will be able to see that there is another more practical, wise and ecologically sustainable way. Among eco-philosophies Buddhist economics is used as a yardstick here to measure buildings, such as the autonomous house, which affect the lifestyles of their occupants. Buddhist economics provides the ideas of a sustainable way of living, while the autonomous house develops and demonstrates the possibility of these ideas in practice. The Vales, the architects, builders and occupants of the autonomous house have executed key principles of Buddhist economics in a real situation. More significantly, the new autonomous house frees the Vales from the modern materialist way of life. It signifies the fundamental idea of Buddhist economics: Right Livelihood. This paper identifies the main principles of Buddhist economics, which are used to analyse the autonomous house from qualitative, moral and philosophical perspectives, to offer new explanations of the latter.

Introduction

It has been increasingly comprehended that the industrial-affluent-consumer society has entered a terminal phase. “The Age of Plenty” has ended (Schumacher, 1993). The problems of existing society with its growth economy are so overwhelming that a “paradigm shift” to a quite different society - a sustainable society - is not only essential but also inevitable (Bookchin, 1980; Milbrath, 1989; Trainer, 1995). One of the crucial factors that will promote transition to a sustainable state for society is a fundamental change in the economy. It is generally accepted that the economy is the means to tackle social problems (Smith, 1993). However, the modern growth economy has become a root cause of the predicaments that man now confronts (Trainer, 1996). It is, therefore, certain that a new kind of economics is needed in order to bring forth a sustainable society. Buddhist economics, popularized in the west by E.F. Schumacher, published originally in 1966 and republished in 1973 in a collection of his well-known writings *Small is Beautiful: a Study of Economics as if People Mattered*, is economics of this kind. While the modern economy acts free of morality, ethics and spirituality (Daly, 1996) Buddhist economics with its holistic and organic approach combines economics with moral considerations and spirituality, and provides an insight into “Right Livelihood”. It consists of the ideas of harmonious attitude towards nature, quality of life, alternative technology and decentralisation.

Brenda and Robert Vale have put these ideas into practice by means of designing, building and living in the autonomous house. The autonomous house, published in the 1975 book of the same name and actually completed in Southwell, Nottinghamshire, in 1993, goes beyond measurements in quantity; it offers a much more sustainable way for improving life in quality. Apart from its technological and technical solutions, focusing on the performance of the building, it has more far-reaching social, economic and philosophical implications and applications. It demonstrates that sustainable living is both cheap in the long-run and possible. The Vales (2003:52) maintain that “demonstration is a very powerful motivator.” After completion of the first autonomous house in Southwell, some five further autonomous houses were built in the next village of Hockerton to designs by the Vales. The local authority is also committed to an expanding programme of zero space heating and autonomous dwellings centered on the Sherwood Energy Village (Vale, 2003). Ted Trainer (1998:26) thinks that demonstration may serve as the best contributor in the transformation to a sustainable society by claiming “sustainable practitioners should put most of their energy into developing and demonstrating alternative lifestyles, settlements and systems, so that when the consumer society runs into really serious problems people will be able to see that there is another way, one that is more sane, workable, attractive, just and ecological sustainable.” The Vales have achieved this through the autonomous house. It is a demonstration of Buddhist economics. It is interesting to note that both Buddhist economics and the autonomous house were accomplished in theory in the late sixties and early seventies. It was the period of the environmental movement: the period when sustainable pioneers began to recognise environmental crises and the “limits to growth” (Meadows et al, 1972). Over three decades later, radical change from a society of growth and greed has not yet been triggered. People in general still give little attention to the limits to growth analysis. Indeed there seems to be less willingness to think about these issues now than there was thirty years ago (Trainer, 1998). This paper, by tracing back to the attitudes of the environmental movement, provides a new interpretation of the autonomous house by means of exploring it in terms of the ideas of Buddhist economics, showing how the autonomous house creates a feasible condition for a sustainable way of life, and in turn could bring forth a sustainable society through change in lifestyles (Milbrath, 1989; Trainer, 1995).

The Holistic and Organic World View

Schumacher (1973:44) began his view of Buddhist Economics by identifying two problems of modern economics: specialisation and freedom from moral values, stating "Economists themselves, like most specialists, normally suffer from a kind of metaphysical blindness, assuming that theirs is a science of absolute and invariable truths, without any presuppositions. Some go as far as to claim that economic laws are as free from metaphysics or values as the law of gravitation." These problems may have stemmed from the mechanistic world view, started in the Age of Scientific Revolution and mainly formed in the Age of Enlightenment. The world view proposed by mechanistic science takes the world to pieces, focusing on objects rather than interrelations between them (Capra, 1983). The mechanistic world view, along with division of labour (Smith, 1937), has created industrialised specialisation. The drawback of specialisation lies in the fact that it blinds people so they take one aspect or one dimension of reality and think of it as total reality (Kumar, 1982). In addition, the mechanistic world view has caused one-sided development of the two modes of consciousness, and in turn a profound imbalance between development of intellectual power, scientific knowledge and technological skills on the one hand, and of wisdom, spirituality and ethics on the other (Capra, 1982). The two modes of consciousness are usually called the rational and the intuitive modes, or the scientific and religious modes. The Chinese have named them the yang and yin. Modern economics, however, has consistently favoured the yang over the yin: rational knowledge over emotional needs, objectivity over subjectivity and economic growth over spirituality. The job of modern economists seems to be to devise well-reasoned models to help society rise above fear, greed and hatred. Rarely, however, do they examine the basic question of fear and the emotional need for security that drives human beings (Payutto, 1994). As a consequence, their theoretical models remain rational solutions to largely irrational problems. Fear and desire drive modern men to their worst economic excesses. The forces of greed, exploitation and over-consumption seem to have overwhelmed modern economics in recent decades (Payutto, 1994). The materialistic society offers people little choice but to exploit and compete for survival in today's dog-eat-dog world. But at the same time, it is obvious that these forces are the primary causes of social and environmental problems. Moreover, like other sciences, modern economics strives for objectivity. In the process, however, subjective values such as ethics are excluded due to the one-sidedness of the approach. Schumacher (1997) believed that economics without spirituality could provide temporary and physical gratification, but that economics could not offer internal fulfilment. By contrast, spiritual economics bring service, compassion and relationships into equal play with profit and efficiency. Both economics and spirituality are needed together.

Unlike modern economics which is guided by the mechanistic world view, Buddhist economics is based on a holistic and organic world view as was shared by mainstream societies in the West before the sixteenth century and in the East before westernisation took effect. According to this world view, the universe is made up of a multitude of objects, but has to be pictured as one indivisible, dynamic whole whose parts are essentially interrelated and can be understood only as patterns of a cosmic process. The focus of this ecological world view is laid on relationships rather than on objects (Bateson, 1979). Under its guidance people lived in small, cohesive communities and experienced nature in terms of an organic relationship, characterised by the interdependence of spiritual and material phenomena and the subordination of individual needs to those of the community (Capra, 1983). For Buddhist economics to be based on the holistic and organic world view depends on four aspects: it rejects industrialised specialisation; it links moral values and spirituality with economics; it holds a harmonious attitude towards nature; and it adopts a balanced view of technology. This is "Middle Way technology" or "intermediate technology." Schumacher (1973: 51) called it "A technology more productive and powerful than the decayed technology of the ancient East, but at the same time non-violent and immensely cheaper and simpler than the labour-saving technology of the modern West."

Based on the holistic and organic world view, the autonomous house also presents the features of Buddhist economics mentioned above. Realising the problems of specialisation in the field of architecture, the autonomous house involves ideas of participation of the users in the process of building. The wide perception of the mechanistic world view in the Age of Scientific Revolution and Enlightenment provided a philosophical support to specialisation in architecture which started in the medieval period, became evident in the seventeenth century, and reached a peak in the Industrial Revolution. Since then it has been further enhanced by the separation of professional institutions, recently between the technologist and the architect, and by professional protectionism. Specialisation has isolated architects from the process of making and the users of the building (Lawson, 1997). The Vales (1991) believe that this separation of designing from making, and designers from consumers, does not necessarily promote better design. The autonomous house, however, is quite different from the modern house as the Vales have woven together the role of the users and the process of building. They themselves were the architects, part builders and the users of the autonomous house (Vale, 2003). They understand the process of building but also emphasised the need to understand it by utilising alternative technology, simple technology that could be constructed and managed by the occupants without recourse to specialised training (Vale, 1975). "The users have been able to deal with a number of operational problems without the need for calling for expert assistance. The simple technologies used, for sewage treatment, water supply and waste water disposal for example, have been easy to manage, and easy to adjust and modify as necessary" (Vale, 2000:233) (Figure 1). This idea of adjustment once something is constructed is also important as it suggests that design is and never should be perfect. Yet the modern method of design leaves all such adjustment to the users. Unless designers also learn from such adjustments design can never move forward in any coherent way, as it used to do with development in the context of the vernacular.

Figure 1: composting WC operated by hand.

Figure2: rain water collection from roof

Figure 3: recycled orange juice containers for rain water storage

Furthermore, the combination of moral values with the way of living in the autonomous house again proves that it is based on the holistic and organic world view. The autonomous house makes its occupants aware of their moral responsibility for the natural environment and others. For example, the water supply entirely depends on the collection of rain water (Vale, 2000) (Figures 2 3). It suggests that when taking a shower, the user cannot let the water run freely, needing to consider the limit imposed by the weather and the availability of water for other users. It was the Vales' intention to change individual values through the autonomous house (Vale, 2000). This is one of the reasons why they selected a house to be autonomous rather than a commercial building due to the universality of a house. As the Vales (2000) have claimed "everyone has to live somewhere, and the home has an immediate impact on personal circumstances and values in a way that the office or workplace probably do not. If sustainability is to become acceptable or desirable, it could be argued that it is only through the home that values can be changed" (Vale, 2000:46). This is what they later coined as "sustainable development begins at home" (Vale, 2002). James Garbarino (1992) holds the same point of view and states that the family is a basic unit that can bring forth a sustainable society. According to a Confucian doctrine, social change starts with change in the family. As the family is the place where values are first established, change in value systems may lead to behavioural change. Research conducted by Robert Vale (2005) demonstrates that reduction in ecological footprints through behaviour changes is more significant and much cheaper than through built environment changes. Like the "Middle Way in technology" of Buddhist economics, the holistic and organic world view is also reflected in the autonomous house through the balanced and holistic approach to technology. The alternative technology used in the house is technology between modern advanced technology such as mass-produced, prefabricated construction with automated controls, and the decayed technology of the past. Only sufficient technology to do the task in hand is used. This kind of holistic and balanced thinking, exemplified by the Vales' choice of power linkage between solar energy and the National Grid, pervaded every other issue they confronted as they built from windows to thermal mass (Perlin, 2000). However, this paper has focussed only on features indetified with Buddhist economics, guided by the holistic and organic world view.

Harmonious Attitude towards Nature

The holistic and organic world view guiding both Buddhist economics and the autonomous house is apparent in the harmonious attitude towards nature. Under this world view in the past, the goals of science were wisdom, understanding the natural order and living in harmony with it (Capra, 1983). Science was pursued 'for the glory of God.' By contrast, under the mechanistic world view, the goal of science has been knowledge that can be used to dominate and control nature, and today science and technology are used predominantly for purposes that are profoundly anti-ecological (Capra, 1982). The universe has been treated as a machine, and the world-machine has become the dominant metaphor of the modern age. The Scientific Revolution transformed nature from sustaining matter into a machine and a source of raw material (Capra, 1983). With this transformation all ethical and cognitive constraints against nature's violation and exploitation were removed. The Industrial Revolution converted economics from the prudent management of resources for subsistence and satisfaction of basic needs into a process of commodity production for profit maximization. Industrialism created a limitless desire for resource exploitation, and the mechanistic world view provided the ethical and cognitive licence to make such exploitation possible, acceptable and even desirable (Shiva, 1989).

Base on the holistic and organic world view, Buddhist economics and the autonomous house both show a positive attitude to nature. The attitude of Buddhist economics is centred on two respects, the frugal use of natural resources and recognition of the difference between renewable and non-renewable resources. From the Buddhist point of view, nature is regarded as income, not capital. The essential difference between non-renewable fuels like coal and oil on the one hand and renewable fuels such as solar power and water power on the other cannot be simply overlooked. Non-renewable goods must be used only if they are indispensable, and then only with the greatest care and the most meticulous concern for conservation. To use them heedlessly or extravagantly is an act of violence, and while complete non-violence may not be attained on this earth there is nonetheless an ineluctable duty on man to aim at the idea of non-violence in all he does (Schumacher, 1973). These ides have been embodied in the autonomous house. One of the primary goals of the autonomous house is to tackle the problem of resource depletion (Vale, 2000). It was designed to avoid the use of materialis with a high energy content, to eliminate toxic materials, and to use waste and recycled materials wherever possible. It is self-sufficient in energy, water supply, sewage treatment and waste water disposal, and is connected to no main services except the telephone and electricity, so that it can export surplus solar power to the National Grid (Vale, 1997). Recognising the problem of non-sustainability and the considerable environmental impact of non-renewable fuels, the autonomous house completely relies on renewable resources. Rainwater is collected from the house roof and that of the conservatory to form the only water supply. Electricity comes from the sun through photovoltaic panels (Vale, 2000) (Figures 4 5).

Figure 4: photo-voltaics and the veggie patch

Figure 5: grid connected PV system

In terms of Buddhist economics, the exploitation of natural resources at an ever increasing rate is an act of violence that must almost inevitably lead to violence between men (Schumacher, 1973). Since the Enlightenment, the new relationship of man's domination and mastery over nature has been associated with new patterns of domination and mastery over women (Shiva, 1989; Plant, 1991), and others (Bookchin, 1980) and the underdevelopment of the Third World (Trainer, 1985). The exploitation of nature and people may result from the unlimited desires of modern man. Since modern man has lost control of his direction owing to the absence of a goal for life, he attempts to regain what he has lost by an inordinate and frantic search for those commodities that will stimulate his sense and thus temporarily quiet his sense of lost direction, or by seeking power that allows him to control the lives of others. This control over nature, other things and other people becomes a surrogate for having control over his own life. Lacking the power, ability and will to submit the direction of his own life to an appropriate final goal, modern man seeks the false remedy of gaining power over nature, things and persons (Smith, 1993). In this sense, awareness of the meaning of life and returning a sense of control to every person are crucial with regard to a sustainable and just society. This can be fulfilled by decentralisation which forms the next discussion point of this paper.

Decentralisation

In Buddhist economics, decentralisation is closely related to the ideas of self-sufficiency, local resources for local needs and "small is beautiful" (Schumacher, 1973). Edward Goldsmith (1972) has claimed that decentralisation is fundamental to the green vision of a sustainable society. Andrew Dobson (1991) has summed up most of the arguments in favour of decentralisation which are outlined below. He states that face-to-face communities encourage a sense of social responsibility which is lacking in the anonymity of large-scale industrial and city life; that local production for local use with less trade and travel reduces a community's impact on its environment; that 'human-scale' forms of living are more congenial than their modern counterparts; and that decentralised forms of production and exchange satisfy a human demand for improvements in the quality of life rather than catering for the modern, misplaced emphasis on quantity. The autonomous house involves these decentralist ideas. Resources utilised in the autonomous house are virtually on-site and local. Its self-sufficiency is a non-violent attack on centralised and industrialised systems. From the point of view of Buddhist economics, people who live in a highly self-sufficient way are less likely to get involved in large-scale violence than those whose existence depends on worldwide systems of trade. Nevertheless, the modern economic system relies on international trade. Adam Smith (1937), who is claimed to be the father of modern economics, maintained that the big market is essential for economic growth. For him, the division of labour is a crucial tool for the accumulation of wealth, but it is limited by the extent of exchange, that is, the extent of the market. Therefore, a big market means a powerful exchange and division of labour, and in turn economic growth. This kind of obsession with bigness has become a stereotype of modern society. Vance Packard (1959:16) realised this desire for bigness, stating "stratification (formalised inequality of rank) is becoming built-in as our increasingly centralised society moves at almost every hand towards bigness. Bigness is a really major factor altering our class system." However, both a giant economy and giant organisations are anti-human (Schumacher, 1997). In a big school, pupils are reduced to numbers; in big hospitals, patients are reduced to numbers; in big factories, workers are reduced to numbers. The pursuit of bigness has led the modern economy to emphasise growth in quantity only. The result is a purely exponential increase in numbers and sizes without considering qualitative factors. Bigness has come to be seen as a symbol of success, but human relationships have become secondary (Schumacher, 1997). Interpersonal relationships have depended on the exchange of labour in a commercialised way. The preference for smallness is obvious in the autonomous house and may be another reason for the Vales' choice of a house rather than a school or a library to be self-sufficient. The localness and self-sufficiency of the autonomous house create a condition for people to start true relationships, rather than those formed on commercial critetria, and it becomes a manifesto, fighting against the centralised economic system.

Another decentralising feature of the autonomous house is its autonomy as its name suggests, or self-governance. The house is not linked to the main services of gas, water or drainage, and it exports surplus solar electricity to the national electricity grid, thus interacting with it (Vale, 1997). In the centralised world, the control of electricity supply is in the hands of a few distant and powerful officials located somewhere in a mammoth central bureaucracy. Virtually all functions performed by government and commerce are organised in this manner. As well as being less democratic than they could and should be, centralised systems involve what can be a heavy overhead cost (Trainer, 1985). If many houses sent surplus electricity to the grid this relationship would no longer be centralised and one way but far more interactive and shared. The autonomous house gives its control to the users who are in control of their own heating, lighting and food production (Vale, 1975). John F.C. Turner (1972:6) who is in favour of the shift of control to dwellers, has claimed, "When dwellers control the major decisions and are free to make their own contribution to the design, construction or management of their housing, both the process and the environment produced stimulate individual and social well-being. When people have no control over, nor responsibility for, key decisions in the housing process, on the other hand, dwelling environments may instead become a barrier to personal fulfilment and a burden on the economy." The autonomous house returns a sense of control to ordinary people, thus relieving the exploitation of nature and others. It has achieved this by means of alternative technology, decentralising technology in Turner's terms (Turner, 1976), or people's technology as Schumacher (1973) called it. Simply technologies used in the autonomous house not only avoid the problem of industrialised specialisation as discussed above, but also serve as a means of decentralisation. The reason that modern technology has become increasingly inhuman is that it is a tool for a few people in control of it to generate wealth. In the industrial-affluent-consumer society, technological inventions are essential to generate new wants to sell goods to people. This can be seen in recent refinements of the technology of the car, making it increasingly complicated and something only specialists can mend, thereby selling the service of the mending as well as the car to the consumer. Alternative technology frees the users from the exploitation of the modern economic system. Turner (1976) believes that if the possibilities of self-governing network structures and decentralising technologies are realised, it is through those which do not demand highly centralised production, distribution or servicing systems that an alternative and viable world order will occur. The Vales (1975:17) are convinced that decentralisation would bring forth an autonomous society "where there would be no growth in the economy, where population size was strictly controlled, where resources were shared equally between every man, where freedom to act was curtailed by the need to survive."

Quality of Life

Buddhist Economics is the necessity of Right Livelihood through which quality of life or well-being can be achieved (Schumacher, 1973). The lifestyle offered in the autonomous house paves the way to the attainment of well-being. No one would deny that happiness is a crucial indicator of the quality of life. However, there exists an erroneous belief that happiness is to be obtained through limitless material acquisition, and that the more production and consumption, the happier. This false belief is preached incessantly by every American television set (Milbrath, 1989). Quality of life seems often to be equated with standard of living due to the lack of moral values and spirituality in modern economics. The standard of living is measured by the amount of annual consumption. Therefore, the logic suggested by modern economics is that people who consume more are happier than those who consume less. Nevertheless, in the Buddhist view, consumption is merely a means to human well-being, and the maximum of well-being should be attained with the minimum of consumption (Schumacher, 1973). Over-consumption and material affluence do not lead people to quality of life, well-being or happiness. In fact, the opposite is true. Trainer (1985) has argued that the more people pursue affluence and growth the worse their quality of life becomes. Human thirst for happiness is unquenchable. It means that human beings have a spiritual nature. They have needs that cannot possibly be satisfied by material objects. The human desire for happiness is infinite, but material things are finite; hence they can never quench the desire. Humans all seek unlimited joy, but material objects, being limited, can never offer that. The limited cannot yield the unlimited. In terms of the teaching of Buddhism, happiness, well-being or quality of life can be attained through the Middle Way, the right amount and knowing moderation, and all of these terms may be considered as synonyms for the idea of balance or equilibrium (Payutto, 1994). Knowing moderation means knowing the optimum amount, how much is 'just right.' It is an awareness of that optimum point where the enhancement of true well-being coincides with the experience of satisfaction. This optimum point, or point of balance, can be obtained when people experience satisfaction at having answered the need for quality of life or well-being. Consumption, for example, which is attuned to the Middle Way, must be balanced to an amount appropriate to the attainment of well-being rather than the satisfaction of desires. Thus, in contrast to the modern economic equation of maximum consumption leading to maximum satisfaction, a sustainable way of living should have moderate or wise consumption, leading to well-being. A further meaning of the term 'just the right amount' is of not harming oneself (by causing a decline in the quality of life) and others (by causing problems in society or imbalance in the environment) (Payutto, 1994).

Figure 6: roof insulation

Figure 7: triple glazed window

Figure 8: wall insulation

The Middle Way has been practiced in the autonomous house by means of comfort, satisfaction of 'enough is best', constraints and responsibility. The autonomous house points the way forward to sustainability by offering its occupants not "luxury", but comfort and services in terms of not "more" but "enough" (Vale, 1975, 1997, 2000) For instance, it has a limited range of electrical appliances---no dishwasher, no freezer---and those it does have are used in unconventional ways; the washing machine is used only with cold water and no heating. Average winter indoor temperatures in the living areas are in the region of 18°C, but the low temperature is mitigated by the high radiant temperature resulting from the thermally massive externally insulated construction (Figures 6 7 8). It may be cold for some, but still comfortable. In the mid-winter the Vales' tea consumption increased--- a very efficient form of interior heating---and they went to bed earlier than usual, getting up with light. This again made it very clear that the house was entirely dependent on the sun. The water consumption is constrained by the amount of rainwater, so the water is carefully used for personal hygiene as mentioned before. The comfort provided by the autonomous house implies the idea of knowing moderation, the optimum amount. This optimum point is reached when the comfort is achieved which ensures true well-being and the satisfaction of 'enough is best'. Consumption in the house services is a merely a means to achieve quality of life, not for satisfaction of desires. The living offered by the autonomous house actually puts brakes on the desire for an affluent and materialistic way of life. It invites the occupants to realise that the meaning of life is not wealth, but "something better than money" (Ruskin, 1909). It saves their time and energy for mental and spiritual development. In doing so, it enhances the quality of life and helps obtain happiness. Happiness can also be attained in the house by doing no harm to oneself (through increasing the quality of life) and others (through taking responsibility for society and the natural environment). The autonomous house sets up the constraints for living, such as the indoor temperature and water consumption. These constraints may not appear desirable for those who have been accustomed to modern, affluent lifestyles. They may even argue that these constraints are the violation of individual freedom. Indeed, these constraints seem to contradict individual freedom on the basis of self-interest, as imposed by the industrial-affluent-consumer society. However, the autonomous way of living meets the basic and intermediate need of all people on the earth. Len Doyal and Ian Gough (1991) maintain that a truly democratic and just society will occur if everyone's basic needs including survival and autonomy, and intermediate needs like health, food, and housing are satisfied. Garrett Hardin (1977) has argued that true freedom is the recognition of necessity, and that the most important aspect of necessity that modern men must now recognise is the necessity of abandoning the commons in breeding and accepting the need for constraint. Freedom based on self-interest is freedom for a few, while constraint means ecological freedom for all people. It is a return to moral codes. At a deeply serious level, constraint means waiting

(Tuan, 1989). Modern consumers are often shocked by having to wait for what they want. Yet without waiting, there is no value. The Vales have (1997) stated "having to wait for the sun in the autonomous house is valuable experience in a world where we are used to getting everything that we want immediately." The autonomous house helps its occupants to realise the value of waiting, thus slowing down the speed of life. It does no harm to others by establishing the constraints.

Another important indicator of the quality of life would be fulfilling work and leisure time. However, modern society, with its growth economy and advanced technology, destroys the nature of work and turns work against leisure. The modern economist would regard work as little more than a necessary evil (Schumacher, 1973). Buddhist economics, however, view work differently. The nature of work has three vital aspects: to give a man a chance to utilise and develop his faculties; to enable him to overcome his egocentredness by joining with other people in a common task; and to bring forth the goods and services needed for a proper existence (Schumacher, 1973). In addition, from the Buddhist perspective, work and leisure do not contradict one another, but are complementary parts of the same living process and cannot be separated without destroying the joy of work and the bliss of leisure. To strive for leisure as an alternative to work would be a complete misunderstanding of the true relationship between work and leisure (Schumacher, 1973). Nevertheless, work offered by modern society is often repetitive, mindless and soul-destroying (Schumacher, 1997). Thomas Aquinas saw each person as a being with a brain and hands, who enjoys nothing more than being creatively, usefully and productively engaged with both hands and brain. But the so-called 'labour-saving' technology is most successful in reducing or even eliminating the skilful and productive work of human hands, which have previously been in touch with real materials of one kind or another. The veggie patch of the autonomous house provides an opportunity for the occupants to use both their hands and their brain, and leisure time productively (Figure 4). For modern people who have become familiar with sitting in front of a television set to be entertained in their leisure time and manipulated by endless advertising, producing their own food at home would be a another kind of 'tough work.' Since modern society has destroyed the nature of work by making work unfulfilling, it is not surprising that the most common leisure activity modern men engage in is watching TV. Producing one's own food as much as possible at home, as happens in the autonomous house is done not just because food is the largest energy flow through any household due to the energy bound up in growing, transporting, processing and retailing it (Vale, 2003) (Figure 9). More importantly, it offers a chance for the occupants to use both their hands and brains, and leisure time productively, and thus feeling fulfilled. There is no doubt that quality of life will be improved once people feel fulfilled.

Figure 9: conservatory for growing food

Conclusion:

The autonomous house has put the ideas of Buddhist economics into practice, and demonstrated the possibility and feasibility of living in a sustainable way. Guided by the holistic and organic world view, it frees people from the exploitation of nature and others through a harmonious attitude towards nature and alternative technology. It non-violently attacks the root causes of the industrial-affluent-consumer society through decentralisation, and improves the quality of life through the Middle Way and using leisure productively. It sets up the constraints against freedom based on self-interest, but offers ecological freedom for everyone. It invites people to change their values by taking moral responsibility for the natural world and others. It is a workable example that means all people could participate in sustainable development and is a fundamentally architectural response to the call of sustainability. It could form a basic unit of a sustainable society, and is the starting point for making the world a better place.

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BIOLOGICAL SPECIES INVENTORY SYSTEM AND ASSOCIATIONS OF SYMBIOTIC SYSTEM: AN EXAMPLE ON THE ARCHILIFE SYMBIOSPHERE I CENTER

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Keywords: species inventory, community ecology, small world network, symbiotic system, urban ecology, green village, biodiversity, symbiolization

Summary

The Archilife Symbiosphere I Center (ASIC) is a human-centered ecosystem with complicate ecological linkages between human, crops, and other biological species. Organisms, providing food production and interacting among species, are all antagonism in the ASIC. It is essential to describe the species composition and their biological association in the “Symbiotic Ecological Environment” (SEE) and to understand the impacts of human decision, operation, and natural factors on the SEE. The objectives of this study were to reveal biological compartments and their roles in the SEE with empirical data from the ASIC. A hierarchy model of system theory, named “symbiome”, was built with examining the characteristics of the ASIC, and was constructed with keynote species, major symbionts, and cosymbionts. The keynote species of symbiome was human. Major symbionts were crop species proven to be adaptable to human digestive system. Cosymbionts were biological species occurred with major symbiont in one of the biological interactions such as mutualism, commensalism, exploitation, and competition. In order to establish a suitable information management system, inventory systems of natural resource management and biological survey were reviewed. Then, a species inventory system for the symbiome was designed for data input and analysis.

1. Introduction

The Archilife Living Research Center was established at Fulong Taipei in October 2002, which consisted of two portions, management building and experiment building. The latter was also named “Archilife Symbiosphere I Center” (ASIC). The research teams of the Archilife Research Foundation (ARF) had worked on various disciplines, such as physical environment, biological environment, agriculture, aquaculture, history, and cultural study since the last 2-3 decades (Huang 2002). Thoughts, discourses, and inventions of these researches became the design groundwork of the ASIC. The ASIC is experimental place for residency, and it is considered as a human-centered ecosystem in terms of ecology. The food chain (or food web) was formed with links (Paine 1980) in the above ecological system; i.e. the predation for human on other biological species.

Based on the awareness of life-threatening by the 100,000-yeared periodical disasters, all Archilife research teams had been focused on the ASIC since 2004, in order to optimize continuously and to improve the ASIC through concentrated efforts. Thereby the maturity of the ASIC would formulate a strategy for Taiwan to cope with such a drastic environment change. The strategy would solve potential problems due to the global climate change, as a regional strategy, in Taiwan. Furthermore, the experience would be expanded gradually and would assist other international communities to overwhelm the crisis.

The most important objective of the ASIC operation was to increase the efficiency of material transfer rates between its bio-processing units. Four main units organized a close recycling living-supporting system (Su et al. 2002). (1) Food supply system, including mainly vertical planting system (Tang, 2005) and vine shelves, produced food by green plants. (2) “Solar dietary” was a way of eating, and used solar energy for food processing. (3) Excretory materials were collected using “dry toilet” system. (4) Secondary “composting system” ensured fully the extermination of disease-caused bacteria and parasites. Above units introduced the solar energy into the symbiotic system, and energy depositing in the plant tissue was digested by human body. Excretion became fertilizer back to the soil. Such symbiotic system, or “Symbiotic Ecological Environment” (SEE), provided food production for human, and its interactions were kept stable among biological species by antagonistic mechanism between subsystems which were organized with each cropped species and its symbionts.

Most biological species were introduced by residents in the ASIC on purpose; however, some of them occurred in a natural process. The pattern may be an analogy to the species colonization process as a volcanic island being formed. Island ecology gathers many theories and examples on phenomenons that biological species colonized in diverse situation. Species richness is one of indicator presenting the degree of species diversity in certain ecological community, which is the union of all biological species in an area (Bagon, et al. 1990). In addition, each species has its unique “niche” in the community where all species are inter-related with prey-predator linkages (Bagon, et al. 1990). Biological association is a subgroup of plant species in a community, which tends to occur in the same space (co-existence). It also means a ranked category in the classification of vegetation (Krebs 1978). A climax plant community is characterized by two or more dominant species which have the life-form typical of formation to which the association belongs (Krebs 1978).

The impact of human activities and decision to the SEE should be fully understood, and even natural factors would be essential. Therefore it is important to know the composition, structure, and interactions of this symbiotic system. The objectives of this study were to establish the framework of collection, database structure, and its management pertaining to the information of biological species in the symbiotic system. Furthermore, a model theory for symbiotic system was developed with the empirical data of the species inventory system for the ASIC.

2. Methods

A broad survey on literatures about inventory database of natural resource management was conducted to look for an existing usable standard, or an existing system needed only slightly modification. If there was not any usable one, a brand new system would be constructed. At the same time, the process of system design went to validation and modification stages with empirical data collected between 2003 and 2007 from the ASIC *in situ*.

A theory of human-centered system, more comprehensive than the classical energy-based ecosystem model, was developed by bibliographic review. A conceptual model was built to clarify the characteristics of the symbiotic system according to above realistic data.

2.1 Coefficient of Association

A plant basket of the vertical planting system (VPS; Tang, 2005) or vine shelves was regarded as a sampling unit (SU). The number of SU that both species present (a), both absent (d), and absent at one and present at the other (b, c) were calculated. Coefficient of association (V; equation 1) represents the strength of connection between two species in a community, and its value is between -1 to +1 (Krebs 1978). If V = 0, then there is no connection. If V > 0 and $\chi^2 > 3.84$ (equation 2), it indicates a positive association. If V < 0 and $\chi^2 > 3.84$, it represents a negative one (Krebs 1978).

$$V = \frac{ad - bc}{\sqrt{(a+b)(c+d)(a+c)(b+d)}} \quad (1)$$

$$\chi^2 = \frac{n(ad - bc)^2}{(a+b)(c+d)(a+c)(b+d)} \quad (2)$$

3. Inventory System

A common structure of database management system for the natural resource management consisted of user and other 5 subsystems (Fig. 1), i.e., administrative subsystem, maintenance subsystem, data collection subsystem, data processing and storage subsystem, and retrieval, reprocessing, and display subsystem (Myers and Shelton 1980). The “species inventory system” in the ASIC adopted data collection subsystem to analyze the developing process, structure, and functions of SEE (Fig. 1). Data sources include reports of the “Archilife SEE Researches”, “Green Paradise Web Site”, the Archilife Intranet, and automatic monitoring system.

3.1 The Format, Attributes, and States of Species Inventory System

The coding process was simple and undemanding. Microsoft Excel™, was used as data processing software for its popularity. The format and states of each attribute had been modified on yearly bases since the operation of the ASIC began in 2004. Two stages of procedure were determined in the very beginning of this project. The primary data set was mainly produced by direct collection from the literature and reports on the

ASIC, while the secondary data set was produced after manually analysis by the database manager (Fig. 1; Table 1).

3.2 Primary Data Set

Primary data set was the group of worksheets containing the original data, which were mainly articles and images. The titles of worksheets were named Reports, BibList, ArtList, and FigList. The coder must be familiar with the building structure and operation of the ASIC (Table 1).

Table 1 Data file and spreadsheet of the specie inventory system for the Archilife Symbiosphere I Center

Filename	Worksheets	Description
PrimaryDataSet.xls		To store the photographs and literatures out of reports, Green Paradise Web Site, and the Intranet of the Archilife Living Research Center in spreadsheets.
	Reports	✓ Containing bibliography of the Archilife Research Foundation reports. All reports until 2004
	BibList	✓ Recording the biological species mentioned in above reports
	ArtList	✓ List of articles containing the occurrence of biological species
	FigList	✓ List of photographs containing the occurrence of biological species
	AMList	✓ List of image taken from the automatic monitoring system
SecondaryDataSet.xls		✓
	SpList	✓ List of species occurred. Summarized from the primary data set
	LocList	✓ List of localities where the biological species occurred
	SrcList	✓ List of data source
	IntAna	✓ Summary of interaction occurred between biological species
	SptAna	✓ Spatial analysis on the occurrence of biological species
	TmpAna	✓ Temporal analysis on the occurrence of biological species
Readme.doc		✓ Illustration document ✓ To interpret the format and construction process of this database

3.3 Secondary Data Set

The secondary data set were the group of worksheets containing records transformed from the primary data set via certain analytical procedures. There were two types of worksheet (6 in total) in the secondary data set. IDList, SrcList, and LocLIst belonged to “structure” sheets, which were only modified as the change and increment of data. IntAna, TSAna, and SpAna were named “analytic” sheets, which were produced after certain data analysis from the primary data set (Table 1).

There were 335 records in SpList which indicated the total number of biological species occurred in the ASIC (Table 2). There were 355 and 155 records in TSAna and IntAna respectively, which summarized the temporal and spatial interaction between biological species in the ASIC. In addition, there were 12, 4, and 12 records in LocList, SrcList, IDList respectively to conclude the localities, data sources, and data types (Table 2).

Table 2 Number of records in the Species Inventory System from 2003-2007

PrimaryDataSet.xls		SecondaryDataSet.xls	
Worksheet	No. record	Worksheet	No. record
Reports	114	SpList	335
BibList	153	TSAna	355
FigList	195	IntAna	155
ArtList	302	LocList	12
AMList	0	SrcList	4
		IDList	12

3.3 Spatial and Temporal Analyses

Between the beginning operation of the ASIC and February 2007, data were collected and analyzed by space and time. The number of species was the most in the VPS (89), which included many plants introduced by residents. Animal species were attracted by those plants as their symbionts (Table 3). There were 48 species occurred in the 3rd floor with horticultural boxes and vine shelves (Table 3). Additionally, there were 1, 11, and 7 species occurred in the second floor, first floor, and basement respectively.

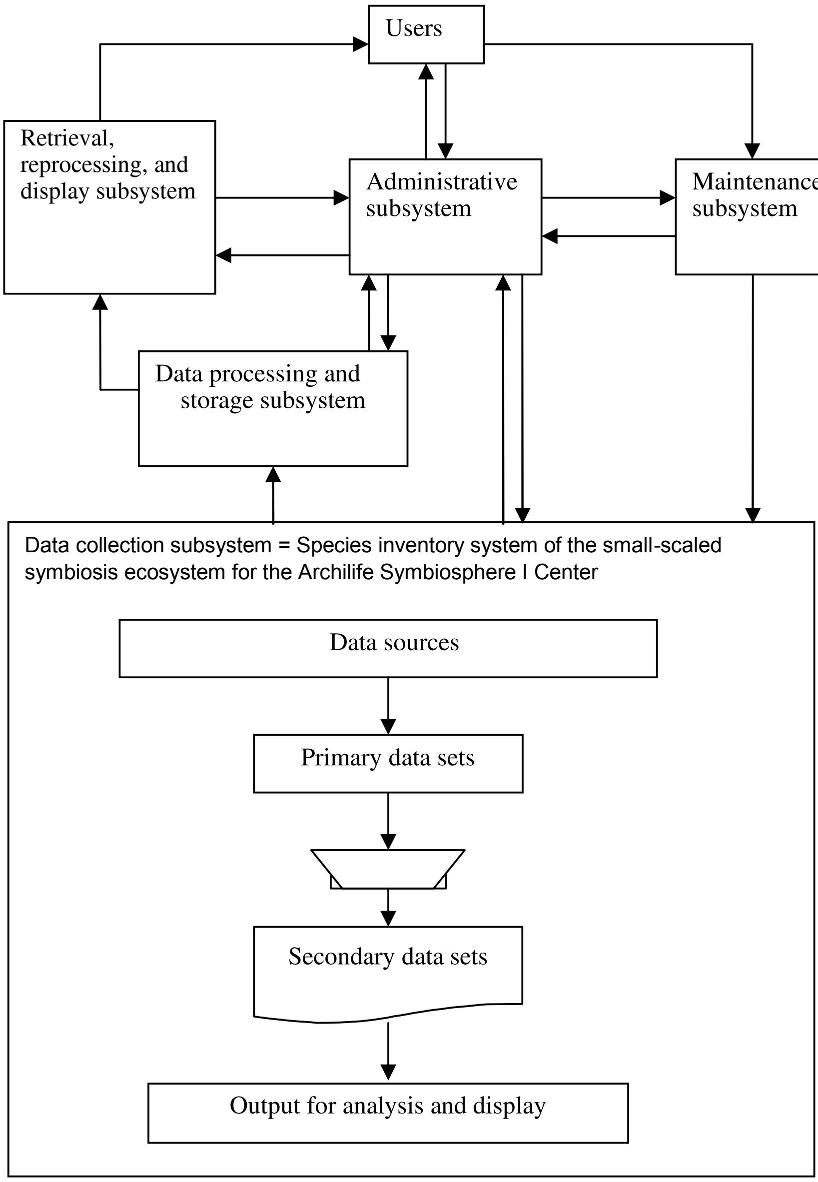


Figure 1 The process of species inventory system of the symbiome for the Archilife Symbiosphere I Center

Table 3 Spatial distribution of number of species recruitment in the Archilife Symbiosphere I Center

Space	No. records	No. Species recruitment
Vertical Planting System	151	89
Attic	3	3
3rd Floor	85	48
2nd Floor	1	1
1st Floor	16	11
Basement	7	7
Fish Pond	14	2
Other	3	2

Spatial effect on the distribution of species occurrence was also able to analyze (Table 4). The number of species introduced into the ASIC was different upon seasons and years. The recruitment of new species was declining year by year. In spring they were the greatest in spring 2003 and 2004; however, were the greatest in autumn 2005 and 2006 (Table 4).

Table 4 The seasonal and yearly variation of species recruitment in the Archilife Symbiosphere I Center

Year	Spring	Summer	Autumn	Winter
2003	53	32	17	11
2004	48	18	5	1
2005	1	8	13	7
2006	8	8	19	2
Total	110	66	74	21

4. Modeling of a Symbiotic System

The concept of symbiome originated from a human-centered prototype which was described by President J. H. Lin of the ARF (Fig. 2A). Symbiosis has been gradually understood as the driving force and mechanism of biological evolution recently (Margulis and Fester 1991).

4.1 Deficiency of Classical Energy-based Ecosystem Model

The biotic community in an ecosystem usually gathers more than 2 biological species. However, 6 basic types of interactions between 2 species have been recognized (Table 5: May 1973; Putman 1994); i.e., mutualism (+ +), commensalisms (+ 0), exploitation (+ -), neutralism (0 0), Antagonism (- 0), and competition (- -).

Most models of ecological systems based solely on prey-predator relationship, a subtype of exploitation. Mutualism and commensalisms have seldom been considered in any ecological system theory. Only prey-predator relationship was recognized as links between compartments in the previous energy-based ecosystem model. Twenty-four attributes were considered to illustrate the development of ecosystem, which were all based on the concept of Bioenergetics (Odum 1969). However, according to the symbiotic continuum theory (Starr, 1975), links between species should be all kinds of biological relationship, which included both positive and negative ones. Only few ecologists noticed above theoretical deficiency (Kareiva and Bertness 1997; Sapp 2004). Stability of a system depends on its week link rather than the strong ones according to theory of small world network (Watt 1999).

Table 5 Types of biological interactions (May 1973; Putman 1994)

		Effect of specie j on i (i.e. sign of a_{ij})		
		+	0	-
Effect of specie i on j (i.e. sign of a_{ji})	+	+ +	+ 0	+ -
	0	0 +	0 0	0 -
	-	- +	- 0	- -

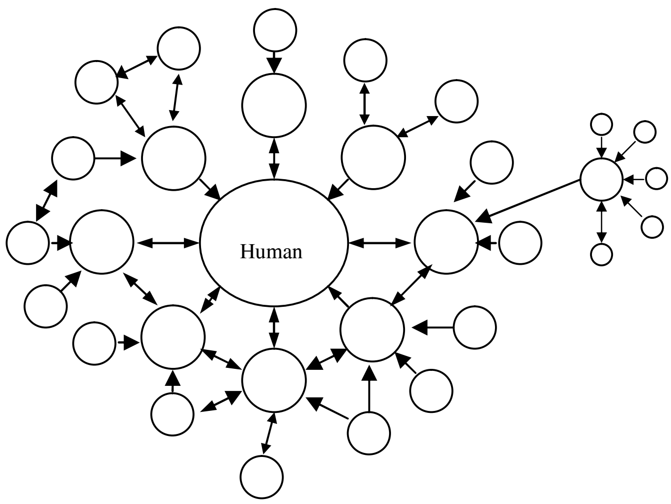
4.2 A Systematic Model Building by the Viewpoint of Symbiosis - Symbiome

A human-centered model (Fig. 2A) rephrased the concept to a human-residential environment, which was very different from the traditional ecosystem model (Table 6). According to the “symbiotic continuum”, the greatest fitness of life history strategy through evolutionary process decided the type of interaction between two biological species (Starr, 1975).

“Symbiome” indicates originally a biological system that organisms (animals, plants, and protists) live closely with micro-organisms (Sapp 2004). On the other hand, endo-symbiosis hypothesis reveals that the complex organisms are a symbiotic system of simple organisms (Margulis and Fester 1991). Therefore, a symbiotic system is a super-organism consisting of many symbionts which has greatest fitness for all kinds, within the abiotic environment. Once the interaction between two species begins, it indicates a simplest symbiome has been formed. The process of expansion of symbiotic system is named “symbiome development”, while the recruitment and extinction of symbionts is called “symbiome assembly”.

Figure 2B illustrates the hierarchy structure of symbiome. Human is in the core. Crop species of plants are “major symbionts” in the primary layer. Human gets benefit by having foods, while crops obtain a secure survival environment. The symbionts of a major symbiont are “co-symbiont” in the secondary layer, which may be the primary consumer, decomposer, bacteria, parasites, and/or habitat-provider of a major symbiont. Any organisms that are the symbionts of a co-symbiont are named “sub-cosymbiont” in the tertiary layer. If human turns out to be a symbiont of certain organism, a small world network may be established.

(A)



(B)

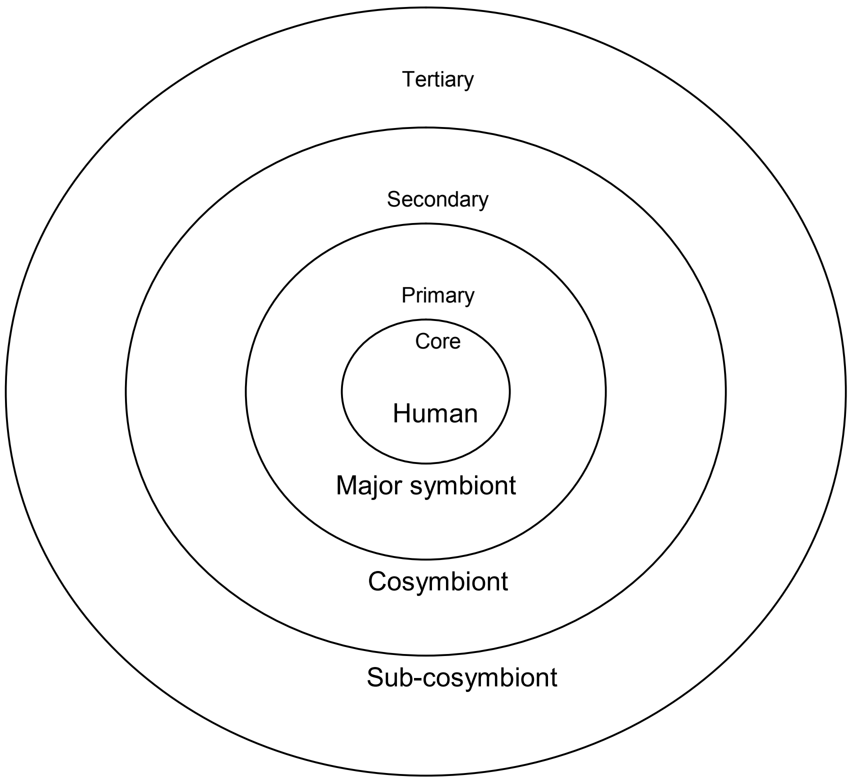


Figure 2 (A) Prototype of the human-centered ecosystem model. Circle indicates symbiotic species. Arrow means formation of symbiosis. Two headed arrow represents obligatory symbiosis, while one headed arrow indicates non-obligatory. (B) Concentric model illustrates the hierarchy of symbiome.

4.2 Interactions among Organisms – Symbiolink

Many biological relationships have been neglected by the energy-based ecosystem model, which only link species with negative interactions (predation). Symbiolink includes positive and negative interactions to form a symbiotic system or symbiosystem (Table 6). Ecosystem consists of biotic and abiotic portions, while symbiome connects biological species with symbiolinks and encloses biotic portion with abiotic environment. Biome is a large ecosystem in a geographic scale, which contains typical animal and plant communities. A large symbiotic system is defined as “symbiome”. Biosphere refers to the range of all organisms on the earth, which symbiosphere indicates the union of all symbiomes.

Table 6 Comparison between energy-based ecosystem (Odum 1997) and symbiotic system

Odum's energy-based ecosystem	Symbiotic system
Biosphere	Symbiosphere
Biome	Symbiome
Ecosystem	Symbiome/Symbiosystem
Interspecific interaction	Symbiolink

4.3 Symbiome and Small World Network

Small-world network is a type of mathematical graph in which most nodes are not neighbors of one another, but most nodes can be reached from every other by a small number of hops or steps. Simplest graph of graph theory indicates the relation of two vertices and one edge. Simplest graphs of graph theory were adopted to build the model of a symbiome. Circle indicated actor and square indicated reactor. The direction of arrow indicated the benefit side (+), and dash line indicated a "00" relationship. Directed graph represents the mutualism, commensalisms, and predation in symbiome, while undirected graph indicates neutralism. If there are N species of symbionts (vertices) in a symbiome (a ring lattice), every species has k symbiolinks (edges) to others. Stability and strength of symbiolinks of a symbiome may be measured with parameters of its particular graph.

5. Realistic Symbiome of the Archilife Symbiosphere I Center

Gynura bicolor was the most abundantly eaten species among 56 species of major symbionts in the ASIC during 2003 to 2006. To illustrate primary and secondary layers of this symbiotic system, the simplest graph of madeira vine (*Anredera cordifolia*) was shown (Fig. 3). Relationships of major symbiont and cosymbionts were illustrated with the analysis of biological association among crops at vine shelves in the ASIC (Fig. 4). Nine out of 28 species co-existed as a big community (Fig. 4). Two sub-communities were recognized, i.e. "lavender sorrel-Asiatic centella" community and "oil grass-vegetable fern" community. The species on the VPS were also analyzed, which were not shown in this paper.

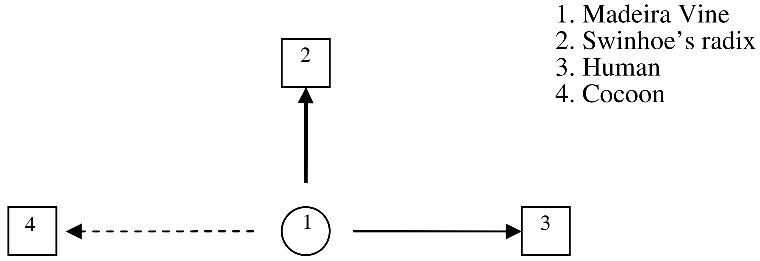


Figure 3 An example expressed relationships among major symbiont (Madeira vine) and its symbionts in the symbiome of the Archilife Symbiosphere I Center. This realistic model adopted simplest graph diagrams. Circle indicated actor and square indicated reactor. The direction of arrow indicated the benefit side (+), and dash line indicated Neutralism (00). There were 7 records from the secondary data set of the species inventory system to generate this diagram.

All crop species are symbiosis with human being and every species has its own symbionts (such as insects and microorganisms). Analysis of biological association clarified the relationships among crops in the first step.

6. Conclusions

The appearance of biological species in the developing process of a symbiotic system might reveal the mechanism of symbiosis. Observations were made and data were collected by the residents. The requirement of a coder for the species inventory system was being familiar with the building structure and its operation, and being capable to use Microsoft Excel, which a common college student can operate. Therefore, a college resident, who living in his/her specific symbiotic community (or a green village), will be able to do the coding and/or the database manager.

After an inventory net work being established, primary data sets will come from different symbiotic communities. Even data from different countries can also be gathered via internet. Only a few analyzers and database managers are needed. This DBMS may become one of the most efficient GBTools to evaluate the status and the degree of symbiolization for a specific green village.

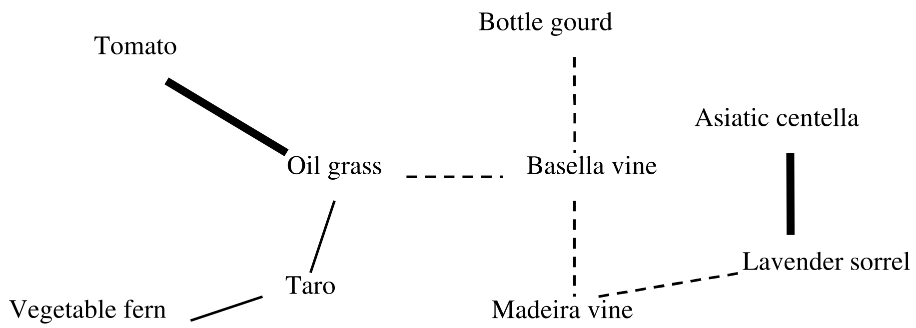


Figure 4 Biological association of crops in the vine shelves of the Archilife Symbiosphere I Center. Solid line indicates the positive association (v>0, p<0.05), while broad solid line indicates strong positive association (v>0, p<0.01). Dash line indicates negative association (v<0, p<0.05).

The key difference between the model of symbiotic system and classical ecosystem is that the relationships of individual species are not only predation but also all positives ones. The parameters to examine the status of a symbiome would be degree of link, stability of community, network efficiency, etc. Therefore, comparison between the symbiome of different symbiosis villages turns out to be achievable. In addition, this brand new concept about human ecosystem would be principles for ecological rehabilitation of an eco-city.

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New economic incentives for sustainable building: Density bonuses and domestic carbon project

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Keywords: density bonuses, carbon trading, economic incentives, eco-conditionality

Abstract

Land use density bonuses and the implementation of domestic carbon projects in the building industry attest to the rise in prominence of an entire panoply of economic incentive tools, such as preferred mortgage loans, the "eco-conditionality" approach to subsidies and energy performance contracts. These instruments serve to complement the range of purely regulatory or fiscal tools for overseeing sustainable construction practices.

1. Land use density bonuses

1.1 Description of the tool

The planning instrument of granting land use density bonuses on building permits is being increasingly applied in various international contexts. A number of Swiss cantons have adopted this instrument in order to promote the construction of buildings that comply with the *Minergie* energy quality label. Other cities across the world, like Arlington County, Virginia and New York City in the United States, have introduced comparable measures revolving around broader environmental criteria.

The 2005 Energy Law in France provides municipalities with the possibility of increasing land use density ratios (building coverage ratios, i.e. the net floor area derived from use of the maximum building footprint allowable on a given parcel divided by the total parcel land area) by up to 20% for energy-efficient construction that relies on renewable energy sources. This net floor area is calculated without including attic or basement space that could not be made suitable for human habitation, nor does it include roof terraces, balconies and loggias.

The application conditions for this density bonus measure were stipulated in a May 2007 decree, which states: "New clustered construction must satisfy a very high-performance energy efficiency standard specifically dedicated to renewable energies (or "THPE Enr") or low-energy consumption buildings ("BBC", on the order of 65 kWh of primary energy / m^2 / year of net surface area in northern France for heating, cooling, air conditioning, domestic hot water and lighting consumption). New single-family homes must consume 20% less energy than the specified thermal regulation amounts and introduce alternative options from among wood sources, photovoltaic cells, solar hot water and a heat pump with an annual performance coefficient exceeding 3.5. For existing buildings, the planned extension must be aimed at achieving energy neutrality, with an overall insulation of upper floors under the attic space and the installation of facilities adapted to wood, photovoltaic, solar hot water or a heat pump set-up. A solar hot water system must cover at least 50% of total needs, i.e. 3 m^2 per housing unit. The photovoltaic modules must account for at least 25 kWh/m^2 of the net floor area, or a surface area equal to 10% of the net floor area.

Beyond just the energy performance conditions, other parameters in the land use plan may be enhanced by means of conditional waivers or in percentage terms (e.g. increase in building height), according to environmental criteria:

- accepting a waiver on the number of mandatory parking spaces in the event of installing a structure to accommodate bicycle parking, which could reduce the need for underground parking by 20% to 50%, depending on the specific context. This could potentially represent one less underground parking level;
- raising the ground coverage ratio (i.e. the percentage of building footprint with respect to the land area of the parcel designated for construction) for dwellings that incorporate a rainwater recovery device; and

- including a range of greened surfaces (e.g. roofs, decks, walls) to help meet the green space requirement on the designated parcel.

1.2 Application examples

This land use density bonus instrument was initially presented to planning directors of 7 municipalities within the Paris Region participated in a series of workshops organized in 2006 by the ARENE regional agency (for the environment and new energies), in partnership with ADEME (Agency for the Environment and Energy Recovery). Since May 2007, several municipalities from the region have also decided to introduce the measure, led by Paris, Bry-sur-Marne and Issy-les-Moulineaux.

Bry-sur-Marne is a very residential suburb located 12 km from Paris with a population of 15,000. The municipal council has authorized a 20% increase in land use density for all single-family type residential zones as well as mixed-use areas with a housing concentration. Four building permits have already been approved with the land use bonus: they concern subsidized multi-family units that have been targeted for additional insulation beneath the roof and double-glazed windows, as well as solar panels for domestic hot water. In practical terms, this possibility of awarding bonuses actually represents one additional building story (i.e. from a 5-story to 6-story building).

1.3 Outlook for sustainable construction

The benefits of building density bonuses are numerous:
- more stringent sustainable construction requirements: the tool serves to introduce demanding energy and environmental performance requirements in construction projects, especially from the standpoint of the "Factor 4" energy policy (i.e. a fourfold reduction in greenhouse gas emissions by 2050);
- a "win-win" strategy: the inherent incentive principle allows rewarding good environmental practices. The classic objection of "investment overruns" is no longer valid thanks to the economic benefit tied to the number of additional m^2 available to project owners for construction. The total cost drops, while the building use value increases and future occupants take advantage by saving on charges.
- a modular tool, in favor of urban renewal: this instrument applies to all existing urban layouts and not just development projects underway in newer districts. It meets the diversity of land use situations and enables proceeding with "customized approaches" depending on planning priorities adopted by municipalities and the level of environmental awareness shown by the local population;
- an easy-to-implement operational tool: it serves the purpose of translating into practical terms the city's environmental objectives at the construction project scale, with a simple activation process (municipal council deliberation);
- an innovation-enhancement tool: municipalities are able to develop new building projects and renovations with truly exemplary qualities. Such a tool incites cross-disciplinary approaches rallying municipality departments around a common project. This aspect provides an initiation for both decision-makers and professionals to energy and environmental performance issues;
- a contribution to both local and global environmental objectives: the resulting projects contribute to combating the greenhouse effect, conserving water and non renewable energy resources, and improving the environment from a local perspective;
- a valuable action lever during this transitional period: the tool offers the possibility of making progress with motivated actors, without having to wait for a consensus opinion and for the group of economic actors to accept mention of imposing strict energy and environmental requirements in urban planning documents.

Moreover, this measure favoring higher building coverage ratios lies within a general framework for raising density and fighting against urban sprawl, by targeting a greater urban dynamic in optimizing urban networks and services through the guarantee of ecological buildings intended not to compromise lifestyle quality.

As part of recent work conducted at the time of France's multi-party environmental debates, it was decided to generalize, based on experience gained from the land use bonus, these incentive measures on the planning code in order to support sustainable construction, and to raise the possible land use density until 30%.

A reasonable hypothesis calling for adoption by 50% of France's municipalities over the time frame through 2012, then reliance upon the bonus in 50% of building permit applications, would lead to a direct savings of 500,000 tons of CO_2 out to 2012 in all of France (based yearly on one ton of CO_2 saved per new or refurbished dwelling or office).

2. Domestic carbon project

2.1 Description of the tool

In France, just a quarter of the greenhouse gas emissions, accounting for 132.8 million tons of CO^2, are actually covered by the European quota exchange system, within the scope of the national quota allocation plan. Sectors of diffuse emissions, such as the construction, are exempt. A domestic "building" project, pertaining to new construction or energy-oriented building renovations, provides the potential for reducing greenhouse gases throughout the entire nation and, as such, is eligible to generate revenue stemming from the sale of carbon credits. These projects are categorized as joint implementation (JI) from the standpoint of the Kyoto Protocol, i.e. they make it possible for economic actors from one country to contact partners in other industrialized countries in order to yield emission reduction units (ERU) that may be sold on the international market.

Several conditions need to be fulfilled for any given domestic project:

- Reductions in greenhouse gas emissions must be realized during the period 2008-2012;
- The project cannot focus on installations with a power rating of more than 20 MW in order to avoid "double counting" with the national allocation plan;
- Cumulative project components, which means that the project could not be conducted under satisfactory economic conditions without the contribution of carbon credits;
- The project sponsor must make use of an efficient tool for regularly tracking emissions, in the aim of accurately evaluating the quantity of $C0_2$ actually avoided;
- Validation of emission calculation methods by the joint ministerial mission to combat the greenhouse effect.

In France, the *Caisse des Dépôts et Consignations* (a public-sector financial institution) launched a call for projects at the end of 2007 as a means of inciting use of this new economic instrument for an investment envelope of 5 million tons of CO_2 equivalent over the period 2008-2012, with an average redemption price on the order of € 10 per ton of carbon. Around 20 projects in all sectors have been already selected, representing more than 2 million tons of $CO_{2.}$

For the building industry, the potential target in terms of actual projects would be in the range of 20 million tons of CO_2 for the 2008-2012 period, on the basis of a theoretical total deposit of 90 million tons of CO_2, i.e. 4 to 5 million tons for the Paris Region alone, which represents some 15% of all emissions from the residential and tertiary sectors. Among these high-potential target projects would be the reduction in HFC emissions by means of fluid substitution or refrigeration installation change, improvement in tertiary building management or the introduction of biomass boilers.

2.2 Application examples

Two major categories of projects can be distinguished in the Paris Region: those centered on making energy supply modifications to buildings, and "CO_2 dedicated" programs:

- shifting in favor of renewable energies for building heating. Given a boiler with a 1 MW power rating, the transition from gas supply to biomass will allow saving approximately 1,500 tons of CO_2 equivalent in emissions each year. To supply a residential building containing 20 units, the transition to a wood-fired boiler compared with a fuel oil- or gas-fired boiler will generate 25 tons in savings per unit, or for the whole building 500 tons of CO_2 equivalent. The resultant carbon credit would be situated around € 5,000 (i.e. € 10 x 500), or 20% for an investment of € 25,000;
- extending the decarbonized heat networks by means of a geothermal connection for buildings conventionally heated with fuel oil or gas;

- developing, for tertiary office buildings, interest in geothermal heat pumps mounted on piles since residential buildings in the Paris Region sit on a sedimentary basin that often necessitates the installation of piles;
- anticipating, for the set of dedicated CO_2 programs likely to be supported by the Paris Regional Council, a subsidy for either the construction of 500 BBC-certified housing units or the renovation of single-family dwellings resulting in a 50% drop in CO_2 level.

2.3 Outlook for sustainable construction

The advantage of domestic carbon projects is to gain access to both the most sensitive sectors, due to the rise in their emission levels, and the most diffuse in terms of emissions by sending a price signal relative to carbon. The French system, backed by the *Caisse des Dépôts et Consignations*, offers an innovative economic mechanism: it actually represents Europe's first domestic carbon system. Moreover, it incites the "decarbonation" step within economic sectors like construction and urban development, while lowering the total cost associated with emissions reduction. Participation in such projects serves to familiarize economic actors with mechanisms relevant to the carbon markets, which will be expanding over the coming years.

3. Conclusion

Land use density bonuses and domestic carbon projects for the building industry provide two complementary, yet distinct, tools. They open the door to incentive measures that make it possible to reward good practices aimed at generating greater energy efficiency and an improved ecological assessment of the buildings in our environment. Beyond their power of legal, fiscal and public subsidy incentives, these innovative tools serve to revamp the range of economic and financial instruments capable of introducing greater durability into the construction sector from the perspective of "carbon neutrality".

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PROMOTION OF GREEN AND SUSTAINABLE BUILDINGS IN A HIGH DENSITY BUILT ENVIRONMENT

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Keywords: incentives, balance, permeability, set-back, mandatory, heritage, labeling, sustainability

Summary

Hong Kong is a very compact city. The current building law controlling intensity of building development was enacted at a time when the city was undergoing fast economic and population growth. In step with the rising aspirations of our society for improved quality of living space and sustainable built environment, the Government launched an incentive scheme to encourage the incorporation of green and amenity features in buildings. Since then, a number of surveys and studies have been carried out to assess the effectiveness of the scheme and to gauge public views on the effectiveness of these green and amenity features and their impact on the urban environment. To further improve the living environment, various options are being considered, including lowering development density in congested localities, introducing measures to strike a balance between the provision of green features and their effects on building height and bulk, promoting building set back, and increasing permeability of buildings and greenery. Other initiatives, including providing facilities for separating refuse at source, introducing a mandatory building energy code, promoting and mandating regular maintenance of buildings, supporting a comprehensive green building labeling scheme and promoting adaptive reuse of heritage buildings, which are conducive to the quality of the built environment, are also being pursued.

1. Historical Development

Hong Kong is a very compact city. It tops the world cities on the number of tall buildings. With a population of nearly 7 million, only 21% of Hong Kong's total land area, equivalent to approximately 226 sq. km., is developed or urbanized, with another 2% occupied by rural settlements. The rest are mainly woodland, farmland and other rural uses including over 400 sq. km. of protected country parks.

The current building law governing the intensity of building development was enacted in year 1962. It was a time when the city was undergoing fast economic and population growth. Since then, buildings have continued to grow in size and height, taking advantage of new building technologies and the prosperous economy. Many commercial buildings in the urban areas have been built to the maximum development potential with a total gross floor area (GFA) equivalent to 15 times the size of the building lot. Given limited land resources, the development potential of building projects in most of the urban area is maximized and the city has developed into a compact and vibrant place. The construction of the mass transit railway has further improved the accessibility of the city and makes life more convenient for all.

2. Incentives for Quality Living

2.1 Amenities in Buildings

With a view to promoting the provision of a range of building features and facilities to improve the livelihood of people in a densely populated environment, the Buildings Department has been providing incentives by exempting amenity features from the calculation of GFA in building developments, including for example air-conditioning platforms, counters for management staff, service rooms, mail rooms, horizontal screens, recreational facilities and club houses (Figure 1). Such amenity features, though not required by statute, are desirable to improve the quality of a building and living standard of the residents. Provision of such features enhances the sense of care and pride for buildings, thereby inducing proper maintenance and repair.

Figure 1 Club house (left) and management room (right) are examples of amenity features

2.2 Green Features in Buildings

In step with the rising aspirations of our society for improved quality of living space and sustainable built environment, the Government introduced measures (two Joint Practice Notes for building professionals in year 2001 and 2002) to encourage the incorporation of green features in buildings for the use and well-being of building occupants.

Under the Joint Practice Notes, eleven types of green features were promulgated, namely balconies, wider common corridors and lift lobbies, communal sky gardens, communal podium gardens, acoustic fins, sunshades and reflectors, wing walls, wind catchers and funnels, non-structural prefabricated external walls, utility platforms, mail delivery rooms with mailboxes and noise barriers. Subject to fulfillment of certain specified conditions and design requirements, these green features may be exempted from GFA and site coverage calculations.

2.3 Adoption of Green Features

Up to end of April 2008, a total of over 190 completed residential projects have been constructed with green features in response to and in accordance with the Joint Practice Notes. During the same period, a total of about 560 new building projects were completed. It may be noted that some features are more popular than others: balconies are by far the most popular green features, 95% of these completed projects have balconies, 44% have wider common corridors and lift lobbies and 64% have utility platforms.

It is very encouraging to see that the industry has taken up the green concept beyond the scope of the Joint Practice Notes. The wider use of precast concrete is a vivid example (Figure 2). Despite the adoption of precast concrete in public housing projects since the 1980's, the uptake of this environmentally friendly construction method had been slow in the private sector. However, since the issue of the Joint Practice Notes, the Buildings Department has given approval to nearly 100 projects using precast concrete elements. The industry has used precast concrete not only to facades, but also to other elements that would not require exemption from the GFA calculations. In fact, about 60% of these projects adopt elements such as precast stairs, semi-precast slabs and precast structural elements.

Figure 2 Precast stair (left) and precast façade (right)

2.4 Surveys and Opinions from Stakeholders

Since the promulgation of incentives to encourage the incorporation of amenity features in buildings and the issue of the Joint Practice Notes, a series of surveys and studies have been carried out to gauge the public response and review the effectiveness of the incentive scheme. This encompasses:

- conducting questionnaire surveys with stakeholders;
- carrying out on-site evaluation on the usage of green and amenity features in sample buildings;
- conducting focus group meetings with green groups and the professional institutes;
- conducting public opinion surveys.

The majority of the respondents have highly rated the effectiveness of the green and amenity features in improving the living environment and quality of living (Figure 3). Mandatory requirement for the provision of these features is however not supported as it reduces design flexibility.

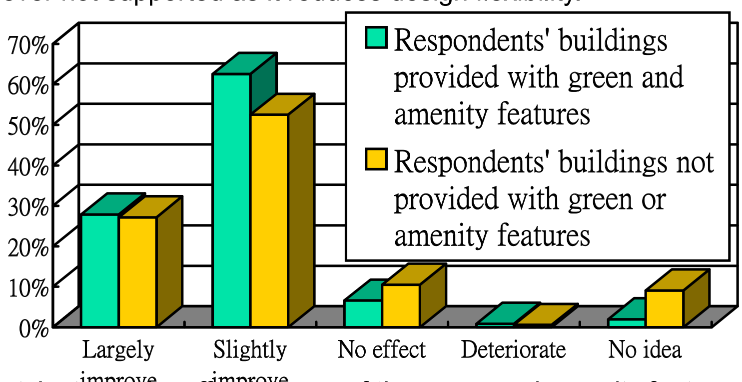

Figure 3 Respondents' rate on the effectiveness of the green and amenity features in improving the living environment and quality of living

There are different views on the impact of the height and bulk of a building on the cityscape of the neighbourhood (Figure 4). Over 60% of the respondents considered that a building which was very tall but occupied a relatively small site area, would be less preferable in terms of its impact on the cityscape and living environment of respondents' neighbourhood, while only around 10% considered a building which was not that tall but occupied a very large site area as less preferable. Protection of important ridgelines and harbour view is also amongst their concerns.

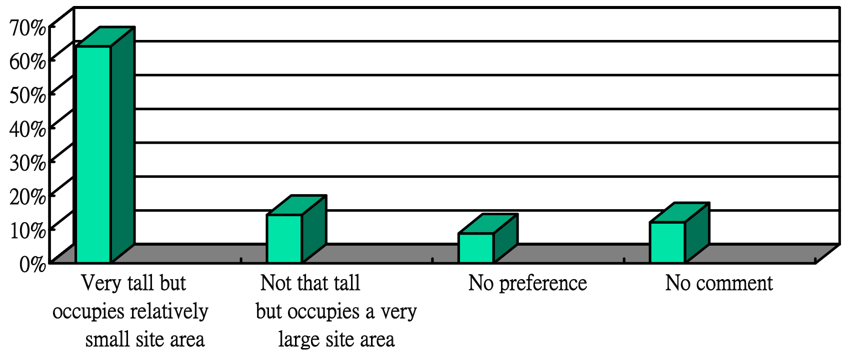

Figure 4 Views on impact of building height and bulk on the cityscape of the respondents' neighbourhood

Many respondents considered it appropriate to exercise suitable control on the amount of GFA exemption. Some have expressed that the magnitude of concessions should be decided after balancing the effectiveness of the incentive and its impact on building bulk.

3. A Balanced Approach

The results of the reviews and surveys have indicated that the incentives are generally effective in promoting the construction of green and innovative buildings. Furthermore, the offer of incentives in the form of GFA exemption is considered to be appropriate and generally welcomed. However, the exemption has an impact on the height and bulk of the concerned building developments. As the city becomes more built up, the effect of high-rise and bulky development is more apparent. It is necessary to take a more balanced approach when granting GFA concessions.

To consider the impact of building height and bulk, it is best assessed by considering the individual building design in relation to its surrounding developments, location and the particular setting of the site or area, the natural topography and the configuration of surrounding streets and pedestrian circulation patterns. Different designs and dispositions of a building, even with the same GFA, may offer different visual and environmental impacts to its surrounding. However, such an assessment entails a complex and lengthy process. It is also site specific and may not fully address district wide concerns.

Another approach is to take a broader view by first reviewing the planning restrictions on development densities and height profiles of the sites and areas and, secondly, reviewing the amount of GFA concessions that may be suitable for different types and densities of development and finally, identifying desirable building forms and configurations that may improve pedestrian comfort and enhance the environment of the surrounding areas.

3.1 Development Densities and Height Profiles

There are many advantages living in a compact urban development. With the associated mixed uses and use of mass public transport, especially rail-based systems, a compact urban development would minimize road traffic and help preserve the rural hinterland from urban sprawl. It can achieve greater energy savings with more efficient utilities services and infrastructural support. However, a high-density built environment may also lead to urban problems, such as stagnant air and heat island effect.

3.1.1 Outline Zoning Plans

To strike a balance between development needs and creation of more open space and less densely built environment, the Government has been reviewing and is undertaking a comprehensive review of the extant statutory Outline Zoning Plans to stipulate additional development restrictions, where justified, for all to follow. Such restrictions may be in the form of lower development density and stepped building heights that may help preserve views, provide visual and spatial relief and achieve wind penetration and circulation. Review priority will be given to those areas subject to high development or redevelopment pressures, waterfront areas along the Victoria Harbour and congested built-up areas. Up to June 2008, 13 revised plans have been published to incorporate building height and/or development density restrictions and concerned parties can voice their views on the proposed amendments.

3.1.2 Lease Conditions

Furthermore, the Government will examine each major sites to be sold carefully and may specify in the Conditions of Sale development parameters like building height limits, maximum GFA and site coverage, setback, non-building areas or open space provisions, where applicable. The Government has also conducted various air ventilation assessments so that any appropriate development restrictions arising from such assessments could be incorporated in the sale conditions.

3.2 GFA Concessions

When reviewing GFA concessions, the Buildings Department is exploring various options to address the concerns of different sectors on the impact on building height and bulk. Such options should strike a balance between the impact of GFA concessions on building height and bulk on the one hand and, on the other hand, the need for the provision of green and amenity features and basic and essential facilities in modern buildings as well as compensation for dedication or surrender of private land for public use.

Measures to reduce the impact of the GFA concessions on building height and bulk that are being explored include:

- reviewing the size of individual green and amenity features such as the sky gardens, podium gardens and recreational facilities;
- reviewing the overall amount of GFA concessions in relation to the size of the development;
- assessing the benefits of combining sky gardens with refuge floors where practicable to help reduce the overall building height;
- assessing a maximum headroom restriction for sky or podium gardens (Figure 5), as preliminary findings of an air ventilation assessment study indicate that the additional positive effect on air ventilation performance tends to diminish when the clear headroom of a covered garden reaches a certain height .

When reviewing these options, tools such as air ventilation assessment survey (Figure 5) and photomontages are adopted to help compare the general effect of building height and bulk on air ventilation and visual impact to the surrounding area.

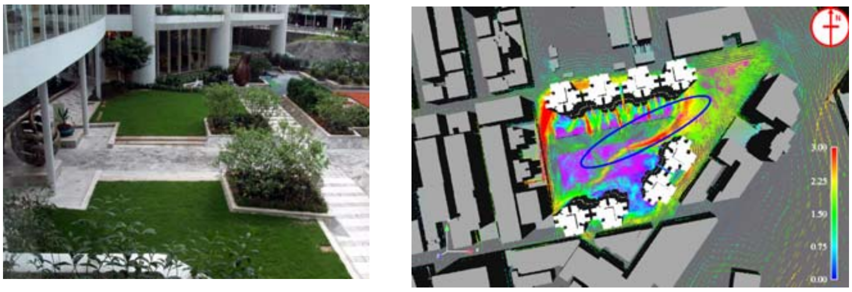

Figure 5 Podium garden (left) and air ventilation assessment survey (right)

3.3 Building Design

In addition to the above measures, the Buildings Department has commissioned a consultancy study entitled "Building Design that Supports Sustainable Urban Living Space in Hong Kong". Results of the consultancy show that better building designs can help reduce the visual and spatial impacts posed by tall and bulky buildings. Better building designs can also help improve the air ventilation between buildings and hence the urban living environment. Recommendations put forward by the consultant that are being considered for application in new development sites include:

3.3.1 Building permeability

Increased building permeability can provide “air paths” through the development site to the neighboring areas (Figure 6). Building permeability may be provided in the form of building separation and by stipulating a maximum permissible length of building facade. Easy-to-use guidelines may be established by making reference to the length of adjoining building facades and the width of the adjoining streets. Design flexibility is given by permitting the use of air ventilation assessment to determine an equivalent performance.

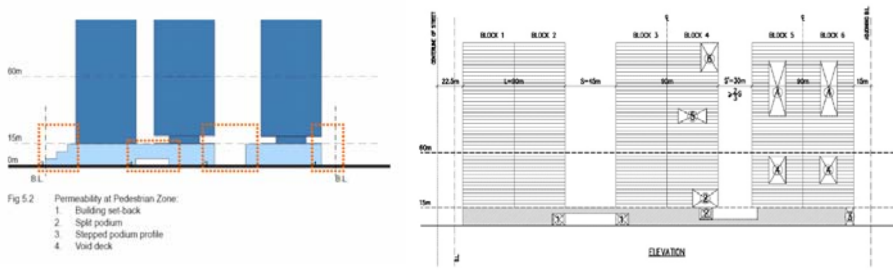

Figure 6 Permeability study diagrams

3.3.2 Building setback

Building setback can help mitigate the deep street canyon effect and hence improve the pedestrian environment (Figure 7). A critical part of air volume affecting the pedestrians at street level has been identified and focus is placed on the improvement to the air volume at this pedestrian zone. Such building setback requirement may be particularly applicable to development sites abutting narrow streets.

3.3.3 Greening

Greenery can mitigate the heat island effect and enhance public health and amenities (Figure 7). Different requirements on the amount of planting area may be applied to different sizes of development sites.

Figure 7 Building setback in Causeway Bay, Hong Kong (left) and a green park in the heart of the dense urban district (right)

4. Legislative Measures

Green buildings do not stop short at the design and construction stage. They should facilitate occupants' pursuit of green life styles and, through regular maintenance, be sustainable to withstand the test of time.

Experience has shown that the offer of incentives in the form of GFA concessions is effective in promoting certain green and amenity features as described above, but not all, in particular those requiring continuing maintenance and management throughout the operational phase of a building. Furthermore, despite the offer of various financial incentives and technical and social support, some owners of existing buildings are reluctant to take up regular inspection and maintenance of the buildings which could lengthen the life cycle and sustainability of a building.

The Government is proposing various legislative measures to help promote a sustainable built environment as detailed below.

4.1 Refuse Storage and Material Recovery Room

There is an imminent waste problem as the landfills in Hong Kong will be running out of space in the early to mid 2010's. To reverse the rising trend of waste requiring disposal, the Government has been taking various measures to promote waste reduction and enhance source recovery of waste for recycling. Through source separation and other complementary measures, the domestic waste recovery rate has increased from 14% in 2004 to 23% in 2007.

A major problem encountered in implementing the source separation of domestic waste programme is that the majority of domestic buildings in Hong Kong do not have a refuse storage and material recovery room on every floor and there is often a lack of space for placing waste separation facilities. Although the building laws have been amended in 2000 to allow such facilities be disregarded in the GFA calculation, it is noted that few new building developments have provided such facilities.

The Government has therefore proposed to amend the building laws to make the provision of refuse storage and material recovery room on every floor a mandatory requirement for new domestic buildings and the domestic part of new composite buildings. Such legislative amendment was passed on 12.7.2008 and the amendment regulation will come into operation on 1.12.2008. Apart from facilitating the recovery of recyclable materials, the provision of a refuse storage and material recovery room on every floor of buildings can also help to alleviate potential fire hazards and hygiene problems.

4.2 Building Energy Codes

There is a strong link between energy consumption and emissions of greenhouse gas. About 50% of the energy consumed was electricity consumption, of which 89% was for buildings. As electricity generation is the single largest source of air pollution in Hong Kong, it follows that improving energy efficiency would also help improve local air quality. It also makes economic sense for the community as a whole to make higher upfront investment in energy-efficient installations which will be more than compensated by the subsequent saving in electricity bills.

However, since 1998 when the Government implemented a voluntary Hong Kong Energy Efficiency Registration Scheme for Buildings, only very few non-government premises have come forward for registration. As voluntary compliance with a higher energy efficiency standard appears not to be forthcoming and amidst growing environmental concerns, there is a need to pursue mandatory implementation of the building energy codes. A public consultation has been conducted early this year and results of which are being compiled. In the meanwhile, the Government will continue with its various energy efficiency initiatives, such as stepping up publicity and educational efforts to change consumers' perception and to encourage the public to take actions to save energy.

4.3 Mandatory Building and Window Inspection Schemes

Since 2001, the Buildings Department has intensified the enforcement actions and embarked on a number of large-scale operations to clear unauthorized building works and repair defective drains and buildings. Results have been encouraging, but government actions have its limitation and active participation of the public will improve efficiency. Afterall, proper maintenance of buildings and premises is the ultimate responsibility of building owners.

To attain a long-term solution to the problem of building neglect, the Government has conducted a series of public consultation and is currently developing a legislative amendment proposal to introduce a mandatory building inspection scheme and a mandatory window inspection scheme.

When developing these schemes, the Buildings Department has reviewed its policy from the owner's perspective and has aimed to strengthen all the support services and assistance available to owners. A Code of Practice will set out the control mechanism, the site supervision requirements and the inspection and repair standards clearly and systematically so that the quality of work can be guaranteed.

To complement the scheme, the support of a non-government organization with special expertise in building management and maintenance, the Hong Kong Housing Society, has been solicited to provide assistance to owners in need. The Housing Society has committed a total of $4 billion to put in place a range of financial incentives, technical support and assistance throughout the rehabilitation process from pre-inspection stage to final completion of rectification works.

In addition, the Buildings Department currently operates a $700 million Comprehensive Building Safety Improvement Loan Scheme that offers low interest or interest-free loans to those owners in need. On top of this, the Government has recently allocated a capital grant of $1 billion for the next five years to establish a Building Maintenance Grant Scheme for Elderly Owners. The objective is to provide financial assistance to eligible elderly owner-occupiers for timely building maintenance and repair and again, the Hong Kong Housing Society will help implement the Scheme.

In the meanwhile, the Buildings Department will strive to continue its enforcement work, in particular against uncooperative owners in the removals of unauthorized building works in order to assist other owners or the owners' corporations to organize building repairs.

5. Green Labelling

Promotion of green and sustainable buildings will be incomplete if there are no benchmarks to help building professionals, the industry and the public to measure the performance achieved and to give recognition to exemplary buildings. Two schemes are being developed and the Government is lending its support to both schemes.

5.1 Voluntary Building Classification Scheme

The Hong Kong Housing Society and related bodies are working on a Voluntary Building Classification Scheme (VBCS) that is specially designed to give positive recognition to properly maintained and well-managed buildings. It focuses on the satisfactory maintenance and management of existing buildings to ensure health and safety to occupants and the public. Buildings accredited with good ratings under the VBCS are proposed to be exempted from the proposed mandatory building inspection scheme.

5.2 Integrated Building Environmental Assessment Method

Features of an existing assessment scheme, the Hong Kong Building Environmental Assessment Method (HK-BEAM), are being refined by incorporating the desirable features of the Comprehensive Environmental Performance Assessment Scheme which was previously developed under a consultancy commissioned by the Buildings Department. Upon completion of various enhancements, this will be an integrated building environmental assessment model for the local construction industry to give recognition to efforts made for greening throughout the life cycle of a building.

6. Adaptive Reuse of Heritage Buildings

Cultural life is a key component of a quality city life. It is also indispensable in any sustainable society. As Hong Kong develops progressively with some of its old and historic buildings replaced by modern ones, people are aspiring for better quality living and, in recent years, have expressed passionately to the conservation of historic sites and buildings.

To demonstrate the Government's commitment to heritage conservation, a comprehensive package of measures has been launched. In February this year, the Government introduced a Partnership Scheme to revitalize historic buildings in public ownership (Figure 8). Under the Scheme, stakeholders and the public are engaged to submit proposals for using these buildings to provide services or business in the form of social enterprises. For the first phase, a total of seven historic buildings have been identified. The response from the public is overwhelming and 113 proposals have been received from various non-profit-making organizations. The Government will provide professional support for successful applicants to take forward their proposals in the areas of heritage conservation, land use and planning, building architecture and compliance with building laws. Where justified, financial support will also be provided.

Figure 8 Lui Seng Chun (left) and Lai Chi Kok Hospital (right) are examples of historical buildings under Partnership Scheme

In addition, the Government has set up an Office of the Commissioner for Heritage to provide a focal point to take forward heritage conservation work. The Buildings Department has also recently set up a dedicated team, the Heritage Unit, to help process submissions related to heritage buildings, to provide technical advice to practitioners and other Government departments and to expedite pre-submission enquiries so that any issues relating to heritage conservation and compliance with building regulations could be resolved at the earliest opportunity. The Unit has also been tasked to prepare guidelines for adaptive reuse of heritage buildings to meet the required health and safety standards.

7. Concluding Remarks

The Government has been engaged in a continuing multi-pronged programme of promoting green and sustainable buildings in Hong Kong. The offer of incentives has encouraged building professionals and developers to enhance facilities and offer a plethora of green features to new building developments. When implementing the incentive scheme, due regard has to be given to the impact on the building height and bulk. Through good planning, environmentally friendly building designs, green life styles, proper building maintenance and adaptive reuse of historic buildings, people of Hong Kong can truly enjoy all the benefits of living in this high density built environment.

POLICIES FOR IMPROVING ENERGY EFFICIENCY IN THE BUILT ENVIRONMENT

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Keywords: efficiency, policy, emissions, measures, barriers, principles

Summary

This presentation covers the broad policy landscape for energy efficiency in Australia, including the role of buildings in energy consumption and in Australia's greenhouse gas emission profile; existing policies which aim to improve building energy efficiency, and the rationale for incentives to bring forward energy efficiency investment; the complementarity of energy efficiency with other measures to reduce greenhouse gas emissions; and the suite of policies recommended by industry to unlock the maximum energy efficiency potential of the building sector, across regulation, voluntary standards, market mechanisms, targeted financial incentives and awareness raising.

1. The opportunity for smarter energy use to reduce emissions

Becoming smarter about energy use is a proven method for households, government and businesses to benefit financially while reducing environmental impact. The Federal Government recognises that smarter energy use is Australia's most cost-effective means of reducing greenhouse gas emissions (Securing Our Energy Future, 2004). Not only does smarter energy use lower the cost of reducing greenhouse emissions, it reduces the costly network infrastructure investments otherwise required to meet growing demand. ABARE estimates that energy consumption (gas and electricity) will increase by 60% over the next 25 years under a "business-as-usual" scenario. The required increase in electricity generation to meet our growing power needs is expected to be 62% from 252 TWh in 2004/5 to 408 TWh in 2029/30.

Around the developed world expert analysis (including the International Energy Agency and UK Stern Review) indicates that improved energy efficiency offers large potential for greenhouse abatement at a positive financial return. This potential is especially large in Australia as its performance in energy efficiency has lagged the rest of the world. As recognised by the State Governments National Emissions Trading Discussion Paper (2007) and the report of the Federal Taskforce on Emissions Trading (2007), programs targeted at energy efficiency will also lower the economic cost of a given greenhouse emissions cap.

The economic potential of smarter energy use has been extensively modelled as part of developing the National Framework for Energy Efficiency, which has shown that 50% penetration over a 12 year period of a low energy-efficiency improvement scenario (excluding the electricity supply sector) delivers the following economic benefits:

- Real GDP would be $1.8 billion higher (+0.2%)
- Employment would increase by around 9000 (+0.1%)
- A 9% reduction in stationary final energy consumption (-213 PJ)
- A 9% reduction in greenhouse emissions from the stationary energy sector (-32 MT).

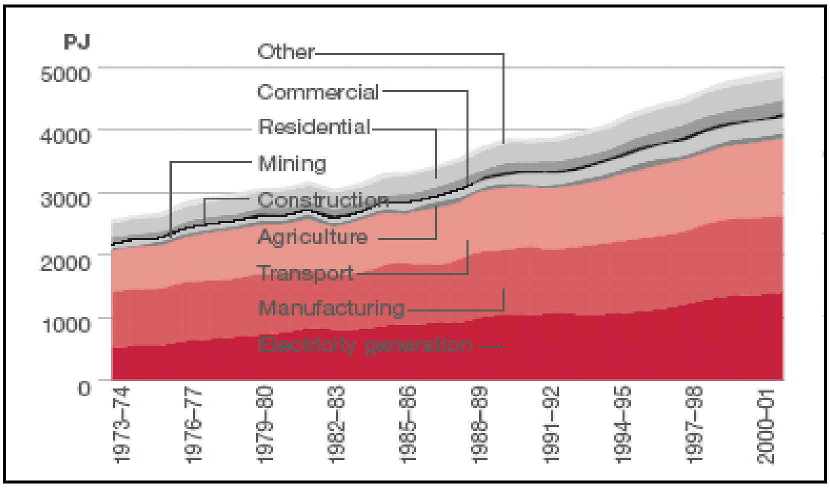

Figure 1 Australian Primary Energy Consumption by sector, 1973-74 to 2000-01

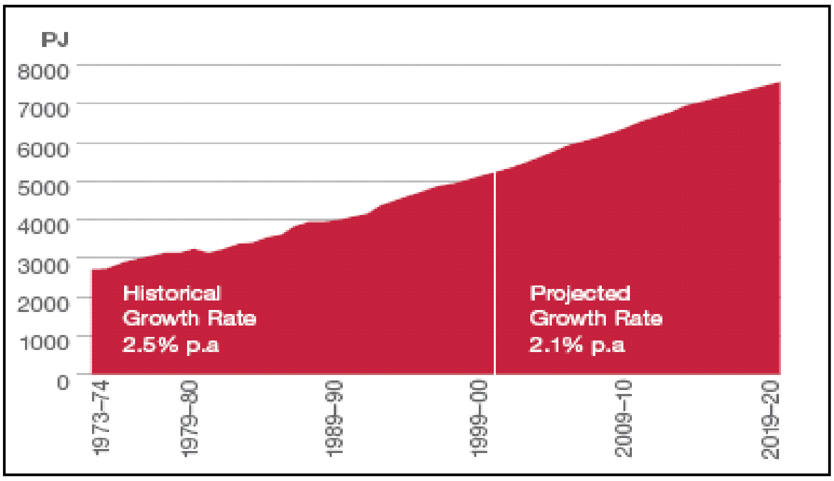

Figure 2 Australian Primary Energy Consumption – historical and projected

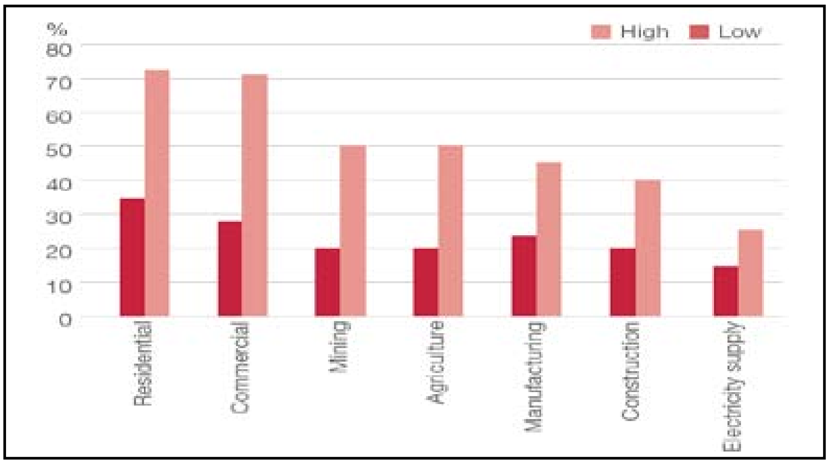

Figure 3 Cost–effective energy consumption reduction potential across sectors - NFEE analysis on percentage cost-effective energy consumption reduction. Low = currently commercially available technologies with an average 4 year payback and High = existing or potential technologies with an average 8 year payback.

These figures show that, outside of industrial efficiencies, cost effective opportunities for pursuing energy efficiency are significant. It is estimated that the buildings sector accounts for 23% of national emissions, given that most of our generated electricity is consumed within buildings.

On the other hand, the task of improving energy efficiency is complex. A key challenge in developing a comprehensive coordinated energy efficiency strategy is the diversity of the ways in which energy is used and the ways in which greater energy efficiency can be encouraged.

Szencorp firmly believes that existing building retrofitting must be the clear focus of any mitigation efforts. New buildings make up a tiny percentage of overall building emissions and policies that target them such as incremental improvements to building codes and standards will not provide the scale of momentum required for implementation of energy efficiency.

2. Barriers to greater energy efficiency

2.1 A behavioural economics approach

There is a general view held by some economic theorists that the potential for cost effective energy efficiency in existing buildings is being taken up; in economic terms, this view holds that agents are behaving rationally in delivering an optimal level of energy efficiency. However the market operates less than perfectly in delivering energy efficiency. Despite the apparent economic incentives, smarter energy use is often not taken up. A great deal of relevant work has been done that examines the true dynamics of decision making for energy efficiency, and its non-rational behavioural aspects (see in particular IEA (2005) and works authored/co-authored by Richard Thaler in "Useful References and Further Reading" listed below).

Clearly, private actors face barriers other than financial barriers, real or perceived, which inhibit better energy practice. As a result incremental increases in financial incentives by, for instance, attributing a price to carbon dioxide emissions through emissions trading will not in themselves unlock the energy savings potential through ever louder appeals to economic rationality; complementary measures are required to be directed specifically at initiating smarter energy use. In relation to energy efficiency a case can be made for what Sunstein and Thaler (2003) called "libertarian paternalism", that is, attempt to steer people's individual choices in welfare-promoting directions without eliminating freedom of choice, to the achievement of broader societal goals.

Barriers to the uptake of smarter energy use practice have been well recognised in many studies (including under the National Framework for Energy Efficiency, and in Issues Paper 5), the most important of which broadly include:

- *Behavioural issues (e.g. lack of priority, short-termism, cultural inertia, non-core business activity)* - electricity typically makes up a small percentage of business costs (estimated by the National Institute of Economic and Industry Research) at under 3% of total expenditure for most economic sectors. Further, there is a lack of understanding of potential cost-effective savings options and available expertise or mechanisms for financing and delivering them.
- *Split incentives* – in many cases the party incurring the capital cost of energy efficiency measures does not receive the saving benefits of the upgrade, e.g. between landlords and tenants of a building.
- *Transaction costs (especially measurement and/or verification)* - the recognition of savings often requires the aggregation of a large number of small energy saving actions, making transaction costs of realising the incentives prohibitive in some cases.
- *Coupling of energy consumption and electricity retailer and distributor profits* (noting that energy savings techniques and products can offer greater margins for retailers than the sale of electricity)
- *Network pricing (avoided infrastructure investment)* - due recognition is not currently given to the important role some technologies can play in reducing network costs and/or peak loads.
- *Bidding schemes* – Efforts put into submitting bids for funding waste scarce industry resources (engineering) and can create long delays or uncertainty for suppliers and customers
- *High hurdle rates and incrementalism* - the selective implementation of opportunities that could be considered "low hanging fruit" impedes implementation and cost-effectiveness of deeper saving programs. Technology for energy savings cannot be applied on a purely incremental basis – often to achieve greater savings projects must be tackled in an integrated way to achieve synergies.
- *Access to capital* – while energy efficiency can provide an attractive return there are many competing and better understood demands for investment capital.

- *Research, development and deployment issues.*

It can be argued that many of these transaction costs and information asymmetries do not automatically and of themselves justify government intervention. However the public good nature of the greenhouse abatement benefits and the reduced overall cost of abatement that can potentially be generated create a clear role for government to provide incentives to accelerate uptake of energy efficiency.

2.2 The need to recognise avoided network and transmission infrastructure

As noted in the fifth dot point above, not only does smarter energy use lower the cost of reducing greenhouse emissions, it reduces the costly network infrastructure investments otherwise required to meet growing demand. From an infrastructure point of view, it is conclusively cheaper to meet growing electricity demand at the margin not by creating new network capacity, but by improving the capability of the existing network by reducing waste. Estimates by NEMMCO put the cost of upgrading/augmenting Australia's electricity delivery infrastructure at approximately $37 billion dollars to 2020; approximately $4 billion a year has been committed for the next five years (sourced from reports at http://nemmco.com.au/nemgeneral/040-0048.htm).

Alongside the network infrastructure savings are savings in electricity transmission losses, which are significant depending on the age and condition of existing infrastructure. It is much more cost effective to generate electricity locally for local use than to create an electricity transport requirement through insistence on centralised power supply. This also carries benefits for the security of supply to particular regions. Current network pricing and regulatory regimes pay little acknowledgement to this aspect of electricity supply, such that distributed/embedded generation appears unfairly expensive in comparison to centralised options (e.g. fossil fuel, nuclear, large-scale wind or geothermal power supply options).

3. Policy design principles for smarter energy end use in buildings

- In order to be effective it is proposed that the following policy principles need to apply to any effective policies that might be put forward:
- *Long term certainty* – policy measures must not be subject to frequent change if they are to be effective in improving market conditions.
- *Technology neutrality* – any policy measures must not "pick winners" among particular technological solutions, thereby allowing for the possibility that better solutions may emerge.
- *Address long term non-price barriers* – while price incentives are important, key barriers to better take-up of energy efficiency are non price barriers.
- *Provide broad based incentives* – ideally measures will be able to apply across sectors, user groups and different actors.
- *Apply nationally* – application of numerous similar schemes at state or local level has led to higher admistrative burdens and administrative complexity, especially for organisations that operate across jurisdictions.
- *Create measurable results* – while gradual transformation of the market is important, measurable results are key to making inroads into greenhouse emission reductions and reducing future economic liabilities.
- *Minimise transaction costs* – efficacy of the measure is important both in terms of its administrative simplicity and its ability to capture small and disparate savings sources.
- *Price energy to more accurately reflect its true cost* – this particularly captures the need to recognise the delivery cost of energy in any analysis
- *Ensure equity for consumers* – any measure must not lead to unfair advantages or disadvantages for particular members of the community.

4. Key Policy Options

Each of the policy instruments is suggested below for consideration alongside the policy design principles in an effort to ensure that, if progressed, efficiency and efficacy of each measure would be maximised.

4.1. Energy Use Target

It is essential to policy development in this area to set out the scale of the expected policy impact, in this case, the quantum of energy to be saved. This target can then form the foundation stone of a comprehensive suite of energy savings actions, delivered by a broad spectrum of policy settings across different tools and audiences.

Given expected electricity demand growth of 2.1% p.a. to 2030 (ABARE 2005), a goal of restricting electricity demand growth to under 1% per year could also be an appropriate first step. This compares to recent EU estimates which set its cost-effective, technically feasible energy savings potential at more than 20%, which equates roughly to a 1% annual reduction in energy use (Commission of the European Communities, 2006).

The suggested target for Australia is relatively unambitious given the cost-effective opportunities that exist. For Australia, a target of restricting electricity demand growth to 1% p.a. means, in absolute terms:

- an electricity saving of 1.1% of total demand each year, or approximately 4000 GWh, which can be allocated to sectors of the economy according to identified potential.
- Greenhouse savings of the order of 4-5 million tonnes annually, cumulatively delivering a national greenhouse gas reduction of over 60 million tonnes by 2020, or more than 10% of current national emissions.

For Australia, a target of no electricity demand growth means, in absolute terms:

- an electricity saving of ~2.1% of total demand each year, or approximately 7000 GWh, *roughly the equivalent of avoiding the requirement to build a 500-1000MW power station each and every year*.
- Resultant greenhouse savings of ~8-10 million tonnes annually, cumulatively delivering a national greenhouse gas reduction of over 100 million tonnes by 2020, or more than 16% of current national emissions.

4.2. Smarter Energy Use Fund

This fund would build on the “Energy Savings Fund”/”Climate Change Fund” model used by NSW, and also cover recognition of distributed generation alongside energy savings, as part of recognising avoided infrastructure costs. The money for the fund could be raised via a levy on electricity network businesses, with the rationale that the extra cost associated will be more than offset by reduced energy consumption that will avoid the need for them to undertake costly network augmentations; essentially the fund should therefore provide a net positive financial outcome or at the very least be cost neutral.

The Government has already earmarked funds raised from the auctioning of permits under an emissions trading scheme to be diverted to energy savings activities, and this is also a likely source of permanent revenue for the Fund.

Impediments to the achievement of our energy savings potential occur across different sectors of the economy, and vary in their nature across the supply chain. Incentive programs must therefore target specific sectoral groups. A fund must therefore be flexible enough to target both “direct measures”, i.e. activities that bring about cost effective greenhouse abatement, and “market transformation”, i.e. those non price barriers that prevent even more widespread take-up of smarter energy use. Beyond this, funds would need to be allocated to research and development in energy efficiency, which does not stand still in a technology sense – new products and techniques are constantly emerging that can improve efficiency outcomes. While a great deal of focus is on costly development of new energy supply technologies, there is little or no focus on development of energy savings technologies.

From an equity perspective, some of the fund could also be targeted at lower income households through a “voucher”-style scheme which allows recipients to spend the money only on specific energy saving appliances. This also allows the fund to remain as broad based and market driven as possible.

A Smarter Energy Use Fund would provide long term certainty if a permanent funding source could be established, such as from the auctioning of permits under an emissions trading scheme. A percentage of the fund could be specified for energy efficiency projects or for use by particular instruments such as energy performance contracting.

Similar funds have demonstrated high transaction costs in conducting “bidding rounds”, however this can be overcome by creating a threshold cost level at which activities could pre-qualify for funding on a rolling basis.

4.2.1 Energy Performance Contracting

Another possible application for such a fund is in seeding or catalysing building energy retrofits using performance contracting. Performance contracting is a well developed technique that allows a specified improvement in building performance to be guaranteed by a specialist energy company, unlocking the potential for private finance to fund the initial upgrade.

4.3. "White Certificate" market-based energy savings scheme

Energy efficiency schemes are in operation in a number of countries with promising early experience emerging (World Energy Council, 2008). An Australia-wide market based mechanism/retailer obligation to support energy efficiency (extending to and expanding on the NSW and Victorian schemes) could operate in a similar manner to MRET. This will be an effective way to target and provide incentives for energy savings improvements for existing buildings across residential, commercial and industrial applications. To overcome transaction costs, pre-qualification of certain technologies would be appropriate, for example greenhouse savings from upgrades of chillers and lighting controls can be assessed according to a pre-approved methodology, rather than having to be assessed on a case by case basis for applicability. Special provision, also, should be given to projects which reduce transmission losses and peak demand requirements (e.g. distributed and intermittent generation technologies).

Such a scheme would run in parallel to an emissions trading scheme and, similar to MRET, would provide an appropriate complementary measure to emissions trading in stimulating investment in particular types of emission reductions activity that have great potential.

It is difficult for such schemes to be technology neutral, because Government must decide what's in and what's out. However, robust methodologies are being developed to ascertain the value of inclusion of particular technologies and activities under schemes such as these.

4.4 Improve baseline performance through standards and regulations

Experience has shown the efficacy of regulation and mandating of minimum efficiency standards for avoiding poor performance. This includes Minimum Energy Performance Standards (MEPS) on appliances, Australian Building Code requirements for residential and commercial construction, and voluntary/de facto standards for commercial buildings, all of which have been deployed to some effect and in which Australia has displayed international leadership. The previous Commonwealth Government's phasing out of incandescent lightbulbs through the setting of minimum energy standards is a good example of this. The regulatory approach may also be applied cost effectively to other product areas.

It is noted that minimum standards tend to capture worst performers only and do not unlock the true energy savings potential, for which further incentives are required.

4.5. Facilitate the creation of an informed market

Smarter energy use is ultimately about informed choice by individuals, not just government intervention. However, government has a role to play in ensuring individuals have the information to make informed choices in household and workplace contexts. A strategic, integrated education program could help to create better informed energy consumers in both households and businesses. This would include, for example:

- A nation-wide roll-out of the greenhouse and energy awareness raising Victorian Black Balloon promotion campaign to other states.
- An improved and enlarged energy performance labelling and disclosure framework for both buildings and appliances. In particular introduction of mandatory disclosure of energy performance of existing residential and commercial buildings when they are leased or sold. This has been a Government commitment under stage one of NFEE but several years on is still yet to be implemented. Requirements for information disclosure have been trialled in the ACT and NSW under the Energy Smart scheme, which highlighted the importance of enforcement of requirements for savings to be achieved.
- Continuation and expansion of energy performance assessment requirements for businesses (Currently Victoria, NSW and the Federal Governments all have their own mandatory energy assessment/audit programs but quality assurance of assessments is missing).
- National roll-out of electricity smart meters in conjunction with in-house displays to provide real-time information about energy use.

- Mandatory, public reporting of greenhouse emissions via a website, just as occurs with the National Pollutant Inventory for other pollutants.
- Supply intermediaries – builders, equipment suppliers, installers, planners, construction consultants and others also have important roles to play in delivering energy smart advice and products. Targeted information and facilitation of behaviour of these sectors towards energy savings is required.

It is noted that the creation of a comprehensive greenhouse and information reporting network under an emissions trading scheme will supersede the need for some aspects of information provision.

4.6. Develop the depth of Australia's skills base to deliver on the potential

The energy services industry in Australia remains small and will need to grow if the energy savings potential is to be realised. Developing Australia's skills capacity and educational infrastructure to deliver on smarter energy use will therefore be required. Training and accreditation programs for industry professionals need to be developed alongside other efforts to grow demand for energy efficiency.

4.7 A note on "green" depreciation

Green depreciation is a form of accelerated depreciation for buildings that meet a specified environmental standard. Some commentators have proposed that applying accelerated depreciation to existing non-residential buildings would provide a strong incentive for building owners to refurbish their existing building stock, bringing about a rapid reduction in the substantial environmental footprint of the buildings sector. This would create a cost to Government in terms of the tax revenue foregone, though this is recouped eventually, restricting the cost to Government to the time value of money. However, there is little if any incentive created by this measure for short to medium term investors looking to buy, upgrade a building and then on-sell, nor in the eyes of developers, designers or tenants. The result would simply be to increase capital gains tax liability (by decreasing the buildings value for calculating capital gains). Only long term institutional investors with a 15 year plus time frame could conceivably benefit, but it is unlikely that this would create more than a marginal improvement in incentive. It is likely that funding directed to specific successful implementation policies through a more direct funding program would achieve more cost effective results than any changes to the tax system, which may also be expensive and difficult to administer.

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GREEN PRODUCTS FOR GREEN BUILDINGS THE ECOLABEL SOLUTION

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Summary

After the design and planning stage of a development the difficult question of choosing environmentally preferable materials can become a real challenge to most developments. Third party ecolabelling offers a solution with credible environmental information that has been independently assessed offering an overall environmental performance picture. ISO 14 024 based ecolabelling programs are spread across the different jurisdictions where new Green Building Councils are emerging having been established many years ago to aid green procurement. These established product based ecolabelling programs offer an important solution to Green Star projects that do now wish to be hampered by the time delays and limitations of green material and product selection in projects. There are however qualifications and analysis required to ensure that you are choosing the right ecolabelling program in considering transparency, life cycle multiple criteria completeness, verification accuracy among other considerations.

1. Introduction

To deliver environmentally preferable building architects and designers need to consider a wide range of design, material, maintenance attributes of a construction. However once the design, location and orientation, size and function attributes have been completed an architect is left with the problem of selecting between materials and products which may appear to have the same look and feel, but have very different environmental impacts. How designers choose different product materials on the basis of environmental performance is fundamental to the outcomes desired by any particular development on environmental grounds. The independent and comprehensive assurance of the environmental loads of a particular material such as carpets, paints, plasterboard, lighting, furniture and fittings, flooring is the preferred international best practice methodology. It is at this crucial stage of the development process that ecolabelling can be a fundamental asset to the environmental performance design tools available to developers.

Ecolabelling is a voluntary method of independent product environmental certification. An ecolabel identifies overall environmental preference of goods and services within a specific product category, based on product life cycle considerations. Ecolabelling programs are third party verification initiatives, which separate them from “green” symbols or claims made by manufacturers and service providers (first and second party initiatives[1]). Certified ecolabelling is not limited to a singular issue of the product. The unique improvement of ISO 14 024 ecolabelling is the use of multi criteria standards developed by considering the product’s whole life cycle. This distinguishes these ecolabels from single issue labels, which focus only on one environmental factor such as energy or water consumption. Unfortunately, by focusing on a single issue these claims / labels neglect all other environmental interactions of the product. This presentation focuses on voluntary third party, multi criteria ecolabelling programs and the contribution these deliver to a “greener”, more sustainable building industry. Furthermore, through a global network of harmonised ecolabelling organisations the tools are already in place to assure a “green” supply chain, which is appropriate in a globalised economy.

1.1 The Global Ecolabelling Network and international harmonising of ecolabelling

During the past three decades there has been growing need to have independent assurance of the environmental performance of products. This has led to the popularity and the emergence of numerous national ecolabelling programs operating around the world using the life cycle based approach to giving comprehensive and comparable information to consumers. The first program (Blue Angel) commenced in Germany in 1977 with most western Countries now having established national programs.

In 1994 some of these national ecolabelling programs founded the Global Ecolabelling Network (GEN) as an umbrella organisation for third party ecolabelling. GEN supports ongoing international and national ecolabelling discussions through a variety of activities. These aim to improve, promote and develop

[1] 1st party initiatives are self claims by the manufacturer and thus by those who directly benefit from the claim. 2nd party initiatives can also have vested interests.

ecolabelling of products, to foster co-operation, information exchange and harmonization among its members to encourage the demand for more environmentally responsible goods and services. By the end of 2006 the Global Ecolabelling Network had 27 member organisations, which operate ecolabelling programs in nations around the world.

In 1996 the International Organisation for Standardisation (ISO) published the ISO 14000 standard series to incorporate the many facets of Environmental Management Systems (EMS). As part of this series the ISO14020 standards were developed in the late 1990s, as a framework for environmental labels and declarations. Within this 14020 series, three types of initiatives are recognised:

Type 1: Environmental labelling programs (ISO 14024), which are voluntary, multi-criteria based, third party programs[2].

Type 2: Self-declared environmental claims (ISO 14021) and

Type 3: Environmental declaration programs (ISO 14025), which are based on life cycle assessments of products, without certification[3].

Several of the GEN member organisations made substantial contributions to the development of the ISO 14024 standard. Since then the GEN member organisations have implemented ISO 14024 as a code of best practice into their programs. This ensures the credibility, transparency and comparability of GEN's programs. In addition by operating under the framework of the same ISO standard, it opened the way to mutual recognition of the different national ecolabelling programs. Recently the ongoing harmonisation has resulted in a GEN Internationally Coordinated Ecolabelling System (GENICES) that enhances co-operation and information exchange between GEN members and increases credibility of the network and international acceptance of its members. (Further details for GEN are available at http://www.gen.gr.jp).

1.2 Striving for a sustainable property industry

Worldwide, the building and property industry impacts significantly on raw materials, energy and water consumption. Furthermore it contributes substantially to indoor air pollution and waste output. However the property industry has recognised that it can strive for sustainability and achieve the delicate balance between environmental, social and economic issues.

The main goal of the Green Building Councils (GBCs) in many countries around the world is to develop such a sustainable property industry. Each drives the adoption of green building practices through market based incentives, to minimise adverse impacts of buildings during their design, construction and operation phases on both the built and natural environment. Through their programs the GBCs aim is to improve the energy and resource efficiency in the property industry, to reduce greenhouse gas emissions, to enhance and protect ecosystems and improve biodiversity. Furthermore the GBCs focus on making buildings more usable, reducing operating costs and improving the social amenity in its industry sector. This needs credible tools to identify criteria to differentiate products along the whole supply chain. This is where the use of ecolabelled products strongly contributes to achieving the goal of the GBCs.

In Australia, New Zealand and other jurisdictions there are bridges growing between the national ecolabelling organization and the Green Building Councils of these countries. The reason primarily is the synergy and efficiency that can be gained by using ecolabelled products as the preferred materials in any new development. The benefits include the benefits of independence, consistent treatment of verifications, assessment against similar criteria, a whole of life assessment, clear pass or fail results, and typically a wide treatment of building products. The additional benefit making this bridge easy is that most ecolabelling organization have been established in their market longer than the respective Green Building Councils thereby having a wide range of products already licenced (see Table 1). Both organizations also share the same philosophical objectives with the aim of recognizing the leading products and building in a particular market at generally the 20-30% mark and the awarding of environmental certification based on an overall life cycle multi-criteria approach with independent verification against pre-determined criteria.

The approach has been successful in Australia fueling both the emergence and development of new national ecolabelling standards for building and construction materials and the widespread availability of certified and independently assessed products readily available to the industry.

[2] ISO 14024 Type 1 environmental labelling program: Voluntary, multi-criteria-based third party program that awards a licence, which authorises the use of environmental labels on products indicating overall environmental preferability of a product within a particular product category based on life cycle considerations [ISO 14024].

[3] ISO 14025 Type 3 environmental declaration program presents quantified, environmental information on the life cycle of a product to enable comparison between products that fulfill the same function. Such declarations are based on independently verified life cycle assessment data, life cycle inventory analysis data or information modules in accordance with the ISO 14040 series [ISO 14025].

Table 1: Corresponding Green Building Council Members and Global Ecolabelling Network Members by Jurisdiction.

Green Building Council Member	Ecolabelling Organisation	Green Building Council Member	Ecolabelling Organisation
Australia (GBCA)	Good Environmental Choice	New Zealand (NZGBC)	Environmental Choice
Brazil (GBCBrasil)	Rotulo Ecologico	Taiwan (TaiwanGBC)	EnviroMark
Canada (CaGBC)	EcoLogo	United Kingdom (UKGBC)	EU Flower
Germany (GeSBC)	Blue Angel	United States of America (USGBC)	Green Seal
India (IGBC)	CPCB	Japan (JSBC)	EcoMark

2. Methodology of ISO 14024 ecolabelling

The goal of ecolabelling is to encourage the demand for and supply of those products that cause less stress on the environment, thereby creating the potential for market-driven continuous improvement, and encouraging innovation in product development and design. ISO 14024 based ecolabelling programs establish product standards by identifying pertinent criteria derived from the methodology of life cycle assessment. With market uptake the standards are revised regularly to raise the benchmark in a process of continuous improvement maintaining the principle of rewarding the top ~20% in a particular market.

Ecolabelling programs undertake verification to measure product environmental performance against criteria in the relevant standard. After a successful verification the ecolabel is awarded as a symbol to customers that the product conforms with the stipulated environmental high criteria so the consumer can make an informed environmentally preferable choice.

2.1 Life Cycle Assessment in standard development

Life Cycle Assessment (LCA) methodology has emerged as an important scientific tool in identifying criteria determining benchmarks for environmental performance. The ISO 14040 standard methodology requires a quantification or qualification of the primary environmental impact categories of a product across the full life cycle including raw material extraction, production, consumption and environmental impacts at the end of life. By undertaking such a comprehensive analysis across different products seeking to fulfill the same function it is possible to identify environmentally preferable material choices, production innovation, considerations for longevity, low toxicity, biodiversity and general priority emissions such as greenhouse gases and water pollution. In particular the ISO 14040 standard provides agreed methodology that has overcome the problem of needing exact quantification of all environmental impact categories. This has been done by prioritization, normalisation and characterisation within the analysis of inventory data and the derivation of suitable, logical criteria for the product standard. Furthermore, Life Cycle Inventory (LCI) data of product systems can be used to check the completeness of the selected, draft criteria. The use of life cycle methodology has ensured an overall scientific approach which results in direct measurable performance criteria.

Non life cycle based environmental performance labels or declarations have the potential to seriously mislead the market and designers by only presenting selected and even irrelevant material as the basis of environmental assurance. As the growth of green markets continues there appears to be a corresponding growth in misleading and selective environmental statement arising in the market.

2.2 Standards development process in ecolabelling programs

The standard development process is very similar for all ISO 14024 based ecolabelling programs as used by member organisations of the Global Ecolabelling Network. To give an overview of the standard development process, below is a description of the process used by Good Environmental Choice Australia.

The aim of the standards development process is to define a set of minimum environmental performance criteria for a particular good or service category. These criteria are put into a standard which is set to a level that only the top twenty percent of the suppliers, manufacturers and providers in the Australian marketplace would be able to meet and thus be certified under the relevant GECA standard.

2.2.1 Initiation of a new standard

Development of a new standard for a product category is usually initiated when GECA receives an application for certification or numerous enquiries from an industry sector regarding the high demand for certification for its products. Where the product does not fit into the scope of an existing standard, a new product category is investigated. GECA always checks whether or not an environmental benefit can be expected by establishing a new standard by considering the size and quantities of environmental emissions and impacts from the product group. In some cases the increasing public interest and awareness of environmental impact from a specific product category gives clear indication that there would be a market benefit and it is suitable to establish a new standard for that product category.

If there is market and environmental benefit the Standards Committee then authorises the development of the new standard. Firstly there is a provisional definition of the product category. Then the initiation phase includes considerations about possible stakeholders and alliances with the industry sector.

2.2.2 Feasibility assessment

The purpose of the feasibility study is to assemble information about market size, competition and structure of the product's marketplace. The study provides indication whether market incentive in the context of competition could be influenced by ecolabelling. Also, at this stage, potentially interested parties and industry associations are identified, who could provide substantial information and technical know-how to assist the development of the standard.

2.2.3 Data collection and assessment

An important basis for the development of a new standard is the assembling of a Standard Expert Panel to form a working group of people from government, research organisations, industry and social groups. GECA Standards Division staff with experience in ecolabelling, ensures that the composition of the Expert Panel has the broad knowledge and experience essential to define environmentally meaningful criteria for the new standard.

The standard incorporates material gathered from a review of existing international ecolabelling standards for a similar product category and reviews available life cycle inventory (LCI) data or new environmental research on the product group. If insufficient data is available at the time, the Expert Panel may start new research on the Life Cycle Inventory of products in that particular category.

The resulting LCI data are used in a streamlined LCA to identify environmental impacts of the products, focusing on impact categories were an environmental impact differentiation between products within the category is apparent.

2.2.4 Setting environmental performance criteria

Based on the Life Cycle Inventory data and the identified key environmental factors, the Expert Panel establishes environmental performance criteria, which provide the basis for an environmentally meaningful differentiation between the products in the category. Recent, relevant, economic and technical developments are identified to ensure the criteria are technically and economically feasible for the leading manufacturers or service providers in the Australian context. Further criteria address more general, holistic concerns of the product category, if they are significant, and point to potential improvements in future technical development of the standard. All criteria are expressed in terms of performance and are directly measurable factors / loads / impacts, instead of descriptive or qualitative design characteristics. Through consideration of the goods and services from the perspective of their whole life cycle, the criteria also prevent the transference of environmental loads as well as eliminating some of the impacts.

Uniquely in Australia the standard also includes a set of criteria to address social issues. These include criteria for compliance with labour law, relevant social legislation, general environmental legislation and fitness for purpose of the product.

2.2.5 Presentation of the draft standard

The preliminary set of criteria is arranged into a draft standard. All aspects of the draft standard are checked for conformance in accordance with the principles of ISO 14 024 and is then presented to the Standards Committee. If the draft standard is accepted by the Committee, all stakeholders are informed and the standard is made publicly available on the GECA website and sent directly to interested stakeholders for comment and consultation for at least 60 days. The comments received are collected and documented. After consultation with the Expert Panel the Standards Division decides how to implement and incorporate the feedback comments into the draft standard. The new standard is finalised, endorse by the Standards Committee and published as final, normally for a period of three years depending on the life span of the product category in the Australian marketplace.

2.2.6 Review of the standard

Whenever technology changes significantly or the market share of leading manufacturers with certified products grows substantially, the standard is reviewed. The review process changes the level of the criteria to be more stringent to reflect the new situation. This is necessary to continue to reward and promote continual innovation in the specific industry sector and to raise the benchmark of environmental performance.

3. Case Study: GECA Furniture & Fitting Standard

As a result of the described methodology in the standards development process, the GECA Furniture & Fittings Standard 28 was published on 29 November 2006. The scope of this standard is written in a prescriptive yet open ended manner with a focus on materials allowing most types of non-electronic office or domestic furniture to be within the scope. GECA utilised input from Australian stakeholders and scientific papers on LCA and heavily on the substantial technical work by the European Union Flower Ecolabel to develop the environmental benchmark criteria for this standard.

Currently, there are over 36 companies licensed with diverse product lines under the Furniture & Fittings Standard and they range from workstations, paneling, chairs to mobile pedestals. Panel boards and chairs have been the most popular products certified because the incentive of the Australian Green Building Council is greater through the awarding of more Green Star Points for these furniture types generating a stronger market stimulus for environmentally preferable furniture.

The reduced environmental impacts from certified products are very broad as each criterion delivers at least one environmental benefit. In this presentation, there are three aspects selected as examples to focus on the issues of material sourcing, air emissions and end of life disposal.

3.1 Key impacts of furniture products

3.1.1 Material sourcing

GECA Standard 28 emphasises the increased use of recycled material as a key factor in reducing environmental impact. Another factor is the origin of the timber used in furniture making, which must come from a documented environmentally preferable source. Specifically, Forest Sustainability Council (FSC) or equivalent certification of the timber must be provided to pass the verification against the standard. In practice this means plantation-grown new timber, or recycled material may be used but timber from an unsustainably managed forest is not acceptable. Moreover, the range of chemicals that can treat the timber is stipulated.

Plastic in GECA-certified furniture can only be of types that could be recycled at local (i.e. non-specialist) facilities. A practical outcome from the standard is that it encourages the use of already-recycled plastic as a raw material.

The GECA Furniture & Fittings Standard does not fully address metal components of furniture currently because the Australian manufacturers are not positioned to be able to meet stringent criteria for proper recycling of the metal content of furniture at this time.

3.1.2 Air Emissions

Engineered timber products and other materials used in the manufacture of furniture often emit Formaldehyde which can be considered to be harmful to human health, both to workers and consumers. The GECA Furniture & Fittings standard defines an upper limit for Formaldehyde emissions from the product. The standard specifies a list of international recognised test methods which can be used to measure the Formaldehyde emission levels and also gives figures for each of these test methods which make it possible to compare these emission measurement results.

The standard also specifies criteria for adhesives used in furniture products by referring to GECA Standard 1 – Adhesives, which sets limits on VOC emissions. GECA also accepts adhesives certified against another relevant eco-standard by other recognised ecolabelling programs of the GEN network. In the same way, the standard specifies types of textiles which can be used in certified furniture by referring to the GECA Standard 19 - Textiles.

3.1.3 End-of-Product Life

The GECA Furniture & Fittings Standard requires that certified products must be easy to take apart to aid the recycling process. In additional as par of the verification requirements the manufacturer must have arrangements in place to acknowledge ownership of the product via a take-back scheme, where obsolete furniture can be re-used instead of disposed of in landfill. This is likely to translate into substantial material recovery from this sector without the necessary requirements of government regulation or joint industry product stewardship initiatives.

In addition, certified products must not contain chemicals that are known environmental pollutants. An example is Organic Tin Catalysts (OTCs) which, if used when making foam padding, must be disposed of by an approved hazardous waste dealer from the manufacturing site.

3.2. Benefits of the GECA Furniture & Fittings Standard

3.2.1 Technical and environmental benefits of the ecolabel awarded by GECA

By setting a standard that a product must pass, the ecolabel awarded by GECA assures the customer that the product has been independently assessed. It also means that the product is preferable, in the top 20 % of its category. If the proportion of certified manufacturers rises, then GECA raises the benchmark to make certification more challenging for the "followers". In this way the process meets the ISO principle to be continuously improving and to ensure that technological innovation is encouraged, and that innovators are given a distinction over competitors.

GECA-certified furniture has been assessed as having a lower environmental impact/ load /burden than a benchmark figure derived by studying the current industry best practice.

3.2.2 Market and Sustainability Benefits

Currently, there are 55 certified Green Star Projects (buildings) in Australia and the majority has incorporated GECA products. This is because GECA certified products satisfy some of the compliance requirements of various Indoor Environment Quality (IEQ) and Material credit criteria in the Green Star Rating Tools. A GECA Environmental Product Declaration (EPD) and Manufacturers GECA Licence satisfy Green Star compliance criteria. This has the added benefit for designers, architects and Green Star Accredited Professionals that complexity, paperwork and documentation time is reduced. The Green Building Council of Australia recognises the quality and assurance provided by the GECA ecolabel.

It is the aim of GECA that certification under the ecolabelling program is incorporated also into corporate and government procurement, such as Request for Tender documentation used by major purchasers. The demand for furniture with an overall lower environmental load and preferable manufacturing processes is given a boost through market demand. Importantly once manufacturing and material changes are achieved the environmental benefits are compounded continually ensuring environmental benefits that accumulate over time. Our experience to date is that these benefits are surprisingly large and permeate across the supply chain even through suppliers of materials that are not certified.

4. International Perspectives

Overseas other GEN members are servicing the building industry with a range of standards that are suitable for their regional jurisdiction. In Europe, the European (EU) Eco-label has twenty-seven product categories including a Hard Floor-Covering Standard, similar to the GECA Standard 40 – Hard Surfacing. The EU Eco-label focuses on a range of environmental and health issues from; minimising the effects of quarried materials on the environment, to reducing harmful air and water emissions as well as encouraging responsible waste management procedures (2002/272/EC). Currently there are seventeen producers and approximately two hundred products throughout Europe that are certified under the EU Hard Floor Covering Standard.

In Korea, the Korean Eco-Product Institute (Koeco) has a subcategory of standards catering for the construction and housing industry. The Construction and Housing Products subcategory contains sixty five standards ranging from Soundproofing Products for Building Floors to Water-saving Faucets and Decorative Textiles. A notable Koeco standard with substantial market uptake is Standard 241 – Paints. The paints standard contains explicit VOC emission limits and detailed testing methods. Despite the standard's stringent requirements, there are seventy-five manufacturers that have been awarded the Koeco ecolabel and four hundred and eighty- five products certified.

Within each country there are ecolabelling programs that enable the building and design industry to define environmentally preferable products. In the absence of relevant standards in a domestic market, GEN organisations have the capability to collaborate with each other and the relevant industry sector to establish standards based on market demand. In this way GEN promotes a synchronised approach to developing standards and thus allows for mutual recognition of certified products by its members.

5. Alternative Approaches to ISO 14024

Globally, there are a range of product environmental certification programs that provide alternative environmental certification approaches for building and interior fit out products. These vary from industry association standards, such as the Australian Business and Institutional Furniture Manufacturer's Association (BIFMA) standards, to industry independent programs such as the GREENGUARD Certification Program, the BRE Environmental Assessment Method (BREEM) and the McDonough Broungart Design Chemistry (MBDC) protocol. While some approaches are still LCA based and all aim to reduce harmful impacts on the environment and assure customer health and safety, none are as comprehensive as ISO 14024 based standards. The ISO 14024 approach to ecolabelling also includes production environmental requirements in addition to environmental criteria and quality assurance requirements.

Standards that are in accordance with ISO 14024 establish multi-criteria environmental assessments of products that cover the whole life cycle of the product. This holistic approach supports overall environmental preferability compared to single issue approaches, such as the GREENGUARD certification programs, which focuses on indoor air quality.

Table 2: Criteria to ensure credibility of an Ecolabelling Program.

Criterion	ISO 14 024 Ecolabels	BIFMA	BREEM	GREEN-GUARD	MBDC
LCA Considerations[4]	Yes	Yes	Yes	No	No
Consultation[5]	Yes	Yes	No	No	No
Transparency[6]	Yes	Yes	Yes	Yes	No
Scientific Basis[7]	Yes	No	Yes	Yes	Yes
Independence[8]	Yes	No	Yes	Yes	Yes
Comprehensive[9]	Yes	No	No	No	No
Selectivity[10]	Yes	Yes	Yes	Yes	Yes
Verification[11]	Yes	No	No	Yes	No
Product Function Criteria[12]	Yes	No	No	No	No
Production Considerations outside of final product[13]	Yes	No	No	No	No

7. Concluding Considerations for the Building Industry

With the variety of ecolabelling programs available to the design and construction industry sector, there are numerous considerations to take account when finding a credible ecolabelling program. Such considerations include programs that are LCA based and have an approach that foresee and consider multiple environmental loads during the entire lifespan of a product or building. This is particularly needed in the building industry where products may not have been manufactured using sustainable materials. Ecolabelling programs also support innovation and technological advancement within a given sector and recognise environmental leadership by producers.

Type III ecolabelling programs contain all these characteristics and are able to clearly communicate to businesses and customers that certified products with their ecolabel are environmentally preferable, compared with other products in the marketplace. ISO accredited ecolabelling programs also inherently assure transparency and credibility in the implementation of such labelling programs. While 'green' building rating tools such as GBCA's Green Star encourage a low environmental impact of a whole building during its design and construction phase, third party ecolabelling programs ensure that the entire supply chain of the manufacturing process supply building materials equally have clear and measurable environmental benefits. The ability of Green Building Projects around the world to have access and to transparent and credible environmental information and generate demand for greener building products is fundamental to changing the building product supply chain. This objective is made easier through using the substantial work in products standards and extensive certifications done by ISO 14 024 based ecolabelling programs.

[4] Criteria are based on indicators arising from life cycle considerations covering the whole products life span.
[5] Program is committed to a formal open participation among interested parties which shall be established at the outset for the purpose of selecting and reviewing product categories, product environmental criteria and product function characteristics.
[6] Program ensures transparency through all stages of its development and operation. This implies that information shall be available to interested parties for inspection and comment where appropriate. Adequate time shall be allowed for comments to be submitted.
[7] The development and selection of criteria is based on sound scientific, regulatory and engineering principles. The criteria should be derived from data that support the claim of environmental preferability.
[8] Program is operated by an organisation independent of vested commercial or other interests. Program independence also extends to how product categories and environmental award criteria are determined
[9] Program ensures that criteria that are stipulated are the most significant environmentally.
[10] Program ensures that voluntary environmental labelling standard criteria are established to differentiate environmentally preferable products from others in the product category, based on a measurable difference in environmental impact.
[11] Verification independence relates to conformity assessment to international environmental auditing requirements (ISO 19011).
[12] The fitness for purpose of the product and levels of performance are taken into account. In the context of environmental labelling, fitness for purpose implies that a product satisfies health, safety and consumer performance needs.
[13] Standards and product function requirements for each product category are set for a predefined period and then are reviewed within a predefined period, taking account of factors such as new technologies, new products, new environmental information and market changes.

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Appendix 1: GECA ecolabel standards related to the Building Industry

Table 3: GECA ecolabel standards related to the Building Industry

Standard	Product Scope
GECA-01 Adhesives	Household and commercial adhesives
GECA-02 Recycled Plastic Products	Products made from recycled plastics
GECA-03 Recycled Rubber Products	Applies to a broad range of products made partially or fully from recycled rubber
GECA-04 Panel Boards	Applicable to a broad range of panel board products for use in interior architectural applications, interior paneling as well as for use in further processed products such as furniture
GECA-07 Wool Carpets	Wool Rich (70%), Wool Pile (100%), Wool Blend and Modular Wool Carpets
GECA-19 Textiles	Textile clothing, interior/indoor textiles excluding floor coverings, yarn and fabric intended for use in clothing or indoor textile products and textile bags such as shopping, laundry and school bags
GECA-23 Architectural and Protective Coatings	Water-based coatings, Solvent-based coatings and Surface-coating systems
GECA-25 Floor Coverings	Includes floor coverings such as parquet, wooden planks, laminate and linoleum. Does not include floor coverings that are applied in a liquid state, or carpet products.
GECA-28 Furniture and Fittings	Applicable to a broad range of categories of final ready-to-use home and office furniture products.
GECA-30 Broadloom Polymer & Polymer Rich Carpets	Includes polymer fibre carpets which include nylon and nylon blends, olefin (polypropylene), polyester (PET) and acrylic
GECA-31 Commercial Modular Carpets	Includes polymer and wool-fibre modular carpets which include nylon and nylon blends, olefin (polypropylene), polyester (PET), acrylic and wool
GECA-33 Building Insulation Materials	Applicable to bulk (resistive-type) thermal insulation materials for use in building applications. It does not include foils, lagging, sarking or specialty insulation materials
GECA-40 Hard Surfacing	Applies to a broad range of products such as Natural stones, Agglomerated stones, Concrete paving units, Terrazzo tiles, Ceramic tiles, Clay tiles and Glass tiles

Appendix 2: International ecolabel standards related to the Building Industry

Table 4: International ecolabel standards related to the Building Industry

Program	Relevant Standard	Classification Number
Chinese Eco-Label	Energy Saving Fluorescent Lamps	HJBZ 15.1-1997
	Energy-saving Low noise Room Air Conditioners	HJBZ 18-2000
	Asbestos Free Building Materials	HJBZ 25-1998
	Adhesives	HBC 18-2003
	Phosphorus Free Gypsum Building Material	HJBZ 29-1998
	Ecotypic Textiles	HJBZ 30-2000
	Wood Based Panels & Finishing Products	HBC 17-2003
	Plastic Water & Sewage Pipes	HJBZ 39-1999
	CFC-Free Foamed Plastic	HJBZ 42-2000
	Products Made From Recycled Plastic	HJBZ 44-2000
	Water Based Coatings	HBC 12-2002
	Metal Welding & Cutting Glass	HBC 13-2002
	Energy Saving Doors & Windows	HBC 14-2002
	Sanitary Ceramics	HBC 16-2003
	Blocks For Architecture	HBC 20-2003
	Furniture	HBC 22-2004
	Wallpapers	HBC 23-2004
Environmental Choice New Zealand	Floor Coverings	EC-28-05
	Synthetic Carpets	EC-33-08
	Furniture & Fittings	EC-32-07
	Gypsum Plasterboards	EC-19-07
	Paints	EC-07-08
	Recycled Plastic Products	EC-04-07
	Recycled Rubber	EC-18-01
	Textiles, Skins & Leathers	EC-31-06
	Thermal (resistive-type)Building Insulants	EC-25-04
	Environmental Leadership Products & Services	EC-34-08
Koeco (Korean Eco-label)	Florescent Lamps	201
	Ballasts for Fluorescent Lamps	202
	Lamps for Built-in Ballasts	203
	Electric Cables	207
	Electric hand Dryers	208
	Water-saving Faucets	221
	Water-saving Toilets	223
	Pipes for Water Works	227
	Paints	241
	Wallpaper	242
	Lagging & Insulating Material	243
	Water-proofing Agents for Construction	244
	Water-permeable Concrete Pavements	245
	Indoor Floor Coverings	246
	Floor Heating Systems	247
	Finishing Materials for Wall or Ceiling	248
	Soundproofing Products for Building Floors	249
	Windows	250
	Adhesives	251
	Access Floors	253
	Decorative Tiles	254
	Fire Sprinkler Head	264
	Recycled Plastic Products	721
	Recycled Rubber Products	722
	Recycled Wood Products	723
	Biodegradable Resin Products	724
	Recycled Construction Material	743
Blue Angel (Germany)	Cadmium –Free Hard Solders	RAL-UZ 68
	Building Materials made primarily from Waste Glass	RAL-UZ 49
	Building Materials primarily made of Waste Paper	RAL-UZ 36
	Electronic Ballasts for Fluorescent Lamps	RAL-UZ 81
	Fabric Towel Rolls	RAL-UZ 77
	Energy Efficient Hot Water Tanks	RAL-UZ 124
	Water Saving Flushing Boxes	RAL-UZ 32
	Independent Gas Heaters & Gas Heating Elements	RAL-UZ 71
	Flexible Floor Coverings	RAL-UZ 120

	Low Energy Hot-Air Hand Dryers	RAL-UZ 87
	Low Emission Textile Floor Coverings	RAL-UZ 128
	Low Emission Floor Covering Adhesive & other Installation Materials	RAL-UZ 113
	Low Emission Composite Wood Panels	RAL-UZ 76
	Low Emission Wood Products & Wood Based Products	RAL-UZ 38
	Low Emission Upholstery	RAL-UZ 117
	Low Noise Construction Machinery	RAL-UZ 53
	Low Pollutant Paints & Varnishes	RAL-UZ 12a
	Low Emission Wall Paints	RAL-UZ 102
	Low Emission Sealants for Interior Use	RAL-UZ 123
	Lead-free Products	RAL-UZ 67
	Recycled Plastics Products	RAL-UZ 30a
	Recycled Board	RAL-UZ 56
	Solar-Powered Products	RAL-UZ 47
	Waste Rubber Products	RAL-UZ 30b
	Wallpapers and Woodchip Wall Coverings	RAL-UZ 35
EU Eco-label	Hard Floor Covers Light Bulbs Paints and Varnishes Clothing, Linen and Indoor Textiles	
Green Seal (US)	Anti-Corrosive Paints Commercial Adhesives Energy Efficient Lighting Paints Recycled Content Latex Paints Windows Window Film	GC-02 GS-10 GS-05 GS-11 GS-43 GS-13 GS-14
EcoLogo Program (Canada)	Acoustic Insulating Products	017
	Adhesives	046
	Asphalt and Concrete release Agents	143
	Compact Fluorescent Lights & Lamps	014
	Construction Framing Materials and Assemblies	151
	Electricity – Renewable Low-Impact	003
	Fibreboard from recycle Resources	018
	Flooring Products	152
	Gypsum Wallboards	020
	Heating/Cooling Systems for Buildings	001
	Mosaic Tiles	167
	Naturally-derived Phenol Substitutes	144
	Particleboard from Agricultural Fibre	019
	Plastic Film Products	126
	Recycled Paper Products	127
	Recycled Rubber Products	128
	Resins for Engineered Wood Products	157
	Roofing Systems – Neoprene Latex	021
	Sealants & Caulking Products	045
	Steel for Use in Construction products	150
	Surface Coatings	047
	Thermal Insulation	016
	Water Saving Products	029
	Wood Treatment - Alternatives	002

MECHANICAL PROPERTIES, WATER SORPTION AND FROST RESISTANCE OF LIME-HEMP CEMENTITIOUS COMPOSITES

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Keywords: concrete, cement, hemp, lime

Summary

This research focuses on the use of different binding agents used in the building material Lime-Hemp Concrete (LHC). It is a light composite building material that consists of building limes and hemp (Cannabis *sativa*). Contemporary LHCs only use the woody core part of the hemp, the shive. Using both hemp shives and fibres may improve mechanical strength. This would also eliminate the need for a fibre separation process which currently is not commercially available in Sweden. This research aims to elucidate the feasibility of using the entire fragmented hemp stem in a LHC. Furthermore the aim was to determine some important material properties of different LHC mixes, using varying compositions of the lime-based binder. Five mixes of the binding agents hydrated lime, hydraulic lime and cement were tested. Specimens were in total cured for 18 weeks at room temperature of which 40 days in a carbonatation room (4.5 vol% CO_2). They were tested for mechanical properties, water sorption and frost resistance. A compressive strength of 0.15-0.83 MPa was found for the five different binding agent mixes tested. Using both shives and fibres in LHC may be advantageous until possibilities to separate hemp fibres from hemp shives are commercially available in Sweden. The research project is ongoing and further experiments will be carried out during 2008.

1. Introduction

In recent years sustainability in architecture has become a key issue for architects and builders. Sustainability in architecture and building can be obtained in different ways. Energy that is used by buildings should be reduced, both during the building process as well as during occupancy. Also, building materials should be renewable and recyclable in the greatest extend possible. Schultmann and Sunke (2007) mentioned that the highest amount of construction and demolition waste over the life cycle of a building occurs during deconstruction. Therefore the use of renewable and recyclable raw materials in the building industry is imperative to reduce this waste.

In present research the use of the renewable material hemp (Cannabis *sativa*) as building material is studied. Hemp is a fast growing annual crop that can reach a height of 1.5-4m in northern Europe (Osvald, 1959). Growing industrial hemp became illegal in Sweden in 1965 but has been legalised again in 2003. According to the Swedish Board of Agriculture, 24 hectares of hemp were grown in Sweden in 2003. In 2007 this was 792 hectares. In the five years that hemp has been grown in Sweden, a viable commercial market has yet to be established. The greater part of the hemp cultivated in Sweden is used as biomass fuel. Hemp is pressed into briquettes and burned for energy purposes. Another part of the cultivated hemp is grown and analyzed for trials and research projects (Rolandsson, 2008). At the Swedish Hemp Seminar in Alnarp, 13th March 2008, it was underlined that there is a very small commercial market for hemp in Sweden. Therefore the Swedish market of non-food crops must find new products and possibilities to use Swedish hemp.

An advantageous application of hemp can be found in a lime-based cementitious building material; Lime-Hemp Concrete (Arnaud and Cerezo, 2001; Arnaud et al., 2006; Cerezo, 2005; Evrard, 2003). Lime-Hemp Concrete (LHC) is a composite building material containing hemp in a lime-based binder. In contemporary LHC the hemp shives, the woody core parts of the hemp plant, are used. The process to separate fibres from shives is complex and expensive, and requires a viable market for hemp fibres. No such commercial fibre separation facility currently exists in Sweden.

The compressive strength of contemporary LHC is not sufficient for the material to be load-bearing. In contemporary LHC only hemp shives were used. The aim of this research was to determine the feasibility of LHC as a load-bearing material using both hemp shives and fibres. Furthermore the aim was to determine some important material properties of different LHC mixtures, using varying compositions of the lime-based binder. Different ratios of hydrated lime, hydraulic lime and cement were used.

Using not only hemp shives, but also its fibres might influence mechanical strength of LHC. Also, this would eliminate the fibre separation process and create a market in Sweden for the entire fragmented hemp stem.

2. Materials and Methods

2.1 Hemp, Limes and Cement

The hemp variety *Futura 75* was used. It was acquired from a local farm in the province of Scania, Sweden. The hemp was spring-harvested in 2006. The entire hemp plant was harvested, baled and stored. Hemp bales were processed in an industrial shredder, displayed in Figure 1. Fibres, shives and dust were not separated in the shredder and ended up in the hemp material used in this research. The shredder cut the hemp plant in particles with an average length of 12 mm. The hemp material consisted of ⅓ parts fibres and ⅔ part shives. A small part of the material was dust.

Figure 1 Shredder.

2.2. Specimen preparation

Test specimens measuring 150×150×150 mm were made. Five mixes of the binding agents were prepared (Fig. 2). The ratio of hemp to binder was 1:3 by volume. The binder mix, water and hemp were allowed to rotate for a few minutes in a concrete mixer (Fig. 3). Test specimens were cast and then cured for 18 weeks. During this time they were exposed to 4.5 vol% CO_2 for 40 days to accelerate the carbonatation process.

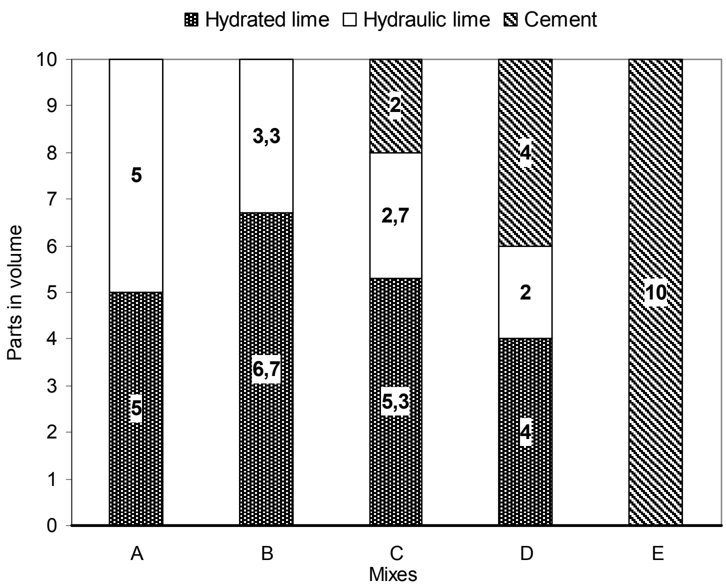


Figure 2 Binder mixes.

Figure 3 Concrete mixer.

2.3. Specimen measurement

A compressive strength test was performed on the test specimens. Six specimens were tested per mix.

Secondly, six specimens per mix were subjected to a total of 25 freeze-thaw cycles. The set temperature was +20 ºC for 12 hours followed by -20 ºC for 12 hours. After the freeze-thaw treatment the test specimens were tested for compression strength.

Thirdly, water sorption was tested by placing three test specimens per mix in a container with 5-10 millimetres of water (Fig. 4). The weight of the test specimens was measured at 12 occasions between 0 and 24 hours from the start.

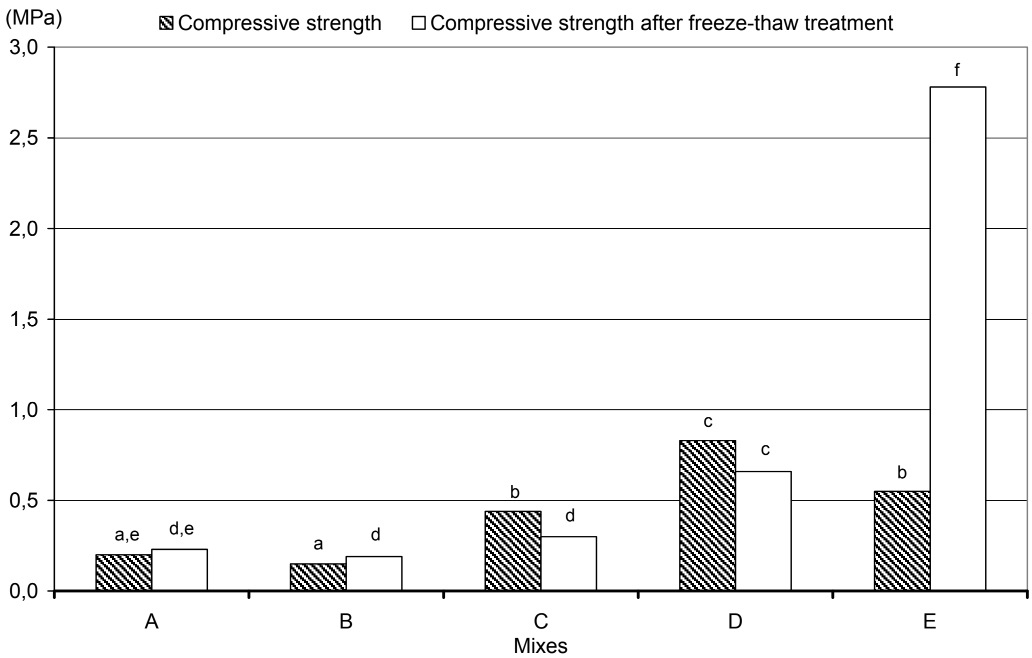
Figure 4 Water sorption test, specimens from mix B.

2.4. Statistical analysis

Statistical analyses were carried out with the software package Minitab 15 for Microsoft Windows (Minitab Inc., State College PA, USA). Appropriate *t*-tests, analysis of variance as well as Tukey's tests were carried out to determine if the tested mixes were significantly different ($P<0.05$)

3. Results

Compressive strengths for the mixes A-E ranged from 0.15 MPa to 0.83 MPa. Compressive strength after freeze-thaw treatment was similar to that of the test specimens that did not undergo freeze-thaw treatment, see Figure 5.



Different letters (a, b, c) indicate values that differ significantly ($P<0.05$).
Comparisons were not made between before and after freeze-thaw treatment for different mixes.

Figure 5 Compressive strength before and after freeze-thaw treatment.

The average water sorption coefficient for the five mixes was 0.15 kg/m²·√s. No significant differences between mixes A-E were observed.

4. Discussion

Compressive strengths of the specimens tested in this research were comparable to values found in other research. Compressive strengths of contemporary LHC were 0.4MP to 1.2 MPa (Arnaud, 2006) and 0.4 MPa (Evrard, 2003). Arnaud (2006) reports that compressive strength of LHC increases with time. This could explain the fact that compressive strength of contemporary LHC which had cured for a longer time, were slightly higher than the values observed in this research.

Not only hemp fibres were included in the hemp material, but also dust. The hemp dust may have had a negative influence on the mechanical properties of the LHC mixes. Also, hemp fibres differ greatly from hemp shives; this may have influenced mechanical strength of the material. However, tensile strength might be improved when using fibres as well as shives.

Comparing compressive strength before and after freeze-thaw treatment, values only significantly decreased for mix C. Values found for mix B and E even showed a significant improvement. Mixes A-E all underwent the same curing treatment. This meant that test specimens containing cement, mixes C-E, were not water cured. Watering fresh cement is very important for curing. Before the freeze-thaw cycles started, the test specimens were placed in water for 24 hours. This probably caused the noteworthy improvement in strength for mix E (binding agent cement).

No significant differences in water sorption coefficients were observed between the mixes. Important is not only water absorption, but also the rate at which the absorbed water can leave the material again, its desorption. In this aspect lime and cement behave differently.

5. Conclusion

Using the entire, shredded, hemp stem in a LHC created a material that seems to have the same characteristics as contemporary LHC. Compressive strength was rather low. Using a hemp material with both shives and fibres did not seem to create a mechanically stronger LHC.

Differences in mechanical strength between mixes were not big. However, mixes D and E showed the best results in compressive strength. Specimens with cement that were water cured after preparation would probably have improved the mechanical properties of the material. Mixes D and E contained most cement. Cement seemed to have a beneficial impact on the mechanical properties of the material. However, using cement in LHC might have a negative influence on the hemp material, which not studied in this research.

LHC is an interesting building material that uses the renewable raw material hemp. It can be used in combination with a load-bearing structure. The impact of freeze-thaw cycles on the material was low. Also water sorption was moderate. This shows potential for the material to be used in a Swedish climate with cold winters and rain all year round. The use of LHC as a building material in Sweden could increase the market for Swedish hemp, while introducing a durable and sustainable building material.

More research is needed in order to explore possibilities of the use of LHC.

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WATER RETENTION CAPABILITY OF MORTARS MADE OF RECYCLED AGGREGATE

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Keywords: recycled aggregate, mortar, workability, water retention capability

Summary

The paper presents results of a study aimed to analyze the applicability of fine fraction of recycled aggregate (RA) in mortar. Mortars were tested for their workability assessed as flow and for their capability to retain mix water when placed on absorptive material. The latter was determined by the gravimetric method. Results are compared to the results obtained on mortar mixtures made of natural crushed aggregate (NA) with the same granulometric composition. Six mortar mixtures were prepared from each aggregate, namely mixtures containing 25, 30 and 35 % of overfill (f_{OF}) at water-binder (*wb*) ratios 0.7 and 0.8. Results show that flow of mortar is ~ 15 % lower when RA is used in comparison to NA mortars, however the difference decreases with the increase of *wb* and f_{OF}. Results of water retention capability are given as time (*t*) evolution of relative loss of water (u_w). Three distinctive regions of the process are perceived and are discussed in the paper. It was determined that in 5 min after placing mortar on a clay brick NA mixtures lose 32 % of water, whereas this value amounts to 26 % for RA mixtures. Maximum water loss was 59 and 45 % for NA and RA mortars respectively. In time interval from 5-60 min u_w shows linear dependency on sqrt(*t*). Values of correlation coefficient (*q*) were found to be ~ 0.038 and 0.030 min$^{-1/2}$ for NA and RA mortars respectively.

1. Introduction

Disposal of construction and demolition debris in landfills is considered as a big environmental problem of modern society and possibilities to implement sorting, recycling and reuse of these materials are studied worldwide. In this respect concrete debris was considered for production of recycled aggregate (RA), which could be used in new concrete mixes. However, studies carried out so far indicate, that fine fraction of RA, consisting of particles smaller than 4 mm, should not be used in concrete but should be replaced by natural sand (Ajdukiewicz and Kliszczewicz, 2002, Chen et al., 2003, Khatib, 2005, Tu et al., 2006). Thus, it is necessary to find alternative applications for the fine fraction of RA in order to implement the »Zero Waste« concept and attempts have been made to use it in mortar mixtures (Corinaldesi et al., 2002, Moriconi et al., 2003, Miranda and Selmo, 2006a-b). Although mortars can be considered as concrete of small sized aggregate with maximum grain size of about 4 mm, they are in fact used for different purposes than concrete and different technology is applied for their processing. Therefore, some specific properties of mortars are required. Most significant characteristics of hardened mortars are strength, elasticity, water permeability and resistance to weather conditions, whereas for fresh mixtures these characteristics are workability, setting time, adhesion and water retention capability. On the opposite of concrete where compressive strength is the major decisive factor of its applicability, the compressive strength of the mortar is found to have a low influence on the masonry behavior. In fact, masonry behavior significantly depends on deformability and bonding capacity of the mortar, which are both influenced by mortar workability (Moriconi et al., 2003). Workability is a significant factor for the successful use of application techniques for finishing layers as well. In the case of mortars workability is manly assessed by setting time, cohesiveness and water retention capacity (De Vekey, 2001). While setting time defines the period after mixing in which mortar can be placed, cohesiveness is essential for the placing itself since the mix should be plastic, adhesive and resistant to bleeding and segregation. Since mortars are often spread over absorptive materials (e.g. clay bricks) water retention capability of fresh mix is very important (Sebaibi et al., 2003). Namely, these materials readily absorb mix water from the mortar and this may lead to irregular hardening. In this case designed properties of the mortar are not achieved. Only by retaining enough water, mortar can preserve adequate plasticity and reach designed properties. Structure and texture of the aggregate significantly affect the quantity of water needed for required workability. It is well established that aggregates with higher porosity and larger surface area per unit volume absorb more water and hence mortar made of such aggregate is stiffer. In the case of

RA grains consist either of (i) natural stone originating from NA used in primary concrete, (ii) cement matrix of primary concrete or (iii) combination of both. Since cement matrix is in general more porous than natural sand, RA can absorb more water which might be released back to the matrix when desiccation occurs and thus effect positively on the hydration process of the mortar. The aim of the research presented in the paper was to asses the applicability of the fine fraction of RA in mortars in terms of mortar workability and ability to retain mix water when placed in contact with absorptive materials.

2. Experimental

RA used in the experimental study was obtained from laboratory samples of concrete with characteristic strength of 30 MPa. This primary concrete was in the form of cubes with sides of 15 cm as are used for compressive strength tests. Cubes were crushed in a mobile machine for recycling the construction and demolition waste. As reference aggregate natural crushed sand was used. This type of NA was chosen because the shape and the texture of the particles are more similar to RA than in the case of alluvial sand. Both aggregates were sieved on a composition of laboratory sieves. Fractions of each aggregate were mixed in mass proportions giving the granulometric composition shown in Fig. 1. The density of NA was determined in pyknometer whereas for RA it was estimated on the basis of primary concrete density. Compacted bulk density of each aggregate mixture was determined by placing three layers of aggregate into a standard 1 dm^3 container where each layer was manually compacted. The volume fraction of void space was calculated as

$$f_V = 1 - \frac{\psi}{\rho} \qquad (1)$$

where ψ is the compacted bulk density (kg m^{-3}) and ρ is the density (kg m^{-3}). Values of ψ, ρ and f_V for NA and RA are summarized in Table 1.

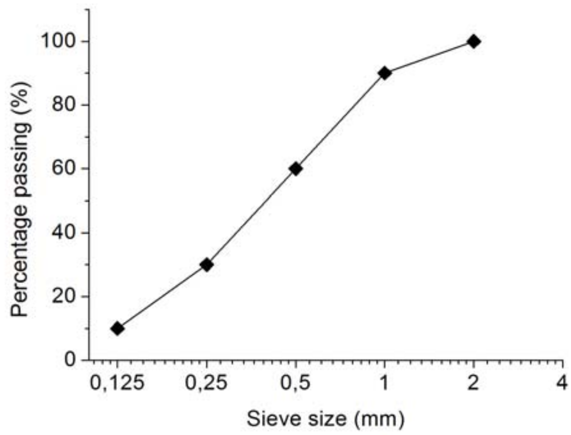


Figure 1 Granulometic curve according to which fractions of natural and recycled aggregate were combined.

Table 1 Density (ρ), compacted bulk density (ψ) and volume fraction of void space (f_V) for natural (NA) and recycled (RA) aggregate having granulometric composition given in Fig. 1.

Aggregate	ρ (kg dm^{-3})	ψ (kg dm^{-3})	f_V (%)
NA	2.787	1.819	34.7
RA	2.130	1.374	35.5

Design of mortar mixtures was based on two variables namely on water-binder (*wb*) ratio and on overfill of the binder paste. In general *wb* is ratio between mass of water and cumulative mass of binder materials, which in the case of mortars are usually cement, lime and gypsum. Overfill of the binder paste is regarded in the following manner: when aggregate particles of given granulometric composition are compacted there is a certain amount of void space between the particles which must be filled with the binder paste. This paste is regarded as a basic binder paste and its volumetric fraction (f_{BBP}) is equal to f_V. However, in order to achieve the adequate workability of the mortar a larger amount of the paste must be present in the mix. Hence, overfill is the excess binder paste present in the mortar mixture which is not needed to fill the voids between the aggregate particles and its volumetric fraction is denoted as f_{OF}. Total volume fraction of binder paste in the mortar is therefore

$$f_{BP} = f_{BBP} + f_{OF} = f_V + f_{OF} \quad (2).$$

For the experimental work six mortar mixtures were prepared from each aggregate. Binder consisted only of cement CEM I 42.5 R. Three mixtures of each aggregate were made with *wb* ratio 0.7 and three with the ratio 0.8. Three values of f_{OF} were used at each *wb* ratio namely 25, 30 and 35 %. Detailed mixture compositions specifying masses of aggregate (m_a), cement (m_c) and water (m_w) are given in Table 2. As may be perceived in Table 1 the difference between f_V of NA and RA is not significant, hence values of f_{BP} for mixtures made of NA and RA at given *wb* and f_{OF} are approximately the same. Consequently mass of cement needed for 1 dm^3 of mortar for equivalent NA and RA samples varies only for ~ 1 %.

Table 2 Mix proportions for 1 dm^3 of mortars made of natural (NA) and recycled (RA) aggregate at given water-binder (*wb*) ratio and volume fraction of overfill (f_{OF}). Masses of aggregate, cement and water are denoted as m_a, m_c and m_w respectively.

wb	f_{OF} (%)	NA mixtures			RA mixtures		
		m_a (g)	m_c (g)	m_w (g)	m_a (g)	m_c (g)	m_w (g)
0.7	25	1365	494	346	1030	500	350
	30	1274	526	368	962	531	372
	35	1183	558	390	893	563	394
0.8	25	1365	451	361	1030	456	365
	30	1274	480	386	962	484	288
	35	1183	508	407	893	513	410

Mortars were prepared with the use of standard laboratory mixer, which has a static pan and a mixing paddle that rotates in two directions. After mixing the consistency of each mortar was determined on a standard flow table. Spread was measured after 10, 15 and 20 jolts and mixture was visually inspected for segregation and bleeding. Measurements of water retention capability were carried out by the gravimetric method. For this purpose frames with dimensions of ~ 96 × 46 × 22.5 mm were placed on fired clay bricks having dimensions of ~ 120 × 65 × 45 mm. Bricks were dried in an oven before the experiment and cooled to a room temperature. Mortar vas placed into the frames as shown in Fig. 2. The following masses were determined: (i) mass of the brick (m_b), (ii) mass of the brick with the frame (m_{b+f}) and (iii) mass of the brick with the frame containing mortar (m_{b+f+m}). Six specimens were made of each mixture and were wrapped into a plastic foil in order to prevent evaporation. One frame together with mortar was removed from the brick in each predetermined period, namely after 5, 10, 20, 30, 60 and 120 min since the mortar was placed. Mass of brick containing absorbed water ($m_{b+\Delta w}$) was measured. Hence, mass of the water lost from the mortar ($m_{\Delta w}$) is determined as

$$m_{\Delta w} = m_{b+\Delta w} - m_b \quad (3).$$

Figure 2 Mortar placed in the frame on the top of the fired clay brick. Photo was taken 120 min after placing and the front of absorbed water is visible on the front side of the brick.

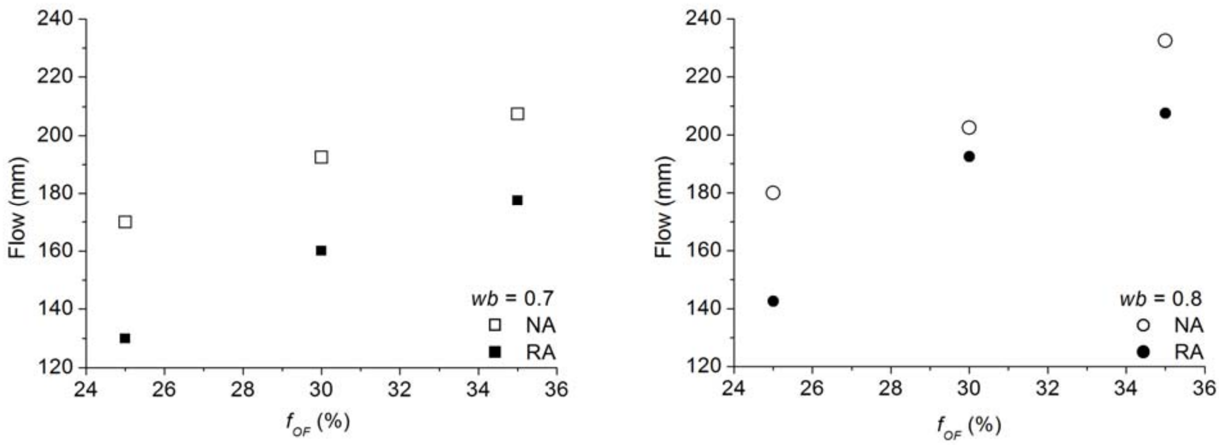
3. Results and discussion

Densities of fresh mortar mixtures are given in Table 3. It may be observed that the values of density of RA mixtures are ~ 8 % lower then values of equivalent NA mortars. Such difference is in compliance with the difference calculated from the rule of mixtures. Namely the volumetric fraction of aggregate in mortars was between 0.42 and 0.49 (calculated from data in Tables 1 and 2) whereas values of density and compacted bulk density of NA and RA differ for ~ 24 % (Table 1).

Results of consistency measurements are given in Fig. 3, where flow measured after 15 jolts is plotted against the volumetric fraction of overfill. Measurements obtained after 10 and 20 jolts gave equivalent results and are not shown separately. Results show that at the same *wb* and f_{OF} flow of mortar made of RA is lower in comparison to NA mixtures. The difference is larger at lower *wb* ratio. This can be explained by the porous nature of RA. Namely part of the mix water together with some cement particles is absorbed by the aggregate and thus, *wb* ratio of the remained binder paste and its quantity between the particles are reduced. As the consequence the lubricant effect is diminished. At higher *wb* ratios the effect of water absorption is less profound since enough water remains in the paste to assure lubrication. In order to achieve the same flow of RA mixture as in the case of NA either *wb* or f_{OF} have to be increased. Higher *wb* will result in lower cement content per unit volume of mortar, whereas increasing the f_{OF} will result in higher cement content and lower volumetric fraction of aggregate. Therefore both parameters have to be optimized. Upon the visual inspection of mortars no segregation was detected, whereas bleeding was observed only on mixture made with NA, having *wb* = 0.8 and f_{OF} = 35 %.

Table 3 Densities of fresh mortars made of natural (NA) and recycled (RA) aggregate at given water-binder (*wb*) ratio and volume fraction of overfill (f_{OF}).

Aggregate	Density (kg dm^{-3})					
	wb = 0.7			*wb* = 0.8		
	f_{OF} = 25 %	f_{OF} = 30 %	f_{OF} = 35 %	f_{OF} = 25 %	f_{OF} = 30 %	f_{OF} = 35 %
NA	2.350	2.305	2.310	2.349	2.351	2.297
RA	2.121	2.154	2.123	2.123	2.133	2.125



(a) (b)

Figure 3 Flow of mortars measured after 15 jolts on standard flow table in respect to volumetric fraction of overfill (f_{OF}) for mixtures made of natural (NA) and recycled (RA) aggregate with water-binder (wb) ratio of (a) 0.7 and (b) 0.8.

Results of water retention capability are evaluated as the relative mass of water lost from the mortar and is calculated as

$$u_w = \frac{m_{\Delta w}}{m_{wm}} \tag{4}$$

where m_{wm} is mass of water (kg) contained in the quantity of mortar placed on the individual brick. It was calculated upon the mass fraction (x_w) of the water in the mix which follows from Table 2 and the difference of measured values m_{b+f+m} and m_{b+f}. Hence

$$m_{wm} = x_w \left(m_{b+f+m} - m_{b+f} \right) = \frac{m_w}{m_a + m_c + m_w} \left(m_{b+f+m} - m_{b+f} \right) \quad (5).$$

Values of u_w plotted against square root of time (t) are given in Figs. 4-6. Results show that kinetics of water loss has three distinct regions. The first region is in the time interval from 0 to 5 min, during which NA mortars lose ~ 32 % of water whereas this value amounts to ~ 26 % for RA mixtures (Table 4). On the basis of collected data no correlation between u_w and wb or f_{OF} is observed. The second region covers the time interval from 5 to 60 min. In this period a linear correlation in the form of

$$u_w = q\sqrt{t} \tag{6}$$

is observed, where q is a correlation coefficient ($s^{-1/2}$). Eq. (6) has the same form as *Lucas-Washburn* equation which describes capillary absorption in porous materials. However in the case of capillary absorption the water source is considered to be infinitive and thus absorption kinetics is governed only by the properties of the absorptive material. In the case of water retention experiments absorption of water is governed by the absorptive properties of the brick, by the permeability of the mortar and by the content of free water in the mortar mixture. Therefore during the first time interval (0-5 min) absorption is fast because the water from the bottom layer of mortar is absorbed and the kinetics is governed mainly by the capillary properties of the brick. In the second interval (5-60 min) absorption is retarded because water must first percolate from the upper layers of mortar to the mortar-brick interface. In general initial set of cement takes place after 60 min which results in the stiffening of the mortar. In this period mix water is being consumed by hydration process so the amount of free water is reduced. Moreover its movement through the mortar is governed mainly by the diffusion mechanism. This results in additional retardation of water loss and presents the third region of the process.

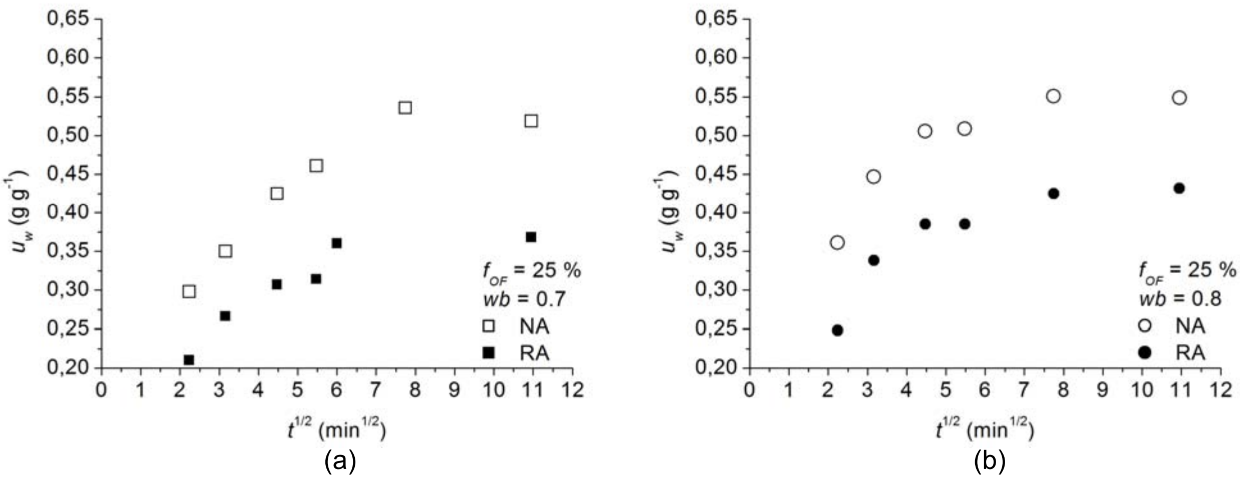


Figure 4 Relative mass of water (u_w) lost in the period of time (t) from the mortar made of natural (NA) and recycled (RA) aggregate containing 25 % of overfill (f_{OF}) and having water-binder (wb) ratio (a) 0.7 and (b) 0.8.

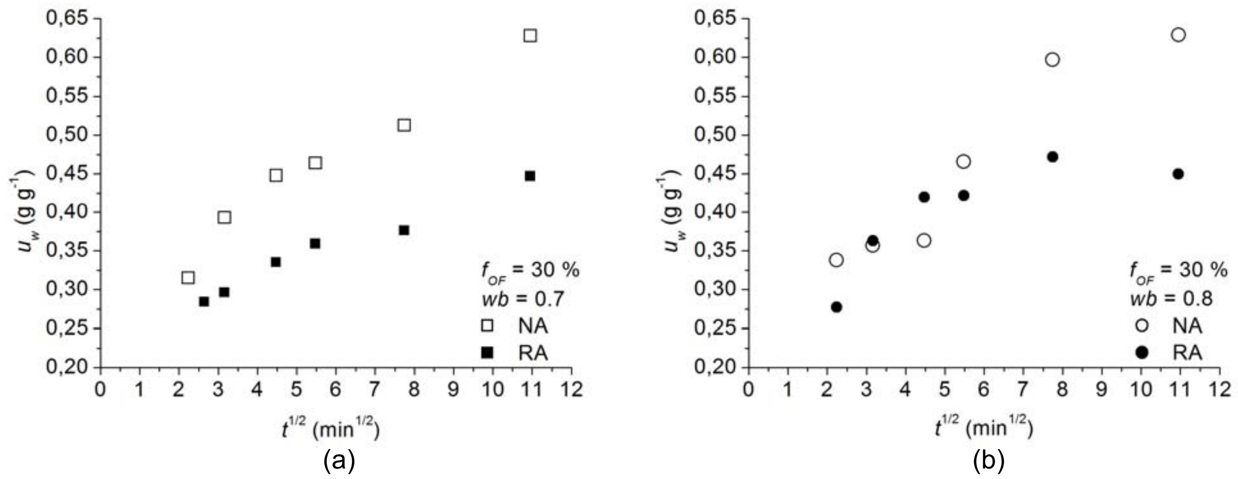
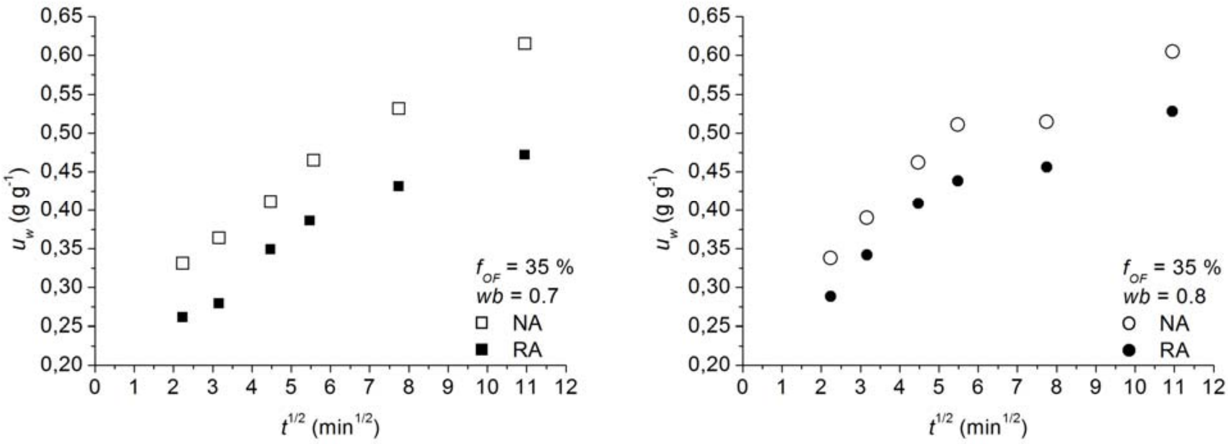


Figure 5 Relative mass of water (u_w) lost in the period of time (t) from the mortar made of natural (NA) and recycled (RA) aggregate containing 30 % of overfill (f_{OF}) and having water-binder (wb) ratio (a) 0.7 and (b) 0.8.



(a) (b)

Figure 6 Relative mass of water (u_w) lost in the period of time (t) from the mortar made of natural (NA) and recycled (RA) aggregate containing 35 % of overfill (f_{OF}) and having water-binder (wb) ratio (a) 0.7 and (b) 0.8.

Values of the correlation coefficient for the second region were obtained by fitting Eq. (6) to experimental data and values of q are given in Table 4 together with calculated and measured values of u_w at t = 5 min, which is the lower limit of the validity of Eq. (6). No correlation between u_w and wb or f_{OF} is observed. Average value of q for NA mixtures is found to be 0.038 min$^{-1/2}$ whereas this value amounts to 0.030 min$^{-1/2}$ for RA mortars, however standard deviation is 0.007 and 0.006 min$^{-1/2}$ respectively. Thus it may be concluded that percolation of free water through the studied fresh mortar mixtures is approximately the same. Still, maximum water loss is on average 59 and 45 % for NA and RA mixtures respectively. Therefore a positive effect of RA on water retention capability of the mortar is acknowledged.

Table 4 Values of correlation coefficient (q) defined by Eq. (6) together with calculated and measured values of relative water loss (u_w) 5 min after placing for mortars made of natural (NA) and recycled (RA) aggregate at given water-binder (wb) ratio and volume fraction of overfill (f_{OF}).

wb	f_{OF} (%)	NA mixes q (min$^{-1/2}$)	NA mixes u_w (g g^{-1}) at t = 5 min Calculated	NA mixes u_w (g g^{-1}) at t = 5 min Measured	RA mixes q (min$^{-1/2}$)	RA mixes u_w (g g^{-1}) at t = 5 min Calculated	RA mixes u_w (g g^{-1}) at t = 5 min Measured
0.7	25	0.043	0.311	0.298	0.035	0.221	0.210
	30	0.033	0.347	0.315	0.019	0.284	0.284
	35	0.037	0.331	0.331	0.033	0.263	0.261
0.8	25	0.031	0.400	0.361	0.028	0.289	0.248
	30	0.048	0.309	0.338	0.032	0.314	0.277
	35	0.033	0.314	0.277	0.030	0.314	0.288
Average		0.038	0.335	0.320	0.030	0.281	0.261
Deviation		0.007	0.035	0.030	0.006	0.035	0.029

4. Conclusions

Due to environmental reasons possible applications of fine fraction of RA obtained from construction and demolition waste are considered. In the scope of presented research work selected properties of fresh RA mortar mixtures were studied and results were compared to mixtures made of crushed NA with the same granulometric composition. Each aggregate was used for preparation of three mortar mixtures with wb ratio 0.7 and three with wb 0.8, where values of f_{OF} were 25, 30 or 35 %. Density, flow and water retention capability of mortars were determined and the following conclusions are drawn:

1. Densities of RA mortars are ~ 8 % lower in comparison to equivalent NA mortars, which is the immediate consequence of lower density of RA.
2. Flow of mortar is ~ 15 % lower when RA is used in comparison to NA, however the difference decreases with the increase of wb and f_{OF}.
3. Water retention capability is given as the time evolution of relative loss of water from the mix and three distinctive regions of the process are detected.

4. The first region is in the time interval from 0 to 5 min after placing mortar on the fired clay brick and in this period NA mixes lose ~ 32 % of water, whereas this value amounts to only ~ 26 % for RA mixes.
5. The second region is in the time interval from 5 to 60 min in which relative water loss is linearly dependent on sqrt(*t*). Values of correlation coefficient were found to be ~ 0.038 and 0.030 $min^{-1/2}$ for NA and RA mortars respectively.
6. In the third region which starts 60 min after placing mortar on the fired clay brick water loss is significantly decreased and maximum water loss was measured to be ~ 59 % for NA mortars and only ~ 45 % for RA mortars.
7. On the basis of the experimental results positive effect of RA on water retention capability of cement mortars is acknowledged.

Study presented in the paper yielded favorable results for the use of RA in mortar mixtures and thus further research work is encouraged. In the scope of future work other properties of RA mortars like mortar-brick bond, strength and permeability should be studied. Different combinations of binders and admixtures should be considered as well.

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COMPARISON OF THE AMOUNT OF MATERIAL AND COST FOR BOTH CANADIAN AND JAPANESE OFFICE BUILDING CONSTRUCTION

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Summary

The objective of this paper is to analyze and compare the amount and cost of major building materials throughout the construction stage for both Canadian and Japanese office buildings. Decision-making for different office construction development scenarios is investigated in assessing the material implementation techniques for both countries. This study provides initial information to characterize materials to explore effective construction techniques and to identify a great impact in many other industries for two regionally and culturally different situations.

Canada and Japan have agreed to the Kyoto protocol and had a common reason to be interested in meeting the CO_2 reduction targets. More fundamentally, the Canada-Japan bilateral trade and economic cooperation framework provides a number of similar construction market structures. It is meaningful to analyze and compare materials and services of both office building construction models to formulate the future industry-wide adopted construction strategies. This study helps to understand the environmental assessment mechanisms for the construction industry to achieve the Kyoto target reductions for CO_2 emissions through Canadian and Japanese office building construction activities.

Different from conventional environmental assessment methods which compare buildings against a common scale and require third-party verification, this paper suggests that the entire building construction process including other related industries' activities should evaluate in the context of building sustainability assessment method.

1. Introduction

Both Canada and Japan have agreed to the Kyoto protocol and have a common reason to be interested in trade arrangements that ease the burdens of meeting the reduction targets for Kyoto emissions. This study uses a Canada-Japan bilateral trade and economic cooperation framework to find a number of methodology-related points for a building construction method. This is because that building construction processes for both countries in procurement of materials, manufacturing, distribution, usage and disposal involve a number of various domestic and international industries' in multiple stages.

1.1 Target for Kyoto Protocol

According to the Kyoto protocol, Canada and Japan must bring down their CO_2 emissions levels over the period of 2008-2012 to a level which is 6% below their respective 1990 level. The total amount of CO_2 emissions has been increasing for both Canada and Japan. Over the period 1985-1995 CO_2 emissions climbed in volume from 435 million tons in 1985 to 478 million tons in 1990 and to 500 million tons in 1995 for Canada and from 895 million tons in 1985 to 1122 million tons in 1990 and to 1213 million tons in 1995 for Japan. The business sector (building construction sector) generates 40% of total CO_2 emission for both Canada and Japan.

1.2 Trading Partner–Canada and Japan

The United States is Canada's number one trading partner with 80% of Canada's exports destined to the US. Japan is Canada's second largest trading partner after the US but in comparison to the US this is extremely small. Approximately 75% of Canada's export to Japan is resource related goods from the agriculture, forestry, marine and minerals sectors and 90% of Canada's import from Japan occupies Machinery and Equipment and Automotive Products. (Figure1 and 2).

Country	Year	Agricultural and Fishing Products	Energy Products	Forestry Products	Industrial Goods	Machinery and Equipment	Automotive Products	Consumer Goods	Special Transactions	Total
US	07	1,473.8	7,537.5	2,000.4	5,333.2	4,910.9	5,999.9	1,061.5	591.8	28,908.9
	08	1,445.5	8,379.6	1,427.5	5,198.6	4,260.2	4,172.7	713.2	506.4	26,103.6
Japan	07	247.3	63.9	132.0	202.1	65.5	5.7	7.8	2.0	726.2
	08	271.6	67.5	86.6	139.3	41.1	3.0	7.9	0.4	617.3
World	07	2,524.6	7,740.5	2,675.8	8,211.6	6,491.6	6,226.3	1,238.4	669.7	35,778.5
	08	2,693.3	8,717.4	2,038.7	7,780.2	5,808.7	4,323.7	917.6	532.7	32,812.3

Figure 1 - Imports from selected countries, customs basis, not seasonally adjusted

Country	Year	Agricultural and Fishing Products	Energy Products	Forestry Products	Industrial Goods	Machinery and Equipment	Automotive Products	Consumer Goods	Special Transactions	Total
US	07	1,118.4	712.4	189.7	4,493.5	4,445.1	4,317.6	1,844.9	200.1	17,321.7
	08	1,195.8	1,175.1	168.7	4,373.4	4,295.5	3,610.2	1,724.5	375.6	16,918.8
Japan	07	5.4	9.6	0.0	95.1	468.4	484.8	85.9	0.2	1,149.5
	08	4.9	0.4	0.1	88.8	522.6	435.3	93.1	0.3	1,145.3
World	07	2,066.7	2,721.0	259.7	7,214.5	9,434.9	5,817.8	4,457.4	229.2	32,201.2
	08	2,171.6	3,744.9	240.1	6,932.3	9,038.8	5,064.6	4,436.6	423.2	32,042.1

Figure 2 - Domestic Exports to selected countries, customs basis, not seasonally adjusted

Looking from a broad macro perspective, the trend of the Canada-Japan trade relationship shows a decline in the trade balance for Canada over the past few years. This is partly due to the draw of a booming American economy during this time coupled with a stagnating Japanese economy. However, this doesn't mean there are no business opportunities for Canadian companies in the Japanese market. As a prime destination for Canadian building industries, the Japanese construction market is worth approximately $200 billion per year. Although entry into the Japanese market can often take time due to the complex nature of Japanese importing regulations and processes, there are many opportunities to explore possibilities to contextualize better the process of building construction for both Canadian and Japanese industries in this sector. From this point of view, it is necessary to understand the weakness and strength to enhance international trading to get construction materials to seek more environmentally friendly construction process.

1.3 Current Construction Market—Canada and Japan

The construction expenditures in Canada in 2006 were $195 billion. Construction activity on non-residential properties was high for a sixth consecutive year in 2006, due in large part to the booming economy of Western Canada. Among the nine provinces seeing growth in non-residential construction, Alberta showed the largest gain, at 40%, followed by British Columbia at 27%. Together, Alberta and British Columbia accounted for about 80% of the total increase in Canada's non-residential investment. Indeed, most of the spending includes government, public, and private non-residential buildings. Combined, these markets are receptive to green building concepts and products. This is evidenced by the growth of the Canada Green Building Council (CaGBC), which aims to advance the design and construction of green buildings in Canada. Since its launch in 2003, the membership of the CaGBC has risen to 1500 members. Members of the CaGBC have the opportunity to influence the direction and pace of the construction industry in Canada.

The Leadership in Energy and Environmental Design (LEED) has had great success to widespread the concept of green building techniques and to encourage the green building market in North America. In 2005-06 the green building market was an estimated US $15.7 billion. Canada has 26% of this market, which is equivalent to $4 billion. 13% is in the private non-residential sector market, 6% is in the residential sector and 7% is in the public sector. In Canada, the private non-residential and public construction market value was $90 billion in 2005. Spending in the residential sector totalled CAD $89 billon.

According to the Japanese Ministry of Land, Infrastructure and Transport (MLIT), total construction investment in the 2006 was estimated at $522 billion. Non-residential buildings represent 21 % of the total construction market. Compared with Canadian construction market, the Japanese market is not booming. However, the Japanese government predicts that construction investment remains stable, ranging from $500 to $550 billion over the next five years. Both the public and private sectors are planning a variety of projects including new buildings such as luxurious residential buildings and large-scale commercial facilities.

The Kyoto Protocol sets legally-binding targets to limit or reduce greenhouse gas emissions. The Japanese government has had a positive influence to increase the green building market growth on the Japanese building construction market. In 2001 the Japanese Comprehensive Assessment Scheme for Building Environmental Efficiency (CASBEE) was presented to accelerate the adoption of green building practices, technologies, policies and standards to the Japanese building market. Despite this strong interest, the market has just started growing and it is not yet widely recognized as one market segment. There is almost no research or statistical information available compared with Canadian green building market. However, this situation is changing quickly and the market is projected to take off in the near term.

Widespread recognized existing building assessment methods in Canadian and Japanese market are now evolving to embrace a broader range of stakeholders. However, while the framing of assessment methods is clearly broadening, both assessment tools still focus on an individual building. This study helps to establish future building assessment methods, likely to link across varying scales – buildings, neighborhoods, city, regions, countries etc – to permit the comprehensive framing of sustainability assessment. The primary future role of building assessment methods is to transform the culture of the construction industry to accommodate sustainability as a common, consistent and integral part of its decision-making (Cole, 2005).

1.4 Classification for Construction Material Flow

Assisting this concept, this paper analyzes the decision-making for the different office construction development scenarios for both two countries – Canada and Japan. To identify the significant economic and environmental impacts for office construction industries for both regions, *direct material* and *indirect material* are classified in this study (Fig.3).

- **Direct material** is calculated by the economic effect for the building construction process using major materials and services.
- **Indirect material** is calculated by the economic effect to produce major materials and services between industries in the economy beyond the direct effect.

This paper only focuses on the comparison for the amount and cost of “direct material" for both Canadian and Japanese office buildings to provide simple and clear construction analysis.

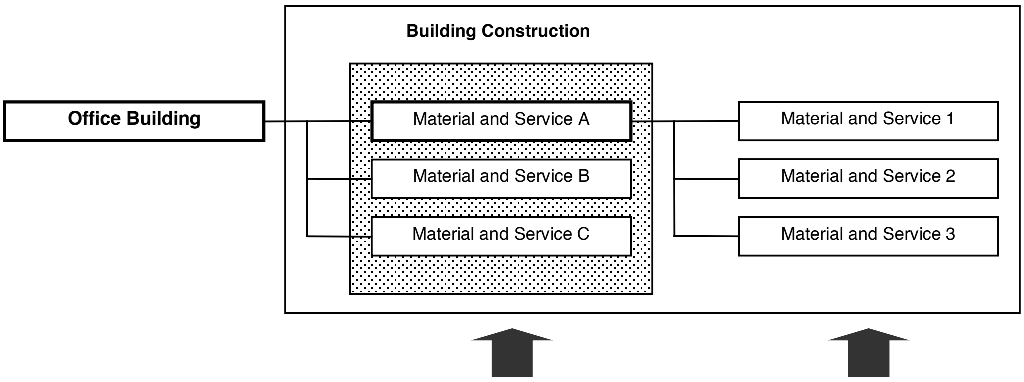

Figure 3 - Entire Economic Impacts for Office Building Construction

2. Analysis and Comparison for Construction Market

The total expenses for direct materials from various industrial sectors (such as steel and concrete) are given in this study. The information is currently produced for the effects of changed methods or conditions on the economics of the construction industry at both Statistics Canada (SC) and the Japanese Ministry of Land, Infrastructure and Transport (MLIT) on an annual basis. Also, SC and MLIT currently develop construction productivity indexes, including the I/O table, at an aggregate level using the different method. It is difficult to get data available which can be used to compare rates of productivity gains in various sectors of the both construction industries. While the data for “indirect materials” presents an overall perspective of construction industry’s activities, direct material analysis could provide a fairly refined level of industrial detail in this study.

2.1 Office Building Construction Price Indexes

The general construction prices for the office building are compared to analyze the difference the office construction market activities between Canadian and Japanese. All prices are collected directly by SC and

MLIT quantity surveyors and include costs for materials, labour, equipment, relevant federal taxes, and contractor's overhead and profit. Due to the lack of historical labeling of green buildings in Canada and Japan, it is difficult to definitively determine how much the green building practice affect in both Canada and Japanese construction market.

Discussed on the Section 1.3, Canadian construction industries are dramatically growing. As shown in Figure 4., it is apparent that interest in Canadian office construction market is also rising. Some involvement such as Vancouver 2010 Olympics is certainly the result of strategic business positioning, while other interest would be more altruistic. The figure shows the average annual increase is approximately 10% from 2004 to 2007 and SC analyzes the office construction market keeps growing. Many stakeholders tend to hold investing to the Canadian office construction market because the additional cost is usually required with the high market growth during construction period.

Figure 4 - office building construction price index 1997=100

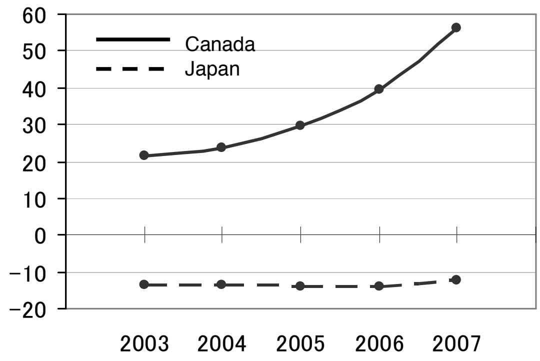

Figure 4 shows the 15% of office construction market approximately decreases compared with 1997 market condition. As Japanese office construction market was surprisingly very strong in 80' to 90', the current steady market situation is preferable for many stakeholders, developers, investors and owners. However, the supply volume of large-scale office buildings within Tokyo's 23 wards in 2006 reached 1.54 million sq.m., nearly double the 2005 level of 0.77 million sq.m. The supply volume in 2007 reached to 1.19 million sq.m, equivalent to 80% of the previous year. Since the majority of new projects consist of small- and medium-scale buildings with total gross floor area between 10,000 and 20,000 sq.m, the supply volume itself doesn't increase in line with the total number of new buildings. Continuing the trend from last year, many of these new plans include rebuilding or replacing existing buildings. Figure 4 doesn't include the construction cost for office renovations.

In this study, "direct materials" are first classified by 15 categories under both Canadian and Japanese construction industry (Figure 5). This data analysis presents how Canadian construction boom affects the cost of the construction materials compared with current Japanese construction market situations. As detailed case studies, the typical mid-size (10,000 m3) and small-size (5,000 m3) office buildings are investigated to estimate the total cost and amount of construction materials for both two countries. These case studies illustrate that the international trade between Canada and Japan provides the influence to the wood industries and the different background of architectural concepts affects the decision-making for a building envelop design. This study indicates the future potential for new office building construction technique and material choice to reduce environmental impacts such as CO_2 emission and energy consumption using the exchange of cross-cultural construction scenarios.

2.2 Direct Material Price Indexes

Using 2004 based Canadian and Japanese statistics information data, the percent increase and reduction for 15 direct materials are shown in Figure 5. Three important direct materials are particularly discussed in this section.

2.2.1 Plywood
Canada is the largest trading partner for Japanese forest industry and provides the 40% of wood products to the Japanese market. Although Japan's forests cover 66% of the land, the Japanese domestic wood products occupies 19.2% in 2003 for total wood products. This is because the Japanese forest industry has been defeated by cheap wood shipped from abroad. As Figure 5 shows, this current trading relationship with other countries influence the price increase for Japanese plywood market. According to the Nikkei Newspaper, the constrain for cutting rainforest in Indonesia and Malaysia to prevent global warming stimulates to increase the price of Japanese wood market. The price of plywood, especially using for concrete frames, is particularly high.

Although the demand for the plywood increases in Canadian construction market, the data shows the price for the domestic wood product market is steady. However, two countries have tentatively agreed on a common standard for construction grade plywood. The implementation of joint standards will enhance bilateral trade. The U.S.-Canadian Free-Trade Agreement has strengthened and enriched wood products trade between the two countries through improved market access.

2.2.2 Concrete
The price of concrete in Canadian construction market jumped 37 per cent between December 2005 and February 2006. Concrete prices are still rising after lumber prices have fallen well below their peak 2004 prices and steel prices have stabilized. SC predicts concrete prices continue increasing because Canadian cement capacity is not be enough to significantly relieve the current construction demand. However, Canadian cement market exports 50% of total production. The effective consideration for the import-export strategies for cement is required to provide enough amount of concrete and to prevent to increase the cost of

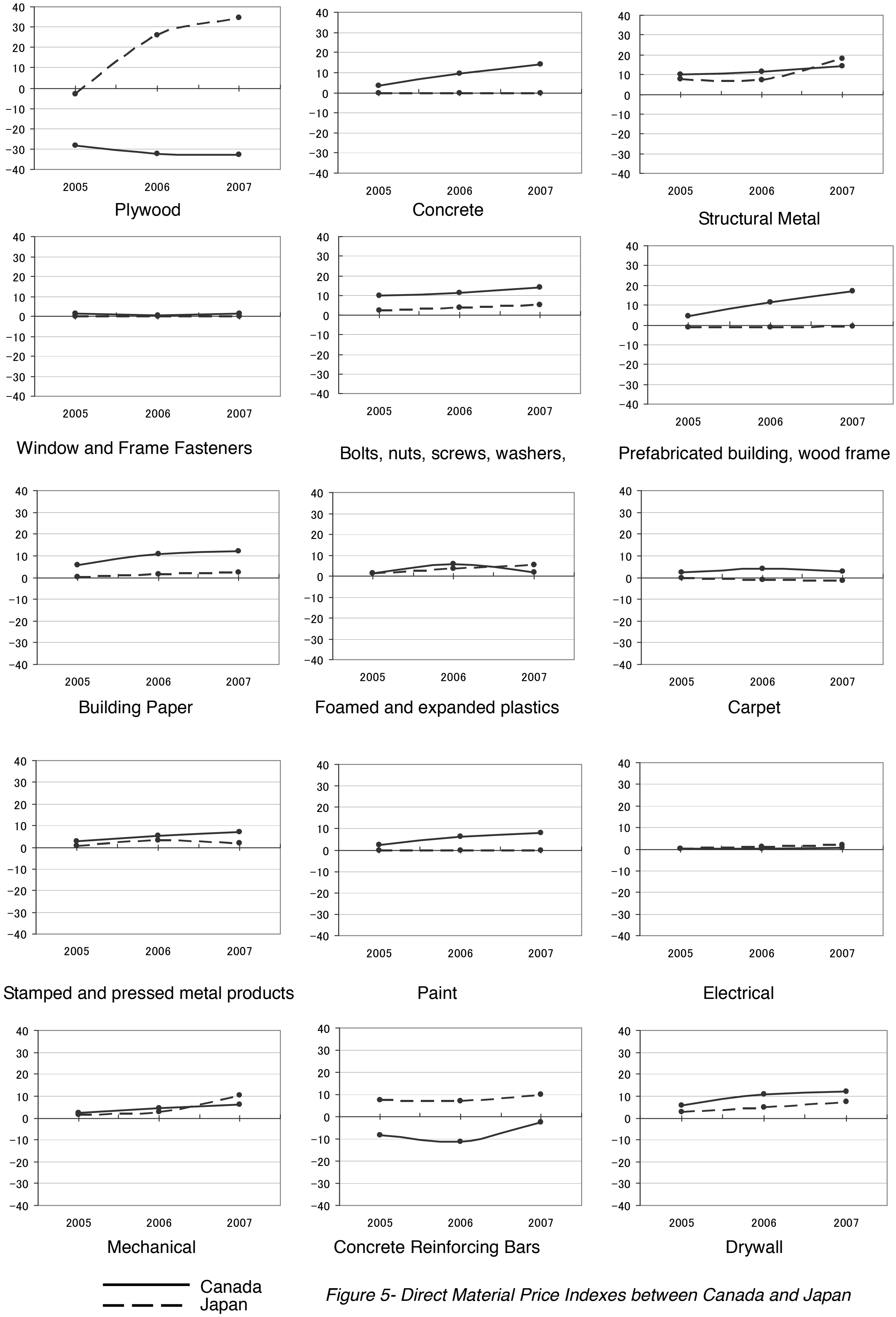

Figure 5- Direct Material Price Indexes between Canada and Japan

concrete for Canadian construction market. On the other hand, the total amount of exported cement is occupied on 9% for Japanese cement production. As Figure 5 shows, Japanese concrete price has been steady in the construction market for 30 years.

2.2.3 Steel and Concrete Reinforcing Bars
Both Canadian and Japanese construction industries indicate that the demand for steel increases and the supply for steel decrease simultaneously. All types of steel have increased in price compared with 2004. Figure 5 shows the structural metal products rise by approximately 20% in Japanese market.

China consumes about 25% of the world's steel supply. As China is a major country in the metal production market, it can redirect previously exported steel to overcome its own domestic demand for the material. This China's rapid growth stimulates to reduce the material's availability on the open market. This international metal market movement relatively affects Japanese market because the more than 90% of metal products are imported. SC predicts the cost of Canadian metal products also increases.

The important discussion in this section is that Japanese construction market strongly depends on the international trading to acquire the huge amount of construction materials such as plywood and steel compared with Canadian market. This market condition provides the high energy consumption and CO_2 emission for the transportation process. However, it is quite impossible to satisfy the entire Japanese market demand with just only domestic products. This market-based building construction analysis raises the issues of the direct martial acquisition for both countries.

3. Analysis for Specific Office Buildings

The scope of a case study is to investigate the amount and cost of office building construction materials to explore how the construction market affects other industries. The sample office buildings in this study chose from two regionally and culturally different countries, Canada and Japan. It is important to explore the different construction trends from two countries' construction market background rather than to focus on characteristics, strength or weakness comparing various office buildings from one specific region. The comparison for both construction techniques is easy to explore effective and ineffective construction method to apply a current each construction market. The key discussions associated with the evaluation for both office buildings are highlighted below:

- the different construction techniques based on building code or bylaw
- the trend of architectural design concept with different culture and social background
- the evolution and cross-cultural exchange for new construction techniques

3.1 Difference from Building Code and Bylaw

The evaluation for building structure is most significant study to find the different conflicting targets for both building construction methods. The reason is that the structure design clearly depends on the cultural and social building construction practice such as a bylaw or a building regulation rather than client and stakeholder interests. Figure 6 presents the amount of major office building structural materials (per sq.m), rebar, concrete, plywood and steel to illustrate the different structural mechanisms. This figure shows that the amount of the total structural components, concrete (0.69m2) and rebar (0.08t/m2), for Japanese office building is larger than Canadian office building. One of the reasons for this difference is the Japanese earthquake resistance regulation. The concrete quantity for building foundations is approximately double compared with Canadian construction techniques to apply this restrict regulation.

3.2 Trend of Architectural Design Concept

Limited property and extremely high land prices have generated Japanese characteristic compact urban centers and high-rise, high-density building. The result of tight spaces severely compromise spatial quality, privacy, natural lighting and ventilation, and view. The property value and building envelop design is most important factor to evaluate building value in the Japanese market. As Figure 6 shows the budget of exterior finish for Japanese office buildings spend more than 100$ per sq.m compared with Canadian office building and use window (curtain wall systems) 50% less than Canadian office. There are two reasons to discuss from two countries' architectural trend. Discussed above, as Japanese urban center is usually dense, curtain wall or expensive exterior materials are only installed on the main building façade to provide uniqueness in the competitive office building market. This design trend usually applies to small-and mid-size office buildings in Tokyo. On the other hand, the implementation of the market-placed curtain wall system is Canadian architectural trend for any size of office building with all faces for a building envelop. These two different architectural interests provide unique window and exterior finish data for both countries.

3.3 Innovative Construction Techniques

A number of innovative construction methods have been introduced and implemented to both construction markets. Increasing the importance and recognition of a green building concept in both Canadian and Japanese market, the designing of new construction techniques also considers to reduce environmental impacts during building construction process. A good example is that an innovative recyclable metal concrete frame system, E-PANET, is widely used for the substitution for plywood concrete frame system in Japanese market. As discussed in section 2.2, it is significantly effective to shorten the cost and amount of plywood to reduce environmental impacts for Japanese building construction process. According to the Nihon Kankyou Seizou, the 27% of commercial construction project uses E-PANET system in Japan.

Region		**Japan**		**Canada**
Size	2400 m²	15,000 m²	3250 m²	12450 m²
General Conditions	90.5 m²	82.6m m²	96.4 m²	77.2 m²
Site Work	144.33 m²	132.3 m²	89.5 m²	69.78 m²
Structure (Concrete and Steel)	473.46 m²	428.52 m²	402.76 m²	414.5 m²
Exterior Finish	379.18 m²	326.4 m²	239.6 m²	253.56 m²
Window	11.11 m²	24.42 m²	86.54 m²	95.7 m²
Mechanical	453.12 m²	398.32	355.21	323.63 m²
Electrical	142.11 m²	1567.34	140.34	139.56 m²

Figure 6- the average amount of major direct materials for office building construction

Region		**Japan**		**Canada**
Size	2400 m²	15000 m²	3250 m²	12450 m²
Rebar	0.08 t/m²	0.09 t/m²	0.06 t/m²	0.05 t/m²
Concrete	0.69 m²	0.71 m²	0.52 m²	0.45 m²
Frame	4.33 m²	4.87 m²	5.67 m²	5.21 m²
Steel	0.05t	0.07	0.09	0.06t
Window	0.14 m²	0.19 m²	0.31 m²	0.23 m²

Figure 7- the average amount of major direct materials for office building structure construction

4. Discussion

What is evident through the issues explored in this pare is a need for a greater understanding of the trend for building construction material industries and a strategic approach using innovative building construction techniques while understating cultural and social background for each countries. The following key points are discussed:

- Increasing building structural efficiency such as mximixing beam spans, downsizing column size, structure weight and foundation requirement
- Implementing suitable envelop design understanding a cultural and social trend
- Exploring new construction techniques
- Selecting appropriate construction materials, environmental friendly production and transportation process

There may be unavoidable situations for building construction scenarios that can be decided by government registrations such as Japanese earthquake regulation or Canadian building bylaw. However, determining a realistic and credible baseline for a building construction method listed above is necessary to answer a question “what is the effective office building construction scenario to minimize environmental impacts and how much impact does office building construction activities affect other industries?”. Exploring the effective implementation for building construction method and material encourage both countries’ construction industries to consider reducing environmental impacts at the building construction stage.

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AN EMPIRICAL STUDY ON OUTDOOR THERMAL ENVIRONMENT OF RESIDENTIAL DEVELOPMENTS AND STREET BLOCKS IN HONG KONG

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Keywords: urban microclimate, outdoor thermal comfort, urban heat island (UHI), residential development, mixed use street block

Summary

Majority of Hong Kong's population lives in high-rise high-density residential developments or mixed use street blocks. In such high-density living conditions, the provision of open space at neighborhood level is of vital importance to enable residents to enjoy better quality of life with the social, psychological and environmental benefits that open spaces can bring. However, when designing these public spaces, the effect of the overall build forms on the microclimate conditions need to be considered. Only when the conditions allow for human comfort would these spaces serve to promote sustainability. One significant factor having adverse effect on human comfort is heat stress. Heat stress in urban areas can be described by Urban Heat Island (UHI).

This study investigates the impact of design-related variables on outdoor micro level heat island effect in residential developments and mixed use street blocks in Hong Kong. It hypothesizes that a significant part of the differences in outdoor temperatures within and between the studied areas can be explained by the impact of design-related variables. The findings of the study will lead to specific environmental design guidelines to help practitioners to make design decisions at micro-urban and urban scales for more sustainable communities.

1. Introduction

Hong Kong has a population of 6.7 million, and a total land area of just 1,100 square kilometres, making it one of the most densely populated cities in the world. Due to the scarcity of available land (around 25% of the total area) for building in Hong Kong, most of the population lives in high-rise high-density residential blocks (privately developed or government subsidized) in urban areas, where the population density averages at around 26,000 persons per square kilometre and reaching 51,000 persons per square kilometer in the most densely populated area. The urban fabric is dominated by tall buildings with limited open space provision. (Figure 1a, b and c from left to right)

Figure 1a Large-scale residential developments with tower blocks of similar height and configurations

Figure 1b Sharp edged buildings of different height in urban street blocks

Figure 1c Newer taller developments form 'walls' surrounding older street block

It is well established that urban open spaces are vital to the well being of city dwellers. Urban spaces contribute to achieving sustainability and their importance for better quality of life is particularly crucial in high density cities such as Hong Kong. In light of the high density high rise environment of a compact city like Hong Kong, where the area of urban open space per inhabitant is only about 2.9 m^2 / inhabitant (Census and Statistics Department, 2001) as compared to the World Health Organization's recommendation of 10 m^2 / inhabitant, the importance of provision of high quality urban open spaces is further high-lighted.

Study by Lo et al (2003) on the analysis of attributes affecting urban open space design and their environmental implications concludes that microclimate is the most important criterion for urban open space users in Hong Kong. Research by S. B. A. Coorey (2008) on design of open spaces in public housing estates in Hong Kong also found that respondents' evaluation of physical environmental quality such as climatic comfort for open space scores comparatively high compared to other attributes such as crowding, privacy, safety and social interaction in achieving users' satisfaction of open space in high density contexts.

In light of these findings, microclimatic conditions are considered integral to the success of an urban open space, since they have significant influence on the level and satisfaction of use. The potential of urban open spaces in providing human comfort and promoting sustainability of urban living greatly depends on their thermal performance.

1.1 Background

Multiple and intensive land use is a sustainable approach in dealing with expanding metropolitan areas. Hong Kong has adopted the MILU model of development to cope with the increasing population and the economic need to expand the metropolitan area on very limited build-able land over the last five decades (Lau et al, 2005). The success of MILU model is evident in the development of Hong Kong into the metropolitan that it is at present, with many cities in China, such as Guangzhou and Shanghai following suite. However, the MILU model has also contributed to the adverse effect on microclimatic condition such as increased Urban Heat Island (UHI) in urban areas due to its typically high-rise high-density built form. The study of UHI in existing MILU developments would serve to inform other cities the possible adverse effects of adopting the MILU model and to make design decisions to avoid such effects.

The study of thermal environment of urban outdoor spaces requires understanding of urban morphology and climatology, both multi disciplinary study areas involving architectural design, planning considerations, building physics and atmospheric sciences. The local climate of an urban area can be greatly affected by the urban thermo-physical and geometrical characteristics and anthropogenic moisture and heat sources present in the area (H. Taha, 1997). In the high-density high-rise setting of Hong Kong, it can be anticipated that the adverse effect on the thermal conditions would be further aggravated since urban heat island intensity (UHI) rises with increased building density and canyon geometry (M. Santamouris, 2001). Hong Kong has one of the highest net urban densities in the world (Ganesan et al 2000). UHI is an outcome of modification brought into characteristic of land use in densely populated areas (Solecki et al 2005). In such scenario it is mandatory to integrate urban climotological elements (Abbate, 1997).

1.2 Hypothesis

This study investigates the impact of different form of open space configurations on outdoor micro level daytime and nocturnal heat island effect in residential and mixed use developments and street blocks in Hong Kong in order to understand the design implications involved in making comfortable outdoor open spaces for people's enjoyment. This paper hypothesizes that a significant part of the differences in outdoor temperatures within and between each studied site can be explained by the different typical open space configurations on the overall environment.

2. Methodology

The methodology used in this study is based on one that has been established by previous research on coastal UHI measurement in Hong Kong (Giridharan et al, 2004). The methodology has been improved by conducting simultaneous measurements at three different geographical zones for any given measurement period. 15 to 20 measurement points were chosen for each sample site, taking into account the maximum possible variations in design-related variables such as sky view factor, height to floor ratio and surface albedo.

Figure 2 Sky view images and photographs showing the variations in design-related variables

The data collection period was from 1300-2200, with hourly data collected at each measurement point. Data were collected simultaneously at 3 sites from different geographical zones for a period of 3 days.

In each of the studied site, 1 mini weather station measuring air temperature, relative humidity, wind speed and direction, and solar radiation was fixed at the most representative of the measurement points and 3 micro-loggers with sensors measuring air temperature, relative humidity and wind speed are fixed at other strategic measurement points, taking into account the variation in design descriptors of their location. Mobile measurement of air temperature, relative humidity and wind speed using an anemometer were carried out at all measurement points.

Figure 3 Photographs showing fieldwork equipment and measurement on site using fixed mini-weather station and mobile anemometer

2.1 Classification of Inner-city Areas

Inner city areas refer to the parts of Hong Kong Island, Kowloon Peninsula and the more urbanized parts of the New Territories which are not abutting the sea front, and are subject to minimal impact of the sea due to high density and height of buildings in the proximity. The characteristics of inner city residential developments and mixed use street blocks are identified as follows:

- Very dense construction and street blocks virtually walled by surrounding buildings;
- Construction materials used for vertical surfaces are of very high heat storage capacity;
- Very high degree of impervious horizontal surface (asphalt, concrete, cement stone paved);
- The block geometry generally traps radiation and creates air stagnation;
- Very tall and sharp edged buildings;
- Very low density of vegetation along the streets;
- Negligible extent of heat sinks due to small urban parks and lack of sizeable water bodies within the micro environment;
- High heat and waste release from residential and commercial space;
- High volume of traffic;
- High levels of commercial and street lightings;
- Canyon geometry ratio in the order of 3 to 6

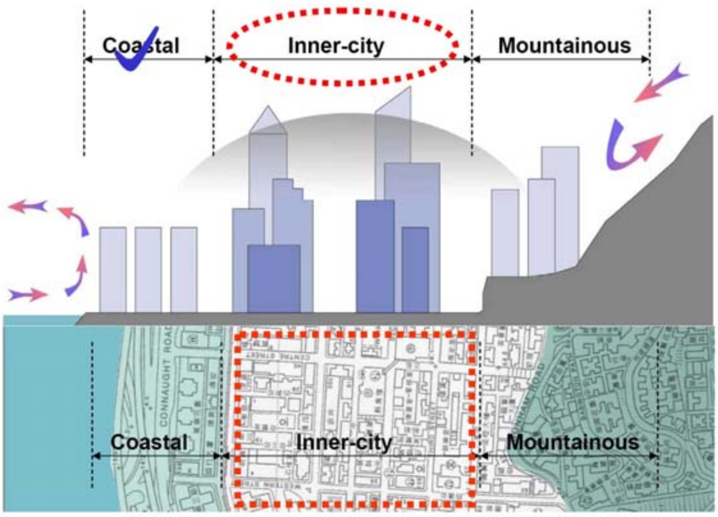

Figure 4 Conceptual section and plan of inner city classification

2.2 Surveyed Sites

A total of 18 sites, including public housing estates, private-sector residential developments and primarily residential mixed-use street blocks of similar scale were surveyed in this study. They are distributed in 6 different geographical zones. The samples are representative of the typical residential environment types in Hong Kong's most populated urban areas, chosen to incorporate the maximum possible variations in design-related descriptors. Attention is paid to select samples which have a larger variation in categories which have shown to make the most impact on UHI from previous study of coastal UHI in Hong Kong. Tower block residential developments as well as MILU street blocks were surveyed.

Figure 5 Location of surveyed sites in 6 different geographical zones in Northern part of Hong Kong Island and Central Kowloon Peninsula

In this paper, only one set of the 3 simultaneously surveyed sites will be discussed, the built form and urban fabric of the three sites are shown in the figures below:

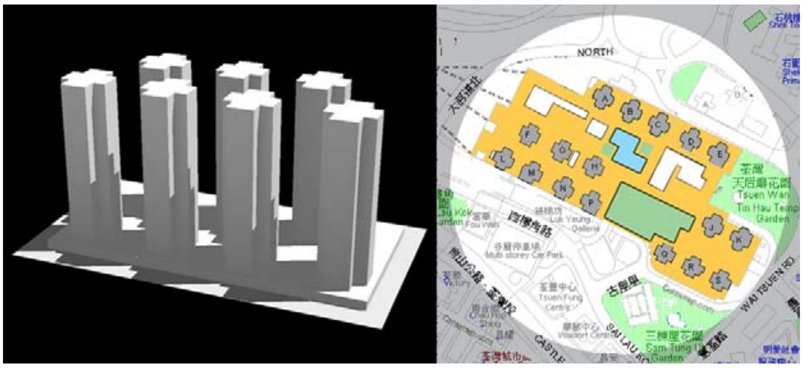

Figure 6 Site A -Towers on podium type configuration typical in residential developments

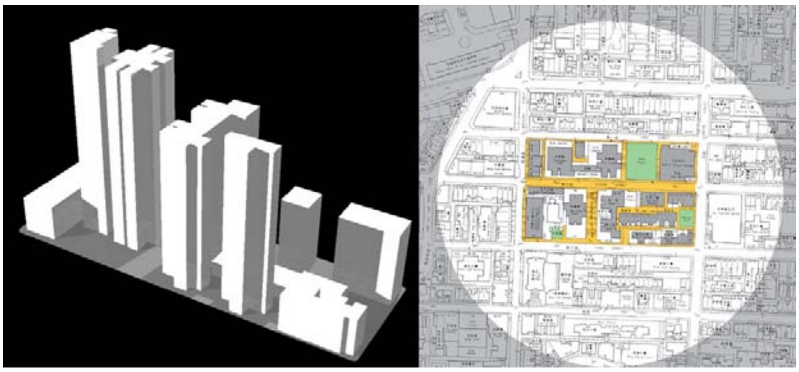

Figure 7 Site B - Mixed use / residential street block with small pocketed open spaces

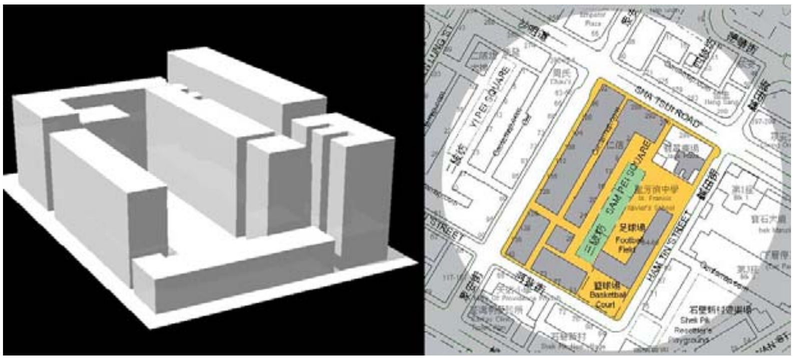

Figure 8 Site C - Mixed use / residential street block with courtyard type centralized open space

3. Findings and Observations

The initial findings show that the majority of urban open spaces in Site A, B and C do not have the ability to improve the urban microclimate and mitigate the heat island effect by reducing summer air temperatures in dense urban areas by 3-4 ºC as suggested by simulation studies (Dimoudi and Nikolopoulou, 2003). The maximum intra-site temperature differences for both daytime and nocturnal measurements were found in Site C at only 1.8 ºC and 1.1 ºC respectively, which are significantly lower than the reduction suggested by simulation studies.

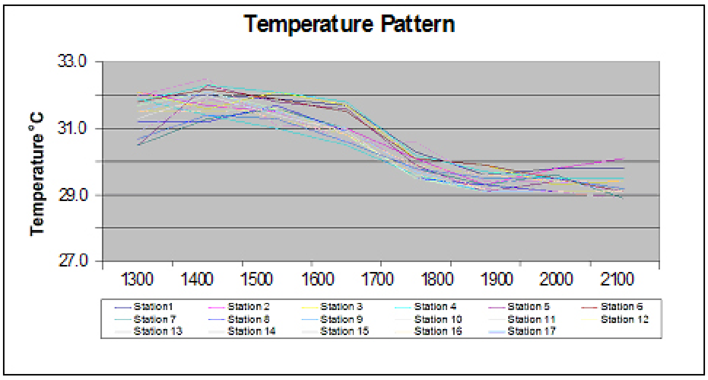

Figure 10 Temperature patterns of all measurement stations of Site C

The lowest temperatures were recorded at the 'central courtyard' type open space and the highest temperatures were recorded at the stations most exposed to heavy vehicular traffic. The lowered temperature measurements were only recorded at the measurement points within the boundaries of the open space, but have minimal effect on mitigating the UHI effect in the surrounding areas. This is probably due to the low level of vegetation present at these urban open spaces and also the low albedo material used in paving these spaces and in the vertical surfaces.

The reduction of the cooling effect can also be explained by the different urban morphology. The cooling effect is more evident in samples where the surrounding building configuration allows for sufficient air ventilation to pass through the open space. The size of the open spaces and their proximity to anthropogenic heat sources such as road traffic also has effect on their thermal performance. Figure 11 shows the comparison of temperature pattern for the main open space of Site A, B and C.

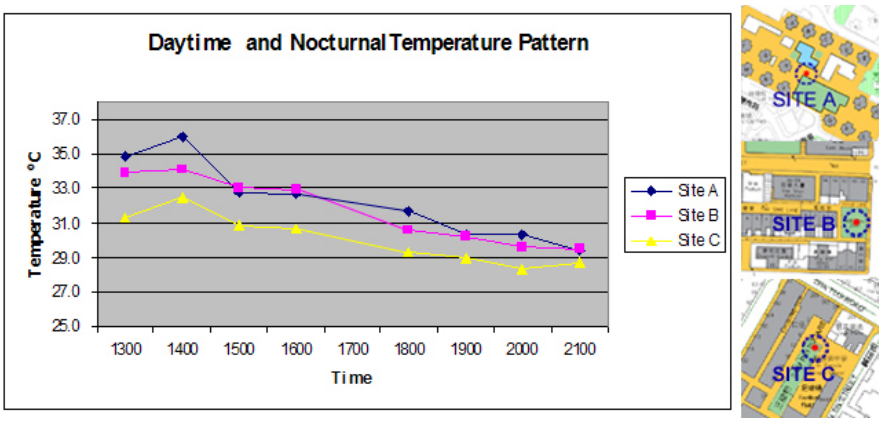

Figure 11 Temperature Pattern of Main Open Space of Site A, B & C

The comparison shows that Site A (podium type open space) and Site B (small pocket open space) has similar temperature pattern, with Site A having a slightly higher mean temperature. Site C ('central courtyard' type open space) has the lowest temperature. The mean daytime and nocturnal temperature difference between Site A and C is 2.7ºC and 1.6ºC respectively.

4. Conclusion

Urban Heat Island (UHI) varies with geographical, latitudinal and urban density and population changes (Oke, 1988). To understand this UHI profile and further derive planning and design strategies for mitigating summertime UHI will greatly benefit the urban thermal environment and improve comfort of users.

This study focuses on potential alleviating function of urban open spaces in high rise high density residential and mixed use developments and street blocks. The initial findings show that different urban morphologies alter the thermal performance of the urban open space. A previous study (Giridharan, Lau et al, 2007) suggested that with the same amount of tree cover in high rise high density coastal building area, the open space in the form of pocket parks comes with lower air temperature of about 0.5 -1.0 °C compared to a landscaped courtyard. While the present study indicates the opposite in inner city area, with temperature of the central courtyard significantly lower than those of the podium and pocket park (Figure 11). The shift of temperature pattern between inner city and coastal area could be due to the influence of sky view factor. Further, as ventilation potential is greatly undermined by surrounding buildings, the pocket park and podium may not enjoy better advection cooling although they are more open than the courtyard space.

Further analysis is needed to determine to how, and to what extent these urban morphologies (building, form, fabric and configuration), and site specifics (volumetric composition, and orientation) constitute to a more sustainable urban environment by providing thermally desirable open spaces for social use.

Acknowledgement

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USER PERCEPTIONS AND FEEDBACK FROM THE 'BEST' SUSTAINABLE BUILDINGS IN THE WORLD

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Keywords: sustainable buildings, user perceptions, environmental quality, questionnaires, commercial buildings, institutional buildings

Summary

During the last four years the authors investigated the performance in practice of a range of commercial and institutional buildings worldwide. Around 30 buildings in 11 countries have been studied - in all cases either recipients of national awards for sustainable design or highly rated in terms of the relevant building sustainability rating tool. These investigations included a questionnaire survey seeking the users' perceptions of a range of factors: Operational (space needs, furniture, cleaning, meeting room availability, storage arrangements, facilities, and image); Environmental (temperature and air quality in different climatic seasons, lighting, noise, and comfort overall); Personal Control (of heating, cooling, ventilation, lighting, and noise); and Satisfaction (design, needs, productivity, and health).

This paper presents the users overall perception scores for the following aspects – lighting, noise, temperature and air quality in summer and winter, comfort overall, design, needs health and productivity, together with comfort, satisfaction and summary indices compiled from these factors. Most buildings had average scores above the mid-point of their respective scales, performing particularly well in terms of lighting overall, design and needs. The performance of the buildings on two rating scales is also presented. These indicate that the majority are performing at the 'Above Average' or 'Good Practice' level

1. Introduction

Over the last decade or more there has been a proliferation of Building Sustainability Rating Tools (BSRTs) around the world. Designed largely to quantify the environmental benefits of adopting particular building design strategies, and usually geared to the environmental issues peculiar to their country of origin, these tools are gaining increasing acceptance. Cole (2005, 2006) provides a useful overview and discussion of a number of the more established BSRTs.

Increasing numbers of owners are now arranging for their buildings to be assessed by the tool relevant to their country or needs; and some major (frequently governmental) tenants are requiring that the buildings they occupy meet a particular level on the relevant rating scale. This trend appears to be due to a number of reasons. Owner-occupiers, particularly where their business has a strong emphasis on sustainable products or services, are highly motivated to be seen to be 'practicing what they preach'; building developers and owners are keen to gain the competitive advantage they perceive from 'going green'; and many tenants, particularly (but not exclusively) government departments, wish to demonstrate their commitment to sustainability in their choice of building.

At present, most of these tools are focused on the design and as-built stages of the building process, taking some account of the quality of the environment that the building is intended to provide for the users. However, with moves afoot to develop BSRTs for buildings in operation, there is the opportunity to make a more direct assessment by, for example, asking the users directly. Given that salary costs are usually many times the building costs, organizations have every incentive to participate. In this paper the authors will present information on how the users perceived a range of aspects of the internal environment in a number of buildings around the world.

2. Research Methods

2.1 General Overview

For the last four years the performance in practice of around 30 commercial and institutional buildings in 11 countries worldwide has been investigated (Baird, 2009). These investigations involved the principal author undertaking one or more visits to each of the buildings, and the personal distribution and collection of a questionnaire survey seeking the users' perceptions of a range of factors: operational, environmental, personal control and satisfaction. During these visits, a formal, structured, transcribed interview was conducted with a key architect and environmental engineer from the design team, and a detailed tour undertaken of each building and its facilities, photographing key features, and collecting relevant documentation.

2.2 Characteristics of the Buildings

The buildings surveyed were as follows, by country:

- Australia: 40 Albert and 60L, Melbourne; Red Centre and Institute of Languages, UNSW, Sydney; Student Centre and General Purposes Building, Newcastle University; Scottsdale Forest Ecocentre, Tasmania.
- Canada: Computer Science and Engineering, York University; Liu Institute, University of British Columbia; Toronto Military Families Resource Centre; National Engineering Yards, Vancouver.
- Germany: Sciencepark, Gelsenkirchen.
- India: Torrent Research Centre, Ahmedabad (both conventionally and evaporatively airconditioned).
- Ireland: St Mary's Credit Union, Navan.
- Japan: Nikken Sekkei HQ, Tokyo; Earthport, Yokohama.
- Malaysia: Menara UMNO, Penang; MEWC HQ, Putrajaya .
- New Zealand: AUT Akoranga, Auckland; Landcare Research, Auckland; Mathematics Statistics and Computer Science, Christchurch.
- Singapore: Institute of Technical Education, Bishan
- UK: Arup Campus, Solihull; City Hall, London; Eden Foundation, St Austell; Gifford Studios, Southampton; Renewable Energy Systems HQ, Kings Langley; Zicer Building, University of East Anglia.
- USA: Natural Resources Defence Council, Santa Monica; NRG Systems, Vermont.

These were selected on the basis of their sustainability ‘credentials’. Virtually all of them were recipients of national awards for sustainable or low energy design, or were highly rated in terms of their respective countries building sustainability rating tool (LEED, BREEAM, CASBEE, Green Globes, etc) or in some way pioneered green architecture. Of course, willingness on the part of the building owner and tenants to be surveyed was also an essential prerequisite, and not all building owners felt in a position to accept our invitation.

Of the 30 buildings, 13 accommodated office activities predominantly, 10 were tertiary level academic teaching buildings, 4 housed laboratories or research organisations, and 2 contained a combination of industrial and administrative functions.

While most of the buildings were in temperate climates of one kind or another (ranging from warm-temperate to cold-temperate) a significant number were located in warm-humid climates. Their systems of ventilation ranged from full air conditioning, through mixed-mode (concurrent, changeover and zoned) to natural ventilation (both conventional and advanced) and in one case Passive Downdraft Evaporative Cooling (PDEC).

2.3 Nature of the Questionnaire

The questionnaire has evolved over several decades, from a 16-page format used for the investigation of sick building syndrome in the UK in the 1980s, to a more succinct 2-page version. Developed by Building Use Studies (BUS, 2004) for use in the Probe investigations (BRI, 2001/2), it is available under licence to other investigators.

The sixty or so questions cover a range of issues. Fifteen or so elicit factual background information on matters such as the age and sex of the respondent, how long they normally spend in the building, and whether or not they see personal control of their environmental conditions as important. However, the vast majority ask the respondent to rate some aspect of the building on a seven-point scale; typically from 'unsatisfactory' to 'satisfactory' or 'uncomfortable' to 'comfortable', where a '7' would be the best score.

The aspects covered in the questionnaire include matters to do with the building overall, such as its design, how well it meets the respondents' needs, the effectiveness of the use of space, how satisfactory are the cleaning arrangements, the availability of meeting rooms, and the suitability of storage arrangements; matters connected with the respondents specific work requirements, health, productivity and degree of personal control; and matters related to the thermal environmental conditions and air quality in summer and winter, as well as the lighting and noise conditions.

Analysis of the responses yielded a mean value (on a 7-point scale) for each variable. In addition to calculating the mean value for each variable, the analysis also computed a number of ratings and indices in an attempt to provide indicators of particular aspects of the performance of the building or of its 'overall' performance.

For this paper, the authors focus on the Rating Scales and Indices (Comfort, Satisfaction and Summary) and on the users overall perception Scores for the following aspects – *lighting, noise, temperature* and *air quality* in *summer and winter*, *comfort overall, design, needs, health and productivity*. In each case the distribution of the ratings or scores will be presented and described.

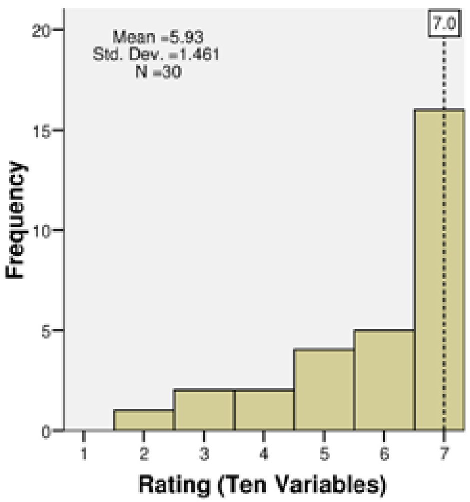
3. Results – BUS 7-Point Ratings

Two rating scales, one made up of '10 variables' and one using 'All variables' (around 45 in total), are used to provide an overall statistical snapshot of occupants responses. Each variable in the rating scale is scored on a scale from 1 to 5 depending on whether they are perceived as being significantly worse, slightly worse, the same as, slightly better, or significantly better than the BUS benchmarks (based on the previous 50 or so buildings surveyed) and the scale mid-point. These scores are then summed and the percentage is then transformed to the following 7-point scale:

1 'Very Poor'; 2 Poor; 3 Below Average;4 Average; 5 Above Average; 6 Good Practice; and 7 'Exceptional'.

The variables included in the 10-variable rating scale are – *comfort overall, design, health, image, lighting overall, needs, noise overall, productivity, temperature in summer overall* and *temperature in winter overall*.

While it could be argued that there is a certain amount of arbitrariness in the selection of the above variables and the terminology of the Rating Scale, and that the scoring process requires careful judgement, they do have the inestimable merit of clarity and simplicity, and can be readily modified



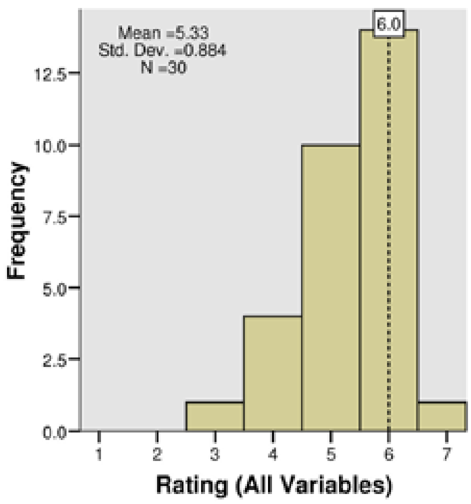


Figure 1 BUS 7-Point Rating Scale (Ten Variables) *Figure 2 BUS 7-Point Rating Scale (All Variables)*

Figure 1 *(ten variables)* demonstrates that, of the 30 buildings in this sample, more than half were in the top 'Exceptional' category with a score of '7'. Only 3 buildings were considered to be 'Below Average'.

This high percentage of excellent buildings continues even when 'All variables' were input into the rating scale as can be seen in Figure 2. Although only one building was still rated as "Exceptional' (7 on the scale), 24 out of the remaining 29 were considered to be 'Good Practice' or 'Above Average'.

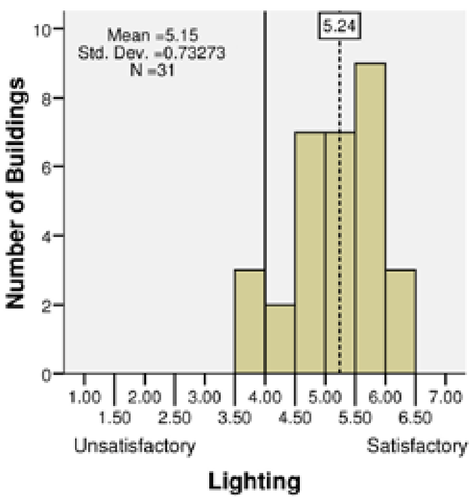
4. Results – Overall Perception Scores and Indices

This section details the average scores for a range of variables associated with the users' comfort and satisfaction with the buildings. The methods of estimating suggested overall indices of comfort, of satisfaction, and of a summary index are detailed, and their results presented.

4.1 Comfort Scores

While the questionnaire sought responses to a large number of factors associated with the different aspects of comfort, the following results focus on users overall perceptions of *lighting, noise, temperature and air quality in summer and winter,* and *comfort overall*. All of these were on 7-point scales where a higher value is better

Figures 3 and 4 illustrate the distribution of two of these factors to illustrate the findings from this set of buildings – one factor which scored relatively highly for most buildings (*lighting*), and one that scored less highly (*temperatures in winter*).



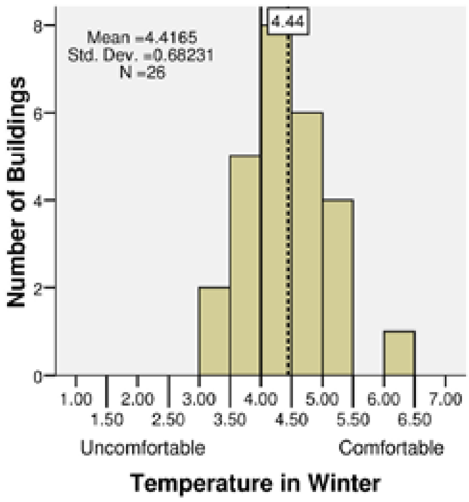


Figure 3 Lighting Overall – Average Scores *Figure 4 Temperatures in Winter Overall – Average Scores*

The mean, median and broad distributional characteristics of all the overall factors associated with comfort are presented in Table 1. Note that the mid-point of the scale is 4.00 and that 'winter time' conditions did not apply for buildings located in the tropics.

Table 1 Scoring for Key Comfort Variables

'Overall' Factor	N	Mean	SD	Median	Percentage of buildings scoring above and below particular scale values < 3.00	< 4.00	> 4.00	> 5.00
Comfort	30	4.91	0.84	4.93	-	17%	83%	40%
Lighting	31	5.15	0.73	5.24	-	10%	90%	61%
Noise	30	4.42	0.83	4.48	7%	30%	70%	27%
Temperature in Summer	31	4.32	0.97	4.42	10%	29%	71%	26%
Temperature in Winter	26	4.42	0.68	4.44	-	27%	73%	19%
Air in Summer	30	4.32	0.86	4.40	7%	33%	67%	23%
Air in Winter	26	4.44	0.61	4.38	-	27%	73%	15%

It can be seen that the mean and median scores are all greater than 4.00, with *comfort overall* approaching 5.00 and *lighting* (see also Figure 3) greater than 5.00. For the majority of these comfort factors, around 70% of the buildings score above the scale mid-point of 4.00, while in the case of *lighting* a figure of 90% is attained. Interestingly, the mean perception of *comfort overall* is higher than the average of the individual factors, possibly indicating a degree of tolerance on the part of the users (Leaman and Bordass, 2007).

4.2 The Comfort Index

The Comfort Index attempts to encapsulate, in a single figure, an overview of occupants' perceptions of the building's comfort performance. This index is formulated from the 'Z' scores for: *overall comfort, lighting, noise, summer and winter temperatures and air quality*. The formula for calculating this index can be described as follows:

$$\text{Comfort Index} = \frac{\mathbf{Z}_{\text{comfort}} + \mathbf{Z}_{\text{light}} + \mathbf{Z}_{\text{noise}} + \mathbf{Z}_{\text{temp/sum}} + \mathbf{Z}_{\text{temp/win}} + \mathbf{Z}_{\text{air/s}} + \mathbf{Z}_{\text{air/w}}}{7}$$

The Z score is derived from:

$$Z = \frac{\text{Actual - Benchmark}}{\text{Standard Deviation}}$$

The Benchmark is based on the average of the previous 50 buildings surveyed by BUS.

The Comfort Index is based on a scale of '-3' to '+3', where '+3' is considered 'best' (the mid-point lies on zero). Figure 5 illustrates how this sample of 'sustainable buildings' performs when measured on this comfort index. The majority of the buildings (24 of the 29 cases considered) were above the mid-point of the scale in terms of comfort, and 10 of these were greater than +1.00. Some 5 cases were less than the mid-point but none of these fell below -1.00.

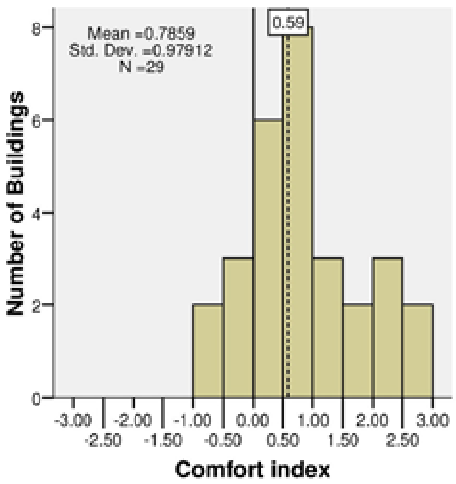
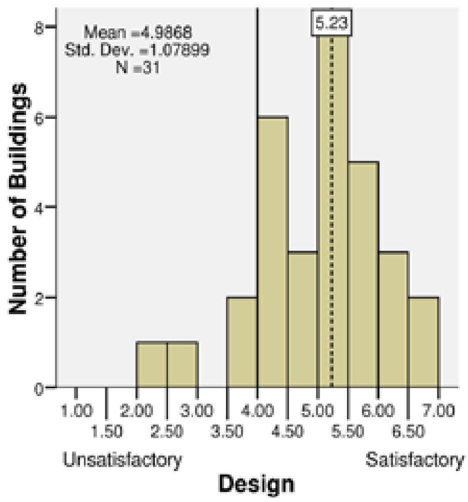


Figure 5 BUS Comfort Index

4.3 Satisfaction Scores

The variables defined as contributing to the users' perception of satisfaction were designated to be *design, needs, health* and *productivity*. The first three of these were scored on a 7-point scale where a higher value is better. In the case of *productivity* users are asked to estimate a percentage increase or decrease.

Figures 6 and 7 provide a graphical illustrations of two of these variables – *design* and *productivity*.



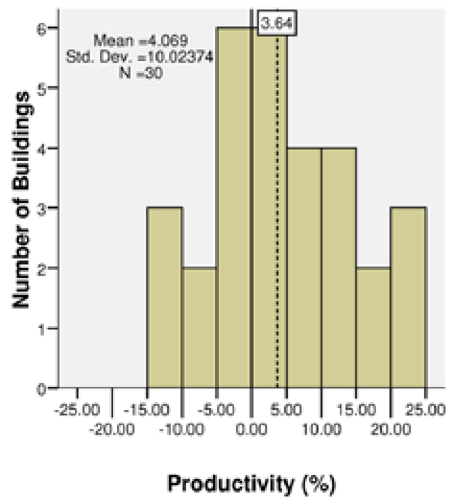


Figure 6 Building Design – Average Scores *Figure 7 Average Productivity Increase or Decrease (%)*

The mean, median and broad distributional characteristics of *design, needs*, and *health* are presented in Table 2. Note again that the mid-point of the scale is 4.00.

Table 2 Scoring for Key Satisfaction Variables

Factor	N	Mean	SD	Median	Percentage of buildings scoring above and below particular scale values < 3.00	< 4.00	> 4.00	> 5.00
Design	31	4.99	1.08	5.23	6%	13%	87%	58%
Needs	30	5.16	0.78	5.26	-	3%	97%	57%
Health	30	4.26	0.71	4.10	-	43%	57%	10%

As can be seen, this set of buildings scores particularly highly for *design* and *needs*, with around 90% above the mid-point in both cases and nearly 60% greater than 5.00. *Health* is not scored quite so highly, but still, nearly 60% made it over the mid-point

4.4 The Satisfaction Index

Similarly to the Comfort Index, the Satisfaction Index attempts to encapsulate, in a single figure, the occupants' overall satisfaction with the building. It is formulated from the 'Z' scores of the overall ratings for: *design, needs, health* and *productivity*. The formula for calculating this index can be described as follows:

$$\text{Satisfaction Index} = \frac{\mathbf{Z}\ \text{design} + \mathbf{Z}\ \text{needs} + \mathbf{Z}\ \text{health} + \mathbf{Z}\ \text{productivity}}{4}$$

The Satisfaction Index is based on a scale of '-3' to '+3' where, as with the Comfort Index, '+3' is considered 'best' (the mid-point lies on zero). As shown in Figure 8, 25 of the 29 cases were above the scale mid-point and 13 of these were greater than +1.00. Only 4 cases were less than the mid-point and again none of these dropped below -1.00. Overall these buildings were found to perform higher in terms of 'satisfaction' (mean = 1.05) than they did for 'comfort' (mean = 0.79).

4.5 Summary Index

The Summary Index is simply the arithmetical average the Comfort and Satisfaction Indices.

Figure 9 illustrates the distribution of this index which, as might be expected lies somewhere between the comfort and satisfaction distribution with a mean value of 0.92. As can be seen, 25 cases (or 86%) are above the mid-point of the scale and only 4 (or 14%) are below.

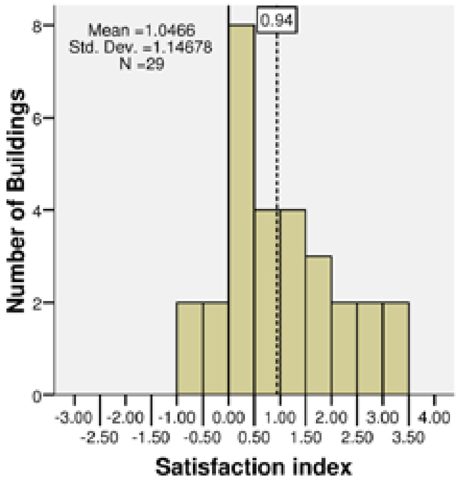


Figure 8 BUS Satisfaction Index

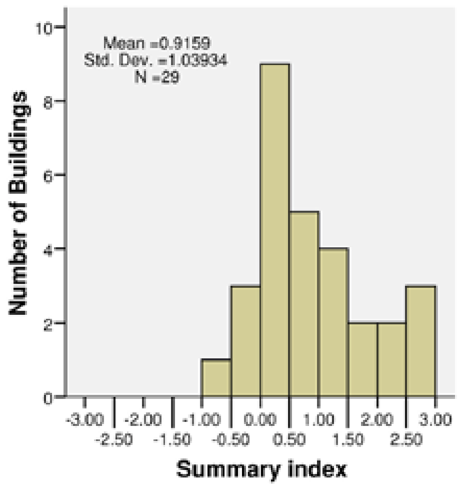


Figure 9 BUS Summary Index

5. Discussion and Conclusions

So what kinds of buildings were being scored highly overall and what design or other characteristics underlie the users' responses?

Looking first at the 7-point rating scale incorporating 10 variables, no less than 16 buildings made it into the 'Exceptional' category with a further 5 close behind in the 'Good Practice' category. 10 out of the 11 countries were represented in these 21 buildings. While most of these were in temperate climatic zones, 3 were in hot-humid climates (2 of them air conditioned). Of the 21, 10 had advanced natural ventilation, 8 were mixed-mode, and 3 were air conditioned.

Taking all 45 or so variables into account proved to be a tougher test on the 7-point rating scale for most of the buildings. The median for the group had slipped from 7 to 6 and only one building retained its 'Exceptional' status. At the other end of the spectrum the lowest rating building had moved up from 'Poor' to 'Below Average'. Overall, only 4 buildings were unchanged and 22 had gone down; 4 buildings had improved their rating – presumably factors other than those included in the 10 variable scale were scoring higher. However, in most cases the overall scores for a given variable tended to be higher than the average of its component variables resulting in lower ratings on the 45-variable scale (in the case of lighting for example, respondents scored aspects such as the amount of daylight, the amount of artificial light, the glare from sun and sky, and the glare from artificial light, as well as *lighting overall*).

The highest ranking was achieved by a building with advanced natural ventilation in a temperate climate, while the lowest had zoned mixed-mode ventilation in a hot-humid climate. Both had been designed with the intent of exploiting natural ventilation for owner-occupier clients who, while nor overtly cognisant of sustainability issues, were nevertheless interested in the long term performance of their buildings.

In terms of overall comfort, this set of buildings performed relatively well overall, with the vast majority (24 out of 29 cases or 83%) scoring above the mid-point of the -3 to +3 scale used in this instance. Of the seven factors assessed, this set of buildings had mean and median scores greater than the mid-point of the relevant 7-point scales (where 7 is best) in every case; and of these, *lighting* scored the best overall. The factors with the largest number of buildings scoring less than the mid-point of the scale were *noise, temperature in summer,* and *air quality in summer*, with around 30% each. This was borne out in connection with the 5 buildings which scored less than zero on the Comfort Index, where these factors were ones which had received relatively low scores.

For the 10 buildings whose Comfort Index was greater than 1.00, all climatic zones and all modes of ventilation were well represented. If there was a common factor it was perhaps the nature of the client organisation. In virtually every case, the client had a particular commitment to sustainability in terms of its products, its business interests, or the image it wished to portray; and in all cases planned to be the long-term owner-occupier of the building.

In terms of satisfaction, overall this set of buildings performed even better than for comfort, with a higher mean and median for the former and 23 (compared to 10 for comfort) scoring greater than 1.00 on the -3 to +3 scale. Nine of the buildings had indices greater than 1.00 for both satisfaction and comfort, though not necessarily at the same level.

Of the four factors taken into account for the Satisfaction Index, *design* and *needs* scored very well, the main exception being a zoned mixed-mode building in a hot-humid climate. As noted previously, *health* did not score quite as well as the other factors. However, with a median of 4.10 compared to recently reported medians of 3.3 and 3.7 respectively for conventional and green-intent buildings (Leaman and Bordass, 2007), this seems a reasonable figure. Finally, users' perceptions of how the buildings affected their *productivity* ranged from -13% to +23% for this group of buildings, and has been found to be highly correlated with *comfort overall* (Baird and Oosterhoff, 2008). The higher positive values appeared to emanate from buildings housing organisations with a relatively strong commitment to sustainability.

In the end, the highest values for the Summary Index were achieved by NRG Systems, the Natural Resources Defence Council, and the Torrent Research Centre (with conventional air conditioning) with indices approaching +3.00. These were closely followed by the Military Families Resource Centre, the Mathematics Statistics and Computer Science Building, St Mary's Credit Union, and the Torrent Research Centre (with passive downdraft evaporative cooling). All were owner-occupied buildings in a range of locations and climates where the client had a strong commitment to sustainability in general terms or, as in the case of the top two, in terms of their business activities.

Reassuringly, at least in terms of the choice of variables that made up the Summary Index, all of the buildings that exceeded a value of +0.5 on the -3 to +3 scale also rated highly ('Excellent' or 'Good Practice) on the 7-point rating scales

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Study on the Effects of Various Mitigation Measures for Heat Island Reduction in the Different Existing City Blocks using Numerical Simulation

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Keywords : Urban Heat Island, Mitigation Measures, Numerical Simulation

Summary

The urban heat island phenomenon is one of the most urgent urban problems in Japan as well as in the world. Various mitigation measures for heat island phenomenon have been recommended in the Sustainable Building Certification System such as LEED in U.S. or CASBEE in Japan. For example, these measures includes roof greening, site greening, high solar-reflection (albedo) painting, reduction of anthropogenic heat etc. In these certification systems, adopting each measure gives a certain credit to the building for urban heat island reduction. The weighting of this credit is usually same for all buildings in all sites. However the effects of these mitigation measures are different for the different buildings or different city blocks. Therefore, the authors have estimated the effect of various mitigation measures on the outdoor thermal environment in the two different existing city blocks in Tokyo city area using a coupled simulation of CFD (Computational Fluid Dynamics) and radiation transfer: One city block is Otemachi as a high-rise office building area and the other is Kyobashi as a middle-rise office building area. The results of this simulation would be helpful to develop the appropriate recommendation system of mitigation measures for the various city blocks.

INTRODUCTION

The heat island phenomenon has become considerably worse, and causes various other problems, such as an increase in the number of heat disorders or tropical nights. The underlying reasons behind the heat island phenomenon are considered to be the release of artificial heat, change in surface coverage due to urbanization, and a reduction in green space. Various measures to moderate the heat island phenomenon have been proposed and researched, and their effectiveness evaluated using numerical simulations. Although these effects are highly dependent on the property of each city block, insufficient comparison has been made of these effects between different city blocks. Therefore, the authors undertook coupled simulations of convection, radiation and conduction to evaluate the outdoor thermal environment over two different present urban blocks in Tokyo: Ōtemachi, as a high-rise business district, and Kyobashi, which is typified by mid-rise business district. The cases are set to compare the effects of measures such as the heat-release point and means of air-conditioning, as well as greening, high surface albedo, and traffic volume.

ANALYSIS

Analysis outline

In this study, the numerical method of coupled simulations of convection, radiation, and conduction developed by the authors (Chen H. et al. 2004) (Yoshida S. et al. 2000) was used. Figure 1 shows an analysis outline. Using input data concerning the place, weather, urban configuration, material and surface, the ground and wall surface temperatures are calculated using radiation simulation. After that, the surface temperature is used as a boundary condition for computational fluid dynamics (CFD) simulations, which are then performed.

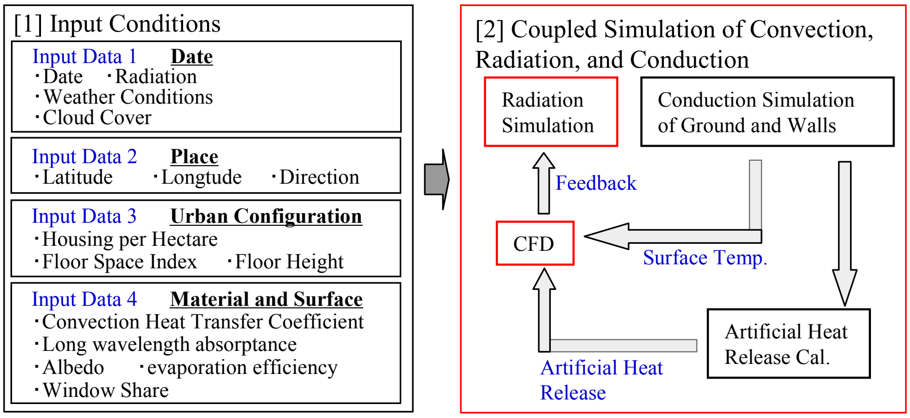
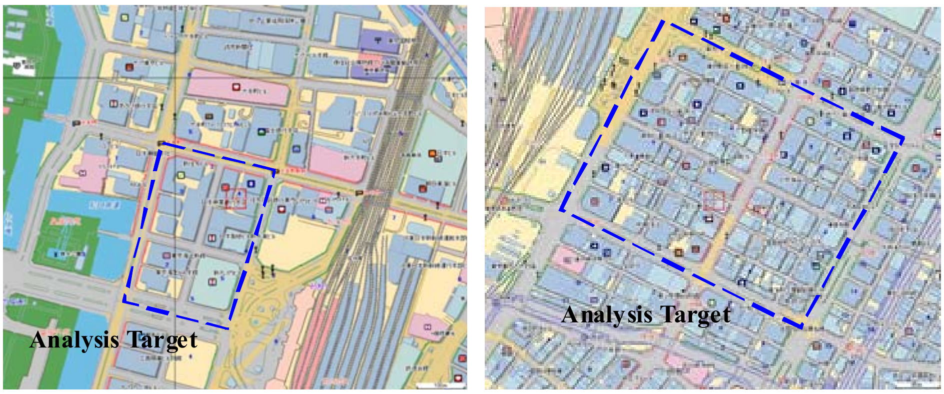
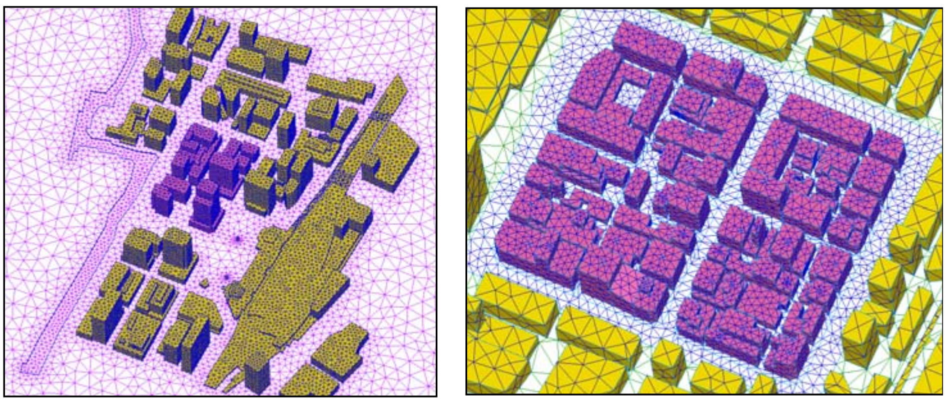


Figure 1: Analysis Outline



(1) Ōtemachi *(2) Kyobashi*

Figure 2: Analysis Targets



(1) Ōtemachi *(2) Kyobashi*

Figure 3: Analysis Models

Table 1: Urban Configuration of Simulation Models

	Ōtemachi	Kyobashi
Mean Gross Building Coverage	75.8%	86.9%
Mean Net Building Coverage	62.9%	71.2%
Legal Floor Space Index	900% or 1300%	600%～800%
Mean Floor Space Index	1179.0%	664.3%
Mean Building Height	67.4m	28.6m

Analysis target and model

Figure 2 shows the analysis targets. Ōtemachi represents a typical high-rise business district, while Kyobashi is a typical mid-rise business district in Tokyo. Ōtemachi and Kyobashi are located to the west and east of Tokyo station respectively. Table 1 illustrates the urban configuration of each domain, as calculated using simulation models. While Ōtemachi has wider spaces between its buildings, those in Kyobashi are crowded. Figure 3 shows the simulation analysis models based on GIS data. They incorporate an unstructured grid system. The model for Ōtemachi is 1,930 m (W) × 2,720 m (L) × 600 m (H), with 379,706 grids. The Kyobashi model is 2,460 m (W) × 3,630 m (L) × 600 m (H), with 372,000 grids. The analysis targets are set on some blocks near the center.

Analysis cases

Tables 2 and 3 show the analysis cases in Ōtemachi and Kyobashi respectively. Ten cases are adopted for Ōtemachi, and nine for Kyobashi. Cases 1-1 and 2-1 are basic cases. Cases 1-0 and 2-0 are without any artificial heat release. Cases 1-3, 1-4, 2-3 and 2-4 involve the buildings' roofs in the target area being changed to high-albedo or greening surfaces. Cases 1-5, 1-6, 1-7, 1-8 and 2-4, 2-5, 2-6 involve high-albedo, greening or water retention of the road and ground surface in the target area. Cases 1-9 and 2-8 concern the release of heat from traffic.

Table 2: Analysis Cases (Ōtemachi)

Case	Road			Ground	Building Surface		Heat Release		Release Point	Search Points
	Water Retention	High Albedo	Traffic Heat Release	Rate of green	Roof greening	High-Albedo Roof	Sensible Heat	Latent Heat		
Case 1-0	0%	0%	No	0%	0%	0%	***0%***	***0%***	—	No heat release
Case 1-1	0%	0%	No	0%	0%	0%	***30%***	***70%***	Roof	Basic Case
Case 1-2	0%	0%	No	0%	0%	0%	***100%***	***0%***	Roof	AC Heat: Sensible
Case 1-3	0%	0%	No	0%	0%	0%	30%	70%	Roof	Roof: Greening
Case 1-4	0%	0%	No	0%	0%	0%	30%	70%	Roof	Road: High Albedo
Case 1-5	***100%***	0%	No	***100%***	0%	0%	30%	70%	Roof	Road: Water Retention Ground: Greening
Case 1-6	0%	0%	No	***100%***	***100%***	0%	30%	70%	Roof	Ground: Greening
Case 1-7	0%	***100%***	No	0%	0%	0%	30%	70%	Roof	Road: High Albedo
Case 1-8	0%	***100%***	No	***100%***	0%	0%	30%	70%	Roof	Road: High Albedo Ground: Greening
Case 1-9	0%	0%	***Yes***	0%	***100%***	0%	30%	70%	Roof	Traffic Heat

Table 3: Analysis Cases (Kyobashi)

Case	Road			Ground	Building Surface		Heat Release		Release Point	Search Points
	Water Retention	High Albedo	Traffic Heat Release	Rate of green	Roof greening	High-Albedo Roof	Sensible Heat	Latent Heat		
Case 2-0	0%	0%	No	0%	0%	0%	***0%***	***0%***	—	No heat release
Case 2-1	0%	0%	No	0%	0%	0%	***100%***	***0%***	**Roof: 50%** **Side: 50%**	Basic case
Case 2-2	0%	0%	No	0%	0%	0%	***10%***	***90%***	**Roof: 100%**	All Heat from Roof AC Heat: Latent 90%
Case 2-3	0%	0%	No	0%	0%	0%	***100%***	***0%***	**Roof: 100%**	All Heat from Roof
Case 2-4	0%	0%	No	0%	***100%***	0%	100%	0%	Roof: 50% Side: 50%	Roof: Greening
Case 2-5	0%	0%	No	0%	0%	***100%***	100%	0%	Roof: 50% Side: 50%	Roof: High Albedo
Case 2-6	***100%***	0%	No	***100%***	0%	0%	100%	0%	Roof: 50% Side: 50%	Road: Water Retention Ground: Greening
Case 2-7	0%	***100%***	No	0%	0%	0%	100%	0%	Roof: 50% Side: 50%	Road: High Albedo
Case 2-8	0%	0%	***Yes***	0%	0%	0%	100%	0%	Roof: 50% Side: 50%	Traffic Heat

Analysis conditions

15:00 on July 23rd – a fine day weather-wise – was set for the analysis. The sun was at an attitude of 45.1º, the wind was southerly at a velocity of 3.0 m/s at a height of 74.6 m. The inflow wind velocity is set at 1/4th power profile. The air temperature was 31.6ºC, with a relative humidity of 58%. Table 4 shows the building and ground conditions. The temperature inside the building was fixed at 26ºC, and the buildings are considered to be made from concrete. The albedo and long wavelength emissivity of concrete were set to 0.2 and 0.9, respectively. Indoor convection heat transfer coefficient was 4.64 [W/m^{2}K].

The ground temperature was fixed at 26.0ºC under 0.5 m, and the ground surface was covered with asphalt. The albedo and long wavelength emissivity of asphalt were set to 0.1 and 0.95, respectively.

The Discrete Transfer Method (DTM) was used for the radiation simulation. In the CFD simulation, the turbulence model adopted was the standard k-ε model. The side and upper boundary was free slip. At the wall boundary, the wind velocity followed the generalized log law.

Table 4: Building and Ground Conditions

Building	Wall	Concrete
	Albedo	0.2
	Thickness	0.2m
	Indoor Convection Heat Transfer Coefficient	4.64 [W/m^{2}K]
	Indoor Air Temperature	26ºC
	Long Wavelength Emissivity	0.9
Ground	Ground	Asphalt
	Albedo	0.1
	Thickness	0.5m
	Long Wavelength Emissivity	0.95
	Ground Temp.	26ºC (under 0.5 m)

Setting of artificial heat release

The buildings' internal heat load was assumed using the product of the total floor area and the unit heat load intensity (Research and Exploratory Committee 2003). While all air-conditioning heat was assumed to be released from the roof in the Ōtemachi area, half of the air-conditioning heat was assumed to be released from the roof with the rest from the sides of the buildings in the Kyobashi area because the Ōtemachi urban block is composed of large buildings which have cooling towers, whereas many small buildings in the Kyobashi area have installed single-room air-conditioners.

ANALYSIS RESULTS

Ōtemachi area

Horizontal distribution of wind velocity and air temperature: Figure 4 shows the horizontal distribution of the wind velocity at a height of 1.5 m throughout Ōtemachi in order to evaluate the pedestrian area. Figure 5 illustrates the horizontal distribution of the air temperature in Case 1-1. There is a relationship in so far as that the air temperature is higher where the wind is weaker. In particular, the wind is weakened and the air temperature rises on the leeward side of the buildings.

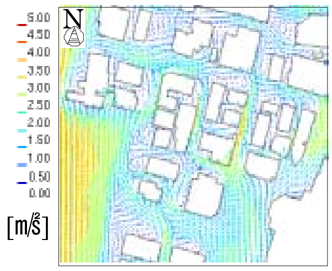
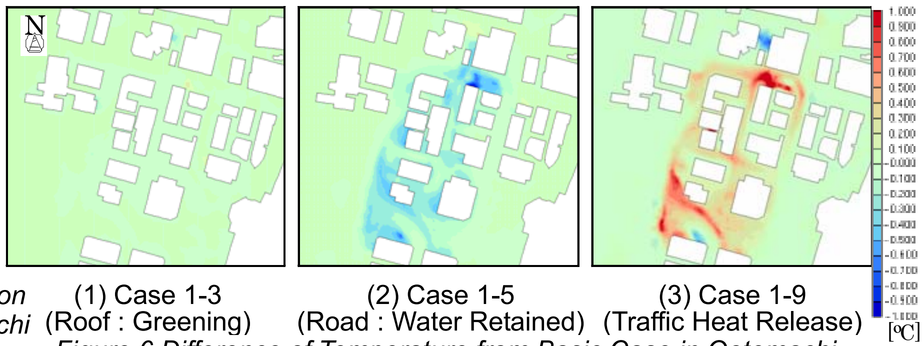


Figure 4 Horizontal Distbution of Wind Velocity in Ootemachi (Basic Case) (Height 1.5m)



(1) Case 1-3 (Roof : Greening) (2) Case 1-5 (Road : Water Retained) (3) Case 1-9 (Traffic Heat Release)

Figure 6 Difference of Temperature from Basic Case in Ootemachi (Case 1-1) (Height 1.5m)

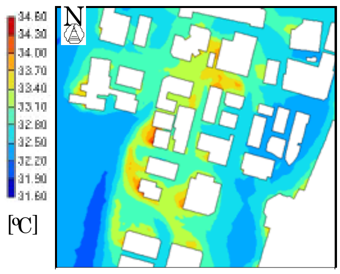
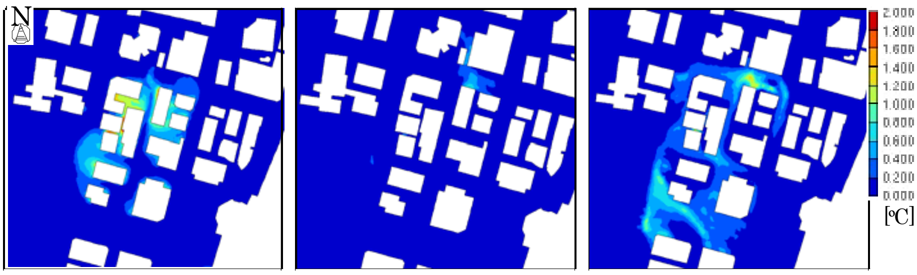


Figure 5 Horizontal Distbution of Temperature in Ootemachi (Basic Case) (Height 1.5m)



(1) Building Surface (2) Air-conditioning Heat Release (3) Traffic HeatRelease

Figure 7 Horizontal Distribution of Impact Index in Ootemachi (Height 1.5m)

Figure 6 shows the differences in air temperature from the basic case (Case 1-1) at a height of 1.5 m. Image (1) shows the result for Case 1-3, in which the roof surface is greened. In Case 1-3, there is not a large difference. Changing the roof material hardly affects the air temperature in the pedestrian area. Image (2) presents Case 1-5, in which the ground surface is changed into a water-retaining material. The air temperature broadly falls. This decrease is particularly noteworthy on the leeward side of the buildings. Image (3) presents Case 1-9, in which heat is released from traffic. The same trend as in Case 1-5 is exhibited, and the maximum increase in air temperature is more than 1ºC.

Horizontal Distribution of Impact Index: In order to compare the influence of surface temperature, air-conditioning heat release and traffic heat release, the impact index, as presented by the author [Note 1] (Chen H. et al. 2007) was calculated. Figure 7 shows the Horizontal Distribution of Impact Index at 1.5 m height. Image (1) shows the affect of a surface temperature rise of 1ºC. The surface temperature of the buildings has a substantial effect on the air temperature. Specifically, it affects the small canopy space and areas next to the buildings remarkably. Image (2) presents the air-conditioning heat release. This has no discernible effect on the air temperature in the pedestrian area. Image (3) is of the traffic heat release. Compared to the building surfaces, this affects a larger area.

Kyobashi area

Horizontal distribution of Wind velocity and air temperature: Figure 8 shows the horizontal distribution of wind velocity at a height of 1.5 m in Kyobashi to evaluate the pedestrian area. Figure 9 shows the horizontal distribution of air temperature. As in Ōtemachi, there is a relationship between the wind and air temperature. However, compared to Ōtemachi, the maximum air temperature is much higher because the buildings are crowded together and the wind has limited opportunity to exhaust the heat from the small canopies in Kyobashi.

Figure 10 shows the differences in air temperature compared to the basic case (Case 2-1) at a height of 1.5 m. Image (1) is of Case 2-4, in which the roof is greened. Image (2) shows Case 2-7, in which the ground and roads are greened or changed to water-retaining materials. While changing the roof material only cuts the air temperature a little, changing the road and ground materials sharply curtails the air temperature. As in Ōtemachi, the air temperature falls in small canopies and where the wind is weak. Image (3) concerns Case 2-9, which is of traffic heat release. The air temperature increases locally. Compared with on the road, in the small canopies, it increases considerably. The maximum increase exceeds 1ºC. There are several locations where the air temperature decreases. The reason is assumed to be that the flow field has been significantly affected by the large traffic heat release.

Horizontal Distribution of Impact Index: Figure 11 illustrates horizontal distribution of the impact index. Image (1) shows the effects of the building surfaces. These have a broad effect on the target area. The impact is especially pronounced near to the buildings and in small canopies where the wind is weak. Image (2) shows the difference from air-conditioning heat release compared to the basic case (Case 2-1). Because half of the air-conditioning heat release is from the sides of buildings in the Kyobashi area, its impact is massive and has a strong local effect. Near to any sideways release of heat generates an air temperature increase in excess of 2ºC. Image (3) concerns traffic heat release. Compared with air-conditioning heat release, its effect is primarily along the road, but it also has a local effect, such as in small canopies.

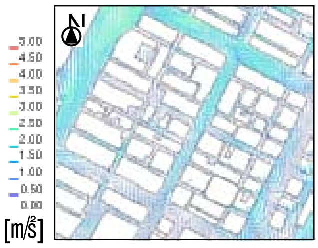
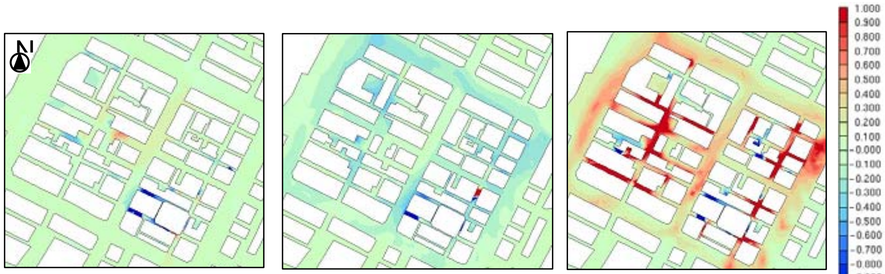


Figure 8 Horizontal Distribution of Wind Velocity in Kyobashi (Basic Case)



(1) Case2-4 (2) Case2-7 (3) Case2-8

Figure 10 Difference of Temp. from Basic Case in Kyobashi (Case2-1) (Height: 1.5m)

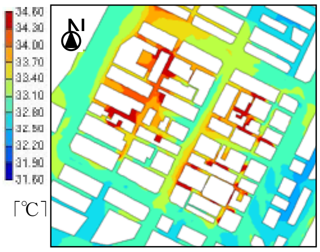
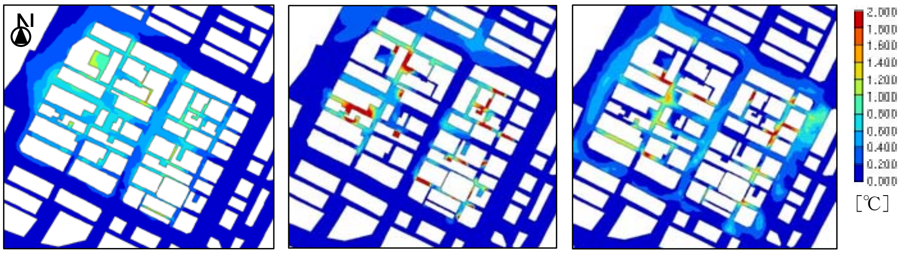


Figure.9 Horizontal Distribution of Temperature in Kyobashi (Basic Case)(Height:1.5m)



(1) Building (2) Air-conditioning (3) Traffic Heat

Figure 11 Horizontal Distribution of Impact Index in Kyobashi (Height: 1.5m)

COMPARISON BETWEEN ŌTEMACHI AND KYOBASHI AREAS

In order to compare the effect of urban block configurations, the mean velocity, mean air temperature, and mean impact index at 1.5 m were calculated. Table 5 shows the mean air temperature and wind velocity in the target area. In both areas, Cases 1-0 and 2-0, in which there is no heat released, the mean wind velocity decreases. Furthermore, the release of traffic heat increases the air temperature by more than 0.2ºC in both areas. In addition, the wind velocity clearly increases in Cases 1-9 and 2-8.

Table 5: Mean Air Temperature and Wind Velocity

Ōtemachi				Kyobashi		
Case	Mean Air Temperature [ºC]	Mean Wind Velocity [m/s]		Case	Mean Air Temperature [ºC]	Mean Wind Velocity [m/s]
1-0	32.96	1.47		2-0	32.99	0.90
1-1	32.96	1.51		2-1	33.19	1.19
1-2	32.96	1.49		2-2	32.97	1.10
1-3	32.96	1.49		2-3	33.07	1.26
1-4	32.96	1.49		2-4	33.20	1.16
1-5	32.82	1.45		2-5	33.18	1.15
1-6	32.93	1.48		2-6	33.05	1.17
1-7	32.86	1.49		2-7	33.07	1.25
1-8	32.82	1.48		2-8	**33.57**	**1.28**
1-9	**33.16**	**1.58**				

Table 6 shows the mean impact index. In Ōtemachi, because the buildings are high, the release of air-conditioning heat from roofs hardly has any effect. For the same reason, the roofs do not have any tangible effect although their surface temperature is high. In Kyobashi, the roofs and south-facing walls have a pronounced effect because the buildings are mid-rise types and the surface temperature of south-facing walls and roofs are higher than the other surfaces. Furthermore, the release of air-conditioning heat has a notable effect too.

Table 6: Mean Impact Index [ºC]

	Ōtemachi	**Kyobashi**
East	0.052	0.005
West	0.042	0.052
South	0.060	**0.117**
North	0.037	0.020
Roof	**0.004**	**0.108**
All Surfaces	0.195	0.303
Air-conditioning	**0.019**	**0.205**
Traffic	0.232	0.381

CONCLUSIONS

(1) In the high-rise Ōtemachi and mid-rise Kyobashi business districts, coupled simulations of conduction, radiation and convection have been performed. With cases showing changes to the heat release point and means of air-conditioning, as well as greening, high surface albedo , and traffic volume, various measures for moderating the thermal environment are quantitatively compared.
(2) In both of the Ōtemachi and Kyobashi areas, artificial heat release from traffic increases the air temperature in the overall target area at a height of 1.5 m; in particular, the leeward sides of the buildings are strongly affected. By the same token, the relaxation measures concerning the ground and road surfaces affect both areas.
(3) While the heat released from the air-conditioning systems does not increase the air temperature at a height of 1.5 m in Ōtemachi, it increases the air temperature locally; and in narrow streets with low wind velocity, the air temperature increase is especially notable. It was shown that the effectiveness of the relaxation measures differs depending on the configuration of the urban blocks.

NOTE

The impact index for outdoor thermal environment focuses on sensible heat to evaluate the influence on air temperature increases of open spaces from heat flux from building walls and the ground, and artificial heat release.
a) Impact index of sensible heat from building surface to outdoor thermal environment [ºC]

$$imp_{jw} = \left(\frac{\Delta T_{airj}}{\Delta T_{walli}}\right) \times (T_i - T_{ai}) \quad (1)$$

b) Impact index of heat release from building equipment to outdoor thermal environment [ºC]

$$imp_{jb} = (T_{jb} - T_j) \quad (2)$$

c) Impact index of traffic heat release to outdoor thermal environment [ºC]

$$imp_{jr} = \left(T_{jr} - T_j\right) \quad (3)$$

Abbreviations:

imp_{jw}: Impact index of building surface at cell j

imp_{jb}: Impact index of heat release from building equipment at cell j

imp_{jr}: Impact index of traffic heat release at cell j

ΔT_{airj}: Air temperature rise at cell j (case of high wall temperature – basic case)

ΔT_{walli}: Surface temperature rise at wall i (i: north, south, east, and west)

T_i: Surface temperature of wall i

T_{ai}: Mean air temperature of cell attached to wall

T_{jb}: Air temperature of cell j considering air-conditioning heat release

T_j: Air temperature of cell j in basic case

T_{jr}: Air temperature of cell j considering traffic heat release

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EXPLORING A 'QUALITY OF LIFE' APPROACH FOR SUSTAINABLE HOUSING IN SOUTHEAST QUEENSLAND. CASE STUDY OF CURRUMBIN ECOVILLAGE, AUSTRALIA

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Keywords: case study, sustainable housing, quality of life, survey

Summary

The main aim of this paper is present initial outcomes from a research project investigating a Quality of Life (QoL) approach to sustainable housing in South East Queensland. Sustainable development models such as balance theory suggest that the benefit of sustainability is to integrate social, economic and environmental needs in the context of maintaining or improving the quality of life. A current report on Quality of Life in South East Queensland and the Queensland Governments State of the Environment index demonstrate a paradox - high quality of life but also increasing environmental impact. How to address this paradox is a major research question addressed in this project. Through examining examples of best practice sustainable housing it is possible to address this question. An example claimed to be best practice' is found in a new project, the Ecovillage at Currumbin on the boarder between New South Wales and Queensland. The paper will discuss research into the key factors of quality of life identified in this project and how these can assist policy makers plan for a sustainable future.

Significant strategies are identified, which bring together both the soft foundations- social and economic systems, and the hard foundation- planning, design and technology systems to create an affordable sustainable housing precinct. A biophysical system mapping methodology is used to describe the main dimensions to best practice' of the hard foundations. Performance monitoring of key quality of life indicators is also used to obtain feed back on the soft foundations.

In conclusion the paper focuses on the arguments for a nexus between planning, design and governance as a mechanism to address the current paradox and maintain quality of life whilst reducing environmental impacts.

Introduction

This project aims to evaluate quality of life and satisfaction measures of occupiers of homes specifically designed to be environmentally sustainable and set within an eco-residential precinct. Currently, the perceived high quality of life in southeast Queensland is being eroded by evidence of mounting environmental un-sustainability. Though taking different theoretical and empirical approaches, most of the quality of life or 'livability' studies conducted throughout the world have been pitched at a regional level or above. A major gap therefore exists in understanding at the level of the precinct and community.

Here, the problem is to differentiate structural and local determinants of quality and satisfaction from those operating at higher spatial scales. State and local governments, however, have been promoting Ecological Sustainable Development (ESD) at the level of individual households with subsidy and other incentive schemes, along with broader initiatives drawing on public funds. Given such expenditure, much of which has proceeded with little foregoing research, the question therefore looms as to whether residential living under ESD premises contributes to quality of life and user satisfaction as has been claimed.

Now the opportunity has arisen to investigate this question in an industry-linkage framework by reference to an incipient residential development project at Currumbin on the Gold Coast. This project is framed according to 'best practice' ESD principles with dedicated technical infrastructure, both public and private, supplied by industry and local government to monitor ongoing environmental impact.

A comparative research design is required to investigate whether this infrastructure and the ethos of the precinct contribute both tangible and intangibly to quality of life and lifestyle satisfaction among residents. More specifically, among the 144 eco-dwellings to be constructed in the next two years at Currumbin, it is proposed to form two samples for comparison with a sample of other residences developed contemporaneously in southeast Queensland but not under the same ESD provisions (the 'control' group).

Both Currumbin samples will have the same ESD infrastructure, but one will additionally receive 'extension services' from researchers and local government in the form of feedback on energy and utility demand and encouragement in the ESD lifestyle. Neither the other Currumbin sample, nor the control group will receive any special contact other than periodic attitude monitoring as part of the research project. Based on longitudinal surveys, the objective is to see how energy and utility use, quality of life estimation, and behavioural patterns vary among the three groups.

In this way, it should be possible to determine the benefit-cost effects on quality of life and ESD measures created by private and public provision of both hard (technical) and soft (extension) infrastructure within southeast Queensland. Though compiled within this region, the results should have validity in similar 'Greenfield' contexts through Australasia. The project thus offers the prospect of evaluating the efficacy or otherwise of particular types of public and private interventions with the advantage of improving existing practice where appropriate.

1. Quality of Life (QoL) research

As stated above, the main aim of this project is to investigate a Quality of Life (QOL) approach to sustainable housing in South East Queensland. Sustainable development models such as Balance Theory (Mawhinney 2002) suggest that the benefit of sustainability is to integrate social, economic and environmental needs in the context of maintaining or improving the quality of life. The argument focuses on the need to address the current paradox where high quality of life in South East Queensland is traded against high environmental impact (Stimson, R., Western J, and McCrea, R., 2003, Queensland Government, 2003. Reading the two major current reports, Stimson et al. (2003) on QoL in South East Queensland and the Queensland Government's State of the Environment Report, one is struck squarely by this paradox. A major research question therefore focuses on how to maintain or improve Quality of Life but within boundaries that limits environmental impacts. The main hypothesis advanced is that a Quality of Life model, based on sub-sectors such as housing rather than geographical regions may provide a mechanism for addressing this significant problem.

Comment [IU1]: Mawhinney, M., 2002, Sustainable development: understanding the green debates, Blackwell Science; Oxford.

The application of Balance Theory as a planning and design approach to sustainable housing has advanced in recent years with the planning and design of a number of sustainable housing projects. A second aim is therefore to examine these projects to assess the quality of life and to identify the important dimensions and priorities within the range of sustainability parameters of social, economic and environmental impact.

Assessment methodologies have advanced in recent years to accommodate a broader, more holist approach, to examining sustainable housing in the context of the Quality of Life paradigm. Whilst this paradigm has resonated at a macro national, and city-scale levels of impact reporting and policy formulation, researchers' have attempted to apply the Quality of Life approach at a meso and micro scale of local development and design, necessitating a refinement of the construct and new research methodologies. The third aim of this project is to utilise these methods, test and refine them as an ongoing support metrics for a Quality of Life approach to evidence based planning and design in South East Queensland.

The quality of life of a population is an important concern in economics and political science. These disciplines have metrics to measure both qualitative and quantitative factors to the phenomena. Quality of Life studies also called Livability studies tend to be macro in scale covering countries, regions or cities, and examine dimensions to, and satisfaction for, peoples' life style in terms of personal physiological needs and desires, and to what extent these are met by the economic and physical environment. Limitations to these studies have been advanced in terms of the lack of holism, i.e. the lack of connection between outputs and input (Luger 1999: 749). For example, it is difficult to identify the precise factors influencing the satisfaction levels found among respondents. The use of these studies at a detailed policy level whilst giving useful information about macro conditions has been questioned. Luger argued that outcomes of QoL studies might be more attributed to demographic, socio-economic and environmental factors rather than economic dimensions. Luger argues that because these factors are not tracked in a traditional QoL model it makes the studies valueless and antithetical with regard to policy formulation. New models of QoL have evolved such as that developed by the UK Government (UK Government 1999, 2005), which follows a 'principles to indicator' approach with broader set s of factors including social, economic and environmental factors (Mawhinney 2000). This approach, it is argued, qualifies as a new QoL paradigm. It offers to address the new framework of sustainability, it examines the phenomena from a range of scales - region, city and neighbourhood and also provides new methodologies for understanding the phenomena. The holistic model may offer a richer information base to facilitate policy formulation for the planning and design of particular aspects of the regional infrastructure such as neighbourhoods and precincts.

Comment [IU2]: Luger, M.I., 'Quality of Life Differences and Urban and Regional Outcomes: A review,' in Housing Policy Debate • Volume 7, Issue 4. 749. ©. Fannie Mae Foundation, 1996

Comment [IU3]: UK Government. *A better quality of life - strategy for sustainable development for the United Kingdom* – 1999, 2005. On line. Available HTTP: <http://www.sustainable-development.gov.uk/publications> (accessed 7 April 2006).

Research in the USA has followed a different path through work by the American Institute of Architects prosing an agenda for change. This organisation has made important submissions to the US Congress to establish policy development and research in this area. Called QoL principles, they provide a planning and design research agenda for built infrastructure but this is broad based and has not been formulated into a QoL model for housing (AIA 2006). Research into QoL for housing is found in the environmental planning field through the work of authors such as Anne Beer and Cathy Higgins in the UK. They acknowledge limitations to the planning process in dealing with housing suggesting…'it is perhaps not surprising that the less quantifiable aspects such as those which influence the quality of human life have been rather neglected in the development of many housing projects' (Beer & Higgins 1997).

Comment [IU4]: American Institute of Architects, 2006. *The AIA's "Win-Win" Agenda for a Better Quality of Life for All Americans,* On line. Available HTTP: <http://www.aia.org/adv_gen_agenda> (accessed 7 April 2006).

Comment [IU5]: Beer, A. and Higgins. C., ditor), 1997, Environmental Planning for Site Development, Spon Press, UK.

1.2 The absence of effective planning and design of sustainable housing

Research in the United Kingdom by the Government Department for Environment, Food and Rural Affairs (DEFRA) has addressed this problem by linking QOL and housing quality and by also identifying key barriers to improvement. In DEFRA's (2001) study of public perceptions, housing quality was ranked ninth as a very important headline quality of life issue along with factors such as climate change and wildlife. Overall, nine out of ten people thought it was fairly or very important. **Existential factors** such as money, health, crime and jobs are primary issues while **biophysical factors** such as neighbourhood, transportation and housing quality and environmental problems are rated more or less equally as second priority issues affecting QOL (DEFRA 2001).

Comment [IU6]:

Comment [IU7R6]:

Comment [IU8]: DEFRA, 2001, *e-Digest Environment Statistics, Public Attitudes*, On line. Available HTTP:<http://www.defra.gov.uk/environment/statistics/pubatt/ch3h07.htm> (accessed 7 April 2006).

1.3 Research into QoL at the sustainable housing precinct level

Research in the UK in addressing the QOL factors has been achieved through the use of demonstration projects, i.e. a project which identifies principles, processes, technologies and tools, in addressing housing quality in the context of sustainability. One notable example is the Bed ZED project - Beddington Zero Energy Development Sutton, UK (BRESCU 2002). This is a zero energy project – the onsite renewable energy generation is balanced with the energy drawn from the grid to create net zero carbon emissions. Beddington Zero also addresses environmental, social and economic issues. In the Bed ZED development, economic parameters support environmental parameters, which in turn supports social progress. For example, the use of retail units within the housing development is aimed at subsidizing the housing rental. This multi-use retail and housing strategy creates a scale effect, which supports the cogeneration energy strategy leading to the zero energy capability of the scheme. Yet, while the project aims to achieve high QoL for its residents, this claim remains largely untested (Dunster, B., 2006).

Comment [IU9]: Dunster, B., 2006, ZedFactory. On line. Available HTTP: < http://www.zedfactory.com/home.html> (accessed 7 April 2006).

The problem of how to maintain quality of life whilst reducing environmental impact is a multi dimensional and multi-disciplinary challenge that is facing South East Queensland today. The Queensland Government's State of the Environment Report (2003) shows disturbing trends in the pattern of human settlement, which cannot be solved through this project, while macro studies of quality of life show approximately 91% of Queenslanders surveyed in November 2001 said they were "satisfied" or "very satisfied" with their quality of life. Yet although most Queenslanders report being happy with their quality of life, a number of the existential factors (money, health, crime and jobs) are showing a lack of capacity in infrastructure to meet the needs of an increasing population. For example health and housing affordability are indicators, which have shown change in recent years with a sharp decline in housing affordability (Queensland Government 2003)

1.3.1 Biophysical impacts

Yet, it is the biophysical factors to QOL (neighbourhoods, transportation, housing and environmental problems), which highlight areas for concern. The rate of growth in travel is higher than the rate of population growth with the number of passenger vehicles registered in Queensland increased from 1.6 Million (0.456 cars per capita) in 1998 to 1.8 Million (0.486 cars per capita) in 2002. The average distance traveled by passenger vehicles increased from 13, 200 km in 1998 to 14, 300 km in 2002; between 1998 and 2002, total annual fuel consumption by all vehicles in Queensland increased by 22%.

It was also found that in the same period the use of public transport reduced, accounting for only 10.1% of journeys to work in southeast Queensland in 2001, down from 11.3% in 1991. The average travel times during peak periods on the main roads into the Brisbane CBD rose by over 7% between 1998 and 2000. With regard to energy, Queensland's total energy consumption rose 21 per cent from 849 petajoules (PJ) in 1994-95 to 1024 PJ in 2000-01, and the main primary energy sources were black coal (45.8% of total energy use), petroleum products (37.1%), biomass (9.0%) and gas (7.6%). Attempts to shift from fossil fuels to renewable energy seem stalled. The proportion of Queensland homes using solar hot-water systems rose from 4.8% in 1994 to 9.1% in 2001 (Queensland Government. 2003).

Water use has stabilized, with average water consumption in the fourteen major urban water authorities in Queensland rated at 220 kilolitres/capita in 2000-01, while rainwater sources depleting due to climate variability. Wastewater has increased with the volume of wastewater receiving tertiary treatment in southeast Queensland rising from 36% in 1998-99 to 48% in 2000-01. Ironically, the proportion of wastewater reused in Queensland is low – an average of 5.7% in nine major urban local government areas.

In contrast solid waste generated and sent to landfill in Queensland fell 13%. The proportion of solid waste recycled in Queensland rose from 3.9% in 1996-97 to 20.4% in 2001-02. This can be attributed to good access to household recycling programs in 2001-02. In terms of housing quality, there was a significant increase in noise complaints since 1999 with both Brisbane and greater Queensland experiencing a sharp decline in housing affordability in the period 2001-03. Urban residential densities in South East Queensland increased 5.1% between 1995 and 2001, requiring the provision of great open space and pedestrian access to parklands etc.

1.3.2 Measures to reduce biophysical impacts

Newman (2006) argues that initiatives to address these issues are found in six main areas; better governance, improved global stewardship in the use of natural resources, biophysical efficiency in settlement patterns, the creation of social capital though community, and finally improving efficiency in business through implementing a Factor 4 policy i.e. double the wealth but also double the resource efficiency (Newman 2006). The research proposed in this application examines initiatives concerning biophysical efficiency in settlement patterns and the creation of social capital though the community implementation of sustainable housing.

Comment [IU10]: Newman, P. and Kenworthy, J, 2006, *Sustainability and Cities Overcoming Automobile Dependence*. Island Press, Washington D.C.

Newman, P., 2006, *Vision and sustainabiltiy in WA*. On line. Available HTTP:<www.sustainability.dpc.wa.gov.au/pdfs> (accessed 9 April 2006).

Initiatives in SE Queensland involve efforts to address the six barriers identified by Wheeler (2003) including, disincentives in the fiscal system, perceived higher costs, lack of consumer demand, lack of investment interest by developers, no agreed standards and a planning system which does not support sustainability.

There are measures in place to provide incentives in the **fiscal systems** for sustainable housing through reduced mortgage costs for green design, subsidies for use of green technologies such as water tanks, solar hot water heaters and photovoltaic systems. It is argued that incentive such as that provided by Bendigo Bank, which provide a 0.50% per annum reduction on the Bank's Residential Variable Rate and no monthly service fee, achieve an interest saving of more than $48,000 over the life of the loan. It is argued that this is sufficient to provide equity for developers and homeowners to improve the design specifications needed to upgrade homes to meet environmental criteria. This also addresses issues identified by Wheeler concerning the **perceived additional costs** of sustainable housing.

Consumer demand is the attention of a number of Federal and State initiatives. The Australian Greenhouse office has developed the 'Your Home' marketing initiative (AGO 2006). This program targets issues such as homeowner perceptions about the quality of life improvements through owning a sustainable home. No exit studies of users of this program have been carried out to gauge the effectiveness of this marketing policy, so it remains questionable about the effectiveness of this costly exercise. In Queensland, further initiatives such as The Sustainable Homes program is a Queensland legacy of the national Year of the Built Environment 2004 (YBE) – a year that highlighted the need for our built environments to become more sustainable through improved design and function. The Sustainable Homes program aims to provide communities in Queensland with display houses that include the principles of sustainable design. Two key objectives of the initiative are to demonstrate and promote the importance of investment in sustainable design at the household and community level, and to increase the demand from homeowners, builders and developers for sustainability practice. Thirty-four homes are to be built and sold six months later. No attempts have been made to monitor or research the benefits of the design of these buildings. Discerning consumers question the value of such an exercise unless tangible benefits in quality of life are demonstrated.

Finally **barriers within the planning system and environmental standards** for sustainable housing remain. Mc Manus (2005:68) argues through what is termed SMART growth policies that the planning system has yet to embrace and gear up to sustainability. SMART growth policies are beginning to be evident in South East Queensland, which does not advocate unlimited growth but appropriate growth avoiding sprawl because of impacts on biophysical factors. It focuses on livability and quality of life and focuses on the need for quality growth (McManus 2005: 65). The planning system has been reformed to address this issue through the Integrated Planning Act, which looks to ecological protection as a key issue but is yet to be fully implemented (Queensland Government 1997 & Brindle 1999). Slack (1999) suggests problems lie in the lack of policy measures and metrics such as indicators at the Local Council level to monitor compliance and performance.

Improved metrics in the form of prescriptive and performance standards such Energy Rating tools are in place. For example BERS (Building Energy Rating Software), which are now adopted by councils to assess housing development has translated into legislation. As of 1 January 2003, minimum energy performance standards have been introduced in to the Building Code of Australia for detached and semi-detached dwellings. Since the BCA is a performance based Code, builders and designers have the option of meeting these new standards in one of two ways: by following the 'deemed to satisfy' prescriptions in the Code; or by achieving the required house energy performance rating using an accredited software tool. The stringency of this standard equates to 4 stars. Queensland has additional measures for water, which are designed to reduce water and energy use by 36 and 33 per cent respectively.

In summary, current research into QOL is seen as a macro level issue with little drilling down to community level impacts of sustainable housing. Input measures are in place to address change i.e. reducing water and energy use for new buildings but that leaves the majority of the housing stock following a business as usual approach.

DESIGN and PLANNING		**OPERATION**
Level 1: Macro	***Sustainable Cities/ Regions***	
Standards/Tools	• None	• Eco Footprinting
Level 2: Meso	***Sustainable Neighbourhoods/Precincts/ Mixed use development***	
• Environmental impact assessment (IEA) • Precinct Planning & Design Standard (proposed) • BRE Sustainable Development Rating, UK		• Eco Footprinting • ISO 14000 • GG 21 Community Standard
Level 3 Micro	***Sustainable Buildings***	
• Green Globe 21 Design and Construction Standard. (Tourism buildings). International • Green Star Rating Tool, Aus. (Offices, schools and other types) • LEED Rating Tool, USA • BREEAM Rating Tool, UK • BASIX, planning tool for houses- NSW Government • EcoHomes, UK		• ISO 14000 • GG Company Standard • NABERS Rating Tool, AUS (NABERS HOME for houses and NABER OFFICE for offices)

Comment [IU11]: Bendigo Green Home Loan. Online. Available HTTP: <http://www.bendigobank.com.au/public/personal/green_loans/residential_detail.asp> (accessed 9 April 2006).

Comment [IU12]: AGO 2006, *Your home*, Online. Available HTTP:< http://www.greenhouse.gov.au/yourhome/index.htm> (accessed 9 April 2006).

Comment [IU13]: Sustainable homes initiative. On line. Available HTTP:< http://www.sustainable-homes.org.au/> (accessed 9 April 2006).

Comment [IU14]: Mc Manus, P., Vortex cities to sustainable cities : Australia's urban challenge, Sydney : University of New South Wales Press, 2005.

Comment [IU15]: Queensland Government 1997, Integrated Planning Act 1997.

Brindle, R., 1999, Integrated planning and sustainable development, Heidi Lansdell,

Comment [IU16]: Slack, T.M., *Planning schemes, ecological sustainability, and the Integrated Planning Act 1997: an evaluation*, UQ, St. Lucia, 1999.

Comment [IU17]: Wilrath, H, 2006. http://www.solarlogic.com.au/ContactUs.htm

Comment [IU18]: Austrlian 2006. http://www.greenhouse.gov.au/buildings/code.html#houses. Queensland Government http://www.lgp.qld.gov.au/?id=2293

Comment [IU19]: Queensland Government 2006. On line, Availbe HTTP: <http://www.lgp.qld.gov.au/?id=2293>

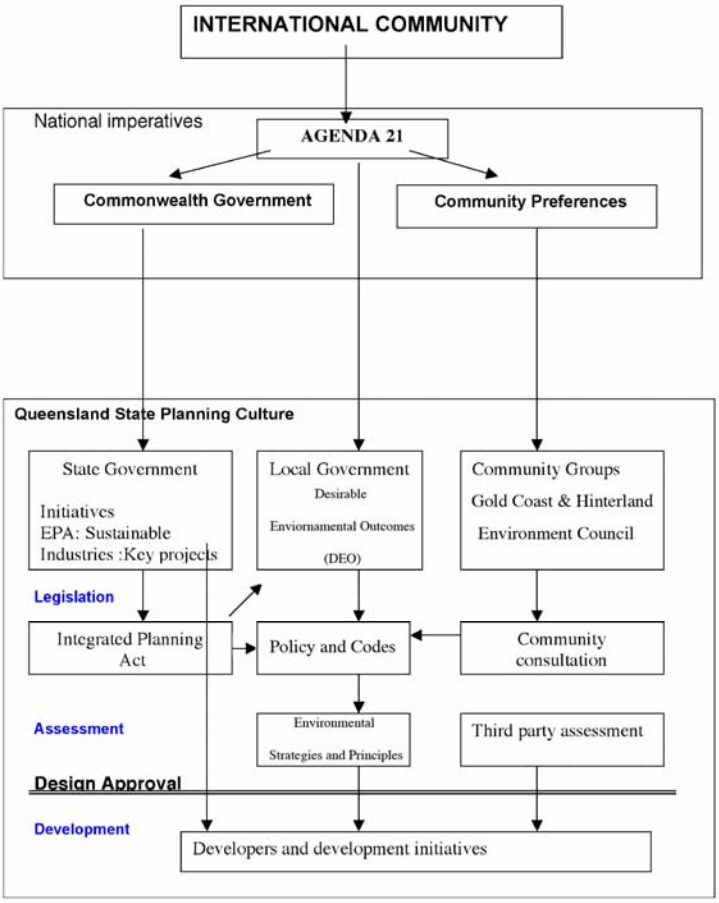


Table 1 Simplistic mapping hierarchy of sustainable development in relation to available standards at three spatial scales- macro, meso and micro, and two modes of delivery- design and operations

Few output metrics are in place in South East Queensland such as monitoring the Quality of Life at a community level in terms of existential or biophysical factors. Models of the interaction of factors at a community level are largely descriptive and lack empirical validation (McManus 2005: 85.)

1.3.3 New methodologies and models

Research into new metrics to examine the sustainability of buildings and precincts is underway at The University of Sydney and the University of New South Wales and through Dr Veronica Soebarto the School of Architecture. Supported by AHURI and the Sustainable Tourism CRC, metrics have been developed for examining sustainable buildings and neighbourhoods. Initial work funded by the Australian Housing Urban Research Institute (AHURI) supported a **Triple Bottom Line monitoring survey** comparing the social, economic and environmental impacts for types of urban subdivisions. This involved developing a new methodology to measure this range of factors. Many of the factors examined issues concerning QoL but also consider the input measures, i.e. characteristics of the biophysical factors as well as existential (commonly found in QoL) and environmental factors.

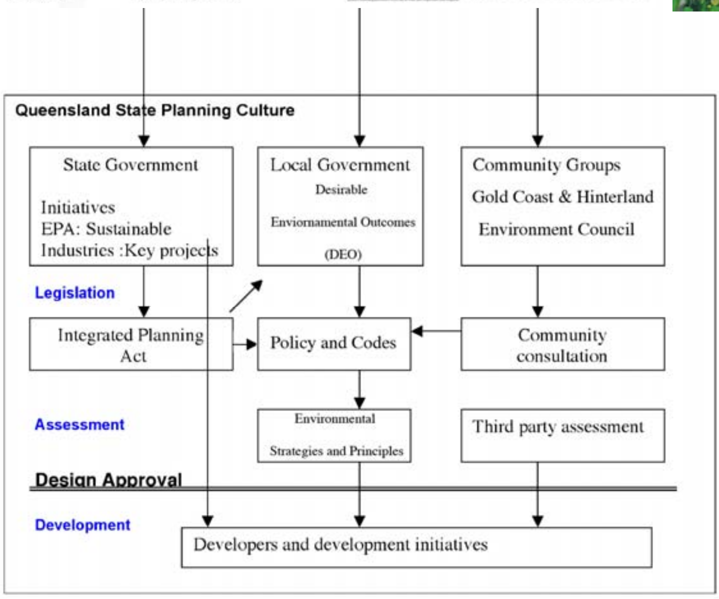
Since this project, work with the Sustainable Tourism CRC has led to the development for new building design **environmental assessment systems** (BEA) such as the new Precinct Planning and Design Standard (PPDS), which can be used for examining neighbourhoods and is now completed. A keynote address by Hyde, Prasad and Blair at the International Sustainable Buildings Conference in Tokyo, 2005 presented work on these methodologies as shown in Table 1. This shows the way a variety of assessment systems and tools apply at different spatial scales and with different modes of delivery- design and operations.

Comment [IU20]: Blair, J., Prasad,D., Judd B., Soebarto, V., Hyde, R.A., Zehner B,. Kumar, A., (2003) *Affordability and Sustainability Outcomes of 'Greenfield' Suburban Development and Master Planned Communities – A Triple Bottom Line Assessment, progress report for the* Australian Housing and Urban Research Institute, University of New South Wales-University of Western Sydney Research Centre, pp24.

Comment [IU21]: Hyde, R.A., Moore R., Kavanagh, L., Watt, M., Prasad, D., And Blair, J. (2005)', Research report: *Green Globe 21 Precinct and Planning Design Standard*, Green Globe 21 Australia, pp. 150.

Hyde, R.A., Moore R., Kavanagh, L., Watt, M., Prasad, D., And Blair, J. (2005)', Research report. *Scoping and Product Development for the Green Globe 21 Precinct and Planning Design Standard*, CRC Tourism, Australia, pp. 100.

Comment [IU22]: Prasad, D., Blair, J., And Hyde, R.A., (2005) 'Triple Bottom Line Assessment and sustainability: A method of performance evaluation,' in the proceedings of *SB05, Tokyo, Actions for Sustainability, The 2005 World Sustainable Building Conference*, p.239 and on CD.



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2. Case Study: The Ecovillage, Currumbin, Gold Coast, Australia.

This case study is presented through first looking at the externalities to the Ecovillage and then on the internalities- the development of control measures used in the project to achieve sustainability.

2.1 Externalities- planning system

In Australia, the delivery process for housing can be fragmented. It is largely a developer led system; a developer purchases the land, forms a sub-division and then sells parcels of the land to sub-developers who can be house owners or owners of other building types such as hotels, retail and so on. Local governments either assume control of the legal title of precinct or it remains under the control of the developer and sub-developers/owners as 'community title'.

Gold Coast Council controls the process as shown in Figure 1. Development control is influences by a range of federal, state and local councils initiatives to promote sustainability. At the State level legislation is dominated by the IPA (Integrated Planning Act), which promotes ecological sustainable development through integrating State and Local Planning systems. The strategic planning and Environmental Impact Assessment process (EIA) has been replaced (Thomas 2005: 121). Local Planning responds to Desirable Environmental Outcome (DEO) statements in the form of policies and codes (Grummit 2006). Community input and environmental impacts are assessed. For example input is sort from local environmental groups such as the Gold Coast & Hinterland Environment Council (GECO). Input is also sort on the environmental principles and strategies used in a development (Grummit 2006). The methodology and procedure for assessment appears dependant on many factors, most important is its significance, that is the scale, complexity and sensitivity of the development to sustainability issues (Thomas 2005: 123).

The objective here is not to critique the planning system for its inability to deliver sustainable outcomes, clearly the IPA legislation places sustainable development on the agenda for developers, but to identify areas, which can be used to improve the level of sustainability in planning and design outcomes.

2.2 Internalities- master planning

This can be achieved by interventions at a number of levels in the system as seen in case of the Currumbin Ecovillage. This development is significant in terms of social, environmental and economic sensitivity to the area.

The Ecovillage at Currumbin, is on a 110 hectare site in the Gold Coast. The project provides for 144 eco-homes in a variety of residential configurations, together with community facilities including a small village centre. The Ecovillage incorporates a wide range of sustainability features including autonomy in water, wastewater and energy; 80 percent open space and more than 50 percent environmental reserve; negligible vegetation loss and extensive native plant regeneration; edible landscapes and permaculture and waste minimisation and recycling. The developers claim it exceeds international and Australian sustainability best practices and has been hailed by government and industry as a leading example of Ecological Sustainable Development (ESD) within the housing sector (Sunager et al 2008).

Substantiating these claims with regard to best practice, there are very different definitions of sustainability with in the international community and with in the Australia. McManus argues that ESD is a uniquely Australian definition, which is more concerned with retaining its ecological systems (McManus 2005). Whilst it is useful at one level applying this definition to urban development is hard. Hence it can be argued that IPA, which has its foundation in ESD, should be augmenting with regard to new definitions of sustainability to deal with the urban contexts and international practices. This problem with conflicts in definitions is that it finds its way into increasing the complexity and ambiguity of procedure and assessment. Thomas reports about the lack of clear procedures with re to implementing IPA. At Currumbin this caused extensive work to achieve Code compliance. The amount of documentation needed to gain planning approval was expensive time, consuming and exhaustive (Walton 2006). Adding environmental criteria such as autonomy of servicing for the site in areas of energy, water and waste means the council needs to condition a range of additional measures into the approval process. In addition a range Codes are needed to cover the biophysical aspects of designing and building houses on the development. Eco Homes are needed so that there is a reduced demand for services. Also, byelaws are need to cover social and management issues to ensure efficient use of resources and cut demand for services. The problems with procedure in this type of sustainable development that is it sits outside normal Code compliance process i.e. it is not assessable under the Planning Code, creating the need for new metrics to support the assessment procedure.

2.1.1 Lack of a common metric for both the regulatory system and the developer

Shane and Graedle (2000) and Mc Manus (2005) point to the importance of using metrics that can demonstrate environmental efficiency measures for environmental impacts assessment. It is argued that metrics cannot fulfil all the needs of planning assessment but could form one part of the process. This is argued on the basis that metrics are generic require interpretation in the local context. In the case of Currumbin a metric was created from a range of authorities such as Gold Coast Water for the water benchmarks, waste treatment from the Environmental Protection Agency. A further development that could expedite the compliance process would be to creating a common metric between regulators and developers. This would seem not only to carry forward the intent of the Integrate Planning Act but also provide simpler procedure for implementing planning approvals of sustainable development of this nature.

2.1.2 Evidenced-based planning at the precinct level

There are benefits in extending the application of the planning system at the precinct level. This can involve ‘conditioning’ measures in post construction process at the time Development Approval is given (Grummitt 2006). The reason for this is that environmental principles enshrine in international policy such as ‘continuous improvement’ can be achieved and planning measures can be validated (Hyde 2006, Hyde et al 2008). The areas of biophysical monitoring and social impacts can be measured. In conditions where both the design and management of a precinct such as the Ecovillage, it is seems imperative that planning policy is reconciled with planning reality. So impact measures can provide evidence to support planning, not as a ‘development control process’ but as ‘development evolutionary process. This quasi- research approach, derived techniques from research are available. These are tested in this research work involving biophysical monitoring and social impact study in the form of a residential satisfaction study.

3. Discussion

The paper is aimed at discussing outcomes from work on QoL of housing in South East Queensland though a case study of the Ecovillage at Currumbin. From this work it is argued that to ensure compliance with sustainability housing objectives the planning, design and operational aspects of the development process should be harnessed and integrated effectively. This has been possible at the Ecovillage, Currumbin, which uses a range of measures to reduce environmental impacts whilst also maintaining and arguably increasing QoL. QoL has been found to be useful as a surrogate indicator for sustainability since it includes social, economic and environmental factors. The **QoL residential survey** developed in the project gives feedback on residents’ issues (Wells 2008). This is status control measure can be used to enhance the development control process to an ongoing evolutional process to support Agenda 21 policy. This argues that the process of sustainability is largely evolutionary involving continued improvement of development over time. To support this view a new **standard for precinct design and planning (PPDS**) is now available to enhance this process (Hyde 2007)) and a new **Sustainable Building Code** used at Currumbin.

To examine ongoing operational performance **biophysical monitoring** has been developed to sample of data from houses. This utilises advances in electronics systems for monitoring has enable a new methodology to be developed. Although an added cost to the project it is providing useful feedback to enable residents to assess if they are meeting environmental targets.

4 Acknowledgements

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INTEGRATED DESIGN PROCESS AND THE CONVENTIONAL PRACTICE: REFLECTIONS ON THE ENVIRONMENTAL PERFORMANCE OF ONE CASE STUDY IN BRAZIL

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Keywords: Sustainability; Environmental performance of buildings; Design method; Integrated Design Process.

Summary

The conventional design practice is characterized by a linear, segmented development process with isolation among design disciplines. Usually the integration between different specialties occurs late in the process, when opportunities for significant changes are very limited. In opposition, the integrated design process supposes the multidisciplinary work of all actors involved from the process outcome. Among the first steps is the discussion and definition of a consensus between client and designers regarding the objectives, methods and responsibilities to achieve the established targets. This analysis is part of a study to develop and include sustainability consideration building delivery process to be proposed to FDE. This paper aims to establish a theoretical reference, consisting of the fundamental elements that characterize integrated design processes, and to use it to analyze one case study, example of the conventional practice. It is intended (1) to identify the methodological elements used in the case study and their alignment with the theoretical reference established; and (2) to investigate the influence of these elements on the environmental performance of the building, discussing the positive results achieved as well as the opportunities that could not be seized. In the case studied, as in other schools built at the same period by the responsible state agency, there where no concerns specifically related to environmental performance issues.

Even though design goals were settled early in the process, those were mainly directed by quality issues, such as rationality, constructability and compliance to budget and schedule restrictions. The studied case revealed that even though the design process established by FDE achieved those goals, it is still distant from the ideal design integration level and lacks the means to comply with more rigorous environmental performance targets. Virtually none of the elements composing the theoretical reference defined was actually implemented in the school design process. Elements that do interfere on environmental performance were specified and built, without further evaluation of their actual contribution. The inclusion of multidisciplinary design meetings, energy, comfort or sustainability specialists and the use of simulation tools to test the design alternatives, as proposed by the integrated design process approach, on the other hand, has proven to help achieving significant reductions in energy use during buildings operation, within construction budgets comparable to buildings with similar use.

1. Introduction

It is widely acknowledged that there are serious social and environmental limitations for an economic development model based on an unrestrained growth of the productive forces. In the pursuit of more sustainable productive processes, the building industry plays a strategic role, as it represents the activity with the largest consumption of resources in the world (Berge, 2000; Silva, 2003). Raw materials sources are not always legal, and in 2001, 84% of the timber was used by the building industry, being most of it composed by native timber illegally shipped to the State of São Paulo, Brazil, as reported by Sobral et al. (2002). The emissions of the sector are also very relevant, as almost have of the municipals solid waste is produced by construction and demolition activities in Brazil (Pinto, 1999).

Within a strategy for the promotion of sustainable practices in the building industry, rating systems - either aiming at environmental assessment and/or certification of buildings - can be instruments of great help. Certification of buildings can stimulate an increased demand for corporate environmental performance demonstration and capacity building of the actors involved in building delivery (entrepreneurs, designers, contractors, suppliers, facilities managers etc). Currently, United States, Canada, Australia, Japan, Hong Kong and almost every European country have at least one evaluation system in place. Even though Silva (2003) defends that the use of other countries tools may lead to a series of distortions and it is necessary to develop a locally driven evaluation and certification system, given the absence of a Brazilian rating system, LEED[TM] certification has been pursued and an adapted version of the French system HQE has just been launched.

On the other hand, certification systems are only one among several necessary means to promote sustainability in the building sector. Increased demand for buildings with better environmental performance is already happening, but serious obstacles are perceived for the implementation of the necessary concepts in the Brazilian context. The difficulty to find reliable information and suppliers that guarantee low environmental impacts of there products are some examples. Another limitation is related to conventional design processes that lack the means to deal with the new challenges posed by sustainability.

In 2007, the first Brazilian regulation for energy efficiency was approved, to be initially implemented in a voluntary basis for commercial, services and public buildings and become mandatory after five years. This analysis is part of a study to include sustainability consideration in FDE's building delivery process to be proposed to that agency in order to, among other factors, comply with the upcoming normative requirements.

This paper aims at establishing a theoretical reference encompassing the fundamental elements that characterize integrated design processes, and use it to analyze one case study, example of the conventional practice. It is intended to: (1) identify the methodological elements used and their alignment with the theoretical reference established; and (2) investigate the influence such elements had on the environmental performance of the building, discussing the positive results achieved as well as the opportunities that could not be seized.

Integrated Design Process guides and study reports describing examples of integrated design processes where consulted for the characterization of the theoretical reference. A collection of publications produced by IEA's Task23 was the main reference used. The case study where investigated through the collection and analysis of design documents.

1.1. Integrated Design Process (IDP)

In conventional building delivery approaches, early design work is developed only by the architect, which submits the plans for the client's approval. Other design disciplines are added to the process only at design documents evolve, in particular at the construction documents stage, when the main characteristics of the building, such as site plan, volume, facade orientation and structural system, are already defined. In such format, the architect is usually responsible for ensuring design compatibility among all disciplines, but the possibility for significant changes is very limited, as it can cause great over work for the actors involved.

It is well recognized though, that possibilities for changing the building performance are great at the beginning and diminish through advancement of design development process. Melhado (1995) defends the need for the constitution of multidisciplinary design teams from early design stages, with coordination procedures methodologically established, instead of the isolation between disciplines and the sequential and non interactive design development. The author adds that a greater integration between the design and production stages is also needed, aiming for quality issues, such as attending the client's expectation, rationality and constructability of the building. In a later work (Melhado, 2001), the concept of concurrent engineering is borrowed from other industrial sectors to name the integration between multidisciplinary work and design and production stages as Concurrent Design of Product and Production (CDPP).

Terminology varies to describe processes that propose the multidisciplinary work of all actors from the design process outset. While Bill Reed defines it as Integrative Design Collaborative (Zimmerman, 2006), the LANL Sustainable Design Guide (LANL, 2002), elaborated by Los Alamos National Laboratory to guide processes of planning, designing, bidding and producing new buildings in the laboratory's campus, uses similar methodological elements under the expression Whole-Building Design.

Another concept is given by the Task23 work group, within the International Energy Agency (IEA) Solar Heating and Cooling Programme (IEA, 2003) that from 1997 to 2002, produced a set of methods and tools aiming at incorporating sustainable aspects in design processes, focusing mainly on energy efficiency. The proposed methodology was denominated Integrated Design Process (IDP), terminology that was adopted for the purposes of this text.

This approach aims for better environmental performance, mainly focusing energy efficiency. Criteria related to use, comfort, environment and costs are also considered. The following objectives are related: (1) maximum environmental (thermal, luminous, acoustic) comfort and air quality; (2) building's functionality, flexibility and adaptability; (3) minimal consumption of non-renewable resources; (4) minimal atmospheric emissions related to global warming and acidification, liquid effluents and solid wastes; (5) minimal negative impacts on the site; (6) life-cycle cost consideration (IEA, 2003). The proposed methodology includes the following fundamental elements: (1) multidisciplinary work of all actors involved from the beginning of the process; (2) discussion and definition of a consensus between client and designers regarding the relative importance of the performance issues and articulation of targets and strategies; (3) the addition of energy, comfort or sustainability and other specialists for specific problem-solving; (4) use of simulation tools to test design alternatives; (5) evaluation of budget restrictions considering the whole building, avoiding separate budgets for different building systems, as extra expenditures for one system (e.g. for sun shading devices) may reduce costs in other systems (e.g. air conditioning); and (6) insertion of a design facilitator in some cases to coordinate the process and contribute with specific information.

Examples of integrated design processes in Europe and North America reveal that each stage of the process is characterized by a series of loops, in which design alternatives are formulated, tested and reformulated until the best solution is reached (IEA, 2002). In each design loop the relevant design team members participate (Figure 1).

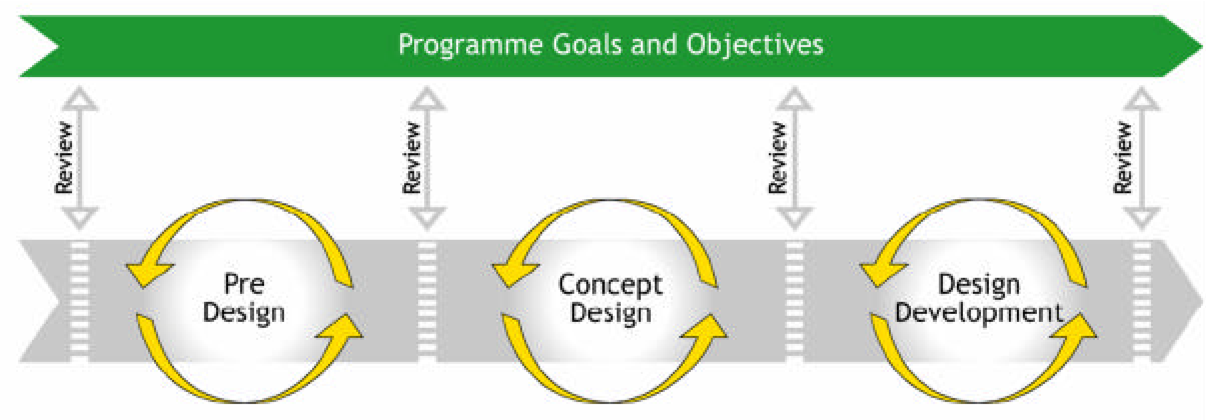

Figure 1 - Integrated Design Process (IEA, 2003)

2. Case Study

The Jardim Dom Angélico II State School (Figure 2 and Figure 3) was built in a poor east side suburban area in the city of São Paulo, Brazil, to substitute a provisory facility consisted of metallic container-like modules, which functioned as school. A small site (approximately 1200 square meters) was selected given the lack of alternative areas in the surroundings (FDE, 2006). The result was a compact three-storey building, arranging the building programme within a built area of 1616 m^2. The design and construction process occurred between 2003 and 2005. The architecture design was developed by the architect Pedro Mendes da Rocha and the structural design was developed by the Kurkdjian e Fruchtengarten office.

Figure 2 - Jardim Dom Angélico II State School (Photos by Nelson Kon)

The Foundation for the Development of Education (Fundação para o Desenvolvimento da Educação FDE), created in 1987, is the public institution responsible for building and administrating schools included in the educational system of the state of São Paulo. According to FDE (2006) schools built after 2003 aim mainly at increased quality and cost reduction, through greater rationality and constructability of projects.

To achieve these goals, the design of new schools is assisted by program elements, building components and construction procedures catalogues, which facilitate the development of projects and quantifications, by providing standard information. These catalogues are permanently updated, being adapted to technology, building materials, standards and legislation changes.

Since 2003, new guidelines have been incorporated by FDE, such as the adoption of industrialized structural systems and of a process management model in which the contractor was in charge of hiring and managing design products at the construction documents stage, resulting in a better integration at that moment.

2.1. FDE's usual design process

FDE is responsible for the building site selection and all technical support for new schools to be built, from the definition of the architectural program to the allocation of financial resources (FDE, 2006). After the site is selected, topographic and soil resistance analysis are carried out. Then an architect is hired to elaborate the concept design and once it is approved by FDE, the design development stage is carried out. Consultation with a structural engineer is made and additional information related to mechanical and electrical systems are provided by FDE. The bidding process is then held based on the documents produced at this design stage.

After bidding, the contractor is responsible for hiring and managing the projects at the construction documents stage. The mechanical and electrical engineers are then included in the process, and meetings for design compatibility verification are realized under the contractor's project manager supervision.

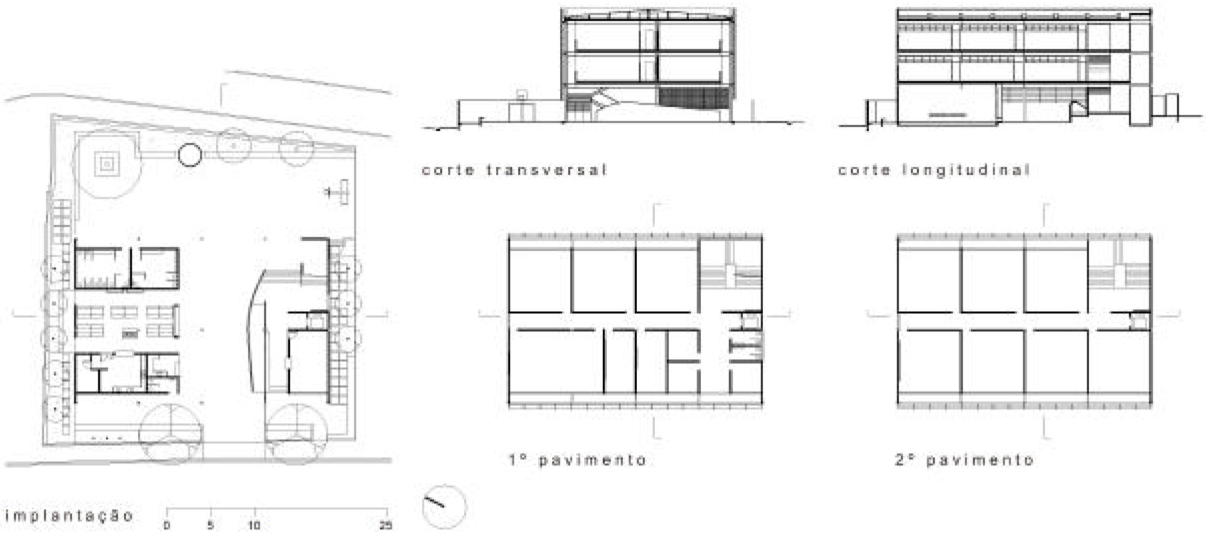

Figure 3 - Architectural drawings for Jardim Dom Angélico II State School.

Even though industrialized concrete structural systems adopted in schools built at the same period, resulted in lower construction costs, a steel frame was applied for greater rationality and constructability of this specific building, reducing the construction schedule while providing higher quality (FDE, 2006).

Environmental performance issues were not among the objectives at the outset of the design process, although some generic guidelines are commonly adopted by FDE to improve users' comfort. External fenestrations comply with current standards and legislation regarding day lighting and natural ventilation. In addition, operable windows between classrooms and circulation spaces enable cross ventilation across the building. Particularly, in this case study, site limitations did not allow for a better orientation, and main facades resulted northeast and southwest. This fact made necessary the specification of shading devices, composed by hollow concrete blocks, which contributed for a better thermal comfort in the classrooms. However, no comfort analysis or simulation tools where used to evaluate the performance of the specified solution. Neither a post-occupancy evaluation was carried out to verify actual comfort and energy efficiency levels of the building in use.

3. Alignment with the adopted theoretical reference

The six key elements identified in section 1.1 for fully integrated design processes refer to team composition aspects, and process development and instrumentation. Considering that, the following observations apply:

- Discussion and definition of consensual basis of design (BOD)

  The goals of greater rationality and constructability have been settled before the design process started by the client, without further discussion and definition of a consensus with designers regarding the relative importance of the performance issues and the articulation of targets and strategies. In this case, there was no environmental performance targets established that could motivate the adoption of methodological guidelines alternative to conventional practice.

- Multidisciplinary work from process outcome

  Figure 4 describes interaction among actors and methods and design aids involved in each design phase. It also reveals that apart from structural design, in the case studied integration among design disciplines occurred only at the construction documents stage, after the building bidding, when significant changes could not be implemented anymore.

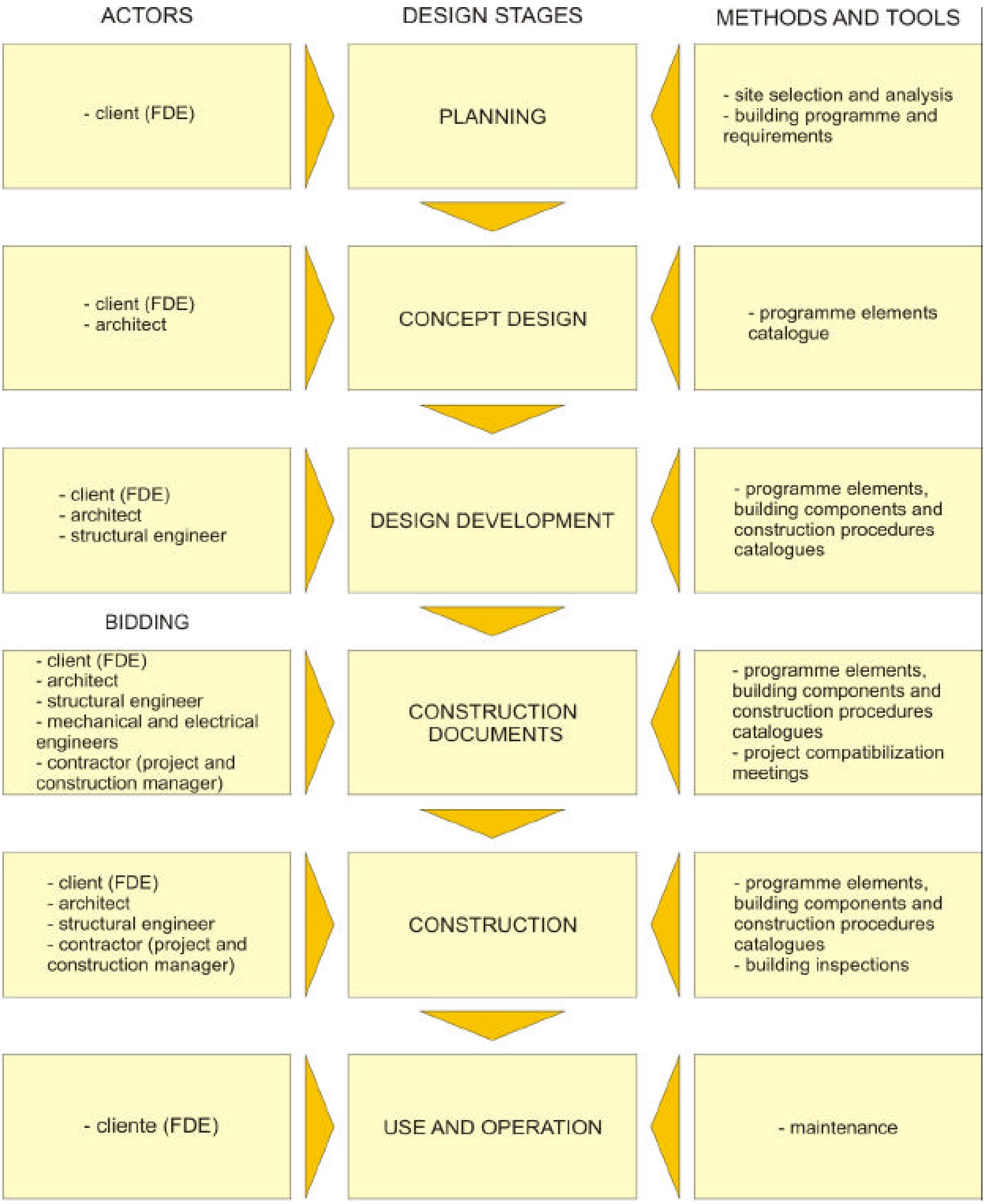

Figure 4 - Design Process of Jardim Dom Angélico II State School.

- Evaluation of budget restrictions considering the whole building

Cost assessment was carried out on a system-by-system basis, without proper consideration of possible synergic contributions that certain expenditure could have on the overall building performance.

- Addition of energy, comfort or sustainability and other specialists, use of simulation tools and insertion of a design facilitator to coordinate the process and contribute with specific information.

Differently from encouraged by integrated design approaches, in the studied process there was no significant concern with the stages before (planning) and after (use and operation) design and construction phases. In examples of Integrated Design Process, such as the Zion National Park Visitors Center (ZNPVC), the multidisciplinary work, the climatic analysis and the use of a simulation tool at the planning stage, enabled the integration between the set of solutions, a fundamental aspect for the achievement of the settled goals (Torcellini et. al., 2005). In the ZNPVC case, an energy performance evaluation carried across the use and operation stage allowed for the correction of some aspects that did not function as originally expected, and results documentation to close the cycle serve as reference for future designs.

FDE provides designers with a robust design handbook, which lists and describes program elements and defines in detail requisites from both the client and the expected user. This handbook so far does not include energy or sustainability performance requirements.

Energy, comfort or sustainability specialists where therefore not included in the process and no simulation tools to test the design alternatives were used. The shading device, specified and detailed in the construction documents, was based on an assembly of hollow-core concrete blocks actually determined by budget restrictions that prevented that the original system, constituted of horizontal metallic elements, was implemented. No evaluation could be made to determine the impact this substitution had on the thermal and luminous performance.

4. Conclusions

In 2007, the first Brazilian regulation for energy efficiency was approved, to be initially implemented in a voluntary basis for commercial, services and public buildings and become mandatory after five years. This analysis is part of a study to include sustainability consideration in FDE's building delivery process to be proposed to that agency in order to, among other factors, comply with the upcoming normative requirements.

In Jardim Dom Angélico II State School's design process, as in other schools built at the same period by FDE in the state of São Paulo, there where no concerns specifically related to environmental performance issues. Even though the design goals were settled early in the process, they were mainly directed by quality issues, such as rationality, constructability and compliance to budget and schedule restrictions. The studied case revealed that even though the design process established by FDE achieved those goals, it is still distant from the ideal design integration level and lacks the means to comply with more rigorous environmental performance targets.

Apart of that, virtually none of the elements composing the theoretical reference defined was actually implemented in the school design process. Elements that do interfere on environmental performance were specified and built, without further evaluation of their actual contribution. The inclusion of multidisciplinary design meetings, energy, comfort or sustainability specialists and the use of simulation tools to test the design alternatives, as proposed by the integrated design process approach, on the other hand, has proven to help achieving significant reductions in energy use during buildings operation, within construction budgets comparable to buildings with similar use.

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URBAN VEGETATION AS A TOOL FOR CLIMATE ADAPTATION

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Keywords: climate change, microclimate, urban, vegetation, green roofs

Summary

Climate change already has a large impact on urban areas throughout the world. The effect will increase in the future, even if we manage to keep emissions at today's level. The impact looks different in different regions, but hotter and longer heatwaves, and local flooding caused by heavy storms, are two severe problems already increasing in Europe and other regions. Societies will need to adapt to a changing climate in many ways. One means of adaptation is increased use of urban vegetation. Competition for urban space will make increased urban park areas unlikely, but cities can be greener by utilizing streets, rooftops, and walls. Large scale city greening, by e.g. greening rooftops, increasing the number of street trees and using climbing plants on walls, can significantly cool the local climate by evapotranspiration. The urban heat island effect and heavy storms caused by large temperature differences between cities and their surroundings, are therefore reduced. Climbing plants can cool buildings during the growing season through shading. Green roofs can cool buildings with poor insulation during the warm season due to evapotranspiration. Urban vegetation will also reduce local flooding by its water uptake during the growing season. Green roofs have a water uptake of at least 50% of the precipitation, on a yearly base, in the temperate region. Local storm water management means that rain water is treated locally to as large extent as possible. Water is retained in ponds, and lead through ditches and swales, which all are more efficient if vegetated. Compared to conventional storm water management in pipes, local storm water management can decrease the risk of local flooding drastically. These measures can together help make our cities more robust and resilient to the impacts of an inevitably changing climate, can in themselves contribute to decreased energy demand and climate impact, and not least contribute to a more attractive and liveable urban environment.

In this paper, different examples and practical experiences of city greening for climate adaptation are presented, and city planning strategies and building sector possibilities are discussed.

1. Introduction

Climate change is already here, and will increase in the future, even if we manage to decrease or keep greenhouse gas emissions at today's level. It's impact is different in different parts of the world, but hotter and longer heat waves, and local flooding caused by increased precipitation and storm frequency, are two severe problems already increasing in Europe and other regions. Societies will need to adapt to a changing climate in many ways. Climate adaptation appears as a needed policy complement to approaches aimed at mitigation climate change under any scenario produced by the Intergovernmental Panel for Climate Change (IPCC), and is increasingly seen as important in the international and national arenas in both developed and developing countries (IPCC, 2007, IPCC, 2001, Storbjörk, 2007). Adaptation is here defined as 'adjustments in natural and human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities' (IPCC, 2001). Taking anticipatory actions well before 2050 results in less total adaptation and impact costs than taking no actions (Kirshen et al. 2008).

In the city, impervious built surfaces replace vegetated surfaces, which provide shading, evaporative cooling, and rainwater interception, storage and infiltration functions. As a result, energy exchanges are modified to create an urban heat island, where air temperatures may be several degrees warmer than in the countryside. Also, the rate and volume of surface runoff of rainwater are larger in cities than in surrounding rural areas. In combination with the urban concentration of population, infrastructure and socioeconomic values, climate change impacts are likely to be more severe in urban areas than elsewhere. The seriousness of the possible impact on the population is illustrated by the estimation that the European summer heat wave in 2003 claimed 35,000 lives (Larsen, 2003)

This paper addresses the question of reducing the increase in future urban summer temperatures and local flooding by adding urban greenery, as well as managing storm water run-off in local, ecological systems.

2. Greening cities

2.1 Cooling

Several studies in recent years have shown that increasing vegetation in the urban context can be an effective way of mitigation the heat island, and benefit urban centres (Dimoudi & Nikolopoulou, 2003, Gill et al. 2006, Alexandri & Jones, 2008). The maximum surface temperature is very dependent on the proportion of green cover; this will become increasingly important in the future (Gill et al. 2006). Adding 10 per cent green cover to areas with little green, such as town centre and high-density residential areas keeps maximum surface temperatures at or below today's levels, even under scenarios of a temperature increase of almost 4°C, according to modelling of Manchester by Gill et al. 2006. On the other hand, if 10 per cent green cover is removed maximum surface temperatures are up to 8°C higher by the year 2080 (Gill et al. 2006). Green roofs are a smart solution for adding urban greenery. A green roof can be everything from a 4-5 centimetre thick mat of drought resistant plants and their substrate, up to a construction with a 10-100 centimetres thick substrate with varied vegetation and/or horticultural possibilities. The thinner roofs have the advantage of being enough light-weight to suit almost all kind of roofs with a slope less than 30 degrees. A thicker roof is heavier and demands a stronger roof construction, but the thicker roof have larger cooling capacity, and absorb larger amounts of rain water. Adding green roofs to <u>all</u> buildings would keep temperatures below today's values in a high emission scenario for 2080 in Manchester (Gill et al. 2006). Alexandri & Jones (2008) modelled air temperature in the canyon between buildings. Temperatures decreased drastically on a warm summer day, when both roofs and walls were covered with vegetation. The decrease varied from -3,5 °C in Moscow to -11 °C in Riyadh, with the cities of Athens, Beijing, Brasilia, HongKong, London, Montreal, and Mumbai in between. Greening every roof in an existing city is perhaps not a very likely scenario. But in the city of Basel, Switzerland, a local regulation states that all flat roofs on new buildings have to be green. Combining the urban vegetation with local storm water management, or bioretention, can even more efficiently reduce urban temperatures, as more available water will increase evapotranspiration (Endreny, 2008). The significant increase in the duration of summer droughts with climate change, calls for a consideration of ensure that urban green areas have an adequate water supply. This could be in part through rainwater harvesting, the re-use of grey water or other solutions (Gill et al. 2006). Rainwater collection on the roofs for irrigation of green roofs is also a possibility. If the question of irrigation is not solved, much of the cooling effects of grass areas and green roofs are lost during hot and dry periods. Trees, if draught resistant species are chosen, can keep the cooling ability for longer periods of draught. Trees have also the additional cooling effect of shading, a factor not included in the model of Gill et al. 2006.

2.2 Decreased risk of flooding

In many parts of the world, climate change will lead to increased precipitation, and increased proportion of the precipitation in the form of storms, which will both increase the rainwater run-off (IPCC,2007). In northern Europe, precipitation pattern changes are already well under way, as a Danish study by Arnbjerg-Nielsen (2006) shows. Grum et al. (2006) states from measured and modelled changes in precipitation, that changed rainfall patterns will require rethinking of current design criteria relating design not only to the traditional drainage system, but that we will see the need to incorporate roads and parks into the active urban drainage system. While urban greenery captures a large share of the storm water, greenery alone is not enough to manage the increased run-off. An effective way of managing storm water is called bioretention, and is a combination of living trees and other vegetation, soil and shallow, short-term ponding Successful, ecologically based designs of novel urban aquatic ecosystems are becoming more common and exemplify stream-floodplain protection, retrofitting of neighbourhood stormwater flowpaths and use of low-impact stormwater/water capture systems as creative solutions to urban storm water management (Grimm et al., 2008). Many cities include the building of local, ecological storm water systems in the development of new areas. That it is possible to retrofit such systems is shown by the examples of Malmo, Sweden, and Freiburg, Germany. In Malmo, a local storm water system was built in Augustenborg, a housing district from the 1950s. The system is made up of swales, ditches, and ponds with regional wetland vegetation, and since it was built in the late 1990s no run-off water has left the area and the former frequent floods are no more.

2.3 Other benefits of greener cities

Adding urban greenery could decrease the need for air-condition and therefore the emission of green house gases. About 3 to 8% of electricity demand in the United States was estimated to be used to compensate for Urban Heat Island effects (Grimm et al., 2008). The greenery, especially trees, is also carbon sequestering and using urban tree planting for CO2 sequestration can be a cost effective means of climate change mitigation (MdHale et al. 2007). Greening cities is thus a good example of synergy between mitigation and adaptation of climate change that is proposed by Swart and Raes (2007). City greening is a way of improving local air quality; city trees remove large amounts of air pollutants, especially ozone and PM10 (McPherson et al. 1997). Green surroundings have a beneficial impact on health and well-being, and gives fast recovery from stress reactions (e.g. Ulrich, 1984, Ulrich et al. 1991). Greener cities will also be of benefit for urban biodiversity, especially if designs aimed at biodiversity amendment are used.

2.4 Green city planning

Cities need to be compact to avoid unnecessary use of productive land. Land for production of food, fuel and building material, is a limited resource that is scarcer than ever (Haber, 2007). Compact cities are also a condition for an effective transport system and are good for regional air quality. For example, Stone et al. (2007) found a 10% increase in population density to be associated with a 3.5% reduction in household vehicle travel and emissions. Dense cities are also a prerequisite for an exciting and attractive urban life that is the goal of a modern urban planner. The challenge lies in making cities greener without them losing their density. Green roofs and climbing plants are efficient in urban climate mitigation, and are important components in making cities greener. Also, all surfaces that do not have to be impervious out of some specific reason should be green. Large trees should be planted in streets, school yards, parks, yards and gardens. A planning instrument called ‘green space factor’ is being used in new housing developments in Western Harbour, Malmo, Sweden. It was first developed in Germany, and is used in many German cities, and is a tool for achieving a certain amount of greenery in the housing districts, including green roofs, climbing plants and large trees.

2.5 Building sector possibilities

The view of many of these issues has changed dramatically over recent years and we are now seeing the emergence of the environmental technology sector as a major growth sector and an important contributor to economic development, whilst also tackling important challenges. The growth of the green roof industry in Germany, Switzerland and Austria has been witness to the potential to build new economies around ecological service solutions in the built environment and many similar developments are in the pipeline and under development. With the political and scientific consensus emerging around the climate challenge, risk capitalists feel increasingly secure to invest in emerging technologies and the climate-related market generating a virtuous spiral for innovators and entrepreneurs to commercialise their ideas and mainstream their pilot projects. The demand for knowledge and technologies for climate adaptation will grow enormously and green and blue solutions have the opportunity to offer cost-effective solutions that not only tackle problems, but are welcomed by urban dwellers as positive enhancements to their everyday environment.

3. Conclusions

The role of the green and blue infrastructure of cities in climate change adaptation, and other ecological benefits for the urban environment, calls for a change of paradigm regarding green planning. On different levels, from the single house, street, housing district and industrial area to the whole city, the green and blue infrastructure should be optimized to fulfil different ecological services of which cooling the city and harvesting of rainwater run-off are two of the most important. Researchers and practitioners in the field of city green planning, storm water management and landscaping should aim at developing the green and blue infrastructure to find solutions for different city types and different climatic regions. One of the questions that remains to be solved is that of rain water harvesting, and possibly reuse of grey water, for irrigation.

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BUILDING INFORMATION MODELS AND INNOVATIVE SUSTAINABLE HOUSING

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Summary

This paper presents findings from the STAND-INN project that describes how standards support innovative sustainable housing that meets user needs and performance requirements with managed environmental and economic impacts during the life span of buildings. The performance approach and tools supporting this approach are described in relation with building information models. The technical aspects of current IFC specification (IFC 2x3) are discussed and explained how sustainability aspects can be modeled. Findings from good examples of innovative sustainable housing are summarized. Experiences from the use of building information models are shared, and an approach to value creation is presented.

1. Introduction

1.1 Innovative sustainable housing in the STAND-INN project

Integration of performance based building standards into business processes using IFC standards to enhance innovation and sustainable development (STAND-INN 2006-08) is an ongoing research project funded in the 6th Framework Programme of the European Commission. It focuses on facilitation of the integration of open standards into business processes, and stimulation of innovation through reference to standards in public procurement. This two year project with 28 members from 11 European countries, five European-wide networks and two Chinese partners will be accomplished by late 2008. (Haagenrud et al. 2008)

1.2 Vision 2030 by the European construction industry

The European Construction Technology Platform Strategic Research Agenda (ECTP 2005b), based on its Vision 2030 (ECTP 2005a), addresses the following key points to be developed

Meeting Clients/User Requirements

- providing a healthy and comfortable habitat for all
- promoting new image of European cities
- developing underground transport to free surface space
- developing mobility and supply through efficient networks

Becoming Sustainable

- reducing resources consumption (energy, materials, water)
- reducing the environmental impact of human activities
- maintaining efficient transport and utility networks
- enhancing our cultural heritage
- improving safety and security

Transforming the Construction Sector

- developing a knowledge-based, client driven construction process
- supported by ICT, automation, high added value construction materials
- making construction workplaces attractive.

In ECTP's Implementation and Action Plan (2007) the two first objectives: meeting user requirements and becoming sustainable should be achieved with the help of the third one: transforming the construction sector. These ECTP objectives to meet client requirements in a sustainable way reflect well the innovative sustainable housing task in STAND-INN that this paper deals with.

1.3 Scope of this paper

This paper presents results from a STAND-INN task addressing IFC and sustainability standards and innovative sustainable housing. Sustainability in this context was defined as **responsible supply, operation and maintenance of buildings that meet the needs of their owners and users over the life span with minimal unfavourable environmental impacts whilst encouraging economic, social and cultural progress**. This paper focuses on the first part of the definition: how to deliver sustainable housing **performance that meets the needs of owners and users** over the life span.

2. Performance in use

2.1 Meeting client requirements

To be able to meet client requirements one should know what these requirements are. In case the requirements remain unexpressed the clients' needs behind these requirements should be captured. Kiviniemi (2005) did some empirical studies in his PhD work at Stanford to find out how the requirements can be traced in the building process. In his interview the replies were "it would be very laborious task to go through the meeting minutes trying to find out the requirements for any specific space or building element" or "the only documents where this could be found are the meeting minutes, but they don't cover all issues". In other words, the requirements are not often documented in the form of requirements. Instead, technical solutions are documented and their conformity is assessed instead of validating the solutions against performance requirements, or original user needs. One approach to meet client requirements is the performance concept.

2.2 Managing the conformity of technical solutions in the building process

Gielingh (1988) defined a General AEC Reference Model (GARM) showing the building process as series of "hamburgers" where performance requirements (FC) are met by technical solutions (SC). The technical solutions, in return, are interpreted as performance requirements at a lower level, and met by more detailed technical solutions. The process continues into a lowest needed level, and conformity should be validated in every phase. This approach should lead to meeting client requirements as long as they have been successfully captured. The solutions that don't meet the requirements can also be accepted if so desired but that decision should be made knowingly, and requirements then changed accordingly. It is important to communicate the consequences of such a decision to the client, since from that on the original requirements aren't valid any longer. Spekkink (2005) has presented the old GARM model twenty years later in a slightly improved form (at right of the figure below).

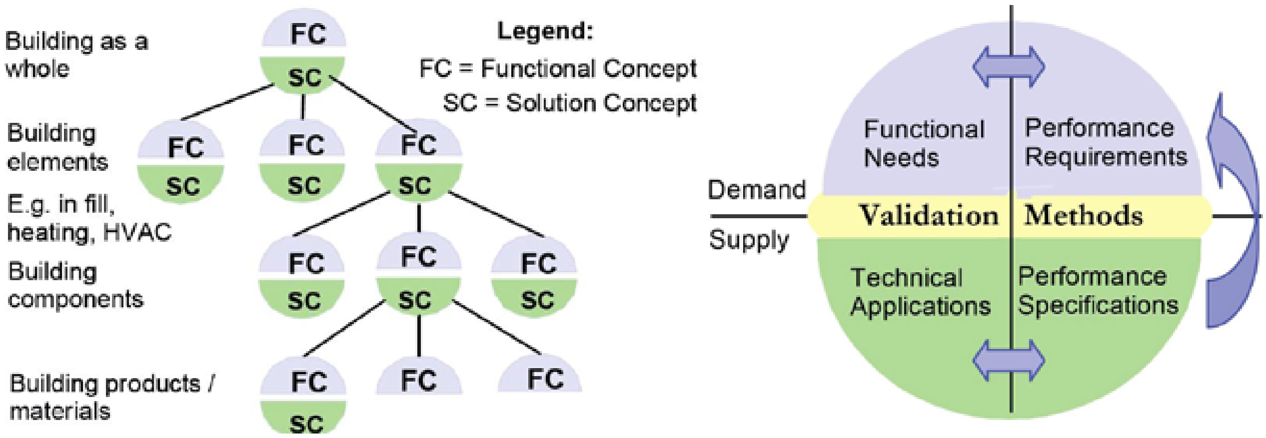


Figure 1 Technical solutions meet performance requirements in a continuous process, and the conformity should be validated in every phase.

2.3 Performance management methods and tools

Various standards and check lists have been developed to help identifying performance requirements and their validation, such as

- ISO6241 Performance Standards for Buildings (1984)
- different versions of CIB Master lists (1964, 1972, 1983, 1993)
- the CIB Compendium of Performance Based Building Models
- Standards on Whole Building Functionality and Serviceability (ASTM 2000)
- FiSIAQ (2001) Classification of Indoor Climate
- ASHRAE (2005) the Commissioning Process.

Different tools that support systematic performance management have been described e.g. in Huovila (2005).

Lützkendorf et al. (2005) surveyed performance tools, standards, checklists and sets of instruments and indicated in which areas they can be best applied. It is worthwhile noticing that these instruments have often been developed for a specific use at first, with more functions and applications pursued later.

Application / Instruments / Tools	A: Performance Requirements[A]	B: Performance Measurement[B] New Build.	B: Existing Build.	C: Performance Assessment[C]	D: Performance Communication[D] Non-rated	D: Rated
1a. Codes and Regulations[a]	Building Decree[1]					
	CPD (93/68/EEC)[2]					
1b. Standards[b]	ASTM standards[3]					
		NOPA M/S[4]				
2. Checklists / guide lines	Healthy Office[5]					
	SIA 112/1[6]					
	Guideline SusCon.[7]					
3. Calculations / algorithms[c]		LCA-Tools[8]				
		LCC-Tools[9]				
			SAP 2001[10]			
4. Measurements[d]			Accounts[11]			
5. Questionnaires[e]			CBE (IEQ)[12]			
	DQI[13]					
6. Building descript./passport[f]					Build. File[14]	
7. Labels / Certificates				ECOHomes[15]		
8. Integrated Tools[g]		EcoProP[16]				
		LEGEP[17]				

Index: fully applicable | partly applicable | not applicable

Figure 2 Typology of selected performance instruments and tools. (Lützkendorf et al. 2005)

One of those integrated performance management tools, EcoProP, contains a pre-set database using the VTT ProP® classification. It differentiates the output (value, performance, quality) and input (cost impacts and environmental impacts). The numerator contains location specific and building performance specific aspects separately. A similar approach with building environmental quality and performance vs. building performance loadings has been adapted in CASBEE, the Japanese assessment tool as shown below.

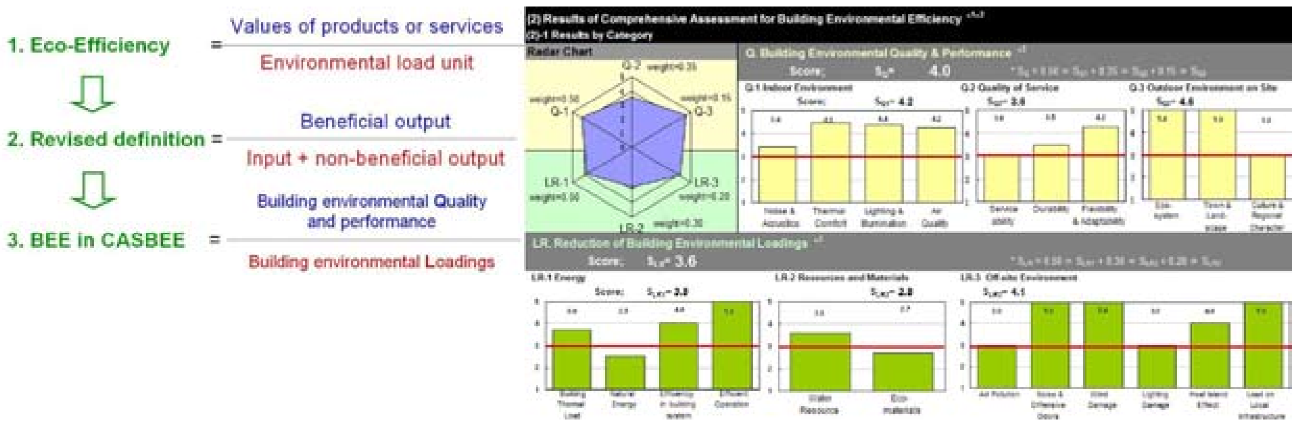


Figure 3 CASBEE environmental rating tool. (Iwamura 2005)

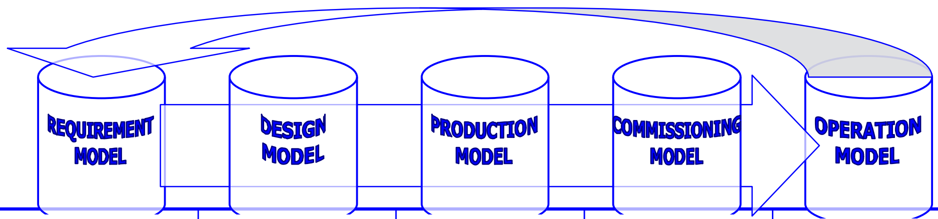
2.4 Requirements model and other Building Information Models

Karud (2007) concluded in STAND-INN that the IFC and use of BIM have great potential for value creation during the whole life of buildings at least in the following areas

1. Focus on customer and end-user requirements and sustainability within the building process and life cycle phases
2. Increasing transparency in the decision-making process and re-engineering the building process with new business opportunities for new and existing actors
3. Cost saving to all actors and a better project economy

4. Improved possibilities for early stage analysis about: best practice design, construction cost, energy consumptions, environmental impacts, lifecycle cost, performance in use, flexibility, adaptability, indoor climate, usability and maintainability
5. A comprehensive and common international knowledge model database with standardized ICT tools, objects and communication rules and available best practices examples.

The following figure tries to illustrate some of these value aspects with the focus on two first ones: end-user requirements, and transparency in decision-making. The content is shortly represented in different phases of the building process. Even though the BIMs are depicted here as separate models, it must be noted that the information exchange standard ensures the interoperability between different information models. In practice, some of these models may be as one model.



	REQUIRED	DESIGNED	CONSTRUCTED	DELIVERED	ACHIEVED
PERFORMANCE IN USE	• user requirements • desired performance in use	• designed technical solutions • estimated performance	• constructed building	• validated conformity	• user satisfaction • performance in use
ENVIRONMENTAL IMPACTS	• targeted environmental impacts over the life cycle	• estimated environmental impacts over the life cycle	• environmental impacts during construction	• estimated environmental impacts in use	• environmental impacts of building and its use
ECONOMIC IMPACTS	• targeted whole life costs • targeted business impacts and value of the facility	• estimated whole life costs	• construction costs	• estimated running costs	• running, maintenance and refurbishment costs, recycling, reuse, demolition and waste disposal costs • value of facility
OTHER	• targeted social, cultural and institutional impacts		• construction safety • construction ethics		• social impacts in the neighbourhood • impacts to cultural heritage

Figure 4 Building Information Models.

Hyvärinen states (in Huovila et al. 2007) that the IFC specification IFC2x3 includes a generic mechanism for expressing requirements as controls (IfcControl), or constraints (IfcConstraint), or merely as property sets. Some explicit entity type and property set definitions exist for requirements capture: e.g. for most typical building space (programming) requirements there is the IfcSpaceProgram entity type (subtype of IfcControl) and its associated Pset_SpaceProgramCommon, as well as a number of property sets directly associated to spaces (IfcSpace or IfcZone), e.g. Pset_SpaceThermalRequirements. However, in general there are no comprehensive and consistent sets of performance indicators organised in accordance to standard building performance classifications (e.g. indoor climate parameters as listed earlier). IFC software support for requirements management is still at an experimental phase.

3. Sustainability over life cycle

3.1 Environmental impacts

Different approaches are applied to manage the environmental impacts of buildings. Häkkinen describes the following ones (in Huovila et al. 2007)

- Life Cycle Assessment for the environmental impacts (ISO 14040 2006)
- environmental declarations (ISO 14020 2000)
- standards for life-cycle management of buildings (CEN/TC350)
- national environmental assessment and classification methods for buildings and building products
- a framework for sustainability indicators of buildings (ISO/TS 21929 2006)
- standards and methods for service life management of buildings (ISO 15686 2006)
- standards for the management of energy efficiency.

A recent EC project Methodology Development towards a Label for Environmental, Social and Economic Buildings (LEnSE) was by the EC to develop a sustainability assessment framework. Its structure is shown in the following figure in three main categories. 36 of their 57 sub issues have been developed and tested on ten pilot buildings.

Figure 5 A sustainability assessment framework (LEnSE 2008).

At present the environmental rating seems to be a burning topic in Europe. In some cases the same buildings are assessed two, or even three times, because in an international market the applicability for a single national rating doesn't always seem to be sufficient.

3.2 Economic impacts

Pulakka (2005) states that life-cycle values are mainly caused by combination of location and most significant characteristics of the facility. Life-cycle economical, energy-saving, eco-efficient, healthy and social facilities are quite similar: durable enough and desirable with functional, change-flexible and unrestricted spaces as well as reliable, advantageous and undamaged systems and other products and materials.

RAE (1998) has published a paper on the long term costs of owning and using buildings. A key point in that paper is that buildings designed for the accommodation of people generating wealth, or people providing a service, must create and environment where people will give their best. The cost of ownership and maintenance of a building is typically about 3 % of the overall costs of the people working in the building.

3.3 Social, cultural and institutional impacts

Sustainable construction is often divided into three dimensions: environmental, economic and social. Sometimes the third category is called as social and cultural to emphasize the cultural heritage aspects of the built environment. When the international work on sustainable development indicators was started, four categories were used: environmental, economic, social and institutional. Over time, the institutional category has mainly been merged into the social one in the context of sustainable construction.

Social aspects in the built environment are much more in focus in the neighbourhood, or at a city level, than in individual buildings. There isn’t clear agreement where the health and safety issues belong to. The indoor climate aspects clearly belong to the building performance category. At the same time its impacts to human health are dealt as environmental loads in the building environmental rating tools. In city indicator systems, health is typically treated as a social element.

Social aspects are present in Corporate Social Responsibility (CSR) strategies by enterprises that may use triple bottomline (economic, environmental, social) reporting. Earlier, many companies published their environmental reports apart to the economic balance sheet. CSR combines separate reports into one. Sustainability Reporting Guidelines is an example of such a system providing a structure also to social aspects that may be relevant to sustainable construction (GRI, 2006).

4. STAND-INN Case studies

4.1 Good practice examples of innovative sustainable housing

STAND-INN D9 collected seventeen good practice examples of innovative sustainable housing from eight countries. They demonstrated the rich nature of innovative sustainable housing from different perspectives covering

- climatic and cultural regions from North to South and Central of Europe
- both new construction and refurbishment
- detached houses and blocks of flats
- individual buildings and neighbourhood scale development
- various forms of ownership: rented flats and owner occupied or tenant right dwellings
- types of sustainability standards as defined in this context (ISO/CEN, guidelines, concepts, tools etc.)
- time scales from ongoing or recently completed projects to the development in the 1990s representing also older technologies
- different aspects to improve end product performance, to minimize environmental impacts and to encourage economic, social and cultural progress.

The objective was to study the use of sustainability standards in those cases. In addition to some ISO or CEN standards, mainly voluntary guidelines (FiSIAQ, IEA Task 13), concepts (Passive House, Zero Carbon) and tools (Ecoprofile, HQE, LiderA, PromisE) were included in the compilation. Thus a broader sample was obtained to complete the picture of endeavours towards innovative sustainable housing. Those good examples were viewed in three main categories that contained each at least five examples from three countries. The categories were detached houses, blocks of flats and groups of buildings, and mixed development, refurbishment, neighbourhood scale and process issues.

The selected examples showed successfully realized features of innovative sustainable housing that address these categories. Considerable improvement was justified in detached houses by implementing the state-of-the-art technologies. The development motivation in those examples varied from private interest of individual experts (architects or thermal designers becoming future owners and users of these houses) to publicity (housing fair, IEA showcase). Reported obstacles did not relate that much with standardization issues. Instead, lack of craftsmanship amongst professionals and resistance to change the traditional way of doing things were mentioned as hindrance. Also in blocks of flats, considerable progress was achieved that reduced environmental impacts and simultaneously enhanced the indoor performance of flats. Measured results of 70 % reduction in space heating (with only 1,7 % increase in construction costs and estimated 5 to 7 years pay back time) and 50 % reduction of total energy use (and 4 % additional building costs with 10 to 12 years pay back time) were obtained.

Neighbourhood development examples raised the importance of social issues as part of the sustainability concept. Sustainable process contained, in addition to resource management, also participatory aspects and focused diversity and integration of the inhabitants. Besides meeting the environmental sustainability objectives the successful cases were reported to be beneficial both to the developers and buyers. Improved comfort level can be seen as a positive side effect of meeting ambitious environmental targets. Some cases influenced in further development of the guidelines, concepts or rating tools, which were considered as "standards" in those good examples.

These case studies show that individual examples of innovative sustainable housing have been successfully realized in many European countries using existing knowledge, tools, standards and guidelines. Since the built environment is the major contributor to sustainability, in addition to occasional showcases, the mainstream practice in housing design, construction, refurbishment, operation and maintenance should be transformed into a sustainable path. Relevant standards and building information models provide a natural vehicle to strive towards that objective which should be beneficial to all, especially the future generations.

4.2 Building Information Models applied by Senate Properties

Senate Properties' is an advanced building owner whose product modeling requirements in 2007 provide an example of technical aspects of the use of IFC. Senate Properties has carried out a number of pilot projects since 2001 to develop and study the use of product models. Based on feedback from these, they have assessed product model technology to be sufficiently ready for putting to use in ordinary project work, and the company decided to require models meeting the IFC standard in its projects as of 1 October 2007.

The modeling of projects is not an end in itself. Instead, its main aim is to ensure that the scope, cost and practicality of the project conform to the objectives. In the first phase, models are required in ordinary projects and only for some of the design jobs of the project. The modeling requirement applies both to construction and to renovation projects. The only projects excluded are those for which no significant advantages are seen in modeling. In the first stage, tens of projects will be modeled, the total volume of which is estimated at hundreds of millions of euros.

The obligatory part is limited to modeling and visualization of the starting scenario and architectural design as well as to the monitoring of the scope and costs performed on the basis of the models. In the architectural design, modeling will be applied throughout the process, starting with the presentation of alternatives based on space models and ending with the tender documents for the contracting stage. In the project planning stage, the main emphasis for modeling will be on supporting the investment decision by comparing alternatives' scope, costs and lifecycle attributes. To facilitate cost control, type data in conformity with the room schedule for spaces will be added to the model. The quantity and scope data obtained from the model in the draft stage will be used to support the production of the building element estimate. Efforts will be made to secure the energy budget of properties by simulating the building's energy consumption before major decisions and by harnessing these results in monitoring the energy consumption of the building during its occupation stage. Efforts will be made to model structural and HEPAC systems in the detail design stage, but the requirement for these models will be decided on a case-by-case basis. The use and data content of the models will be binding requirements in design agreements.

The level of modeling required from 1 October 2007 is just the first step in going over to the broader use of models. Senate Properties will develop modeling requirements together with property owners in the Nordic countries, the USA and the Netherlands. The aim is to go over to all-embracing, integrated model-based operations in designing, building, and property servicing and maintenance in the next few years.

Senate Properties' modeling guidelines specify the data content requirements for models to the participants in the project at each stage of the design. The guidelines comply with the main lines applied to decisions to be made in Senate Properties' investment process. In the first phase, all design software packages which have passed IFC 2x3 certification may be used for modeling.

4.3 Value creation in VTT's Digitalo owned by Senate Properties

VTT's goal is to provide modern work spaces that support interactive collaboration and innovative ways of working for its employees. Digitalo is an example of systematic requirements management procedure where an active end user strives towards an optimum value in the process.

According to Senior Vice President Jyrki Kalavainen at VTT Real Estates

- instead of defining needed room spaces, it is important to identify the user needs with help of understanding the ways of working

- in Digitalo project, VTT wanted the representatives of the real users of the building to be involved in the process from the very beginning
- the process started with studying the ways of working of the planned users of the building and the distribution of working time between different kinds of tasks
- the architectural and real estate consultancy company Evata defined alternative concepts for the spaces based on identified user needs
- the needs for spaces that support interactive ways of working were emphasized by VTT
- on the basis of the process, VTT and Senate Properties were able to formulate a building plan, which does not fix the room spaces but describes the needed quality of the spaces. In addition, requirements were also set to energy-efficiency and life-cycle management of the building
- continuous management of efficient use of spaces and space costs was monitored and various situations could be affected.

VTT’s strategic goals were taken as a starting point for the design of Digitalo. VTT's strategy characterizes VTT as a technology intensive innovation organization. The primary objective is to strengthen interactive ways of working and to promote innovation processes. Interaction is believed to improve communication and transfer of tacit knowledge. The efficient use of ICT is in central role. The desired ways of working can be characterized with the help of four areas of strength: cooperation, knowledge, creativity, and efficiency.

The project sought to create a modern work space in an office building that supports interactive and innovative ways of working, communicates VTT's brand and image as a high-end technology solution provider, and is in accordance with sustainable building principles, especially in terms of energy-efficiency and life-cycle costs, adaptability, indoor conditions and service life.

Senate Properties see the benefits of the use of BIM as follows

- improved management of investment costs (especially the extent of design based on space models and space group models)
- better focus on life cycle costs (in addition to investment costs)
- validating the conformity of performance objectives
- amelioration of communication especially towards the customer, and between the design team
- in addition to management of the performance of the building, monitoring of environmental impacts will become extremely important (e.g. energy consumption will be simulated in modeling and measured and followed-up in use)
- early analysis of alternative solutions aims at an overall optimal solution in regard with all objectives.

The first steps are to model architectural design. Models in other domains will be decided case specifically. Along with time, increased interest and improved skills will most likely lead into a state where all actors volunteer to work with BIMs without request.

5. Conclusions

The policy and process related problems connected with the efficient implementation of sustainable building technologies affiliate also with the deficiency of business models of the sector. The building and real estate sector has acknowledged the importance of customer orientation, but this does really affect the business processes. Eco-efficient building calls for demanding and conscious customers, functioning value chains and capabilities to make use of sustainable building knowledge in marketing and efforts of exportation. Effective business models of sustainable building from the viewpoints of demand, value chains and competitiveness should be investigated and analyzed. The problem is also related to the possibilities and importance of business image and brand building.

Although the level of knowledge of sustainable building technologies is high in some European countries, this knowledge is diverged into separate solutions of materials, products, building services and methods of information management. In order to proceed we should develop

- ways to capture and formalize end-user needs and tools for requirement management
- integrated design methods, tools and practices
- comprehensive concepts of eco-efficient building (e.g. local/national Passive Houses)
- interoperable Building Information Models to cover the whole life cycle.

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SUSTAINABLE BUILDING AND BIM

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Keywords: sustainable building, building information modelling, information management, environmental assessment tools

Summary

Aspects of sustainable building include the aspects of building performance, environmental, economic, and social impacts. Sustainable design and life cycle (LC) management of buildings need new type of information compared to traditional building processes. Because of the abundance of required information, efficient information-technological solutions are needed. Building Information Modelling (BIM) is becoming momentous in AEC industry and real estate sector to share and exchange information among stakeholders, and the use of BIM is currently emerging around the world. BIM should also be able to support the supply, integration and management of information throughout the building LC. LC information can be given in terms of product data and different kinds of assessment and simulation models. With help of this information, aspects of energy, indoor environment, environmental impacts, LC costs and service life should be able to be considered in design and maintenance. BIM in its different stages should be provided with all initial information that is needed in the implementation of LC methods. Additionally, the results of assessments should be integrated with the different stages of BIMs in terms of indicators and guidelines. The paper discusses some of the problems of integrating LC information with BIM and highlights the expected benefits.

1. Sustainable building

According ISO TS 21929 (ISO 2006a), sustainable construction brings about the required performance with the least unfavourable environmental impact, while encouraging economic, social and cultural improvement at a local, regional and global level. The concept of sustainable building is wide. As summarised by Shelborn et al. (2006), one of the key issues in making construction projects more sustainable is overcoming the obstacles of capturing and managing the knowledge needed by project teams to affect such change. There is still a need for a structured approach for the implementation of sustainability practices and methods within construction projects. Indicators, checklists and assessment tools for sustainability in construction are available, but these do not provide a comprehensive solution.

Design tools for sustainable building should be able to simultaneously address a number of performance aspects and integrate the information into the design environment. Kohler and Lützkendorf (2002) mention six criteria for integrated building life-cycle assessment: 1) adaptability to building life cycles, different actors and decision levels, 2) adaptability to different types of impacts, 3) consideration of absolute and relative targets, 4) relying on explicit physical framework, 5) linkage of needed data with normal professional working environment, 6) scaling of needed data with process phases and availability of accurate information.

An important approach to seek solutions for the problems of sustainable building is with help of information management, and there integrated Building Information Modelling (BIM) offers a potential. The scope of this paper is to study the management of sustainable building with help of BIM from the view point of:

- Assessment of environmental impacts
- Assessment of energy consumption
- Service life design
- Maintenance manual
- Optimization of building refurbishment
- Sustainability rating of buildings

The starting point for this paper is that life cycle assessment methods and sustainability indicators are able to support sustainable building and construction in requirement setting and design for required performance and life cycle. Sustainable building assessment methods are believed to support sustainable building, because those enable the comparison of alternative solutions and thus enable the consideration of sustainability aspects in decision making. However, the use of these methods in building planning and in design for sustainable buildings is problematic, because a lot of data is needed in order to be able to assess alternative solutions. Thus the assessment is often done only for the final solution instead of collecting data for design options. Design for sustainable buildings needs integrated methods which should provide the process with easy-to-use and comprehensive product information and integrated calculation and simulation facilities that enable the comparison of design options and the effect of changes automatically or with reasonable extra work (Häkkinen & Pulakka 2007).

Furthermore, even more problematic is to understand, how sustainability aspects could be considered already in the preliminary planning process where decisive decisions are already done. It would be important to integrate environmental indicators and data to the design process in order to rationalise assessment and thus also to support planning and design for sustainable building. The premise of this paper is that this can be done with help of BIM.

Integrated building information modelling is becoming very important in AEC industry and real estate sector and the use of BIM is currently emerging around the world (GSA 2007, NBIMS 2007, Senate Properties 2007, Statsbygg 2007).

2. Building Information Models

BIM denotes the creation and use of coordinated, consistent, computable information about a building project during design, construction and building operation and management. BIM can also be defined as the collection of objects that describe a building (Lima and Hans 2007). Software applications of BIM work with 'objects', which represent all elements of building construction including physical components, spaces, processes, actors involved, and relationships between these objects. In most cases the complete design information of a building consists of several domain specific design BIMs, such as architectural, structural. HVAC, and electrical BIM. Integrated BIM is a combination of these individual BIMs. In this paper the term BIM is used to describe the integrated BIM; total repository of all BIMs containing the information of a building. BIM covers not only geometry, spatial relationships and geographic information and quantities, but also properties of building components. Quantities and shared properties of materials can be extracted. It can be used as the source of information for the analyses of the solution as well as to store the results of analyses. BIM can be used to represent the entire life cycle of the building including the processes of construction and facility operation.

Because of enabling the sharing of information and because of working with objects, BIM could significantly support the management of information needed in design for sustainable building. Important questions are how to integrate and what is the degree of linkage or inclusion of different data bases and tools with domain specific BIMs. In most cases, the BIM should offer a framework and the source of information concerning the design solution, while the specific assessment and simulation models and the needed background data (for example the environmental data of products) are not embedded but linked with help of identities and interfaces (Häkkinen 2007).

The usage of BIM in sustainable building and construction depends on the implementation of BIM and this varies in different countries. The Finnish Senate Properties is one of the forerunners in mobilizing BIM, and this paper refers to the guidelines "BIM Requirements 2007 in different phases of the design and construction process" adopted by Senate Properties. The guidelines have been formulated by Kiviniemi et al. (2007). Senate Properties is a government owned enterprise that is responsible for managing the Finnish state's property assets and for letting premises. The building stock comprises university, office, research, cultural and other buildings (Senate Properties 2008).

According to the Senate Properties guidelines, the different phases of construction projects and related BIMs are the following:

- Analysis of needs and objectives
  Requirement model: Project requirements and requirements of the authorities
- Design of alternatives
  Alternative mass and spatial models
- Early design
  Architectural model, structural model, HVAC model, Electrical model
- Detailed design
  Architectural model, structural model, HVAC model, Electrical model
- Bidding phase
  Approved detailed design and Construction model
- Construction and commissioning
  Construction model and As-built model
- Facility management and maintenance
  Maintenance model

3. Sustainable building standardisation

Standardisation of sustainable building methodologies is necessary in order to integrate sustainable building aspects with BIM processes. It is necessary to standardise the definitions and semantics of this information.

The general principles on life cycle assessment of products and services have been agreed upon and made public with help of ISO standardization. In addition to general methodologies, applied methods for building products are being standardized by ISO. There is also a European process going on, which aims at the development of harmonized life-cycle standards for buildings and building products. ISO TC 59 SC 17 "sustainability in building construction" is working on several documents:

- IS0 CD 15932-2 General Principles;
- IS0/PTR 21932 Terminology;
- IS0 /TS 21929-1Sustainability indicators Part 1: framework for the development of indicators for buildings;
- ISO DIS 21930 Environmental declarations of building products; and
- ISO DTS 21931-1 Environmental performance of construction works Part 1- Buildings.

ISO has also leaded the process of developing standards for service life planning. ISO 15686-1 (ISO 2000), ISO 15686-2 (ISO 2001) and ISO/DIS 15686-8.2 (ISO 2006b) give general principles for service life planning, describe service life prediction procedures and give guidelines for reference service life. Standard ISO 15686-1 presents a basic methodology in the area of service life design, but the methodology requires considerable knowledge about the age and degradation of components and materials.

From the view point of information management, the above mentioned standards rather work with principle methodologies. In order to enable integration of sustainable building methodologies with BIM, the definitions of information contents should be further developed. Also the specifications for data representations that have exact representation syntax which could be made use by software are missing.

Sustainability in construction is also studied at European level within the CEN TC 350 "Sustainability of construction work". This TC deals with the aspects of sustainability at the levels of products and buildings. Aspects especially considered include environment, health and comfort, and life cycle cost. CEN/TC 350 will develop voluntary horizontal standardised methods for the assessment of the environmental performance of new and existing buildings and for the environmental product declaration of construction products, in the framework of the integrated performance of buildings. The becoming standards will be relevant for the assessment of buildings over its life cycle. The results from the standards mandated by the M/330 (energy performance directive) will be integrated into the assessment of the environmental performance of buildings in the framework of integrated performance of buildings.

On the basis of the EC standardisation mandate M/330 EN CEN is developing methodologies for the calculation of the energy uses and losses for heating and cooling, ventilation, domestic hot water, lighting, natural lighting, passive solar systems, passive cooling, position and orientation, automation and controls of buildings, and auxiliary installations necessary for maintaining a comfortable indoor environment of buildings.

4. IFC

IFCs (abbreviation is originally based on the terms Industry Foundation Classes) aim at providing an open definition for data structures to capture and exchange information (IFC 2007). The development, maintenance and implementation of IFC include to the purposes of the buildingSMART initiative of the International Alliance for Interoperability (IAI). The purpose of IFC within buildingSMART is "enabling interoperability between AEC/FM software applications" (International Council of the IAI in November 2006). IFCs express common agreements on the content, structure and constraints of information to be shared and exchanged by several participants in construction and facility management projects using different software applications. The result is a single, integrated schema representing the common exchange requirements among software applications used in construction and facility management processes (Lima and Hans 2007).

Although sustainable building related information has not yet been agreed on the level of IFCs, the use of BIM could strengthen and rationalize the management of sustainable building. IFC incorporates a mechanism called Property Sets which allows information publisher to allocate new properties to an object. This enables IFC to be used for representing also product specific information. For example the environmental assessment of a design solution can be supported with help of BIM by attaching environmental information to BIM objects (defined by IFCs) via the Property set mechanism or simply with linking the object to external data bases, whereas the existing sustainability standards can be made use of. This is further discussed in sections 5.3 and 5.4.

5. Integration of sustainable building tasks with BIMs

5.1 Introduction

There are different solutions for integrating life-cycle analysis software and BIM. These include separate software solutions that are able to use file exchange with BIM or that can be integrated with a BIM server using a specific API. The analysis software can then have its own library for those pieces of information that are not included in BIM. The analysis software could also be implemented by programming new functionality to BIM software. An intermediate solution for these is the integration with help of parametric formats (e.g. GDL) that allow representing not only product information but also calculations used in analyses (Siltanen et al. 2008). This paper deals with the needed contents of product information assuming that a separate software solution connected to BIM is the most likely in terms of easiness to realise and use. VTT has also developed a prototype software solution which uses design information represented by IFC together with separate product information represented in PMO ontology and calculates environmental results by combining the effects of different building elements (Siltanen et al. 2008).

5.2 Service life design

Service life design needs information about the age behaviour of building elements and components. As defined by ISO 15686, this is information about the effect of different parameters on service life; these parameters include for example the quality of workmanship, quality of materials, building structure and details, environmental conditions, user conditions and quality of care and maintenance.

Service life prediction methods have been developed for construction products which are exposed to weather conditions (for example Shohet et al. (2002) and ENNUS (2006)). There is a growing awareness worldwide about the importance of the maintenance of constructed facilities as shown by Shohet et al. (2002) and about the significance of maintenance from the view point of sustainable building as summarised by Häkkinen, Vesikari and Pulakka (2007). One of the most important parameters affecting the efficiency of maintenance management is the precision and the reliability of the predicted service life of building components.

ENNUS®-programmes support service life assessment of building structures (Nilsson, Vares and Vesikari 2007). The programmes help designers to determine parameters that affect the service life of a building structure and to predict service life in accordance with the factor method presented in ISO 15686-1. These parameters include materials, details, assembling, outdoor and indoor conditions, use conditions, and care and maintenance.

Service life assessment methods support the design for required service life the better the more simultaneously the assessment can be done with the very design process. This can be supported by BIM. When integrating service life assessment with BIM, the initial data needed for defining the values of parameters should be available through the properties of the model or with help of integrated databases. Part of the needed data could be made available with help of an integrated database; this may concern for example material properties. However, also the design solution itself affects service life. Thus for example the structural model should include all information about the quality of structures that is needed as initial information for the service life assessment of structures. The structural model software should support the designer to define the structural parameters needed in the assessment of service life.

The assessment software itself can remain a separate tool that is compatible with the model. The interfaces can be made by converting native data formats into IFC representations. In the case of ENNUS® software described in (Häkkinen and Vares 2007) the integration of the ENNUS® tool with BIM was done by converting XML file produced by standard Excel methods to IFC (Fig. 1 and 2). The results of the assessment for different building parts and systems should be imported as service life indicators to BIM. The formats of information should follow the definitions given in standards dealing with service life planning. Even applications using relatively simple data structures (e.g., service life assessment tool ENNUS is a simple Excel spreadsheet) benefit from the ability to utilise BIM. BIM can be used in this case for transferring data between life cycle phases, as well as getting initial information from the building information model.

5.3 Environmental assessment

The basic principles and declaration formats of environmental assessment in terms of LCI or LCA have been agreed upon with help of standardisation processes. The environmental standards provide the needed definitions for the contents of environmental information. The building level assessment can be done by summing up the product level environmental profiles and by considering the bill of quantities.

Information needed from BIM includes data about properties and quantities of different components and elements. In order to make the environmental assessment for a design or for a part of a design, this information should be linked to a database that includes the environmental profiles of building components and elements. The environmental assessment of a building can be integrated to BIM similarly as cost assessment is already done at present. The integration requires that product specific and energy related environmental profiles are available, for example, in the form of an XML database.

The final result from assessment should be enclosed as environmental impact indicators to BIM (design model). According to ISO TS 21929 an environmental indicator of a building addresses an environmental aspect either in terms of loadings or impacts. Environmental loadings are the use of resources and the production of waste, odours, noise and harmful emissions to land, water and air.

Different kind of environmental information is needed in different stages of the process. During the design phase relevant generic environmental information should be available. This information should describe the average environmental performance of products without being producer specific information. Generic information should be replaced by product and producer specific information in building construction phase, when the contractor wants to analyse the importance of individual product choices and store the environmental indicators to the as-built model.

Environmental information may also include instructions for the building use and final disposal. This includes information about indoor emissions of building products and instructions for recycling. The integration of this information with BIM can be dealt with similarly as the care and maintenance information presented in section 5.5.

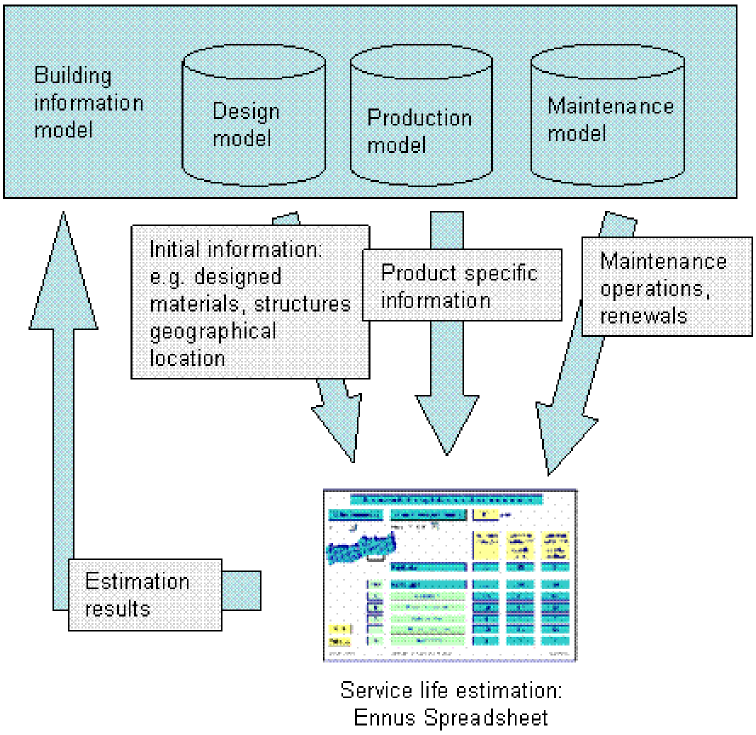

Figure 1 Information flows between ENNUS Spreadsheet and BIM.

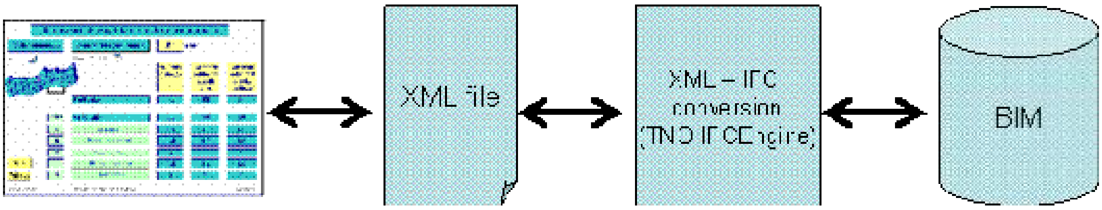

Figure 2 Implementation of the interface between building information models and ENNUS.

5.4 Energy consumption estimate

The initial data needed in design for energy efficiency includes information about local environmental conditions, technical performance and capacity of building elements and HVAC units and systems, position of the building in the building lot, spaces, arrangement of spaces, and intended user profiles. Depending on the complexity of the design and the needed level of accuracy of the assessment, the amount of data needed may be extensive.

Different kinds of assessment and simulation methods and tools are available for the assessment of energy consumption of buildings. In order to enable the energy consumption assessment with help of BIM, 1) the model should provide all data needed in the calculations and 2) there should be a suitable interface between the model and the assessment software.

The product related information needed in calculations does not need to be included in the model (as attribute data of objects) but it can be integrated data collected into a compatible database and linked with the model. Probably the best solution is that the assessment is not done within the model but with help of a software solution that is compatible with the model. The results of the assessment should be imported as energy-efficiency indicators of the design model and correspondingly later as indicators of the later stages of BIM. These indicators should follow the formats and expressions (units etc.) agreed upon in standardisation.

Similar conclusions have also been done by Morrissey et al (2004) when they analyse the assessment of building performance within BIM. Analysis will be achieved by querying an archive of performance objectives and performance metrics that are programmed within the BIM. Once the user has selected the performance metrics, a critical analysis may be preformed for all related design decisions and management operations. This leads to large sets of data that must be elicited at various stages and from various sources. Storage in a single IFC database would lead to a model that would be oversized and unmanageable. Performance metric data should be separated from the main model with storage occurring in XML files. The XML files should be referenced within the BIM and their associated sets of data may be elicited from a database in order to analyse the performance of the building.

5.5 Maintenance manual

Building maintenance needs system-specifically grouped and scheduled information of all care and maintenance measures. This information should be given in terms of recommendations and instructions and formulated during design and construction. For example the Finnish building regulations require the provision of care and maintenance information in all significant building projects. In order to support maintenance management, this information should also be updated during the use and maintenance phases of the building.

Building refurbishment needs information on realised building solutions and information about the requirements concerning the handling and treatment of products to be demolished, surface treated etc. When the optimum maintenance and refurbishment processes (both in terms of quality of measures and scheduling of those measures) are sought, same kind of information about the age behaviour of different building elements is needed as within service-life design. Additionally, information about costs of alternative measures is required.

VTT have proposed simple methods for sharing and integrating product-specific instructions-type-of-information with BIM (Siltanen in Häkkinen et al. 2004 and Heinonen in Häkkinen et all. 2007). A framework for a web browser (Fig. 3) based database was created where manufacturers can store all product specific service life information. The service life information was defined with using XML description language.

The project suggested that the process could operate in such a way that the concept-developer requires all the suppliers of the concept to include service life information into the database with help of which the compiler of the maintenance information collects and arranges the building information to form an organised and scheduled product information set for care and maintenance. The maintenance model should be provided with methods and tools with help of which product specific maintenance information can be arranged and collected as building system specific information. The contents of this information should enable the effective implementation of maintenance considering the different periods and types of inspections, care, repair and renewals.

Figure 3 LifePlan database system.

5.6 Optimization on building refurbishment

Especially the managers of municipal and state infrastructure are realising the need for effective tools to manage the large asset base. Decision support tools are needed in order to support understanding and decisions on its value, condition, remaining service life, needed maintenance and optimal scheduling of operations. For example Söderqvist and Vesikari (2006), Bucher and Frangopol (2006) and Vanier (2001) have introduced methods for the optimisation of lifetime maintenance of buildings. MaintenanceMan is a tool, which supports the optimization of building refurbishment measures (Vesikari 2008). The tool uses service life models with help of which it is possible to predict the service life of the modules. The tool allows studies at different risk levels. The optimization criteria are life cycle costs (LCC) and environmental impacts. MaintenaceMan works on modular basis so that the building is divided into structural parts or modules.

In order to rationalize the use of these kinds of tools in the design of refurbishment options, the maintenance model should include the needed initial data, and correspondingly the design model software and the construction model software should support the designers to provide all needed initial data to the model. This includes information about materials, structures and environmental conditions. Additionally, the maintenance model should support the maintenance managers to update this information. The optimization also needs information about LCCs. This should be available through a separate integrated database, because it is both product specific and user specific information. If the results of optimization (the favourable maintenance and refurbishment strategies and their life cycle costs) were wished to be used as guidelines for future measures, this information should be imported to the maintenance model.

5.7 Sustainable building rating systems and their relation to BIM

Sustainable building rating systems have been developed in international cooperation and nationally in a number of countries all over the world. The majority of the existing environmental assessment methods of buildings evaluate environmental performance of buildings relative to explicitly declared or implicit benchmarks (Cole 2005). Typically, the environmental performance is described with help of indicators which try to express both the environmental impacts as well as other performance aspects such as indoor conditions. Methods which are widely well-known are for example the BREEAM (2008) (UK), LEED (2008) (USA) and GB Tool (Kimberly et al. 2006). The point of view has gradually widened from sole environmental assessment to overall assessment of sustainability aspects of buildings.

LCI/LCA approaches are partly being adopted into the environmental rating systems (for example in the German (Schminke 2008), Finnish (PromisE 2008) and Australian systems (GREEN STAR 2008)) to deal with the environmental impacts of buildings. However, the overall sustainability of a building does not only depend on the direct environmental loadings induced by the building and its use, but also on the quality of the building as a place to live and work, accessibility and interface with surroundings, quality of process (for example the participation of all concerned, probability of non-desired risks).

The potential of rating systems to support sustainable building design and sustainable refurbishment of buildings would be improved, if the systems were integrated with BIMs. This would require that the BIM processes supported the determination of the building specific values for the indicators and calculation of the final results with reference to given benchmarks. With regard to LCI/LCA related indicators and indicators that are based on the characteristics of building products and energy-efficiency indicators, the determination of indicators' values can be based on the principles described in sections 5.3 and 5.4. However, with regard to some indicators - like accessibility, adaptability - the development of a specific model-checking software solution might be the best solution.

6. Conclusions

Tools of LCI/LCA assessment, energy consumption assessment, service life assessment, maintenance manual, optimization of refurbishment and sustainability rating are important methods in design for sustainable buildings and in sustainable use and refurbishment of buildings. The use of these methods requires the availability of tools and a lot of additional information compared to a traditional building process. In order to rationalize the use of these methods and to support the use of methods during the design processes, the methods should be integrated with BIM processes. This paper describes the data contents related to different assessment methods and discusses the principal solutions how to integrate the methods and the required data with BIM in the different stages of building process.

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AN EVALUATION OF THE EFFECTIVENESS OF THE GREEN BUILDING PERFORMANCE TOOL IN SINGAPORE

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Summary

Construction has been accused of causing environmental problems through excessive consumption of global resources from building and construction activities. There have been research on green building design and green materials to minimize environmental impacts. Rating tools such as the BREEAM in the UK, the LEED in the US and the GreenStar in Australia allow for benchmarking and rating building performance in energy efficiency to promote sustainable development and reduce greenhouse gas emissions. In Singapore the Green Mark assessment scheme was introduced in January 2005 by the Building and Construction Authority. It is a government initiative to promote environmental sustainability in buildings in Singapore. It was initially a voluntary programme for new and existing buildings but was made mandatory on 15 April 2008. This paper discusses the introduction of the scheme as the first government-implemented environmental assessment scheme in Singapore. This paper is based on an online questionnaire survey undertaken in January 2008 to examine the impact of the scheme in the construction industry since its introduction. It also provides an overview of the principles of the scheme in enhancing sustainability awareness in construction and presents the survey results, recommendations and direction for future research.

1. Introduction

Building, together with the transport sector, are the key industries in most countries with the greatest impact on urban environment (Ng & Hirota, 2007) and environmental building assessment methods are growing in importance in improving sustainability of the built environment (Ding, 2008). Eliminating or reducing environmental impacts through design of environmentally certified buildings is the primary purpose of building assessment tools (Chau et al., 2000; Seo et al., 2005; Ding, 2008). Secondly, it aims at providing the means for stakeholders to make property investment decisions based on environmental performance of buildings (Shiers, 2000; von Paumgartten, 2003). Finally, it aims to achieve the goal of improving quality of life for building occupants (Ding, 2005; Ha¨kkinen & Nuutinen, 2007).

In January 2005, the Singapore government, through the Building and Construction Authority (BCA), made a commitment to reduce environmental impacts by introducing the Green Mark assessment scheme. It is an initiative to guide the construction industry to move towards more environmentally friendly buildings. So far, over 60 buildings have received Green Mark certification by BCA, ranging from public sector institutional projects to private sector projects (BCA, 2008a).

This paper provides an overview of the Green Mark scheme as the first government-implemented environmental assessment tool in Singapore. This paper is based on an online questionnaire survey undertaken in January 2008 to review the impact of Green Mark scheme in the construction industry since its introduction in 2005. The survey seeks to examine whether there is an uneven uptake of environmental consideration across all the stakeholders in the development process and the increase in market awareness of the benefits of green buildings. This paper also discusses the principles of Green Mark, its implementation and its impact on sustainable buildings in Singapore.

2. The Green Mark Scheme – An overview

Green Mark is a credit award scheme that aims at promoting sustainability in the built environment. In particular the main objectives of the Green Mark scheme are (BCA, 2008a):

a. to promote sustainable development by improving environmental performance of buildings;
b. to employ market forces to bring about environmental awareness and to improve quality of life for occupants;
c. to raise awareness of developers, facility managers and occupants of the benefits of green building;

d. to encourage the best environmental practice in building design, operation, management and maintenance; and

e. to establish key performance indicators for benchmarking green building performance.

The Green Mark scheme attempts to combine features from three major green building rating systems to evaluate environmental performance of buildings and to improve quality of life. They are the Building Research Establishment Environmental Assessment Methods (BREEAM) in the UK, the Leadership in Energy and Environmental Design (LEED) in the US and the GreenStar in Australia. The Green Mark scheme, similar to BREEAM, LEED and GreenStar, gives outcomes as a certificate awarded to individual building based on credits for a set of pre-determined performance criteria.

The assessment classification is based on the total number of credits. This certificate provides recognition for the building environmental performance. The classification rankings in Green Mark are Green Mark Certified (scores 50 to <70), Gold (scores 70 to<80), Gold^{PLUS} (scores 80 to <85) and Platinum (scores 85 and above). Assessment method and certification process provide means of distinguishing green buildings and promoting their uses. The documentation format, third party assessment and post-occupancy evaluation provide a systematic approach to the certification process.

Based on the structure of BREEAM, LEED and GreenStar, six assessment criteria were identified. These assessment criteria contribute to the credibility of Green Mark by ensuring that green building environmental performance goals match up to the desired international rating standards in a transparent manner (Fowler & Rauch, 2006). Other credibility concerns include measurement of environmental impact, market transformation, quality of life, and a track record of accomplishment through post-occupancy evaluation (Lutzendorf & Lorenz, 2006).

Table 1 - Comparison of performance scores for BREEAM, LEED, GreenStar and Green Mark

MAIN ASSESSMENT CATEGORIES	BREEAM '98		LEED 2.1		GREEN STAR v.2		GREEN MARK	
	Points	% of total points	Points	% of total points	Points	% of total points	Points	% of total points
Site/Project development & ecology	128	11	14	20	8	6	10	10
Energy efficiency & atmosphere	208	17	17	25	24	18	30	30
Water efficiency	48	4	5	7	13	10	20	20
Indoor environment quality & environmental protection			15	22	27	20	15	15
Innovation & design			5	7	5	4	15	15
Materials & resources	104	9	13	19	20	15		
Transport	240	20			11	8		
Pollution & emissions	154	13			14	10		
Health & Comfort	150	13						
Management	150	13			12	9	10	10
TOTAL	**1182**	**100%**	**69**	**100%**	**134**	**100%**	**100**	**100%**

The Green Mark assessment scheme covers a wide range of green building issues, environmental impact, resource exhaustion, emissions to environment, indoor environmental quality, and management quality as well as other social aspects in Table 1. The table provides a comparison of assessment criteria between Green Mark and the BREEAM '98, LEED 2.1 and GreenStar v2. Green Mark places a lot of emphasis on energy and water efficiency which are the two main areas of concern in Singapore.

The intention of the Green Mark assessment scheme is to evaluate environmental impact of new and upgraded buildings using locally developed benchmarks and weighs established for each criterion. The values for benchmarks were classified into two main types: numerical and text based. The numerical values reflected the scores achieved and the text scores reflected the building performance grade. The numerical sore range from 0 to 100 and the five text scales represent minimum acceptable scale, average, good, excellent and outstanding performance achieved using best available technology and affordable cost.

In order to accelerate the Green Mark scheme in construction the government launched a Green Mark Incentive Scheme (GMIS) to encourage the adoption of green building design, technologies and practices. GMIS provides developers and building owners with financial incentives for buildings with Green Mark Gold rating or higher in new constructions or retrofitting of existing buildings.

3. Assessing the impact of Green Mark Scheme

3.1 Research method

Green Mark has been a voluntary requirement for the design and construction of projects in Singapore for about three year. In order to examine the impact of Green Mark in promoting sustainability in the construction industry, an online questionnaire survey was developed to investigate its role and impact. The survey was designed and distributed online so that it could obtain a wider coverage and provide a quick and easy platform for the return of the completed survey. The purposes of the survey were to examine the level of acceptance of Green Mark since its introduction in January 2005 and to explore the role of Green Mark in the construction industry in enhancing sustainability in construction projects. The survey also assesses the impact of its implementation as voluntary to the design and construction for buildings.

The questionnaire was divided into three parts. The first part was intended to obtain general details of the respondents and contained eight questions. Information about the demographics of respondents and details of their professions and organizations were the focus of this part. Part two was intended to examine the viewpoint of respondents in respect to their understanding and acceptance of the green buildings, and it contained 12 questions. Some of the questions were designed as a standard Likert scale where respondents were asked to rate each questions from low to high or from strongly disagree to strongly agree. Part three contained eight questions and was designed to identify the level of expertise the respondents have in the operation of the Green Mark scheme.

The online survey was assisted by the Royal Institution of Chartered Survey (RICS), the Chartered Institute of Building (CIOB) and the Singapore Institute of Architects (SIA) in distributing the survey to their members. The anonymous questionnaire was sent to members of RICS, CIOB and SIA as well as to 150 practitioners in the construction industry in Singapore via email with a URL containing the online survey in January 2008. Many participants also forwarded it to URLs of other practitioners in the industry. Therefore it was difficult to determine the exact response rate. Completed questionnaire were received via online and the survey was concluded in mid March 2008.

3.2 General Information

In mid March 52 completed questionnaires were received and analyzed. Of the returned survey 74% were from male respondents whereas female respondents contributed 26%. The survey respondents came from a variety of backgrounds and details are included in Figure 1. Project managers, Architects and quantity surveyors made up of the majority of the respondents and contributed 18%, 24% and 25% respectively to the total returned surveys whilst the rest was distributed among property managers, developers, engineers and others. Figure 2 presents the survey by age group. The age distribution of the respondents was evenly distributed. Regarding work experience 48% have less than 15 years, 44% have between 16 to 35 years and 8% have more than 35 years respectively. The majority of the respondents, about 49%, work for large companies with staff over 100 and have been established over 40 years in the construction industry.

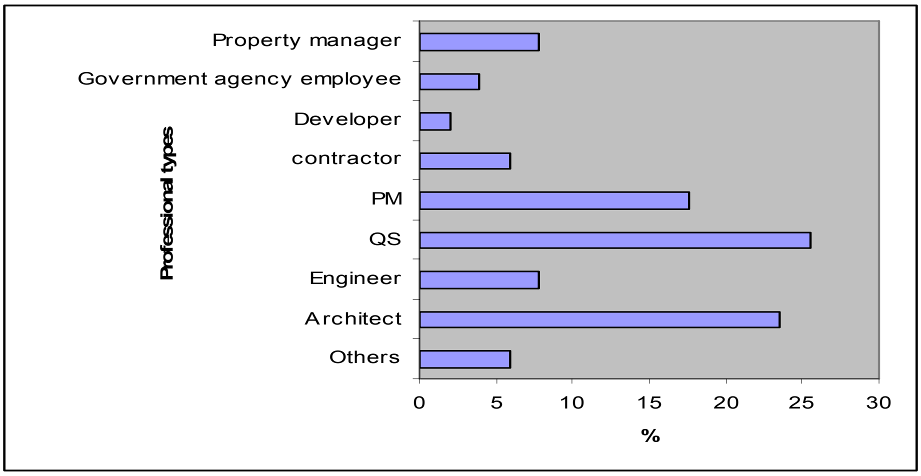

Figure 1 Summary of respondents by professional

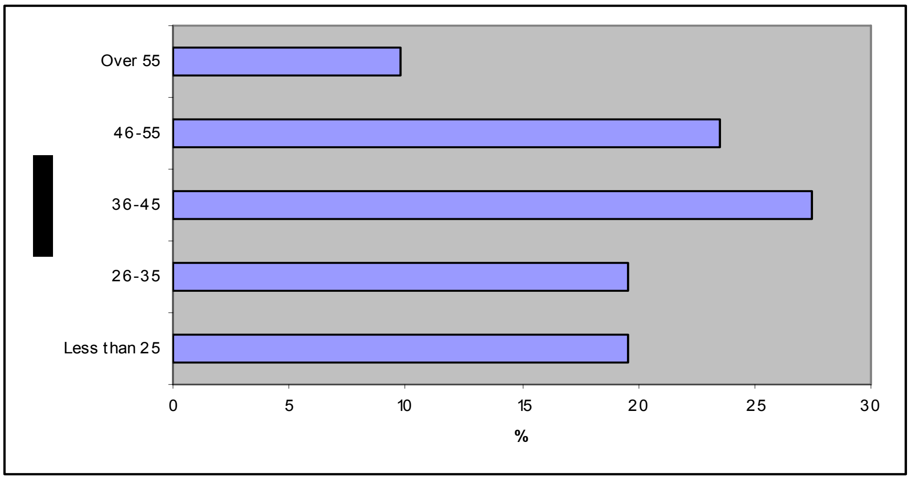

Figure 2 Summary of respondents by age

3.3 Greening the construction industry

The survey indicated that the majority of respondents are well aware of the environmental issues in the construction industry. Approximately 95% have expressed their concern about the environment and 59% have work experience in environmentally related projects. Of the 59% respondents having work experience in environmentally related projects about 50% are engaged in the design whilst 29% are involved in the construction and the rest in maintenance and assessment. Regarding work experience in environmentally related project approximately 82% have only two years work experience in about five projects. About 18% have up to 15 environmental projects with about ten years of such work experience.

In Part II survey respondents were asked to provide their opinions on greening the construction industry in Singapore. The questions were designed using a standard Likert scales, ranging from strongly disagree to strongly agree. The results indicate that over 90% of respondents agreed that environmental issues are important and should be incorporated in the design and construction of projects. About 90% believed that the demands for green buildings in the society will continue to grow and will eventually become an important source of workload in construction.

The respondents were asked to comment on whether research and development in green buildings in the construction industry is sufficient in Singapore. However only 12% agree that the construction industry has done enough to protect the environment whilst 66% disagree and 22% having no opinion. Some propose that the government needs to re-evaluate current regulations and policies in order to develop new directions and guidance for improving sustainability in construction. Some suggest that more grants and funding should be used to encourage research and development in renewable energy development, green technologies and materials, and so forth.

Concerning protection of the environment some suggested using severe legislations, regulations and by-laws as means to protect the environment. Approximately 74% believed that the laws and regulations will become more demanding in construction in the next few years. They recommend on one hand heavy penalties or taxes be imposed on those who pollute the environment. On the other, encouragement may be given by the government to those who pursue environmentally friendly projects through tax incentives or financial benefits.

3.4 Impact of Green Mark Scheme in construction

The Green Mark scheme was introduced in January 2005 as an initiative to raise environmental awareness among construction professionals in the design and construction of projects. However the long-term impact of Green Mark is yet to be reviewed. From the survey 45% of respondents have used Green Mark before of which 81% have used it for less than 5 projects whilst 19% used it for between 6 to 15 projects. Of those who had used the Green Mark before, about 65% used it as a design tool whilst 35% used it just for marketing purposes.

In assessing the impact of Green Mark in the construction industry respondents were asked to rate questions that were designed on a standard Likert scale from strongly disagree to strongly agree. The results are summarized in Table 2. Based on the returned surveys, professionals in the construction industry are generally well aware the importance of Green Mark in construction. The survey results indicated that 70% agree that the scheme is useful in assessing environmental performance of buildings. Green Mark is reasonably user friendly and 54% agreed that the information on the website is sufficient. With regards to assessment criteria 63% believe that Green Mark can help to provide better sustainability outcomes in construction. About 74% of respondents found the assessment criteria achievable.

Table 2 Summary in the use of Green Mark in the construction industry

Proposition	Responses (%)				
	Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
The Scheme is useful in assessing environmental performance of buildings	4	4	22	59	11
The information on the website is sufficient	4	15	27	46	8
The criteria set in the Scheme are achievable	4	0	22	67	7
The Scheme will help to provide better sustainability outcomes of buildings	4	4	22	59	11
The assessment criteria are sufficient to cover the environmental aspects promoting green buildings	4	11	22	44	19
The cost of building green under the Scheme will be more expensive than traditional developments	4	7	22	37	30
The duration of building green under Scheme will be longer than traditional development	4	30	26	26	15
The Scheme should be used by all types of projects in the construction industry	4	0	19	62	15

Since the introduction of the Green Mark scheme there have been substantial discussions on increased construction cost and time due to compliance with the scheme. The use of Green Mark may have impacted on the overall construction cost due to incorporation of green features in buildings. Some have raised concern that compliance to Green Mark will escalate the overall budget which will impact on financial return. Approximately 67% of the respondents agree that the implementation of Green Mark has increased the overall construction cost but only 41% agree that Green Mark may increase the overall construction duration. In accordance with a preliminary study undertaken by the BCA the Green Mark certified buildings have a cost premium between 0.3% to 8% depending on the awards and building types (BCA, 2008b). The Green Mark Certified buildings are at the lower end of the range whilst Gold Platinum has the highest costs premium of up to 8% due to higher performance designs. The higher cost premium of green buildings is recovered from long-term energy and water cost savings.

There is no great disparity in the payback periods for the Green Mark certified buildings ranging from 2 years to 8 years (BCA, 2008b). However it is hard to ascertain whether Green Mark has increased the construction cost and time and further research is needed. About 77% of respondents agree that Green Mark should be applied to all types of construction. However many believe that the scheme needs further development to improve it usefulness. There is no indication of the details of improvement that needs to be made in Green Mark.

The respondents were also asked to comment on the limitations of the scheme in enhancing sustainability performance of buildings. They raised the issue that some developers may like to get the certificate at the lowest pre-determined costs. Developers in Singapore are not likely to spend more than the construction budget if there are no real benefits of green features such as solar, rainwater storage and so forth. Unfortunately wind tunnel tests or acoustic design are usually last on the list as they have initial costs which may lead to other costs. Too much emphasis on green features will lead to the presumption that green buildings are expensive and thus lessen the motivation to building green. They believe that in order to make Green Mark more successful team work and team participation from all construction professionals are important. The government can make Green Mark a requirement for the approval of building plans. They also suggest that sufficient information on green buildings should be made available through the development of a vibrant database that has information of all green innovations in the world as reference materials.

Some raise concerns that Green Mark, like other environmental building assessment methods such as BREEAM, focuses on the evaluation of design against a set of sustainability indices. The scheme includes six main areas (refer to Table 1) but does not include financial matters in the evaluation framework. This may contradict the ultimate principle of a development, as financial return is fundamental to all projects. It is important to include economic analysis in the framework and to emphasize potential long-term savings in order to convince people to adopt sustainable practices when building,

In addition, building life cycle has not been incorporated in the evaluation process in the Green Mark scheme. As Curwell (1996) states, life-cycle analysis is important in environmental assessment of buildings as it gives a balanced assessment between a development and the environment. Therefore, a whole-of-life approach is an essential method to evaluate and integrate the costs and benefits associated with sustainable construction. Kats (2003), states that the lack of life cycle costing is one of the obstacles to sustainable buildings. Therefore the ongoing maintenance, repair and replacement of the building should also be included in the evaluation process.

Further, embodied energy has not been included in the evaluation process although it is growing in importance. Construction consumes energy in two principal ways. Firstly, it consumes energy through the construction of buildings and related facilities. In general the energy is used to produce building materials and their subsequent on-site assembly at their final destination. Secondly, it consumes energy in the later use of the building and related facilities in the form of heating, ventilation and cooling, lighting, hot water, and appliances and equipment. It is important to assess the building's entire life cycle on the environment including energy consumption embodied in the process of recovery of raw materials and the manufacturing process. Therefore using low embodied energy materials and recyclable materials have become extremely important (Weir & Muneer 1998). The energy embodied in construction can represent up to one-fifth of national energy consumption (Treloar et al 2001) and it is significant because it occurs immediately and the total energy consumed in the production of building materials can be equal, over the life cycle of a building, to the requirements for operational energy (Pullen 2000).

4. Conclusion

The literature review of existing assessment tools and design methodologies has shown a plethora of environmental issues addressed. Study revealed that not all tools have taken account of economic and social parameters. It is evident that a more holistic approach would result in a more pragmatic and operational outcome. It seems that intentions behind the design of these assessment tools are to be guidelines during the design process and as general green assessment rather than as a specific architectural evaluation tool of building performance.

Construction is one of the largest users of environmental resources and one of the largest polluters of the man-made and natural environment. The improvement in the performance of buildings with regards to the environment will indeed encourage greater environmental responsibility and place greater value on the welfare of future generations. There is no doubt that Green Mark contributes significantly to achieving the goal of sustainable development within construction. On one hand, it provides a methodological framework to measure and monitor environmental performance of buildings, whilst on the other it alerts the building profession to the importance of sustainable development.

The questionnaire survey has provided a preliminary investigation on the impact of Green Mark scheme as introduced by the BCA in January 2005. However, Green Mark has limitations as examined in this paper reducing its effectiveness and usefulness. There is a requirement for greater communication, interaction and recognition between members of the design team and various sectors in the industry to improve and promote the use of the scheme. In considering the advantages and disadvantages that the Green Mark Scheme may have, it has come into effect quite smoothly and with continued improvement and updating, it could become one of the most important planning and design tools in the construction industry.

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SUSTAINABILITY IN OFFICE BUILDING DESIGN - ASSESSMENT METHODOLOGY: THE CASE OF FLORIANÓPOLIS, SC, BRAZIL

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Summary

The increasing concern regarding climate change and the future of the planet has led to the adoption of sustainable construction principles being a globally attractive alternative. Almost every developed country has its own method for environmental assessment of buildings; developing countries have more recently started to follow a similar track. The main objective of this paper is to present a proposal for a sustainable building assessment tool for office buildings applicable from the design stage. To achieve this objective, a checklist was drawn up based on existing environmental assessment methods for office buildings and complementary references. The checklist includes six categories: Land use and occupation; Water; Energy; Materials and resources; Transport and accessibility; and Indoor environmental quality and health. It was evaluated by specialists regarding its adequacy and relevance to the Brazilian context. The checklist was applied to 17 office buildings in a data survey and these data resulted in benchmarks that were used as the basis for the proposed method to evaluate sustainability of Brazilian office projects at design stage. The results were: validation of requisites for building sustainability assessment; evaluation of office buildings located in Florianópolis-SC, southern Brazil; benchmark definition; tool to guide designers towards more sustainable approaches; and methodology to evaluate sustainable office building design.

1. Introduction

Data from the Fourth Intergovernmental Panel on Climate Change Report (IPCC, 2007) show the alterations in the global climate due to human intervention and a projection of what is to come due to the increase in the global greenhouse gas emissions. Among the short and mid-term options the report classifies, with a high degree of certainty, that efficient buildings and a change in lifestyle and population consumption standards can considerably reduce climate change. This highlights the importance of the application of the sustainable development concept to the civil construction industry, since the way in which constructions are designed, constructed and operated directly influences the consumption of natural resources and the comfort and health of the building users. Buildings and civil workplaces are considered the physical products with the greatest useful life that society produces. They modify the nature, function and appearance of urban and agricultural areas. Housing and the infrastructure required for transport, water supply, sewage systems and energy to support the necessities of the increasing world population present a considerable challenge in terms of sustainable construction.

The impact of the construction industry on the environment is well documented (UNEP, 2003; USEPA, 2004; WINES, 2000; JOHN, 2000; IPCC, 2007) and it is clear that this industry is addressing the situation. This impact occurs throughout the production chain: from the conception of a building until its demolition. Design decisions, such as the location of the building, its orientation on the land and the specification of materials and components directly affect the consumption of natural resources and energy, the optimization or not of the building construction and the effect on its neighborhood. Added to this, raw materials are *per si* great consumers of natural resources and energy. Construction generates a great amount of residues, aggravated by the losses in the processes which are not optimized. In the operation and maintenance of a building, there is a high consumption of water and energy and considerable generation of residues. Finally, in the demolition stage more residues are generated in great volumes.

Within this perspective lie the proposals for sustainable constructions, conceived to make rational use of natural resources (materials, water and energy), to provide user comfort, to reduce the costs during the useful life of the building and to modify as little as possible the environment into which the building is inserted. The first point to consider in the search for this type of construction is that the concerns must start at the initial stages of planning and design, continue during the construction and participate in the operation and maintenance stage. The building design (conception) appears as the basic stage, where the agents involved must achieve integrated solutions to reach a high performance of the building during its useful life, considering environmental, social and economic aspects. In this context, the introduction of mechanisms to manage sustainable requisites during the design process represents an important means by which to improve the performance of the building construction sector.

To achieve sustainable constructions, it is necessary firstly to define a reference to establish the criteria used to analyze the inclusion of environmental, social and economic concerns into the conception and execution of the constructions. Currently, almost all developed countries have their own environmental performance assessment system. More recently, some developing countries have also initiated the elaboration of proper methodologies, with the focus on sustainability, that is, weighing up the balance between environmental, social and economic aspects. These include initiatives in South Africa (GROBLER; SINGH, 1999; GIBBERD, 2002), Brazil (SILVA, 2003), Chile (CARVAJAL, 2005), China (LIU *et al.*; 2006) and India (IGBC, 2007).

Despite the existence of several models, Silva (2003) confirms the hypothesis that the existing international models for environmental assessment of office buildings are not suitable for application in Brazil, it not being feasible to simply copy, translate or apply a foreign method in the Brazilian context (or in any another country other than the country where it was developed). Even though the success of foreign methodologies has been verified, the unsuitability of their evaluations to application in Brazil goes beyond the withdrawal or inclusion of requisites, and adaptations are therefore very different from the original methods. This is partly because the majority of the aspects are evaluated on the basis of standards and legislation from the original country. The risks of the homogenization and consequence loss of the regional characteristics of the countries, in these cases, are always present. Therefore, the importation of methods can be detrimental to the environmental progress of the countries where they are being applied, since the methods are inevitably based on the implicit cultural and construction traditions of their original country (COLE, 2005).

Another drawback in this regard is the lack of standards and references related to sustainability in the Brazilian construction industry. The sustainability concept - not always addressed in an objective way – is often used only as marketing instrument. Initiatives that clearly define the performance criteria and parameters of the constructions can raise the sustainable development of a subjective plan to a more effective and realistic level, enabling, from the conception of the project, a reduction in the energy and water consumption, production of residues, and costs during the useful life of the building, along with improved user welfare. Additionally, through the formalization of a sustainable building evaluation methodology it is possible to: a) establish measures of sustainability for requisites in the Brazilian context; b) define sustainable building by the establishment of measured standards; c) seek the integration of all construction designs; d) enhance discussion between engineers and designers in the preliminary stage of the project conception; e) recognize sustainable initiatives in the construction industry; f) increase the perception of the consumers regarding the benefits of sustainable constructions; g) stimulate competition between companies; h) identify wasteful focuses and techniques to eliminate or to minimize them; i) improve the reputation of and confidence in companies that demonstrate responsible actions; and j) eliminate expensive options and reduce the costs of reforms.

2. Objective

The main objective of this article is to present a proposal for a methodology to evaluate the design of sustainable office buildings in Brazil, based on the case of Florianópolis, SC.

3. Methodology

3.1 Analysis of environmental assessment methods for office buildings

Existing methodologies for office building assessment were analyzed, with an emphasis on the design stage, for the identification of its arrangement and the requisites considered. The selected models were:

1. BREEAM - Building Research Establishment Environmental Assessment Method; United Kingdom (BRE, 2006): the first system of environmental evaluation of buildings which served of a basis for other systems;

2. GBTool – Green Building Tool; international consortium (IISBE, 2005): a second-generation environmental performance assessment system for buildings, based on research;
3. LEED - Leadership in Energy and Environmental Design; United States (USGBC, 2006): currently the method with greatest growth potential due to the massive investment that is being made to promote its dissemination and improvement;
4. CASBEE - Comprehensive Assessment System for Building Environmental Efficiency; Japão (JSBC, 2006): inspired on GBTool and based on new concepts such as Building Environmental Efficiency (BEE);
5. Green Star Office Design; Australia (GBCA, 2005): based on existing methodologies such as BREEAM and LEED;
6. NF *Bâtiments Tertiaires - Démarche HQE Bureau et Einseignement*, France (CSTB, 2005): differentiated methodology where the whole project is managed, providing the possibility to adapt the evaluation of the environmental performance to the context of each project, allowing the designs to focus on specific realities and priorities separately from those of the entrepreneurs;
7. SBAT - Sustainable Building Assessment Tool; South Africa (GIBBERD, 2002): first initiative for development of systems for building sustainability evaluation in developing countries;
8. Model considered by Silva (2003); Brazil, that pioneered the work on sustainability evaluation of Brazilian office buildings throughout their lifecycle[1].

3.2 Determination of Sustainable Requisites to Evaluate

Definition of sustainability requirements to be assessed at design stage was based on the analysis of the requisites which constantly appear in existing methodologies (cited in the previous item) and in complementary documents such as standards, legislation, regulations, theses and other Brazilian publications. Such documents were analyzed for identification of the requisites applicable to the Brazilian context, seeking to include environmental, social and economic aspects affected by implementation of a new building development. Requisites were structured in a checklist format for each of the following six categories: 1) Land use and occupation; 2) Water; 3) Materials and resources; 4) Transport and accessibility; 5) Energy; and 6) Indoor environmental quality and health.

3.2.1 Consultation to a panel of experts

To evaluate whether the selected requisites were pertinent to the Brazilian context, Brazilian academics and other stakeholders (architects and engineers), specialists in each category, were approached. All the professionals are involved with the subject of sustainable construction and participate or have previously participated in a design project following LEED specifications[2]. Experts on each category were requested to give an evaluation that consisted of following items:

- Would you include any requisite not covered by the checklist?
- Would you exclude any requisite that, in your view, is not applicable to the Brazilian reality or that does not differentiate a sustainable construction from a non sustainable one?
- Does the measurement form provide an adequate survey of the necessary data?
- Is the standard/reference material appropriate or would you use a different data/info source?

Academic specialists were consulted first, to best calibrate the checklist and proposed metrics and data sources. In case significant changes were proposed, checklists could be updated prior to consultation with technician/market specialists. No great alterations were required though, and the original checklist was sent to the technician specialists. This survey was limited to 16 specialists and, in these authors opinion, the views were very optimistic (the great majority of the requisites were kept).

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[1] Although already exists this initiative to assess Brazilian buildings, the limits of the system were defined in order to include the construction stage and the building use (some aspects of planning and design are considered, but not in the same level of detail), as well as the evaluation of the agents involved in the process, initiated by the construction company. The suggested model is for application to buildings with occupation above 80% and time of use between 1 and 3 years.

[2] At the time this study was carried out, LEED was the only environmental certification system used in the Brazilian market.

3.3 Data collection for Benchmark Definition

After the inclusion of the considerations from specialists, the final checklist was used for the data survey on the buildings in Florianópolis. Florianópolis is the capital of Santa Catarina state, located in Southern Brazil, at latitude 27°40' south and longitude 48°33' west. The results of the survey served as the basis for benchmarks definition.

3.3.1 Office building sample

Sample definition criteria included typology (office building projects), period of approval (between 2000 and 2005), and size (3 or more storeys, and one or more garage levels). Such criteria were used to screen a report of design approvals issued by Florianópolis Urban and Public Services Secretariat (*Secretaria Municipal de Urbanismo e Serviços Públicos* - SUSP). The resulting sample included 17 buildings and encompassed 11 from the largest construction firms in Florianópolis.

3.3.2 Data collection

Checklists of each category guided data collection. Table 1 shows an example of the requisites included in the Water category.

Table 1 - Example of requisite included in the checklist for the Water category

Req	Requisite	What to evaluate	How to evaluate	How to get the information
Water				
A-1	Potable water reduction	**1.1.** Reduction in potable water used for irrigation	To verify whether landscaped areas are present. To verify the existence of efficient irrigation technologies; usage of rainwater or graywater for irrigation; lack of permanent installed irrigation system. If applicable, calculate the percentage reduction in the use of potable water for irrigation.	Design analyses/ on-site verification

Data collection consisted of: design analyses, interviews with designers, constructors and buildings managers, calculation and recording of variables. Obtained data were recorded on auxiliary spreadsheets, carefully designed so that all information required to evaluate the requisite was identified and registered (Table 2).

Table 2 - Example of checklist auxiliary spreadsheet to record collected data

WATER

A-1. Potable water reduction

A-1.1. Reduction in potable water used for irrigation

Are there landscaped areas on site?			Yes ( )	No ( )
If affirmative:	Are they native landscapes?		Yes ( )	No ( )
	Are there irrigation systems installed?		Yes ( )	No ( )
	If affirmative:	Is high-efficiency irrigation technology in use?	Yes ( )	No ( )
		Describe:		
	Is there on-site rainwater collection for irrigation?		Yes ( )	No ( )
	Is there on-site water recycling for irrigation?		Yes ( )	No ( )
	If irrigation is carried out using rainwater or recycled water, calculate the percentage of potable water reduction for irrigation:			

3.3.3 Analysis of results and benchmarks definition

On analyzing the data collected through application of the checklist it was possible to observe the requisites that already constitute market practices, those that were recently added to some buildings and those not addressed by any of the studied cases. According to the assessed requisites, building performance was classified according to three levels:

B – Good, current practice or minimum performance required for a sustainable construction;

I - Intermediate performance;

S - Advanced performance in relation to current practices, which can be achieved using existing practices and technologies.

In this work, authors decided to experience a three-level performance scale for benchmarks (similar to HQE) as the definition of a more detailed performance scale (as in GBTool and CASBEE) would be more complex and require higher amount of data, unavailable at the moment.

From the data collection results, and researching standards, legislation and specific literature, benchmarks were then defined. Due to the lack or outdating of some standards, and in the absence of local or national parameters, benchmarks recommended by the international methodologies analyzed were applied.

Besides the evaluation criteria that defined levels B, I and S, mandatory criterion were determined, in relation to legislation and standards currently enforced. Such criteria are mandatory in any building, but were included as sustainability criteria and the results of the data collection showed that they were often ignored or disrespected.

3.4 Proposal for the Evaluation Methodology for Sustainable Office Building Design

The presentation structure of the proposed methodology is summarized in Table 3:

Table 3 - Sample for presentation of the proposed methodology

X. CATEGORY		**Level**		
		B	**I**	**S**
X.1 SUBCATEGORY				
X.1.1 Performance requisite				
indicator	level B criterion	**B**		
	level I criterion		**I**	
	level S criterion			**S**

The mandatory criteria are presented according to the example in Table 4.

Table 4 – Sample for mandatory criteria presentation

X. CATEGORY	
X.1 SUBCATEGORY	
X.1.1 Performance requisite	**Mandatory**
mandatory criterion	

To complete the methodology, factor like target for application, evaluation timing and results presentation format were defined.

4 Results

4.1 Definition of Requisites for Evaluation of Sustainable Office Building Design in Brazil

The set of requisites defined for data collection was sufficient to cover, if not all, most main questions related to sustainable constructions. Definition of the requisites and their validation by the specialists resulted in checklists and auxiliary spreadsheets for data collection. Such tools are expected to allow for good repeatability of the method used in this study when applied in other evaluation contexts, either at whole building level or at specific aspects. Development of a reproducible method, besides facilitating other data collection ventures, will assist in the definition of new performance parameters and the recognition of the particular characteristics of each region, allowing the definition of performance parameters that better represent the national reality.

4.2 Implementation and Validation of the Requisites in Data Collection

The data collection carried out for 17 office buildings allowed the validation of the essential requisites for sustainable office constructions. From evaluated requisites, energy efficiency should be highlighted as this study applied for the first time the methodology of the Regulation for Energy Efficiency Level of Commercial, Service and Public Buildings (BRAZIL, 2007) and tested its ease of application. In a general way, it was verified that interpretation and application of the Regulation's text was sufficiently clear. Results from this experience based updating of the regulatory text.

4.3 Evaluation of the Panorama of Florianópolis Office Buildings regarding Sustainability

Data collection results provided a current panorama of office buildings in Florianópolis regarding sustainability. In a general way, it could be perceived that the constructions fell short from the performance expected. Even mandatory requisites are, in some cases, disregarded. Resolution 307/02 of CONAMA (regarding disposal of the construction and demolition waste), Resolution 09 from ANVISA (that fixes the indoor air parameters in mechanically ventilated buildings) and Standards NBR 9,050/04 and NBR 13,994/00 (regarding accessible design), for example, are generally disregarded, even though they are basic requisites for any construction.

It was found that some requisites, although their positive impact on the environment is public knowledge, is still not market practice and was not taken into consideration by any of the studied buildings, for example, the existence of facilities for the adequate collection and storage of recyclable materials. Moreover: some requisites were actually applied not because of their environmental or social impact, but rather due to low cost or availability of specific items and materials in the marketplace..

Requisites such as the organization and protection of water systems, the use of water-saving devices, specification of materials in conformity with technical standards and use of certified wood had been incorporated into the local construction business.

Some good examples were also observed, representing performance practices superior to the typical construction market in Florianópolis. Amongst them can be cited the development of a Study of Neighborhood Impacts; the use of the rainwater for sanitary flushing and the analysis of suppliers for specification of environmental-friendly materials.

4.4 Definition of Performance Parameters to be achieved in Sustainable Buildings

The results obtained in the Florianópolis office building evaluations were the main reference for the definition of the performance parameters. In cases where the results of the data collection were not sufficient for the basis of a definition, additional information was obtained from specialists, standards, Brazilian publications and benchmarks used in international methodologies which fitted the Brazilian reality.

Silva (2007) states that the creation of a benchmark database for each indicator is fundamental in order to provide meaningful evaluations and to mark out the limits for the establishment and updating of sustainability goals. Benchmarks reflect local construction standards and can vary according to the regional context. Therefore, to obtain national indicators, data collection must be carried out in several locations in order to identify the regional differences and suitability of the performance parameters of each requisite for the context into which they are inserted. The definition of benchmarks in this study contributes to filling the gaps in Brazilian research, to be complemented by a collective, coherent and constant research effort to keep it disclosed and up-to-date..

4.5 Establishment of Criteria for a Tool to guide Designers in the Development of Sustainable Design

During the interviews it could be noted that some constructors and designers are unaware of certain requisites related to sustainable construction and the reason for their inclusion. Moreover, it was observed that, either due to misinformation or opportunism, some constructions address one or another requisite in order to appeal to the marketing of "environmentally responsible constructions". One positive point observed is that all the interviewees demonstrated great interest in the subject of the research and requested feedback at the end of this study. Thus, it can be concluded that the clear definition of sustainable requisites will provide an important guide to aid constructors and designers to incorporate them into projects and will define objectively what a construction must achieve in order to be considered sustainable.

4.6 Proposal of a Methodology for Evaluation of Sustainability of New Office Building Designs in Brazil

The main objective of the study was achieved with the proposal of a methodology to evaluate the sustainability of new office building designs in Brazilian, whose benchmarks are suited to Florianópolis, SC. The method here considered illustrates in a sufficiently clear and representative way the building performance achieved.

The structure chosen – inspired by the French HQE approach - and the criteria based on performance levels - where all the constructions must present at least one basic performance - were adjusted to the Brazilian reality. Due to the number and wide-ranging particularities considered by the French methodology, the authors believe that, from the models currently available in the Brazilian market, this model could provide a more appropriate assessment of sustainability performance of buildings. Suitability of such approach is also being investigated for residential constructions.

In order to demonstrate the application of the proposed methodology, the performance obtained for three of the evaluated buildings is presented in Fossati (2008). In that work, all the guidelines for methodology implementation were traced, from the application target to the presentation format of the final evaluation results.

5 Conclusions

In the carrying out of this study it could be noted that a reduction in the impact of the civil construction industry and the achieving of more sustainable buildings are not simple tasks and require agreed and simultaneous actions covering diverse topics. However, the authors believe that, in a near future, the consideration of sustainability will be a primary requisite for engineers and architects, as are other technician requisites such as structural, fire and user safety, for which the majority of standards guide the designers in the generation of adequate solutions.

Concerning initiatives related to sustainable constructions in Brazil, this has been summarized by Silva (2007) who states that Brazil has already made some effort to establish sustainable indicators; however, these vary widely and are defined by criteria and methodologies which are not necessarily replicable, and that for the country to advance in the development of sustainable indicators it is necessary to: define a consensual methodology to structuralize indicators; collect data; define national indicators, and become aligned with international trends, as well as produce a block of local indicators in each case; to measure or to attribute values; and to interpret and, eventually, add indicators. A robust database must be created and kept up-to-date and be widely accessible.

The research presented in this paper offers an important contribution in the development of sustainable constructions in Brazil, presenting a replicable methodology; carrying out of data collection; defining requisites aligned with international methodologies and initiating the formation of a database. It can also contribute to other developing countries in the development of their own research and reproductability of the method can facilitate data collection needed for the definition of performance parameters and recognition of the particular characteristics of each region.

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PILOTING 4D SUSTAINABILITY ASSESSMENT SOFTWARE IN THE NETHERLANDS

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Summary

There is now widespread popular awareness that on local, national and global scales buildings have very significant and increasing environmental impacts. In response, industry stakeholders are seeking to adopt sustainability decision-support tools that are needed from early project initiation, concept design to detail design, construction and post occupancy. But even with new advanced tools emerging it is still very difficult to deliver the technical as well as practical information needed to support cost effective holistic decisions. There are a broad range of stakeholders involved and an industry sector cultural resistance to advanced information and communication technology.

The Australian Cooperative Research Centre for Construction Innovation has developed and trialled novel decision-support tools for Architectural, Engineering, Construction Property and Building practitioners. One such tool LCADesign, with a rapid take off from 3D Computer Aided Drafting models was developed to automate assessment of building environmental costs. While LCADesign has been tested in Australia, Holland California and Germany the focus of this paper is to describe lessons learned in 2 trials in Holland including on the new KPMG Commercial Office building Slavenburg BV delivered in Rotterdam.

The paper outlines how this tool works and has been applied in Dutch pilots along with DesignBuild procurement strategies applied to integrate effort to deliver more sustainable building. Issues met, new approaches tested and lessons learned in these pilots are discussed and recommendations for future management approaches are presented.

1 Introduction

Along with community concern about induced climate change, biodiversity and habitat loss stringent government environmental legislation on development applies in most modern jurisdictions worldwide. The Intergovernmental Panel on Climate Change (IPCC) (2007) attributed the world's hottest climate on record this last decade to greenhouse gas generation mostly from fuel use in operations to generate electrical energy. Countries reliant on fossil fuels in electrical power generation are major contributors to such climate change especially from buildings. Building operations, for example, account for;

- 40% of all energy consumed in Europe according to S Sattery (2005);
- 35% in America (Organisation for Economic Cooperation and Development (OECD) (2003)
- 25% in Japan according to the United Nations Environment Program (UNEP) (2003).

The World Business Council for Sustainable development (WBCSD) 2007) has stressed that delivery of more sustainable outcomes is driving uptake of new Architecture, Engineering, Construction (AEC) Property and Building solutions. Brandon and Hampson (2004) reported that the top global trend identified by AEC stakeholders was sensitivity to sustainable development which will be enabled by uptake of advanced information and communications technology (ICT). Scuderi, Jones and Watson (2005) also found a broad spectrum of stakeholders seek more user-friendly and integrated eco-profiling tools.

To equip industry moves toward sustainable development and uptake of enabling ICT, the Australian Cooperative Centre for Construction Innovation (CRC CI) initiated development of novel building eco-profiling software reported in Tucker et al (2003). To leverage uptake of sustainable development improved project contracting and management practice solutions are also emerging.

The purpose of this paper is to discuss a Dutch pilot of automate building environmental assessment software. It seeks to show LCADesign (Life Cycle Assessment of Computer Aided Design) software capabilities along with approaches to integrate effort and facilitate such ICT adoption in project delivery and to discuss market research related to uptake of LCADesign.

2 Green Building Market Strategic Analysis

2.1 Demand Trends

Five years ago, the OECD (2003) reported that many global industry groups were calling for more integrated sustainable energy responses. The Australian Environmental Labelling Association (AELA) (2004) then reported 80% of people buying environmentally preferred products. According to AELA (2004) Government and consumer preference for minimum energy, water and pollution was driving demand for green building benchmarks in Australia.

AELA (2004) and Scuderi et al (2005) both found that despite a lack of objective information consumer demand was forcing greener market responses. Scuderi et al (2005) also argued that instruments in government environmental policy and regulation were increasingly strong market influencers.

Jones et al (2006) found consumer demand for more sustainable development initiatives coupled with the buying-power of Government and Community green procurement initiatives constituted the main market influencers in Australia. Now the IPCC (2007) climate change warn there is an urgent global need for much more sustainable development of stationary and transportation energy infrastructure. And the WBCSD (2007) reports that client demand for increased renewable content in energy supply is increasingly high globally.

As to the key green building market drivers on a global scale the UNEP (2003) pointed to alliances of local Governments working on the United Nations Agenda 21 while the WBCSD (2007) points to the work of the International Green Building Council (GBC).

2.2 Barriers to Building LCA

Sarja (2002) found very significant building environmental impacts are common on internal, local and global scales and LCA was the best method to asses them. He concluded that delivery of more sustainable buildings required timely, cost-effective LCA for whole of building life decision-making.

Grant (2004) found lead industry players recognise that LCA was needed to provide quantitative eco-profiles to inform decision-makers in supply, design and procurement. However, despite the many green design tools Watson et al (2004) found few AEC practitioners use them routinely as most fail to deliver relevant information needed to support broad stakeholder engagement essential for more sustainable project delivery. They also argue that conventional ICT for building LCA has severe time and cost limitations as most are reliant on:

- subjective rather than objective, transparent or quantitative measurement (Seo 2002);
- no data input from or interactivity with Computer Aided Design (CAD) (Tucker *et al* 2003);
- tedious manual data entry to calculate outcomes in spreadsheets (Grant 2004);
- incorporation of subjective and often contentious or poor information (Mitchell et al 2005) and
- much new technical language for project teams to assimilate (Huysmans *et al* 2007).

Huysmans et al (2007) recently reported that stakeholders need capacity to deliver rapid, comparative quantitative building assessments of "what if" scenarios to assist decision-making.

3 Advanced ICT for Automated LCA

Advanced ICT now used in all modern CAD tools offer users very significant time, cost advantages (Watson et al (2004)). The CRC CI exploited such ICT to deliver novel building software to meet core market demand for real-time, cost-effective LCA for building environmental appraisal from concept to detail design. The main aim of this LCADesign software was to avoid manual transcription of data in assessments reliant on ISO 14000 Environmental Management Series (EMS) methods for LCA, Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA).

The software uses industry foundation class (IFC) global data transfer protocols to access and view element volumetric, spatial and specification data embedded in three dimensional (3D) CAD files. In addition to automated take-off from BIMs IFC protocols allow software interoperability as e.g. in other CRC CI developed software tools to automate planning, scheduling, quantity survey, checking and specification applications. Automated take-off from such building information models (BIM) files allows LCADesign users to quickly conduct whole building LCA (Tobias and Haymaker 2007).

The CRC CI has trialled LCADesign in real world pilot projects in Australia, The Netherland, California and Germany in partnership with commercial providers, since 2005. The Dutch pilot tested an LCADesign prototype that accounted for resources, energy and pollution associated with operations from acquisition, refining, manufacture, transport and assembly to construction plus maintenance and replacement phases considering renewal schedules. The new version commercialise late in 2007 conducts operational energy and water LCA as well.

3.1 What LCADesign Does

LCADesign integrates outputs of global standard:

- BIMs used in modern design documentation practice;
- life cycle costing for economic prices and schedules considering service life;
- ISO 14000 EMS LCA methods for improvement assessment;
- LCI databases of national building industry supply chains and
- EcoIndicator-99 LCIA methods to calculate mid-point damages and impacts.

The software factors BIM volumetric data with rules defining design element compositions and densities, LCI results and LCIA algorithms to produce a 4^{th} D, an ecoprofiling dimension: via LCA of building models. Results can be as LCI, EcoIndicator-99 defined damages and impacts as well as single point scores. Users may choose standard and eco-preferred selections or develop new rules linked to extensive LCI datasets. Figure 1 depicts how it works as users:

1. create and import a CAD mode saved as an IFC file into LCADesign;
2. tag objects by group type and apply reasoning rules to link tags with material inventory;
3. select metrics to calculate LCA results and display environmental impact
4. compare selected and eco-preferred options to show improvements.

LCADesign produces eco-profiles in charts of relative intensity per square metre floor area (M2) for e.g. walling and fenestration to compare intensities of resource input and pollution output LCI, plus carcinogens, climate change and fossil fuel impacts as well as damages to human health, ecosystem quality and resource depletion. It also calculates an eco-point score normalised to average per capita annual impact. With such indicators users can view and apply changes to reduce particular or total score or drill down through breakdowns of results in exportable tables and charts.

For example Figure 1.4 shows LCADesign of 35 year old 7668 m2 offices in Melbourne, Australia made of reinforced concrete slabs, beams and encased steel columns with steel edge beams (Seo et al 2004). The column chart shows floor finishes associated with highest embodied resource depletion. This was from four new installations of renewable sheep wool pile jute fibre hessian-backed carpet over 35 years but with carbon sequestration completely offsetting the building shell’s climate change impact.

4 Dutch LCADesign Pilot

Slavenburg BV, a Dutch company piloted LCADesign in the Netherlands on a new 25,000 m^2 gross floor area office building with a 13,000 m^2 semi-basement car park for 1000 office workers in Rotterdam. The client for this pilot was KPMG, an international audit, tax and advisory services company. To deliver the best value proposition for budget and add value from integrating design & construction disciplines KPMG applied a new procurement strategy using a DesignBuild rather than traditional tendering.

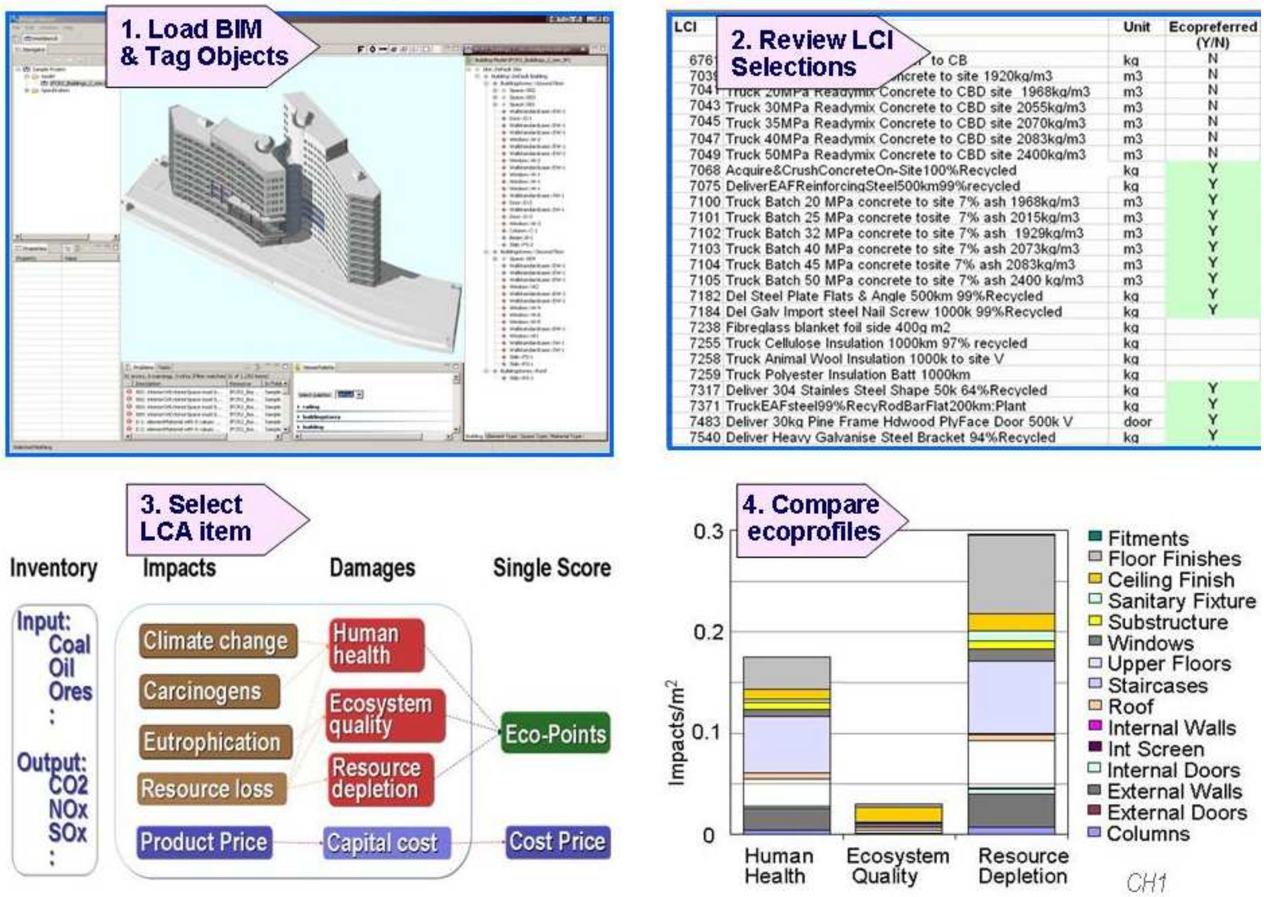

Figure 1 Four steps in LCADesign

4.1 Procurement: Design Build Versus Traditional

Traditionally design and construction are distinctly separate stages when a client's architect designs and documents a brief and tenders for a contractor whose bid is selected usually on price. In DesignBuild projects are tendered on preliminary design with room for bidding parties to add value to the proposition. For sustainable building it contractually provides one point of responsibility for project delivery plus integrated:

- project management of otherwise fragmented processes, and
- decision-making to leverage economic and environmental cost savings.

Another advantage is that with such contracts contractors can apply their sustainable building knowledge to integrate effort from design concept and detailing through construction scheduling and BIM applicable in Facility Management and disposition. While WBCSD (2007) reports stakeholder consider investment in sustainable building is too expensive, Huysmans et al (2007) argue that integration can save costs when contractors invest in sustainability measures right from project initiation through building delivery to handover.

4.2 Pilot Analysis Results

At the time of the pilot the Dutch real estate market was not strongly driven to conduct full building LCA as it was considered a research tool rather than a building tool. In fostering innovation, it was more feasible for Slavenburg BV to conduct an LCADesign Pilot. as they lead the KPMG project and could integrated effort fully throughout the project. The pilot compared a Dutch-developed GreenCalc spreadsheet tool against the Dutch version of LCADesign with GreenCalc analysis on three Dutch reference buildings by TU Delft compared to LCADesign of substructure, structure and inner floors and walls.

In the KPMG project pilot the building shell and interior structural elements from underground garage to level 14 were analysed by level. Figure 2a show level 1 with highest damages to resource depletion, ecosystem quality and human health from in situ slab and beam cast concrete floor elements. Had >95% recycled steel electric arc furnace rather than basic oxygen furnace steelmaking route 8% scrap steel been available for this high strength low alloy steel application it would avoid the extra damage.

Figure 2b shows contributions of embodied water and greenhouse gas to the Eco-Indicator 99 point score where inner upper floors have higher embodied water and greenhouse gas. Roofing had high embodied water from steel coil rolling, quenching and finishing operations.

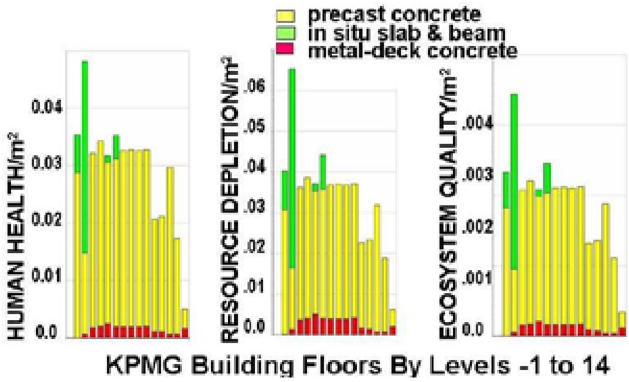

Figure 2a Shell Concrete Impacts by Level

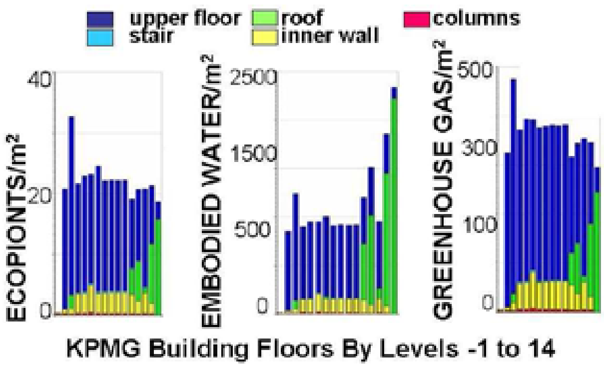

Figure 2b Internal Element Impacts by Level

4.3 Issues Arising during the Dutch Pilot

Slavenburg was responsible for building design, production and delivery so once the commitment was made it was feasible to produce a BIM. Producing one entails more effort in the earliest design stage to derive many benefits later in concurrent engineering, 4D construction modelling and in facility management phases (Huysmans et al 2007).

Traditionally with different partners responsible for different parts of the whole construction process, it is most difficult to develop and apply such integrated tools. From the outset of the pilot the Dutch construction sector was found to be underdeveloped in BIM capability to support design and construction companies in Architecture, BIM development as well as Scheduling.

Because Dutch architects are rarely given the time and money to produce elaborate models was one reason why Slavenburg found lacked experience in producing BIMs for the LCADesign pilot. Nevertheless a new BIM was produced from scratch separately by an architect in Melbourne Australia. So the dominant and traditionally fragmented procurement approach with different liabilities and responsibilities had created an adverse climate for BIM development.

During BIM development barriers arose including stakeholder aversions to advanced ICT, iterative processes and client involvement. There was scepticism that advanced ICT could be reliable, accurate and add value to project delivery processes, communications or workflow.

Project partners prefer not to handover preliminary designs and have them resurface later as the architect responsible and liable for detailed design models strictly control exposures. But a good LCA in design development depends on being able to change it on lessons learned. So project partners need to anticipate, enable and control an iterative process. The LCADesign pilot was a very ‘open’ and ‘honest’ way to assess design on environmental impacts but project teams fear openness as clients may make more changes that interfere with and delay schedules.

4.4 Key Learnings

From the inexperience, delays and aversions the project partners determined that the local industry needed to learn more about and adapt to BIM development. They also suggest that in future project partners needed to become more confident about increasing reliance on ICT where the program does the work. Delays in developing the BIM meant LCADesign analysis was already too late to influence most design decisions.

Nevertheless the pilot study showed the partners how to further improve building performance and Slavenburg has since completed a second LCADesign pilot on another new building in design development.

5 Global BIM Drivers, Obstacles and Advantages

Jones et al (2006) BIM find uptake is set to increase building design, construction and management productivity and quality. Building information modelling delivers a continuous flow of high quality, reliable, integrated and fully coordinated information on project design scope, schedule and cost concerns with:

- Valuable design information and data in digital easy to update, share formats;
- Consistent real-time relationships between digital design data and parametric models.
- Models exploited throughout design, construction and management of building lifecycles.

An Autodesk (2004) poll found ICT was changing business and professional practice with.

- More clients expecting more sustainable intelligent integrated buildings, automated performance and more advanced professional service delivery.
- A shift toward design-build and integrated service delivery with speedier collaboration, virtual project teams and management, stronger collaboration creating more sophisticated service delivery.
- Calls for simultaneous rather than sequential decision-making processes with collaborative services and new design authoring tools focused on enhancing process.

Significant leadership challenges are presented with significant change required to shift entrenched thinking and behavioural patterns in industry providers. Multidisciplinary providers in architecture, construction and real estate organisations and champions are to drive these changes forward. Building owners, however, may become primary drivers of change to recoup advantages in intelligent facilities (Jones et al (2006)).

As a design, delivery, and management approach BIM offers new data-driven models and building lifecycle management solutions facilitating a design firm’s capacity to do building and sustainability performance analyses in-house. Benefits include:

- Provision of integrated coordinated models and visualisation of the end product in 3-D,
- Helping clients visualise future buildings and scheduling in project delivery,
- Interference detection prior to construction which reduces waste and errors, and
- Accessible information for more-accurate early-pricing and better management (Jones et al (2006)).

Owners are increasingly demanding and paying for digital models. When models are used effectively, architects can employ a project's digital design data to provide new services including move management, energy analysis, digitally integrated cost estimating and renovation phase planning for additional fees and gain new sources of income.

5.1 Technologies Involved

In modern design and documentation software BIM is established and used to simulate building elements as 3D objects volume and space in a geometric building modelling environment, to generate 2D documentation and extract object data to provide information about element quantities and properties. LCADesign requires such an object model of drawn objects, tagging of element functions, attribution of accurate quantities to objects and application of generic or creation of new formulas and rules that define all groups of objects and composition of all product types in the building that are to be analysed.

BIM technology helps coordinate various building representations in documentation and as it is data-rich data its functionality can extend into building information modelling. Being CAD-based it can be easy to implement and yield immediate benefits with little or no process change. Effectiveness is contingent on user discipline and reliability and it cannot ensure high-quality, reliable, integrated and fully coordinated information needed for highest levels of building information modelling benefits (Jones et al (2006)).

5.2 Benefits In Design, Construction And Management In Use

In the traditional design phase untimely changes to work scope, schedule and costs waste time and money during a project. With building information modelling more critical information is immediately on-hand so decisions can be made more quickly and effectively. Project teams are able to:

- Make changes in design or documentation without re-coordination and manual checking;
- Do all design and documentation work concurrently;
- Automatically coordinate change consequences to eliminate mistakes and improve work, and
- Create visualisations and regulatory approval documents for faster better work outcomes.

In the construction phase by exploiting building information modelling then data on quality, schedule, and cost is concurrently available. The builder can accelerate quantification of building elements and activities for estimating and value-engineering purposes and update estimates and schedules.

The consequences of proposed or procured products can be more easily studied and understood, so the builder can quickly prepare plans showing site use or renovation phasing for the owner which communicates and minimises the impact of construction operations on the owner's operations. Better document quality and construction planning also means that less time and money is spent on construction process and administration issues and more of the owner's construction dollar goes into the building than into administrative and overhead costs.

In the management in-use phase such building information modelling can deliver concurrent information on building usage, performance; occupancy, contents, performance life and financial aspects over future times including:

- Digital records of renovations and improve move planning and management.
- Acceleration and adaptation of standard prototypes to site conditions in large estates.
- Physical data on finishes, tenancy assignments, furniture and equipment inventory.
- Financial data on lease-able areas, rental income, cost allocations for management.
- Consistent access to information to improve revenues and cost management (Jones et al (2006)).

6 Green Development

From 2008 new EU legislation on building energy use will apply an Environmental Product Data Management (EPDM) standard to assess the energy-use of buildings. With the current Dutch EPDM standard most new buildings built under current legislation will get the highest score 'A' rating so it will only improve building sustainability if partners go beyond 'A' ratings. To improve such outcomes one imperative is to further develop and exploit the sustainable building business case facilitated by tools like LCADesign. Mapping LCADesign to ratings such as the Australian GBC GreenStar USA GBC LEED systems is underway. Members of the Dutch and Australian construction industry also need to make the different quality of more sustainable buildings transparent and to pressure developers, contractors, architects and investors to show stronger progress.

7 Conclusions

The paper discussed a Dutch pilot of LCADesign, new CRC CI software that automates building environmental assessment. Experiences were discussed from a Dutch DesignBuild procurement strategy to integrate effort and pilot novel approaches to support practitioner decision-making for sustainable building. Barriers found included some aversions to ICT, iterative processes and client involvement. The Dutch construction sector was found to be underdeveloped in ICT to support the business and partners found industry needs to adapt to BIM development.

The authors discussed how LCADesign can provide quantitative dimensionally relevant building environmental assessment effectively, quickly and cost effectively. The paper also outlined an emerging business case for adoption of LCADesign based on meeting the need for fast country-specific user-friendly quantitative eco-profiling software to assess specification, procurement and design. The main benefit of LCADesign is the ease of deriving dimensionally relevant eco-profiles without re-entry of data as it allows:

- rapid analysis with data already in the software used to calculate eco-profiles;
- users to almost eliminate error from manual data entry, and
- re-analysis of altered designs to optimise eco-efficiency.

In striving for a more environmentally sustainable construction industry, ratings and real estate it is important to adopt new approaches to facilitate integrated project management and ICT so developers, contractors, architects and investors can better work together. Recommendations for further industry development include that procurement and design should increasing specify delivery of building information model with industry foundation class software to uptake the advantages from BIM.

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ENERGY-ENVIRONMENTAL RETROFIT OF AN EXISTING BUILDING: FROM ZERO TOWARDS BEST PRACTICE ENVIRONMENTAL SUSTAINABILITY LEVEL

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Summary

ITC-CNR carried out a specific energy retrofit case-study which includes the assessment of the environmental and energy sustainability of a building and the support to the definition of construction and technological solutions with low environmental impact involving the application of RES systems integrated into the building.

This case-study consists in the assessment of the energy, environmental and economic performances of a residential/commercial building design located in Northern Italy, conducted by ad hoc assessment tools, such as SBTool (assessment in a holistic approach), PHPP (energy analysis) and RetScreen (RES application feasibility study), aimed at pursuing the "best practice" solutions in a specifically defined performance scale, supporting designer's activities.

Costs analysis were also lead in order to prove that the solutions presented affordable investment costs and remarkable advantages on the energy efficiency and indoor comfort. The developed analysis related to the extent of the main renovation interventions investments on the envelope and systems, the relative simple payback times, the externality costs of the interventions and the LCC analysis of the applied technological and constructive solutions.

The case study allowed to verify the possibility of bringing a zero level building close to the best practice level by applying efficient technical and economic solutions.

1. Methodological approach

The energy-environmental performances of the building design were assessed by means of SBTool (the GBC system tool). The assessment was based on the calculation of a certain number of performance indicators relative to the building, divided into categories and assessment areas, which were assigned a score.

Each score was calculated according to laws and regulations in force or to the methods described in the technical-scientific literature, at times with the help of ad hoc calculation programs such as PHPP [3], for the heating primary energy requirement and RETSCREEN [4] for the energy contribution from renewable resources; scores were assigned by comparing the calculated indicator values with those of the relative performance scales, defined in advance. Once the building was evaluated, the analysis of the performance indicators scores led to hypothesize improving interventions aimed at enhancing its energy-environmental performances with better regard to the criteria which have recorded the worst scores. After bringing about the foreseen modifications, the energy-environmental performances of the new building design were newly assessed to demonstrate they had improved: in fact the objective of the interventions was to bring the building sustainability level to the "best practice" score (level "3").

1.1 SBTool

SBTool was contextualised for the verification of the environmental sustainability of a building (or a project) through a series of steps listed as follows:

1) <u>Definition of the "assessment checklist":</u> selection of the criteria for the energy-environmental assessment of the building. Regarding typology, intended use and life-cycle of the building the most convenient criteria are chosen in order to determine and assess its energy-environmental performances (SBTool

suggests a maximum number of 145 criteria but the person in charge of the assessment can modify the system by choosing the number of criteria that best suit his needs).

2) "Weighting": assignment of relative weights to the single criteria. In consequence of the evaluation of building construction type and general context (State, Region, location…), the criteria are assigned different important degrees so that they can contribute to different extents to the definition of the final result.
3) "Benchmarking": definition of performance values scale (benchmarks) for each performance indicator. The benchmark scale is defined relating to the building energy-environmental performance criteria from a base level to a best practice level, to which compare the different technological and construction solutions of the building to be assessed.
4) "Assessment": assessment of the design solutions with respect to the pre-defined benchmark levels. Each criterion gets a score by comparing the performances of the building that has been assessed with the formerly defined benchmark values.
5) "Rating": final score calculation of the building environmental sustainability level by aggregating and weighing the single criteria assessment scores.

SBTool is composed of six connected files in worksheet format, each of which has to be filled in by the actor concerned. The assessment involved the following three actors:

- designer: his task is to derive and enter the design input data into the tool in order to proceed with its sustainability assessment;
- person in charge of the assessment: his task is to check the input data accuracy and adjust criteria weights according to the design typology;
- third party (i.e. public administrator): his task is to fix the benchmark values and all the parameters which concern the intervention context (i.e. weather data location).

The design assessment is based on the weight of the different parameters which are ordered in groups and characterized by a progressive subordination relation one another: criteria, categories and assessment areas. At each level the assessment scores vary in a range from –1 to a maximum of 5, defined as follows:

-1 represents a performance below the standard and the current practice;
0 represents the minimum acceptable performance level defined by laws and regulations in force, or if no reference standard applies, it represents the current practice;
3 represents a significant improvement over current standards and practice, it's considered as the best current practice;
5 represents an experimental considerable improvement with respect to the best current practice

The scores assigned to each criterion are weighted and aggregated to define the scores of the categories which are in turn weighted and aggregated to define the scores of the assessment areas; the weighting and aggregation of these last scores give the building final score.

2. Description of the case study

The design to be evaluated with the assessment tool formerly described is the executive design of a building, named Porta Mulina, located in a sub-urban area in the North-west of the city of Mantova, in Northern Italy. It is a three-floor building with different intended uses: car park (in the basement – below grade), commercial area and dwellings for families and students.

It is located in a developing suburban area characterised by an intensive building trade and with the following features:

- presence of a lake;
- presence of historical value buildings together with new service building complexes (university, hospital, etc);
- location in a village on the outskirts of the city and linked to it.

The building has a net surface of 2,457 m^2 (excluding car park) composed of a commercial area located on the ground floor and a residential area of 24 housings located on the three above-ground floors; this last area is basically divided into two parts: the Northern side where the family dwellings are located and the Southern side dedicated to students housings.

It is also provided with a basement car park (below grade) and an external parking area, which is going to be integrated with green areas.The building is fitted with a gas-powered heating system which supplies heat through steel baseboards. The number and disposition of hot-water and heating boilers can vary depending on to the building intended use: in the students dwellings there are two boilers on each floor (one every three housings), the family dwellings have an independent heating system while the commercial area has a central heating system.

Figure 1 First floor plan

Figure 2 West prospect

2.1 Building design assessment

The building environmental sustainability assessment was led with SBTool considering the following assessment areas: Site Selection, Project Planning and Development, Energy and Resource Consumption, Environmental Loadings, Indoor Environmental Quality, Service Quality, Social and Economic Aspects.
The six assessment areas were chosen among the seven areas proposed by SBTool: areas B, C and D are compulsory to perform the assessment while the others can even not be included in the evaluation. Weights were assigned basically by adopting the default values suggested by SBTool and adapting them, where necessary, according to the design needs. Each area is divided into categories and each category into criteria. For the purpose of the case-study twenty criteria were examined; they are listed in the following table together with their relative weights. Criteria can be quantitative, then associated to a numeric indicator, or qualitative, then related to a scenario.

The benchmark values of the performance scales relating to which scores are assigned to criteria, categories, assessment areas and to the building, were defined according to certified and recognized methods referring to laws and regulations in force or, if lacking, to updated specialized publications. In some cases SBTool default values were used.

Table 1 Evaluation criteria

	CRITERIA		WEIGHTS within group
A	**Site Selection, Project Planning and Development**		**4.8%**
A1	Site Selection		0.0%
A2	Project Planning		50.0%
	A2.1	Feasibility of use of renewables	60.0%
	A2.7	Collection and recycling of solid wastes in the community or project	40.0%
A3	Urban Design and Site Development		50.0%
	A3.3	Encouragement of walking	60.0%
	A3.4	Support for bicycle use	40.0%
B	**Energy and Resource Consumption**		**23.8%**
B1	Total Life Cycle Non-Renewable Energy		38.5%
	B1.1	Annualized non-renewable primary energy embodied in construction materials	25.0%
	B1.2	Annual non-renewable primary energy used for facility operations	75.0%
B2	Electrical peak demand for facility operations		0.0%
B3	Renewable Energy		38.5%
	B3.2	Provision of on-site renewable energy systems	100%
B4	Materials		0.0%
B5	Potable Water		23.0%
	B5.2	Use of potable water for occupancy needs	0.0%

C	**Environmental Loadings**		**23.8%**
C1	Greenhouse Gas Emissions		100%
	C1.2	Annual GHG emissions from all energy used for facility operations	100%
C2	Other Atmospheric Emissions		0.0%
C3	Solid Wastes		0.0%
C4	Rainwater, Stormwater and Wastewater		0.0%
C5	Impacts on Site		0.0%
C6	Other Local and Regional Impacts		0.0%
D	**Indoor Environmental Quality**		**23.8%**
D1	Indoor Air Quality		25.0%
	D1.3	Off-gassing of pollutants from interior finish materials	33.3%
	D1.8	IAQ monitoring during project operations	66.7%
D2	Ventilation		25.0%
	D2.1	Effectiveness of ventilation in naturally ventilated occupancies	100%
D3	Air Temperature and Relative Humidity		25.0%
	D3.2	Air temperature in naturally ventilated occupancies	100%
D4	Daylighting and Illumination		25.0%
	D4.1	Daylighting in primary occupancy areas	100%
D5	Noise and Acoustics		0.0%
E	**Service Quality**		**9.5%**
E1	Safety and Security During Operations		0.0%
E2	Functionality and efficiency		37.5%
	E2.5	Spatial efficiency	50.0%
	E2.6	Volumetric efficiency	50.0%
E3	Controllability		37.5%
	E3.4	Degree of personal control of technical systems by occupants	100%
E4	Flexibility and Adaptability		0.0%
E5	Commissioning of facility systems		0.0%
E6	Maintenance of Operating Performance		25%
	E6.3	Development and implementation of a maintenance management plan	100%
F	**Social and Economic aspects**		**14.3%**
F1	Social Aspects		100.0%
	F1.2	Access for physically handicapped persons	50.0%
	F1.3	Access to direct sunlight from living areas of dwelling units	50.0%

Once all the indicators have been calculated and all the scenarios hypothesized and after comparing them with the benchmark values, each criterion is assigned a score. These scores, weighted and aggregated, provide the category scores and the assessment area scores. The final building score results from the weighting and aggregation of these last ones. The building design calculated score was equal to 0.0, which corresponds to a barely acceptable sustainability level. Four assessment areas out of six got a higher score, although not significantly higher, but the two areas with a negative score are those with the greater weight and therefore they weigh on the final score of the building.

2.2 Improving interventions

The building design was subjected to some improving interventions in order to bring its sustainability level form the minimum value to the "best practice" one. The adopted solutions can be grouped in the following design actions:

- integration of systems using energy from renewable sources
- modification of façades
- modification of the internal and external distribution of housing units
- three-dimensional development of the ground-floor
- modification of opaque and transparent partitions
- modification HVAC and electric systems
- preparation of a maintenance plan

Each action affected one or more assessment indicators thus modifying the score resulting from the corresponding criteria evaluation. The adopted operational design actions aimed at improving the energy-environmental performances of the building design are listed as follows and grouped according to the criteria they have influenced (if an action is listed more than once it is because it affected more than one criterion).

Table 2 Assessment area A: Site Selection, Project Planning and Development

criterion	Improving actions
A.2.1	- solar PV and solar thermal system analysis led with RetScreen software - design of a solar PV on-grid system - design of a solar thermal system for district hot water with RetScreen software

A.2.7	- setup of an inorganic waste disposal plan
	- arrangement of areas for separate collection of rubbish
A.3.3	- creation of outdoor green areas and parking areas; vehicle admittance is restricted to residents
	- arrangement of facilities for disabled people connecting the raised square to the sidewalks
A.3.4	- creation of bicycle parking areas in the basement of private housings
	- arrangement of a bicycle parking area inside the building for special housings
	- arrangement of bicycle parking areas in the roofed parking area for commercial area users

Table 3 Assessment area B: Energy and Resource Consumption

criterion	Improving actions
B.1.1	- replacement of all the insulating synthetic materials with non-toxic and wood-fibre materials
	- replacement of wooden door and window frames with PVC frames
B.1.2	- decrease in the thermal transmittance value of roofs, walls and floors towards non-heated zones
	- use of low-emission glasses and certified PVC frames
	- modification of the East prospect and creation of overhangs projecting from the wall's plumb-line and full-height corner windows
	- ad hoc insulation for all shape and material discontinuity points (except for the landing)
	- modification of the hot water supply system
	- modification of the number of building boilers and of hot water delivery and return pipes
	- modification of the heating system typology
	- use of low consumption lighting devices
B.3.2	- design of a solar PV on-grid system
	- efficiency and productivity analysis of the PV system
	- design of a solar thermal system for district hot-water
B.5.2	- use of low water flushing systems for WCs
	- use of taps and fittings for the commercial area with controlled delivery

Table 4 Assessment area C: Environmental Loadings

criterion	Improving actions
C.1.2	- decrease in the thermal transmittance value of roofs, walls and floors towards non-heated zones
	- use of low-emission glasses and certified PVC frames
	- ad hoc insulation for all shape and material discontinuity points (except for the landing)
	- modification of the hot water supply system
	- modification of the number of building boilers and of hot water delivery and return pipes
	- modification of the heating system typology
	- use of low consumption lighting devices

Table 5 Assessment area D: Indoor Environmental Quality

criterion	Improving actions
D.1.3	- replacement of all the insulating synthetic materials with non-toxic and wood-fibre materials
	- replacement of all the used materials with equivalent ones holding a certificate of non-toxicity
	- use of non-toxic photocatalytic paints
D.1.8	- setup of an annual plan of indoor environment monitoring
D.2.1	- design of family dwellings living rooms with window openings on different sides
	- design of family dwellings bedrooms with window openings on different sides
	- use of mobile partition walls between living room and study area in the students housings
	- use of open space partitions in the commercial area between utility rooms and exposition rooms
	- openings on the different sides of the housing units located at the corners of the building
D.3.2	- decrease in the thermal transmittance value of roofs, walls and floors towards non-heated zones
	- use of heating radiant floors in order to maintain an even indoor temperature
D.4.1	- modification of the window opening size
	- modification of the type of window frame
	- use of wall-embedded subframes instead of internal flush subframes
	- use of low-emission glasses with a high lighting transmission factor

Table 6 Assessment area E: Service Quality

criterion	Improving actions
E.2.5	-
E.2.6	-
E.3.4	- installation of separate counters for heating and hot water supply systems
	- installation of on/off devices for water supply within commercial and dwelling areas
	- arrangement of a radiant floor heating system with independent take-off branches for each heated zone
	- monitoring system of zone temperatures (thermostats), independent for each heated zone
	- installation of on/off devices for heating supply within commercial and dwelling areas
E.6.3	- setup of a 25-year maintenance plan

Table 7 Assessment area F: Social and Economic aspects

criterion	Influencing actions
F.1.2	- arrangement of a students apartment accessible to disabled people on each floor
	- arrangement of a bathroom accessible to disabled people in each housing unit
	- arrangement of a bathroom accessible to disabled people in each commercial unit

	- arrangement of 14 car-parks reserved to disabled people within the roofed parking - design of external driving ramps to connect different levels that can be used by disabled people (max slope 8%, intermediate landings every 10 m, continuous handrail 70 cm high), except for the driving ramp
F.1.3	- modification of the East prospect involving the creation of overhangs projecting from the wall's plumb-line and corner south-facing windows in order to facilitate sun penetration in high-occupancy areas (living room areas for family dwellings, study areas for students dwellings)

The new building design was assessed with SBTool and was assigned a new score. The following tables and graph synthesize and represent graphically each assessment area score and the building final score before and a after the improving intervention; some absolute calculated results referring to significant criteria and representative of the building energy performance are listed too.

Figure 3 Comparison between the graphs of weighted scores of the existing building and the improved one

Table 8 Comparison between the weighted scores of the two cases-study

			Existing building	Improved building
A	Site Selection, Project Planning and Development	5%	**0.2**	**3.1**
B	Energy and Resource Consumption	24%	**-0.3**	**3.0**
C	Environmental Loadings	24%	**-0.2**	**2.7**
D	Indoor Environmental Quality	24%	**0.1**	**2.6**
E	Service Quality	10%	**0.5**	**1.9**
F	Social and Economic aspects	14%	**0.4**	**3.7**
	Total weighted building score		**0.0**	**2.8**

Table 8 Comparison between the absolute performances of the two cases-study

		Existing building	Improved building
1	Total net consumption of primary embodied energy for structure and envelope, GJ/m2	37.8	32.1
2	Net annualized consumption of embodied energy for envelope and structure, MJ/m2*yr.	378	321
3	Net annual consumption of delivered energy for building operations, MJ/m2*year	476	176
4	Net annual consumption of primary non-renewable energy for building operations, MJ/m2*yr.	478	181
5	Net annualized primary embodied energy and annual operating primary energy, MJ/m2*yr.	856	503
6	Total on-site renewable energy used for operations, MJ/m2*yr.	0.0	21.6

The hypothesized design variation for the arrangement of Porta Mulina led the building to score a total of 2.8, just a bit less than the best practice sustainability level. By analysing each assessment area scores it seems evident that only one area (E: service quality) got a lower-intermediate sustainability level, lower than 2, whereas all the others got high scores in almost all criteria.

The energy-environmental performances of the building have globally improved (in fact the ones that remained on constant values were already referring to well scored criteria): it means that it is possible to apply retrofit actions to improve the energy-environmental sustainability of a zero level building improving its weak points and without worsening its initial positive performances.

2.3 Is the investment convenient?

In order to assess if the future stream of benefits can justify the costs of the above mentioned interventions, a cost benefit analysis was lead. It involved a comprehensive economic evaluation of all the costs and benefits associated with the proposed project options, including financial, environmental and social ones. The objective was to determine the most economical use of resources.

The first step was to quantify costs and benefits: in this case study cost inputs included the cost of the improving interventions and external costs, such as the CO_2 emissions[1]. Besides benefit inputs included energy-savings and emissions avoided. In order to check if the present value of all the benefits exceeded the present value of all the costs the Net Present Value (NPV) was calculated together with the Internal Rate of Return (IRR) of the two options: the existing building and the improved one.

The cost of the interventions was calculated by using the Work Breakdown Structure (WBS), that is a referenced project tool[2]. The WBS comprises discrete work packages, called elements, that describe a specific item. By descending levels of the WBS, elements get greater and greater detail. The number of levels of the WBS depends on the size and complexity of the project. In this work, the decomposition was carried out at the level of individual elements. The following table show the costs difference for each major group of building elements.

		Existing building		Improved building	
	Total cost (€)	**1.836.179**		**2.094.611**	
00	Site works	137.882	7,5%	149.515	7,1%
01	Structures	373.263	20,3%	499.196	23,8%
02	Closures	485.947	26,5%	508.560	24,3%
03	Interior partition	434.431	23,7%	463.136	22,1%
04	Exterior partition	43.237	2,4%	19.213	0,9%
05	Energy systems	213.664	11,6%	349.430	16,7%
06	Other plants	104.716	5,7%	105.562	5,0%

Figure 4 Comparison between the costs of construction of the existing building and the improved one (%)

The total cost of the improved project resulted bigger than the existing one (+ 14,07%). The group of elements that affected more this increase was the energy systems one (from 11,6% to 16,7%). According to this result, it was very meaningful to verify whether the investment was convenient, considering its benefits spread over many years.
Costs and benefits were discounted using a discount rate of 8% during a period of 30 years in order to not calculate the costs of special maintenance interventions[3].

The investment performance criteria considered were Net Present Value (NPV) and IRR (Internal Rate of Return), including both the financial analysis and the economic one. Even if these indicators were applied just to the buildings and not to the whole territorial system, interesting outcomes emerged. The NPV of the investment concerning the existing building resulted positive (€ 7.000) and the IRR was equal to the discount rate (8%). It means that was quite indifferent to carry out the investment or not. Considering the benefits rising from the environmental strategies adopted by accounting the externalities (reduction of general environmental costs), the NPV resulted more than twice the NPV of the existing building (€ 16.000) and the IRR was a little higher than the discount rate (8,1%). In this case benefits were double: private benefits concerning the cut of energy costs and public ones regarding the reduction of CO_2 emissions.

The conclusion is that it is important to get incentives from local governments both in term of promoting the use of energy efficiency measures and in term of direct subsidies. Furthermore, incentive policies would allow an increase of demand of such technologies and the consequent reduction in prices according to the market laws.

It is also meaningful to underline that the Cost Benefit Analysis should be applied in two different steps of the investment project: *ex-ante* (before designing) in order to evaluate different options and *ex-post* (after designing) with the aim of monitoring the outcomes of the investment.

3. Conclusions

The described analysis underlined the importance and utility of multicriteria approach tools, like SBTool, to design energy efficient and environmental sustainable buildings both in the primary design phase (ex novo or retrofit) as a support to design, and at the end of the project, for the global building assessment. This

[1] The costs of CO_2 emissions were calculated with according to the methodology proposed by the ExternE Project (see References).
[2] A Work Breakdown Structure is a results-oriented family tree that captures all the work of a project in an organized way. Considerable thought and planning should be given to its development and implementation so that subsequent changes are minimized.
[3] The cost of usual maintenance interventions was the only one took into account.

analysis focused on the former aspect in order to verify whether the improving actions hypothesized for a building design could actually improve its energy-environmental sustainability level.

A preliminary assessment of the building is important because the choice of efficient envelope and technological systems solutions, with a low impact on the environment, can be already addressed in the first design phases, by setting as targets the specified best practice indicators in the criteria performance scales. Also, when there are big gaps between targets and building performances, it is possible to correct them by acting on its envelope and systems features, in order to obtain a globally positive assessment. Obviously the use of tools and approaches which innovate the current design practice may make it necessary to develop new professionals able on the one hand to plan and manage an integrated design approach, where the different involved professionals interact, and on the other hand to support the designer regarding highly specific subjects related to the energy efficiency of the building, indoor comfort, environmental impact and so on.

Costs analysis were also lead in order to prove that the hypothesized solutions presented affordable investment costs and remarkable advantages on the energy efficiency of the buildings.
Energy and environmental issues on a global scale and the higher and higher performance requirements of final users show how topical is the need of objective and referenced assessment tools. They should be used together with costs-benefits analysis tools in order to prove the economical sustainability of the project.

The developed analysis intended to test the actual resources needed for this innovative approach on a real study case, with expected positive results for all the involved stakeholders: the case study management allowed to verify the possibility of bringing a zero level building close to the best practice level by applying efficient and effective technical and economic solutions.

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SOLAR ENERGY SYSTEMS INTEGRATED IN LOW-ENERGY BUILDINGS. STRATEGIES AND BUILT EXAMPLES FROM CZECH REPUBLIC

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Summary

In the first part, the paper summarizes basic information about solar energy under local condition of the Czech Republic and brings general ideas about possible way of expressing the energy performance of a building. It is suggested to create an energy matrix with information about energy needs and energy used by different energy carrier, considering the energy savings due to better energy standard in the same way. The second part of the paper informs about new development of residential area consisting of 13 passive houses. The priorities (renewable materials, renewable energy) and overall design approach are discussed. The final results are presented. The PV-systems are used at two houses, the first one is equipped by 8,45 kWp on-grid system, roof integrated. This house reached the level of zero-energy house, considering the energy demand and production within one year. The design of the second house was focused on energy security: a back-up system is combined here with PV in order to guarantee grid independent operation for 24 hours. The residential area is in operation since 2007. The zero-energy house serves as an information and educational centre. Long-time monitoring of energy parameters and indoor quality are running.

1. Solar energy use under real local condition

Solar irradiation can be understood as a significant energy source for buildings and especially low-energy and passive buidlings are known for its broad utilization. However, unlike convectional energy sources, solar energy can vary considerably with geographical location as well as in time. Furthermore, the amount of incident solar radiation can be decreased for many reasons, as for example by local shading, elevated horizon, pollution or high water vapor content in the atmosphere and others. Therefore it is crucial to perform a detailed study of really available solar energy before designing elements and devices for its active or passive use in buildings.

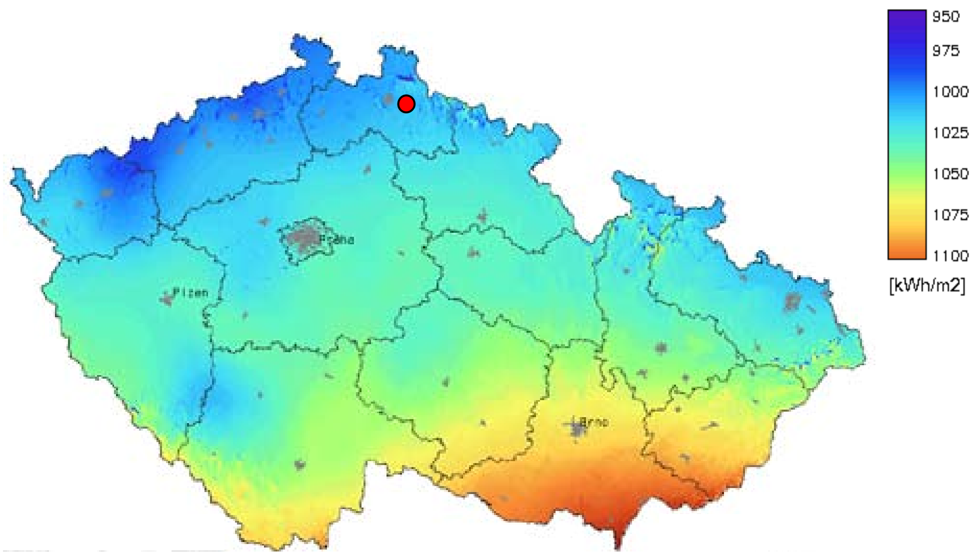

Figure 1 Solar map of the Czech Republic showing yearly sum of global irradiation on horizontal surface in kWh/(m2.a) [PVGIS]. The location of interest (Koberovy) is marked by a red dot.

Solar data for the location of interest are usually obtained from a meteorological database and common tools (Meteonorm, PVGIS) allow the user to get desired solar information based on selected slope, orientation and other parameters. The building designer then proceeds with more detailed analysis and optimizes solar energy use to match the overall building design.

In general, solar energy in the built environment can be used for passive and/or active solar heating, hot water preparation, cooling and electricity generation. As an example of solar energy utilization in passive house design, the Koberovy project is presented here. The Koberovy project consists of 13 passive houses located in the northern part of the Czech Republic (see Figure 1). The available solar radiation at the location was studied using Meteonorm hourly data. The total annual amount of solar radiation on horizontal plane is 1 030 kWh/m^2 from which 41 % comes as direct radiation and 59 % as diffuse radiation. Furthermore, 33 % can be expected in spring, 42 % during summer, 17 % in autumn and only 8 % in winter. From the very first stage of the design process it was assumed that a large-scale on-grid PV system and a solar thermal system for hot water preparation would be placed on a south facing 45° sloped roof. A standard analysis based on solar geometry and Perez model of diffuse radiation was performed in order to calculate the optimum position for each system based on the following strategy: The on-grid PV system would generate most electricity when placed in optimum position for year-long period. On the other hand, the solar thermal system providing hot water is most effective when generating heat evenly during the year, not exceeding the needs of the house in summer to an undesirable level. It was concluded that the optimum position for an on-grid PV system is at 35° south-oriented where 1 215 kWh/m^2 of available solar radiation can be expected (see Figure 2, left). Systems for hot water preparation should be optimized for April and September (100 % coverage, recommendation for central European conditions) resulting in the optimum of 50° south-orient ed which usually means coverage of 60 % to 70 % of annual energy need for hot water preparation. Furthermore, it was in question whether the solar thermal system can actively support heating. In this case the optimum position would be 60° south-oriented, c alculated for winter season. However, during this period only 145 kWh/m^2 of available solar radiation can be expected (see Figure 2, right), which would lead to ineffective over sizing of the system in terms of collector area as well as storage tank volume. It is a general problem when designing an active solar heating system for a passive house – the heating season is shortened to few months, during which the available solar radiation is low. One possible option is to place larger number of collectors, preferably in vertical position to avoid summer problems; another is to install a storage tank for seasonal accumulation. In case of the Koberovy project, it was decided to optimize the solar thermal system for hot water preparation only.

Next question was if to install the solar systems roof-parallel (45°) or whether to place them in the optimum position, i.e. 35° for PV and 50° for solar thermal , respectively. It can be seen from the solar analysis (see Figure 2) that the area close to the optimum position is rather flat meaning a certain deviation from the optimum is possible without much loss in solar energy gain. In the Koberovy project the solar systems were installed roof-parallel. In general, if the overall concept is strictly solar oriented, the building form should be adjusted accordingly. However, in many cases this is not possible due to lot orientation, local regulative, etc.

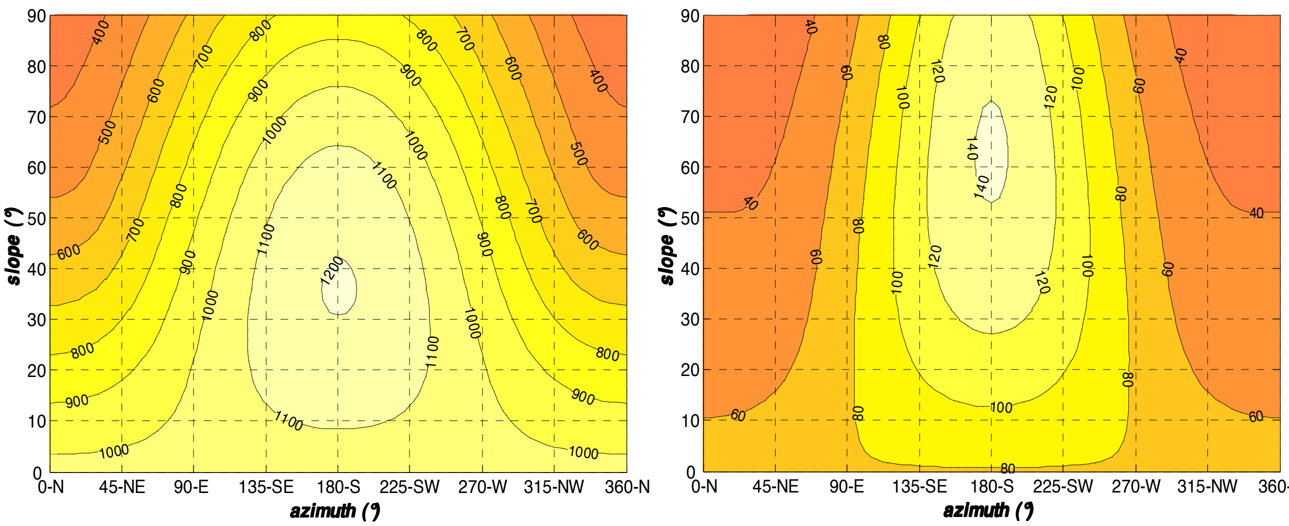

Figure 2 Yearly (left) and winter (right) sum of global irradiation on surfaces of various slopes and orientations in kWh/m^2 for the location of interest (Koberovy, Czech Republic) – based on Meteonorm data.

2. Energy problem consideration

2.1 Background

In generally, the overall energy problem of a house or other unit can be described in an *energy matrix*, bringing relations between all types of *energy demands* (typically: space heating, hot water, electricity for household technologies, electricity for appliances) and *energy carriers*. One of possible forms of such matrix is that the energy savings due to better building design compared to standard solution are classified as a special sort of energy carrier with zero negative impact on environment – see Table 1. As a standard solution one can understand the business-as-usual design, corresponding exactly to the current standard for particular case. Such a simplifying approach can help to set priorities concerning operation energy in the preliminary design stage.

The data in energy matrix can be expressed in the form of final energy (at the system boundary of the building) or – in more instructive way – in the form of primary energy (see Gemis, 2008).

Table 1 Operation energy matrix with examples of energy carriers

Energy service ↓		Energy carrier								
			Conventional			Renewable				Savings due to better building energy design
		Identification number	1.1	1.2	1.x	2.1	2.2	2.3	2.y	3
		Type	Gas	Electricity	….	wood	solar thermal	PV	….	
		conversion factor for primary energy →	1,1	3,0		0,05	0,05	0,2		0
A	Space heating									
B	Space cooling									---
C	Hot water									---
D	Electricity for technology									---
E	Electricity for appliances									---
F	Other									
	Total									

2.2 Studies on solar system integrations

From this perspective, the optimal use of solar energy is a logical further step in the development of passive houses - see Feist at al. (2007). The substantially reduced space heat demand to the today level of best-available technology (BAT) here represents about 1/3 of total energy need of the whole household unit only.

The sizing of solar thermal system for hot water preparation is limited usually by 60-70% covering of the yearly energy demand. Larger solar thermal installations can be effectively used for supporting of space heating also in the climatic condition of the Czech Republic, but only to limited extend. The corresponding heating system (low-temperature heating) has to be designed in parallel.

Therefore an integrated design approach is strongly needed here, starting at the first design study. Solar collector areas have to be placed close to vertical position on relatively large areas (façade installation, at balconies etc.), which could be very challenging for visual concept, too.

Another approach can be using building integrated photovoltaics (PV): Larger systems are usually connected to public grid, smaller PV-installations can serve as supporting systems for the particular house. In any case, an extra attention should be given to attractive visual form of installation, together with correct solution from building physics point of view.

From the point of view of architecture and building science, the term *solar system integration* is a real keyword that can be understood in different ways:

- Integration of a solar energy unit into the energy balance of the building
- Integration as an architectural design (visual) and structural problem
- Integration from a building-physics point of view
- Integration into building construction costs and operation costs schemes (project cash-flow), etc.

3. Residential area in Koberovy

3.1 Overall design approach

The concept of sustainable building was consequently followed by designing a new residential area in Koberovy (a village in the northern part of the Czech Republic, in a protected landscape area called Bohemian Paradise – see Tywoniak and Moravek (2006). Strong limits concerning the form of buildings are given here in order to reflect local tradition. Together 12 single family houses + one house of the same size and structure serving as an information and education centre for energy saving technologies are in operation since September 2007.

The design priorities were formulated by the developer at the beginning:

- urban concept allowing passive solar use together with privacy of clients
- passive house standard level or closed to should be reached
- maximum use of renewable construction material
- maximum use of renewable energy for operation of each house
- comparable investment costs with other developments in the region combined with very high indoor quality
- use of advantage the construction of all houses at the same time

Figure 3 Part of new residential area in Koberovy

3.2 Form and load bearing structure

The houses have timber framed load bearing structures completed by extensively insulated envelope. The slope of pitched roof was set by authorities at 45°, which is close to, but not an optimum either for solar thermal or photovoltaic systems. The houses have unified structure and form. They differ slightly in lengths and in the form of open car ports and garden service rooms only. The size and place of openings and the different surface layers of the walls (plaster on external thermal insulating system or wooden covering) were designed according to wishes of clients individually.

The structural solution consists of wooden skeleton in the first floor and nailed roof truss in the attic. Its bottom part creates the ceiling joist directly. The amount of structural timber is significantly reduced here compared to usual two-by-four system.

Note: In generally, the number of houses with timber structures is very low in the Czech Republic. Among low-energy and passive houses is their relative amount much higher, with increasing tendency. Two reasons are often discussed in this respect: The advantage of placing of higher thickness of thermal insulation without exceeding acceptable overall thickness of the building envelope and the minimizing of ecological footprint by using renewable materials.

3.3 Building envelope and details

Thermal transmittances of the building components were calculated carefully considering even small thermal bridging elements – see Table 2. All areas with significant multi dimensional heat transfer were quantified and included in U-values or added to the heat transmission, respectively.

Table 2 Thermal transmittance (U-Value) and heat transmission

Thermal transmittance	U [W/(m²K)]	
	Design values	Required values according (Czech standard)
Slab on grade	0,17	0,45
External wall	0,11	0,3
Pitched roof	0,09	0,24
Roof in attic space	0,09	0,24
Entrance door	1,14	1,70
Windows	0,84	1,70
Heat transmission (according to EN ISO 13790)		
Heat transfer coefficient	67,2 W/K	100 %
Ventilation heat transfer coefficient	6,4 W/K	↕ 6,4 %
Transmission heat transfer coefficient	60,8 W/K	93,6 %
Thermal bridges – total effect	1,4 W/K	(2,2 %)
Thermal bridges – positive	↕ +4,8 W/K	
Thermal bridges – negative	-3,4 W/K	

Table 3 Expected energy balance of a house with a large building integrated PV system

Energy service ↓	Energy carrier [MWh]						
	Type	Conventional	Renewable				Saving due to better building energy level[2)]
		Electricity	Wood	Solar thermal	PV		
	Primary energy conversion factor →	3,0	0,05	0,05	0,2	Total	0,0
Space heating		1,5	1,5	0,1		3,1	12,5
Hot water		0,4	0,3	2,1		2,8	---
Electricity for technology		0,9				0,9	---
Electricity for appliances		2,4				2,4	---
Total		5,2	1,8	2,2	*(7,7[1)])*	9,2	
Note: Division by energy carrier as a design assumption only. Thermal energy is collected in central accumulator regardless to its origin.							

[1)] *PV-generated electricity is not connected to the energy systems of the house.*

[2)] *Calculated for the parameters of the house's envelope according to Czech standards (2007)*

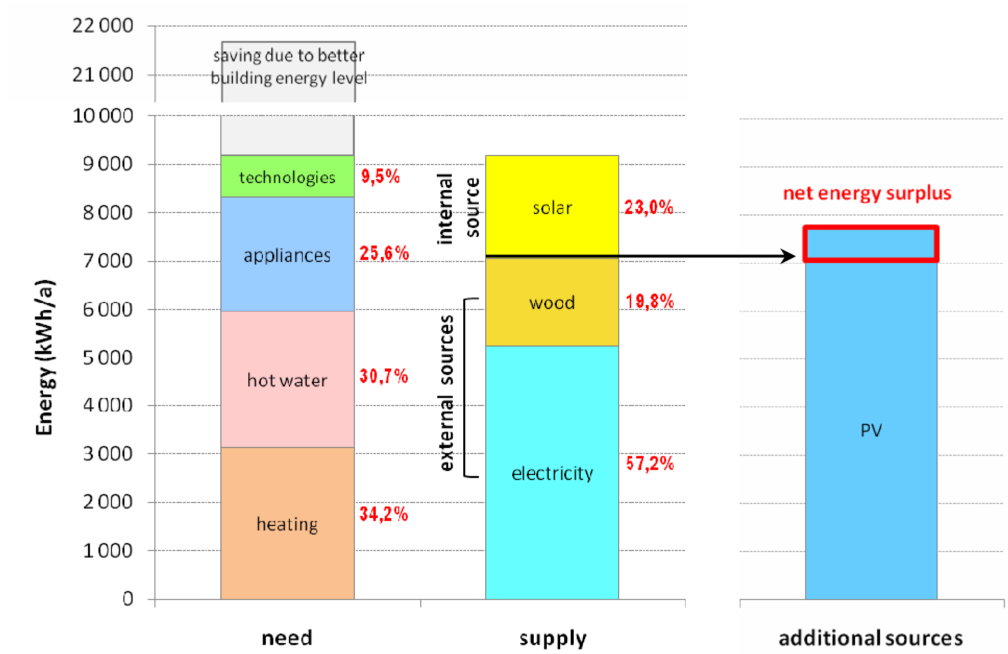

Figure 4 Breakdown of energy needs and supplies of a typical passive house in the Koberovy project (left). When an additional source (large building integrated PV system) is used, its production can be included in the overall energy balance resulting in a zero energy or even energy plus house (right).

The energy balance described above still does not provide sufficient information on overall sustainability of the performance of the house during its operation. For this reason, the energy balance was transferred into primary energy balance using different conversion factors for the respective energy carriers used to cover energy needs of the house (see Table 3). Values of the conversion factors were calculated using specialized tool GEMIS.

The impact of a large building integrated PV system on the primary energy balance of the house was calculated under the following assumption: The PV system produces green electricity having the conversion factor as low as 0,2. On the other hand, the PV-generated electricity is not connected to the energy systems of the house but is fed into the local grid (on-grid PV system), while the house uses standard electricity mix from the very same grid having conversion factor of 3. However, it can be assumed that the grid serves as an infinite accumulator and that the house can virtually take all the green electricity back. Such reasoning allows using the conversion factor of 0,2 for the electricity mix taken from the grid, of course, to an amount not exceeding the PV-production.

The following figure shows the primary energy balance for a passive house without and with a large building integrated PV system.

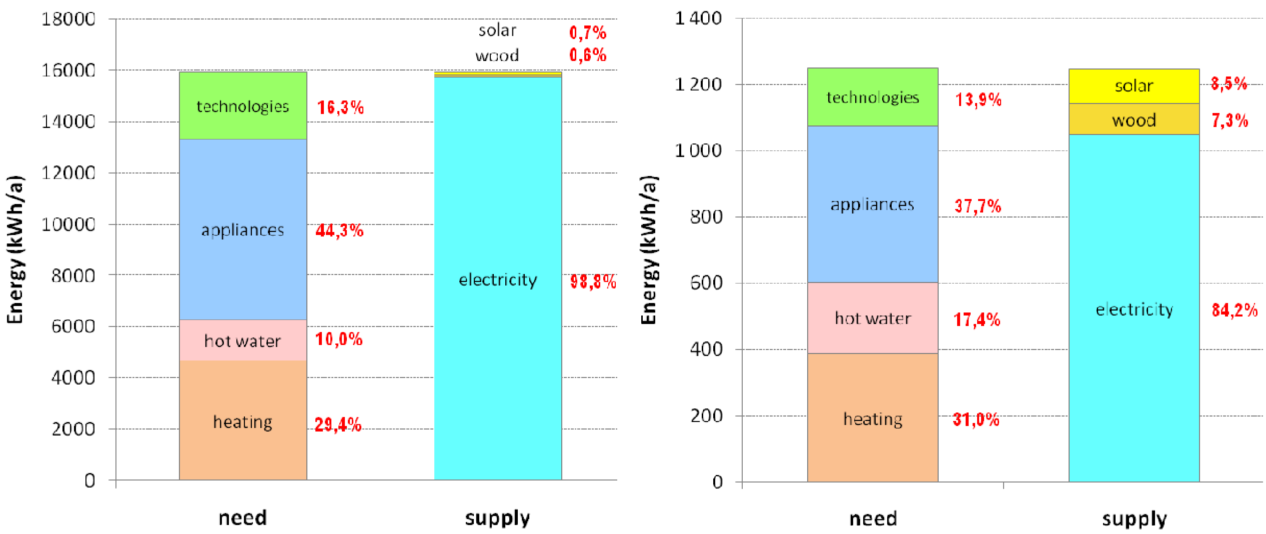

Figure 5 Breakdown of primary energy consumption of a typical passive house in the Koberovy project (left). When a large building integrated PV system is used, its production significantly lowers the overall primary energy consumption of the house (right).

It can be seen that integration of a large scale on-grid PV system (8,45 kW_p in this case) lowered the primary energy consumption of the house 12,5 times resulting in the specific primary energy need of 8,5 $kWh_p/(m^2.a)$, while the passive house concept requires 120 kWhp/(m2.a) - see Feist at al. (2007). For the design without a large scale PV system the specific primary energy need is 107,9 $kWh_p/(m^2.a)$, which is still well below the requirement. In general, use of a PV system can be a favourable option to decrease primary energy consumption of a building when other measures are not possible or suitable.

3.4 Heating and ventilation concept

The energy system of each house consists of a central thermal accumulator (0,615 m^3) with an integrated hot water preparation system and connection to a mechanical ventilation unit with a highly efficient heat recovery – see Tywoniak (2007). Energy from several inputs is used in the thermal accumulator - solar thermal circuit, wooden stove circuit and electrical heating rods, if needed. The doubled earth heat exchanger with a closed loop was developed to have higher efficiency in summer to avoid possible overheating, as described in Kopecky (2007).

3.5 Optimized solar use

Hot water is prepared from approx. 70 % by solar-thermal collectors installed on each house. Every individual unit consists of 3 solar thermal collectors having total area of 6 m2 in vertical oriented strip. The collectors are roof-integrated with smart design in detailing (see Figure 4). The hot water is stored in the central thermal accumulator.

3.6 PV roof

The house for information and education is equipped by large photovoltaic system (PV), total area of 62.9 m^2 with 8,45 kW_p, fully integrated in pitched roof 45° (Figure 4). The annual energy production of the PV system should be approximately equivalent to the amount of energy supplied to the house from external sources. This would lead to a zero-energy house over the year. The produced electricity will be sold to the local distributor to avoid losses resulting from the inequality between the production and consumption curves. However, it also means that the PV system is not connected to the energy systems of the house and has to be treated independently when calculating energy balance. According to the data in Table 3 the energy to be delivered from external sources is approx. 7 MWh/a. Expected yearly PV-production is about 7,7 MWh/a (AC).

In principle, integration of a large on-roof PV system has unquestioned impact on the overall appearance of the house. Therefore, full structural integration of the PV modules into the roof was one of the important requirements. Properly chosen supporting structure made it possible to replace traditional roof tiling by PV modules. The fact that the crystalline silicon PV modules operate best when their temperature is kept low has led to the design of a 100 mm high ventilated air gap at the back of the modules.

Figure 4 House for information and education with large PV-roof (zero-energy house) in Koberovy (50°37'29" N, 15°13'42" E)

3.7 PV for higher independency

Passive houses have generally low energy demands, however it does not prevent them form impacts of black-outs. On the other hand, when a certain minimum of electricity is delivered from a back-up system, the passive houses are able to withstand the back-out with less harm than usual buildings. To explore the potential of solar driven electricity back-up, one another house in the Koberovy project was equipped by a smaller PV system (1,1 kW_p only) extended by batteries and electronic control unit to guarantee grid-independence for basic operation in the house in case of black-out. The PV system operates in two basic modes. The first mode applies when the electricity supply from the grid is undisturbed: a grid-tied DC/AC inverter is in operation, PV-produced electricity id fed into the grid and the batteries are kept charged. The second mode applies when the grid is not detected: an island DC/AC inverter is in operation using electricity from the batteries and feeding AC power into the selected circuits in the house. All technological equipment, like fans of mechanical ventilation, circulating pumps together with selected lighting can be in use at least for 24 hours of energy delivery break.

4. Conclusions

Koberovy – houses reached the level of passive house standard at acceptable costs, which are fully comparable with other new developments in the region. The Koberovy project was a big challenge for the general contractor, who was for the first time faced to a) passive house approach, b) use of wooden structure. Very intensive and consequent supervision on construction site and technical support was therefore needed, together with repeated checking the quality during finishing works (air-tightness by blower door – see Novak (2008)), to avoid problems and un-acceptable "improvisations" on site. At the urban level, this new residential area is already quite well integrated in the structure of the existing village and accepted by local people. The long-time monitoring of the energy flows, indoor quality and effects of solar use has started at four selected houses here. The general solution is repeatable, regardless to the form of particular building, the building envelope can be further simplified and the air tightness concept improved. The high quality detailing is necessary to attract the people to follow the passive house strategies and to use solar energy at all.

Basically, solar systems have a real chance to be a part of buildings on a larger scale only if the stakeholders (developers, building owners, architects and building designers, facility managers, etc.) are familiar with these technologies. The solar system should be designed very consequently considering the energy targets and the overall sustainability parameters, like primary energy, embodied carbon dioxide values, etc.

It was clearly shown that the only effective way to zero-energy house (possible future target?) starts at well adopted passive house principles. The search for overall attractive solutions can be understood as an opportunity for "inventory" of our design habits. Especially at housing projects the basic structures should be highly effective not only to save materials (and embodied energies) but also to help to create a "financial space" for use of advanced technologies for saving of operation energy and to minimize the ecological footprint in general.

Acknowledgements

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FENESTRATION GUIDELINES FOR IMPROVING ENERGY CONSERVATION IN AN THE OFFICE BUILDING WITH A DAYLIGHT CONTROL SYSTEM

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Keywords: LEED, Daylight Control System, Energy Conservation, eQUEST, U-factor, SHGC, Fenestration

Summary

An energy efficient design is an important component for a sustainable and LEED certifiable building. Moreover, innovative technologies such as daylight control systems have led to the improvements in electrical energy reduction. However, while previous researches have pointed out the problems of daylight control systems they have focused almost exclusively on the electrical savings to be gained by such systems. There is a lack of comparative study on the different fenestration systems and a need to evaluate the total energy performance with a daylight control system. The aim of this paper is to investigate, by using an eQUEST energy simulation program, how the energy demands in an office building change with daylight control and a variety of fenestration systems. Specifically, the impacts on energy performance with daylight control are analyzed for building size, window area, glazing type and properties such as U-factor and SHGC for two geographical locations in the U.S. The results are compared with a reference model that uses the ASHRAE standard and the methodology of the LEED 2.2 green building rating system. The results demonstrate the potential of energy savings by integrating a daylighting control system with design decisions to optimize the fenestration. In addition, this paper provides fenestration guideline that can be used to assist in the window design, selection and placement of windows with daylight control systems.

1. Introduction

1.1 Building Energy Use

Buildings are responsible for an increasing share of the total energy consumption in the U.S., consuming 40% of the nation's primary energy. During the last two decades (1990–2005), the primary energy consumption of U.S. buildings has grown by 31% and CO_2 emissions have increased by 39%, making them responsible for 22% of the world's carbon dioxide emissions. Building emissions in the U.S. are equal to the combined emissions of Japan, France, and the U.K. The energy usage is especially high for electrical consumption, with commercial and residential buildings in the U.S. consuming 72% of the nation's electrical energy. It will have grown to 80% by 2030. A comparison of building types shows that commercial buildings use 18% and office buildings represent the largest portion of the energy use in this sector. Mercantile, education and health-care follow. Moreover, even though it is predicted that residential energy consumption will decrease, commercial consumption is predicted to increase by 20%. Among the energy usage, artificial lighting is one of the major energy consuming items in commercial energy end-use (around 26%) and this growing trend will continue (U.S Department of Energy 2007).

1.2 Background Study

In order to reduce energy consumption in commercial buildings, there has been great demand to design energy efficient buildings. Based on the above reference data on building energy use, this paper will focus on the energy consumption of a typical office building in different U.S climate zones. There are numerous energy saving strategies that consider architectural design, engineering, HVAC systems, renewable energy, weather, climate zones, environmental factors and so on. However, in this paper, energy simulation was conducted to evaluate the energy conservation impact of daylight control and window type. In other words, the main objective is the analysis of energy performance using different window designs including factors such as area and other properties (U-factor and SHGC) with a daylight control system. A variety of studies dealing with the two parameters of daylight control and fenestration can be found in the cited reference. The sections below will discuss two types of studies; electrical energy saving with daylight control and energy performance with different window designs.

1.2.1 Electrical energy saving with daylight control

Energy is not saved by daylighting. Energy is saved by dimming down or switching off electric lights (Leslie 2003). Lighting control integrated with daylighting is recognized as an important strategy in energy-efficient building designs and operations (Li and Tsang 2005). The purpose of daylight control systems is to maintain target illuminance levels regardless of the amount of available daylight. To satisfy such a purpose, the electric light output is continuously adjusted based on the changes in the available daylight, as measured by photosensors (Choi et al 2005). These systems consist of three basic components; a photosensor, lighting controller and dimming unit. A photosensor detects luminous flux and converts this into a signal this is sent to the controller, which in turn processes the signal and defines the desired dimming level. (Choi and Sung 2000) By using simulations and actual measurement, previous researches have shown that daylight control systems can reduce the electrical energy consumption in office buildings by as much as 30–70% (Li et al 2006, Doulos et al 2008). Moreover, in the New York Times Headquarters daylighting mockup test, the daylighting control systems demonstrated very reliable performance after they were commissioned properly. The average lighting savings were 20–23% and 52–59% for two target areas of the mockup (Lee and Selkowitz 2006).

Although researchers agree on the benefits of daylight control systems, there is a difference about their real savings and actual energy consumption (Roisin et al 2008). Moreover, research has also shown that daylight control systems do not show the guaranteed energy reductions after construction (Floyd and Parker 1995, Atif and Galasiu 2003). Therefore, based on previous researches, a consideration of total energy performance is needed when the daylight control system is installed because previous researches focused solely on the electrical savings from artificial lighting reductions, and did not address the effects on total energy performance with daylight control. In an effort to overcome these problems, this paper includes an analysis of total energy consumption with daylight control and various combinations of fenestration parameters.

1.2.2. Total energy performance related to window with daylight control

Building façades can make a major contribution to the overall energy savings (Saridar and Elkadi 2002). Moreover, windows are responsible for 22% of the heating loads and 32% of the cooling loads in commercial building component loads (LBNL 1998). Windows plays a major role in determining the thermal performance of a building and represents a major opportunity to conserve energy (Sekhar and Toon 1998). Nonetheless, fenestration type and design have often not been considered in the early design stage even though they can play a large role in determining total building energy usage. For example, Aboulnaga (2006) examined the status of buildings in Dubai to investigate the problems associated with misuse of glass. The results revealed that window were misused in 70% of the buildings. Therefore, in order to save energy, more consideration about windows is essential to create low-energy building.

Summing up the background study, there are problems with a daylight control system when it is used without considering all of the fenestration parameters. This means that there is a limited understanding of the links between daylight control systems and fenestration including design and type. Although almost all researches guarantee the electric energy savings, the total energy consumption should be verified. In order to effectively increase energy saving, the window systems associated with the daylight dimming control systems should be addressed. Therefore, to take full advantage of their savings potential, this paper presents a methodology to analyze the potential for energy savings with a daylight control system and different window systems including a consideration of window area and properties.

2. Main Research Objective

The main purpose of this study was to establish guidelines to improve energy conservation in an office building with daylight control used in conjunction with different window systems. The study presented here is based on simulation results. This study is divided into two parts. The first determines the energy conservation for different combinations of window properties in terms of global energy consumption. To increase achievable LEED credits for the optimization of energy performance, energy savings were determined by comparisons with the ASHRAE Standard. In the second part of the study, the impact of different parameters including floor area, window size and properties is analyzed. Then, selected results from a series of parametric analyses are discussed.

This section is meant to provide guidance in the process of choosing windows by evaluating the influence of the window area and type on the energy use. These results provide the minimum fenestration criteria for architects with regard to the selection of the U-factor, SHGC, and window sizes.

3. Methodology

3.1 Model Description and Assumptions

Since the LEED green building rating system was designed to guide high-performance commercial projects, with a focus on office buildings, this research considered the energy usage in three typical office buildings (USGBC 2005). Simulations were run for the open plan office buildings. Obstructions due to interior and exterior features and surrounding buildings were not considered. Three building models were selected for the analysis. Typical seven-story office buildings were considered. Approximately calculations were made for these based on Huang and Franconi (1999) and each simulation model had square geometries because Cho (2007) showed that more than 30% of high-rise office buildings have a square shape. Two statistical references show that the range of average floor area for an office building was 1,022-2,183 m^2 (11,000-23,500 sq.ft) before 1980 and 1,486-2,416 m^2 (16,000-26,000 sq.ft) after 1980 (LBNL 1998) and that from 1959 to 2003, the average office building floor area has been 1,319 m^2 (14,200 sq.ft) (EIA 2006). For these reasons, three different office building sizes were selected for this paper to represent typical small (Office 1), medium (Office 2) and large (Office 3) typical office buildings. Therefore, we decided to focus our study on the seven storey office buildings with square geometries. Fig. 1 provides a representation of the building models and the data and assumptions are presented in Table 1 and 2.

Figure 1 Perspective of simulated model

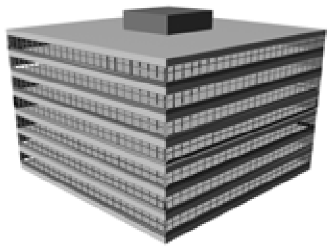

Table 1 Description of three office types

	Office 1	Office 2	Office 3
Dimension	24.5 X 24.5m (80 X 80 ft)	36.5 X 36.5m (120 X 120 ft)	49 X 49 m (160 X 160 ft)
Floor Area	595 m^2 (6,400 sq.ft)	1,338 m^2 (14,400 sq.ft)	1,821 m^2 (25,600 sq.ft)
Perimeter Zone		4.6m (15 ft)	
Floor to Floor Height		4m (13 ft)	
Floor to Ceil Height		2.7m (9 ft)	
Number of Floor		7	

The floor space was divided into a core zone and open office area, regular occupancy area. The four zones, the open-plan office area, are oriented to the north, south, east, and west, respectively. The perimeter zone was 4.6m wide around the floor and the floor-to-floor height was 4m (13 ft) with a 2.7m (9 ft)-high ceiling. Lighting density was 11.84w/m^2 (1.1w/sq.ft) based on the ASHRAE/IES standard office value. As shown in Table 3, the occupancy and operation schedules, heating, ventilating, and air-conditioning system, and envelope construction including insulation values were set in accordance with the ASHRAE Standard 90.1–2004, IESNA and the default values for a high-rise office building in the eQUEST energy simulation program.

Table 2 Summary of Details on Simulated Models

Parameters		Value / Descriptions
Building Type		Office, High-rise
Insulation	Roof / Wall / Floor	R-19 / R-13 / R-19
HVAC System	System Type	Variable Air Volume
	Cooling type	Chilled Water
	Heating type	Hot Water Fossil Fuel Boiler
	Design Temperature	Summer : 23.9 C° (75 F°), Winter : 22.2 C° (72 F°)
Schedules	Occupancy	Weekday (8:00-17:00)
	Operation	Weekday (7:00-18:00)

3.2 Daylight control system

Using daylighting controls, the electric lights were dimmed continuously by photosensors in each perimeter spaces. The dimming range was from 100% to 10% of the lighting output. A daylight control sensor was placed in the center of the each perimeter zone at 2.3m (7.5 ft) from the exterior wall. The required design illuminance level was 500 lux (50 foot candles) at workplane height during office hours (IESNA 2000).

3.3 Weather and climate zone

In order to verify the influence of the climatic and geographical location, the methodology was demonstrated in a typical open plan office in a cooling-dominated location (Houston) and a heating-dominated location (Chicago) in the U.S. (Lee and Tavil 2006). Due to the new weather classification, Houston and Chicago represent the hot and cool climate types, respectively. Specific climate data is shown in Table 3 (ASHRAE 2004, Briggs et al 2002).

Table 3 Weather data

	Houston	Chicago
Latitude / Longitude	N 29.95 W 95.35	N 41.98 W 87.90
Climate Type by ASHRAE Standard	2A	5A
Climate zone name	Hot	Cool

3.4 Fenestration Systems

As mentioned earlier, the main objective of this study was to verify the impact of the fenestration system used with a daylight control system. Therefore the study considered two main parameters; window size (WWR) and window properties (U-factor and SHGC).

The first, window area is represented by the window-to-wall ratio (WWR). The window positions and sizes are shown in Figure 2. Simulations have been performed with incremental glazed façade areas ranging from 15% to 50% at increments of 5%. These are presented in Ghisi and Tinker (2005) and in the author's previous research (Ko et al 2007). Due to the prescriptive limit of the WWR in the ASHRAE standards, a vertical fenestration of less than 50% was considered. Moreover, in previous researches on window size, Keighley (1973) showed the results that visual satisfaction is achieved when window area is 30% and, in relation to window shape, Dogrusoy and Tureyen (2007) found in a survey that horizontally continuous windows were the most preferred window types. Moreover, Cuttle (1983) showed that 25% or more large horizontal windows were the most appreciated. These findings and the standard were used in the selection of the fenestration shapes and sizes used for 3D models simulated in this paper.

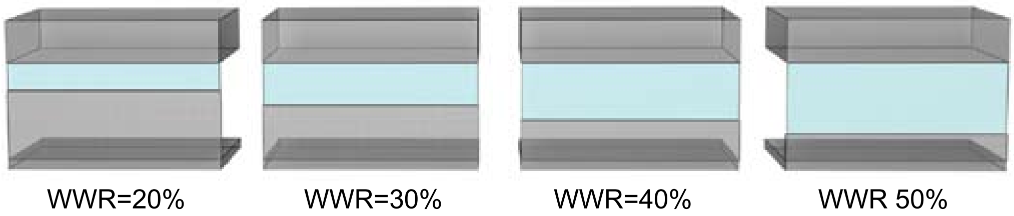

Figure 2 Proposed Façade Compositon and WWR

In relation to the second parameter, the current ASHRAE Standard for non-residential buildings is based on two window properties; the U-factor and solar heat gain coefficient (SHGC). Therefore, five different types of glazings with various U-factors and SHGCs were considered, as described in Table 4. Each glazing's type was selected by typical thermal performance of the window type (ACEEE 1996, NFRC 1999). Glazing 1 (G1) is the required window property of the ASHRAE standard in each climate zone. In order to determine the fenestration guideline, simulations were performed with five different kinds of glazings by decreasing the U-factor and SHGC.

Table 4 Analysis of five glazing properties

Type	Houston			Chicago			
	U	SHGC	Type	U	SHGC	Type	
G 1	1.22	0.25	Single-Pane	0.57	0.39	Double-pane	ASHRAE Standard
G 2	0.98	0.20	Single-Pane, Tinted	0.46	0.34	Double-Pane, Low-e, Gas-fill	20% reduction of ASHRAE Standard
G 3	0.73	0.15	Double-Pane	0.34	0.23	Triple Pane	40% reduction of ASHRAE Standard
G 4	0.49	0.10	Double-Pane, Tinted	0.23	0.16	Triple-Pane, Low-e, Gas-fill	60% reduction of ASHRAE Standard
G 5	0.24	0.05	Triple-Pane, Low-e, Gas-fill	0.11	0.08		80% reduction of ASHRAE Standard

3.5 Simulation Program: eQUEST

To investigate the impact of fenestration properties with a daylight control system, energy simulations were carried out for the above described typical office floor and two cities in the U.S. A parametric simulation is presented using eQUEST. It is the most updated to date building energy use simulation tool. Moreover, it is free and contains a complete version of DOE-2.2 and its documentation. eQUEST and PowerDOE feature the identical DOE-2.2 simulation engine. It is the newest DOE-2 building energy simulation and cost calculation engine (Hirsch 2003 and 2006). DOE has been used extensively for more than twenty-five years for both building design studies, the analysis of retrofit opportunities, and for developing and testing building energy standards in the U.S. and around the world (Crawley et al 2008). In this study, eQUEST was used to calculate energy consumption with a given fenestration system when a daylight control system was installed.

3.6 LEED 2.2: Optimize Energy Performance

To evaluate and calculate the energy conservation, LEED 2.2 criteria were considered in this research and the expected results can be applied to the LEED green building rating system in order to increase the achievable LEED points. There are six categories; sustainable site (SS), water efficiency (WE), energy and atmosphere (EA), material and resources (MR), indoor environmental quality (EQ) and innovation design (ID). Among these categories, energy saving is dealt with "EA credit 1. Optimizing Energy Performance" and it offers up to 10 points. These 10 credits contribute to 39% of the credits required to be certified by the LEED Green Building Rating System. In this credit, LEED 2.2 required at least two points after June, 2007.

The aim of optimizing energy performance can be achieved by increasing energy savings to above the baseline. There are four compliance path options as described in Table 5.

Table 5 Four compliance path options in 'optimize energy performance'

Type	Path Options	Detailed requirement	Points
1	Whole Building Energy Simulation	- Energy analysis for the Building Performance Rating - Must comply with ASHRAE Standard and include all the energy costs and compared against a baseline building.	1-10
2	ASHRAE Advanced Energy Design Guide for Small Office Buildings 2004	- Buildings must be under 20,000 sq.ft and office occupancy and comply with all applicable criteria for the climate zone in which the building is located.	4
3	Advanced Buildings™ Core Performance™ Guide	- Buildings must be under 100,000 sq.ft and may NOT be health care, warehouse or laboratory projects.	2-5
4	Advanced Buildings Benchmark™	- Projects registered after June 26, 2007 may not use this option	1

In this research, to increase points and evaluate the entire building performance, option 1 was selected. This requirement pertaining to the goal of optimizing the energy performance is the attainment of a percentage of energy savings, which is determined by the difference in the proposed or designed model and the baseline building model. The ASHRAE Standard 90.1-2004 was used as the baseline model. The equation for the energy saving calculation is described below in Eq (1). Table 6 shows the minimum energy cost savings percentage for each point threshold. The percentage of saved energy compared to the baseline model determines the achievable points (USGBC 2005).

$$\text{Energy Saving (\%)} = \frac{(B - P)}{B} \times 100 \qquad (1)$$

where B is the base model (ASHRAE standard model); P, the proposed model (designed model)

Table 6 Possible points by Energy saving (%)

New Buildings	Existing Building Renovations	Points	New Buildings	Existing Building Renovations	Points
10.5%	3.5%	1	28.0%	21.0%	6
14.0%	7.0%	2	31.5%	24.5%	7
17.5%	10.5%	3	35.0%	28.0%	8
21.0%	14.0%	4	38.5%	31.5%	9
24.5%	17.5%	5	42.0%	35.0%	10

4. RESULTS

This paper compares the energy consumptions by using different window systems, for two locations in the U.S. with energy simulations have been carried out using the computer program eQUEST. The objectives were to (i) to evaluate the impact of façade design alternatives – glazing area and other properties with daylight and control (ii) to provide fenestration guidelines on selecting glazing area and other properties for use with daylight control at the early design stage in order to increase energy conservation.

The simulated results, energy usage differences between G1*(ASHRAE Standard without daylight control) and Glazings 1, 2, 3, 4, and 5 for Houston and Chicago, are displayed in Tables 7 and 8, respectively. Table 7 and 8 show the energy consumption (btu/sq.ft) and saving when Glazings 1-5 are used with daylight control system. Even though hundreds of parametric simulations were done in the original study, here the most representative data of Office 2 are shown.

Table 7 Energy Consumption and Savings, Houston

	WWR	15%	20%	25%	30%	35%	40%	45%	50%
G1*	Btu/SF	5095.5	5201.7	5313.1	5441.0	5592.0	5745.5	5895.0	6044.9
G1	Btu/SF	4654.8	4791.6	4951.5	5115.1	5281.3	5446.6	5610.8	5772.5
	Saving	8.6	7.9	6.8	6.0	5.6	5.2	4.8	4.5
G2	Btu/SF	4583.1	4681.3	4806.6	4937.6	5075.0	5210.4	5348.9	5483.5
	Saving	10.1	10.0	9.5	9.4	9.3	9.3	9.2	9.1
G3	Btu/SF	4508.5	4570.2	4651.3	4743.3	4843.1	4947.9	5051.8	5155.5
	Saving	11.5	12.1	12.5	12.8	13.4	13.9	14.3	14.7
G4	Btu/SF	4437.1	4464.8	4505.9	4551.6	4607.2	4666.7	4733.0	4801.0
	Saving	12.9	14.2	15.2	16.3	17.6	18.8	19.7	20.6
G5	Btu/SF	4384.2	4379.1	4379.2	4383.9	4391.3	4399.9	4411.6	4426.1
	Saving	14.0	15.8	17.6	19.4	21.5	23.4	25.2	26.8

(G1*: meet ASHRAE requirement without daylight control, G1-5 : with daylight control)

Table 8 Energy Consumption and Savings, Chicago

	WWR	15%	20%	25%	30%	35%	40%	45%	50%
G1*	Btu/SF	5455.2	5614.0	5777.1	5936.1	6103.7	6267.9	6429.6	6592.4
G1	Btu/SF	5219.2	5382.2	5541.4	5705.2	5876.8	6047.8	6219.3	6383.6
	Saving	4.3	4.1	4.1	3.9	3.7	3.5	3.3	3.2
G2	Btu/SF	5132.7	5263.4	5374.1	5493.9	5620.3	5749.4	5882.1	6013.4
	Saving	5.9	6.2	7.0	7.4	7.9	8.3	8.5	8.8
G3	Btu/SF	5032.7	5118.2	5196.6	5266.4	5340.4	5419.4	5504.3	5590.5
	Saving	7.7	8.8	10.0	11.3	12.5	13.5	14.4	15.2
G4	Btu/SF	4932.7	4981.5	5013.3	5042.6	5079.4	5123.0	5168.5	5207.6
	Saving	9.6	11.3	13.2	15.1	16.8	18.3	19.6	21.0
G5	Btu/SF	4809.6	4817.5	4809.1	4799.4	4788.8	4780.8	4775.8	4777.4
	Saving	11.8	14.2	16.8	19.1	21.5	23.7	25.7	27.5

(G1*: meet ASHRAE requirement without daylight control, G1-5 : with daylight control)

As expected, more energy is saved by using advanced windows. The results of the simulation show that, if windows with lower U-factors and SHGCs are installed, this results in a higher savings in total energy use. The achievable energy savings range from 5.2% to 35.7% (office 1), 4.5% to 26.8% (office 2), 3.8% to 21.2% (office 3) in Houston, and 3.4% to 34.4% (office 1), 3.2% to 27.5% (office 2), 2.9% to 22.2% (office 3) in Chicago. Comparing the office areas, greater energy saving can be achieved in office type 1, and maximum reduction was 35.7% and 34.4% (G5 window with a WWR of 50% and daylighting control), in Houston and Chicago, respectively.

However, as shown in Tables 7 and 8 and in Figure 3, Glazing 1 and 2 provide another perspective on the energy impact of windows with daylight control. It was found that the total energy savings with daylight control could be reduced with Glazings 1 and 2 (Houston) and Glazing 1 (Chicago). This means that when the building was equipped with a window of type G1 or G2, it had lower total energy savings, even though the window area was increased and larger windows and daylight control are widely known to increase electric energy savings. Although they had lower window properties (G2) and ASHRAE window (G1), the energy saving with lighting control did not follow this trend in the case of G3, G4 and G5.

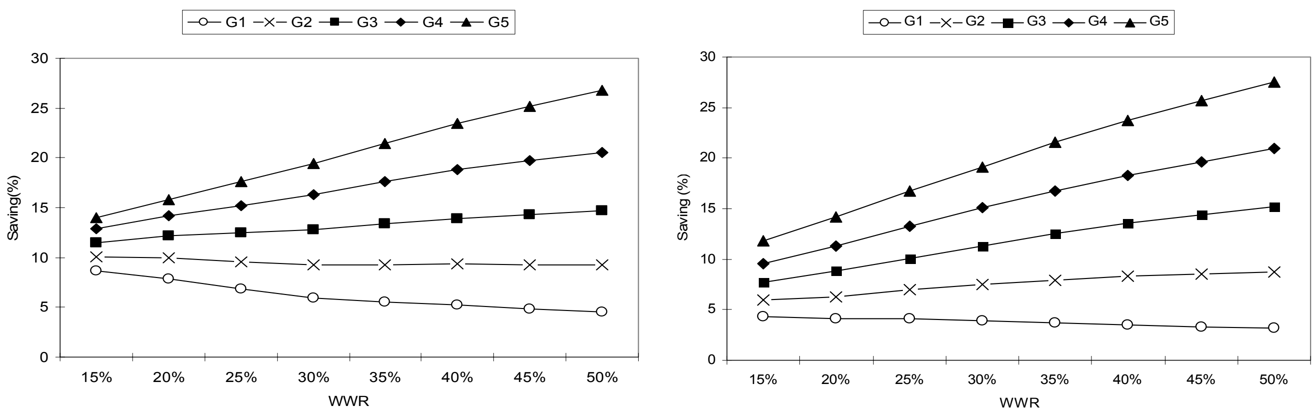

Figure 3 Energy Saving with Daylight Control as a function of Window Type (Houston and Chicago)

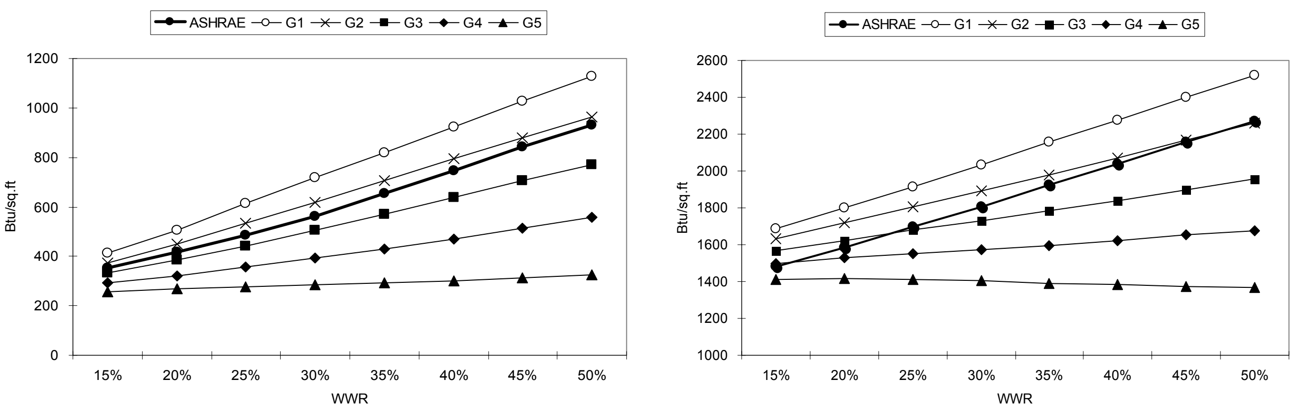

Figure 4 Annual Heating Energy Consumption as a function of Window Type (Houston and Chicago)

In order to verify the reason for this more analytically, Figure 4 shows the annual heating energy (space heating and hot water). Although it is not shown in this paper, electrical consumption was reduced 10-20% in all the glazing cases just as mentioned above based on previous researches. However when the annual cooling energy consumption was compared to G1*(ASHRAE), G1 and G2 consumed more energy than G1*(without daylight control) when daylight control was installed. We can notice that when increasing the percentage of glazed surface was increased, the annual heating energy was increased in associated with the window systems. The explanation is that the larger window area and properties could have caused the increased of heat losses in the winter because of the windows and dimmed artificial lighting.

Therefore, with regard to the weather data in Houston and Chicago, the use of a higher performance window (U-factor<0.73, SHGC<0.15 in Houston and U-factor<0.34, SHGC<0.23 in Chicago) is recommended in order to increase the energy savings and achievable LEED credits. The results of the simulation show that, if the glass type is very well chosen with daylight control, the building can perform better than the used and designed building. Furthermore, in order to obtain more LEED credits, glass characteristics and the type and size of the windows should also be considered by architects and engineers in the schematic design process.

5. Conclusion

The objective and methodology of integrating daylighting control and the fenestration system was developed and presented. In order to overcome the limitations of the previous studies, the detailed building energy simulations were carried out using eQUEST and simulation procedures were conducted using different combinations of the U-factor, SHGC and WWR when a daylight control system was used. The final step was a comparison of the energy consumption of the reference building (no daylight control with ASHRAE standard) to the simulated model with daylight control when different kinds of glass were installed (G1–G5). The significant findings are listed below.

• The energy saving was increased by using the high performance windows with daylight control because the total energy consumption was significantly reduced by the low U-factor and SHGC of the windows.

• With lighting control, although energy saving also can be increased using more advanced window and larger windows (G 3,4 and 5), it can be reduced when the U-factor and SHGC exceed the minimum criteria specified in this study, as in the case of Glazing 1 and 2 (Houston) and Glazing 1 (Chicago).

• Increasing window size does not necessarily result in more energy savings because of the complex relationship of heating, cooling and lighting energy requirements. Generally, utilizing a glazing with good thermal properties, energy savings will increase with increasing window size but this is also dependent on climate. As shown in Figure 3, G1 and G2 in Houston that increasing window size increases energy required whereas for G3, G4 and G5 increasing window size actually decreases energy required (increases energy savings).

• In relation to the annual heating energy, G1 and G2 consumed more than G1*(without daylight control) when daylight control was installed due to the increased loads associated with the heat losses in the winter from the windows and dimmed artificial lighting.

• Therefore, for a fenestration property guideline, the recommendation is to increase energy conservation with a daylight control system as follows; U-factor<0.73, SHGC<0.15 in Houston and U-factor<0.34, SHGC<0.23 in Chicago.

This paper provides a fenestration guideline to increase energy saving and obtain more LEED credits based on the LEED 2.2 green building rating systems. Moreover the fenestration problems can be found or fixed to determine energy savings resulting from building and building envelope installation retrofits because 44% of the glass used in nonresidential window stock in 2005 was clear, insulated glass, even though the usage of clear glass was decreased from 2001 (EIA 2003, AAMA/WDMA 2006). It is hoped that these criteria will enable architects and engineers to achieve better fenestration performance through a consideration of window properties, daylight control systems, and local climate types.

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STATE-OF-THE-ART OF SUSTAINABLE ENERGY-EFFICIENT BUILDING ENVELOPES IN NORWEGIAN OFFICE BUILDINGS

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Keywords: climate, robustness, simulation, survey

Summary

Nine energy-efficient office buildings in Norway were studied in order to get an overview of the state-of-the-art of low energy office buildings in Norway. This paper includes a description and classification of the energy concepts and the corresponding technologies for reducing energy consumption in the buildings. Then, the implications of these technologies are studied with the help of a simulation model and the key issues that influence the energy performance of these buildings with special emphasis on envelope performance are reported. The results show that a careful design of climate adapted and super-efficient envelope systems with very good air tightness, moderate window sizes as well as ventilation systems with excellent heat recovery system can further enhance energy-efficiency. The local climate (and change) has a significant influence on the energy performance and should therefore be taken into consideration. Expected climate change over the next 50 years will influence the energy consumption and can cause great uncertainty in future energy consumption of office buildings.

1. Introduction

More efficient use of energy in the built environment is essential to reach political goals within Norway and the European Union on reliable energy supply and reductions of emissions of greenhouse gases. The built environment affects nature through energy use, emissions and use of raw materials. The total energy use in buildings accounts for about 40% of the total energy use in the country, excluding the energy sectors (Statistics Norway 2006). The construction industry may thus make significant contributions to environmental improvement through energy efficiency and utilization of renewable energy.

In order to realize energy performance requirements of a higher standard in the new Technical Regulations, it is necessary to develop new design strategies to meet these requirements - without sacrifices in other performance codes, standards or guidelines. Prior experience related to the introduction of new energy performance requirements has shown that the design energy performance levels are either not met, or they are fulfilled at the expense of indoor climate, technical quality (e.g. moisture related problems), or architectural quality. Facing the future risks of climate change, Norway also provides a unique “laboratory” for testing of the robustness of new building envelope solutions (Lisø 2005).

Therefore it seems appropriate to determine the parameters of building design that have the biggest influence on energy consumption of buildings. This work is a part of the Norwegian project entitled Climate Adapted Buildings (CAB) that runs from 2007-2009 and is financed by the Norwegian Research Council. Special focus has been put on the building envelope and some parameters that have an influence on the building load (Andresen et al. 2005). The starting point was to focus on office buildings but other building types will be studied in the near future.

2. Objectives

The project’s principal objectives are to develop more energy-efficient building envelope assemblies and new methods for the design of building envelopes in harsh climates, resulting in more accurate and geographically dependent design guidelines. The project includes analyses of building envelopes applied in different kinds of climates, different uses, and different construction methods.

Energy-efficient office buildings in Norway were studied in order to get an overview of the state-of-the-art of low energy office buildings in Norway. This paper includes a description and classification of the energy concepts and the corresponding technologies for reducing energy consumption in the buildings. Then, the implications of these technologies are studied with the help of a simulation model and the key issues that influence the energy performance of these buildings with special emphasis on envelope performance are reported.

3. Methodology

First, a survey of energy efficient office building projects in Norway has been conducted. Nine projects have been identified that met the following requirements:

- Energy consumption data (designed/measured) available
- Reduced energy consumption (compared with Norwegian average)
- Construction details available

The findings of the survey included the following issues:

- Context: climate, surroundings, building use
- Energy concept
- Envelope construction
- Energy performance – calculated/measured (have been reported in (Haase and Andresen 2008))

Then, a reference building was chosen because for this case monthly measured energy consumption data was available. The 3-storey building is 116m long and 18.1m wide and comprises 6 300m^2 heated floor area as illustrated in Figure 1. The construction of internal structure consists of medium weight furniture, medium weight partition construction with a thermal capacity of 12 Wh/m^2/K. For full hourly simulation the software SCIAQ Pro was used and then input parameter were changed one at a time. Detailed input data and validation with measured data have been reported (Dokka and Dokka 2004; Haase and Andresen 2008). The parameters listed in Table 1 have been studied with input and output variations as summarized in the same Table. Robustness estimation has been applied using the following equations (Lam and Hui 1996; Lomas and Eppel 1992).

$$SC1 = \left\{ \frac{d(OP)}{d(IP)} \right\} \tag{1}$$

with

d(IP) = overall change in input

d(OP) = overall change in output

$$SC2 = \left\{ \frac{d(devOP)}{d(devIP)} \right\} \tag{2}$$

with

d(devIP) = overall change in input deviation

d(devOP) = overall change in output deviation

SC1 and SC2 are sensitivity coefficients that give an indication of each parameter of the sensitivity of the output towards changes in the input. SC1 is often used in comparative energy studies because the coefficients so calculated can be used directly for error assessment. SC2 have the advantage that the sensitivity coefficients are dimensionless values expressed in percentage.

With the help of equation 1 it is possible to determine the robustness RI of the parameter by calculating the amount of change in input parameter (in its specific unit) that will result in a 10% change in output.

$$RI = 10\% \times OP_{BC} \times \left\{ \frac{1}{SC1} \right\} \tag{3}$$

with

RI = robustness indicator of parameter

OP_{BC} = output basecase (= 102kWh/m^2/a)

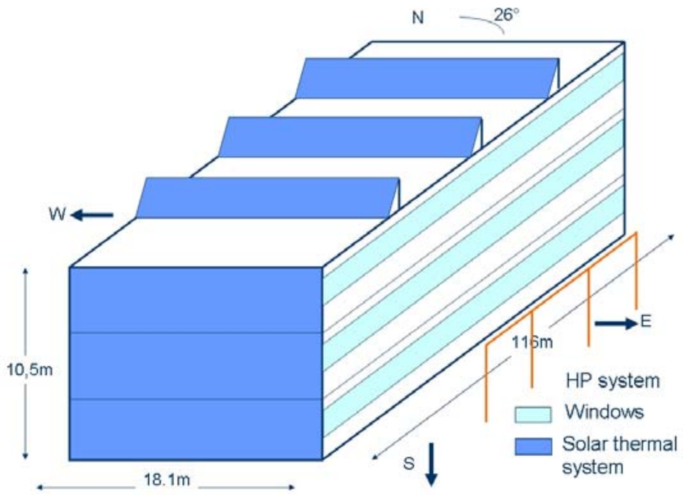


Figure 1 Model set-up

Table 1 Parameter for robustness analysis

Parameter	description	unit	Input min	Input max	IP range	Output min [kWh/m²/a]	Output max [kWh/m²/a]	OP range [kWh/m²/a]
Climate	annual average temperature	[°C]	4,70	7,80	3,10	86,56	151,30	64,74
Air tightness of the building envelope	air changes	[ach at 50Pa]	0,03	0,40	0,38	92,14	128,98	36,84
U-value	floor	[W/m^2/K]	0,10	0,20	0,10	102,99	103,01	0,02
	roof	[W/m^2/K]	0,15	0,25	0,10	101,25	104,88	3,63
	wall	[W/m^2/K]	0,15	0,30	0,15	101,47	106,11	4,64
Windows/glazing type and size	U-value	[W/m^2/K]	0,80	2,00	1,20	95,64	109,33	13,68
	WWR	[-]	0,22	0,99	0,77	98,62	125,47	26,86
Shading and daylighting systems	Fs	[-]	0,40	1,00	0,60	98,75	102,49	3,75
Efficiency of heat recovery system	ny	[-]	0,55	0,90	0,35	77,89	108,05	30,16
heating capacity	Ch	[W/m^2]	10,00	90,00	80,00	98,15	102,00	3,85
Occupancy		[persons/m^2]	0,00	0,15	0,15	101,34	107,11	5,77
cooling set point temperature	set point temperature	[°C]	21,00	27,00	6,00	101,94	176,08	74,13
Heating set point temperature	set point temperature	[°C]	18,00	24,00	6,00	91,00	129,42	38,41

4. Results

4.1 Survey

The key parameters of the buildings construction are described and performance data is summarized and results are shown in Table 2 and 3. The energy concepts have been categorized according to Dokka and Hemsted (1996). For projects that have been completed the surrounding context and building use is described in the following sections. The climatic context for each location is given in Table 2 as annual mean temperature (Tmean).

Table 2 Results energy concept

			Category											
Name	**Location**	**T(mean)**	**1**		**2**								**3**	**4**
			double-facade	superwindow	double-facade	earth coupling	heat pump	hybrid ventilation	passive cooling	PV-roof	biomass	thermal collector	demand control	district heat
Bravida	Fredrikstad	6.7°C		X			X				X	X	X	
Hamar Rådhus	Hamar	4.1°C	X		X									
Miljøsenter Bli.	Oslo-Blindern	5.9°C		X			X			X	X		X	X
MMS Horten	Horten	6.5°C					X							
Nydalspynten	Oslo	5.9°C		X					X		X	X	X	
Røstad	Levanger	5.0°C				X		X						
Sig. Halvorsen	Sandnes	7.4°C					X							
Telenor Kokstad	Bergen	7.8°C	X		X		X							X
Vestveien	Ski	5.5°C		X		X		X	X					

4.1.1 Bravida

Situated shortly above the Swedish border, Fredrikstad is a city and municipality with 71 000 inhabitants and covers a area of 290 km^2 at the mouth of the river Glomma about 100 km south of Oslo on the east coast of the county of Østfold.

The building is situated next to a 4 lane road (110) and its main axis is in North-South direction reducing south facing façade. The site of the building is embedded between a large 4 lane road in the west and mostly residential buildings on the east. The building was completed in 2002. It comprises of 6 300m^2 mixed offices and commercial space. The 3 storey complex (2 100m^2 per floor) consists of two buildings that are linked with an atrium that also hosts the staircase and lift. On the flat roof there are three shed roofs containing solar thermal energy systems, one system is integrated into the roof of the atrium, thus reducing solar heat gain into the atrium, and one system is integrated into the south facing facade.

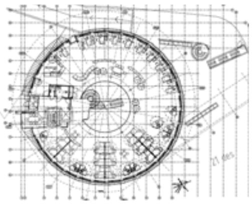
The south facing façade does not provide windows. Instead, solar thermal panels are vertically installed. East and west facing façade comprises strip windows of the entire length of the building. The windows are equipped with 2 layered 12mm glass with argon filling with a U-value of 1.3 $W/m^2/K$).

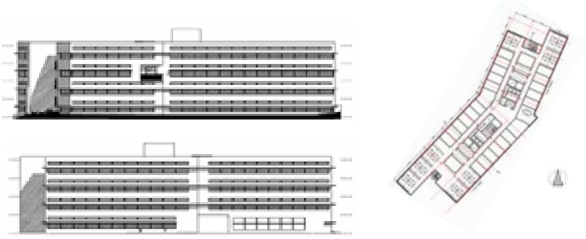
4.1.2 Hamar rådhus

Hamar is a town and municipality in the county of Hedmark, Norway. The city is located on the shores of lake Mjøsa, Norway's largest lake, and is the principal city of the Hedmark County. Hamar is situated in the heart of the country and covers a area of 351km^2 and approximately 27 500 inhabitants.

The Hamar Town hall was completed in 2001. Snøhetta Architect AS was commissioned by the Municipality of Hamar to design the new town hall. The centre of Hamar is the pedestrian walkway in the middle of town, with the library, cinema and farmer's market on Stortorget (the big square) on the western side, and Østre Torg (the eastern square), which sits on top of an underground multi-story carpark, on the eastern side.

Table 3 Results of survey

Surveyed building	Year of constr.	Location	heated area [m^2]	Building	Geometry and orientation
1 Bravida	2003	Fredrikstad	6 300		
2 Hamar Rådhus	2001	Hamar	10 500		
3 Miljøsenter Blindern	2006	Oslo-Blindern	15 000		
4 MMS Horten	1996	Horten	3 700		
5 Nydal-spynten	appr. 2008	Oslo	2 700		
6 Røstad	2002	Levanger	792		
7 Sig. Halvorsen	2006	Sandnes	?		
8 Telenor Kokstad	2000	Bergen	26 800		

9	Vestveien	appr. 2008	Ski	3 200	

The building is 5 stories tall and has a gross floor area of 10 500 m^2 and used as an office building. The depth of the plan is approximately 17m and the floor to ceiling height is 3m. The town hall has two double facades; the south façade and the north façade. The main reason for choosing a double façade in the north façade was to screen the interior from the traffic right outside this façade (Kleiven and Aschehoug 2005).

The outer layer is 8 mm glass while the inner is 2 layered 'energy glass' from Saint Gobain of type Planitherm Futur 1.1. The north facing facade is next to Hamars main traffic road, so the main reason for using it was it noise reducing function. The noise reduction was calculated during the early design stage to be 30 dBA. The south façade is used in combination with an automatic controlled solar shading system placed in the cavity for preheating ventilation air during the winter.

4.1.3 Miljøsenter Blindern

The new built office building **Miljøsenter Blindern** is located in Oslo. The capitol of Norway, and has in excess of approximately 530 000 inhabitants and covers an area of 453 km^2.

The building is situated in Blindern, where the many University buildings are located. It consists of an existing building complex and a new built extension. The extension complex is in completion phase (expected date end of 2007). The new extension complex is being built on the south facing orientation and attached through an atrium. It comprises 15 000m^2 offices and laboratory space in a 4 storey high building (3 storeys above ground).

4.1.4 MMS Horten

The 3 storey high building is situated near the water front next to the harbour in Horten, Norway. Horten muncipality has approximately 24 800 inhabitants and covers a area of 69 km^2 in Vestfold.

The long axis of the building is orientated in east – west exposing the long façade to the sun. The brick building comprises an atrium with metal sheet block that is placed in the centre. It is mainly used as office building, now occupied by the kusteverk.

4.1.5 Røstad

The new built office building of the Nord-Trøndelag College (HiNT) in Levanger is located 80 km north of Trondheim, Norway. The region has 17 000 inhabitants, of those approximately 7 000 in the village of Levanger which is known as the "green town" on account of its avenues and green areas. It is also a "school town" with a steadily growing college community.

The site is located near the city center on a slope overlooking the fjord. The building has two storeys, no basement, but instead a culvert for supply of ventilation is embedded in the ground along the central axis of the wing. The HiNT-wing has a net area of 478 m^2, of which 269.5 m^2 are used as office cells. Each cell is about 9 m^2. The gross area of the wing is 835 m^2, of which 112 m^2 is used for culvert, air intake tower and exhaust tower (Mathisen et al. 2005). Venetian blinds on west facing and roller blinds on east facing façade are automatically and simultaneously controlled for each façade, with a possibility for individual control.

4.1.6 Sig. Halvorsen

The new built office building **Sig. Halvorsen,** located in Sandnes, Norway (south of Stavanger). Sandnes has a population of 57 000 inhabitants and is located on the south-western coast of Norway. The coast is very flat, while the inland area is more dominated by mountains and fjords. The building is situated in an industrial area with low rise buildings surrounded.

4.1.7 Telenor Kokstad

The new built office building **Telenor Kokstad,** located in Bergen, Norway. Bergen municipality has approximately 239 300 inhabitants and covers a area of 465 km^2. The city is clambering up the mountainsides, looking over the sea, forming a spectacular amphitheatre.

The building complex is located central in Kokstad, one of Bergen most attractive new outskirts. The area is facing in south direction towards the Flesland airport. Prevailing winds are in the summer periods cooling from nordwest and in the winter periods wet temperate winds from south-southeast. The building was completed in 2000 and consists of a straight protecting complex in the north with four wings facing south, creating three protected gardens. It comprises 26 800m^2 office space for 1 100 office workers in 5 storeys with a large parking area underneath (10 000m^2). The technical installations were designed for a flexible use of the building offices.

4.2 Robustness study

The results are shown in Table 4. Results for SC1, SC2, and RI are given in the last three columns together with the deviation ranges of the input (IP) and output (OP). It can be seen from Table 4 that SC1 gives a good indication of the sensitivity of each parameter. The larger the number for SC1 the larger the sensitivity of this parameter to changes in the output. SC2 gives a percentage of this sensitivity but is related to the varying changes in input. RI gives comparable numbers that are related to the input units. The greater RI the better is the robustness of its parameter.

Results for SC1 give a clear indication of the sensitivity of each parameter. Large numbers indicate a strong sensitivity while small numbers indicate a weak sensitivity. It can be seen that e.g. the window size (WFR), the occupancy, and the U-values of roof and wall have the largest numbers, indicating the strongest sensitivity. On the other hand, e.g. heating capacity and U-value of floor have the smallest numbers, indicating a weak sensitivity. Results for SC2 relate to the deviation in input (and output) and are given in percentage. The highest percentages can be found for the cooling set point temperature, followed by the heating set-back temperature and the climate. This has to be used with care since the deviation in input is the basis for the percentage.

The last column with results for RI gives a clear picture of the robustness of each input parameter. It shows that e.g. a change of 10% change in annual energy consumption is caused by an annual mean temperature change of 1.62 °C, 1.48 ach (at 50Pa), etc.

Table 4 Results robustness study

Parameter	description	deviation range IP [%]	deviation range OP [%]	SC1 = d(OP) / d(IP)	SC2 = d(devOP) / d(devIP) [%]	RI = (IP value that changes OP 10%)	
Climate	annual average temperature	160.9	63.5	6.29	39.4 %	1.62	[°C]
Air tightness of envelope	air leakage	250.0	35.8	6.88	14.3 %	1.48	[ach at 50 Pa]
U-value	floor	50.0	0.0	0.24	0.0 %	42.3	[W/m^2/K]
	roof	50.0	3.5	36.28	7.0 %	0.28	[W/m^2/K]
	wall	75.0	4.5	30.92	6.0 %	0.33	[W/m^2/K]
Windows/glazing type and size	U-value	85.7	13.4	11.40	15.7 %	0.89	[W/m^2/K]
	WFR	233.3	26.3	87.94	11.3 %	0.12	[-]
Shading and daylighting systems	Fs	120.0	3.7	6.24	3.1 %	1.63	[-]
Efficiency of heat recovery system	μ	58.3	29.3	86.16	50.2 %	0.12	[-]
heating capacity	Ch	160.0	3.8	0.05	2.4 %	212	[W/m^2]
Occupancy	persons/m^2	150.0	5.7	38.45	3.8 %	0.27	[pers./m^2]
cooling set point temperature	set point temperature	15.4	30.0	7.64	194.8 %	1.34	[°C]
Heating set-back temperature	set-back temperature	35.0	16.2	2.37	46.2 %	4.31	[°C]
lighting load	Inst. load	175.0	28.8	1.68	16.5 %	6.07	[W/m^2]
Equipment load	Inst. load	175.0	30.1	1.73	17.2 %	5.91	[W/m^2]

5. Conclusions

5.1 Energy efficient office buildings in Norway

The results show that a very airtight envelope is an important step towards low-energy buildings. The climate has a large influence on the energy performance and should therefore be taken into consideration. Expected climate change over the next 50 years will influence the energy consumption and can cause great uncertainty in future energy consumption of office buildings.

It could be demonstrated that a careful design of climate adapted and super-efficient envelope systems with very good air tightness, moderate WFR as well as ventilation systems with excellent heat recovery system can further enhance energy-efficiency. In a well designed energy efficient office building further increase of thermal insulation does not reduce annual energy consumption significantly.

5.2 Robustness of parameter

This work tried to focus on parameter related to building envelope construction. Other parameters have been included in order to find out the relative significance of the parameter. Some parameters are difficult to measure and it is very important to see the robustness of each parameter. Results for RI for each parameter give a good indication of its robustness and the possibility to compare the parameters. A change in annual mean temperature of 1.62 °C for example results in the same change in output as a change of U-value of the walls of 0.33 $W/m^2/K$, a change in efficiency of the heat recovery system of 0.12, or a change of the internal load of app. 6 W/m^2. Further reduction of U-values for the floor or of the capacity of the heating system for example does only marginally effect the annual energy consumption.

5.3 Limitations and further work

Local sensitivity analysis gives only results for changing one parameter at the time. Synergy or other effects of changing more than one parameter could not be analyzed in this work. Future work will focus on this aspect and apply a global sensitivity analysis to the problem. It is hoped that these findings will assist in setting up future analysis work. More work is needed in order to accurately quantify the consequences and to develop envelopes that are capable of adapting to the changing climate. The supporting effect towards other energy concepts as heat pumps, natural/hybrid ventilation should be fully explored in order to realize sustainable energy-efficient buildings in Norway. A sensitivity analysis should be applied in order to evaluate the parameter with the biggest influence on building lifetime energy consumption.

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A LARGE ROOFTOP GARDEN ON A COMMERCIAL BUILDING IN JAPAN AND ITS THERMAL ENVIRONMENT DURING SUMMER

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Keywords: greening, thermal environment, rooftop, commercial building, energy, SET*, human behavior

Summary

The effects on both the indoor and ambient thermal environments of a rooftop garden on a large-scale commercial building were studied from three standpoints. Firstly, the thermal insulation effect of the rooftop vegetation was estimated. Measurements of heat transmission through the ceiling slabs both with and without vegetation showed an approximately 4.5% reduction in the annual cooling load due to the vegetation. Secondly, mitigating effects of the vegetation on urban warming were evaluated from surface temperature measurements by an infrared camera on fine days in summer. The vegetation was expected to reduce the sensible heat emitted into the atmosphere to 37.2% less than that with the whole rooftop garden covered with colored concrete. Thirdly, since the rooftop garden is mainly planned for visitors, the thermal environment of resting places and foot paths, and the behavior of visitors in summer were observed. The SET* evaluation results show that people do not feel “hot” in the tree shade or the shade of the tower building on sunny days. The mean residence time of the visitors tended to be longer in the tree-shade than in the sun under strong solar radiation, while on cloudy days or in the evening places without tree shade tended to be preferable and had longer mean residence time.

1. Introduction

Greening of cities is an urgent requirement in Japan. The main objectives are mitigation of urban warming (so-called a heat island phenomenon) and improvement of the landscape. For urban warming, improvement of roofs and rooftops are the first priority because they are the hottest places in a city during daytime in summer. Thus, many local governments have already started subsidizing green roofs.

Mitigation of urban warming by rooftop vegetation has been discussed in many studies and its validity has been established (e.g. Takakura et al., 2000, Wong et al., 2003). Reduction of cooling and heating load is said to be relatively small because its influences is limited to the top floor. However, large rooftop gardens have become popular in recent years. They not only conserve energy for a large top floor but also produce a large cool area in the city.

Little is known about the thermal environment of a rooftop garden with many tall trees where people can enjoy staying. It is thus important to understand the relationship between the thermal environment and human aspects such as a thermal sensation and people’s behavior. Thorsson (2003) investigated human behavior in a park, a plaza and an open café which was partially shaded. She showed that the ratio of people in the shade increased as the mean radiant temperature increased in all places, particularly in the café. She also suggested that human behavior was influenced not only by the thermal environment but also by psychological aspects.

This study focuses on the three aspects of thermal environment in a rooftop garden of a large-scale commercial building: energy conservation, mitigation of urban warming and human comfort.

2. Summary of object building

The building investigated comprised nine stories above ground and four under ground, and was located in the center of Osaka, Japan’s second largest city. Its gross floor area was 167,200 m^2 and its rooftop area was approximately 8,000 m^2 including approximately 3,300 m^2 of vegetation at the time of this research, which was from 2003 to 2005. (After its grand opening in 2007 it had a gross floor area of 243,800 m^2 and its rooftop was approximately 11,500 m^2 including approximately 5,300 m^2 of vegetation.) Photo 1 shows an overall view of the building, taken during this research in 2004. The garden was distributed on a terraced rooftop from the 2nd to the 8th floor, which faced north and sloped an average of 16.3%. A 150 m tower building was located to the west of the rooftop garden and cast its shadow on the garden in the afternoon. Footpaths passed through the site from top to bottom and several rest areas were arranged along the paths.

Photo 1 Overall view of building (left). Enlarged image of rooftop garden (right).

3. Reduction of Heat transmission into building due to vegetation

3.1 Measurements

The temperature on the underside of rooftop slab was measured at both vegetation and non-vegetation points. Fig.1 shows a floor plan of the rooftop garden and the measuring positions including those mentioned in chapter 5 (see legends). Points G and N indicate measuring points with and without vegetation, respectively. Fig.2 shows cross-sectional views of the ceiling slabs and the measuring positions. Measurements were carried out from August 2003 to March 2005.

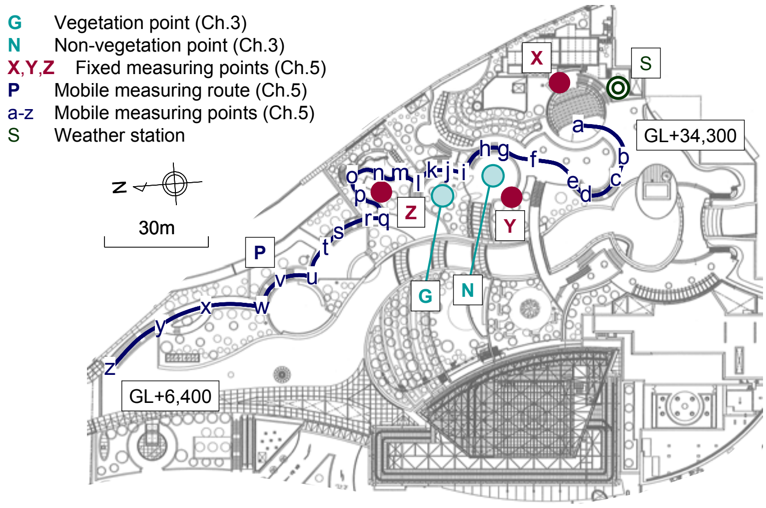

Figure 1 Floor plan of rooftop garden and measuring positions including those mentioned in chapter 5.

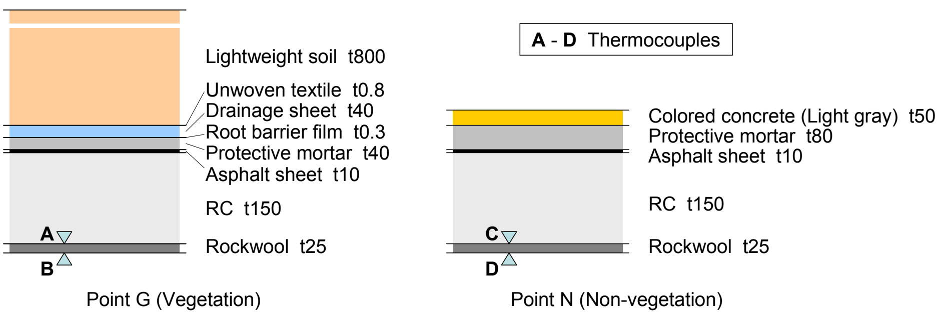

Figure 2 Cross-sectional views of ceiling slabs.

3.2 Results

Fig. 3 shows annual variations of surface temperature on the underside of the rooftop slab (points B, D in Fig.2) and the outdoor air temperature from April 2004 to March 2005. The temperature at point D (non-vegetation) changed and fluctuated following the air temperature, while that at point B (vegetation) changed gradually within a narrow range between 22 and 29 deg. C throughout the year. This indicated that the vegetation and earth of 80 cm thickness improved the top floor's insulation.

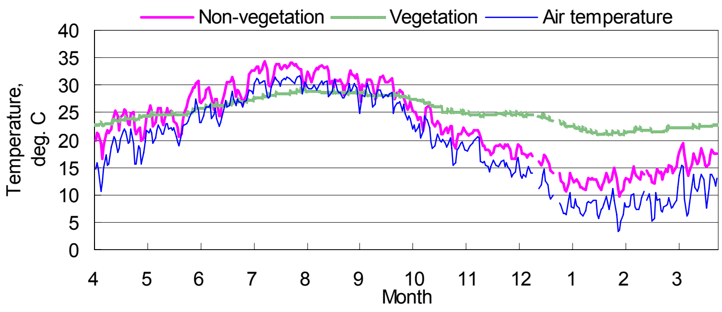

Figure 3 Annual variations of daily mean temperature on underside of rooftop slab from April 2004 to March 2005.

Fig.4 shows diurnal variations of heat transmission into the room through the ceiling slab measured on 9 July 2004. Those at the non-vegetated point varied between 2.6 W/m^2 and 7.6 W/m^2, while those at the vegetated point varied between -0.7 W/m^2 and 0.3 W/m^2. The maximum difference in heat transmission between two points was 7.6 W/m^2 at 20:00 h. That is to say, vegetation with adequate earth has the potential to remove most of heat transmission into a room even during the hottest season.

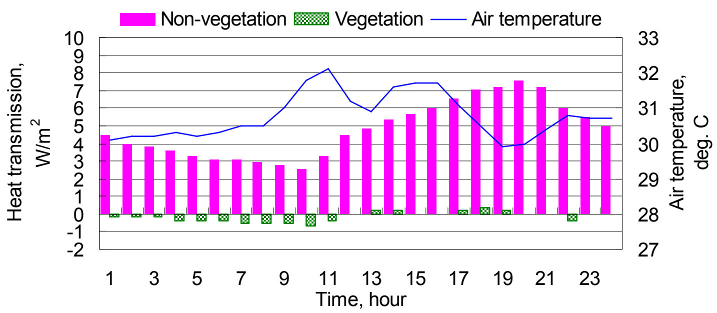

Figure 4 Diurnal variations of heat transmission into room through ceiling slab measured on 9 July 2004.

Accumulated heat transmission at the non-vegetated point during the cooling period (May – Sept.) was -3.7 MJ/m^2, while that at the vegetated point was 19.0 MJ/m^2, making a total reduction of 22.7 MJ/m^2. Total cooling load on the top floor during the cooling period was assumed to be 50,242 MJ when the object area was 100 m^2, the cooling period was 1,000 hours, and the cooling load was 34.9 W/m^2 from building fabrics, 20 W/m^2 from people and 70 W/m^2 from lighting. Since the reduction in cooling load by the rooftop vegetation was 2,274 MJ per 100 m^2, the reduction ratio was estimated to be approximately 4.5 %.

4. Reduction of sensible heat emitted into atmosphere by vegetation

4.1 Measurements

Thermal images of the targeted building and its surroundings were captured by an infrared camera (TH9100MV, NEC San-ei Instruments, Ltd.) from the top of an adjacent high-rise building. Images were taken at intervals of 5 minutes for one day from 00:00 h on 29 July 2005.

4.2 Results

4.2.1 Diurnal variations of surface temperature of various materials

Fig.5 shows diurnal variations of mean surface temperature of vegetation (trees), colored concrete (Light brown), asphalt paving, train tracks, a water cascade and building wall facing east. The average temperature was calculated from the numerical data of target areas in thermal images. The asphalt paving rose to approximately 51 deg. C, while vegetation rose to around 35 deg. C at maximum, which was nearly equivalent to that of the water flow. The colored concrete, which is a typical paving material for foot paths, rose to 43 deg. C, which was approximately 10 degrees higher than that of the adjacent vegetation. During night, the temperature of the artificial materials remained a few degrees higher than that of the vegetation and water due to their higher heat retention.

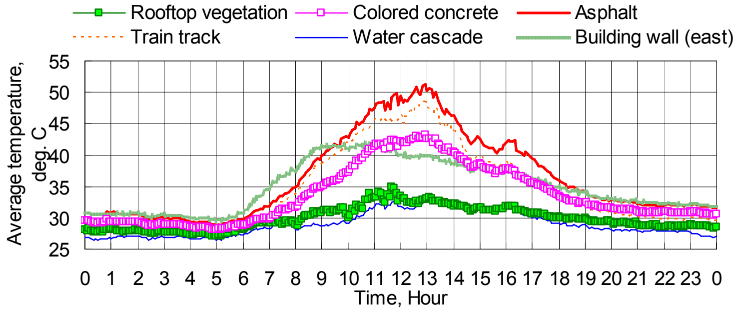

Figure 5 Diurnal variations of mean surface temperature of various surfaces on 29 July 2005. Note that the colored concrete was light brown, which was different from the place measured in Ch.3

4.2.2 Estimation of accumulated sensible heat from various materials

Fig.6 shows accumulated sensible heats Q_s [MJ/m^{2}day] on 29 July 2005 estimated as follows. Data were accumulated for 24 hours.

$$Q_s = \sum_{t=0}^{23} HS = \sum_{t=0}^{23} \left[\alpha_c (T_s - T_a)\right] \quad (1)$$

$$\alpha_c = (5.3 + 3.6U)/0.86 \qquad U \leq 5.0 \quad (2)$$

where HS [W/m^2] is the sensible heat flux from the surface, T_s [K] is the surface temperature obtained in the previous subsection, T_a [K] is the air temperature, α_c [W/m^{2}K] is the heat-transfer coefficient, and U [m/s] is the wind speed. The maximum wind speed was approximately 3.3 m/s on the test day. Eq. 2 is usually applicable to a plane surface. The sensible heat flux emitted from the vegetation is generally difficult to evaluate because of its form, so it was estimated by assuming that it was a plane surface.

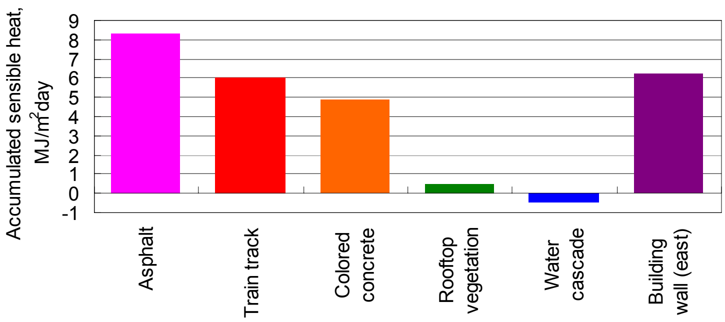

Figure 6 Accumulated sensible heats from various surface materials on 29 July 2005.

The figures show how much each material heated the atmosphere during the 24 hours of the test day. The total sensible heat per day from the vegetation was slight: approximately one seventeenth of that from the asphalt paving or approximately one tenth of that from the adjacent colored concrete. This suggests that the vegetation on this building reduced the sensible heat emitted into the atmosphere to 37.2 % less than that with whole rooftop garden covered with the colored concrete. The building wall facing east also had a large impact on the urban warming. (Unfortunately the southern and western walls of the tower building were out of sight in the thermal images. In general, a western wall emits the largest amount of sensible heat of walls facing the four cardinal points, particularly in summer.)

5. Thermal environment in rooftop garden

The rooftop garden was open to the public, and was mostly used by customers visiting shops in the commercial complex. Due to its terraced form, people who intended to take a rest outside or to stroll through the rooftop garden usually went up to the top floor first and then down the paths.

5.1 Thermal environment at rest areas

Measurements were carried out on 28 - 30 July 2005. The points X, Y and Z in Fig.1 indicate the rest areas and also the fixed measuring positions, in which several benches were installed. Fig.7 shows hemispherical photographs taken using a fish-eye lens at those points. Table 1 shows measuring factors and measuring instruments.

Point X Point Y Point Z

Figure 7 Hemispherical photographs taken at points.

Table 1 Measuring factors and measuring instruments

Measuring Points	Measuring Factors	Measuring Instruments
Fixed Measuring Points	Air Temp. Humidity	HMI41/HMP45, Vaisala ('04) TR-72U, T&D ('05)
	Globe Temp.	TR-71U, T&D ('05) Globe Thermometer, φ15cm
	Solar Radiation	PCM-01, Prede ('04, '05)
Mobile Measuring Points	Air Temp., Humidity Globe Temp., Wind Velocity	AM-101, KEM ('05)
General Weather Points	Air Temp., Humidity Wind Velocity & Direction Solar Radiation	MAWS201, Vaisala ('04) RS-11, 12, ESPEC ('05) KADEC-KAZE, KONA ('05) MS-61, EKO ('05)
Adjacent Building Points	Thermal Images	TH9100MV, NEC San-ei ('04, '05)
	Video Images	Digital Video Camera ('04, '05)

Figs.8 (a) - (f) show the total vertically emitted solar radiation, wind velocity, air temperature, wet-bulb temperature, MRT (Mean radiant temperature) and SET* (Standard new effective temperature, Gagge, 1986) measured on 28 July 2005. SET* is a thermal index defined as the equivalent dry bulb temperature of an isothermal environment at 50% relative humidity in which a subject, while wearing clothing standardized for the activity concerned, has the same heat stress (skin temperature) and thermoregulatory strain (skin wettedness) as in the actual environment (ASHRAE, 2001). It is usually used to indicate indoor thermal comfort. However, in recent years it has often also been used as a most suitable index for evaluating outdoor thermal comfort. SET* was calculated using MRT (Mean radiant temperature) [K] estimated from observation data such that:

$$MRT = T_g + 2.37\sqrt{U}\left(T_g - T_a\right) \tag{3}$$

where T_g [K] is the globe temperature measured using a globe thermometer.

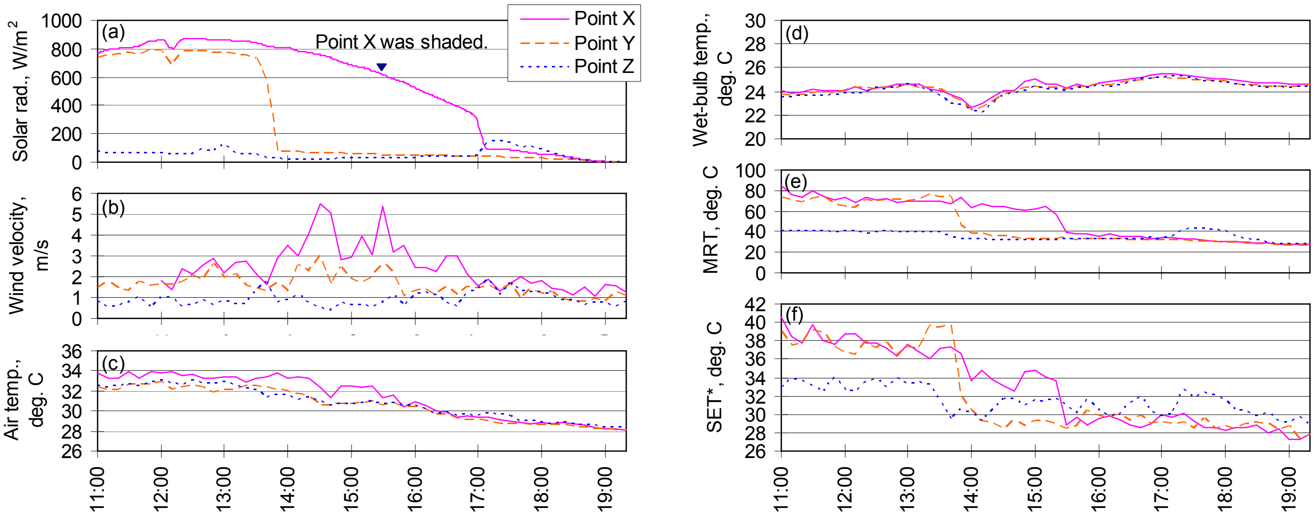

Figure 8 Vertical quantity of total solar radiation (a), wind velocity (b), air temperature (c), wet-bulb temperature (d), MRT (e) and SET (f) measured at the points X, Y and Z on 28 July 2005. Note that the total solar radiation measured at the point S was used instead of that of the point X.*

On the test day, point X, located at the top of the rooftop garden, was in a sunny location. Point Y was in the shade of the tower building after 13:30 h and point Z was in the shade of trees all day. The wind velocity at the top of the garden (point X) was 3 - 5 m/s in the afternoon, and this was the highest of the three points because it was in a relatively open location. The wind at point Y was lower than that at point X because the rooftop garden had a terraced form and the intermediate floors were partly surrounded by walls. Point Z had the weakest wind of around 1 m/s because it was sheltered by trees. The air temperature at point X was higher than that at the other points by 1-2 degrees in the afternoon, which was probably due to the colored concrete surround. At points Y and Z, it shifted at a similar level, that is, the air temperature in and out of the tree shade was of almost the same scale. The humidity was almost the same at the three points, that is, the quantity of water vapor in the tree shade was not exceptionally high.

It is suggested that the differences between the SET* values of the points were mainly affected by air temperature, wind velocity and MRT. The SET* values at points X and Y were extremely high before they were shaded by the tower building, after which they became lower than that at point Z. The weaker wind at point Z seemed to make the SET* value higher than at points X and Y. Yamashita et al. (1991) examined the relationship between the SET* values and the thermal comfort outside in summer. It is suggested that 33 deg. C of SET* indicated the boundary between hot and warm in the seven classes from hot to cold. Consequently, it can be said that people on the rooftop garden feel “hot” if they are in the sun, while in the tree shade or the shade of the tower building they do not feel “hot” and outside tree shade is preferable.

5.2 Thermal environment along footpath

The points on Line P in Fig.1 indicate the measuring points where the instruments were successively moved. The data were collected within a few minutes at each point and the total time per run was around 1.5 hours. Five runs (RUN 1 - 5) were carried out per day at roughly two-hour intervals. Figs.9 (a) and (b) show the height above the ground and the view factors of each material surrounding the measuring points. The view factors were calculated using hemispherical photographs assuming that a man was a rectangular parallelepiped. The number on the abscissa indicates the distance along the path. Note that the right end of abscissa is the start position corresponding to the top of the rooftop garden. From the distributions of view factors it was found that people on the path were surrounded by vegetation at a high ratio particularly at around the middle and end of the path.

Fig.9 (c) shows the time variations of SET* values on the path. The SET* values at most parts of the path are lower than 33 deg. C for all RUNs except RUN 1. This means that the footpaths offered “non-hot” conditions during most of the afternoon when the number of customers visiting the shopping complex gradually increased.

5.3 Thermal environment and residence characteristics

The relationship between thermal environment and residence characteristics were investigated from 2 - 4 August 2004 and from 28 - 30 July 2005. The numbers of visitors entering and leaving points X and Z were counted every ten minutes by video images.

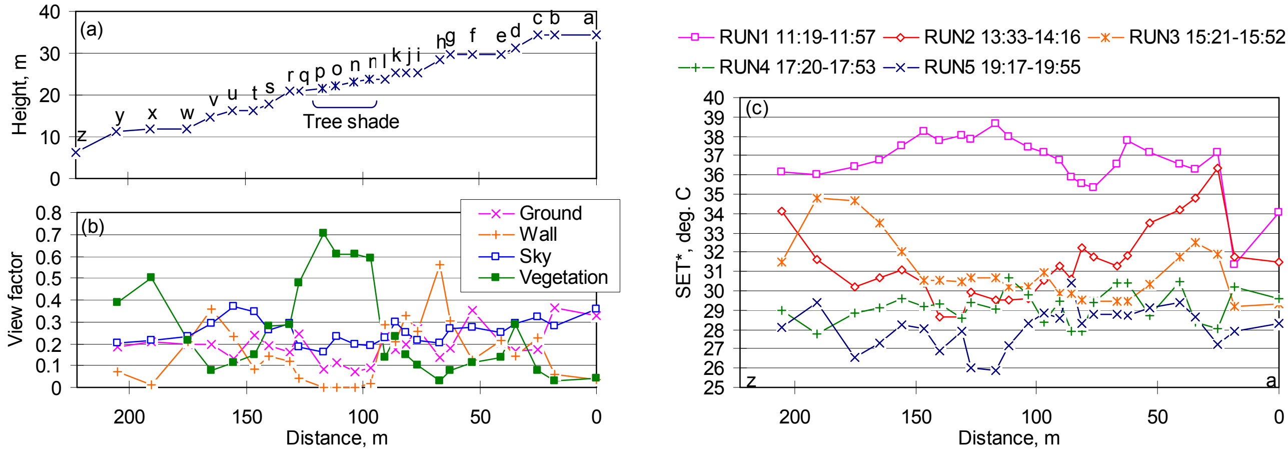

Figure 9 Height above ground (a),view factors of each material (b) and time variations of SET on path P (c) at RUN 1 - 5 on 28 July 2005.*

Fig.10 shows the relationship between the total numbers of visitors at points X and Z from 11:00 h to 15:30 h. Accumulated solar radiations are also indicated as proportionally sized circles. The cumulative number of visitors tended to be relatively small on the day with abundant solar radiation at both points. Furthermore, point Z, in the tree shade, seemed to be preferable as a place to visit. In contrast, the cumulative number of visitors tended to be large on the day with little solar radiation at both points. Furthermore, point X, which had no tree shade, seemed to be preferable as a place to visit.

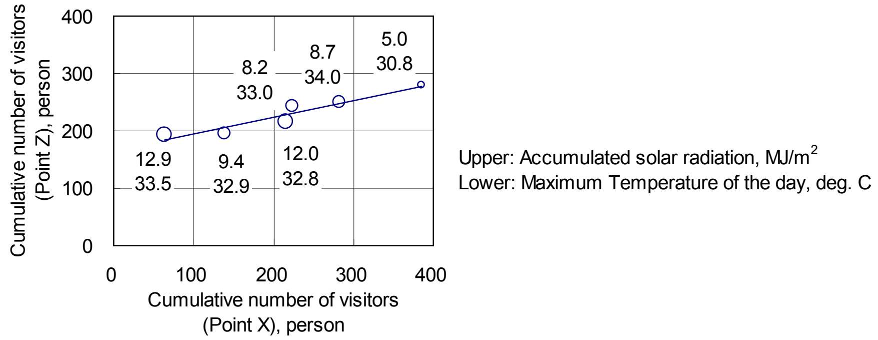

Figure 10 Relationship between cumulative number of visitors at points X and Z from 11:00 h to 15:30 h.

The mean residence number L [person] was calculated such that:

$$L = \lambda W \quad (3)$$

where λ [person/min] is the arrival rate and W [min] is the mean residence time.

Fig.11 shows the relationship between the solar radiation and the mean residence number (a), the solar radiation and the mean residence time (b) at the points X and Y on the sunny days (02/08/04, 28/07/05 and 29/07/05). No apparent relation was found among the figures.

Fig.12 shows the results when the solar radiation in Fig.11 was substituted for SET*. This clearly shows that both the mean residence number and the mean residence time had a negative correlation to the SET* value. Consequently, it can be said that outdoor human behavior is affected not only by solar radiation but also by air temperature, wind velocity, humidity and radiation from the surroundings. In other words, SET* seems to be an appropriate index for evaluating the outdoor thermal environment, particularly where people enjoy staying or strolling in summer.

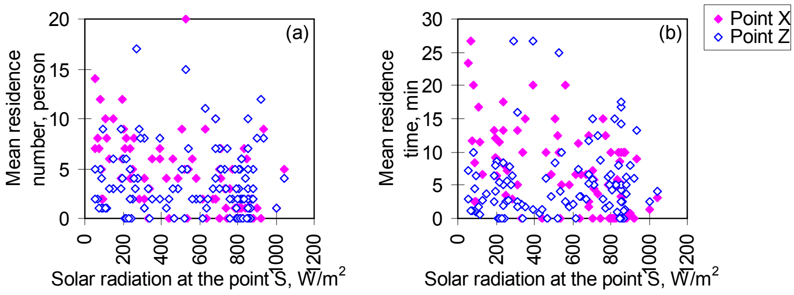

Figure 11 Relationship between solar radiation and mean residence number (a), solar radiation and mean residence time (b) at points X and Y on the sunny days (02/08/04, 28/07/05 and 29/07/05).

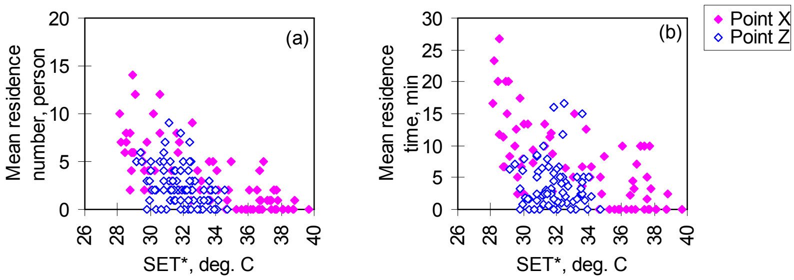

Figure 12 Relationship between SET and mean residence number (a), SET* and mean residence time (b) at points X and Y on the sunny days (02/08/04, 28/07/05 and 29/07/05).*

6. Conclusions

Reduction in a building's heat load, reduction in sensible heat emitted into the atmosphere and the thermal environment in pedestrian spaces in summer were investigated for a large rooftop garden on a commercial complex. Results are summarized as follows.

Reduction in annual cooling load due to vegetation on the rooftop was estimated to be approximately 4.5% compared with colored concrete.

Reduction in sensible heat emitted into the atmosphere by vegetation was estimated to be 37.2 % compared with that when the whole rooftop garden was covered with colored concrete.

The SET* evaluation results show that people do not feel "hot" in the tree shade or the shade of the tower building on sunny days.

Both the mean residence number and the mean residence time had a negative correlation to the SET* value. The mean residence time tended to be longer in the tree shade than in the sun under strong solar radiation, while on cloudy days or in the evening, places without tree shade tended to have a longer mean residence time.

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UNDERSTANDING CITIES AS SOCIAL-ECOLOGICAL SYSTEMS

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Keywords: social-ecological, system, complexity, cities, ecosystem, resilience

Summary

This paper builds on earlier ecological approaches to urban development, as well as more recent thinking in the fields of sustainability science, resilience thinking and complexity theory, to propose a conceptual framework for understanding cities as social-ecological systems (SESs) as a point of departure for further dialogue in the study of urban sustainability. It proposes that cities should be understood as (1) complex, adaptive systems that are (2) integrated across spheres of matter, life and human social and cultural phenomena (or mind), (3) are structured as nested systems that allows interaction across scales and levels of organisation, and (4) that what differentiates cities (and SESs) from other types of ecosystems is the introduction of abstract thought and symbolic construction that allows for considered novelty, communication of ideas across time and space, and therefore learning, and reflexive thinking.

1. Introduction

As we are improving our understanding of the intricate relationship between human well-being and ecosystem integrity, it is becoming clear that the great global challenge of urban development in the 21st century lies in finding ways in which city planning and management address not only the needs of urban dwellers in large, rapidly growing and mainly poor cities, but address these needs in a way that acknowledge the interdependent relationship of cities and the ecosystems of which they are part. There is growing consensus that a reductionist command and control approach is perhaps not the most appropriate way of interacting with what is in essence a dynamic complex adaptive living system; and that resilience and adaptation are factors of urban sustainability as important as (if not more than) conservation, efficiency and equity. This necessitates a quite dramatic mind shift in how cities are viewed. The notion of cities as ecosystems can be traced back at least to the 1960's and the thinking of Howard Odum and Ian McHarg. More recent thinking attempts to describe the interface space between humans and nature (of which cities are one example) as social-ecological systems. However, while there is general consensus that social-ecological systems refers to the human-nature relationship, exactly how this relationship is to be comprehended and structured as an integrated system is not clear. This paper builds on earlier ecological approaches, as well as more recent thinking in the fields of sustainability science, resilience thinking and complexity theory, to propose a conceptual framework for understanding cities as social-ecological systems as a point of departure for further dialogue in the study of urban sustainability.

2. An Ecological Approach to Cities

Applying ecological thinking to cities is not a new idea and has led to several different approaches, some from the perspective of the science of ecology (such as urban ecology), some using ecological concepts as metaphors or guidelines for human activities (e.g. urban metabolism, ecological footprinting and carrying capacity), and some using nature itself as the metaphor to guide the physical development of cities (e.g. ecological design and engineering, biomimicry).

There are, however, major differences between what Tansey (2006) refers to as old ecological thinking and new ecological thinking. Within old ecological thinking, ecosystems are described as though they follow a linear evolutionary process towards a steady-state climax community; and as closed, localised systems with circular metabolisms that self-regulate into an equilibrium state which results in no waste and maximum resource efficiency (Alberti *et al.*., 2003; Tansey, 2006). New ecological thinking, in turn, shifts from an equilibrium to a non-equilibrium model that sees ecosystems as open, dynamic and highly unpredictable, driven by processes and often regulated by external forces, not necessarily internal mechanisms (Alberti *et al.*., 2003). Some of the foundational concepts of new ecological thinking include complexity, resilience, non-linear system dynamics, adaptive management, and emergence. This expands the ecological metaphor to acknowledge not just the flows of matter, energy and information within the system (the 'economy of nature'), but also the importance of context and relationship, as well as the fundamental role of change and adaptability in an essentially unknowable and unpredictable larger system. New ecological thinking also includes humans as components of ecosystems (McDonnel and Pickett, 1993; Alberti *et a.l*, 2003).

Urban ecology initially concerned itself with ecological studies in urban environments, seeing the city as a particular form of landscape (Weddle, 1986). Cicero (1989) identified four types of such studies: 1) comparing different land-use types within an urban setting; 2) comparing an urban area with a nearby 'natural' area; 3) gradient analysis that assess the ecological effect of urbanization along a gradient such as from inner city to periphery; and 4) urban succession or development dynamics of ecosystems where urbanization is seen as a 'disturbance' similar to fire or flood. However, recent thinkers (e.g. Rees, 1997; Grimm *et al.*, 2000; McIntyre *et al.*, 2000; Alberti *et al.*, 2003) have argued for a new theoretical framework that would include humans into ecosystem studies, and especially the study of human-dominated ecosystems such as cities, and have themselves proposed such frameworks.

A number of these frameworks are based on the concept of resource flows, as explained by Grimm *et al.* (2000:574): "The concept of ecology of cities has to do with how their aggregated parts sum, that is, how cities process energy or matter relative to their surroundings." Amongst the routes proposed that could be used to understand the ecology of cities are: material and energy flow accounting (e.g. Odum, 1967 & 2002; Odum, 1997; Haberl *et al.*, 2004), whole-system metabolism (Girardet, 1996) and the estimation of the ecological footprint of the city (Rees and Wackernagel, 1994; Rees, 1997). These routes take existing ecological methodologies and apply them to the dynamics of resource use in cities.

A second approach to applying ecological thinking to cities is through ecological design and engineering. The argument is that if cities are seen as another of nature's biological systems then they should follow the 'rules of nature'. These rules have been defined as the four laws of ecology by Barry Commoner: "Everything is connected to everything else; everything has to go somewhere; there is no such thing as a free lunch; and Nature knows best" (cited in Ross, 1991:194). Karl-Henrik Robèrt's *Natural Step* (Robert, 1995) describes these rules as four system conditions: we should not take more from the Earth's crust than is slowly redeposited; nature cannot sustain a systematic increase of chemical compounds - we cannot emit more waste products than nature can process; the physical basis for the earth's productive natural cycles and biological diversity must not be systematically deteriorated; and there must be fair use of resources in order to meet human needs on Earth. Frijtof Capra (1996) and Janine Benyus (2002) also identified additional rule sets that make similar statements.

The logical progression from this was that the infrastructure of cities (as ecosystems) should be designed to follow these laws. This approach was introduced into modern 'sustainability' thinking by theorists such as Howard Odum (1967), Ian McHarg(1969), who built on the thinking of Frederick Law Olmsted, Ebenezer Howard and Patrick Geddes to suggest city planning, management and design that learn from and co-operate with nature. From this starting point a number of contemporary scholars and practitioners (e.g. Todd and Todd, 1993; Lyle, 1994; Girardet, 1996; Van Der Ryn and Cowan, 1996; McDonough and Braungart, 2002; Eisenberg and Reed, 2003) developed the basis of what is now referred to as ecological design. Kibert (2006) describes three versions of ecological design: strong ecological design based on principles of biomimicry and cradle-to-cradle design; weak ecological design based on minimizing lifecycle impacts; and intermediate ecological design based on the synergistic integration of built environment systems with ecosystems.

However, the metaphors of ecology cannot be applied to the city without taking into account the human component. Arida, (2002:xix) recounts that Saint Isidore of Seville (c. AD 560-636) traced in his Etymologies the origins of the word city to different sources: "the *urbs* (or stones) of the city, laid for practical reasons, and *civitas*, the emotions, rituals and convictions that take form in a city". Saint Isidore would point out that the approaches described above focus on the *urbs* – on the physical aspect of human activities within an "ecosystem created by humans specifically for dwelling" (as cities are described by Stearns and Montag, 1974). Yet, apart from regulatory suggestions, the *civitas* is not addressed. While attempts have been made by ecologists and sociologists to understand how the social aspect of humans can be included in the study of city as ecosystem, Alberti *et al.* (2003) pointed out that neither of these sciences can explain how integrated human and ecological systems emerge and evolve, because human and ecological factors work simultaneously at different levels. Calls for a "new integrative ecology that explicitly incorporates human decisions, culture, institutions and economic systems" (Grimm *et al.*, 2000:575) has led to a new field of research that focus specifically on coupled human-nature systems, now referred to as social-ecological systems, which will be explored in the next section.

3. Understanding Social-Ecological Systems

Cities are arguably the most closely coupled human-nature system and therefore presents a particular challenge to research on social-ecological systems. The exact nature of social-ecological systems (SESs), or what it is that differentiate SESs from other types of ecological systems, is still open to debate. The Resilience Alliance (2006) describes SESs as "complex, integrated systems in which humans are part of nature." However, while there are numerous methodologies and conceptual frameworks for studying aspects of social-ecological systems, the understanding of how the social and ecological components are to be integrated into one system is still evolving. Grimm *et al.* (2000) suggested a modelling framework that would include variables in social patterns and processes and human perceptions as drivers of change together with ecological drivers. Alberti *et al.* (2003) proposed a similar conceptual model that links human and biophysical drivers, patterns, processes and effects. However, both these models are limited to a view of humans as another species of mammal with no attempt to address those aspects that differentiate social-ecological systems from other types of ecological systems. Haberl *et al.* (2004) moves some way towards addressing this gap by suggesting that social-ecological systems should be seen as a 'biophysical' sphere of causation governed by natural laws, and a 'cultural' or 'symbolic' sphere of causation reproduced by symbolic communication.

An analysis of papers published over the past ten years in the main journal of social-ecological system research, Ecology and Society, suggested the following four propositions as a point of departure for formulating a conceptual framework for understanding the nature of SESs:

- *Proposition 1*: A social-ecological system is one integrated system that spans across matter, life and human social and cultural phenomena (or mind).
- *Proposition 2*: A social-ecological system consists of relationships between elements at a number of scales and within nested systems.
- *Proposition 3*: SESs are systems that are complex and adaptive, with properties of self-organization and emergence.
- *Proposition 4*: What differentiates SESs from other systems is the introduction of abstract thought and symbolic construction.

3.1 SESs as integrated systems of matter, life and mind

Four frameworks that aim to unite matter, life and mind through an evolutionary hierarchy were explored: the 'Spheres of evolution' of Vladimir Vernadsky, Pierre Teilhard de Chardin and others that describes what Barrett (1985) describes as a 'noosystem', Kenneth Boulding's 'Hierarchy of Systems Complexity', Herman Dooyeweerd's 'Cosmonomic Idea of Reality', and Ken Wilber's 'All-Quadrants All Levels (AQAL)' framework. A synthesis of these frameworks suggests that SESs are made up of three distinct, but nested and interpenetrating, spheres or domains of existence: the geosphere (matter), the biosphere (life), and the noosphere (mind). These spheres represent a continuum of increasing complexity and consciousness, with matter as the first (lowest) level, life as the next level emerging from (and thus including) matter, and mind as the last (highest) level emerging from life. Thus, life requires matter in order to exist, and mind requires life and, therefore, matter for its own existence.

Within these spheres there are certain modalities, or irreducible areas of functioning, each with its own set of 'laws' that governs existence within that particular level of functioning, and supports the emergence of the next level. These 'laws' are deterministic at the lowest levels and become increasingly normative in the higher levels. SESs span across all three spheres and the modalities within each of the spheres, although elements within SESs can exist at different levels. As elements of the system become more complex and conscious they inhabit higher levels of development, but at the same time contain all the properties of the lower levels.

Apart from the 'vertical' dimension provided by the holarchy of development, each level of development also spans horizontally across four quadrants of interior, exterior, collective and individual. SESs thus represent the combination of the 'exterior', as created by biogeochemical processes (in which humans have come to play a disproportionate part), and the 'interior', as created by, and experienced through, the human psyche and processes of thought, including the "shared cultural worldspace" (Wilber, 2000). It is proposed that SESs are not seen as made up of humans, their social structures, and the technological and cultural artefacts that support these structures (the social system) on the one hand, and everything else that constitutes life and the universe (the ecological system) on the other. Instead, humans are placed within nature as an integral part of the processes of change and co-evolution. Thus at the exterior level, humans and their artefacts are an indivisible part of the biosphere and they, like any other organism, participate in and co-create the metabolic and change processes that shape the biosphere. Humans are bound by the same laws that apply to other organisms when operating at the lower modalities, but their interior processes allow humans to apply these laws to create and adopt technologies that introduce novel components to the system at scales both above and below that of the individual human. However, this is only one part of the picture. SESs consist of many types of hierarchies with elements interacting across the various levels and types of hierarchy. The next step is to understand the holarchic and cross-scale nature of this structure, and the interrelationships between elements operating at the various levels.

3.2 Nested Across Multiple Scales

Hierarchies of scale are just one aspect of the multilayered structure of SESs to understand. Also important are hierchies of level, and in particular the concept of holarchy, which can be seen as the nested hierarchy of whole/parts or holons. Another multi-level conceptual framework that is prominent in the literature on the study of SESs is that of panarchy.

Hierarchies of scale have to do with the quantifiable and measurable aspects of a system (Gibson *et al.*., 2000). The most commonly used hierarchies of scale fall into three categories: temporal, numerical and spatial. In hierarchies of scale the next hierarchical level is the sum of the previous levels (e.g. one kilometre equals the sum of a thousand metres or of a million millimetres) and the difference between levels is merely a quantitative one. Hierarchies of level, on the other hand, are concerned with organization and structure and, as described by Simon, this category of hierarchy is the ordering structure of complex systems (Simon, 1962). In essence, hierarchies of level refer to a structural organization whereby a system (mechanical or natural) is constructed by first constructing simple sub-assemblies, which in turn are connected into a subsystem of a higher order. These sub-systems are in turn connected to create the final system. The system is therefore constructed from the bottom up in increasing levels of internal complexity.

The difference between hierarchies of level and those of scale is that the difference between the hierarchical levels in the system is also qualitative and functional. The entities at level three have properties and functions substantially different from those at levels two or one. This is also where the major difference between mechanical systems and natural systems enters. With mechanical systems, the properties of levels two and three can be predicted with a certain amount of certainty from the properties and interactions of the elements at the levels below. However, in natural systems the properties of each level that emerges from the interactions at lower levels cannot be “strictly and totally deduced from their components” (Wilber, 2000:54) and are qualitatively different. The most important aspect of this category of hierarchy is that each element is simultaneously a whole (as an individual entity) and, as an element in the system at that level, a part of a larger whole. The whole can thus be seen as an emergent property of the structural relationships and interactions of the parts. This type of hierarchy is referred to as a holarchy (Koestler, 1975:103).

Furthermore, each holarchic level operates according to its own set of rules or patterns that determine behaviour at that level. However, lower levels can influence higher levels through upward causation and higher levels can control or influence what happens at lower levels through downward causation (Roger Sperry cited in Wilber, 2000:28). This notion of interaction and influence across different hierarchical levels is the central tenet of the next major concept to be discussed, namely panarchy.

As part of their quest to develop an integrative theory for understanding processes of change happening globally, Holling, *et al.*. (2002) coined the term ‘panarchy’ to provide an organizing framework for theory dealing with cross-scale dynamics in natural and social systems. The term is a complex wordplay on the idea of hierarchy (of level and scale) combined with the prefix ‘Pan’ to indicate change across the whole. The panarchy framework is based on two premises. The first is the idea of the adaptive cycle and that the levels of the panarchy can be drawn as a set of nested adaptive cycles arranged as a dynamic hierarchy in space and time (Holling, *et al.*., 2002:101). The second is that the adaptive cycle phases at different levels interact or connect with one another. The panarchy is constructed gradually as potential accumulates at one level, until a threshold is passed that allows the establishment of a slower and larger level. Conversely, the panarchy collapses or enters state breakdown when there are simultaneous crises at different levels (e.g. all levels of the system enters the breakdown phase of their individual adaptive cycles at more or less the same time) or a crisis cascades across all levels. From this point of view, the objective of sustainability initiatives is not to resist or reverse change, but to accept that change is inevitable and manage the phase changes within systems in such a way that the system does not lose its fundamental identity and tip into another stability domain, or that such collapses do not cascade upwards into the larger system. This means managing the capacity of the system to experience shocks while retaining essentially the same function and structure, and therefore identity, a concept known as resilience. A resilient social-ecological system has a greater capacity to avoid unwelcome surprises (regime shifts) in the face of external disturbances and so has a greater capacity to continue to provide us with the goods and services that support our quality of life

(Walker and Salt, 2006:37). In order to understand how resilience can be managed, it is necessary to understand the characteristics of SESs as complex, adaptive systems.

3.3 Complex and Adaptive

SESs are complex, in that they are diverse and made up of multiple interconnected elements, and adaptive, in that they have the capacity to change and learn from experience. Lucas (2004) explains that the essence of complex adaptive systems is that they self-organize to optimize the function of the system, creating new niches as necessary, and changing their composition to fit the changing patterns they encounter. Unlike mechanical systems, where systems and parts have fixed functions that either work or do not, adaptive systems have flexible functions that adjust to the context of their environment. A key aspect of these types of systems is that their constituent agents are constantly making predictions based on its various internal models of the world (its implicit or explicit assumptions about the way things are out there), and adapting to each other and to the external environment. These adaptive responses and interactions allow the system as a whole to undergo spontaneous self-organization into collective structures with properties that cannot be predicted from the properties of the parts, and which the agents may not have possessed individually (Waldrop, 1992) - a concept referred to as emergence. Furthermore, the connections or interactions between the elements of the system are non-linear and contain feedback loops, which implies that small causes can have large results. Understanding SESs as complex, adaptive systems therefore means that the important properties to consider are those related to change and the system's ability to deal with change – for example, resilience, adaptability, transformability, connectivity and diversity.

One of the hallmarks of complex systems is the aggregation of local actions into well-defined global patterns such as cities and neighbourhoods (self-organized criticality) (Miller and Page, 2007). Within these systems, microlevel agents interact to create the global properties of the system. These global properties then feed back into the microlevel interactions. This happens in both physical and social systems. What differentiates physical systems from social systems is that the agents in social systems often alter their behaviour in response to anticipated outcomes. This brings us to what it is that differentiates SESs from other ecological systems – their capacity for abstract thought and symbolic construction.

3.4 A Capacity for Abstract Thought and Symbolic Construction

As Westley, *et al.*. (2002:108) describes, the ability of humans to make sense of their world through abstract thought and symbolic construction allows "the formation of social systems and a 'virtual reality' through which options and scenarios can be explored and new possibilities can be imagined". They suggest four elements of the dimension of symbolic construction: the creation of a hierarchy of abstraction (which allows the agent to separate him/herself mentally from the realm of time and space); the capacity for reflexivity; the ability to remember the past and learn from it (hindsight) and imagine the future and plan for it (foresight); and the ability to externalize symbolic constructions in technology. Furthermore, the ability to use symbols and with symbols, language, allowed humans to develop sophisticated means of communication that allow abstract ideas to be communicated not just across vast distances, but also across time. This ability to communicate across space and time allowed for the creation of the three dimensions of social systems identified by Giddens (1979), that is the structures of signification (the social rules that govern meaning), domination, and legitimisation (the rules that actors draw upon to sanction their own behaviour as well as that of others, according to Abou Zeid, 2007).

It is this sophisticated interior aspect and the opportunity it creates for novelty, foresight, reflection and learning, as well as the beliefs, norms and values that are formed at this intangible level, that differentiate SESs from other ecological systems. It not only allows the development of novel social and technological systems that determine the nature of interactions between humans and other aspects of the biosphere, but also allows humans to engage in reflection regarding the meaning and consequences of these interactions.

4. Discussion

The easiest way to illustrate how the above framework applies to cities is to use a narrative example of how a system perturbation such as crime at the level of the individual agent cascades through the different levels and spheres of the city system. In the imaginary city of Ezulweni a burglar breaks into the house of a middle-class couple, stealing their electronic goods and second car. According to his value system (a noosphere concept) he is perfectly justified in doing this as a form of wealth redistribution after his ancestors have endured years of oppression under the wealthy elite. Outraged and fearful, the couple install burglar bars in front of their windows and security gates at the doors (a noosphere response to a biophysical threat resulting in a change of their biophysical environment). A couple of weeks later, the burglar breaks into another house down the road, and then another. He is bold because the social structures that are supposed to protect the community from crime are hampered by a lack of biophysical resources (e.g. patrol vehicles) and normative dysfunction (a demotivated police force) and he no longer has any fear of being caught. Fearful of becoming the next victims, all the houses in the neighbourhood install bars (adaptive behaviour). However, this does not stop the burglar as he merely uses a crowbar to break through the security bars (adaptive behaviour). His success further emboldens his friends, who also try their hand at a little burglary, which escalates the perceived threat and with it fear. The neighbourhood install alarm systems and start building walls around their properties. At this point, while each agent is still acting in response to an external driver (the burglar) and the response of his neighbours, their combined efforts are already having an effect on the function and identity of the neighbourhood (a scale up), and on the local economy as businesses opened up to exploit the new niche presented by a need for security (abstract thinking allowing them to predict a market opportunity). The walls mean that neighbours no longer have social contact (which has implications for social cohesion) and people no longer walk down to the corner store (which adds to local traffic and carbon emissions). The criminals, finding that all these new security measures cannot be overcome by a mere crowbar, up their game and introduce firearms, turning the crime of burglary into robbery and vehicle hijacking (thus upping their effects on the hierarchy of significance). This increases the levels of fear within the neighbourhood, where people respond by either moving (leading to a drop in property values), or increasing their security by purchasing firearms themselves (thus escalating the levels of violence and altering value systems). However, firearms costs money and the thieves find they need higher levels of sophistication to achieve their aims. This leads to criminal specialization and organised crime syndicates with accompanying changes in the value systems of the communities from which the criminals hail. Powerless to stop the criminals on an individual level, the householders now organise themselves and close off their neighbourhood with fences, gates across formerly public streets, and armed security guards. With this action they cause a number of changes to the larger urban system. Firstly, the structure of the city is changed, disrupting traffic patterns and increasing the burden on roads outside the enclosed neighbourhood, which increases congestion and with it, air pollution. Increased levels of air pollution have a detrimental effect on human health within the city and add to global carbon emissions and therefore climate change. In addition, the property values of those houses outside the walls plummet and some houses are simply abandoned, leading to a deteriorating urban environment. Frustrated, the criminals also move their efforts to other, more vulnerable neighbourhoods where householders go through the same cycle until eventually the city becomes fragmented into security enclaves and a new phenomenon – the gated community – emerges in new development, forever altering the character of the city. To this, the city authorities finally respond by introducing legislation that bans enclosed neighbourhoods, but this cannot be enforced as the situation has already escalated out of hand and the city does not have the funds to take all these communities to court to enforce the legislation. In the meanwhile a large economic sector has developed around crime and security and this sector contributes significantly to both the national GDP and the tax base, while providing many low-skilled jobs.

One can continue to unpack this story in many different directions, but the point is that small individual actions have come together to influence the system at much larger scales. These actions were driven by a combination of social and individual value systems across a range of ethical norms, and were enabled by social structures to effect a lasting change on the biophysical system of the city, as well as the national economy and aspects of the global biophysical system. As the story unfolded there were key points at which there was an opportunity to change the trajectory of the story. However, as the changes cascaded up levels, the interventions that would have been required increased in scale and cost. Unfortunately, because many of the changes were initiated at an individual level, they were not picked up by the social structures that should have responded before these changes have already cascaded up a level. If city authorities had understood cities as social-ecological systems where individual actions, driven by value systems shaped by a changing environment, can have far-reaching effects on the identity of the city, they would perhaps have tried to intervene earlier, rather than when it was too late to do anything but adapt to the changes.

5. Conclusion

Understanding cities as social-ecological systems with complex, adaptive behaviour requires the urban sustainability debate to shift from a quest for the ultimate rules for city planning and design, to finding ways that accept and embrace change and novelty while building the capacity for resilience in the interaction between noosphere and biosphere. This would require a rethink of indicator systems to monitor changes not only in the biosphere, but also in the noosphere, (e.g. changes in norms and values) and track the systemic influences and the complex, adaptive processes found in cities. It would further require that planning and regulatory processes are guided by an understanding of systemic interactions; take into account issues of behaviour, relationship, resource flows and resilience across the social-ecological system; and acknowledge that uncertainty and unpredictability is a characteristic of cities that requires adaptive management and flexibility in implementation. Lastly, it requires that the conceptual and other models used to inform systemic planning processes account for the flows between interior aspects (e.g. value systems or structures of legitimisation such as regulations) and both interior changes (e.g. a shift towards a specific value system such as environmentalism) and exterior change (e.g. changing value systems driving the development of new technologies). It must further be able to close the loop by accounting for changes in the exterior related to manifestation of interior events (e.g. the use of a new technology increasing pollution levels).

The ideas outlined in this paper only begin to scratch the surface of a very complex, yet compelling, way of looking at cities. It is hoped that the pebbles it has dropped in the pond will spread beyond this conference to further enrich and stimulate the debate and contribute to a better understanding of how best to achieve sustainability in cities.

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THE CONCPET OF PROGRESS AND PROCESS IN A SUSTAINABLE SOCIETY

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Summary

In common parlance, the word “progress” has come to be synonymous with such words as advancement, growth, development or improvement. This usage of the term has caused confusion and even harm, particularly in terms of sustainable development. This paper clarifies the meaning of the term by placing it in three categories: the idea of process, the idea of evaluation, and the idea of control. The paper then suggests a new understanding of the term with reference to a sustainable society. Progress is in one sense essentially a process, not an achievement or an end. Progress signifies evaluation and betterment with regard to basic and intermediate needs, morality and spirituality. Progress implies the idea of controlling or overriding the natural world which is an obstacle for sustainability. With these principles progress of architecture is explored. In addition, this paper discusses the importance of the ideas of process for a sustainable society by maintaining that the absence of these ideas has led to many problems in education, technology, economy and architecture in modern society. A sustainable society is an inevitable and progressive step towards the common future. Sustainable architecture as a reflection of such a society is also a step forward in the history of architecture.

Introduction

Problems of the industrial-affluent consumer society are ubiquitous. Environmental crises, overpopulation, shortage of food and resources, poverty, unemployment, falling quality of life, family breakdown, inequality in the distribution of wealth and in gender, just to list a few, are the predicaments that modern society experiences (Carson, 1962; Black, 1970; Ehrlich, 1970; Goldsmith et al, 1972; Meadows et al, 1972; Schumacher, 1974; Shiva, 1989; Ponting, 1991;). Aurelio Peccei (1976) called the predicament “the world problematique.” Other commentators have suggested current society has entered a “terminal phase” (Trainer, 1995), “the end of the era” (Schumacher, 1997) and the emergence of a quite different society--- a sustainable society (Pirages, 1977; Bookchin, 1980, 1982; Milbrath, 1984, 1989; Trainer, 1985, 1995; Tokar, 1987; Dobson, 1991; Garbarino, 1992; Robinson, 1994). The challenge which all people are now confronting is difficult because to sustain life requires paradigm shifts in almost every sphere of life: education, technology, science, economy, politics, and especially in world view, values and ethics. One of the obstacles is the problem of the concept of progress in existing society, particularly in architecture. People often think that a sustainable society is a regressive step as it appears to restrict human activity, and that sustainable architecture moves architecture backwards as it often looks like vernacular architecture with simple technologies. This paper sets out to examine the problem of progress in modern society and architecture, clarify it in terms of a sustainable society, and demonstrate that a sustainable society is an inevitable step to move human civilization forward, and that sustainable architecture progresses architectural history.

Definitions of Progress

Progress is one of the most abused words in the contemporary vocabulary. Etymologically, progress is of Latin origin, and combines two elements, pro and gradus, meaning to walk forward. In general usage, the term has come to be synonymous with such words as advancement, growth, development and improvement (Bossard, 1931). Historically, the earliest connotations of the term have been rather general and simple, involving essentially a philosophy of life or of history, and constituting a speculation on the nature and direction of the changing life stream. J.B.Bury (1920) who wrote so illuminatingly about the idea of progress, considered it to mean that “civilisation has moved, is moving and will move on a desirable direction towards general happiness enjoyed by all the members of society…The idea of human progress is a theory which involves a synthesis of the past and a prophecy of the future” (1920:2-5). Nicholas Rescher (1997) also defines progress in this manner as a matter of change in a direction of betterment, and believes that progress has two dimensions: retrospective (how far humans have come) and prospective (where they have yet to go). For him, a crucial measurement of progress is to see whether the human condition of children’s children--- and their children’s children will be better. Aldous Huxley (1938) maintained that “real progress is progress in charity, all other advances being secondary thereto.” For him, progress can be achieved by the most nearly free, ideal man, (the non-attached man in his terms), who always combines virtue with insight. The man of non-attachment means non-attached to the self and to what are called ‘the things of this world’ (1938:3-4). This has been associated with the teachings of traditional philosophers and the founders of religions with attachment to an ultimate reality greater and more significant than the self. This doctrine can be found at the very heart of the teachings of Buddha, of Lao Tsu and the Gospel of Jesus. The practice of non-attachment entails the practice of all the virtues and of charity (Huxley, 1938). As people become non-attached, progress in charity will be ensured and thus human society progresses. James H. S. Bossard (1931) has provided a more comprehensive framework to understand the nature of progress, which involves three ideas: the idea of process, the idea of evaluation and the idea of control. Using this framework, this paper will carry out an analysis of progress.

Progress as the Idea of Process

Virtually all usage of the word progress harks back to the idea of a reaching out or movement towards a given end or ends. Nowhere is there any conception of stability, but everywhere an acceptance of the idea of movement or change. Progress, in other words, is in one sense essentially a process, not an achievement (Bossard, 1931).However, progress as the idea of process is largely neglected in modern society (Bossard, 1931; Wright, 1997). The ignorance of this idea lies in the fact that the process of fulfilling an end with a means is omitted because the means becomes the end. The neglect of the concept of process is visible in almost every aspect of affluent-industrial consumer society.

Modern education has become an end, not a means. In terms of vernacular wisdom, education is not an end, but a means to an end, that is, schools do not educate children only for the purpose of educating them, but to fit them for life. The goal of education is to discipline individuals to be the whole person of spirit, mind and body. Schumacher (1974) claimed that the primary aim of education is to teach values and wisdom, and that the teaching of specialised knowledge is secondary. The holistic development of the whole person may help create what Huxley called the man of non-attachment. Therefore, progress in charity is assured, and in turn society moves forward. On the contrary, current education institutions prepare and select specialised workers, experts and professionals for jobs in the industrialised production system as “they are predominantly geared to the reproduction of industrial-affluent consumer society” (Trainer, 1995:166). Specialisation is the product of industrialisation, owing to the division of labour (Smith, 1937), along with the modern concept of progress. This is guided by the mechanistic world view derived from the scientific revolution which was mainly formed at the time of the Enlightenment. The drawback of specialisation is that it puts sole focus on objects rather than relationships (Capra, 1982a), and that it blinds people to see only one aspect or one dimension of reality and think of this as the total reality (Kumar, 1982). In addition, the focus on the significance of success in present education results in education as a means becoming an end. This emphasis reinforces the obsession with being seen to be successful in life, with being promoted, rising in power, wealth and prestige, and therefore being richer and consuming more (Trainer, 1995). It produces men of attachment. Therefore, current society is regressive as it cannot progress in charity with regard to Huxley’s theory and it omits the idea of process.

The lack of process can be also found in modern technology. Obviously, it is wise to regard technology as a means to achieve a better life. Unfortunately, it is not the case in existing society. Once technology ceases to be a means, but becomes an end in itself like a stimulant, it will unavoidably develop by its own law and principles, and then become inhuman. The appearance of inhuman technology is virtually everywhere in the present. Faster travel has increased the risk of accident and environmental pollution, creating diseases unheard of in the past; modern medicine rapidly cures the malady but generates side-effects requiring further treatment; and more significantly, industrialisation on the basis of the division of labour, with its advanced technology has created mindless, repetitive and soul-destroying work. This has destroyed initiative and rotted brains and soul of a vast number of workers, lessening their dexterity, lowering their social status and reducing the chance for them to work, thus worsening the problem of unemployment. Thomas Aquinas defined each person as a being with brains and hands, who enjoys nothing more than to be creative, usefully and productively engaged with both (Capra, 1982a). However, the so-called ‘labour-saving’ technology is most successful in reducing or even eliminating the skilful and productive capacity of human hands, which had previously been in touch with real materials of one kind of another (Schumacher, 1974). When industrial society does not provide an opportunity for its members to be the whole person, it is hard to say that society still progresses. It is no wonder that Huxley (1938) stated that all today’s technological progress is regressing in charity and that technology developed for its own sake may have a hidden cause—attachment to wealth. Since the desire for wealth is not limited by the final gaol to acquire “something better than money” (Ruskin, 1909), and modern people are educated to be passive consumers and attached to materialistic affluence, prodigious technology, as a means to accumulate wealth, inevitably becomes an end in itself. This leads to discussion of another ignored facet of progress, the idea of process in the economy.

The absence of the idea of process in the modern economy lies in the fact that it operates free of morality, ethics and spirituality. Morality, it could be argued, represents the way that people would like the world to work—whereas economics represents how it actually works (Levitt & Dubner, 2005). When the world driven by its economic system does not run in the way morality expects, the economic system is an end in itself due to the fact that it is no longer limited by morality, ethics and spirituality. Schumacher (1997), however, believed that economics without spirituality can provide temporary and physical gratification, but that it cannot offer internal fulfilment. By contrast, spiritual economics brings service, compassion and relationships into equal play with profit and efficiency. Both economics and spirituality are needed together. But today there exists the erroneous belief that being rich is being happy (Schumacher, 1997), and that "I produce and I consume, therefore I am" (Smith, 1993:183). The truth is that when life seems better and much more comfortable, people feel worse and less happy (Batra, 1991; Easterbrook, 2003). Human thirst for happiness is unquenchable. It means that human beings have a spiritual nature. They have needs that cannot possibly satisfied by material objects. The human desire for happiness is infinite, but material things are finite; hence things can never quench the desire. The limited cannot yield the unlimited. Only an infinite entity can satisfy the infinite human hunger for happiness. Spiritual activity is simply a pursuit of the infinite entity (Batra, 1991). The modern economic system is not subject to morality or spirituality, but rather based on the philosophical foundation that the greater the production and consumption, the happier the person. However, since consumption is merely a means to human well-being, the aim should be to gain maximum well-being with minimum consumption. The optimal pattern of consumption, producing a high degree of human satisfaction by means of a relatively low rate of consumption, allows people to live without great pressure and strain and to fulfil the final goal of life: well-being, happiness and spirituality.

The absence of the idea of process in the modern economic system may also result from the loss of traditional wisdom, in that the focus of modern education is laid on specialised knowledge rather than wisdom. In the Western epistemological tradition the most important key to wisdom, the understanding of reality, has been the concept of causation (Smith, 1993). As Aristotle put it, "Men do not think that they know a thing till they have grasped the 'why' of it." Aristotle pursued this investigation by showing that there are four conceptually distinct and essential causes for every rational human activity utilising material resources: the *causa materialis*, the *causa efficiens*, the *causa formalis* and the *causa finalis*. An example is the building of a house, wherein the wood and other materials are the *causa materialis*, the carpenter's labour and the tools are the *causa efficiens*, the blueprint or plan in the carpenter's mind is the *causa formalis*, and the need to have a home for shelter and comfort is the *causa finalis*. To fully understand this act of building a home, it would be necessary to investigate all four of these causes. The same methodological approach needs to be used to examine the modern economic system with the intention of fully comprehending it. In current analysis, however, in economics as well as in other theoretical sciences, two of the types of causes advanced by Aristotle have been largely omitted: the *causa materialis* and the *cause finalis* (Georgescu-Roegen, 1971). In its search for understanding and its quest for reform, modern economics has tended to utilise only the *causa efficiens* and the *causa formalis*, and of these two it has emphasised the *causa efficiens* much more than the *causa formalis*. More accurately, the *causa formalis* is often submerged by the *causa efficiens*. The omission of the *cause finalis* exactly signifies the absence of the idea of process in the modern economic system as it is not a means to an end, but an end in itself free of moral and spiritual constraints.

The loss of progress as the idea of process seems also true of architecture. Architectural design has become a means and simultaneously an end owing to the specialisation of industrial society. As a consequence, the process of building and interactions with the consumers of buildings are neglected. However, in the days of vernacular architecture, the users of buildings understood the process of construction, even if they were not themselves builders (Vale and Vale, 1991). The Eskimos, for instance, built igloos by a natural unselfconscious action-based approach rather than the highly self-conscious and introspective mode of thinking which the modern architect has come to manipulate (Figure 1). For the former, there was no design problem but rather a traditional form of solution with variations to suit different circumstances which were selected and constructed without a thought to the principles involved (Lawson, 1990). Currently, the consumer is supposed to be moved by the architecture, and if not moved, then usually this is because the consumer has failed to understand the purpose of the architect rather than the architect understanding and responding to what the consumer wants. Moreover, in the vernacular process, designing is also very closely associated with making. The Eskimos did not require an architect to design the igloo in which they sheltered while hunting. In most vernacular societies the craftsman offered a complete design-and-build service to customers (Lawson, 1990). In the modern world, things are different. An average modern house and its content represent the products of industrial specialisation and ignorance of the idea of process. The house itself was probably designed by an architect and sited in an area designated as residential by a town planner. Inside, the furnishing and fabrics, the furniture, the machinery and gadgets have all been created by specialised designers who may have never even once dirtied their hands with manufacture of these artefacts. The architect has perhaps muddied his boots on the site when talking to the builder once in a while, but that is about as far as it goes. Architectural design spontaneously as a means and an end has separated the architect from the process of building and the occupant. Nevertheless, this separation does not necessarily promote better design, as Brenda and Robert Vale (1991) have claimed," a green dimension to such issues recognises that a common base must exist between all concerned, whether artist or layperson. Since the journey into space, the fragility of the world has both shocked and challenged. It has become apparent how dependent each person is on the next, for all belong to the same whole (1991: 7).

The importance of progress as process is that the course of the solution to social problems is itself a social process, and that the solution is crucial for progress in society. In other words, progress may mean the process of solving problems. It ought to be kept in mind that education, architecture, technology or economy are a means to well-being, happiness and spirituality, but only when each is a means to an end, not an end in itself.

Figure 1: The Igloo (Source: www.alaska-in-pictures.come)

Progress as the Idea of Evaluation

The term progress not only indicates the process of change but also it signifies its evaluation. It is at once a phrase, not only of description, but of appreciation as well (Bossard, 1931). Progress, along with freedom and democracy, is the manifesto of modernism (MacIntosh, 2007). However, progress stamped in particular by the Enlightenment, expresses more explicitly the self-image of the modern age, and is predicated on the proposition that development of science and technology, and economic growth more or less automatically lead to an increasingly humane society (Burgen et.al, 1997). In reality, the outcome, an increasingly inhuman society, is the opposite to the promise of modern progress. It results from the fact that science, technology or economy are all means, but are utilised to evaluate progress. This also explains the absence of the idea of process in modern progress as discussed above. To assess progress with means makes science, technology, economy and in turn the whole modern social system free of morality and spirituality. Scientific and technological advancement and economic growth as the judgment of progress are problematic.

The Age of Enlightenment, and the theory of progress to which it gave rise, were centred on the sacredness of two categories: modern scientific knowledge and economic growth. It was believed that with the guidance of science and economic growth, society could progress. However, Vandana Shiva (1989) maintains that the unbridled pursuit of progress started to destroy the life-support systems of forests, water and land. The act of living and of celebrating and conserving life in people and in nature seems to have been sacrificed to progress, and the sanctity of life has been substituted by the sanctity of science and growth. If progress based on the advancement of science and technology and economic growth threatens survival itself, there must be something seriously wrong with the evaluation. What none of the thinkers of the Enlightenment envisaged, and their followers today have failed to perceive, is that human life can become more savage, irrational and self-destructive even as scientific advance accelerates (Gray, 2004). The modern stereotype that progress of society merely relies on improvement in scientific and technological knowledge, and economic growth has been cultivated since the Enlightenment when the striking disparity between the development of intellectual power, scientific knowledge and technological skills, on the one hand, and of wisdom, spirituality and ethics on the other was triggered. From that time onwards, scientific and technological knowledge have grown exponentially, while there has been hardly any progress in the conduct of social affairs (Capra, 1982b). Ravi Batra (1991) has stated that spirituality is the foundation of human progress, and that progress in an intellectual and physical sense is impossible unless there is a spiritual betterment at the same time. The reason why progress cannot occur in the physical arena through economic growth and the intellectual through the development of science and technology lies in the very nature of the universe which exists in a vibrational flow balanced by positive and negative forces. The Chinese have named them the yang and the yin. The earth and the atmosphere surrounding it are finite. Any positive waves in this finite realm will have to be counterbalanced by a negative wave (the balance between the yin and yang). Therefore, any invention, creating a positive wave of physical comfort is matched by a corresponding negative wave leading to discomfort (Batra, 1991). For example, air conditioners create physical comfort of some sort, but use CFCs which are closely linked with the greenhouse effect and the ozone hole. In view of the interdependent nature of the natural world, it is not surprising that the result of new scientific inventions will be exactly counterbalanced by their side-effects. Consequently, if life becomes easier in some respects, it will become harder in others.

Economic growth as a means, and as used to evaluate progress, also reflects the obsession with the yang side of progress in modern society. Using the wisdom proposed by Aristotle, the problem with economic growth as an evaluation can be explored. The absence of the *causa finalis* leading to ignorance of the yin of progress, morality and spirituality, has been examined above. Here, the focus is laid on the neglect of the *causa materialis* in the 'growth' economy. Modern economics has been overwhelming devoted to economic growth. The term economic growth has in practice and in theory meant growth in Gross National Product (GNP) (Ekins, 1986). An economy that is growing at 3 per cent per annum is thought to be performing adequately. More growth is splendid, less growth is worrying, and no growth or negative growth indicates widespread economic failure. The assumption is that all problems are to be solved, or at least ameliorated, by an ever growing GNP (Daly, 1996), and that more is better, and big is good (Ekins, 1986). Nevertheless, the problem with GNP is that it counts consumption of natural capital as current income, and does not distinguish between renewable and non-renewable materials (the ignorance of the *causa materialis*) (Schumacher, 1974). For instance, people devote more effort and resources to mining poorer mineral deposits and to cleaning up increased pollution, and they then count many of these extra expenses as an increase in GNP and congratulate themselves on the extra growth. Some resources, such as air, seem to have no price and ownership in a modern economic sense. As a result, people make a profit, not by the efficient use of resources, but shifting the capital cost, which they should pay, to others including their future generations. Taking alternative fuels such as coal, oil, wood and water power as an example, the only difference recognised by modern economy is relative cost per equivalent unit. The cheapest is automatically the one to be preferred, as to do otherwise would be irrational and 'uneconomic'.

According to Mihajlo Mesarovic and Eduard Pestel (1975), Growth can be roughly divided into two types: undifferentiated growth and organic growth. The former refers to mere growth in quantity. The later, in contrast, involves a process of differentiation. The support for the idea of undifferentiated growth being uniform growth and organic growth being growth with differentiation is visible in Herbert Spencer's theory of progress. He (1907) identified progress with evolution. Organic evolution is organic progress and the law of organic progress is the law of all progress. This law, as basically conceived, is the same whether one considers the development of the earth, or of life on its surface, or of a variety of achievements of its people. It consists of the transformation of the homogenous into the heterogeneous (undifferentiated growth into organic growth). Economic growth in modern society is obviously undifferentiated growth as its sole focus is on quantity without concerning its function and the needs of 'the whole organism'. It is rational to think that the goal of economic growth is to meet the physical, intellectual and spiritual needs of all people. However, when modern economy with its productive capacity and an ever increasing rate of growth could easily provide all that people require, it fails to meet the needs of huge numbers of people, or does so in an extremely wasteful way (Trainer, 1996). Len Doyal and Ian Gough (1991) believe that basic needs, survival and autonomy, and intermediate needs like food, water, a non-hazardous environment and significant primary relationships are the fundamental indicator of social progress. Apparently, economic growth has failed to satisfy these needs. It threatens survival and makes people depend on each other in a commercialised way. Pure interpersonal relationships have to be secondary to economic growth. Millions of people cannot access food and clean water. It all implies progress based on economic growth and advancement of science and technology is regressive indeed, and that the evaluation of progress in modern society is problematic.

Modern architecture suffers the same problem. Technological advancement has been an underlying feature of modern buildings (Guo, 2006: 38). Modern pioneer architects were often proud of using advanced technology in their designs as a reflection of the modern concept of progress. However, it is simple technologies that free people from exploitation and which are in the control of the users as found in the autonomous house (Vale and Vale, 2000) (Figure 2), that ensure well-being, In contrast, some so-called 'landmark' sustainable buildings follow the modernist route so as to look 'progressive', and thus be accepted by mainstream society. For instance, Millennium Tower by Norman Foster in Tokyo (Figure 3), has been cited as a good example of sustainable building (Edwards, 2001: 32), although it does not do much in terms of sustainability. Green architecture might look more like vernacular buildings than modern high-tech ones (Vale and Vale, 1991: 181), and have more in common with the vernacular (Guo, 2006:109-121). In terms of the new concept of progress, vernacular architecture appears to be more progressive as it meets people's basic needs, creates a sense of belonging, and provides a built environment for their well-being (Figure 4). Furthermore, the construction industry is dedicated to the capitalist economy (Brolin, 1976:16). Modern architecture has become a big 'consumption box' in which people live. Urbanisation prepares the consumer and the labourer for the growth economy. When considering the nature of a sustainable society, it is no wonder that the ideals of green visionaries were often rural. This is what Nancy John Todd (1977) has called "a revitalisation of the countryside," a changed direction away from urbanisation.

Figure 2: the autonomous house looks ordinary from road

Figure 3: Millennium Tower (Source: http://i166.photobucket.com)

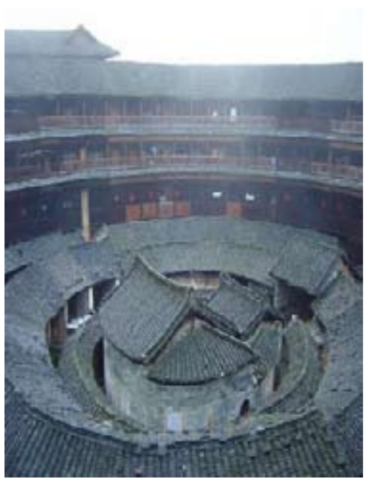

Figure 4: Roundhouse in China (Source: http:// 211.89.225.4:82)

Progress as the Idea of Control

The idea of control over nature is the very core of the modern concept of progress and of universal faith in its promotion (Bossard, 1931; Rescher, 1997). However, the controlling attitude to nature has led to the absence of the *causa materialis* and human inability to recognise that the modern industrial system, with all its intellectual sophistication, consumes the very basis on which it has been erected. It lives on irreplaceable capital, fossil fuels, which it cheerfully regards as income. The idea of domination and mastery over nature is clearly reflected in modern ideologies. Jonathon Porritt (1984) maintains that not only socialism but also capitalism are dedicated to industrial growth, to the expansion of the means of production, to a materialist ethic as the best means of meeting people's needs, and to unimpeded technological development. Both rely on increasing centralization and large-scale bureaucratic control and coordination. From a view point of narrow scientific rationalism, both insist that the planet is there to be conquered, that big is self-evidently beautiful, and that what cannot be measured is of no importance. He then further suggests that to move human society forward there is need to replace the super-ideology with a different world view—a 'systems' view. A 'systems' view, in the sense of general systems theory (Bertalanffy, 1968), is also known as the organic, holistic and ecological world view shared by mainstream societies in the West before the sixteenth century, and in the East before westernisation took effect. According to this world view, the universe is made up of a multitude of objects, but has to be pictured as one indivisible, dynamic whole whose parts are essentially interrelated and can be understood only as patterns of a cosmic process.

Before 1500 the dominant world view in Europe, as well as in most other civilisations, was organic. People lived in small, cohesive communities and experienced nature in terms of an organic relationship, characterised by the interdependence of spiritual and material phenomena and the subordination of individual needs to those of the community. In the Age of the Scientific Revolution (the sixteenth and seventeenth centuries), this ecological attitude changed into its polar opposite; from yin to yang, from integration to self-assertion. From that time onwards, the goal of science has been knowledge that can be used to dominate and control nature, and today both science and technology are used predominantly for purposes that are profoundly anti-ecological (Capra. 1982a). The universe has been treated as a machine, and the world-machine has become the dominant metaphor of the modern age.

The world view proposed by mechanistic science has exerted negative influences on modern society. These can be seen in the shift from wisdom to knowledge, specialisation, and universal faith in progress based on the development of science and economic growth, as discussed above. Vandana Shiva (1989) has woven together a critique of mechanistic science and the Enlightenment's theory of progress, showing how they simultaneously lead to the despoliation of nature, the oppression of women, and the practice of inappropriate and destructive development projects in the Third world. Unlike the claim of the Enlightenment that science and economic growth are universal categories of progress, she believes that the modes of thinking and action that pass for science and growth respectively are not as universal and humanly inclusive as they are made out to be. Modern science and development are projects of male, western origin, both historically and ideologically. They are the latest and most brutal expression of a patriarchal ideology which is threatening to annihilate nature and the entire human species. The rise of a patriarchal science of nature occurred in Europe during the Age of Scientific Revolution. During the same period, the closely-related industrial revolution laid the foundations of a patriarchal mode of economic development in industrial capitalism. Contemporary science and development conserve the ideological root and biases of the scientific and industrial revolutions even as they unfold into new areas of activity and new domains of subjugation.

The scientific revolution in Europe transformed nature from sustaining matter into a machine and a source of raw material (Capra, 1982a). With this transformation all ethical and cognitive constraints against its violation and exploitation were removed. The industrial revolution converted economics from the prudent management of resources for substance and satisfaction of basic needs into a process of commodity production for profit maximization. Industrialism created a limitless desire for resource exploitation, and the mechanistic world view proposed by mechanistic science, and provided the ethical and cognitive licence to make such exploitation possible, acceptable and desirable (Shiva 1989). The new relationship of man's domination and mastery over nature was thus also associated with new patterns of domination and mastery over women (Shiva, 1989; Plant, 1991), others (Bookchin, 1980), and the underdevelopment of the Third World (Trainer, 1985). As mentioned above, because of the loss of the *causa finalis*, there is an unsatisfied craving in modern man. Since he has lost control of his direction, he attempts to regain what he has lost by an inordinate and frantic search for those commodities that will stimulate his sense and thus temporarily quiet his sense of lost direction, or by seeking power that allows him to control the lives of others. This control over, nature, other things and other people, becomes a surrogate for having control over his own life. Lacking the power, ability and will to submit the direction of his own life to an appropriate final gaol, he seeks the false remedy of gaining power over nature, things and persons (Smith, 1993). Progress on the basis of scientific development and economic growth through controlling nature and others is guided by the mechanistic world view and has caused the ignorance of the *causa materialis* and then the environmental crisis, and exploitation. With universal faith in science and economic growth and without the *causa finalis*, modern society actually has lost its direction and become increasingly patriarchal and exploitative.

Modern buildings echo this attitude of overriding nature in order to 'progress'. Guided by the mechanistic world view, modernist architects cheerfully regard architecture as machinery. 'Machine beauty' is an important indicator to judge aesthetics of modern buildings. Modern architecture, based on a confrontation with nature, has lost the craft of materials, the understanding of climate and adaptation to site, the sense of place and locality, the spiritual links of home, family and community, all of which can be found in cultural traditions (Pearson, 1989:21). It is an architecture that has to rely on fossil fuel energy sources to make it work, leading to 50 per cent of world fossil fuel consumption being used for serving buildings (Vale and Vale, 1991: 23).

Conclusion: Sustainable Concept of Progress

When modern education prefers specialised knowledge to wisdom and cultivates people to have attachment to 'the things of this world'; when modern architectural design ignores the process of building and the users of buildings; when super technology turns out to be so inhuman that it destroys initiative; when modern economy, free of morality and spirituality, promotes the cult of materialistic affluence; when the economy grows, but people are less happy; when the focus of scientific development and economic growth is laid only on the yang side of progress; when GNP increases at the cost of natural capital and does not distinguish between renewable and non-renewable materials; when growth in the modern economy is undifferentiated growth, devoted to quantity rather than quality, and bigness rather than smallness; when there lacks the wisdom of the *causa materialis* and the *causa finalis* in the economic system; when economic growth does not meet the needs of a majority of people; when progress of modern society is based on the exploitation of nature, women and developing countries; when the modern concept of progress neglects the idea of process and is evaluated by advancement in science and technology, and growth in economy; when progress promised by modern society has sold out future generations and leads mankind in the direction of self-destruction, it is really hard to say that modern society still progresses. A better interpretation is that it has entered a terminal phase and that the modern concept of progress is severely problematic.

If the general analysis of the problem with the modern concept of progress is basically correct then there is no escaping the conclusion that human beings need a different kind of society; a sustainable society and a new concept of progress. Sustainable progress is necessary to move human civilisation forward. In a sustainable society, progress as the idea of process is emphasised. It is a process, not an achievement or an end. In fact, sustainability could be defined as the process of solving problems caused by affluent-industrial consumer society. It should be realised that the process of tackling problems is itself progress. Education will then be a means to cultivate the whole person of spirit, mind and body. Architecture will recognise the significant role of the process of buildings and the users. Technology and economy will increase the welfare of all people. Technology ought to be technology with a human face such as intermediate technology, radical technology, alternative technology, and appropriate technology. Economics ought to include morality and spirituality like Buddhist economics. Sustainable progress, guided by the holistic and organic world view, would be measured by the satisfaction of the basic and intermediate needs of every person, the balance of physical, intellectual and spiritual development, the harmony of the yin and the yang, rather than advancement of science and economic growth. It includes the idea of control not over nature, women and the Third world, but over the self, over attachment to material affluence, and over behaviour that impacts on the earth and others. A sustainable society is an inevitable step towards the common future as it provides the clear direction to sustain life and achieve something better than money in life. Sustainable architecture as a reflection of such society is also a progressive step in the history of architecture.

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Possibilities of Green Building Design Process Optimization

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Summary

Computer tools available nowadays are used in assessing the environmental impacts of buildings and aid in making design decisions especially when examining different options, as defined by the designers. The number of decision variables in building assessment tasks is bigger than in traditional optimization problems. Some communications e.g. Grosso (2002) and Sowa (2007) showed that the overall assessment is not sensible on changes of important decision variables. Other studies in optimization techniques are defining the number of decision variables that can effectively be used in optimizing complex problems with the number of variables being between 8 to 12 Paczkowski et al.(2004). To overcome the problem some special techniques can be applied. One is: evolutionary optimization technique where the problem of finding the set of decision variables that are giving the best assessment rate is decomposed into subset of optimization problems. Finally, the possibility of automatic optimization within given restrictions can be performed as it is presented on the example of designing the new building.

1 Assessment methods

During the last 18 years considerable research has been focused on the development of systems to assess the environmental performance of buildings, based on different initial assumptions and prepared for different purposes. The best-known existing system is the Building Research Establishment Environmental Assessment Method (BREEAM), developed by BRE and private-sector researchers in the U.K. This system provides performance labels suitable for marketing purposes, and has captured increasing interest in the new office building market in the U.K. Many national systems have been developed by different countries world wide as HQE in France, Eco-profile in Norway, Ecoeffect in Sweden, LEED in US, CASBEE in Japan. Every country in Europe has attempted to develop an adaptation of an existing system or an altogether entirely new system. Several other systems (largely inspired by BREEAM and Green Building Challenge initiative) are in various stages of development in Europe and the World. There are also more specialized systems of interest that are more closely tied to Life Cycle Assessment (LCA), including ECO QUANTUM (Netherlands), ECO-PRO (Germany), EQUER (France) and ATHENA (Canada). Several of these systems have taken the next step; a labeling system that clearly indicates the building's approximate performance to end users.

Recent development of the assessment method has been to use the LCA methodology in order to create uniform, properly structured method which takes into account the environmental impact of materials and used fuels, does not cover important issues as indoor environment, quality of management, functionality, and adaptability.

In many methods, the environmental performance assessment framework is structured hierarchically in levels, with the higher levels logically derived from the weighted aggregation of the lower ones, these levels in many cases are defined as following: performance issues, performance categories, performance criteria, performance sub-criteria. The nesting principle is used to describe buildings at necessary detailed levels.

The performance scales which are described quantitatively can generate assessment in one of three ways:

- by the distance between a “best” performance target and the benchmark divided by agreed number of maximum score (e.g.
- by the declaration of a fixed interval and assignment of scores
- by percentage of fulfilling the criteria.

The qualitative criteria should be translated to the taken scale that finally is the same as the quantitative one. An example of qualitative criteria is the conclusion of existence or non existence of specific features. The assignment of score in this case depends on assessor’s choice.

Finally, the assessment is assembled from over 100 features that are integrated using weights in one or few scores, in CASBEE case integration means use of eco-efficiency principle. The weights used for this purpose are defined separately and have been the subject and result of advanced analysis, as some of features are cross cutting and/or could be contradictory.

All the assessment methods can be applied as decision supporting tools, where the user can examine influences of the decision on the final score. Thus, the natural extension of such supporting tools is the possibility of applying optimization techniques that can find a set of decisions leading to the best solution. The best solution is defined by the best integrated overall score or profile. Grosso on Sustainable Building 2002 in Oslo reported the results of sensitivity analysis of GBTool 2002 that indicated limited possibility of optimization techniques application.

Table 1 Variation of GBTool score on changing chosen parameters

Benchmark		**Relative Score Variation**				
Type	*Relative Variation*	*Category*		*Issue*		***Total***
		Type	*Variation*	*Type*	*Variation*	
Daylight Factor B13	25%	Illumination	100%	IAQ	20 %	10 %
Embodied Energy B37	25%	Energy	81,3 %	Resource Consumption	50 %	10 %
Embodied Energy B37	25%	GHG	41,6 %	Loadings	14,3 % %	10 %
End - use Energy B91	26%	Energy	27,3 %	Resource Consumption	33,3 %	22,2 %
End – use Energy B91	26%	GHG	54,5 %	Loadings	50 %	22,2 %
Water Consumption B109	37,5 %	Water	142 %	Resource Consumption	100%	11 %

Sowa reported similar results at the Conference on Indoor Air Quality held in Warsaw 2007, when examining the CASBEE tool. In this case, the sensitivity analysis on overall BEE score has been presented on significant changes of parameters of indoor environment by +/-2 points, while the adequate loading remain unchanged. The overall score remain within the same class.

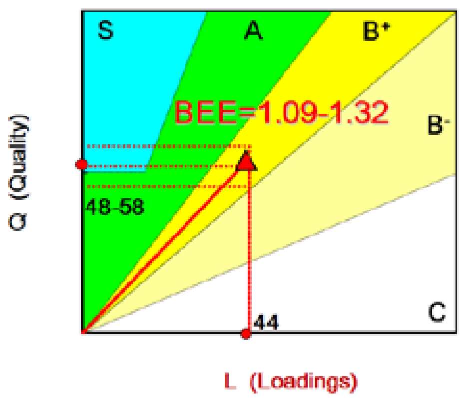

Figure 2 Variation of CASBEE score on changing chosen parameters.

The conclusion that can be drawn from the above examples is a potential difficulty in constructing optimization procedure for hierarchical assessment problems due to the number of parameters, levels of branches and crosscutting issues.

Further, the considerations will be restricted to design stages and the use of assessment methods as a design decision making tool. It would be ideal if the automatic supporting design decision process can be proposed. In optimization literature e.g. Jedrzejuk (2006), Paczkowski et al. (2004), Marks (1997) the complex problems are solved by different approaches: multi criteria optimization (where all the criteria are taken into analysis with adequately chosen data); evolutionary optimization (where the complex optimization problem is decomposed to consecutive sequences of simple problems) or by finding sets of independent decision variables.

2 Definition of optimization problem

One of the possible optimization techniques is the reformulation of the assessment problem as a multi criteria task. Can the criteria used in assessment methods be qualified as criteria in optimization problem? Assessment of existing buildings is not related to decision making process as it is a case of optimization in designed buildings. In case of existing buildings it is enough to have criteria and knowledge of the state of the art of the object. In optimization problems it is necessary to define set optimization criteria, decision variables and restricting conditions. Also, the object of optimization should be very precisely defined e.g. building volume, desired indoor environment etc. If the land is under the considerations of optimization it is necessary to define requirements related to the site.

Most assessment tools follow the building LC stages as construction phase, operation, adaptation to changing requirements and demolition. Some of these requirements can be taken as optimization criteria (energy use) some have restricting character (adaptation, or access to installations). Examining structures of assessment tools for the purpose of optimization seems to justify the decomposition of the assessment to four tasks: optimization of building structure, optimization of site, optimization of construction process, optimization of building operation. Every one of these decomposed elements can be solved separately as the separate criteria of optimization depend on separate decision variables.

2.1 Optimization of building structure

Three groups of criteria can be identified for the building structure construction stage: minimum of energy or energy cost used during the life cycle with exemption to operational energy (cost), minimum operational energy, minimum of environmental impact.

Following criteria from assessment categories can be taken as optimization criteria:

- Resource consumption – minimum cumulative and operational energy, minimum use of products and materials,
- Environmental loadings - minimal green house gases emissions, minimal ozone depletion gases, minimal acidifying gases, minimal sewage, minimal water use.
- Indoor Environment – is considered a restriction.

Further, the listed criteria are accompanied by following restrictions:

- Resource consumption – restrictions on building footprint, requirements related to the reuse of onsite elements,
- Environmental loadings - local noise distribution, shading on neighboring buildings, thermal impact on a ground.
- Indoor Environment – moisture accumulation in building structure, materials with low VOC, low fiber emission materials, transfer of pollutants among building zones, localization of air inlets and outlets, regulation of ventilation air volume, provision of efficient ventilation system, provision of adequate filtration, control of internal temperature, provision of adequate air humidity in winter and summer, avoiding air drafts, provision of day lighting, adequate access to external space, adequate distance to neighboring buildings, access to sun rays, provision of adequate noise insulation, limitation of noise distribution within the building and noise generated from installations.

2.2 Application optimization technique

The example of optimization can be given as an achievement of predefined target expressed as a desired energy standard of designed building. This is a common situation where the investor sets requirements in performance term by e.g. defining maximum desired energy consumption or building energy class. This is a problem that has the horizon defined in energy terms but the same technique can be applied to open problems where there is no demand for energy standards. The goal of optimization is to find a choice of appropriate building materials that will minimize the normalized sum of following elements: cumulated energy (E), emission of carbon dioxide (C) and construction costs (K) achieving a predefined target of operational energy (choice of elements in the criteria can be different than the referred e.g instead of CO2 emission we can have any other environmental impact that can be valuated). These coefficient depend on actual configuration of a building represented by a vector of decision variables x. Formally such a problem belongs to a category of multi criteria optimization which after introducing weighted goal function F(x) can be described as: find optimal configuration x ensuring minimal total cost of a building:

$$\min F(x) = w_E E(x) + w_C C(x) + w_K K(x) \qquad (1)$$

taking into account constraints resulting from available construction technologies.

Weights in this formula are positive scaling coefficients. Moreover w_E and w_C also include appropriate units recalculating energy and carbon dioxide emission to subsidiary costs. Functions E, C and K are sums of unit costs of individual components. Choice of decision vectors which characterize actual configuration of the building unequivocally can be troublesome. The natural solution to this problem is binary variables x_i=0 or 1, which means the presence or absence of a particular component. Taking this into account function K can be written as a sum of unitary costs:

$$K(x) = \sum_{i=1}^{N} k_i x_i \tag{2}$$

In the same way we define functions of energy and carbon dioxide emission. Restrictive conditions take in this case the following form:

$$\sum_{i \in D} x_i = 1 \tag{3}$$

This is equivalent to the choice of exactly one alternative of a class of components (for example wooden or aluminum window). Finally, mathematical model of decision problem leads to binary programming Gajewski et al. (2007). The major difficulty in such approach is large number of decision variables. Genetic programming which enable effective search of the set of acceptable solutions can be an alternative for direct methods of binary programming.

3 Example of calculations

The example of the optimization method is presented on a base of design of single family house. The house is one floor with usable attics, floor on ground with footprint 70 m^2 and 406 m^3 of volume.

Information taken from design documentation as well as from database containing values of cumulative energy (E_i), cumulative emission (C_i) of CO_2 and cost of construction (K_i)of building element or installation were used for preparation of data for poly-optimal procedure and presented in Table 1. Column Opty represents values of criterion function calculated from the formula:

$$\text{Opty} = w_1 E_i + w_2 C_i + w_3 K_i \tag{4}$$

where :

w_1 – average cost of production of 1 MJ of primary energy in Poland 0,03 PLN/MJ (1euro=3,5 PLNł)

w_2 – average cost of short term emission of 1 kgCO2 permit in Poland = 0,076 PLN/kgCO2

w_3 – weight for construction cost =1

Table 1. Data for optimization procedure

Element of construction	Description	E_i MJ/m^2	C_i kgCO_2/m^2	K_i PLN/m^2	Opty PLN
External walls					
	two layer wall: 25 cm ceramic hollow block MAX 25,18 cm of insulation+ plaster	5682	609	225	442
	two layer wall: 25 cm silica hollow block 1600,18 cm of insulation+ plaster	5542	449	279	479
	two layer wall: 24 cm of aero concrete 500, 18 cm of insulation+ plaster	3301	274	254	374
	multi layer wall:24 cm aero concrete, 18 cm of insulation, 12 cm aero concrete + plaster	3249	269	310	428
Internal walls					
	25 cm ceramic hollow block MAX + plaster	2331	301	80	173
	25 cm silica hollow block 1600 + plaster	2090	131	134	206

	25 cm silica T BSD + plaster	2192	139	109	185
	24 cm aero concrete 600 + plaster	1141	69	112	151
Division walls					
	10 cm gypsum plaster board	290	70	44	58
	8 cm silica brick 1600 + plaster	1019	157	31	73
Ceilings					
	roofing paper + cork board + ventilation space + insulation + Akerman ceiling 15 + cement - lime plaster	3179	195	365	475
	roofing paper + cement layer + insulation + reinforced concrete plane + cement - lime plaster	429	7	235	249
	24 cm ceiling plane Ytong P3, 3 500+ insulation + cement - lime plaster	809	125	359	393
Roof					
	roofing paper 0,004 + pine boards 0,025 + insulation + hard board 0,02	3507	512	221	365
	ceramic tile 0,015 + roofing paper 0,004 + pine boards 0,025 + vapor insulation foil + gypsum plaster board 0,0125	4321	375	311	469
	cement tile, + roofing paper 0,004 + pine boards 0,025 + insulation + vapor insulation foil + gypsum plaster board 0,0125	4106	379	290	442
	roofing paper 0,004 + pine boards 0,025 + insulation + hard board 0,02	3838	550	226	383
Floor on ground					
	pine boards 0,015 + joint less floor 0,015 + insulation + water insulation + layer of concrete 0,1 + sand 0,015	4045	391	271	422
	Pine boards 0,015 + concrete layer 0,04 + insulation + water insulation + concrete layer 0,15 + sand 0,3	3692	355	334	472

Calculation performed using data from table 1 allowed to indicate the elements of building for which the criterion Opt reached its minimum. Results of the optimization procedure are collected in table 2.

Table 2. Results of optimization procedure

Element of construction	**Description**	**E_i**	**C_i**	**K_i**	**Opty**
External walls	two layer wall: 24 cm of aero concrete 500, 18 cm of insulation+ plaster	3301	274	254	374
Internal walls	24 cm aero concrete 600 + plaster	1141	69	112	151
Division walls	10 cm płyta gypsum – plaster board kartonowa	290	70	44	58
Ceilings	roofing paper + cement layer + insulation + reinforced concrete plane + cement - lime plaster	429	7	235	249
Roofs	roofing paper 0,004 + pine boards 0,025 + insulation + hard board 0,02	3507	512	221	365
Floor on ground	pine boards 0,015 + joint less floor 0,015 + insulation + water insulation + layer of concrete 0,1 + sand 0,015	4045	391	271	422

The calculation is showing the best solution in terms of minimalization of value of criterion F(x), where the decision variables were technological solutions for walls, roof and floor. These solutions can afterwards be used in assessment method to be assessed in the overall framework of assessment procedure. Such approach is not proven to be globally optimal, but is helpful guide in a search for optimal solution.

4 Conclusions

Assessment, by its virtue, is a different process than the designing but the assessment structure can be used to formulate the optimization problem. The general optimization problem has to be decomposed to basic problems that afterwards can be solved by using one of optimization techniques. Genetic and evolution algorithms have become the universal and widely used tool in the global optimization of functions. Usage of the methods that are based on natural selection, cross-breeding and mutation enables an effective search in the domain of the admissible solutions. A feature that distinguishes the genetic and evolution algorithms among other methods of optimization is looking for the best solution starting from some population of points in the solution space not from the single point. This particular feature induces the high efficiency of these methods, which has also been proven in the presented work. In the calculations, the database (developed within the research grant 4 T07E 028 28- Poly-optimal design method of environmentally friendly buildings) that contains the values of CO2 emission coefficients for the main processes and structural materials most popular in Poland has been used. The work was performed within the adaptation of environmental assessment method E-Audyt, Panek (2002) to public buildings and forms a part of works executed within a scientific project STEP undertaken by Warsaw University of Technology and Norwegian Technical University Trondheim.

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BIOINSPIRED ARCHITECTURAL DESIGN TO ADAPT TO CLIMATE CHANGE

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Summary

International research suggests that the built environment may be responsible for at least a third of global green house gas (GHG) emissions and that measures should be implemented to mitigate these. It is also the built environment, as the principle habitat of humans that will need to adapt to climate change impacts to keep people comfortable and safe. Architects and designers may need to explore new ideas that are reflective of a shift in both climate and in expectations of the built environment. This paper explores the potential of biomimicry, where organisms or ecosystems are mimicked in human design. The question is posed: in what way is mimicking the living world useful in the design of buildings that are able to either mitigate green house gas emissions or adapt to climate change impacts?

This paper investigates two possible options for an architectural biomimetic response to climate change. The first is integrating biomimetic technologies able to mitigate green house gas emissions into buildings. The second approach is use biomimicry to adapt to the direct impacts of climate change on the built environment. Documented successes and potential benefits and difficulties inherent in such approaches are discussed.

As well as a reduced or potentially negative carbon footprint for the built environment, this paper analyses further significant benefits that such an approach may offer. It is posited that the incorporation of an understanding of the living world into architectural design could be a significant step towards the creation of a built environment that is more sustainable and one where the potential for positive integration with and restoration of natural carbon cycles is increased.

1. Introduction

As the impacts of climate change increase, policies and actions to mitigate green house gas emissions must expand rapidly. This will be particularly crucial in the built environment. Not only is the built environment responsible for at least a third, and potentially more of global green house gas (GHG) emissions, leading to climate change, it also will have to adapt to climate change impacts, as the principle habitat of humans (Hunt 2004; Lend Lease Corporation, et al, 2007). O'Connell (2003) points out that *'investigation into the… effects of climate change, the synergy between adaptation and mitigation strategies, and understanding the importance of adaptation… is seen as critical...'*

Parallel to this, the definition of cutting edge sustainable architecture is changing rapidly. Aiming for 'neutral' or 'zero' environmental impact buildings in terms of energy, carbon, waste or water are worthwhile and difficult targets. It is becoming clear however, that buildings will need to go beyond having little negative environmental impact in the future, to having net positive environmental benefits (Rees 1999). Reed (2007) describes the transition from conventional practice (negative environmental impact), to sustainable architecture (zero impact), through to design with positive environmental impact, termed by him restorative, or regenerative design. By looking to the living world, there may be models that can be mimicked to create and maintain a resilient and adaptable built environment, and possibly improve its capacity for contribution to restoring or regenerating the health of ecosystems (Pedersen Zari and Storey 2007).

2. Biomimetic Architecture

Biomimicry is the emulation of strategies seen in the living world as a basis for design. It is the mimicry of an organism, an organism behaviour, or an entire ecosystem, in terms of its forms, materials, construction methods, processes, or functions, (Pedersen Zari and Storey 2007). It is a source of innovation, particularly in the creation of more sustainable and potentially regenerative architecture (Reap, Baumeister, and Bras 2005). In a similar way to the functioning of an ecosystem for example, a building could be designed to: produce energy and nutrients (materials); clean air and water; use and transform waste; and store carbon in a complex, adaptive and cyclic system (McDonough and Braungart 2002).

Looking to plants or animals that are highly adaptable or ones that survive in extreme climates or through climatic changes may provide insights into how buildings can or should function. Examining the qualities of ecosystems that enable them to be resilient may also offer potential avenues to follow. Although no comprehensive body of research has applied biomimicry to the impacts of climate change in the built environment, several noteworthy examples of biomimetic architecture, or technologies able to be applied to the built environment exist that will be examined in the following sections of the paper.

3. Climate Change and the Built Environment

Changes in climate that will affect the built environment are numerous and have been explored by several researchers. Impacts also will vary greatly depending on the local quality and density of the existing built environment and which specific local climate changes occur. The impacts that climate change will have on the built environment are both direct and indirect. Direct impacts will affect the actual physical fabric of the built environment. Indirect impacts will affect the economic, social and environmental context that the built environment operates in and will therefore also have implications for the built environment (O'Connell and Hargreaves 2004).

Providing detailed explanations of each impact is beyond the scope of this paper; however some of the main direct impacts that appear in a survey of international research[1] have been summarised in Table 1. Such changes to the climate are expected to increase in intensity in the future (IPCC 2001). These factors suggest a re-evaluation of the existing built environment, and that preparations for adaptations or additions may be necessary.

Table 1 Direct Climate Change Impacts on the Built Environment

Potential Direct Climate Change Impacts:	Consequences for the built environment:
Changes in temperatures (Likely to increase in most areas)	Increased overheating and air conditioning load Decreased winter space heating Decreased water heating energy
Increased intense weather events.	Damage to buildings and infrastructure
Changes in precipitation patterns	Damage to foundations Increased inland flooding Damage to facades and internal structure due to rain penetration Increased subsidence Increased erosion, landslips, rock falls Changes in aquifers and urban water supply and quality. Increase pressure on storm drainage Increased storm water run off and leaching of pollutants into water ways or aquifers
Thermal expansion of oceans and changes in the cryosphere (ice systems) such as retreating snow lines, ice packs and melting glaciers	Increased coastal flooding Increased erosion Changes in sedimentation patterns Changes in water tables and possible infiltration of aquifers. Relocation from coastal areas Loss of inter tidal areas acting as buffer zones
Changes in wind patterns and intensities	Changes in wind loading on buildings
Increased air pollution	Increased ventilation needed and provisions for clean air

4. Responses to Climate Change in the Built Environment

As acknowledged by several sources, even if all GHG emissions were immediately halted, the climatic impacts of past emissions would still be experienced. O'Connell and Hargreaves (2004) also point out that despite international treaties such as the Kyoto Protocol, global GHG emissions are increasing. It is important therefore that professionals of the built environment are not only able to mitigate the causes of climate change, but are also able to adapt to the impacts.

The responses to climate change in the built environment broadly fall into two categories:

1: Mitigating the cause of climate change by reducing GHG emissions.

2: Adapting the existing and future built environment to predicted climate change impacts.

Many technologies and established design techniques already exist that are able to mitigate the causes of climate change, adapt to the impacts or climate change and work towards restoring the healthy functioning of ecosystems and global biogeochemical cycles (including the carbon cycle). Lowe (2000) estimates for example, that reductions of 80% in carbon emissions associated with the built environment are possible using current technologies. The potential of well known design techniques to reduce dependence on fossil fuel derived energy, such as passive solar architecture for example are also well understood and documented. However, new techniques, or technologies that are able to mitigate and adapt to climate change with significant other benefits may be revealed by careful study of how organisms and the ecosystems they create are already able to do this. *'Climate change* [is] *now widely viewed as the main challenge facing humankind for this century. We believe that Biomimicry has a huge potential to tackle some of major issues raised by this global change'* (Biomimicry Europa 2006).

5. Biomimicry to mitigate green house gas emissions

Several examples of new technologies illustrate biomimicry that is focused on mitigating GHG emissions, and can be divided into three categories. The first approach is mimicking the effectiveness of living

[1] See reference section for papers referred to in summarising main direct impacts.

organisms and systems in transforming materials and energy in a way that is less resource intensive that what humans typically do. The impetus is that by being more energy efficient, less fossil fuel is burnt and therefore less GHGs are emitted onto the atmosphere.

The second approach is to devise new ways of producing energy to shift human dependence on fossil fuels, and therefore prevent additional GHGs from being emitted.

The third is looking to the living world for examples of how organisms or processes within them are able to sequester and store carbon. Mimicking this comes with the intention of preventing GHGs that are emitted through human activities from reaching the atmosphere and causing additional climate change.

5.1 Biomimicry for energy effectiveness and energy efficiency

Various biomimetic technologies and products have been developed for the purposes of improving energy efficiency. There are numerous examples of living organisms and systems that are highly energy effective and that could yield an understanding of how humans could build and carry out their activities without a dependence on fossil fuels (McDonough and Braungart 2002).

An example of such an approach is DaimlerChrysler's prototype *Bionic Car*. In looking to create a fuel efficient, large volume, small wheel base car, the design was based on the aerodynamic boxfish (*ostracion meleagris*). The chassis and structure of the car are also biomimetic, having been designed using a computer modelling method based upon how trees are able to grow in a way that minimises stress concentrations. The resulting structure appears almost skeletal, as material is allocated only to the places where it is most needed (Vincent et al. 2006).

Mick Pearce's Eastgate Building in Harare, Zimbabwe and the CH2 Building in Melbourne, Australia are examples of architectural biomimicry using this approach to address the causes of climate change. Both buildings are based in part on techniques of passive ventilation and temperature regulation observed in termite mounds, in order to create a thermally stable interior environment that uses much less mechanical cooling (and therefore produces less GHG emissions). Water which is mined (and cleaned) from the sewers beneath the CH2 Building is used in a similar manner to how certain termite species will use the proximity of aquifer water as an evaporative cooling mechanism.

Improving energy efficiency in general is an important part of addressing climate change, but is however an intermediate step. As McDonough and Braungart (2002) point out, improving efficiencies, or 'being less bad' helps to reduce the intensity of GHG emissions but does not challenge basic assumptions about how we make and operate our technologies and does not address the underlying causes of climate change such as dependence on fossil fuels.

The *Bionic Car* illustrates the point. It is more efficient in terms of fuel use because the body is more aerodynamic. It is also more materials efficient due to the mimicking of tree growth patterns to identify the minimum amount of material need in the structure of the car. The car itself is however not a new approach to transport. Instead, small improvements have been made to existing technology without a re-examination of the idea of the car itself as an answer to personal transport.

Improving energy efficiencies does however allow positive changes to be made to existing technologies and buildings rather than make a complete rebuild necessary and is therefore an important step in the transition of the built environment in positively addressing climate change.

5.2 Biomimetic energy generation for mitigating climate change

Several biomimetic technologies or systems aim to replace the use of fossil fuels as the primary energy source that humans use in an attempt to mitigate GHG emissions in the long term. Looking to the living world for inspiration is appropriate because almost all other organisms source energy from renewable sources, predominantly contemporary sunlight (Kibert, Sendzimir, and Guy 2002). An example of research in this direction is the development of artificial photosynthesis, that may eventually be applied to solar cell technology, such as the work done at Arizona State University (Benyus 1997; Moore et al. 2004) and by scientists in Australia (Davidson 2003).

Sea and wave energy technologies are also in development that mimic how sea kelp or tuna tails work in water. Australian company BioPower, is testing prototypes in Tasmania, Australia in 2008. According to company literature, the power generators oscillate in ocean waves and currents rather than rotate like a turbine. Through the use of permanent magnet motors, the low-speed high-torque oscillation is converted into high-speed low-torque rotation. It is anchored to the ocean floor by the use of a series of small root-like devices to avoid large and complicated drilling and installation. The generators rotate freely to orient themselves towards currents and in the same way can lie flat in storm events to avoid damage (BioPower Systems 2007).

Finding methods to replace the use of fossil fuels with contemporary sunlight and other renewable energy sources, is an approach to mitigating the causes of climate change conducive to a long tem solution. Significant time and resource needs to be applied to develop such technology however. While replacing the use of fossil fuels will prevent some additional GHG emissions from being created, biomimicry may also offer ways to address excess carbon dioxide already in the atmosphere.

5.3 Biomimetic Sequestering and storing carbon

There are several organisms and processes in nature that are able to store, sequester or recycle carbon, that are being investigated in the development of technologies that can be applied to industrial processes and the built environment.

In Quebec for example, C02 Solutions is developing carbon sequestration technology based on certain chemical processes that occur in the human body. The technology mimics the enzyme carbonic anhydrase which is able to convert carbon dioxide into bicarbonates (C02 Solution 2007; Geers and Gros 2000). In keeping with Benyus's (1997) observation that processes in the living world tend not to need huge amounts of energy to work, the C02 Solution process works at atmospheric pressure and ambient temperatures, thus it is highly energy efficient (Fradette 2007).

According to the company's literature, the process generates environmentally benign bicarbonate, which can be stored or reused in industrial process in cement works or paper mills. The aqueous solution where the conversion of carbon dioxide to bicarbonate occurs is reused in a closed loop. The technology is intended to be able to be retrofitted onto existing facilities such as power plants, cement works and oil sands operations, or integrated into new ones (C02 Solution 2007; Atkinson 2007).

Another example of the potential of biomimicry is illustrated by research conducted at the Rocky Mountain Institute in the United States, investigating an alternative material to concrete. Cement production accounts for approximately 5% of the world's anthropogenic carbon dioxide emissions (Vanderley 2003). This new material mimics the abalone, which is able to grow a crack resistant shell harder than any ceramics humans are able to create, using only seawater and a series of proteins (Benyus 1997). This process of bio-mineralisation stores carbon much like the growing of forests, locks carbon into the structure of the trees and soil for some time. The concept was that the new material would be able to grow over a structure, with the simple additive of seawater, using proteins imitated from the abalone (Koelman 2004).

As several authors point out, there is no waste in non-human living systems (Kibert, Sendzimir, and Guy 2002; McDonough and Braungart 2002). Detritus is an important part of continuing the process of cycling nutrients and is a fundamental part of the health of an ecosystem (Odum 1969). In using biomimiry to address excess carbon in the atmosphere, researchers such as Benyus have advocated using it as a resource rather than considering it a source of pollution (Benyus 2007). In response, some biomimetic systems look at how biomimicry may be used to replace fossil fuels and store carbon at the same time. An example is a proposal for biofuel crop plantings to be based on how naturally occurring prairies grow, resulting in a controversial net reduction of atmospheric carbon, while improving the fertility of the land (Russelle et al. 2007; Tilman, Hill, and Lehman 2006).

A company formed out of recent research done at Cornell University called Novomer, are examining mimicking carbon sequestration in living organisms, particularly plants, by turning carbon dioxide into carbon-based polymers, or biodegradable plastics. The zinc-based catalyst that is needed for the process works at ambient pressure and temperature. The use of carbon dioxide and monoxide as feedstocks, rather than corn or starch as is used in other biodegradable plastics, means that the plastic does not compete with food production, and may help in sequestering and storing carbon. More research is yet to be done into the characteristics of its carbon release properties on decomposition (Patel-Predd 2007).

A challenge with this approach to addressing climate change impacts is that sequestering carbon by itself does not deal with the problem of excessive burning of fossil fuels, causing climate change, but rather is an anther interim step in becoming more sustainable (Fradette 2007). The issue of depletion of fossil fuels themselves is also not addressed, and there are several logistical, economic, technological and environmental problems with current attempts at carbon sequestration (Schiermeier 2006). Its benefit however is that such technologies may help to retrofit and adapt existing building infrastructure, while addressing GHG emissions in the short to medium term (Herzog 2001).

Several of the examples of a biomimetic approach to carbon sequestration or storage discussed reveal that secondary and useful products are made, such as plastics and potential new building materials, without toxic by-products and the use of high amounts of energy. There may also be important restorative capacity in lowering the amount of atmospheric carbon by using carbon dioxide as a feedstock for new materials. More research needs to be done to investigate the feasibility of this. The built environment uses at least 40% of the materials consumed by the global economy (Rees 1999), so building materials that store carbon long term, or that are made from carbon dioxide itself, if appropriate, durable and safe, have potential to have significant positive benefit in mitigating the causes of climate change.

6. Adaptation to Climate Change

Biomimicry offers several avenues in addressing the issue of adaptation to climate change. The first is responding to anticipated direct impacts of climate change on the built environment (see Table 1). The second is a more comprehensive approach to altering the built environment to be more adaptable as a whole system.

6.1 Responding to Direct Impacts of Climate Change

Several architectural examples of biomimicry exist that look to respond to direct impacts of climate change. Two proposed architectural projects discussed here might be suitable responses to changes in precipitation patterns and a projected water shortage for example.

Grimshaw Architects have used biomimicry to design a building that can desalinate seawater with minimal energy input. They propose that the desalination plant will form a large outdoor theatre called *Teatro del*

Agua in the Canary Islands. The Namibian desert beetle, and the hydrological cycle itself, have been used as inspirations for the design. The stenocara beetle lives in a desert with little rainfall but is able to capture moisture from the swift moving fog that passes over it by tilting its body into the wind. Water condenses on the surface of the beetle's back because its shell is cooler than the surrounding air. Droplets form on the alternating hydrophilic – hydrophobic rough surface of the beetle's back and wings and roll down into its mouth (Parker and Lawrence 2001). The hydrological cycle is based of course on evaporation and precipitation.

The Grimshaw design team in collaboration with Seawater Greenhouse have taken an understanding of these examples from the living world and in 2005 proposed the unique desalinisation process. Seawater will be passed over a series of evaporative grills and, as the sea breeze moves through them, some of the water will evaporate, leaving salt behind. The moist air then continues until it hits pipes holding cool seawater, pumped up from the deep ocean. As the warm moist air touches the cool pipes, condensation forms and clean fresh water trickles down to be collected for use. The seawater pumps are powered by wind turbines using the same sea breeze and any excess water and the resulting cooling can be transferred to neighbouring buildings. This kind of biomimetic system may be useful in areas that are coastal and have difficulties sourcing fresh water, exacerbated by climate change.

Matthew Parkes of KSS Architects demonstrates biomimicry also inspired by the Namibian desert beetle's unique features, with his proposed fog-catcher design for the Hydrological Center for the University of Namibia (Killeen 2002). In a low rainfall environment part of the building is carefully designed and orientated to capture the water from the fog without the use of pumps and large amounts of energy.

This approach has a number of benefits and difficulties associated with it. It requires people to accurately know what the impacts of climate change will be, and to allow enough time to research and implement possible responses to it. A benefit of such an approach however, is that technologies and architectural responses to direct impacts may be transferable to other places that have similar issues. This process of developing technological solutions for individual buildings fits into the current method of extending and renewing the built environment, which is typically a building by building or addition by addition process (Brand 1984). This approach is helpful for a gradual response to the impacts of climate change, particularly if the ability to research, develop and test technologies continues. The living world offers numerous examples of organisms that effectively solve the same problems the built environment will face. Organisms and ecosystems exist that effectively manage overheating, high winds, and erosion for example.

Developing individual technologies or buildings to deal with the myriad of direct climate change impacts on the built environment does not however ready the built environment for unpredicted changes, or address multiple impacts concurrently. Understanding local built environments as whole systems in terms of their strengths and weaknesses may be effective way to plan for future unpredictable climatic changes.

6.2 Improving the built environment as a system

Although ecosystems are typically resilient and many are able to move though massive changes while still supporting organisms to survive, the ability of ecosystems to adapt to the rapid changes that may become apparent through climate change is largely unknown. Mimicking ecosystems may however offer insights into how the built environment could function more like a system than as a set of individual objects (Pedersen Zari and Storey 2007). Ecosystems are readily available models for designers to examine in creating robust, resilient and adaptable systems. Several authors advocate methods for incorporating an understanding of ecosystems into architectural design (Graham 2003; Kibert, Sendzimir, and Guy 2002; Van der Ryn and Pena 2002; McHarg 1992; Reap, Baumeister, and Bras 2005).

As described by Pedersen Zari and Storey (2007), a comparative analysis was conducted of related knowledge of ecosystem principles in the disciplines of ecology, biology, industrial ecology, ecological design and biomimicry and was used to formulate a group of ecosystem principles aiming to capture cross disciplinary understandings of ecosystem functioning. Features of ecosystems that make them resilient were identified in subsequent research as: capacity for self healing; capacity for decentralised organisation; complex feedback loops; interdependence of organisms; diversity in types of organisms and relationships; a responsiveness and dependence on local conditions; and optimisation of the whole system rather than single parts. How such principles may meaningfully be applied to the existing built environment requires more investigation. There are however two notable examples of mimicking ecosystems for greater adaptability that may offer insights.

In designing the Lloyd Crossing Project proposed for Portland, Oregon in 2004, the design team including Mithūn Architects and GreenWorks Landscape Architecture Consultants used estimations of how the ecosystem that existed on the site before development functioned. The stated goals of the project included: reducing environmental impact to pre-development levels; achieving carbon balance; and living within the site's rainfall and solar budget. By understanding the system that had worked previously on the same site, the design team were able to determine appropriate goals for the ecological performance of the project over a fifty year time period (Portland Development Commission 2004).

Examples of successful industrial ecology such as the Kalunborg Project, in Denmark also demonstrate the advantages of a systems approach in creating a resilient and robust environment where energy and materials are circulated and shared, eliminating waste and duplication of effort or energy use in some areas (Jacobsen 2006).

A benefit of such an approach is that through careful urban planning and an integrated and multidisciplinary design method, buildings as part of a larger system, able to mimic natural processes and functions in their creation, use and eventual end of life, have the potential to adapt more readily to climate change. That a greater understanding of ecology and systems design is required on the part of design teams is implicit with such an approach. Increased collaboration between fields that traditionally seldom work together such as architecture, urban design, and ecology would also be required. Systems based climate change adaptation challenges conventional architectural design thinking, particularly the typical boundaries of a building site and time scales a design may be initially designed for.

Barriers include the current competitive economic context of the built environment in many places in the world. Encouraging greater interdependence and the sharing or exchange of resources between buildings requires a different economic and legal frame work to operate than that which is currently in place. The final drawback to this approach is that because it requires communities to become linked, interdependent systems, it requires a coordinated and cooperative approach from land owners and authorities to make it happen at a large scale, which may prove difficult in some areas. The built environment obviously varies greatly between different areas and climates and economic contexts, and systemic approaches that are appropriate to specific places will also vary greatly (Reed 2007). Because there may therefore be limited transfer of knowledge between differing geographic regions, the adoption of such an approach may be slow. Although there are some draw backs to a whole systems based adaptation of the built environment, it may be a suitable solution for a longer term response to addressing climate change impacts.

7. Benefits of a Biomimetic Approach to Architecture

This paper demonstrates that various biomimetic ideas can be applied to a short, medium and long term response to climate change. Biomimetic approaches to climate change mitigation and adaptation in the built environment are diverse and are not preventative of other non-biomimetic approaches being employed. While existing technologies will be crucial in the short and medium term, biomimetic approaches may form an important part of long term solutions to climate change, particularly in the replacement of the use of fossil fuels, development of technologies to address direct impacts on the built environment, and importantly in systemic improvement of the built environment based on ecosystem based biomimicry (Fig 1).

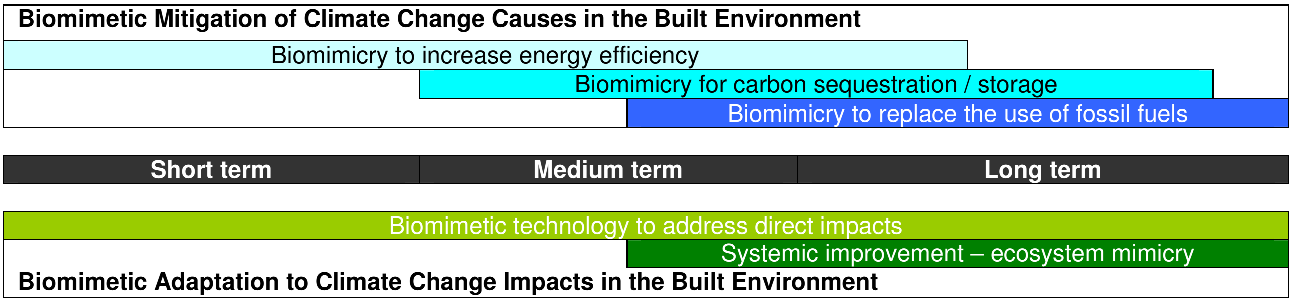

Figure 1 Time line of biomimicry approaches to address climate change

As well as a reduced or potentially negative carbon footprint for the built environment, other significant social and economic benefits of biomimicry in the built environment may exist. Several authors investigate the relationship between bio-inspired design and improved psychological and physical health (Pedersen Zari 2008; Kellert 2005). It is possible, that with a greater understanding of the living world, and its relevance not only to increasing sustainability, but also its possible contribution to psychological wellbeing, architectural design will change accordingly. Links with increased human productivity in commercial buildings that demonstrate aspects of bio-inspired design have been demonstrated (Heerwagen et al. 1998).

As GHG emissions are increasingly regulated, buildings that do not met legal or performance expectations may be more difficult to sell, lease or insure and may have higher financial life cycle costs. There is also growing evidence of 'sustainable' buildings demanding premiums over conventional ones. (Fullbrook, Jackson, and Finlay 2006).

It is posited that the incorporation of an understanding of the living world into architectural design could be a significant step towards the creation of a built environment that allows for positive integration with and restoration of natural carbon cycles. Increased positive integration with ecosystems and a restorative rather than damaging effect on ecosystems may have significant benefits on maintaining biodiversity and the ecosystem 'goods and services' that humans are dependant on for survival (Daily et al. 2000). If the built environment is to become truly regenerative it will increase human and community wellbeing as well as that of ecosystems.

8. Conclusion

The built environment is increasing held accountable for global environmental and social problems with vast proportions of waste, material and energy use and green house gas emissions attributed to the habitats humans have created for themselves (Doughty and Hammond 2004). It is becoming increasingly clear that a shift must be made in how the built environment is created and maintained (Reed 2007). Mimicking life, including the complex interactions between living organisms that make up ecosystems, is both a readily available example for humans to learn from and an exciting prospect for future built environments that may be able to be entwined with the habitats of other species in a mutually beneficial way while addressing climate change causes and impacts.

New approaches will be useful to professionals and governing bodies as they address climate change impacts in the built environment. By looking to the living world, there may be models that can be mimicked to create and maintain a robust built environment, and possibly improve its capacity for contribution to restoring or regenerating capacity in ecosystems. Several case studies have been used to exemplify this.

This paper has considered the different ways that biomimicry may be applied to both climate change mitigation and adaptation to direct climate change impacts. This has illustrated the ways in which mimicking the living world is useful in the design of buildings that address climate change. Distinctions between the different kinds of biomimicry and their short, medium or long term potential in addressing climate change in the built environment has also been examined.

Technologies that increase energy efficiencies and are able to sequester or store carbon may form part of an important short to medium term approach, but should be seen as intermediate steps. As well as a reduced or potentially negative carbon footprint for the built environment, examples of developing biomimetic technologies reveal approaches that use current excess carbon dioxide as a resource for new materials. Design that mimics how ecosystems are able to function in a resilient way, has the potential to form part of a long term response to climate change in relation to the built environment. Along with this, biomimetic technologies that address direct climate change impacts, and biomimetic technologies or systems that prevent further GHG emissions could be implemented alongside systemic change in the built environment.

It is posited that the incorporation of an understanding of the living world into architectural design could be a significant step towards the creation of a built environment that is more sustainable and resilient and is able to adapt to climate change.

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SUSTAINABILITY ASSESSMENT OF BUILDINGS IN CEN/TC350 “SUSTAINABILITY OF CONSTRUCTION WORKS”

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Summary

The significance of the construction and real estate sector for sustainable development is broadly recognized in Europe. Reflecting this recognition, systems for description, quantification, assessment and certification of sustainable buildings have been development in many countries. A current task is to develop these systems to enable a better inclusion of life cycle analysis methodologies, regarding environmental, social and economic assessment. Consequently, these assessments will, among other information sources, need to apply data comprising environmental as well as health information related to construction products. This provision and communication of information relies on the format of environmental product declarations (EPDs). For both, the assessment of sustainability aspects of buildings and for the description of construction products, the goal is to develop a European wide, unique set of rules, in line with the requirements of relevant ISO standards. The task to establish this European set of rules is handled as a standardization task in CEN, under CEN TC350 "Sustainability of Construction Works". To reach market acceptance, and to fulfil the ISO 15392 general principle "holistic approach", aspects of sustainability are to be considered in its context, not as separate items. Thus, sustainability assessment of a building constitutes a part of an assessment of integrated building performance. The consideration of sustainability aspects is supposed to also have a positive impact on the quality of products and processes. The intention is to also investigate how the quality of building design, technology and functionality has an influence on the economic, environmental and social performance of buildings.

1 CEN TC 350 – goals and content

1.1 Scope and structure

The standards developed under the framework of CEN/TC350 provide a harmonized European system for the assessment of environmental, social and economic performance of buildings based on a life cycle approach as a contribution to implementing sustainable construction. The standardised application of life cycle approach means that the assessment of environmental performance is based on the Life Cycle Assessment methodology [ISO 14040, ISO 14044] and the assessment of economic performance is based on the Life Cycle Costing [ISO 15686-5] methodology and the rules for the service life issues are based on the guidance of Service Life Planning standard series [ISO 15686]. The goal is to develop and implement a system of sustainability assessment of buildings that, at the same time and on same equal footing, allows for the assessment of the environmental, social and economic performance of a building taking into account its technical quality and functionality / serviceability.

The results of assessment help users to understand the impact that a building has from one hand on the environment and from the other hand on the occupant and other users. Social performance includes amongst others the building related considerations of users' health, comfort and safety aspects. The aim of the results of assessment is to allow the client, occupant, owner, investor, designer and others involved in construction and operation to make rational decisions and choices regarding the building.

Figure 1 presents the structure of CEN/TC350. The "general framework standard" establishes the concept of "sustainability assessment of buildings" and describes the context of the environmental, economic and social performance on one hand, and technical characteristics and functionality on the other hand.

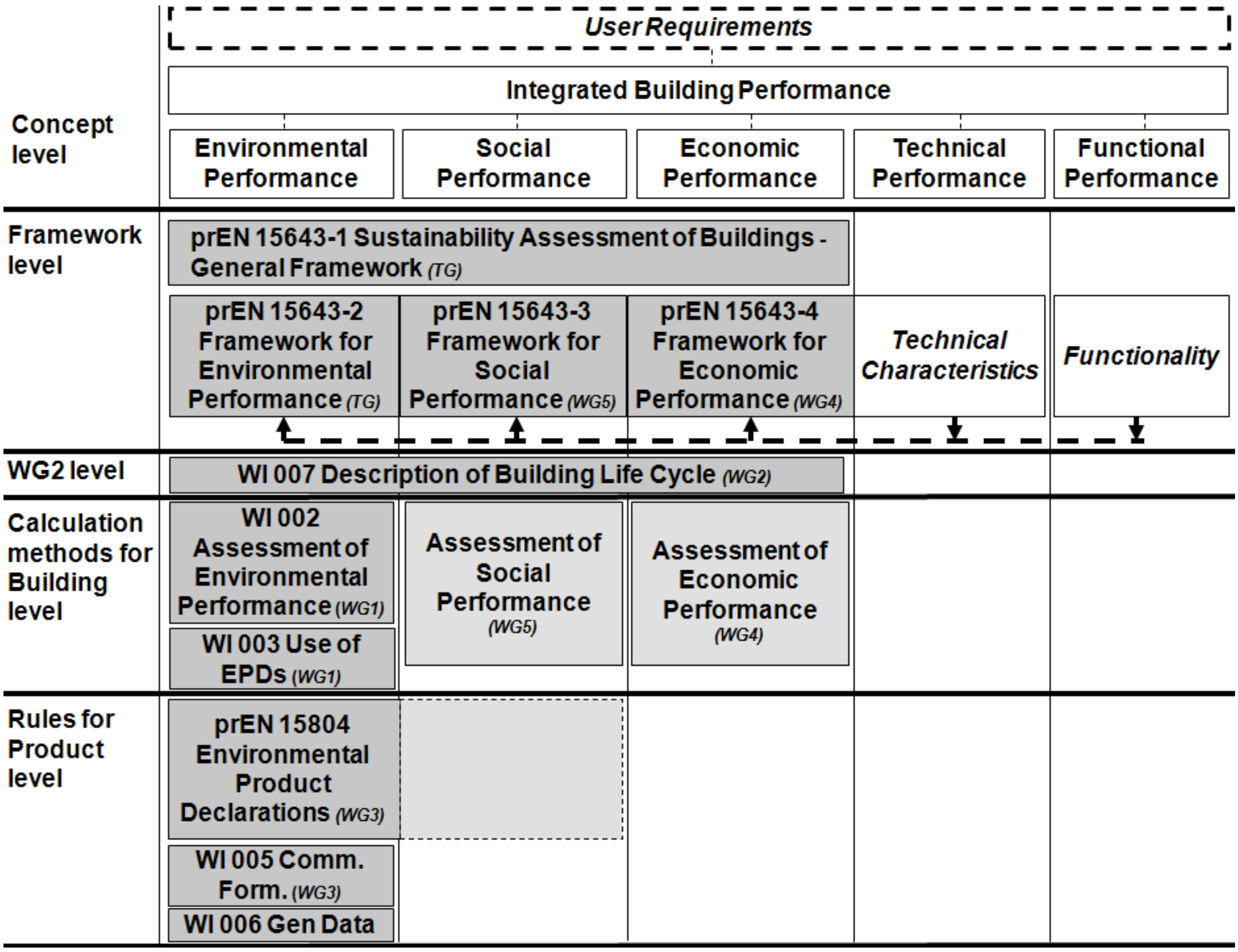

Figure 1: The suite of standards of CEN/TC350.

The suite of standards of CEN/TC350 for the sustainability assessment of buildings has been structured into three horizontal levels (framework, building and product) and into three vertical columns (environmental, social and economic) while always taking into account technical and functional performance characteristics.

1.2 Object of assessment and system boundaries

In this European standardised system of CEN / TC 350 the building, including its foundations and external works within the area of the building site, is the object of assessments and the source of impacts over its life cycle. This clarification means that in order to assess environmental, social and economic performance of the building the physical system boundary for the assessment excludes impacts of non-building related appliances, because the object of assessment is really the building and not the processes carried out in the building. Non-building related appliances are domestic, commercial and industrial appliances and other non-building related goods e.g. entertainment electronics, washing machines, refrigerators, cooking appliances, office electronics and appliances of industrial processes. The impacts of building related appliances are included in the assessment, because they are part of the technical building system, covering the systems for heating, cooling, domestic hot water, ventilation, lighting and integrated building automation and controls.

The suite of standards within CEN / TC 350 is only dealing with the analytical part of the building assessment system, and not with the valuation part. For this reason, these standards do not provide valuation methods and do not set levels, classes or benchmarks for any measure of performance. It is clear that the valuation methods for interpretation of the results are also needed, but because of their nature being always subjective value choices and "political" decisions, they have not been seen as a workable subject for the European standardisation at the moment. Consequently, CEN/TC 350 regards the establishment of assessment and weighting factors to be the task of other bodies, or to be handled as part of national assessment systems.

However, initiatives like LEnSE (http://www.lensebuildings.com) and UNEP-SBCI (www.unepsbci.org) discuss the international approaches to weighting and benchmarking, both internationally and on a European scale.

1.3 The importance of functional equivalent

In communication of the results of the assessment and comparisons of those results between alternative design options in the design stage or between finished buildings a "fair basis" must be always secured. For this purpose, the concept of "functional equivalent" was established. The functional equivalent allows the results of assessments to be provided in a systematic and comparable way. Communication of the assessment results for the environmental performance, social performance and economic performance of a building follows same the requirements.

The functional equivalent should be derived from the requirements for technical performance and functional performance of buildings to form the basis for comparison. The technical and functional requirements can include for example requirements for structural safety, fire safety, indoor air quality, security, adaptability, energy efficiency, accessibility, de-constructability, recyclability, maintainability, durability and service life of a building. These requirements become fixed when they are prescribed in the client's brief or in the project specification. It is clear that these performance requirements influence the results of the assessment and therefore they need to be taken into account in the assessment. Therefore, the requirements for technical and functional performance of the building must be taken into account in the establishment of the functional equivalent through technical and functional requirements defined for the project specific building.

Because of its importance, the functional equivalent must be always communicated together with the results of the assessment. In order to give a short overview also about how a building fulfils its user requirements, the deviating technical and functional performance with the respect to the required technical and functional performance and the possible demands for the environmental, social and economic performance defined in the client’s brief or in the regulations are also communicated together with the functional equivalent and the assessment results. .

1.4 Interrelationship between building level and construction product level

In order to have a transparent and truly performance based European system for the assessments the CEN/TC350 standards only take into account performance aspects and impacts that can be expressed with the quantitative indicators. These quantitative indicators are defined in the framework level standards that set the requirements for the building level and product level to use, in principal, the same set of indicators. In carrying out assessments it is possible only at the building level to provide necessary scenarios and a functional equivalent for the building. Consequently, assessment at the building level means that the descriptive model of the building with the major requirements for technical and functional performance of the building has been defined.

2 Sustainability assessment of buildings

2.1 The multi-step procedure

Developing European standards for sustainability assessment of buildings as a contribution to implementing sustainability of construction works is a multi-step procedure in CEN/TC350. The concept, see Figure 2, combines approaches established in the context of "sustainability in building construction" [ISO 15392: 2008], "service life planning" [ISO 15686] and also "performance based building" [CIB 1982], [Huovila 2005], [Lützkendorf 2005a], [Preiser 2005].

According to priorities set by the European authorities, the suite of standards for the assessment of environmental performance is going to be finished first. The assessment result according to this first step suite of standards to be developed by CEN/TC350 doesn’t yet allow a full sustainability assessment of the building. A precondition for the complete assessment of sustainability aspects of a building is the development and application of the assessment methodologies for social and economic performance. The framework standards for assessment of social performance and for assessment of economic performance of buildings are also under development in CEN/TC350.

The environmental indicators are stated in the framework standard for the assessment of environmental performance. In order to prevent formation of potential trade barriers in the global perspective, the defined environmental indicators are in line with the defined indicators of ISO 21930 (Sustainability in Building Construction - Environmental Declarations of Building Products).

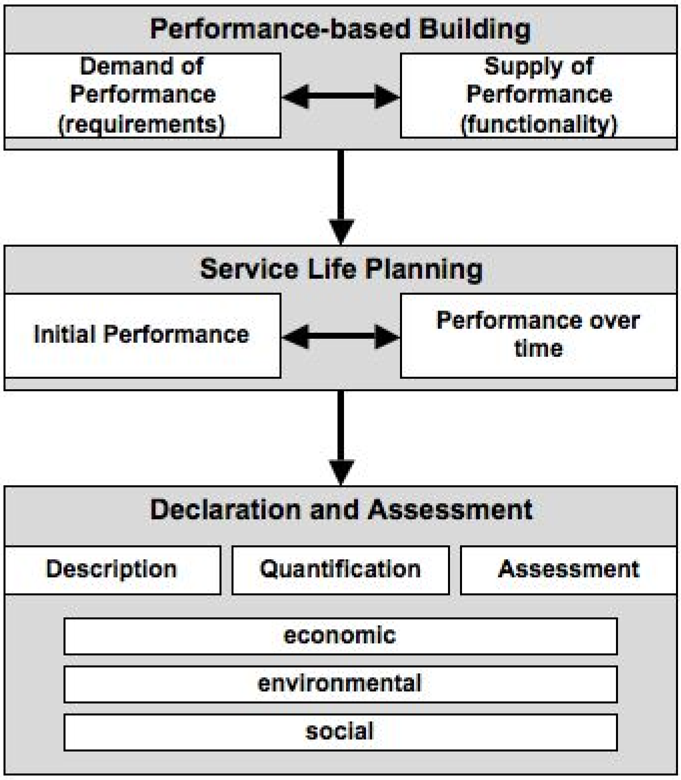

Figure 2: Performance-Based Building (requirements and performance), Service Life Planning (initial performance and performance over time) and Sustainability Assessment (description, quantification and assessment) in context. [Trinius 2007]

2.2 Communication format

Within the suite of CEN/TC350 standards there are also requirements for communication of the results of the assessment in order to ensure that the results can be understood and interpreted in a transparent and systematic way. According to the general framework standard the results of the assessments must be organised and made available for communication as shown in figure 3 below and expressed with the indicators given in the framework standards for the assessment of environmental, social and economic performance of a building without any further aggregation of the defined indicators.

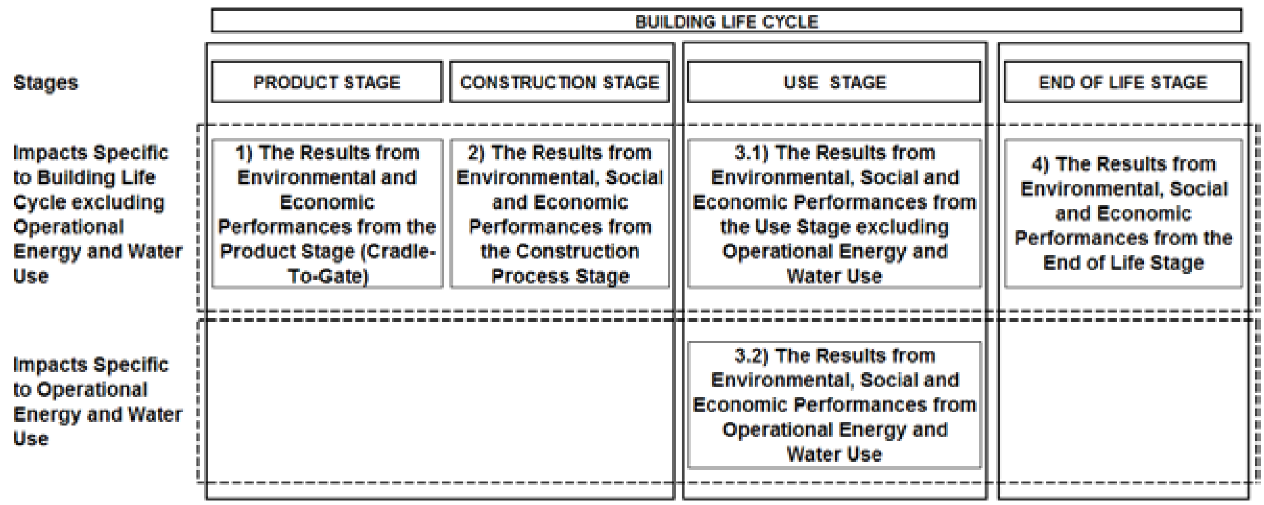

Figure 3: The organisation of the result of the assessment.

The organisation of the result of the assessment of environmental, social and economic performance is to be made available for communication in accordance with the life cycle stages and the normative groups of information.

If necessary for the national, regional or local preferences, it is permissible to communicate the results of the assessments with more aggregated groups of information and/or with more aggregated indicators after valuation, but the possible aggregated results must be clearly separated from the standardised assessment results as additional information.

The Strategic Advisory Body on Environment [SABE 2007] describes a standardised "building pass" – the potential to include sustainability assessments in such a building pass needs to be considered and further discussed.

2.3 Convergence with the performance based building concept

Performance based building is a well established concept dealing with the total quality of buildings, mainly in terms of functionality and technical performance, see [Foliente 2006] and the documents of the Performance-Based Building thematic network PeBBu (www.pebbu.nl). Meanwhile, the approach based on a rather technical description and assessment of performance and functionality is moving towards the inclusion of a consideration of economic, environmental and social aspects [Lützkendorf 2005b]. The description and assessment of sustainability aspects considers economic, environmental and social performance. This performance relates to the technical performance and functionality requirements. In other words, a bridge between performance based building and sustainability in building construction is emerging, the two concepts are coming together.

Summary and outlook

The inclusion of economic and social performance enables us to make the move from an assessment of environmental impacts to a broader assessment of sustainability aspects. With the clear reference to the performance and functionality of the building, the established concepts of performance-based building and service life planning of buildings can be included, resulting in a clear move towards an integrated assessment of sustainability. This assessment is a necessary and significant element in the discussion of the total quality of buildings and the built environment.

The standardization work in CEN/TC350 is still ongoing. European stakeholders still hold the possibility to get involved in the process and to contribute to the standard development through their national standardisation bodies. The standardisation work in international bodies (ISO) is largely concluded – however, the authors are open to communicate and discuss the development on a broad international scale.

Acknowledgment

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SUSTAINABLE BUSINESS – GREENING HOTELS

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Keywords: sustainable building, retrofit, hotels, serviced apartments, local government, water, waste, energy

Summary

The City of Melbourne's Savings in the City program is an integrated environmental program to help city hotels cut energy, water and waste consumption. The program provides leadership, support, recognition, toolkits and advice on environmental management and demonstrates that an industry-specific approach is beneficial in delivering desired environmental outcomes.

The Savings in the City program has 30 participating hotels and serviced apartments, large and small. The Savings in the City program has resulted in significant savings:

- *waste* figures alone show that hotels are saving on average 4.8 litres per guest per night which equates to 2410 tonnes annually. For the initial two years of the program 628 truckloads of waste have been saved by the 30 hotels.
- over the last two years an average reduction of *water* use of 15.3 litres per guest per night and that's an equivalent saving of 45 megalitres.
- energy figures demonstrate the total *energy* saved by the 30 hotels over the last two years equates to 24,769 tonnes of greenhouse gas or the equivalent amount of energy used by 2890 households.

The program has identified a range of on-going data challenges which need industry-wide resolution, and has demonstrated that motivation for delivering environmental change is complex and seemingly more dependent on advisory support than financial support.

The potential roll-out of the program across the accommodation industry is currently under negotiation with a pilot roll-out currently underway in the Geelong Otway Region. Most of the hotels are part of international chains are expanding their sustainability efforts beyond those of the hotel in the *Savings in the City* program.

Savings in the City Green Hotels have been 2008 finalists in the Banksia Awards and UNAA World Environment Day Awards in the local government category.

1. Introduction

The City of Melbourne has been running an environmental program called *Savings in the City Green Hotels* since 2005 to help hotels cut energy and water consumption, and reduce the amount of waste sent to landfill.

The *Savings in the City* assists hotels to:

- review and benchmark their current level of environmental performance;
- identify priority actions to save water, waste and energy;
- implement actions including behavioural change in a cost effective manner.

Savings in the City aligns with the City of Melbourne's key environmental strategies including the *Zero Net Emissions*, *Total Watermark* and *2020 Vision for Sustainable Waste Management*.

Fifteen hotels initially joined the program in 2005 on the basis they undertake a waste audit and become Waste Wise Certified. From there, a further fifteen properties joined in 2006.

These properties represent a cross section of the Melbourne accommodation industry from 3.5 star to 5 star properties with sizes ranging from 24 rooms to 548 rooms. The thirty selected properties are located within the City of Melbourne and comprise of twenty-one hotels and nine serviced apartments. For the purposes of this report, all properties will be referred to as hotels.

2. Program Partners

It was important in designing *Savings in the City* that it helped the hotels to undertake environmental programs and not just confuse them. Therefore links were made with the existing programs in order to increase their uptake.

The primary connections built into the *Savings in the City* program are:

- the Green Globe international tourism certification program run by EC3 Global;
- the Waste Wise program run by Sustainability Victoria;
- the WaterMAP program run by City West Water;
- the Our Water Our Future program run by the Smart Water Fund; and
- hotel industry groups: Hotels and Motels Association Australia (HMAA) and the Australian Hotels Association (AHA).

3. Data Collection

3.1 Benchmarking Waste, Water and Energy

An integral part of the *Savings in the City* program is the collection of annual water, waste and energy bill data from participating hotels. Annual guest night data is also required for comparative analysis.

Savings in the City encourages all hotels to collect this information as part of regular accounting processes. Hotels can then enter the annual results into the Earthcheck benchmarking tool.

3.2 Earthcheck

Earthcheck is the benchmarking tool used in the Green Globe program that has been made available for the *Savings in the* City participants. It is an internationally-trusted system of indicators that allows individuals, enterprises, and destinations to systematically measure, benchmark, report and manage their performance.

The City of Melbourne has funded participating hotels to use Earthcheck. This has been offered at a reduced rate by EC3 Global as part of our partnership arrangements. Without the *Savings in the City* program each hotel would fund their own use of Earthcheck as part of Green Globe annual membership fees.

Earthcheck has now developed a new introductory package where members such as hotels can get access to the Entry Level software. This software allows members to measure their core areas Energy, Water, and Waste. The software also has an Auto Reporting feature which means members are able to graph their results from within the Earthcheck Benchmarking Software.

To date, the City of Melbourne has had a large role as the intermediary in helping hotels to collect their data to send to Earthcheck. This has been very time-consuming for City of Melbourne (and its consultant), and it was hoped that more of the hotels would have become independent in this data gathering. The City of Melbourne increasingly requires hotels to show commitment and knowledge growth in this area.

3.3 Reliability/Confidence of data

The *Savings in the City* program relies on the assurance that the water, waste and energy bill data supplied by hotels is correct. The City of Melbourne does not have the resources to determine the accuracy of data supplied by hotels.

The City of Melbourne has supplied hotels with a simple Microsoft Excel spreadsheet to help them retain the relevant bill data over the financial year (Hotel Enviro Collator). However, some hotels still require intensive effort and support by the City of Melbourne to assist them with the gathering of this information.

The City of Melbourne continues to hope that hotels will be self sufficient enough to enter their bill data directly into the Earthcheck™ website. Some progress has been made with this, however the most hotels are still very dependent on assistance to do this.

The *Savings in the City* program has collated 3 years of energy, waste and water data. Council feels relatively confident about the data quality as large inconsistencies can easily be identified and discussed with hotels.

Savings in the City feels that trusting the hotels about their data collection is an important approach as it allows the City of Melbourne to spend more time helping the hotels with environmental initiatives rather than chasing up data management issues.

3.4 Laundries

Laundering of hotel linen is a significant contributor to hotels' overall water consumption. Though some hotels wash their linen on the premises, and should be able to directly measure water consumption, most hotels have these items laundered off-site.

Investigations from City of Melbourne have shown:

- It appears that many laundries are undertaking water efficiencies and have developed baseline figures of 11 litres/kg for their own modified water-saving equipment, and 25 litres/kg for laundering performed on-site at hotels using conventional equipment.
- According to City West Water's *Water Efficiency Handbook*, p. 27, a rate of 12-15 litres/kg represents best practice in this area.

One laundry has calculated that an average hotel sends 7.2 kg of linen per day to laundry for each occupied room. Multiplying the number of rooms sold in a given period by this figure will produce a simple estimate of overall laundry water usage for each hotel, if laundry is done off-site.

City of Melbourne used this information to add 10% to the total water use of those hotels that do laundry off-site. Whilst this figure has not rigorously been developed, it is indicative, and it is consistent.

The first year of data collection for *Saving in the City* did not consider off-site water use for laundry, and therefore the water figures are distorted when comparing 04/05 to 05/06 to allow for the addition of 10% of water use. Only two hotels do on-site laundry.

To date *the Savings in the City* program has not taken into consideration the energy consumption associated with laundering off the premises. According to the *Savings in the City Energy Wise Toolkit,* laundries can account for 10% of the total energy consumed in a hotel.

3.5 Privacy

It is important that hotels participating in this program can trust that their information will be used for environmental analysis and improvement, and that it will not be made available to the public.

The City of Melbourne has devised a system that gives the hotels the recognition they deserve without disclosing their operating details. This is reflected in the program's Five Level Recognition System.

4. Commitment of Hotels to *Savings in the City*

4.1 Take-up of hotels

A total of thirty hotels have been selected for the *Savings in the City* pilot program.

Of the 30 Hotels, seventeen hotels have supplied the City of Melbourne with three years of data (04/05, 5/06 & 06/07). This success rate of 57% demonstrates that there is a need for further independent initiative to be shown by many of the hotels, however the data that has been collected by 17 hotels in *Savings in the City* is one of the best data sets in the accommodation industry.

4.2 On-going commitment from hotels

To motivate hotels to make environmental improvements, *Savings in the* City needs to further consider ways of communicating the success of high-achieving hotels. Suggestions include: clearer presentation of performance on website, more case-studies, promotion of active hotels to conference organisers, Lord Mayor letter of achievement etc.

Commitment is also gained from the hotels by applying the following methodology:

- existing resource use is benchmarked whilst training hotel staff on this process;
- behaviour change provisions for staff and guests are incorporated into the program;
- hotels consider a business case and financial model to encourage immediate action;
- case studies are developed to promote good efforts of hotels;
- rewards, promotions and case studies are developed by the hotel industry as motivation; and
- provision for on-going self-management, including data management.

These steps are shown in Figure 1.

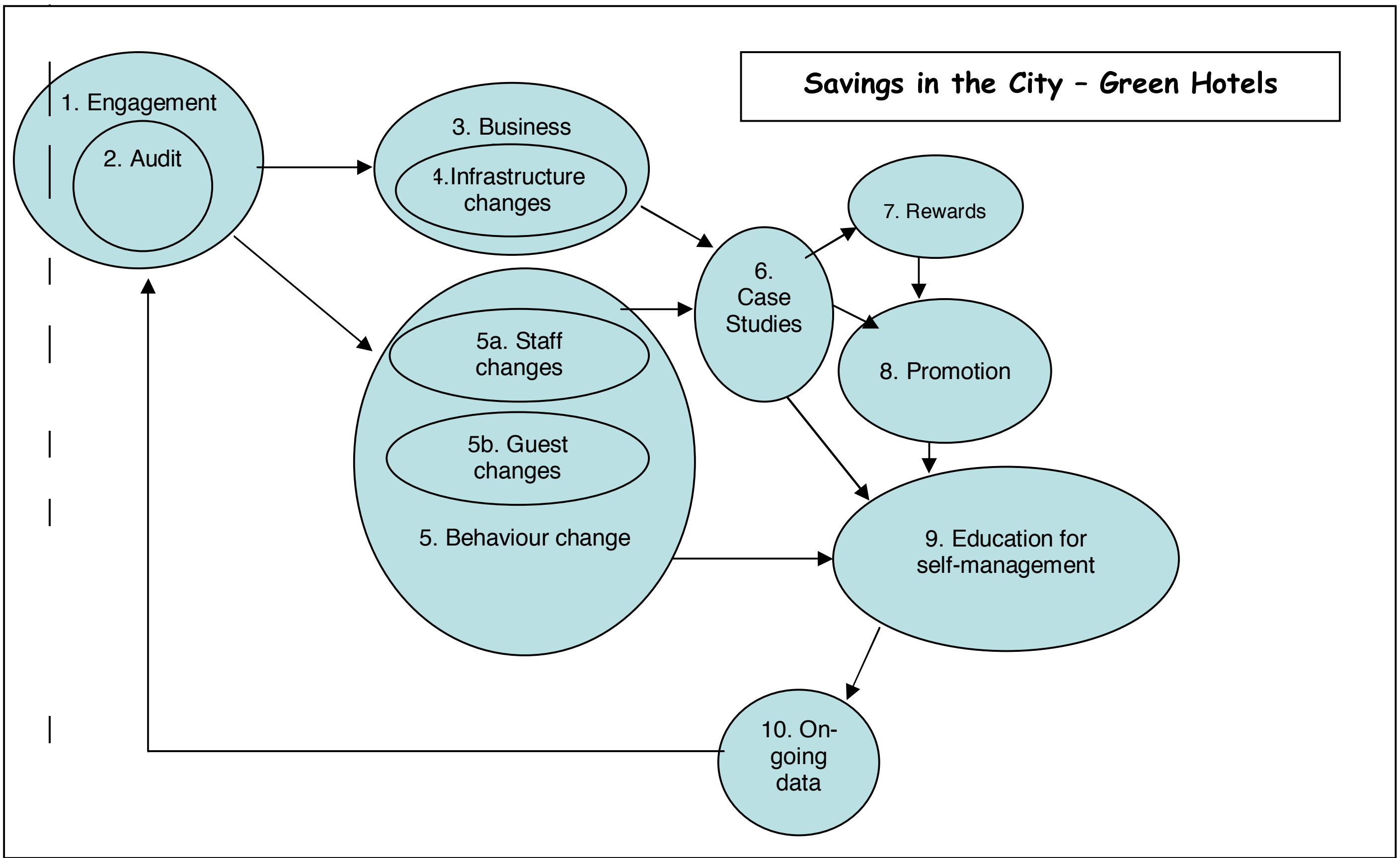

Figure 1: Implementation methodology for hotel environment initiatives

5. How much water, energy and waste should hotels be using?

5.1 Baseline and Best Practice

First year data for 2004/2005 was collected for 22 of the hotels in the *Savings in the City* program. From this Council identified:

1. Baseline – the average of all hotels in the *Savings and the City* program.
2. Best Practice – 30% less than the baseline value.

These values helped hotels to understand how they were performing relative to others, and provided a motivating tool to help hotels reach or better the current baseline and best practice values for each of the water, waste and energy modules.

These figures for waste, water and energy were compared on a per guest per night basis. This is important as it takes into account the occupancy rates of a hotel when calculating their water, waste and energy efficiency.

5.2 Comparing *Savings in the City* Hotel Baselines to National Hotel Baselines

A comparison of *Savings in the City* hotels against national averages provided unanticipated results.

Waste: 'Savings' hotels average 12.7 litres/guest/night well above the national hotel average of 4 l/g/n.

Water: 'Savings' hotels average 257.6 litres/guest/night well below the national average of 700 l/g/n.

Energy: 'Savings' hotels average 189 megajoules/guest/night well below the national hotel average of 300 m/l/n.

Earthcheck is unclear why there is such a discrepancy in our results. The likely reasons are that the national data set is small and predominantly Brisbane based. Earthcheck is due to revise the national data set.

In the meantime, the *Savings in the City* hotels are working off the Melbourne sample set as this is a more accurate and local reflection of resource use.

5.3 Setting the Best Practice Standards

For consistency, *Savings in the City* has applied the Earthcheck methodology for setting best practice standards. This is calculated as 30% less than the average waste/water/energy use. As performance improves, it is necessary to update best practice figures annually.

It is worth noting that City of Melbourne would like to see a more rigorous system for setting best practice targets in the future.

5.3 Current Baseline and Best Practice Standards

Table 1: Melbourne baselines and target figures for hotels and serviced apartments in 2006/2007

Savings in the City	Hotel baseline benchmark (average)	Hotel best practice targets	Serviced Apartments baseline benchmark (average)	Serviced Apartments best practice targets
Waste	11 litres/guest/night	8 litres/guest/night	10 litres/guest/night	7 litres/guest/night
Water	262 litres/guest/night	183 litres/guest/night	197 litres/guest/night	138 litres/guest/night
Energy	188 megajoules/guest/night	132 megajoules/guest/night	93 megajoules/guest/night	65 megajoules/guest/night

5.5 Comparison of properties

The City of Melbourne acknowledges that it is possible to group properties based on additional criteria such as comparing hotels by their star rating, number of rooms, recreational facilites, or number of meals served. This would provide a clearer comparison. Due to resourcing limitations *Savings in the City* has limited its refined grouping to the break up of accommodation services into hotels or serviced apartments.

It is important to note, that the ranking element of the *Savings in the City* program has been designed as a simple tool to motivate hotels to perform better and is not a public ranking for which hotels are accountable.

A NABERS hotel rating tool is currently being designed and it is hoped that it will provide some resolution to these performance data management issues.

6: How to publicly recognise hotel efforts?

6.1 Hotel Recognition System

This City of Melbourne has developed a five level recognition system to show the progress of hotels in making environmental improvements.

The system has been designed to:

- not disclose any private information relating to operating costs and performance of hotels;
- enable hotels that were already relatively efficient to be recognised;
- recognise the efforts made by hotels that may not necessarily show up as resource savings (for example, with some data anomalies it may not be possible to pick up efficiencies even though hotels have been making great efforts); and
- link to the Waste Wise Certification system.

6.2 Certification System

Some hotels have requested that our recognition system be elevated to a certification system.

This is not considered appropriate at this stage as *Savings in the City* is a pilot program that the City of Melbourne is only committed to until the end of 2008. The City of Melbourne is seeking for other organisations to continue the program on an on-going basis; possibly HMAA, AHA or Sustainability Victoria. If this on-going commitment were to be made, a proper certification system would be established.

To keep hotels processes simple, any certification system would need to be consistent with:

- the upcoming ResourceSmart certification being developed by Sustainability Victoria (which extends Waste Wise to cover water and energy); and
- Green Globe certification procedures; and
- recently released NABERS hotel rating tool.

7: Findings

7.1 Waste

The waste module was the first undertaken and linked to the Waste Wise program already in operation by Sustainability Victoria. Sustainability Victoria funded the module and recognised the value of the *Savings in the City* program as a way of encouraging more businesses to become Waste Wise Certified.

As a result from this work with 15 hotels, a Waste Wise Hotels Toolkit was developed and distributed to the wider hotel industry.

Data from the first year of the program has shown a 35.5% reduction in waste to landfill which has been achieved thanks to the waste savings of 36% (17) of participating hotels (Table 2). Some hotels are not yet active in waste management with four recording increases in waste to landfill.

Table 2: Reduction in average amount of waste to landfill

	Average amount of waste sent to landfill
Year 1 (04/05)	12.66 litres/guest night (baseline)
Year 2 (05/06)	11 litres/guest night (12.2% reduction)
Year 3 (06/07)	8.05 litres/guest night (35.5 % reduction from 04/05)

The waste module differs significantly to the energy and water module because savings are reliant a lot more on behaviour change and a lot less on infrastructure requirements.

80% of waste in typical hotel can be recycled or composted. Waste initiatives have included:

a) Staff and contractor training to change disposal habits

b) Placement of bins, systems and signage to facilitate waste reduction, sorting and management

c) Recycling bottles, metals, plastics, paper and corks from kitchens

d) Minimising and recycling paper from offices and receptions

e) Several of the hotels have linked to a local food charity organisation that collects food that cannot be used and turns it into nutritious meals for the homeless. They also take half empty shampoo bottles.

Sustainable purchasing has not yet been strongly progressed by hotels and is perhaps a further initiative. Attempts to arrange organic waste collection have not proved viable because of the expense (primarily due to the lack of demand in the city for an organic collection service). Two hotels have set up on-site composting systems.

Table 3: Figures and commentary on reduction of waste to landfill

Waste		
Savings	**Commitment of Hotels**	**Comment**
Litres of waste saved: • 16 out of 20 hotels have made reductions in waste to landfill; • 4 out of 20 hotels have increased their waste to landfill; • On average, hotels are saving 4.8 litres/guest/night. • Total savings 8034 m3 or 2410 tonnes annually. These savings are equivalent to a reduction of 401 garbage trucks from being dumped at landfill (the year before in 05/06 the hotels saved 227 garbage trucks from being dumped at landfill). Altogether 628 truckloads saved.	• 8 of the 22 hotels were meeting base year Best Practice standards when they joined the program, now 19 are; • 13 of the 22 hotels were meeting base year Baseline standards when they joined the program, now 19 are.	The majority of hotels have seen a reduction in the waste that is disposed to landfill each year, with over 86% of reporting hotels (22) now meeting the base year Best Practice level. This overall performance exceeds the SITC program's target of 56% of hotels that was to be met by December 2008

7.2 Water

Results from the water module are varied and overall comparatively low. The average water use decreased by 4%, due to the efforts of 40% (12%) of the hotels that recorded water savings (Table 4).

Note that the water figures are distorted for 05/06 and 06/07 as it was necessary to increase all water consumption figures for hotels by 10% to account for water used for off-site laundry (this had not been accounted for in 04/05).

Table 4: Reduction in average amount of water consumption

	Average water consumption
Year 1 (04/05)	273 litres/guest night (baseline)
Year 2 (05/06)	256 litres/guest night (6% reduction)
Year 3 (06/07)	262.8 litres/guest night (4% reduction from 04/05)

Water efficiency audits have shown that it is possible to reduce water consumption by an average of 20% without compromising guest comfort. With many hotels spending $200,000 or more on water bills this provides a solid business case for investing in water efficiency. Water initiatives from the hotels in the program have included:

a) Staff training to change water use habits particularly in the kitchen.

b) Some guest education through signage or welcoming guests to use a shower timer provided.

c) Inserting flow reduction valves and low flow showerheads to reduce the flow of water. Only 20% of hotels in the program had acceptable shower flow rates of less than 9 litres per minute.

d) Upgrading toilets to dual flush – well established with 80% of toilets already dual flush.

e) Using more efficient appliances including washing machines, ice makers, steamers, and dishwashers.

f) Water-efficient pools and gardens.

Hotels have not yet progressed greatly on water efficient cooling towers and fire-sprinkler testing systems. Alternative water sourcing has only been pursued by two hotels in the form of rainwater tanks. It is considered that it is more economically feasible for hotels to concentrate on water saving because of the financial benefits as their first response to water management. A Water Wise Hotels Toolkit has been developed as a guide.

The water module has provided disparate results for reasons which are not yet understood. This could reflect problems with data collection, billing methods, leaking pipes or other reasons.

Close analysis of this module has interestingly shown that providing a free audit (as was done for ten hotels) did not result in these hotels making greater water savings than the hotels that did not receive the audit. Only four of the ten audited hotels decreased their water use. The program has instead shown that that the best way to spur action is through 'hand-holding' and being in contact with hotels to encourage and give advice.

Table 5: Figures and commentary on reduction of water consumption

Water		
Savings	**Commitment of Hotels**	**Comment**
Litres of water saved: • 12 out of 19 hotels have made water savings; • 7 out of 19 hotels have increased their water use; • On average, hotels have decreased their water use by 15.3 litres per guest night (which is a saving of 1.5 buckets per guest per night) • Total savings of 25.4 megalitres. • This is equivalent to saving or 25.4 Olympic swimming pools annually. (the year before in 05/06 the hotels saved 20 Olympic swimming pools)	• 7 of the 22 hotels were meeting base year Best Practice standards when they joined the program, now 10 are; • 13 of the 22 hotels were meeting base year Baseline standards when they joined the program, now 15 are.	The water module commenced in Year 2 of the *Savings in the City* program in September 2006. Whilst some hotels have successfully implemented projects that have seen reductions in water use, not all hotels have focussed greatly on this area. 10 of the 22 reporting hotels (45%) now meet the base year Best Practice levels, slightly below the SITC target of 50% for Dec 2008. It is expected that better results will be seen in the 07/08 data once the hotels have implemented water action plans.

7.3 Energy

Energy is the most recent module undertaken in the *Savings in the City* program. As a result the savings are only starting to show with the average energy use decreasing by 3.2%, which has been achieved by the efforts of only 43% (13%) of the hotels (Table 6).

Table 6: Reduction in average amount of energy consumption

	Average energy consumption
Year 1 (04/05)	177.4 MJ/guest night
Year 2 (05/06)	171.8 MJ/guest night (3.2% reduction)
Year 3 (06/07)	137.14 MJ/guest night (23% reduction from 04/05)

Energy management in hotels can reduce energy by approximately 20% per hotel. Initiatives undertaken by hotels include:

a) Lighting efficiencies – less lights, more efficient lighting, and motion sensor controls.

b) Upgrading and/or greater maintenance of heating, ventilation and air-conditioning systems

c) Installing variable speed drives on motors so they aren't needlessly running at full capacity all the time

d) Installing energy management systems to automatically and efficiently control building services.

Table 7: Figures and commentary on reduction of energy consumption

Energy		
Savings	**Commitment of Hotels**	**Comment**
Megajoules of energy saved: • 14 out of 20 hotels have made energy savings; • 6 out of 20 hotels have increased their energy consumption; • An average of 38.5 megajoules /guest night saved (which is a saving of 200 black balloons per guest per night). • Total of 64,170 GJ saved annually This is equivalent to 24,769 tonnes of greenhouse gas, or annually saving the same amount of greenhouse gases as generated by just over 2000 average Victorian houses (up from the equivalent of just over 890 average Victorian houses).	• 10 hotels were meeting Best Practice standards when they joined the program, now 12 are; • 13 hotels were meeting Baseline standards when they joined the program, now 17 are; • 2 hotels have made reductions of more than 40%.	The energy module is commending late in Year 2 of the *Savings in the City* program. At the time of data collection, audits had not been piloted with hotels, and the proposed energy saving kit not published. This module is the scheduled to commence in March 07, and so results will be most clearly seen in the next two financial years. Whilst awaiting the energy module, some hotels have been able to undertake ad-hoc energy efficiency measures. These actions were motivated by the program, and have been undertaken by keen hotels.

10: The Future of *Savings in the City – Green Hotels*

10.1 City of Melbourne's commitment to the *Savings in the City – Green Hotels* program

The City of Melbourne developed *Savings in the City* as a pilot program that would:

a) demonstrate the effectiveness of supporting an industry sector (hotels) to achieve environmental efficiencies;

b) develop the necessary tools to guide that sector (toolkits, spreadsheets and training programs);

c) develop the program design for replication on an on-going basis (recognition system, templates, toolkits and partnerships).

The City of Melbourne feels that it has demonstrated the effectiveness of the *Savings in the City* program through the following indicators of success:

a) significant, and growing savings by hotels in water, energy and waste;

b) growing knowledge and engagement by participating hotels;

c) support from a range of stakeholders, and success in obtaining grant funding for the program;

d) hotels (other than participating hotels) wanting to be involved in the program.

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1.1 Resources provided to hotels

The *Savings in the City* program has provided participating hotels with a large amount of informal and formal support and resources to assist them in reducing their water, waste and energy use. Information seminars have been held on water, waste and energy. These seminars have provided opportunities for hotels to gain technical advice on resource efficiency measures as well as providing a forum to discuss obstacles and solutions of emerging technologies.

The *Savings in the City* program as developed three toolkits on water, waste and energy use in hotels. Participating hotels have also been provided with these toolkits so that they can gain an understanding of where water and energy is used in their hotel, where waste can be reduced and what the opportunities are for making savings. The toolkits also have case studies and details about energy, water and waste saving technologies.

The toolkits also to provide a means for hotels to conduct their own audits and as a briefing tool to engage consultants to carry out the audits.

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1.1 Resources provided to hotels

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built this environmental reporting into their accounting procedures.

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For the remainder of the hotels, the collection of environmental billing data is a considered a burdensome task requiring the collection of (hopefully) archived bills.

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To assist hotels with the collection of this information, the Hotel Enviro Collator spreadsheet was created.

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Data Required

Each hotel is to provide Earthcheck with the following annual data:

~~Electricity – kilowatt hours~~ Section Break (Continuous)

Gas – megajoules

Water – kilolitres

Waste to landfill – metres[3]

Guest Nights - guest numbers

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The more years of data that is collected the more we

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can feel confident about data quality as large inconsistencies can be identified and discussed with the hotels.

THE BUILDING SECTOR FACING THE CLIMATE CHANGE CHALLENGE: HOW TO TURN CONSTRAINTS AND WEAKNESSES INTO OPPORTUNITIES, THE CDM EXAMPLE

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Keywords: SBCI, building, climate change, energy efficiency, CDM, Kyoto Protocol, negotiation

Summary

The building and construction sector is accounting for a significant and increasing part of the worldwide energy consumption and is responsible for an important greenhouse gas emissions share. On another hand, this sector has a huge impact on social and economic development for developing, transition as well as industrialised countries. This is why is has to be considered as a key sector regarding sustainable development and climate change issues. Taking advantage of the UNEP (United Nations Environment Programme) SBCI initiative (Sustainable Buildings and Construction Initiative) which gathers private and public buildings and construction stakeholders, the topic of this paper will be, after having presented a general overview of this sector and the challenge of reducing climate change impacts, to evaluate how we can mobilise in an appropriate way Kyoto flexible mechanisms. The paper will use the first SBCI report's results "Buildings and climate change: status, challenges and opportunities" and results of the ongoing work on climate change issue. On this topic, one key element will be to evaluate why, despite eligibility to receive support from the Clean Development Mechanism (CDM) and the Joint Implementation (JI) funding Kyoto Protocol mechanisms, only very few building related projects have been registered or implemented. For that purpose, barriers will be identified and potential measures to overcome them will be highlighted taking into account the need to work on baseline issues. Finally, we will present a set of recommendations in order to ensure that energy efficiency improvements in buildings will be fully supported and eligible both on the current Kyoto Protocol and also in the post 2012-agreement which is under negotiation.

1. Introduction

The building and construction sector is accounting for a significant and increasing part of the worldwide energy consumption and associated greenhouse gas (GHG) emissions share. On another hand, this sector has a huge impact on social and economic development for developing, transition as well as industrialised countries. This is why it has to be considered as a key sector regarding sustainable development and climate change issues.

Taking advantage of the UNEP (United Nations Environment Programme) SBCI (Sustainable Buildings and Construction) Initiative, the topic of this paper will be to evaluate how we can mobilise in an appropriate way the Kyoto Flexible Mechanisms and especially the CDM (Clean Development Mechanism). For that purpose, we will take advantage of SBCI reports "Buildings and climate change: status, challenges and opportunities", “Assessment of Policy Instruments for Reducing Greenhouse Gas Emissions from Buildings” and the results of the ongoing work on climate change issue undertaken by UNEP Risoe Center and the SBCI Climate Change Think Tank.

After having presented the SBCI Initiative and its objectives, we will draw a general overview of the building sector and the challenge of reducing climate change impacts. We will evaluate why, despite the eligibility to receive support from the Kyoto Flexible Mechanisms, only very few building related projects have been registered or implemented. For that purpose, barriers will be identified and potential measures to overcome them will be highlighted. Finally, we will present a set of recommendations which could contribute ensuring Energy Efficiency (EE) improvements in buildings to be fully supported both in the current Kyoto Protocol and in the post 2012-agreement under negotiation.

2. The UNEP Sustainable Buildings and Construction Initiative

The UNEP Sustainable Buildings and Construction Initiative was established in 2006 as an UN-building sector partnership with the objective of promoting sustainable buildings, in particular those that are energy efficient. The specific goals of SBCI are to provide a common platform for all building and construction stakeholders to collectively address sustainability issues of global significance, to establish globally acknowledged baselines for sustainable buildings and construction practices, principally those based on the life cycle approach, to develop tools and strategies for achieving wide acceptance and adoption of sustainable building practices throughout the world and to promote adoption of the above tools and strategies by key stakeholders.

These goals have been translated in to the current SBCI work program to the following focus areas: (1) Influence the Kyoto Protocol to provide, under the international climate change framework, positive and realistic incentives for the building sector to use more energy efficient solutions when constructing and refurbishing buildings, (2) Encourage and support national level policy makers to change market conditions in favor of stakeholders who provide sustainable building solutions, especially stakeholders adopting life cycle approaches, (3) Establish a global "common language" on sustainable buildings by developing global benchmarks keeping in mind that SBCI not intends to develop standards, as they need to be developed and adopted at the national level, (4) Highlight the benefits of adopting sustainable building practices in developing countries.

The SBCI focus areas are closely linked and mutually supportive of each other:

- The work on the Kyoto Protocol serves to establish policies and economic tools that make investment in sustainable and energy efficient buildings attractive.

- The effort on policy tools serves to establish corresponding tools at the national level, and also systems and standards that will encourage sustainable building approaches in other ways as well.

- The benchmarking aims to provide a common language for building sector stakeholders so that they can understand, identify and quantify benefits from sustainable buildings. Again, this can be used to develop national certification systems, reporting standards, sustainable property investment analyses, financial tools, etc… It is important to understand that this work does not aim to replace or compete with existing national systems but to complement them by promoting adoption of similar systems in other countries and by attracting more building projects to be certified under existing systems.

- The work on sustainable buildings in developing countries highlights the contributions sustainable buildings make to other national development priorities, such as poverty reduction and shelter for all. This agenda being most important in markets where the awareness is low.

For more information regarding the Initiative, thank you to visit the www.unepsbci.org website.

3. The building sector's high energy efficiency potential

Buildings are responsible for 30-40% of total worldwide final energy use and associated GHG emissions, both in developed and developing countries and this figure should continue increasing due to the high demand in developing countries. Energy is mainly consumed during the use stage of buildings for heating, cooling, ventilation, lighting, appliances etc… and only a small percentage (10-20%) is used for materials manufacturing, construction and demolition. According to the Intergovernmental Panel on Climate Change Forth Assessment Report, building's sector related GHG emissions could increase by 32% in a low growth scenario, and up to 81% in a high growth scenario in 2030 which main part coming from developing countries.

On another hand, the combined GHG mitigation potential by 2030 in non-OECD and Economy In Transition countries can reach up to 3.15 Gt $CO_{2\text{-eq}}$, which is significantly higher than the OECD countries 1.8 Gt $CO_{2\text{-eq}}$ potential. This being considered and whatever the scenarios, it is clear that the building sector's energy saving potential is very high. The IPCC AR4, based on the results of over 80 worldwide surveys, shows that the global reduction potential can reach 29% in 2020 of the projected baseline emissions and 31% in 2030 for residential and commercial buildings. But, in any case, and unfortunately, the building sector's GHG emissions will remain at 30% of the worldwide GHG emissions.

In addition, it is necessary to underline that the mitigation costs for tapping such high reduction potential are very low from a life-cycle point of view. With proven and commercially available technologies and processes, the energy consumption in both new and old buildings can be cut by 30-50% without significantly increasing the investment costs. The IPCC AR4 report states that the building reduction potential is relatively independent from the cost per ton of $CO_{2\text{-eq}}$. The report estimates that, in 2030, 5.5 billion tons of $CO_{2\text{-eq}}$ could be mitigated for less than 20 US$/ton and 6.1 for100 US$/ton (see Figure 1).

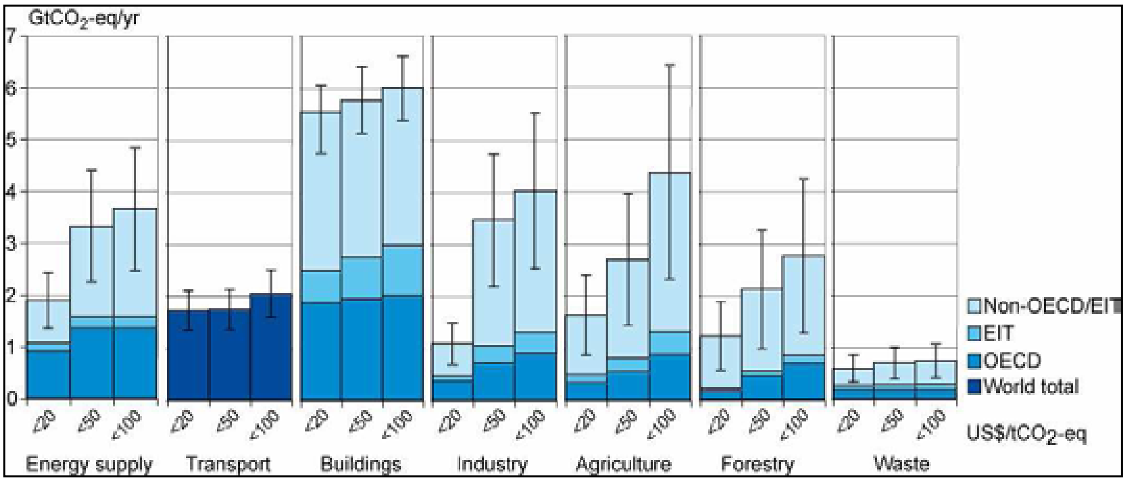

Figure 1 *2030 emission reduction potential in different sectors depending on reduction measure costs (US$/co2 equivalent) - Source: IPCC, 2007*

This potential can be achieved through a range of measures including smart design, improved insulation, low energy appliances, high efficiency ventilation and heating/cooling systems, significant integration of renewable energies, appropriate maintenance schemes and building users' behaviors encouragement to conserve energy. These technologies and concepts have been already widely tested and are fully commercially available.

4. Generic barriers to EE in the building sector

Barriers to building's energy efficiency measures financing. Energy Efficient Buildings (EEB) construction requires additional funds at the initial stage compared with standard ones, because design, construction materials, heating/cooling equipments and appliances are more expensive. However, these additional costs only represent 5% to 10% of the total building cost for new buildings according to the World Business Council on Sustainable Development 2007 report. Furthermore, if we consider a lifecycle analyse, the energy saved would easily cover and even exceed these initial investments. Despite these considerations, investors are still reluctant as short term investments decisions are based on immediate costs rather than long-term investment plans.

Among others, one of the main identified reasons is the high credit risks perception due to the lack of financial history and financial tools for EEB projects investment's evaluation and pay back ability of such projects. Building and construction professionals are facing difficulties to provide relevant data and information for projects risks assessments and to convey projects benefit in terms of investment in the context of a controlled risk-return environnement, which is a prerequisite to any bank decision process. These high perceived risks are resulting from a combination of many criteria, such as multi-ownership of buildings, relatively small size of the investment, construction and building sector's organisation, lack of information, and shortage of expertise to ensure deliverability of energy savings.

Contradictory interests, the landlord/tenant paradox. Buildings normally have a long life cycle with only limited interaction between stakeholders involved in the different phases. The parties typically making decisions about the building design (designers and investors) are seldom the ones who would benefit from energy efficiency improvement and its reduced associated costs (owners and users).

For example, in most cases, in existing buildings, owner and occupant are different. The first one (the landlord) is interested in limiting its investment as he will not be concerned by the energy bill and he will not naturally invest in high efficiency equipment. The tenant will be the one to pay for the energy bill, but he will not be really interested in paying for energy efficient equipments (such as boilers, efficient windows…) that he cannot take with him. Investing in energy efficient equipments and buildings will not be a natural move and this is a critical barrier. This paradox remains a reality for all types of buildings and even if this problem is well identified and the solution well known, coordination of all the concerned stakeholders remains clearly a challenging issue.

A highly fragmented sector. The building sector is a very fragmented one with many stakeholders involved in the various phases of the construction such as developers, capital providers, designers, engineers, contractors, agents, owners, users, and local governments. In addition, the complexity of interaction between them reinforces the difficulties to conduct a project with an EE friendly environment approach. This barrier is well illustrated in the WBCSD's "operational island" graphs (see figure 2). The first pyramid describes the different technical disciplines involved, the second one the building delivery process and the third one emphasizes the ineffective coordination resulting from functional gaps and management discontinuities. The whole process is definitely not optimised and not integrated even if some players try to optimise their own part of the process.

In addition to this complexity and due to the construction history (uncertain business environment, construction bubbles, recession cycles…), this sector is generally conservative and risk-adverse to new approaches. This is all the truest as incentives for energy savings and associated benefits are also split between the different players and with regards to the different phases of the building cycle. Therefore, investment decision process will not go naturally to long term energy prospective. Last but not least, this leads to higher transaction and management associated costs and this is even more significant if we keep in mind that most of the projects are dispersed and small by nature.

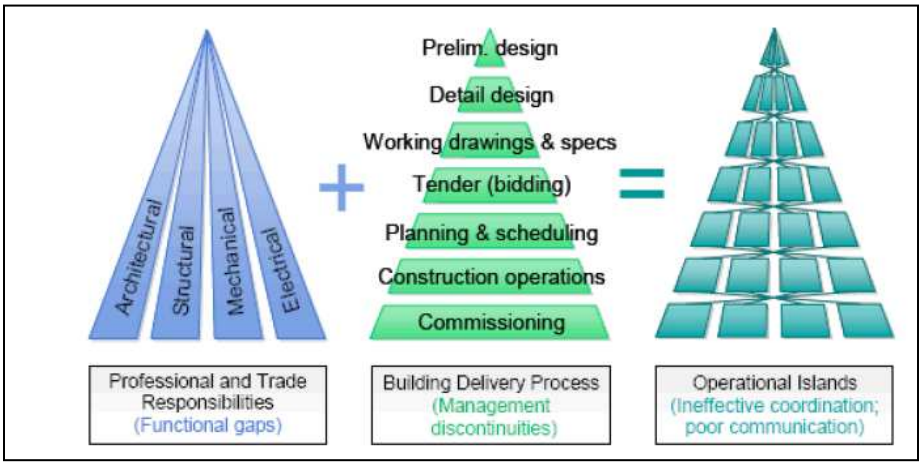

Figure 2 WBCSD's "operational island" graphs or how the construction sector is fragmented and complex – Source: WBCSD, 2007

Insufficient and ineffective governments' policies. This issue is definitely a strategic one and in order to illustrate the need for government support, the UNEP SBCI "Assessment of Policy Instruments for Reducing Greenhouse Gas Emissions from Buildings" report released in September 2007 by CEU (Central European University) has provided very interesting results. A global review of lessons learned from existing policy instruments in more than 50 countries around the world have been realized and the conclusion is that many policy instruments are not only effective in achieving emission reductions, but also result in net savings to society, up to US$ 200 per ton of $CO_{2\text{-eq}}$ avoided.

Having a look to developing countries, standards and regulations for EE in the building sector are generally lacking. In addition to governments' limited capacity and resources to design and implement appropriate policies and programs, the difficulties for their concrete implementation are generally underestimated. For example, in China, officially 70% of the new buildings in big cities reach the requested compliance level, but, in reality, it seems that only 30% fulfil the requested expectations. Considering small cities and rural areas, this is even more difficult, as for less developed countries. Beside the lack of government policies, and even when existing, clear implementation programmes with appropriate monitoring tools are not well defined and, in some cases, requirements are mostly qualitative.

EEB real costs and benefits misperception. Numerous studies have illustrated the misperception of building and construction stakeholders with regards to EE solutions and associated costs and benefits.

A study on additional costs perception has been conducted by WBCSD in 2007. It concluded that estimated over cost for an energy efficient building is considered between 11% and 28% of a "business as usual" one. As mentioned before, real figures are different as for Industrialised Countries 5% to 10% seems more realistic even if it is a little bit more for Economy in Transition ones. In addition, IPCC AR4 also underlines that, when existing, information about energy efficient solutions is not really appropriate to the different stakeholders' expectations (banks, developers, investors, builders, users…).

Another conclusion of the study is that, even if professionals seem to be aware of the importance of EE measures, they underestimate the GHG emissions sector contribution (19% which is quite far from the approximately 40% real contribution). "Lack of personal know-how about how to improve a building's environmental performance" and "lack of knowledge about where to go for good advice" are ranked as major barriers in the decision making process.

5. The Kyoto Protocol and the building and construction sector

A few words about the Kyoto Protocol. The United Nations Framework Convention on Climate Change (UNFCCC) was signed during the Earth Summit in Rio de Janeiro in 1992. UNFCCC Annex I countries are mainly OECD countries (Organisation of Economic Cooperation and Development) and countries undergoing the process of transition to a market economy. Countries have committed themselves to return jointly or individually under their 1990 level of GHG.

The Kyoto Protocol was adopted at the 3rd session of the Conference of the Parties (COP3) to the UNFCCC held in Kyoto, Japan, in December 1997. This Protocol defines quantified greenhouse gas (GHG) emissions reduction targets for UNFCCC Annex I Parties (now called Protocol Annex B countries) in order to reduce collectively their GHG emissions by 5.2% below their 1990 level on a committed 2008-2012 period. Each Annex B Party has different GHG emission ceiling for the first commitment period called "assigned amounts Unit" (AAU) calculated as follows: "the base-year emissions" x "emission reduction target" x "5". The base-year emissions being Party's aggregate 1990 GHG emissions. Non Annex B countries have also agreed to reduce their emissions but without any binding obligation under the "common but differentiated responsibility" principle.

Beside national policies and measures, Annex B Parties can meet their objectives using 3 market mechanisms called the "Kyoto flexible mechanisms": the Joint Implementation (JI), the Clean Development Mechanism (CDM) and the International Emissions Trading (IET).

The first one (Article 6 of the Protocol) allows Annex B countries to implement projects in another Annex B country; the correspondent credit will be issued based on the amount of emissions reductions achieved by the project activities. The credit from the JI is called Emission Reduction Unit (ERU).

The second mechanism, the CDM (Article 12 of the Protocol), allows Annex B countries to assist non Annex B countries in implementing project activities to reduce GHG emissions and corresponding credit (Certified Emission Reduction – CER) will be issued based on associated emission reductions.

The third one, the IET (Article 17 of the Protocol) allows Annex B countries trading AAU, CERs and ERUs with others Annex B countries.

The objectives of these market mechanisms is to decrease total cost of Annex B countries to achieve their collective emission reduction targets and to encourage technologies transfers in "cleaner" projects in non Annex B countries.

A few considerations about CDM projects' eligibility. The purpose of this paper is not to go too much in details in Kyoto Protocol concrete implementation, but in order to clearly illustrate building and GHG mitigation link under this Protocol, it seems important to explain how projects process implementation is arranged and which concepts are required. Having said that, some compulsory criteria are needed to be able to qualify a project as a CDM one. The so called Marrakech Accords specify that emissions reductions have to be real, measurable, benefit to the mitigation of climate change and contribute to the host country national sustainable development goal.

The baseline for a CDM project activity is the scenario that reasonably represents GHG emissions that would occur in the absence of the proposed project activity. To establish scenario and emissions baseline, concerned stakeholders can use approved and new methodologies to demonstrate additionality and to refer to monitoring concerns. The difference between the baseline emissions and GHG emissions after implementing the CDM project activity is emission reductions. A CDM project activity is additional if GHG emissions are reduced below those that would have occurred in the absence of the registered CDM project activity.

Today, the CDM is known as one of the most important international market based mechanisms to reduce GHG emissions. End of 2007, the 2700 CDM including registered projects and the ones waiting for validation were representing more than 600 million tonnes of $CO_{2\text{-eq}}$ abatement per year. As an example, if we consider the price for a ton of CO_2 between 10 and 30 US$, this would mean a market potential value between 6 and 18 billion US$...

The building sector and the Kyoto Protocol flexible mechanisms. Even if buildings are eligible for the Kyoto Protocol flexible mechanisms, only a small number of the projects in the CDM/JI pipeline are related to energy efficiency in building (as of 8th November 2007, 14 out of 2700 projects). In addition, within these 14 projects, no significant Certified Emission Reduction credits (CERs) have been generated.

With regards to the building sector's large emission reduction potential, it is clear that so far, CDM has not been able to attract significant number of projects. This has been underlined in the IPCC's AR4, which indicates that CDM, as designed and implemented today, creates low CO_2 mitigation effectiveness and furthermore is not cost-effective for the building sector. If we go back to the figure 1 data, which means that, in 2030, between 5.5 billion and 6.1 billion tons of $CO_{2\text{-eq}}$ could be mitigated, with a price for a ton of CO2 between 20 and 100 US$, this represents a potential market value between 110 billion and 610 billion US$. This calculation is a little bit simplest regarding the EEB building barriers but the purpose here is just to illustrate that a significant amount of money can be mobilised to support project implementation.

6. The CDM process weaknesses to support EEB projects implementation

As already mentioned and despite a real potential, some limitations in modalities, procedures and methodologies in CDM current arrangements make this market mechanism not effectiveness to support EEB projects implementation. Without being exhaustive, some key issues need to be considered.

Additionality requirements can be considered, in some cases, in opposition with mandatory policy implementation strategies or, at least, can make standards and regulations implementation difficult. This point has to be linked with baseline considerations and, even if it is a clearly identified problem, nothing, for the moment, has been clearly answered in order to overpass this difficulty. A tentative answer is highlighted in the Program of Activities (PoA) and CDM Program Activity (CPA). The first one is a voluntary coordinated action by a private or public entity which coordinates and implements any policy/measure or stated goal which leads to GHG emissions reductions. The second one is a project activity under a program of activities, representing a single or a set of interrelated measures to reduce GHG emissions applied within a designed area defined in the baseline methodology. The objective is to encourage voluntary actions keeping access to CDM potential additional revenue having in mind policies implementation according to a pre-define action plan. It can be also underlined that current PoA guidance states that only one single approved baseline and monitoring methodology can be applied under a program which means that even if a project intends to mix different methodologies for different efficiency measures, they can not be eligible in the same CPA under one PoA. To illustrate this purpose, it means that project which includes envelop improvement, energy efficiency measures, solar water heater and electricity generation can not be applied under the same PoA because they refer to four different approved methodologies. This conducts to unnecessary complexity associated to highest transaction and management costs and even disadvantages putting forward “best building practices” to be eligible (and so visible) under the CDM.

The above concern can be called the “baseline” one. Another key issue is linked with the existing methodologies and associated monitoring requirements. First of all, existing methodologies are technologies oriented and do not answer overall building performances (but building’s answer to climate impacts is not only related to addition of efficient technologies but also to a lot of different items such as design, users’ behaviors…). Another related point is the size of individual projects and even if existing methodologies such as AMS-IIC (demand-side energy efficiency activities for specific technologies such as lamps, refrigerators, appliances…) or AMS-IIE (energy efficiency and fuel switching measures) are applicable to buildings and also concern small scale projects, they are still technologies oriented and require difficult and complicated real measurements and audits on all installed technologies to demonstrate emissions reduction reality. In addition, the associated amount of CERs is not generally significant enough to encourage projects developers entering into the process and to cover management associated high costs.

The lack of existing baseline for new buildings due to the complex nature of an EEB project by definition and the difficulty to have a comparative base for the evaluation of the project emissions reductions is also another important point. Moreover, each project being unique because of using different approaches to reduce GHG emissions makes the problem even more difficult. For what concerns refurbishment of existing buildings, this can be over passed if accurate existing data are available, which is not the general situation. For those who decide to still go into the process, this conducts to very conservative baseline scenario and for what concerns monitoring and auditing processes to difficulties to demonstrate reality of emissions reductions. This point is of the utmost importance and explains why so far no new building has been approved in the CDM process. In addition, the existing arrangements answer neither to the evaluation of thermal performance buildings improvements nor to energy end-use patterns for heating and cooling. Once again, this comes from the existing technologies oriented methodologies which do not reflect small projects with many end-users having different behaviors (comfort, culture and consumption habits).

The above points lead us to another difficulty as soft measures are not taken into account in the current arrangements. We all know, how from a life cycle perspective, it is crucial to encourage energy consumption reduction during the building operation. This can be done through appropriate procedures but also by motivating and associating end-users to the process. The AR4 report shows that energy savings can reach up to 38% in cooling and 62% for heating.

Last but not least, the ownership and the benefit of the potential CERs issued will not easily answer the numerous stakeholders concerns in a project implementation.

The above list is not exhaustive but already reflects a lot of complexity and limitations to support EEB projects implementation. This is even more true for low income residential buildings where sustainability criteria is the first concern as the point is to improve poverty reduction but where the availability of funds is not so evident and where CDM revenue can not fill the gap.

How CDM process can contribute to EEB projects implementation. As described in the EEB barriers presentation, the building sector is a very fragmented one with numerous and sometimes contradictory interests if we consider a life cycle approach. For what concerns the CDM process, it is clear that the management issue is of the utmost importance. Reaching the real, measurable and verifiable emissions reductions objective means that all the building and construction process needs to be properly arranged. Without going to much in details in the monitoring process, it has to be done by a third party auditor authorized by the national designated operational entity which is an independent legal entity accredited by CDM executive board that can validate proposed CDM projects, verify and certify GHG emissions reductions. To summarize, CDM requirements can be compared in a way to a quality insurance approach. Having that in mind, it can be easily imagine how this process can encourage investors and decision makers to clearly support EEB projects with real GHG mitigation.

Another very interesting item is linked to requirements for validated methodologies which allow replicability from a project to another one. What we try to say here is not to minimize what was stated in the previous chapter but just to say that as soon as a methodology has been approved it can be easily re-used for numerous projects. The issue will be then to have a clear picture of the concerned perimeter.

As far as user's behavior change is concerned, monitoring requirements, which conduct to have a clear picture of emissions reductions reality, can clearly encourage end-users in the global energy saving effort by raising their interest to be associated to the global performance of the building and even to obtain parts of the benefit. This can be called a "virtuous quality performance circle approach".

For what concerns implementation of government policies (standards and regulations) which are by nature top-down approaches, CDM can support market transformation through the above quality approach process and through the scale-up effect by encouraging more voluntary projects because of the additional revenue when trading CERs. In that way, CDM can contribute to fill in the gap between policy enforcement and policy compliance.

Going back to the financing question, CDM can support EEB projects implementation by reducing investments and financial risks perception, by demonstrating opportunities to support life cycle based investments and to have additional funds to cover transaction and higher management associated costs. For the first point, it will encourage numerous small projects to be implemented in a coordinated manner using the same process. The quality insurance control mechanisms minimize the risk of payment default. In addition, all the above comments can be also a good communication tool to be compared to all voluntary initiatives such as LEED, HQE, BREEAM… in order to raise interest of potential stakeholders. This can be a real interesting point as far as we deal with sustainability criteria in the host countries and that, in many cases, international funds will be mobilized.

7. The way forward… How to transform and adapt CDM constraints into opportunities to improve building sector GHG emissions reductions

What has been presented so far may look like quite a not so optimistic picture. This is not really true if we consider that all concerned stakeholders have now a very clear picture of the situation and that the concern about climate change mitigation is agreed by everybody. Considering the high building contribution to climate change, everybody is now aware and we collectively need to work on this issue as urgently as possible. We need to work on best ways to over pass barriers, to take advantage of the already successful arrangements and even to go through new options. Besides the need to develop national regulations and standards for energy efficient buildings and/or sustainable ones, key topics to work on can be summarized as below (definitively a non definitive list):

* Allow energy performance based methodologies instead of technology ones as described in the current Kyoto Protocol arrangements. As explained before, the technology based does not reflect EEB projects reality. In addition, such approach is in line with thermal regulations implemented or in development and per square meter energy performance is also a common used indicator for a global approach of energy concerns in buildings. Such approach can support removing several of the economical, technological and associated barriers. For example, it can over pass restrictions of bundling different measures in the same project and also it would avoid uncertainties regarding eligible measures. This would allow flexibility for taking into account factors such as design, use of building materials and user's behavior improvement. Last but not least, such performance approach would also encourage a building's lifecycle energy efficiency approach and would also reinforce interest for future improvements. This topic has to be linked with the next point.

* Need to develop common baselines. As already explained, having such information for each country is of the utmost importance to facilitate project implementation process. This work has to be prepared by hosted Designated National Authorities (DNA). If each country defines and agrees on an average ratio per type of building and per type of use according to climate conditions and to EEB rules, it can significantly attract project developers in the CDM market. This point is very important for new buildings but also concerns refurbishment needs. Large-scale surveys and building benchmarking efforts need to be undertaken in order to be able to propose to CDM Executive Board realistic figures.

* Mobilize all public and private building and construction sector stakeholders by developing appropriate tools such as financial ones, evaluation and monitoring of EEB projects. CDM, as described, can make coherence by the associated requirements. Coming back to support the implementation of national

standards for energy efficiency in buildings, allowing CDM and associated CERs could provide incentive to EEB projects in countries where the enforcement capacity of standards is low.

* Reinforce capacity building through guiding materials and standardization of activities and documentations for EEB projects and related CDM activities. Even if some examples exist and if quite a significant literature on the overall process is available, only a few of it has been designed to answer building and construction sector's needs. Such tools need to cover all project phases from design, commissioning, monitoring to the financial one. On this subject, good case studies and demonstration projects can be push forward. The first one being to make easy duplication and the second one to develop innovative approaches.

8. An urgent need for advocacy

The first crediting period has started less than one year ago and we already know that reaching objectives will not be as easy as expected. Negotiation process for next period has also started and the challenge is much more difficult as it is commonly agreed that reduction objectives will be much higher for Annex B countries and that the involvement of developing countries will be also a determinant aspect.

Going back to the building and construction sector, and if we consider the high GHG contribution and the even higher mitigation potential, would working on an international agreement without incorporating the buildings and construction sector have sense?

Regarding Kyoto flexible mechanisms and even if we surely need to work on an adaptation, we can take advantage of the existing experience to propose, as soon as possible, a new and adapted approach. The above recommendations have not to be considered as a conclusion. They are just recommendations and in-depth actions need to be implemented as urgently as possible. SBCI will definitely contribute working on this challenging issue by pushing forward the buildings and construction at the top priority of the political agenda in the framework of the UNFCCC ongoing activities.

Before concluding this paper, it is important here to highlight that the above contribution is based on a collaborative work including UNEP SBCI Secretariat and Members, UNEP RISOE Center, SBCI Climate Change Think Tank Members and all SBCI associated partners and initiatives. Thanks to all of them.

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SUSTAINABLE LAND USE: APPROACHES FOR AN INTERNAL DEVELOPMENT OF NATURAL, SEMI-NATURAL AND URBAN LANDSCAPES

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Keywords: urban sprawl, sustainable land use, internal development, driving forces, approaches

Summary

Our built environments drive human, organisational and regional productivity and contribute to the national economy. During the last decades the development of our surroundings has led to a worldwide phenomenon that has often been associated with prosperity and quality of life: urban sprawl. But what is the price we have to pay for it? The impacts of urban sprawl to our Natural Capital and to the dimensions of sustainability (integrative perspective, intragenerational and intergenerational equity) are significant.

There is growing recognition that internal prior to external development[a] of our built environments is an appropriate strategy to encounter a further increase of land use. In this regard, important questions emerge in three main fields. *Land use:* How did the landscape as well as its use evolve? How will it develop in future? *Driving forces:* What are the driving forces of urban development? Which stakeholders are involved? *Approaches:* What kind of planning and regulation approaches are adequate to slow up or even stop the trend of land use? How well are these instruments known by the planning authorities?

For the case of Switzerland, the paper will analyse and discuss today's situations for these three fields. It will demonstrate that efforts on several levels are needed in order to reach a sustainable land use and that there *are* ways to face the continuous settlement expansion. However, a Swiss-wide survey amongst selected municipal and cantonal planners revealed that there is an insufficient awareness and implementation of both already existing and innovative instruments.

1. Introduction

1.1 Urban Sprawl

According to Jaeger et al. (2007) urban sprawl can be paraphrased as follows: Urban sprawl is a phenomenon optically perceivable in the landscape. The more a landscape is interspersed with buildings the more it is sprawled. The degree of sprawl is the extent of the landscape's building development and its dispersion. The more an area is built up and the more dispersed the buildings are, the higher urban sprawl therefore is. The socio-economic driving forces of urban sprawl characterise the development of built environments in most of the countries worldwide. The European Environment Agency states in its report, that Europe-wide urban sprawl is increasing in a mechanistic way in areas where unplanned, decentralised development dominates (European Environment Agency EEA 2006). The report also describes, why urban sprawl matters: "Sprawl threatens the very culture of Europe, as it creates environmental, social and economic impacts for both the cities and countryside of Europe. Moreover, it seriously undermines efforts to meet the global challenge of climate change. Urban sprawl is synonymous with unplanned incremental urban development, characterised by a low density mix of land uses on the urban fringe. Classically, urban sprawl is a US phenomenon associated with the rapid low-density outward expansion of US cities, stemming back to the early part of the 20th century. It was fuelled by the rapid growth of private car ownership and the preference for detached houses with gardens. In Europe, cities have traditionally been much more compact, with a dense historical core shaped before the emergence of modern transport systems. Compared to most American cities, their European counterparts still remain in many cases compact. However, European cities were more compact and less sprawled up until the mid 1950s than they are today, and urban sprawl is now a common phenomenon throughout all Europe. Moreover, there is no obvious slowdown of these trends." The report therefore suggests to develop European guidelines in order to coordinate and monitor urban planning in Europe.

[a] The term "internal development" is also known as "in-fill development" or "inward development".

1.2 Sustainable Development

The Swiss understanding of sustainable development is described by the federal council of Switzerland in their strategy-report from 2002 (Schweizerischer Bundesrat 2002). For them the most adequate definition of sustainable development is still the definition from the conference of the World Commission on Environment and Development in Rio de Janeiro in 1987, which the chairmen called the “Brundtland-Definition”. Accordingly, a development is sustainable as long as it can assure that the needs of the today’s generation can be satisfied without affecting the possibilities of future generations to satisfy their own needs.

Hence, the Swiss developed an enhanced three-dimensional model, which adds a spatial dimension for the global long-range effects and a time dimension for the intergenerational equity to the three common dimensions of environment, economy and society. The sustainability-model of the Swiss federal council therefore includes three main principals: integral, well-balanced consideration of the environment, economy and society; consideration of the interests of future generations (intergenerational equity); consideration of the interests of all residents worldwide (intragenerational equity) (Wachter 2006). The strategy Sustainable Development 2002 includes ten spheres of activity with 22 tasks altogether; the sphere of activity no. 7 is dedicated to the spatial development and the development of settlements. The strategy also demanded a monitoring for sustainable development. Therefore an indicator system for the evaluation of sustainable development called “MONET” was created and applied. Three of the nearly 120 MONET-indicators are directly linked to the topic of urban sprawl: “settlement area”, “average settlement area per capita” and “land usable for agriculture”. While the settlement areas in total and per capita still grow, the areas potentially suitable for agricultural use decrease.

1.3 Urban Sprawl versus Sustainable Development

There is no doubt that positive effects come along with urban sprawl. Our built environments drive human, organisational and regional productivity and contribute to the national economy. Low-cost land at peripheral locations is made accessible by high-capacity highways which makes detached housing affordable to almost everyone. In addition, the development of settlements on greenfield areas rather than brownfield sites (previously developed land) may contribute to the conservation of precious and intact heritage sites in historical town centres.

On the other hand, there are many aspects of urban sprawl which are not considered to be sustainable. First of all there are *practical concerns.* For many residents in suburban areas, urban sprawl is associated with over-average expenditure of time for commuting. Apart from that the growth of urban sprawl generally involves the loss of high-quality agricultural area. Furthermore, the building zones are too large and are sometimes situated in strategically unsuitable areas (ARE Bundesamt für Raumentwicklung et al. 2005). The 2005 report on spatial development also accentuates, that the population and workplaces are excessively concentrated in the Swiss metropolises. Therewith, the “city system Switzerland” threatens to loose its balance.

Ecological concerns: Urban sprawl is also associated with an increase in traffic as well as in the consumption of energy and space (e.g. Binswanger et al. 2004). The ongoing urbanisation (sealing and fragmentation of the landscape), the increasingly intensive agriculture, the standardisation of the characteristic landscape as well as the development of tourism and traffic infrastructures put the biodiversity at risk. Many species which used to be widespread are nowadays endangered (BFS Bundesamt für Statistik 2008).

There are also *economical concerns.* According to the Federal Office for Spatial Development, the competitiveness of metropolitan areas as well as touristy destinations suffers (ARE Bundesamt für Raumentwicklung et al. 2005). They are not protected long term. In some rural areas the economical substance is decreasing. Thereby, the ability of those areas to develop autonomously lessens. Urban sprawl often also aggravates a cost-efficient public service. Thus, the development of infrastructures for sewage, water supply, traffic and electric power in a spatially dispersed settlement can lead to up to three times higher costs per capita than for an inwardly dense settlement development. As the beneficiaries of the infrastructures are often not compensating for the entire financing, these higher costs do not only strain private households but also the public authorities (ECOPLAN 2000, Schultz et al. 2006).

Furthermore, there are *societal concerns:* Urban sprawl can encourage social exclusion and contribute to the atomisation of family life. Moreover, it complicates the preservation and development of urban quality (Wachter 2006). In agglomerations there is a tendency towards social and functional segregation (ARE Bundesamt für Raumentwicklung et al. 2005).

One can express *aesthetical concerns* as well. Urban sprawl affects the characteristic landscape and is complicit in the sterile and uniform character of so many dispersed, peri-urban developments. Precisely the “spoiling” of the characteristic landscape could have a negative impact on tourism, which is so essential for many Swiss regions.

Last but not least, a non-sustainable today’s land use is likely to delicately narrow the potential possibilities of development for future generations (ARE Bundesamt für Raumentwicklung 2006).

Despite the fact that urban sprawl can show positive effects, the negative impacts in terms of sustainability prevail (figure 1). As the impacts of urban sprawl on sustainability are mainly negative, it is only logical that 2002 the federal council of Switzerland for the first time not only complained about urban sprawl, but has since aspired to stabilise the indicator “average settlement area per capita” at around 400 m^2 (Schweizerischer Bundesrat 2002).

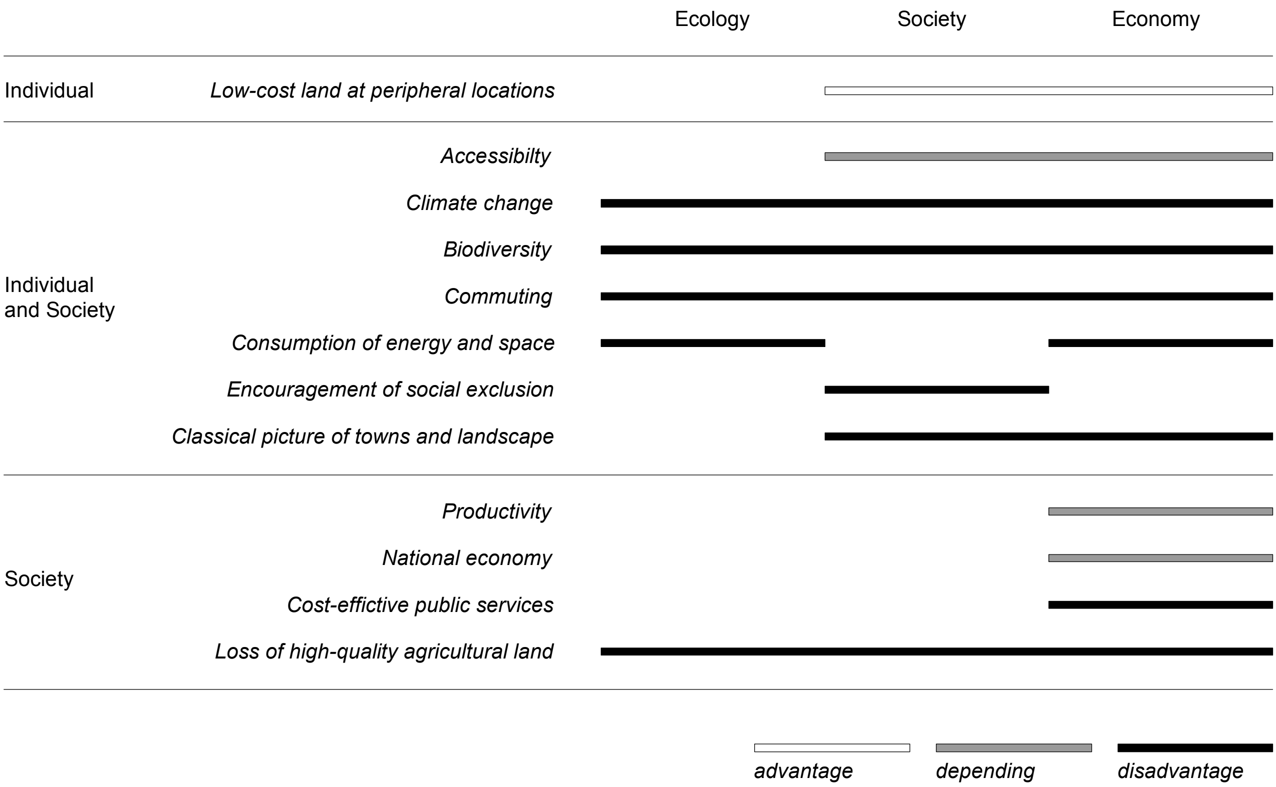

Figure 1 Main advantages and disadvantages of urban sprawl.

1.4 Urban and Regional Planning in Switzerland

Urban sprawl is not a topic discovered nowadays. Already in the first article of the Swiss spatial planning law from 1979 they say: "The federation, the cantons and the municipalities take care that the land is used thriftily" (Bundesversammlung der Schweizerischen Eidgenossenschaft 1979). In the 1980s there were several studies on the use of land, and from 1985 to 1991 proposals for a thrifty land use were developed in line with the national research programme 22 called "Land Use in Switzerland". In his 1996 report on the main features of the Swiss spatial development, the federal council records that "the existing capacious reserves of building zones within already built-up areas could theoretically meet all building demands" (BRP Bundesamt für Raumplanung et al. 1996).

Within the 2005 report on spatial development (ARE Bundesamt für Raumentwicklung et al. 2005), not only the situation of the Swiss spatial development was analysed, but also a main urban and regional planning strategy was developed. A first strategic approach consists in striving increasingly for internal instead of external settlement development. The second approach aims at preserving and enhancing the "city system Switzerland" – a network of towns which characterises the spatial structure of Switzerland.

Basically, the Swiss spatial planning disposes of good planning instruments which impact surely must not be underestimated. Since tasks of internal development are usually more complex than those of external development (higher number of stakeholders, more conflicts of interests, uncertainties, risks and surprises), the usual formal instruments normally are not sufficient to clarify the emerging questions. They have to be complemented by innovative informal procedures and instruments (ARE Bundesamt für Raumentwicklung et al. 2005; Scholl 2007). Thereby, the existing legal instruments provide enough tolerance for an optimisation of the existing mechanisms, also allowing unconventional and innovative solutions (Näf-Clasen 2006). However, as long as the stakeholders do not have any economical and actual incentives for a reduction and qualification of land use, and as long as the possibilities of regulation by the spatial and urban planning authorities remain restricted, the success of any land use policy will remain limited (Schultz et al. 2005).

2. Land Use

Switzerland is situated in the centre of Western Europe. With its total land area of 41'284 km^2 it belongs to the smaller states of Europe. The north-south-dimensions amount to 220 km, from west to east there are up to 350 km. The natural and cultural area is strongly affected by the Alps which cross Switzerland from west to east. The Alps form a distinctive both climatic and hydrological parting line. The major part of the federal territory is situated to the north of the Alps and is characterised by a moderately humid climate. To the south of the Alps, Mediterranean influences affect the climate and vegetation (BFS Bundesamt für Statistik 2008).

In 1997, a good 25% of the total 4.13 million hectares (ha) were non-productive areas and around 30% were forest areas. 1.57 m ha or approximately 37% were agricultural areas and 0.28 m ha or just under 7% of the territory were built-up areas (BFS Bundesamt für Statistik 1997). With a population of over 7 million people, land is a very restricted resource in Switzerland and is threatened by the increased standards regarding dwelling and transportation.

In Switzerland, the lifestyles and hence the forms of housing schemes have changed vitally during the last decades. The 2005 report on spatial development depicts the current trends of spatial development in Switzerland (ARE Bundesamt für Raumentwicklung et al. 2005). Due to the shift towards a service economy (tertiarisation), modern media and the enormous mobility, a clear rapprochement between the urban population in the centres and agglomerations and the rural population has occurred. The classical picture of settlements with a clear borderline between towns and countryside is becoming more and more a phenomenon of the past. The functional areas interwoven with the town are no longer limited to clearly bordered areas, but can stretch over dozens of kilometres across wide surrounding areas. The areas within the original city boundaries together with their first agglomeration belts still feature high densities regarding to the building development, residents, jobs as well as cultural, economic and social activities. They are surrounded by sparsely populated areas, where agricultural zones with expanded single family house settlements, unstructured industrial and commercial areas, shopping centres and theme parks with huge parkings alternate. This settlement formation is hardly structured by intentionally designed public space anymore. Instead, the spatial structures are determined by the improved accessibility.

2.1 Previous Evolution of Landscape and Land Use

Between the first survey of the Swiss area statistics 1979/85 and the update 1992/97, land use changed as follows. Increase: forest areas +1.4%, built-up areas +13.3%. Decrease: agricultural areas -3.1%, non-productive areas -0.1% (BFS Bundesamt für Statistik 1997). The absolute changes are shown in figure 2.

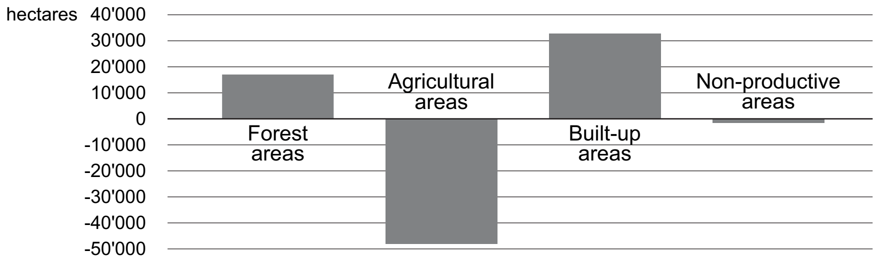

Figure 2 Evolution of land use between 1979/85 and 1992/97. Source: ARE Bundesamt für Raumentwicklung et al. 2005; BFS Bundesamt für Statistik 1997

Thus, the built-up areas grew by 0.86m^2 per second on average between 1985 and 1997, namely at the cost of agricultural land. This growth however has to be differentiated spatially. Within 12 years, the built-up area of the midland increased twice as much as the average and amounted to 14% of the total area by the end of the 1990s. Accordingly, the population density in this area adds up to approximately 450 persons per km^2 (Swiss average: 173 Personen/km^2). The rural built-up areas of the midland are growing faster in percentage than the urban agglomerations (Haag 2007).

2.2 Future Evolution of Landscape and Land Use

Current values of land use change are surveyed in line with the ongoing Swiss areal statistics 2004/09. First results from 623 municipalities of western Switzerland show a slowed evolution of the landscape: From 1981 to 1993 the built-up area in this part grew by 15%, whereas from 1993 to 2005 the area grew by 9%. In the same periods, the loss of agricultural areas was reduced from 3.1% to 2.1%. A comparatively weak business activity and therefore limited economic development during the nineties could have been the reason for this deceleration (BFS Bundesamt für Statistik 2008).

3. Driving Forces and Stakeholders

There are manifold reasons that lead to an undamped growth of settlements. Alongside with population growth (natural population development plus migration), urban sprawl is an expression of a change in life style with higher claims regarding dwelling and transportation.

According to Haag (2007) the socio-economic developments in Switzerland are reflected by the way people dwell. The financial autonomy of the younger and the older generations, the high percentage of employed persons as well as the well developed welfare all support the trend towards small independent households. Thus, the number of single-person households increased above average from 1970 to 2000. A further expression of the societal prosperity can be seen in the increase of size of newly constructed flats. Thereby, the flats' floor area increased without necessarily adding to the number of rooms, which means that there was a rise in comfort and quality. The average dwelling area per capita increased from approximately 24m^2 (1950), to 34m^2 (1980) and then up to 44m^2 (2000). Furthermore, the desire of a lot of Swiss to own a detached house in the countryside is unbroken. That way, 75% of all newly erected buildings for dwelling in 2004 were detached houses. Finally, the number of second homes has increased, both in touristy villages and – job-related – larger towns.

Haag (2007) detects land prices and today's transportation as further driving forces of urban sprawl. Low-cost land at peripheral locations is made more and more accessible by high-capacity highways. And as transportation is still rather cheap in Switzerland, purchasing a plot of land in the countryside and commuting long distances by car often pays off financially. Moreover, dispersed settlements of detached houses can hardly be made efficiently accessible by public transport.

During the twelve years between the first and the second Swiss area statistics, not only the dwelling areas increased, but also the industrial and commercial areas namely by a good 24% (BFS Bundesamt für Statistik 1997). The positive economic development was doubtlessly one reason for this growth during that period.

The municipalities' planning sovereignty and the tax competitiveness respectively certainly also contribute to the continuous expansion of the settlement areas. Assuming that wealthy habitants prefer living in detached houses and aspiring to attract appealing taxpayers, a lot of municipalities have provided building zones of unreasonable sizes for detached housing. Many municipalities still follow this formula today although the correlation "more detached houses, higher tax revenue" may not always be true (anymore) (Schultz et al. 2006). Once building zones are provided though, only few incentives remain to conserve undeveloped land.

As abovementioned driving forces of urban sprawl display, various stakeholders with different motivations are involved in the processes of settlement area expansion. According to Maurer (2007), stakeholders are the most important source to uncover exposed and hidden intents and solve problems. Therefore, the causes and effects of urban sprawl have to be pointed out increasingly to the involved stakeholders and the public – this primarily applies for investment costs and ongoing "shadow costs" from external development for municipalities, private households and companies respectively (Reiss-Schmidt 2007).

4. Approaches

4.1 General Approaches

As mentioned earlier, a main urban and regional planning strategy was developed in line with the 2005 report on spatial development (ARE Bundesamt für Raumentwicklung et al. 2005). A first strategic approach consists in striving increasingly for internal instead of external development. The second approach aims at preserving and enhancing the network of towns.

4.2 Planning and Regulation Approaches

It was also outlined that in Switzerland municipalities are very autonomous and dispose of a great freedom of action regarding urban and regional planning. In terms of internal settlement development, the municipalities therefore play a key role. The growth of settlements however has to be spatially differentiated. In towns different driving forces are active than in agglomerations or mountainous areas. Varied approaches are therefore needed for the different municipalities.

The complexity of the challenge reveals that only a combined bundle of actions could possibly be successful, whereupon the tax, zoning and urban and regional planning laws, dwelling and town planning promotions as well as transport policy would have to be involved. The combination of instruments as well as their intervention intensity would have to be chosen in a way that assures an altogether equitable distribution of benefits and charges and that preferably avoids negative economic and social impacts (Jörissen et al. 2007).

A compilation of *existing* Swiss strategies and instruments are classified into the following categories (Stauffiger 2006):

- urban compaction,
- restriction of the settlement area,
- careful handling regarding development outside the zoning-plan,
- constrict traffic volume and infrastructure,
- improvement of settlement quality,
- regional planning,
- strengthening of nature and landscape conservation,
- raise awareness for land waste problem,
- constrict construction of second homes.

The following *innovative* strategies and instruments were designated:

- formulation of regional land saving mission statements,
- compaction model,
- promotion of alternative forms of housing schemes,
- compilation of municipal or regional area pools,
- sealing regulation,
- handout for property owners and house builders.

Jörissen et al. (2007) split the bundle of instruments for Germany into the following main categories:

- planning law instruments,
- potential of regional cooperation,
- informational instruments,
- fiscal instruments,
- economic incentives and
- financial promotion instruments.

Based on computer simulations, they discovered that it is a matter of actions with relatively moderate and justifiable intervention intensities that would lead to the achievement of the sustainable land use goals. As the simulations show, the impact on economic indicators like gross domestic production, employment and rental costs are likely to be marginal.

4.3 Self-assessment of Planning Authorities

In the preceding paragraph it was mentioned that only a combined bundle of actions could possibly be successful regarding the achievement of the sustainable land use goals and that in terms of internal settlement development, the municipalities would play a key role. Repeatedly appearing in the literature is also the strategy called "regional cooperation" that involves regional planning associations and the cantons in Switzerland. In this context, an important question is not only how far the addressed instruments are discussed in the literature, but how well they are known and applied by the executive public planning authorities. Therefore, in line with a master thesis at our chair of sustainable construction, we carried through a Swiss-wide survey amongst selected planners (Albisser 2007). Our master student conducted 33 interviews in total, the coverage of Switzerland is displayed in figure 3.

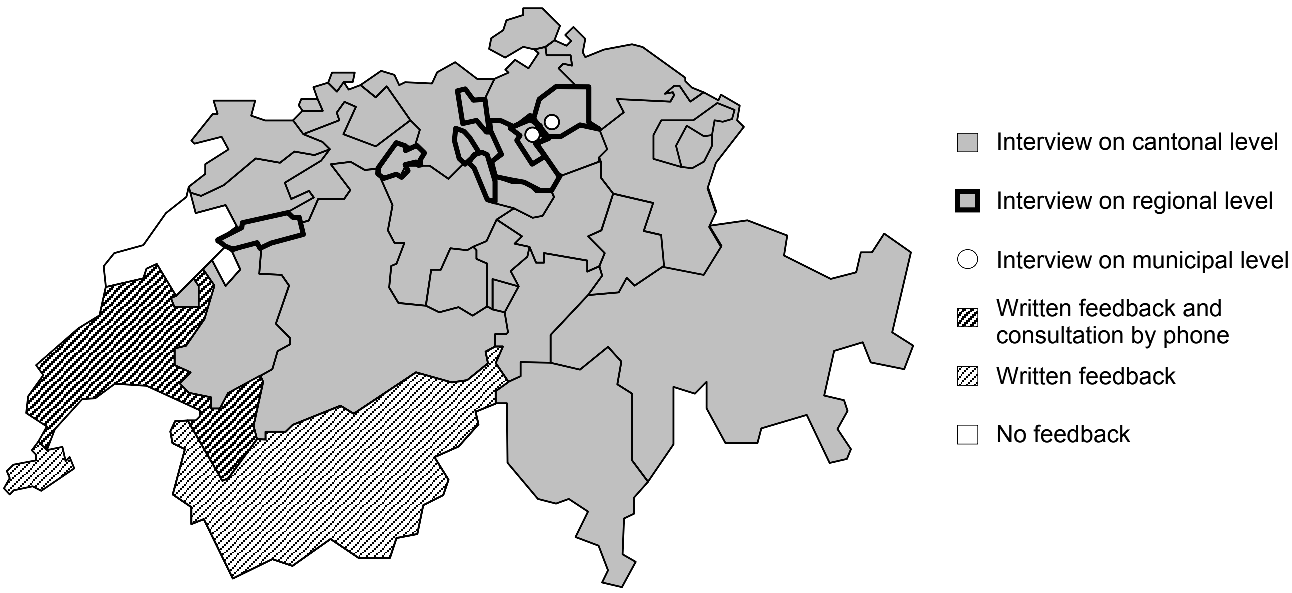

Figure 3 Coverage of the survey.

In order to find out how the planning authorities would self-assess their work towards an internal settlement development and their knowledge about instruments and tools to control it, they were interviewed about topics like internal development in general, the reception of the federation's goals, the application of formal and informal instruments, etc. The survey lead to interesting results which are summarised in the following.

According to the planners, the autonomy of the Swiss municipalities slows coordinated action. Rural municipalities in particular continue to prioritise economic interests over the goals of sustainable land use. Furthermore the up-to-dateness and acuteness of the land use topic is Swiss-wide insufficiently known. Thus according to the interviews the awareness within the authorities, politics and the population is only around 36%, within the economic field even only around 20%. Besides that, the awareness alone does not automatically ensure that the general principles concerning traffic and economic and municipal development are concretised. Moreover, the efforts and projects of the Federal Office for Spatial Development are not always known well by the cantons. This suggests a certain shortcoming of cooperation. In terms of innovative instruments, cantons initially respond to such rather tentatively. According to statements from cantonal planners, especially the mechanisms and effectiveness of new instruments are often said to be vague. Last but not least, an insufficient awareness of already existing instruments can be detected. Thus, it can be explained why the planners mainly refer to the formal, well-established planning tools when being asked what instruments they would apply regarding internal settlement development (table 1).

Table 1 Applied instruments by cantonal planning authorities according to interviews

canton	instruments referred to																instruments available																
	cantonal directive plan	regional directive plans	municipal directive plans	special uses plans	new cantonal laws	agglomeration programmes	self-regulat./econom. demand	competitions	sales law contracts	transfer of development costs	market value taxation	promotional programmes	own specialist department	intensive personal contacts	redensification	others	agglomeration programmes 1	agglomeration programmes 2+	land register cant.	land register mun.	land register plan.	restriction of settlement area cant.	restriction of settlement area mun.	restriction of settlement area fix	zoning rearrangement	out-zoning	increase of zoning density	surplus absorption	mixed use	compensation with undev. area	fusion of municipalities	market-oriented instruments	introduction of new instruments
AG	■		■	■														■		■		■			■		■	■	■		■		
AI				■						■						■						■		■	■	■	■	■	■			■	■
AR				■					■													■											
BE			■					■										■							■	■	■	■	■				
BL				■				■									■		■			■		■			■		■				
BS	■											■					■					■		■	■		■	■	■				
FR		■			■												■		■			■			■	■	■		■			■	
GE	■			■					■								■		■			■		■	■	■	■		■	■			
GL														■											■	■					■		
GR				■													■					■		■	■	■		■			■		■
JU														■			■		■						■	■							
LU	■																■			■		■		■	■	■	■		■				■
NE	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇
NW				■																			■		■	■	■		■				
OW				■											■								■		■	■	■		■				
SG												■						■							■	■	■		■			■	■
SH	■																■		■				■		■	■	■				■		■
SO						■		■									■					■		■	■	■	■		■				
SZ			■	■																		■		■	■		■		■	■			
TG	■										■						■					■		■	■		■		■	■			
TI															■			■			■				■		■		■				
UR																						■		■	■	■	■						■
VD													■					■	■			■		■	■	■	■		■		■	■	■
VS	■		■														■		■				■		■	■	■	■	■	■			
ZG				■			■										■					■			■	■		■					
ZH		■																■	■						■	■	■		■				

It would not be adequate to question the Swiss subsidiarity principle or the guarantee of ownership by means of constitutional amendment. This would not be successful on a political level anyway, given that in most cantons not even the surplus absorption can be implemented. In urban areas the federal instrument "agglomeration programme" is at least encountering wide acceptance and has – even though it also addresses further aims – advanced internal development because of a close linkage of traffic and settlement development topics.

5. Conclusions

It was demonstrated that urban sprawl can not be encountered effectively by traditional means. Instead, efforts on several levels are needed in order to head for a sustainable land use.

In Switzerland however, the political goal to stabilise the average settlement area per capita at around 400 m^2 lacks a subsequent determination of serious actions. As abovementioned examples from abroad show, there *are* ways to face the continuous settlement expansion – provided that the issue does not remain a mere lip service.

Swiss urban and regional planning experts are currently discussing various instruments to control urban sprawl. It is crucial though, that approved instruments further establish among spatial planners throughout the country. Besides that, there is need of continued research in two ways. On the one hand, the different instruments' impacts on sustainability have to be analysed more precisely. On the other hand, it is important to detect what mix of instruments will be appropriate to encounter urban sprawl best possible in the various spatial settings and on the different planning and political levels (municipality, canton, federation).

Unfortunately, it seems this goal has not been recognised on all levels so far. And due to the federal structure of Switzerland, presumably there won't be an earnest agreement in near future. Today, energy and climate change are en vogue, if ecological topics have any priority at all. At least, the "Swiss spatial development concept" currently being compiled, may soon provide detailed information about the intended future development of Switzerland. These results will hopefully have a certain impact on the spatial development goals on both cantonal and municipal levels.

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BARRIERS TO DECONSTRUCTION AND MATERIALS REUSE

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Keywords: deconstruction, reuse, recycling, construction and demolition waste, standards, sustainable

Summary

Deconstruction may be defined as the disassembly of structures for the purpose of reusing components and building materials. The primary intent is to divert the maximum amount of building materials from the waste stream. Top priority is placed on the direct reuse of materials in new or existing structures. Immediate reuse allows the materials to retain their current economic value. Though definitely on the rise, deconstruction and reuse of building materials is faced with several challenges such as, consumer tastes and perceptions concerning used and recycled building materials, additional time required to dismantle buildings, lack of markets for used components, and the fact that building codes and materials standards often do not address the reuse of building components. In the end, the increased use of reused and recycled building materials is in the hands of the architects, builders, and consumers that use them. Slowly but surely, perceptions have become increasingly positive over the last few years. The natural trend towards increased social and environmental responsibility, along with the maturation of the deconstruction industry, will aid in the effort to improve perception of reused and recycled building materials. This will increase the profitability of the building materials salvage market, making deconstruction a more desirable business alternative. This paper discusses these challenges and suggests ways to make deconstruction and reuse of building materials an alternative to demolition and landfill.

1. Introduction

In the United States every year construction industry contributes to a large amount of waste to municipal solid waste stream. The US Environmental Protection Agency (EPA) has estimated that total waste generated from construction, renovation and demolition of buildings, roads, bridges, and dams was 295 million metric tones (MMT) in 2003 (RCRA, 2004). Building related C&D waste was estimated to be 143 million metric tons in 2000 (Chini and Bruening, 2005). It is estimated that 70 MMT of this was the product of demolition. Table 1 summarizes estimated waste due to building and infrastructure related construction and demolition as well as municipal solid waste (Chini, 2007). The table also shows estimated weight of recovered materials. As Table 1 shows only concrete and steel have a recovery rate of 50 per cent or above. The recovery rate for other materials is not significant, but it is increasing due to rising cost of landfilling waste, stringent new government regulations, and a steady growing concern for the environment.

Figure 1 shows that over 27% of the waste that is generated from construction and demolition of buildings is wood waste. If a portion of this can be reused back in the construction industry in place of virgin lumber, this would mean a great reduction in harvesting, transporting, processing, and other energy intensive steps that are used to produce virgin lumber (Chini and Acquaye, 2001). The United States is fortunate to have a vast supply of trees that are harvested each year. In fact, about one-third of the US land mass is currently forested; from this over 255 MMT of wood are produced each year (Falk 1997). In the past century over 4 billion metric tons of lumber have been produced, and much of it still exists in buildings around the country. According to Horne-

Brine and Falk, if only 2% of these buildings were deconstructed each year, with only 25% of the lumber being reclaimed, it would supply up to one quarter of the overall lumber market in the United States for over 50 years (Horne-Brine, Falk 1999).

Table 1 C&D waste generation and recovery (MMT)

Material	Building C&D Waste	Infrastructure C& D Waste	Steel Products	Municipal Solid Waste	Re-covered
Concrete	55	127	-	-	91
Wood	36	-	-	27	10
Drywall	13	-	-	-	2
Roofing	10	-	-	-	NA
Steel	9	12	59	13	70
Bricks	4	-	-	-	NA
Plastics	4	-	-	24	1

NA: the recovered weight is Not Available

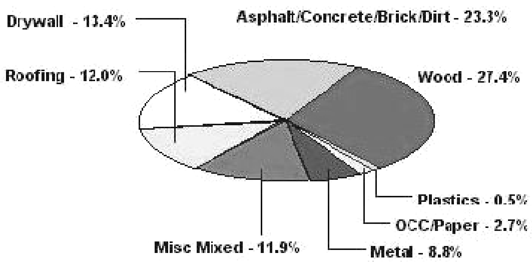

Figure 1 Waste Generated by Construction and Demolition (MSW Factbook 1997)

Deconstruction may be defined as the disassembly of structures for the purpose of reusing components and building materials. The primary intent is to divert the maximum amount of building materials from the waste stream. Top priority is placed on the direct reuse of materials in new or existing structures. Immediate reuse allows the materials to retain their current economic value.

Deconstruction of buildings has several advantages over conventional demolition and is also faced with several challenges. The advantages are an increased diversion rate of demolition debris from landfills, "sustainable" economic development through reuse and recycling, potential reuse of building components, increased ease of materials recycling, and enhanced environmental protection. Deconstruction preserves the invested embodied energy of materials, thus substituting recovered existing materials for the input of embodied energy in the harvesting and manufacturing of new materials.

The challenges include: consumer tastes and perceptions concerning used and recycled building materials, existing buildings have not been designed for dismantling, dismantling of buildings requires additional time, lack of markets for used components, building codes and materials standards often do not address the reuse of building components, and the fact that buildings built before the mid-1970's contain lead-based paint and asbestos containing materials.

Though definitely on the rise, perceptions of reused and recycled building materials must be improved in order for the long term profitability of deconstruction to increase. This paper discusses ways to rectify the many doubts consumers have concerning recycled and reused building materials.

2. Consumers Tastes

The successful implementation of deconstruction relies on successful resale of recovered building components. If materials cannot consistently be marketed and sold in a timely manner, it is virtually impossible for deconstruction to be profitable. For this reason, consumer tastes and perceptions concerning used and recycled building materials is often a barrier to the successful implementation of deconstruction. The most influential persons regarding the purchase of used and recycled building materials are the architects, the builders, and the consumers.

2.1 Planners

Architects and landscape architects have the potential for impacting the use of used building materials in new construction. Although architects tend to be more open to the use of used and recycled materials than builders, their perception overall appears to remain negative. Brand or manufacturer loyalty poses one barrier to expanding the use of used and recycled building materials. Currently, architects are more likely to specify a particular product from a product line or manufacturer they trust than to establish a non-brand specification which allows used materials to fill that specification.

2.2 Builders

Builders and their subcontractors play an important role in the selection of construction materials. In an industry that is conservative the movement towards new products is slow. This attitude reflects real worries in construction, where products that are not up to high standards of quality and safety can cause disastrous accidents. For this reason, builders are the market segment that is slowest to accept used and recycled building materials. Contractors view the use of reused and recycled building materials negatively because they perceive them to have the following characteristics (Grothe and Neun, 2002):

- Dimensional Problems: Contractor's view finding used materials that fit into a pre-dimensioned space as more difficult than purchasing a new product.
- Inconsistency in Supply: Contractor's perceive the inconsistent availability of the right quantity and size of used materials as inconvenient.
- High Risk: Due to the high personal risk involved when something goes awry in the construction process, builders are reluctant to trust used and recycled products.
- Poor Quality: It all boils down to the overall perception that used and recycled materials are of lesser quality than virgin materials.

2.3 Consumers

Those people purchasing commercial and residential construction, as well as those renovating buildings, are extremely important in driving the environmentally sound construction movement, including the use of recycled and reused building materials. The prevailing attitude remains that reused and recycled building materials are "substandard but environmentally friendly." Many architects and builders have admitted that they would use more used and recycled products if their clients directed them to do so.

3. Lack of Design for Deconstruction Strategies

The aim of design for deconstruction is for the next generation of buildings to be more efficiently disassembled at the end of their useful lives. More efficient disassembly implies a process that is quicker, causes less damage to recovered building components, and is safer for the workers involved. The problem facing the industry today is that the benefits of design for deconstruction will not be realized until many years from now. Currently, the lack of design for deconstruction in the buildings that are coming to the end of their useful lives is a major barrier to efficient and profitable deconstruction (Chini and Balachandran, 2002).

Buildings that are approaching the end of their useful lives today were not built with deconstruction in mind. Deconstruction is a fledgling industry, much younger than the houses being deconstructed. There are several aspects of design for deconstruction that are currently hindering the materials recovery process. These are lack of kept construction records, abundance of hazardous materials, use of adhesives to hold fasten building components, and lack of labeling of building components.

3.1 Construction Records

Today, buildings to be deconstructed do not contain of the original construction information. This lack of information drastically decreases the speed and efficiency of the deconstruction process. The presence of blueprints, materials lists, location of wiring systems, and photographs of connections used in the construction of the building would aid in the planning and implementation of its dismantling (Guy, 2001).

3.2 Abundance of Hazardous Materials

Government policies concerning hazardous materials abatement are higher for deconstruction than they are for demolition. This is due to the higher exposure levels for deconstruction workers. These stringent policies increase the cost and time necessary to complete a deconstruction project. Additionally, hazardous materials drastically increase the salvageability of building components. Wastes are defined as hazardous by EPA if they are specifically named on one of four lists of hazardous wastes or if they exhibit one of four characteristics: ignitability, corrosivity, reactivity, or toxicity. Typical examples of C&D wastes that are considered hazardous according to EPA's definition are:

- C&D debris containing mercury: fluorescent lamps, thermostat probes, old paint
- Lead-based paint debris: woodwork, siding, window and doors painted before 1978
- Asbestos debris: Insulation, resilient floor covering, siding shingles, roofing products, and cement products made with asbestos before 1977

3.3 Use of Adhesive

The use of various glues and adhesives in the installation of building materials may increase the stability of those building systems but it serves to decrease the efficiency of the deconstruction process and increase the likelihood of damage during extraction. This is particularly true with glue use on wood products and the grouts used in masonry construction. The glues previously used in wood construction tend to cause splitting and cracking of the wood during extraction. Certain mortars used to bond bricks are not conducive to later separation and cleaning of the bricks. It is only possible to clean bricks that are bonded with soft lime mortar. Those bricks that are bonded with Portland cement based mortar cannot be effectively separated and cleaned.

Currently, it is not standard practice for building components to be labeled before installation. The recovery process is slowed by the necessity to identify the components makeup, how it was fastened, what kind of chemicals may or may not be present, etc…

Design for deconstruction will identify issues involving labeling of building components to speed up the deconstruction process.

4. Additional Time

The successful large scale implementation of deconstruction in the United States is contingent upon increasing the efficiency of the deconstruction process. Currently, time constraints pose a legitimate threat to the growth of the deconstruction industry. In the construction industry, where time is of the essence, the extra time involved to remove a building via deconstruction, as opposed to removal through demolition, may be a deterrent. The level of efficiency on any project is directly proportional to its profitability. Deconstruction must become a more profitable industry if it is to be implemented on any substantial level.

Several factors are limiting the efficiency of the deconstruction process. As discussed earlier, the lack of design for deconstruction has a negative effect on its efficiency. However, the benefits of designing buildings for disassembly will not be felt until the useful lives of the next generation of buildings have expired. There are other factors affecting the efficiency of deconstruction that can be and are being improved right now. One of the major factors affecting the efficiency of the deconstruction process is the current lack of tools available that stimulate the speed of deconstruction while minimizing the damage incurred by recovered materials.

To date, the tools used during the deconstruction process have generally been the same hand tools used in the construction process. These tools were not designed with the efficient, safe disassembly of buildings in mind. For example, crow bars are frequently used tools on deconstruction sites for prying apart building components such as wooden planks. However, a crow bar was not designed to pry apart wooden planks without damaging them. Consequently, the planks are often split during extraction. This damages the wood, reducing its reusability and thus its resale value. Tools must be developed that facilitate the speed and safety of materials recovery during deconstruction while at the same time minimizing the damage incurred by those materials.

The lack of deconstruction training available is also a barrier to its growth as an industry. Development of programs that promote deconstruction of buildings as an alternative to traditional demolition by training contractors how to effectively dismantle structures with the purpose of reclaiming materials will facilitate the full-scale implementation of the deconstruction industry.

5. Lack of Markets for Used Components

The economic structure of the deconstruction industry requires that the recovered materials be sold in order to achieve any level of profitability. Thus, access to salvaged materials markets is a critical element to the successful implementation of deconstruction. At this juncture, a lack of markets for used building materials is a barrier to deconstruction. The strength of the used building materials market in a given area is directly related to the area's local attitude toward used building materials and the population and location of the area.

As discussed earlier in this chapter, perception of low value of salvaged building materials remains a problem in the construction industry today. This perception of low value has a direct influence on the demand for salvage materials. Thus, the presence of negative perception has an adverse affect on the market for used components. As time passes, the continued effort of the deconstruction industry to educate the public on the benefits of using salvaged building components will serve to alleviate this issue.

Large metropolitan areas tend to support the strongest used building materials markets. There is obviously a positive correlation between the size of a city and its demand for consumer goods. Additionally, the available building stock for deconstruction will tend to be greater in highly developed areas such as large cities. Export Markets in border and port cities create an additional market for used building materials. These markets have the capability to increase the consumer base for deconstructed materials exponentially. Export of used building materials is a strong market in the Miami area, and exporters were identified as a major customer group for recovered materials. Several used building materials markets in the Miami area sell approximately half of their material to exporters from Central American and Caribbean countries.

The problem facing the deconstruction industry at this point is that the majority of towns in the United States are not large, port cities with high public perception of used building materials. A major focus of the construction industry must be to network together those areas that may not be able to establish strong reuse markets with those that can. The use of the internet creates an additional medium to obtain and sell used building materials. "Internet sales have the potential to change existing market relationships by allowing end users to purchase materials at reduced prices from sources other than their traditional supplier" *(Grothe and Neun, 2002).* Currently, Internet sales are more conducive to the sell of high-end salvaged building materials because of the intensely high demand for these goods, particularly high-quality structural timbers. Low-end materials do not benefit as well from the internet because added shipping and processing fees tend to negate the money saving benefits of these materials.

6. Lack of Standards for Reuse of C&D Materials

The success of any recycling effort is tied to the marketability of the products that are recycled. The National Demolition Association (NDA) suggests that the U.S. EPA develops a program that analyzes the marketability of the components of the various elements of the demolition waste stream and promotes the reuse of these materials. NDA believes that the EPA could produce a substantial increase in the recycling and reuse of C&D materials by establishing purchasing guidelines and specifications for these materials. The guidelines could contain quality assurance components that would allow specifying agencies to feel comfortable with the use of these materials (NDA Report, 2004).

Total building related and infrastructural concrete waste generated annually in US is estimated to be about 200 million tons (Sandler, 2003). It is estimated that about 100 million tons of concrete is recycled annually into usable aggregates. This is roughly 5 percent of 2 billion tons total aggregates market. The rest is supplied by virgin aggregates from natural sources. If the EPA, working with the Federal Highway Administration and the state transportation agencies, would develop model specifications for the quality of recycled material, this total recycling number would increase dramatically. Standardization of the specifications for the reuse, on a national level, could produce a boom comparable to President Clinton's paper recycling directive.

Similarly, establishing criteria for the reuse of wood products generated on deconstruction sites could significantly increase their reuse. Lumber re-grading for structural use, has become a hot topic in the deconstruction industry. The grade stamp on lumber verifies the quality of each piece of lumber. Currently, existing grading rules can be used to grade salvaged lumber. However, these rules do not specifically address salvaged lumber. Current grading procedures are time consuming and expensive. Grading of salvaged lumber, other than in very large quantities, is not cost-effective. Because the extent to which salvaged lumber defects and their affect on its strength are somewhat uncertain, grading agencies are hesitant to give it their stamp of approval. When they do, they minimize risk by downgrading the lumber or restricting it from particular applications. These issues create a barrier to the implementation of deconstruction by raising costs and reducing the possible applications of salvaged wood. In addition, structural salvaged lumber would draw a much higher price on the market than non-structural wood. Currently, steps are being taken to develop a nationally recognized salvaged lumber re-grading system.

Other materials produced through deconstruction including roof shingles, carpet, drywall, glass, ceiling tiles, plastics, and other construction products are being studied to see if they too can be recycled or reused in an economically viable manner.

7. Setting Goals

Although the federal government has largely avoided any effort to set C&D recycling rate targets, many states and smaller jurisdictions have active programs that encourage C&D waste recycling.

California adopted a legislation in 1989 that requires counties to recycle 50 percent of their waste streams. With C&D material making up such a large percentage of those streams, it did not take long for county and city officials to begin devising C&D recycling initiatives. City of Oakland requires contractors to submit a job-site recycling and waste reduction plan along with their initial bids to the city. The contractor that wins the bid must also submit required reports prior to receiving the final payment. In San Jose, contractors have the option of bringing material to one of more than 20 city-certified facilities (www.sjrecycles.org) that are expected to meet pre-determined recycling rates. The City Council in Irvine requires builders of large projects (more than one residential unit; nonresidential structures measuring 5,000 square feet or more and nonresidential properties that are 10,000 square feet or more) to submit recycling plans. Companies will have to pay a material diversion deposit to the city that will be refunded after the project is complete. At least 75 percent of concrete and asphalt and 50 percent of other C&D debris must be taken to material recovery facilities for a company to get its deposit back. In Sonoma County, California C&D waste loads that have not been sorted for recyclables must pay a 25 percent surcharge for the county to handle resorting (Taylor, 2007).

The commonwealth of Massachusetts bans certain materials from its landfills to obtain an 88 percent statewide recycling rate by 2010. In mid 2006 a ban on the disposal, or transfer for disposal, of asphalt pavement, brick, concrete, wood, metals and old corrugated containers became the rule in Massachusetts. The state's Department of Environmental Protection singled out those materials based on a belief that healthy recycling markets existed for all of them. The goal is to add additional C&D materials such as gypsum wallboard, asphalt shingles, carpet and ceiling tiles in the future (Taylor, 2007).

The regional government for the Portland, Oregon has approved construction and demolition recycling legislation that will go into effect in 2009. The policy requires mixed loads of C&D debris to be sorted for recyclables prior to dumping, leaving no more than 15 percent recyclables in the remaining material. The regulation is part of the agency's overall plan to increase recycling rates in the Portland area by 64 percent by the end of 2009. It is anticipated that this policy will keep an approximate 33,000 tons of C&D material out of landfills, enough to boost the overall recycling rate by 1.25 percent (Taylor, 2007).

Chicago recently adopted an ordinance requiring a certain percentage of construction and demolition waste to be recycled — 25 percent for projects that had a permit issued in 2007, and 50 percent if the permit is issued in 2008 (Martin, 2007).

8. Deconstruction is Cost Effective

In almost all cases, the cost of deconstruction is higher than that of demolition. This is due to the labor intensive nature of deconstruction. However, the salvage value regained in deconstruction often makes it more cost effective than demolition. Because the labor intensive factor of deconstruction is somewhat unavoidable, it is important to focus on minimizing other factors in the cost to make it more competitive. Minimizing costs and maximizing salvage value of building materials is essential to maximizing the potential of deconstruction. Having well trained workers can have a major impact on overall cost. A high level of safety reduces overall costs of deconstruction projects.

According to a survey conducted by the New Jersey Department of Environmental Protection, recycling C&D materials is usually the most cost-effective and environmentally friendly method of disposal. Builders and contractors can save money recycling their construction and demolition materials. The average cost to recycle concrete rubble is $4.85 per ton vs. an average of $75 per ton to haul and dispose of the material in a New Jersey landfill. Similar cost savings came from recycling asphalt ($5.70 per ton) and bricks and blocks ($5.49). Even recycling wood at $45.63 per ton and trees and stumps at $37.69 per ton is economical compared to the $75 average transportation and disposal cost, according to the survey.
(www.state.nj.us/ep/dshw/recycle/builderinfo.htm).

9. Recommendations

In the end, the increased use of reused and recycled building materials is in the hands of the architects, builders, and consumers that use them. Slowly but surely, perceptions have become increasingly positive over the last few years. The natural trend towards increased social and environmental responsibility, along with the maturation of the deconstruction industry, will aid in the effort to improve perception of reused and recycled building materials. This will increase the profitability of the building materials salvage market, making deconstruction a more desirable business alternative.

The following aspects of the industry and consumer perceptions must be addressed in order to rectify the many doubts consumers have concerning recycled and reused building materials.

9.1 Information Availability

Aided by the numerous industry associations and increased publicity, information accurately explaining the benefits of recycled and reused building materials has become much more accessible over the last few years. However, as a whole, public knowledge concerning these products is too low. The natural increase in available information and networking that will occur naturally as the industry grows should help to rectify this problem.

9.2 Overcoming the Perception of Risk

Because of the perception of risk, products must show they perform as well or better than virgin products. Component recertification processes must be refined and standardized before this can occur. Additionally, recycled products should be tested and certified in order to offset the high-risk aversion of the industry.

9.3 Economic Incentives

In a market economy, decisions involving which resources are used are primarily driven by economic forces. Therefore, the most effective ways to promote deconstruction industry are to use economic incentives to promote efficient recourse use and minimize waste generation. These include waste generation fees and credits to reward purchase of products that rely on recycled materials. Developing more efficient recycling technologies and developing markets for recycled materials or products are essential for recycling industry to flourish. Government should also play a role through government purchasing programs that increase demand for products with recycled contents.

9.4 Guidelines and Specifications

As the National Demolition Association suggests the federal government should establish specifications and purchasing guidelines for each recovered material; take a leading role in promoting the development of new technologies and processes that will produce durable, economical, high quality recycled products; and develop national inspection standards for recycling facilities.

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Development of the life-cycle C&D wastes assessment method for buildings

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Summary

Actions for reduction of C&D wastes and setting forward recycling become more important in late years, because of an enormous the amount of resources consumption and C&D wastes are made in building construction and demolition works, the shortage of final disposal sites in Japan. In this study, the assessment method for the amount of resource consumption and C&D wastes that are generated in the future were developed. By use of detail cost estimate method, variety and quantity of resources from buildings were calculated in detail with this method. To develop the method, following things were done. List up general specification of building components and materials made up for each component. With each component, data of weight, resource category and way of waste treatment etc. are collected. For the effective maintenance and improvement, the rule for the estimation of C&D wastes from maintenance and improvement process are established. For the effective planning with C&D wastes treatment, the rule for the separation of C&D wastes are established from the investigation of actual C&D wastes treatment and recycling arts in Japan. And some building models are calculated by the method and the result of the assessment method are surveyed.

1. Introduction

The construction industry is required to reduce and recycle construction waste because of the shortage of remaining landfill capacity and issues related to limiting resource consumption and waste generation. For this reason, the separation of demolition and recycling of construction materials is enforced by *The Construction Materials Recycling Act* was enforced in 2000, and a variety of measures have been implemented. While these instruments have proved to be moderately successful from the viewpoint of achieving target values such as defined recycling ratios for C&D waste, the establishment of evaluation methods and measures for reducing resource consumption in individual buildings is not yet considered to be satisfactory.

We therefore developed a standardized method for assessment “life cycle C&D wastes” (hereinafter referred to as LCW) based on estimating standards. Such a method would facilitate the estimation and determination of the category and the amount of resources of the building required by upstream levels of the construction workflow, such as at the projecting, planning, designing and estimating phases, and could be used to precisely calculate the amount of waste generated by the building activities in the future. Using this method, the “lifecycle” of a building is defined as the period from the beginning of construction activities at a site to the termination of reform, renewal and demolition activities of the building.

While LCW assessment methods have been employed in previous studies, these authors restricted their attention to the most frequently used of the resources in their LCW assessments and other materials were not considered. The contribution of these minor materials is difficult to consider because they require considerable labor to evaluate. However, since the LCW assessment method proposed in this study makes it possible to determine the amount of resources required and estimate costs at the same time, it does not require the separate assessment of the materials necessary for conducting assessments and can thus more accurately determine the variety and the amount of materials.

Using this method, it is possible to determine the variety and the amount of resource consumption of a building, and to classify these into categories according to available or future recycling techniques can be applied. This method can determine the category, category and the amount of resources of the building, and it is considered effective for managing resources and C&D wastes, as well as the renovation history of buildings in the future.

2. Summary of LCW assessment method

The applicable range of this method is as follows:

- Object for evaluation: individual buildings

- Values to be calculated: the amount of resources and the amount of C&D wastes

In terms of the amount of waste, this method calculates construction waste (limited to solids) likely to arise from a construction (or demolition) site. This method is presented as a prototype and was developed by limiting its application range to the following applications:

- Housing complexes and offices

- Construction materials used in construction work (excluding materials related to equipment or packing materials).

Figure 1 shows the assessment flow of LCW.

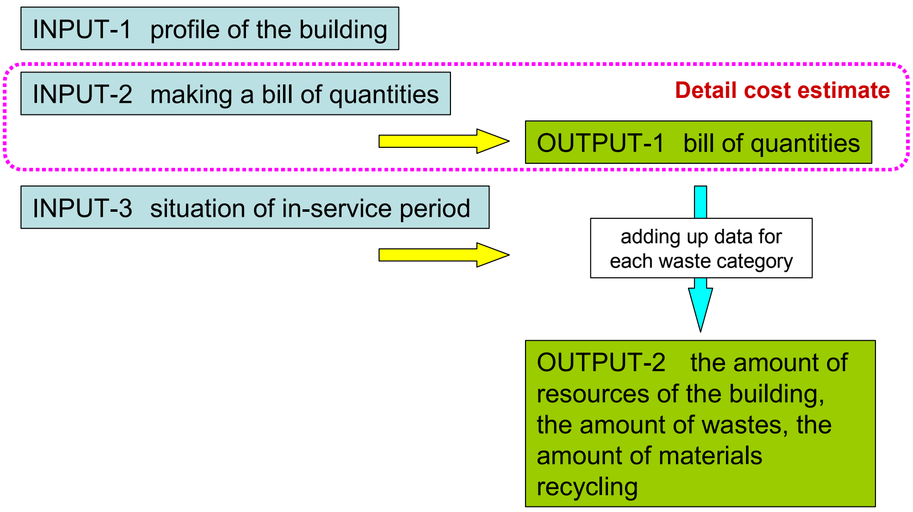

Figure 1 the Assessment Flow of LCW

3. Outline of the development of the LCW assessment method

This method aims to calculate the amount of materials and C&D wastes generated at each stage of the building life cycle while estimating costs at the same time. We therefore conducted a thorough review of price information for construction work and related materials (e.g. "Japan Building Cost Information" and "Construction & Material Costs in Japan", both published by the Construction Research Institute). However, since more than ten thousand items are described in these periodicals, we prepared a list of approximately 1,000 items having different sizes, shapes and elements. In considering these items, we added any relevant information regarding their specifications and units, which would normally accompany the process of obtaining quotes. We added these metadata to the items being considered, as well as the construction methods and specifications used in a case study of two actual building examples.

We broke down the selected and extracted specifications into each composite material, and collected and organized data such as the mass-based quantities used per unit and categories of materials to be discharged as C&D wastes.

The composite materials and the quantities used per unit were collected with relative ease from the construction coefficient information. However, since usage was primarily measured in "m^2", etc., not by the unit of mass, the mass of the materials used was determined based on product catalogs and the physical properties of each material.

Waste categories were prepared based on the categories provided under *The Waste Disposal and Public Cleaning Law* while considering the current situation of waste disposal. For recycling, it is important to collect the waste after separating the materials and building materials. As a result of classifying materials as those that can be recycled using current technologies, and those for which it seems feasible that recycling technologies will be available in the near future and that are listed in the Waste Disposal and Public Cleaning

Law, the number of categories under consideration increased to over fifty. Table 1 shows the waste categories.

Table 1 Waste Categories

category				content
industrial waste of stabilized type	wreckage 1	A		concrete waste
	wreckage 2	B-0		wreckage 2
			B-1	brick, stone, roof tile waste
			B-2	roof tile
	wreckage 3	C		concrete waste with asphalt, asphalt waste
	ceramic waste	D-0		ceramic waste
			D-1	glass waste
			D-2	ALC, tile, ceramic waste
			D-3	glass wool
			D-4	silicate calcium
			D-5	tile, brick, ceramic
			D-6	rock wool
			D-7	ALC
			D-8	ceramic board
	plastic waste 1	E-0		plastic waste
			E-1	PVC pipe waste
			E-2	polyolefin floor tile
			E-3	PVC tile carpet waste
			E-4	FRP product waste
			E-5	thermoplastic resin product waste
			E-6	heat-hardening resin product waste
			E-7	expanded polystyrene product waste
	metal waste 1	F-0		metal waste 1
			F-1	reinforcing steel 1
			F-2	reinforcing steel 2
			F-3	product waste using metal
	metal waste 2	G–0		metal waste 2
			G-1	aluminum product waste
			G-2	electric cable waste
			G-3	stain less waste
	rubber waste	H		natural rubber waste
	other 1	I		board with metal and plastic
	mixed waste 1	J		mixed waste of A to I
industrial waste of controlled	polluted mud	K		polluted mud
	ceramic waste and wreckage 1	L-1		plaster board
		L-2		wood wool cement board
	ceramic waste and wreckage 2	M		ceramic waste and wreckage with organic waste
	plastic waste 2	N-1		wall paper waste
		N-2		plastic products with wood powder
	metal waste 3	O		metal waste with organic waste
	wood waste	P-0		wood waste
			P-1	wood waste from lumber
			P-2	wood waste from wooden board
			P-3	particle board
	paper waste	Q		wall paper waste
	waste textile	R-1		tatami
		R-2		tatami made by plastic
		R-3		other waste textile
	oil waste	S		oil waste
	other 2	T-1		fluorescent lamp
		T-2		air-conditioning equipment
		T-3		kitchen unit, bath unit
	mikxed waste 2	U		mixed waste of J to S
other	soil from the construction site	V		soil from the construction site

(shaded) materials which is assigned by *the Waste Disposal and Public Cleaning Law*

We set four levels of separation and established recycling scenarios with different degrees of separation and disposal in order to consider the countermeasures required for separation and disposal.

The establishment of the policy required for each scenario is shown below:

Scenario I: Separation to the level required by *The Construction Materials Recycling Act*

Scenario II: Scenario I plus separation into valuable resources and normal-level separation

Scenario Ⅲ: Scenario Ⅱ plus separation of materials which is assigned by *The Waste Disposal and Public Cleaning Law* or materials with well developed disposal systems that are currently available

Scenario Ⅳ: Full separation (assuming that a disposal facility using a as-yet-unavailable technology is constructed)

Each scenario assumes a well-established recycling method. Since pre-consumer wastes are processed separately from post-consumer wastes that have been earmarked for different levels of disposal or recycling, the scenarios were developed separately, an example of which is shown in Table 2. Each waste is separated and collected based on the selected scenario. For example, consider “E1 PVC pipe”; pre-consumer wastes from construction are separated and collected as “E-0 waste plastic type 1” in Scenario Ⅱ and as “E-1 PVC pipe” in Scenario Ⅳ. Conversely, the materials arising from demolition materials are separated and collected as mixed waste in Scenario Ⅱ and as “E1 PVC pipe” in Scenario Ⅳ.

Table 2 Example of Separation and Established Recycling Scenarios

category			separation and established recycling scenarios							
			Ⅰ		Ⅱ		Ⅲ		Ⅳ	
			pre-consumer	post-consumer	pre-consumer	post-consumer	pre-consumer	post-consumer	pre-consumer	post-consumer
plastic waste 1	E-0	plastic waste	—	—	—	—	—	—	—	—
	E-1	PVC pipe waste	J	J	E-0	J	E-1	E-1	E-1	E-1
	E-2	polyolefin floor tile	J	J	E-0	J	E-2	E-5	E-2	E-5
	E-3	PVC tile carpet waste	J	J	E-0	J	E-3	E-3	E-3	E-3
	E-4	FRP product waste	J	J	E-0	J	E-0	E-4	E-0	E-4
	E-5	thermoplastic resin product waste	J	J	E-0	J	E-0	J	E-0	E-5
	E-6	heat-hardening resin product waste	J	J	E-0	J	E-0	J	E-0	E-6
	E-7	expanded polystyrene product waste	J	J	E-0	J	E-7	E-5	E-7	E-5

4. Examples and LCW considerations for the results obtained using this method

A summary of the buildings used for the assessment of LCW is shown in Table 3.

Figure 2 shows a breakdown of materials considered for the assessment of materials resource of the building.

Table 3 Summary of the Building Model Used for the Assessment of LCW

building use	office
structure	SRC
floor number (above ground)	8
floor number (under ground)	0
building area	350㎡
total site area	2,400㎡

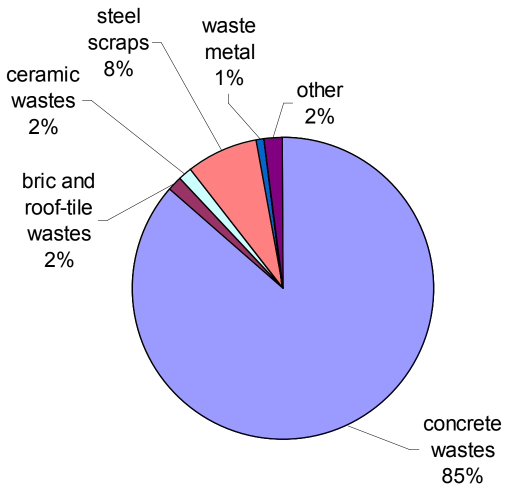

Figure 2 Break Down of the Amount of Resources of the Building Model

Concrete wastes accounted for 85% of the entire resources. *The Construction Waste Recycling Law* prescribes that concrete wastes and wood waste be separated and recycled, which translates into a marked reduction in the mass volume of construction waste and promotes recycling.

Figure 3 shows the amount of materials for recycling and final disposal for each separation and recycling scenario. The amount of waste recycled in Scenario I (at a level required by the Construction Waste Recycling Law), Scenario II (normal-level separation at present), and Scenario III (at an advanced level in the present situation) were all similar. The amount for final disposal in Scenarios II and III were slightly less than that obtained for Scenario I. While the amount recycled in Scenario IV (full separation) was less than other scenarios, the final disposal amount for this scenario was considerably larger than the others. In developing this method, it was anticipated that the higher the scenario (the separation level) was, the greater the amount of material would be sent for recycling and the lower the amount for final disposal would be. However, since the higher the level of separation involved more advanced recycling technology, the results differed from what was expected (Fig. 3). Especially, the low rate of recycling of concrete wastes, which constituted 85% of the amount of resources of the building, had a marked effect on the results, since only aggregates are removed and used as resources in Scenario IV.

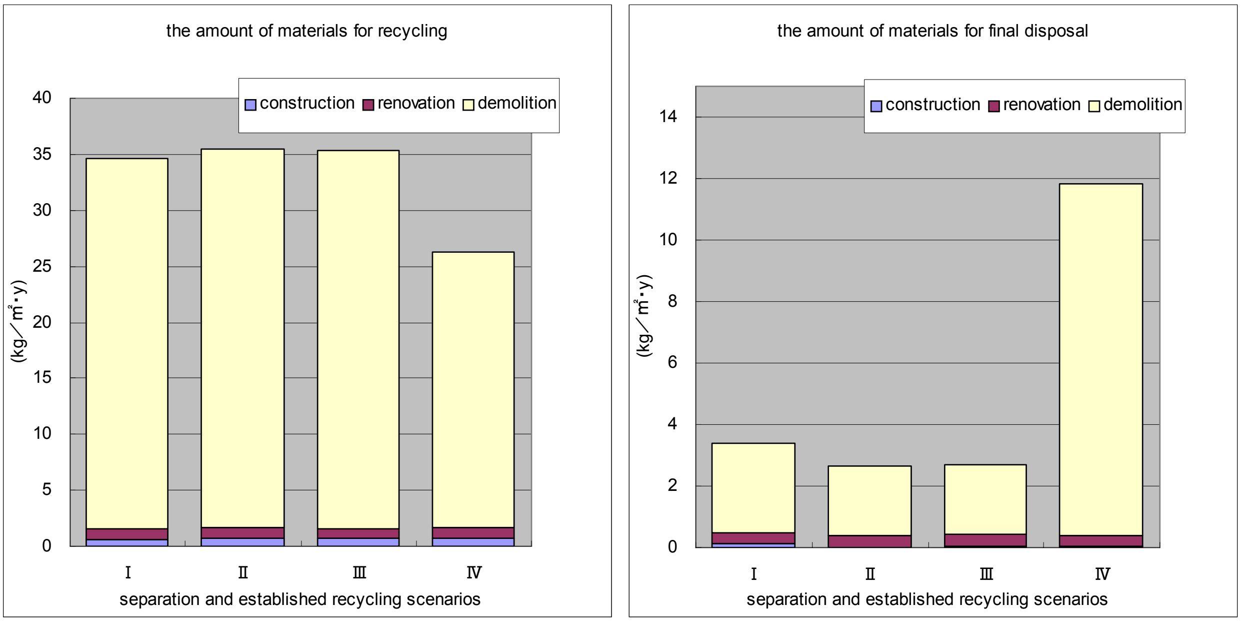

Figure 3 the Amount of Materials for Recycling and Final Disposal for Each Separation and Recycling Scenario

However, the assessment results do reflect the present situation of C&D waste disposal in the area of construction. From the viewpoint of the amount of materials for recycling, the current levels of recycling has reached a certain level, and even in the event that higher levels of separation and more advanced recycling methodologies are employed, the effect on the amount of C&D wastes generated from one building and, by extension, by the entire nation, would be minimal.

From the viewpoint of effective resource utilization, it is necessary to evaluate not only the amount of materials for recycling, but also the change in obtained for each scenario. Figure 4 shows the kind and the amount of materials for recycling of calcium silicate boards for each separation and recycling scenario.

When Scenario IV is excluded and only the amount is considered, Scenario I (at a level required by *The Construction Materials Recycling Act*) is more advantageous than Scenario II (current normal-level) and Scenario III (current advanced-level). Taken together, these findings may indicate that separation for recycling is at a level that is currently adequate for the requirements of the Law. However, the calcium silicate boards can be used as fuel, even though recycling is not effective if the fuel efficiency is poor. Conversely, under Scenario IV, they are recycled as raw materials for calcium silicate boards and circulated as building materials; therefore, the latter process is a more effective way of recycling. These findings indicate that a single quality index is not sufficient for evaluating recycling efficiency.

While the method described here does not include a method for quality evaluation, we believe that qualitative evaluations can be undertaken by considering the amount of energy consumed by each recycling method and by estimating demand. The development of a quality evaluation method will remain an issue for future research.

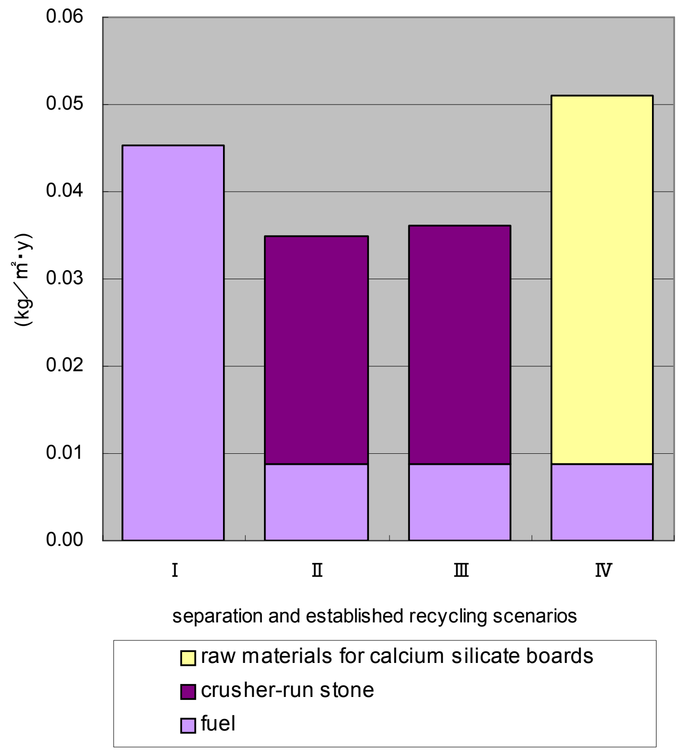

Figure 4 shows the kind and the amount of materials for recycling of calcium silicate boards for each separation and recycling scenario

5. Perspectives

Use of this method made it possible to obtain details of the amount of resources of the building, using categories that employ current or potentially feasible recycling techniques. We intend to develop the method further in the future in order to apply the technique to the management of historical information as well as for resource management. The development of this method required the collection and organization of data required for assessment the amount of resources and waste for commonly used construction specifications. Since we prioritized the collection of data in order to obtain a rough calculation, this data considered here includes data with low general applicability. We are therefore interested in refining the accuracy and use of data in the future by acquiring new data.

THE WASTE COMPONENT OF "SUSTAINABLE BUILDINGS" – VOLUNTARY OR MANDATORY?

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Keywords: waste management, buildings, rating tools, Australia

Summary

Several planning and building regulatory bodies throughout Australia, including federal, state, territory and local governments are well on the way to implementing mandatory sustainability requirements for energy and water into their planning and building processes.

However, there are currently no national and few state or territory Government or industry regulations specifically requiring new or existing buildings to comply with any sustainable waste management and recycling requirements. A small number of state and local government authorities require particular sustainability assessments for residential and non-residential planning applications, including the need for a waste management plan for either or both the construction and operational phases of the building.

National voluntary rating tools such as Green Star and the recently released National Australian Building Rating System (NABERS OFFICE Waste) are useful for measuring waste generation and diversion from landfill, and comparing performance against benchmarks for a range of building typologies.

This paper identifies current Australian mandatory and voluntary sustainability assessment tools for buildings that include a waste management component. The waste and recycling requirements of the tools are compared and the need to regulate the building industry to achieve state-based waste minimisation targets is discussed.

1. Introduction

According to the Green Building Council of Australia (GBCA), the impact of buildings on the environment is significant. Reportedly, activities around buildings consume 32% of the world's resources including 12% of its water and up to 40% of its energy. They also produce 40% of waste going to landfill and 40% of air emissions (GBCA, 2003).

These figures are likely to vary from region to region, and in Western Australia for example, the waste to landfill from the construction and demolition of buildings is actually above average. A recent study undertaken for the Commonwealth Department of Environment and Heritage revealed that in Western Australia up to 55% of all waste to landfill (compared to 34% across other states) is derived from the construction and demolition sector (Hyder Consulting, 2006). It should also be noted that waste from buildings during the operational phase (classified as commercial & industrial waste) continues to contribute waste to landfill for the remainder of the life of the building.

The Basel Convention defines wastes as "substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law" (Basel Convention, undated). The generation of waste represents poor use of resources which are not just limited to the materials used in the product, but also the energy and water consumed during the process of extracting natural resources and in manufacturing and transportation.

The environmental impacts from landfills are significant and while existing landfills are filling rapidly, new landfill sites are becoming less available. Landfills are also a source of greenhouse gases (mostly methane) that contribute to climate change. By diverting waste away from landfill to recycling there is potential to save significant tonnes of greenhouse gases. The savings would be derived from not only the reduced production of landfill gas, but also the reduction of lost embodied energy in the resources. Embodied energy is defined by the total life cycle energy used in the collection, manufacture, transportation, assembly, recycling and disposal of a given material or product (Greater London Authority, 2008).

Federal and State Governments are working with local governments (who manage municipal waste and own a large number of Australia's landfills), industry and the community on strategies to avoid and reduce the generation of waste, recover the waste that is generated and appropriately manage landfills.

Most of Australia's state and territory government's waste management policies include targets for reducing waste to landfill. In Victoria for instance, Sustainability Victoria through its *Towards Zero Waste Policy* has committed to a target of reducing the amount of waste to landfill from 4.2 million tonnes (2007/08) to 2.44 million tonnes by 2014. It is also aspiring to the recovery of 75% of the total amount of waste generated for reuse, recycling or conversion to energy by 2014 (Sustainability Victoria, 2007).

South Australia in its *Zero Waste Strategic Plan* has set a target of reducing waste to landfill by 25% by 2014 (using 2002/03 data as the baseline) (Zero Waste SA, 2005).

For New South Wales, the Department of Environment and Climate Change in its Waste Strategy 2007 states targets for recycling of commercial and industrial waste from its baseline of 28% to 63% by 2014 and construction and demolition waste from the 65% baseline to 76% by 2014 (DECC NSW, 2007).

Whilst there is a significant amount of waste produced from buildings (both in their construction and operation) producing the associated impacts on climate change and the rapid filling of landfills, there is a disconnect between state and territory governments who are actively seeking waste reduction target achievement and the inclusion of buildings in any waste reduction regulatory requirements. It appears that the few localised mandatory sustainability requirements set by a small number of organisations and the voluntary building rating tools are the main drivers for encouraging a reduction of waste to landfill from buildings.

2. Existing mandatory state and local government and voluntary national waste management and recycling requirements

National mandatory requirements pertaining to recycling from construction sites or from operating buildings currently do not exist. However in some Australian States, such as Victoria and Western Australia several state and local government organisations include mandatory waste management and recycling requirements in their planning and development application process. Listed in table 1 are some of the mandatory sustainability requirements set by five organisations. Table 2 lists the three national voluntary rating tools.

Table 1 List of mandatory sustainability assessment tools and/or guidelines for the built environment and their key waste management and recycling requirements.

Organisation and name of tool or guideline	Key waste management or recycling requirements
VicUrban – *Melbourne Docklands ESD Guide* (2006)	• Provision of recycling facilities in all new developments • No recycling performance targets stipulated
Manningham City Council – *Doncaster Hill Sustainability Guidelines* (2004)	• Waste management and avoidance plans required for construction and operational phases • Waste management design strategy • No recycling performance targets stipulated
Moreland City Council – *Sustainable Design Scorecard* (2005)	• Waste management design strategy • Construction phase waste management plan with a 60% recycling performance target • No operational phase recycling performance targets stipulated
Department of Sustainability and Environment Victoria – *Environmentally Sustainable Design and Construction Principles and Guidelines* for Victorian Government departments (2003)	• Waste management design strategy • Construction phase waste management plan with a 90-95% recycling performance target • Operational waste management plan with a 80% recycling performance target
Armadale Redevelopment Authority, Western Australia – *Sustainable Audit Scorecard* (2003)	• Operational phase recycling strategy with a 50% or 75% recycling performance target • No construction phase recycling targets stipulated

Table 2 List of national voluntary rating tools for the built environment and their key waste management and recycling requirements

Organisation and name of tool or guideline	Key waste management or recycling requirements
Green Building Council of Australia: Green Star – Office Design v3; Green Star - Office As Built v2; Green Star - Healthcare (Pilot)	• Awards innovation • Waste management design strategy • Construction phase waste management plan with a 60% to 80% recycling performance target • No operational phase recycling performance targets stipulated
Green Star – Office interiors v1	• Waste management design strategy • Fit-out phase waste management plan with a 40% to 80% recycling performance targets • No operational phase recycling performance targets stipulated
Green Star – Office Existing (Extended pilot)	• Commitment to waste reduction/recycling monitoring and landfill disposal targets • Demonstrate recycling storage area
Green Star – Education (pilot)	• Waste management design strategy • Construction phase waste management plan with a 60% to 90% recycling performance target
Green Star – Shopping Centre (pilot)	• Waste management design strategy • Construction phase waste management plan with a 60% to 80% recycling performance target • Operational phase waste management plan with annual non-prescribed waste reduction targets.
National Australian Built Environmental Rating System - NABERS OFFICE Waste	• Applies to operational phase of offices only • Very detailed ongoing assessment and analysis, monitoring and performance based.
Urban Design Institute of Australia (UDIA) Qld - EnviroDevelopment (currently under development in WA, SA and Vic)	• Waste management design strategy • Construction phase waste management plan with a 40% minimum recycling performance target • No operational phase performance targets stipulated • Mainly applies to multi-residential developments
Sustainability Community Rating (VicUrban) • Urban Renewal Community v2007 • Master Planned Community v2007 • Provincial Community v2007	• 90% of infrastructure and building construction and demolition waste to be recycled and or reused.

These case studies show that use of waste management plans and target-driven requirements is achievable and can produce positive outcomes. Ultimately, these requirements will only prove effective if there are mechanisms for ensuring that waste management plans are actually adhered to on construction sites and during the building's operations. Sound data collection, recording and reporting systems are crucial elements in the ability to measure performance, and such systems are not always easily implemented. Data collection is discussed further in section 3.

3.1 How do waste management requirements in these tools compare?

Tables 1 and 2 provide a summary of the types of sustainability assessment tools and guidelines that exist today for the built environment. This includes those mandatory, location-specific requirements and the national voluntary programs. It can be seen that mandatory waste management requirements only apply to those few locations in Victoria and Western Australia. The organisations that have developed and/or implemented them should be regarded as leaders in incorporating sustainability requirements, including waste management and recycling, into their planning application processes.

Table 3 sets out the phase of a building's lifecycle each tool applies. As can be seen only 3 tools include waste management requirements for each phase of the building (design, construction and operational).

Table 3 The building phase or phases to which each tool applies

Organisation and name of tool or guideline	Design phase	Construction phase	Operational Phase
Armadale Redevelopment Authority WA Sustainability Audit Tool (Mandatory)	✗	✗	✓
Doncaster Hill Sustainability Guidelines (Mandatory)	✓	✓	✓
EnviroDevelopment (Voluntary)	✓	✓	✗
ESDC Guidelines Vic Government (Voluntary)	✓	✓	✓
Green Star - Office Design v 2, Office As Built v 2, Healthcare (Pilot) (Voluntary)	✓	✓	✗
Green Star - Office Interiors v 1 (Voluntary)	✓	✓	✗
Green Star - Office Existing (Extended Pilot) (Voluntary)	✗	✗	✓
Green Star - Education (Pilot) (Voluntary)	✓	✓	✗
Green Star - Shopping Centre (Pilot) (Voluntary)	✓	✓	✓
NABERS OFFICE waste (under development) (Voluntary)	✗	✗	✓
Sustainable Community Rating (Voluntary) Master Planned Community; Urban Renewal Community; Provincial Community	✗	✓	✗
SDS (Mandatory)	✓	✓	✗
VicUrban Melbourne Docklands ESD Design (Mandatory)	✗	✗	✓

3.1.1 Mandatory tools and guidelines

It is important to understand the objectives of each tool and guideline before comparing their functional differences. For instance the guidelines developed for the Melbourne Docklands precinct, Doncaster Hill precinct and Victorian Government Departments all aim to inform stakeholders of the ecological sustainable design principles, frameworks and practices for their respective development areas. Both the Melbourne Docklands and Doncaster Hill frameworks are bound by policy and are incorporated into the planning and development application process.

The Guidelines for Victorian State Government departments are not incorporated into any local or state authority planning process, but rather are designed to be incorporated into the tender process for capital works. There is a high risk that the principles may not be included as there does not appear to be a mechanism that enforces their inclusion throughout the tender process, building design, construction and operation. Further these Guidelines specify that a voluntary rating tool be used to provide an environmental impact rating for the building. This would only apply if the development was an office, healthcare or education facility.

In comparison to the three sets of guidelines the mandatory assessment tools developed by the Armadale Redevelopment Authority (ARA) and the City of Moreland provide a basis for calculating a numeric score against the level of sustainability a building is predicted to achieve. While the tools specify performance requirements to be met, there is no mechanism for checking whether the development actually achieved the predicted performance targets once the building has been constructed. Furthermore, the assessment tools focus on two different phases of the building. The ARA tool focuses on waste from the operational phase, while the City of Moreland tool, the Sustainability Design Scorecard (SDS), only applies to the construction phase of the development.

This demonstrates that the tools used in different parts of Australia are not comparable and the data from the performance targets (if collected from each development and aggregated) are unlikely to be meaningful on a national level. Furthermore, the mandatory assessment tools and guidelines that exist today have been developed for a range of purposes and for a specific group of buildings i.e. Victorian Government, Melbourne Docklands or Doncaster Hill precincts.

3.1.2 Voluntary assessment tools

The national voluntary rating tools are also selective in the types of buildings in which the tools apply. There are Green Star tools that apply to offices, health care facilities, education facilities, shopping centres, multi unit residential and mixed use developments. The National Australian Built Environment Rating System (NABERS) only applies to buildings that are offices while EnviroDevelopment seems to only applies to multi-residential developments in Queensland, although the UDIA in other states such as Western Australia, South Australia and Victoria are looking to adopt similar models.

VicUrban, the Victorian Government agency for sustainable urban development, has initiated in partnership with industry the Sustainable Community Rating. While three tools have been developed (Master Planned Community, Urban Renewal Community and Provincial Community), only the Master Planned Community tool has been road tested (Sustainable Community Rating, 2007).

While there is a small amount of overlap with mandatory tools in terms of the geographic locations in which they apply, the voluntary national tools can generally apply to certain commercial building typologies in any location. This increases the number of buildings within Australia that are able to adopt the rating tool and proactively drive the reduction of waste to landfill. The EnviroDevelopment and Sustainability Community Rating tools can apply to communities located anywhere in Queensland and Victoria, respectively and the tools cover mainly residential developments and in Victoria, mixed use developments. The way Green Star tools are designed to award innovation is a clever way to encourage the building and property industry to think of alternative ways for a building to function so as to minimise its impact on the environment. By awarding points for adequate recycling storage and collection access, it encourages designers to focus on the practical issues of waste management and recycling. Many existing buildings are restricted in their ability to recycle simply because there is not the space to store recycling bins, balers and other waste handling equipment.

The Green Star tools also award points for incorporating building materials with recycled content. This is another very positive aspect to the tool that helps to drive the demand for recycled building products by providing a ‘pull’ along the recycling supply chain. Supporting the end markets and in turn, the whole recycling industry, makes it easier for construction sites overall to recycle.

A downfall of the waste management aspect of the Green Star tools is the component that specifies performance recycling targets at the construction phase. As the tool is a predictive one, there is no mechanism to actually check that the predicted target was actually achieved and it may be questionable as to how appropriate the recycling practices and systems in place actually are once the construction phase is underway.

Another concern with the Green Star tool is the fact that credit points relating to waste management and recycling within the tool are optional. Obviously buildings that wanted to achieve a higher rating would need to comply with the criteria, but it is not essential for every Green Star rated building.

Furthermore, it has been observed that there are problems with recording and reporting data to enable performance to be measured. For instance, in Western Australia anecdotal evidence suggests that some recycling companies do not have the means for recording the weight of materials from individual building sites (in most cases weighbridges are not installed at recycling facilities) and the composition of mixed loads of recyclables would need to be known before the volume can be converted to weight.

In addition, it appears that little effort is put into setting up robust data recording mechanisms for individual construction sites. It is acceptable under the Green Star Office Design & Office As Built v3 tools for those projects who engage a recycling contractor to sort and recycle construction waste on the project’s behalf, and does so on a bulk basis instead of a project basis, to use the recycling facility’s average recycling rate for the total material that comes through the gate. The recycling contractor is required to provide this evidence (GBCA, 2008). Although useful, this information is not accurate for individual construction sites, who may or may not benefit from such a method.

The recycling rate methodology and data collection mechanism is something that should be incorporated into any waste management plan, to ensure that only contractors who are able to provide the necessary data are employed to collect and recycle the material.

3.1.3 Comparison between mandatory and voluntary guidelines and tools

When comparing mandatory tools with voluntary tools, in all cases except for the Moreland City Council SDS tool, there are no specific recycling performance targets for the construction stage in the mandatory tools. In comparison, voluntary tools provide more exacting targets that provide credibility but can be off-putting to developers and planners perhaps due to the difficulties in obtaining accurate data and reporting performance.

While the requirements for each guideline or tool vary there are some similarities. In the design phase many tools require either a waste management plan and/or dedicated storage area to be incorporated into the project. Construction waste management plans are a requirement of all tools and guidelines that do actually include the construction phase in the assessment.

However, very few of the tools actually specified what should be included in a waste management plan. They also fail to provide a methodology for evaluating the recycling performance, including recording and reporting systems. A little more detail of such requirements would allow for a more standardised approach and ensure that the plans were not only meaningful and useful but had the ability to be compared in a consistent manner.

One general observation is that the waste management components of the mandatory tools are usually less onerous and specific than the requirements of voluntary rating tools. For example, the *Doncaster Hill Sustainability Guidelines* (2004) in Victoria require on-site waste management separation and recycling during the construction phase, with no specific targets, while the voluntary Green Star - Office Design v3 tool requires a waste management plan and contract provisions to reuse and /or recycle from 60% to 80% of construction waste by weight.

Overall, there is greater focus on the waste minimisation aspects of the construction stage of buildings than the operational phase. Further, the waste performance measures for the operational phase of buildings are where there is the widest variation in performance across the tools. Except for NABERS Office Waste, the waste requirements range from having a "commitment to recycle", to education programs, to percentage targets, to waste management plans. The NABERS Office Waste tool is clearly the most comprehensive tool in terms of operational performance; however, it is only limited to the Building Code of Australia class 5 office buildings.

It is important to note that the effectiveness of recycling systems during the operational phase relies heavily on the design of the building. However, there should be just as much emphasis placed on the requirements of operating waste management plans, including the need to meet recycling targets.

In saying this, the ARA tool specifies targets such as either a 50% or 75% recycling rate of the total waste stream from the operational phase of buildings but fails to state whether this is by volume or weight, an important factor when it comes to determining whether or not compliance was or was not achieved. It is important to note here that mass is the standard unit of measure for waste and if this is not stipulated in the guidelines, there is potential for waste to be measured by volume. While volume can be converted to mass (if the composition of the waste is known), it is necessary to ensure that data is recorded accurately by using a consistent unit of measure.

Finally, many of the tools could be strengthened by requiring or providing evaluation tools for ongoing reporting of criteria such as recycling rates or achievement of waste minimisation targets, particularly if standardised against other similar buildings to allow owners continued opportunities to show off their environmental credentials.

3.1.4 The need for a national mandatory approach

As waste from the demolition and construction sector contributes approximately 34% of all waste to landfill in Australia (and in some states, significantly more) (Hyder Consulting, 2006), stakeholders within the industry should firstly be required to meet standard proportional recycling targets for all new and existing buildings. Consistency in performance requirements will then help to drive markets for recycling of building materials. By also incorporating standard proportional use of building products containing recycled materials in the construction of new buildings, recycling markets will continue to grow and develop.

An example of where this is already occurring is in the United Kingdom. As from April 2008 it is a legal requirement for construction sites in England to have a formal Site Waste Management Plan (SWMP) for developments over £300,000 and for those over £500,000 a more detail plan is required (Building Research Establishment, 2008). Implementation is enforced by both local authorities and the Environment Agency. The United Kingdom's Building Research Establishment (BRE) has developed a free software tool for preparing, implementing and reviewing a SWMP. This tool is called SmartWaste Plan and helps manage all aspects including the creation of a SWMP to measuring and reporting waste generation.

BRE's *Code for Sustainable Homes* also requires the mandatory use of a SWMP (BRE, 2008). The Code came into effect in May 2008 and to satisfactorily comply with the Code, compliance assessments conducted both at the design phase and at the completion of construction must be successful. A final assessment certificate is issued upon compliance.

The United Kingdom's regulatory model shows that it is possible to prescribe national waste management requirements for building sites and that they can be readily enforced. This type of model should be considered when investigating suitable options for Australia.

It is imperative that any national Australian approach includes, like the United Kingdom model, a mechanism for ensuring compliance as well as verifying performance. The data to prove performance must be collected in such a way that it will enable data to be aggregated on local, state and national levels. This will enable governments to more easily and accurately determine the effectiveness of waste reduction and climate change policies and achievement of targets, particularly for reduction of total waste to landfill, the quantity of construction and demolition waste generated and proportion of construction and demolition waste recycled. It will also help to highlight opportunities for improvement in the future.

The consistency in requirements will help the building and property industry develop standard waste management plans with standard data collection and reporting requirements for individual building sites. This information will enable building owners, developers, construction companies to report aggregated recycling performance rates to interested parties. This data will also be critical for large building companies to comply with greenhouse gas reporting obligations, such as the National Greenhouse Energy Reporting System, who would also be keen to demonstrate and promote the tonnes of CO_2 equivalent they have saved.

4 Conclusion

Current and proposed sustainability legislation for buildings ensures consistent standards are required to be met for energy and water in new homes and some commercial buildings. Holistic sustainability requirements for other building typologies across Australia are *ad hoc*, with some state and local government organisations in Victoria and Western Australia leading the way in requiring new developments to incorporate sustainability into the design at the planning stage of projects.

The waste minimisation requirements in both mandatory and voluntary assessment tools vary across the design, construction and operational phases of buildings. Voluntary tools such as Green Star and NABERS Office Waste require more rigorous performance requirements than mandatory tools. The waste components in the mandatory tools tend to be vague and performance requirements largely non-specific. Furthermore, processes for checking compliance and/or actual performance once the buildings are constructed appear to be lacking in the majority of the tools.

The voluntary tools go some way toward specifying meaningful waste minimisation performances in the design and construction phases of buildings, but the waste management components within tools such as Green Star do not necessarily have to be met in order to become a Green Star rated building. Further, the tools only apply to certain building typologies and no tools address waste minimisation on single residential building sites.

While the waste management and recycling requirements within the few mandatory sustainability rating tools for new and existing buildings are varied, the organisations who prescribe the conditions should be commended for at least incorporating them. The voluntary tools with their more onerous waste management requirements are also a great step in the right direction. However, those buildings located within a geographic region whose local authority does not require waste-related sustainability requirements or whose owner has not prescribed an aspiration for the building to meet any voluntary sustainability status or branding, are unlikely to assist state and territory governments to achieve their demanding waste to landfill reduction targets.

Therefore, the introduction of consistent mandatory requirements for waste minimisation into sustainability tools for buildings, or separate legislation, will be of paramount importance in achieving some of the goals of many state government policies. This would also be instrumental in assisting the development of localised recycling markets, which in turn could result in a greater range of building materials with recycled content for use in new buildings in the future.

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ADAPTABILITY POTENTIALS IN HONG KONG PUBLIC HOUSING

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Summary

How sustainable the public housing is planned, designed and constructed can largely determine our way of life in the future. A favorable public housing built environment must be one that sustains ongoing wellness and integrity of the natural environment as well as the individual and their society. Public Housing in Hong Kong has been undergoing a tremendous change for the pass 50 years. It has progressed from housing policy to housing design development. Over the course of a building's lifetime, change is inevitable, in social, economic and in physical renovation in response to the needs and expectation of occupants. In theory, building that is more adaptable will be utilized more efficiently, and stay in service longer.

As the world faces resource scarcities, ecological problems, and environmental impact, a concern and consideration for the adaptability of building, and designing building with adaptability in mind is becoming a critical consideration. A report study on LCA and LCC models conducted by Housing Authority is used as a tool to explain the feasibility of the concept of adaptability that should be adopted for future. This paper is intended to share some information on issues of building adaptability in existing public housing stocks and examine the concept of adaptability potential towards sustainable public housing design in Hong Kong.

1. Overview of Hong Kong

1.1 High Density Living and Land Shortage

Hong Kong is a classic example of a compact city undergoing phenomenal changes. Given the hilly territory that presents physical and economic constraints, it is known that there is 20% of land that is build-able within an area of 1,100km^2. Apart from land reclamation due to insufficient build-able land area, as asserted by Fung (2001), the government of Hong Kong has opted for a high density approach to accommodate the growing population in order to reduce the demand for extensive land reclamation. Introduction of high-rise building had become the norm in all practice of planning, design and construction - including public housing. Current public housing is approximately 40 stories high with 10 stories added over the past decade.

1.2 Building Stock and Life Span

To cope with the population growth and needs in the past, there were huge amounts of building constructed. Although there are no concrete figures on the building stock currently, there were huge masses of construction material flow estimated in Koenig and Liu's study (2000) in which they found over 40% of the material flow contributed to construction materials.

According to the Citizen Party Hong Kong (1998), the average lifespan of a building is about 30 years, sometimes even less. Many of these structures, especially older buildings, have been built with low standards with insufficient maintenance throughout occupancy. Some current public housing estates are in similar condition. Concerning the global environmental impact, building stock in Hong Kong induces the largest energy and massive flow of materials of all production sectors. It represents the largest financial, physical and cultural capital of industrialized societies. What the building stock can offer at this point remains a challenge for Hong Kong.

1.3 Construction and Demolition Waste

Renovation work carried out by dwellers in Hong Kong is a most wasteful business. MDR (1994) concluded that "fit out" is a waste of public resources as large amounts of "fit out" provided by the developer has been discarded before use. This implied that the public housing design tends not in competency of occupant's needs. In the study of Koenig and Liu (2000), construction & demolition (C&D) waste has also increased 4 times in 26 years. There is similar waste with construction material consumption.

Based on a short mean life span of buildings of 30 years, the percentages of renovation and demolition waste in the total building (C&D) waste are very high. Current statistics from Environmental Protection Department (EPD, 2006) shows that 27% of disposal in the landfill came from (C&D) waste which account for 4,125 tonnes per day. Clearly, early demolition of buildings contributes the largest portion of building (C&D) waste and presents an issue on environmental impact.

2. Overview of Public Housing Development

2.1 Emergence of Public Housing

The development of public housing in Hong Kong can be traced back to 1953 when a large fire broke out in one of the squatter areas, Shek Kip Mei, leading to 50,000 people rendered homeless. The Hong Kong Government carried out a massive *Resettlement Program* to house the homeless within a short period of time. By 1973, nearly 50% of population lived in public housing which accounts for around 1.8 million people. Following the steps of industrialization and improvement of the economy, the Hong Kong Government gradually upgraded the living standard and environment of the public housing.

2.2 Public Housing Design from 50's to Now

There is a significant change in the public housing design approach from 1950s to now as shown in Figure 1. In 1950s, buildings were designed and built to suit the environment within the limitations of the material availability, current technology and land conditions. Public housing structures built later in the 1960s has increased in value by having more features such as individual toilets and vertical transportation systems. Then, the extensive concept of 'efficiency through uniformity'- a standardized housing form - became dominant in the 1980s. As described by Yeung (2003), it has reduced cost and time consumed for design and construction.

At the end of 1980s through 1990s, the Harmony and Concord types were developed as new housing prototypes. The concept of modular planning and standardization was adopted in the Harmony Blocks with the purpose of reducing labor costs, accelerating construction speed, and upgrading construction quality. Without much doubt, Jia (2000) expressed that this approach has made these factory produced components, mechanized construction and prefabricated concrete building elements possible in housing construction.

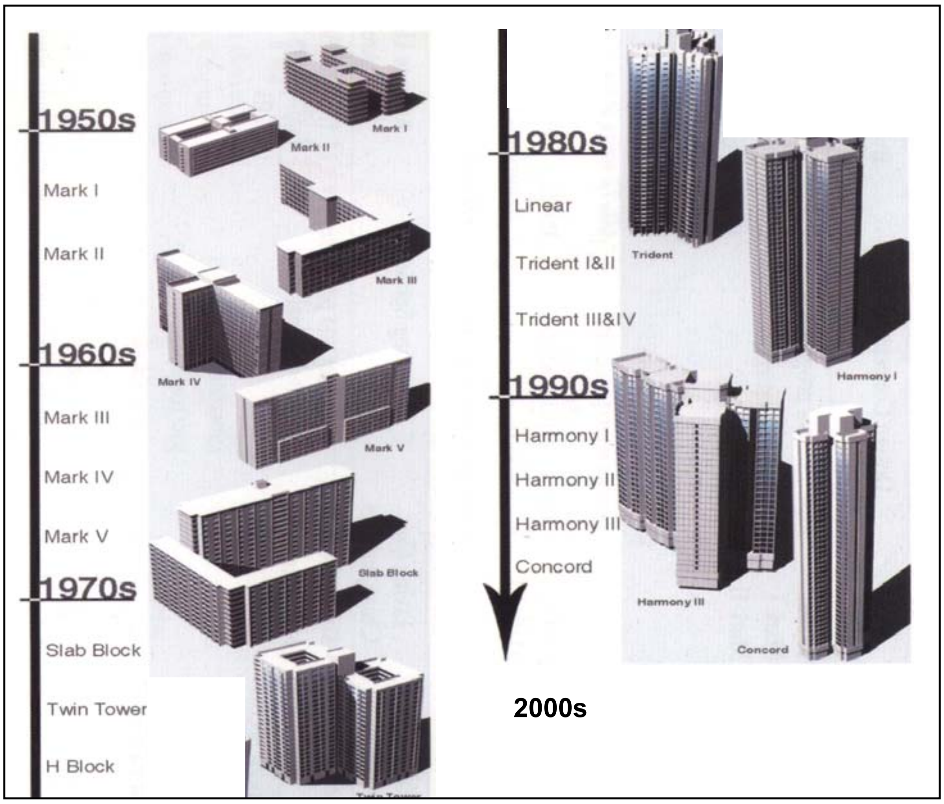

Figure 1 Housing types from 1950s to 1990s.

In 21st century, it is site oriented, environmental consciousness, quality, durability, adaptability and efficiency in the use of resources became the key considerations for the design and construction of public housing. A few effective measures such as segregation of waste material during demolition; and prefabrication of building elements have been employed to enhance environmental protection.

As asserted by Ng (2002), a housing unit must be able to cope with the different spatial needs associated with the growth and aging of occupants, and changes in family structure. Thus, flexibility and adaptability in the design of flat units are important considerations to meet the changing needs of people.

However, to what extent the adaptability qualities and potential in existing and future public housing in order to be sustainable remain a challenge for Hong Kong and the success of the intention depends upon actual performance later.

3. Overview of Building Adaptations

3.1 Role of Building Stocks

Cities and towns account for a huge proportion of the world's consumption of natural resources and world's production of pollution and waste. In the future, the urban building stock will also become the largest raw material resource for new buildings. The existing building stock is a financial and physical assets, a sustainable society is not possible until the resources can be managed sustainably. According to Douglas (2006), maximizing the reuse of old building is a key of sustainability.

As the world faces resource scarcities, ecological problems, and contends with the environmental impact of building and construction, a concern and consideration for the adaptability of building is becoming relevant, especially in Hong Kong. These trends and relevancy has also been asserted by Kohler (1998) in his earlier study.

Current public housing stocks built in 60s and 70s as shown in Figure 2 such as in Shek Kip Mei Estate, So Uk Estate and Ngau Tau Kok Estate are facing demolition due to these buildings becoming obsolete. Lessons are learnt based on what and how they were built and how these building were maintained. There is nothing much we can do to these building stocks now to revitalize them, but the sustainability of future public housing can not be overlooked. After all, the future of public housing is part of the total building stocks.

Figure 2 Illustrations of public housing stock built in 60s and 70s

3.2 Adaptability Implications

3.2.1 Avoidance of Building Obsolete

A combination of interrelated conditions has made many buildings functionally obsolete. Such interrelated conditions are over-building at once; the economic recession and subsequent real estate crash; structural changes in the economy; innovations in communication and information technologies; changing preference on how we work and live and other factors as well. According to Gause (1996), the issue on obsolescence can be avoided if an anticipation of change - socially and economically - is predicted and considered carefully when planning for the adoption of the adaptability concept.

3.2.2 Extension of Building Life Span

The service life of every building is unique and its lifespan is strongly determined and influenced by change in the economy, society and the environment over time. Under a suitable building condition, adoption of adaptability to a building will eventually result in an efficient use of building and extend a building life span.

3.2.3 Reduction of Environmental Impact: Waste, Energy, Gaseous

Buildings should be looked as resources, and building that is unable to adapt will be demolished. Some useful results can be found in Larsson's (1999) research study. Materials that are not recyclable from demolition can consequently induce higher levels of demolition waste.

Apart from that, new build building requires more energy flow (embodied energy including initial energy & transportation energy) and further gain environmental burden since new construction contribute a huge amount of materials in contrast with adapting existing building. Adapting existing building will lead to reduction in green house gas emissions. Therefore, designing building with adaptability potentials will definitely contribute to the reduction in a negative environmental impact.

3.2.4 New Value and Product Generation

Once a building is determined to be in good condition to be adapted for reuse, it is feasible to generate new function and significant value to the building and the community. It is the adoption of this concept that enhances its acceptability and generation of new market for recycling products as well as an educational tool to inform new vision and responsibility to reduce environmental impact.

3.3 Building Adaptability Criteria

Adaptability is the key attribute to building adaptation. According to Douglas (2006), adaptation refers to any work to a building over and above maintenance to change its capacity, function or performance. That is any intervention to adjust, reuse or upgrade a building to suit new conditions or requirements. Adaptability refers to the capacity of buildings to accommodate substantial change as expressed by Grammenos (1997), Russell and Moffatt (2004) and HKBEAM (2005). In theory, building that is more adaptable will be utilized more efficiently, and stay in longer service, because it is responsive to change at a lower cost compared to a newly built project.

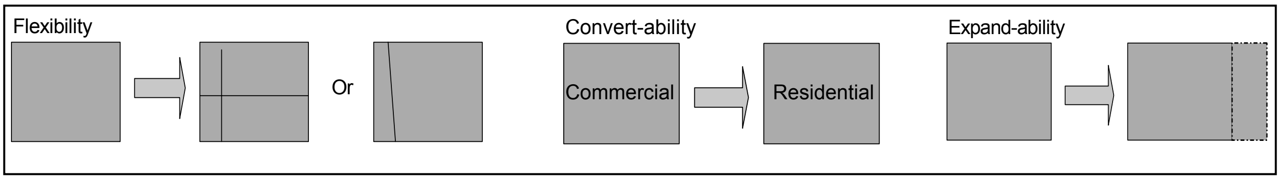

Figure 3 Illustrations of adaptability criteria

Flexibility; Convertibility; Expandability; Dismantle-ability; Disaggregate-ability are the five criteria of adaptability. Among all criteria, flexibility, convert-ability and expandability which are shown in Figure 3 are more common. Flexibility enables minor shift in spatial planning, reconfiguration to the layout is very typical. Convertibility allows for change in use within the building economically, legally, and technically. Expandability makes allowance for increase in volume or capacity, inserting another level to the building vertically or inserting addition horizontally is very common.

3.4 Feasibility of Inherent Adaptations

Criteria such as flexibility, expandability and convertibility are more likely feasible for building stock adaptation. However, careful assessment on the appropriateness on the concept adoption is required. In Hong Kong, the low adaptability of some building design has limited the usage range. These buildings were not plan, design and construct to allow for flexibility to accommodate the continuous changing economy, living standards, control regulations and technology.

Feasibility is a significant critical path in the process of building adaptations in any construction project at any levels. Three primary factors determined the adoption, such as viability (economic feasibility), practicality (physical feasibility) and utility (functional feasibility). Viability is usually the most important and influential of the assessment criteria because ultimately, all development decision is dependant on financial considerations. A good starting point in assessing the significance of the estimated cost of adaptation is to compare them with redevelopment programs whereby it defines the context of existing building and inevitably involves demolition and erection of new building. Life Cycle Assessment (LCA) and Life Cycle Cost (LCA) can definitely be used as part of future planning tool and adoption for building adaptability.

The practicality of undertaking an adaptation scheme is influenced by the extent of access required for the work and the condition that building is capable of adaptation without major or long term disruption to its use and its structure. In congested urban city such as Hong Kong, some of the key barriers public housing stocks offered are little structural change and access room on site for contractors and their storage.

Any successful adaptation project, however, must fulfill the spatial requirement needs of the building's occupant. In the outset, the aim should be to minimize wastage of underused space on one hand. The distribution of building stock by age gives some indication of the adaptability. The larger the coverage areas of building at same age within a context, the better the feasible of its utility for adaptations.

4. Findings of LCA/LCC Model

There are at present no comprehensive data sets of environmental information in relating to product manufacture, use and disposal for the Hong Kong region. The Housing Authority sees the essence to use materials in a productive and efficient way as a common objective of the different players in the Life Cycle of a building in their specific decision making situations they need with different tools and reference values. The best method of establishing such information is through the comprehensive life cycle mapping of construction materials in terms of cost and environmental burdens resultant from the existing building designs. As a consequence, international data has been sourced and analyzed to provide an underlying basis for the Housing Authority LCA/LCC model.

To examine if the concept of adaptability is feasible to widely adopt in Hong Kong public housing, report study of LCA/LCC (Life Cycle Assessment/ Life Cycle Cost) conducted by Housing Authority is observed and investigated. It is used as tool to understand how improvement in the sustainability performance of Hong Kong's buildings through adaptations can be achieved, through the identification of the economic and environmental profiles of the buildings' designs.

Functional units such as piles; RC walls; windows etc. were used in the study and the ranking results obtained from the study are listed below and in Figure 4:

4.1 Initial Cost Ranking and Environmental Impact Result

In terms of the overall expenditure profile, it is relatively unsurprising that the items with largest physical quantity dominate the top level. According to results obtained from Housing Authority (2005), it is clearly demonstrated that approximately 20% of the functioned units have a cost impact in excess of HK$1 million. Equally, these 20% of items also constitute 86% of the total capital cost.

Referring to Figure 4, the top 10 functional units, in terms of capital cost are piles followed by RC walls and RC slabs etc. At the same time, these RC walls, pre-cast facades and RC slabs yet are the dominant functional units in contribution to environmental impact.

	Life Cycle Cost Impact	Life Cycle Environmental Impact
1	RC Slabs – Fairfaced	Precast Facades – Type 1
2	RC Walls – Fairfaced	RC Walls – Fairfaced
3	Wall Finishes – Internal Flat Areas	Precast Facades – Type 2
4	Floor Finishes – Kitchens and Bathrooms	RC Slabs - Fairfaced
5	Piles	RC Water Tanks
6	Small Power Installation – Flats	Aluminium Windows – Bedrooms
7	Panel Walls – Internal	RC Walls – Generally
8	Fresh Water System - Distribution	Aluminium Windows – Living Area
9	Lighting Installation – Flats	Piles
10	Internal Waterproofing	Mains & Distribution

Figure 4 Top 10 LCA and LCC ranking functional units. Source: Final Report of LCA and LCC Study of Buildings Materials and Components

4.2 Initial Quantity (Mass) Ranking Result

As with all other aspects, the large quantity items (RC slabs; RC walls, piles) dominate the results and again the structural items top the results listing. In this case the options available for assessing alternative strategies will be more limited without fundamentally revising the structural design of the building. The above results ultimately are not remarkable and it was within expectation. In the context of the whole life profile these items do not have as large an impact since they are not replaced frequently. However, due to their dominance at the initial stage they remain in the top rankings even on a whole life basis.

4.3 Whole Life Cost and Environmental Profile

From the report of Housing Authority (2005), it is found that over 90% of the total impact is attributable to just 17% if all the functional units. This implied that the environmental impacts are concentrated on a small group of items such as structure and services of building in which these items contribute to a substantial capital cost at the same time. Similar situation will carry through to the whole life profile and rankings.

4.4 Implications of Result

The assessment has been carried out on the basis of functional units, rather than individual. This approach reflects how materials are actually combined into the building. Base on the ranking on Life Cycle Cost impact and Life Cycle Environment Impact indicated in Figure 4, on the whole architectural items, whilst significant, are generally less dominant than the structure and building services items in cost terms. Similarly, structural elements dominate in environmental terms since their impact is driven largely by the substantial mass of the material they contain. Thus, the study method and results does make clear implications on how much wastage and environmental burden if no adaptation is adopted appropriately.

The results did not show whether adaptability is a good thing to be applied, but the studies shown that over 60% of building mass are from the structure and building block. This again implies that if building stock is to be demolished, there will be big portion (or percentage) of cost, energy, and resources became less useful. However, waste, and chances of adding burden to the environment are definite considerations.

As asserted by Yeang (1995), if the building be regarded as a form of energy and material resources that is managed and assembled by the designers into temporary form, the demolition at the end of the period with the materials should be either recycled within the built environment or assimilated into the natural environment.

5. Conclusions

Given the data obtained and implications derived from LCA/LCC study, improvement made to new built, to extend future building life span and reduction in construction and demolition waste by adaptation is rather relevant. In Hong Kong, one of key challenges would be provision on housing needs. Due to the limitation of land for further urbanization, and increasing demand of public housing and increasing demolition waste, it seems adoption in design for adaptability is valid, so that public housing life can be extended and reduce further land reclamation, as well as further demolition waste in future.

Even a new building will become obsolete over time under some conditions such as new technologies required and new functionality. So a building has to respond to the present state and also to the future, even unanticipated, changes in requirements, and this at a minimum transformation cost. The importance of new structure should not be overlooked. After all, today's high technology is tomorrow's low technology. The adaptability of new and modern public housing is just as important as that of old construction. Therefore, it is important that adaptation should be taken into account in either existing public housing stock or new build schemes.

The consequences are clear as shown in Figure 5, that a series of reduction in environmental impact can be achieved. Adaptability prevents, in many cases, the premature demolition of buildings, adding many years to the life span, which is a significant contribution to sustainability. Adaptability has to be incorporate at the early stage of planning and design.

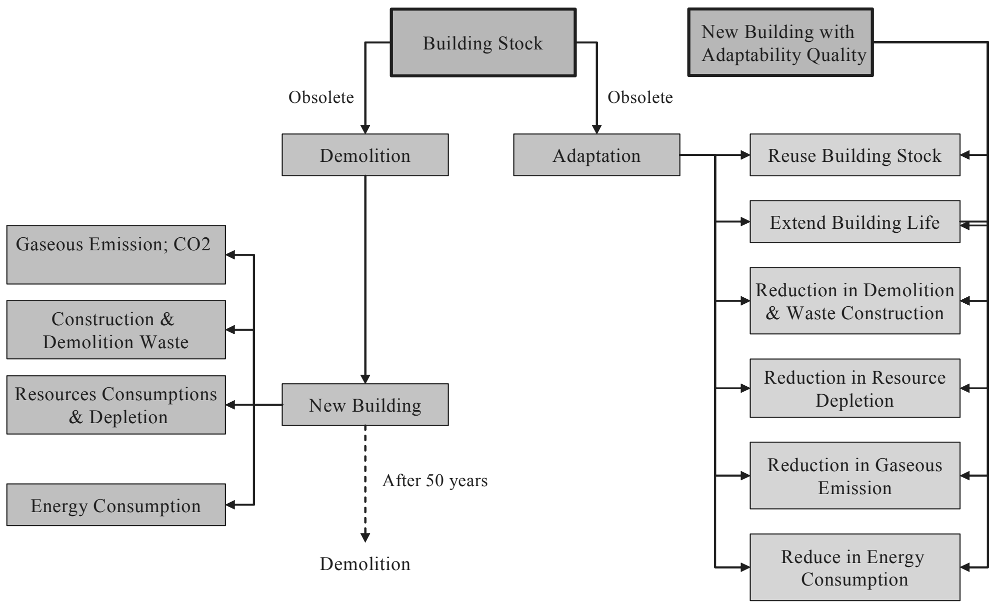

Figure 5 Illustration of consequences of adaptation of building stock & adaptability on new building

5.1 Design Strategies Adoption

Sustainable built environment with adaptability should aim to save resources, reduce waste and become a high quality stock of society and emphasis the well-being of the citizens on the quality of their environment, whether man made or natural, which accommodate human needs and aspiration.

What is needed is a way to protect all natural resources and to live within the carrying capacity limits of our environment, minimizing negative impact and make efficiency use of these resources.

Apart from using strategies such as design for long term needs and climatic responsive approach and using designing product with dismantle-ability as suggested by Kohler and Schwaiger (1998) in new public housing design in Hong Kong, "Open Plan Concept" as suggested by Kendall and Teicher (2000) and Wood (2003) and design building integrity as suggested by Russell and Moffatt (2004) which provide extra load capacity to foundation and superstructure to certain extent will reinforce the feasibility of the adaptation which can all be adopted to a certain extent as pilot study for its actual performance.

How the design strategies can be employed in practice and catering to functional needs and requirement in design can be shared later in oral presentation.

5.2 Way Forward

We know that the situation in Hong Kong is unlikely to remain static – change is inevitable and the pace of change is trending greater due to technology advances. The development of adaptability as a potential market in an adaptable structure, will present both challenges and opportunities to Hong Kong for building sustainable building into the future.

This sustainable housing design requires a holistic approach. Thus, participation and contribution of all construction stakeholders and developer and governmental representatives are essential. Integrating soft system such as highly organized site logistics and management and new procurement methods in tendering and contracting will also be required to try out new adaptability concepts and advanced construction technologies.

It is important to give credit to buildings that are designed in ways that extend their useful lifetime, and use materials and space efficiently. Designing and building with adaptability potentials in Hong Kong public housing to new scheme not only meets basic needs of present but more importantly future generation.

The way forward is to do more valuable relevant studies and hope to generate and produce a set of design guidelines to inform and make policy for all to comply in the future.

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ANALYSIS OF THE MICROCLIMATIC IMPACT OF GREENING IN HIGH RISE URBAN BUILT ENVIRONMENT USING SITE MEASUREMENTS AND SKY VIEW IMAGE PROCESSING TECHNIQUES

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Summary

Urban greening is believed to be capable of providing passive cooling by its shading and evaportranspiration[1]. High density in high rise milieu could influence greening cooling effects by altering solar and infra-red radiation exchange within so called urban canyons in ways differently with that within low rise settings. One of the most significant differences is that tall buildings can shade the greening at ground level instead of being shaded by them. In this scenario, an increase of built density could dilute cooling effect of greening by both shading and evapotranspiration in daytime, while increase of either building or tree canopy density could hamper irradiative cooling by reducing visible sky area at night. To test this hypothesis, site measurements at typical points in selected high rise residential developments in Shanghai is carried out. Microclimatic data and site-specific parameters are recorded in clear and calm days. A tool to measure built density and tree canopy density is developed using fish eye lens digital sky view imaging and WINSCanopy software. Temporal and spatial variations of microclimatic data are correlated to site parameters to evaluate their significant levels. The findings are useful for landscape and urban planning practice in high rise built environments with an aim to improve their bioclimatic performance and to mitigate urban summer heat islands.

1. Introduction

The economic booming of China is accompanied by the radical developments of many cities. However, the highest priority being given to economic growth in these cities causes various loads on the urban environment, which seriously affect the urban living standards. The urban heat island[2] is a particular phenomenon derived from these cities. It can give rise to many problems, such as the change of ecosystems of wildlife and vegetation, degraded outdoor thermal comfort, increasing number of heart stroke patients, expansion of infectious diseases (e.g. the SARS breakout in Hong Kong), and increasing demand for cooling energy consumption, and thus threaten the living environment and health of urban habitants.

Urban greening is believed to be capable of providing passive cooling by its shading and evaportranspiration (Kozlowski et al. 1997; Oke, 1987). But hitherto most of the relevant studies use built sites featuring low rise and high density, while study on greening cooling effect in high rise high density urban built environments, which are commonly found in modern Asian cities such as Hong Kong and Shanghai, is scarce.

2. Literature review

2.1 Previous research on cooling effect of urban greening

Bonan measured the microclimate of a low-rise residential area in a hot-arid climate, and found that plant species, water availability and housing density all contribute to forming a thermal-pleasing environment (Bonan, 2000). Shashua-Bar studies cooling effect of vegetation in various configurations of streets and small public spaces in cities with a hot-arid summer climate, by empirical modeling (Shashua-Bar et al. 2000). They conclude that site-specific effects (tree characters, site geometric configurations, water regime, etc.) are quite minor. This may be because that variation of site-specific effects among sites is small, and the finding could be different in a high-rise built setting in the subtropical climate of Shanghai.

The present study focuses on urban greening at micro scale. The aim is to assess the micro scale influence by greening as a joint function with other land use and built form variations. Unlike at larger scales, at micro scale, climatic impacts of greening is inevitably altered by urban built properties such as sky view factor,

[1] Evapotranspiration (ET) is the sum of evaporation and plant transpiration.
[2] The urban heat island is the temperature difference between developed areas and its surrounding undeveloped areas.

surface thermal properties, radiant environment, etc. (refer to Oke, 1989, for a detailed explanation of the energy exchange between urban trees and its street canyon environment.) Therefore, for study at this scale it is important to take all the above factors into consideration, for a comprehensive understanding of how greening performs in various urban settings. On the other hand, study of urban greening at this scale is scarce in sub-tropical Asian cities.

2.2 Research objectives

The present study aims to investigate the cooling performance of greening within a high rise residential development, and to understand the contribution of built density, land use and building layout to this cooling performance.

2.3 Brief description of the site under survey

The Brilliant City Project is located in Putuo District, Shanghai. The Suzhou River runs across by its southern side, and Shanghai Metro Line No.3 runs along its northern boundary. The site area is 49.5×10^4 m^2; the total floor area 160×10^4 m^2; Floor area ratio is about 3.2, and green cover ratio is 45%. The majority of the residential towers are at a height of 100m, the height defining high rise and super high rise buildings in China building codes. Because of the vast site area while the limit in man power and instruments, the site is divided into the east part and west part, divided by Zhongtan Road. Each site is to be surveyed on separated days.

Figure 01: Satellite image of the Brilliant City, Shanghai

3. Methodology

3.1 Selection of dependent and independent variables

Table 01: Lists of Dependent and independent variables

Descriptors	Independent Variables
Planning and Building design descriptor	Building View Factor (BVF) Sky View Factor (SVF) Ground Surface Albedo (AL)
Vegetation descriptor	Leaf Area Index (LAI) Tree View Factor (TVF) Green Coverage Ratio (GCR)
Natural descriptor	Wind Velocity (VW) Solar Radiation (SR)

Dependent variable: UHI_{day} and UHI_{night}, but only UHI_{day} is discussed in this paper due to page limit.

3.2 Measurement procedures

The site work can be divided into two parts: climatic measurement to record microclimatic variables such as temperature, wind speed, solar radiation etc. and site survey to measure design variables in planning, building design and land-use descriptors (Table 01) .

3.2.1 Climatic measurement

Measurement was carried out in Brilliant City West (referred to as BCW hereafter) on 26 September 2007 and in Brilliant City East (BCE) on 27 September 2007. In BCW 15 measurement stations were selected, and in BCE 14 stations. The criteria of selection are to maximize the possible variations in planning and design and land use variables. The overall sample size is 29.

The climatic condition of the dates under measurement is summarized in Table 02. Compared with institutional data, the on-site observation found that on 26 September it is quite cloudy, and mean solar radiation intensity measured on site (1pm to 6pm during mobile measurement) is 316.45W/m^2. It is considerably lower than 393.82 W/m^2 of 27 September.

Table 02: Climatic conditions on the survey days (from 0600 hours to 2200 hours)

Date (Sept.)	Air Temp. (^{o}C)			RH (%)	Cloud Cover (0800, 1400 and 2000)			Wind Velocity (m/s)		Solar duration (hr)	MSR (MJ/m^2) (0600 - 1800)
	Max	Min	Ave	Ave	08	14	20	Max	Ave		
26	29.7	21.8	26.6	77.1	7	4	0	2.6	1.48	8.4	1.50
27	32.3	23.7	28.6	72.5	1	3	0	2.9	1.24	8.6	1.50

Note: MSR - Mean hourly solar radiation
Data source: Shanghai Observatory

Among stations in each site, a pair of two stations was selected with similar building but different greening surrounding environments. A pair of Hobo weather stations was installed at these two stations, which records air temperature, relative humidity, wind speed and global solar radiation from 6am to 10pm at the height of 1.5m above ground. Another weather station was placed on rooftop of one of the residential buildings on site at the height of about 100m above ground. As it has the minimum obstruction of view to the sky, it is used as a reference of global radiation received on site. The effect of aerosol on radiation reduction is not considered in the study.

The rest of stations were covered by mobile measurement. Handhold Kestrel Pocket Weather Tracker was used to record air temperature, relative humidity, wind speed and wind direction 1.5m above ground. Mobile measurements covered the period from 1PM to 10PM and were taken every two hours. Totally 5 rounds were made at each station.

All on-site measured temperature readings were calibrated on a pro-rata basis to match the record timing at Nanhui Observatory, which is located to the south-eastern of the site and in rural area. UHI at a station is then calculated using measured temperature minus temperature recorded at the same time at Nanhui Observatory. The average UHI of round 1, 2 and 3 (1pm to 6pm) is taken as the daytime UHI; the average UHI of round 4 and 5 (7pm to 10pm) as the nocturnal UHI.

Table 03: Specification of the instruments in use

Instrument	Model	parameter measured	Accuracy	Operating Range
HOBO weather station kits	Temperature/RH Smart Sensor: S-THB-M002	Ta, RH	± 0.2^{o}C over 0 to 50^{o}C; ± 2.5%RH from 10 to 90% RH	- 40^{o}C to +75^{o}C; below 95% RH
	wind speed smart sensor: S-WCA-M003	WV	± 0.5 m/s ± 3% at 17 to 30 m/s ± 4% at 30 to 44 m/s	0 - 44 m/s
	Global radiation sensor: S-LIB-M003	GR	± 2% at 45^o from vertical	0 - 1280 W/m^2 over a spectral range of 300 -1100 nm
Kestrel Pocket Weather Tracker	Kestrel 4000	Ta	± 1 ^{o}C	- 45.0 to 125.0 ^{o}C
		RH	3.0 %	0.0 to 100.0 %
		WV	Larger of 3% of reading or least significant digit	0.4 to 40.0 m/s

3.2.2 Site survey

Site survey was conducted to measure on-site design variables including Sky View Factor (SVF), Building View Factor (BVF), Surface Albedo (AL), and greening variables including Tree View Factor (TVF), Green Cover Ratio (GCR), and Leaf Area Index (LAI).

To measure SVF, BVF and TVF, Hemispherical sky images were taken at each station using Nikon fish eye lens and digital camera, and then the magnitudes of SVF, BVF and TVF of each station were calculated using the image by WinsCANOPY™ software.

Surface properties of an about 1000m^2 area with a radius of 17-20m centred by each measuring point were elaborately recorded using a site survey form. These properties include percentages of soft and hard paving materials. In soft materials a sub-categorization was done to classify various vegetation (grass, shrub and tree) and water bodies. In hard paving materials, sub-division was done based on colour and paving materials. GCR is directly calculated from the surveyed data. LAI is estimated by surveyed data and other research findings on LAI (Ong, 2003; Scurlock et al. 2001). AL is estimated using surveyed data and other research findings on thermal properties of urban materials (Oke, 1987; Santamouris, 2001; Taha, 1997).

4. Analysis and discussion

4.1 Impacts of tree canopies and building canopies on radiation and temperature

4.1.1 Comparison of two stations

In BCE measurement on September 27, 2007, two stations with similar built canopies but different tree canopies, No.8 and No.9 were installed with weather stations to monitor and compare their micro climatic environments. The profiles of air temperature and global solar radiation were plotted and related to their hemispherical sky images. (Figure 02)

Figure 02: measurement point P8 （Left） and P9 (Right)

Table 04: Comparison of P8 and P9 in surface and geometry properties

Stn No.	Ground Cover proposition (%) (within 17m radius area of stations)						Geometry: View Factor (%)		
	Soft paving					Hard paving	SVF	CVF	
	Green Cover ratio	*Grass*	*Shrub (<1m)*	*tree (>1m)*	*Water*			*TVF*	*BVF*
8	45	*0*	*0*	*45*	5	50	27.79	13.73	70.03
9	55	*5*	*40*	*25*	5	40	15.14	39.03	68.69

Note: CVF: canopy view factor, including TVF and BVF.

4.2.2 Analysis and discussion

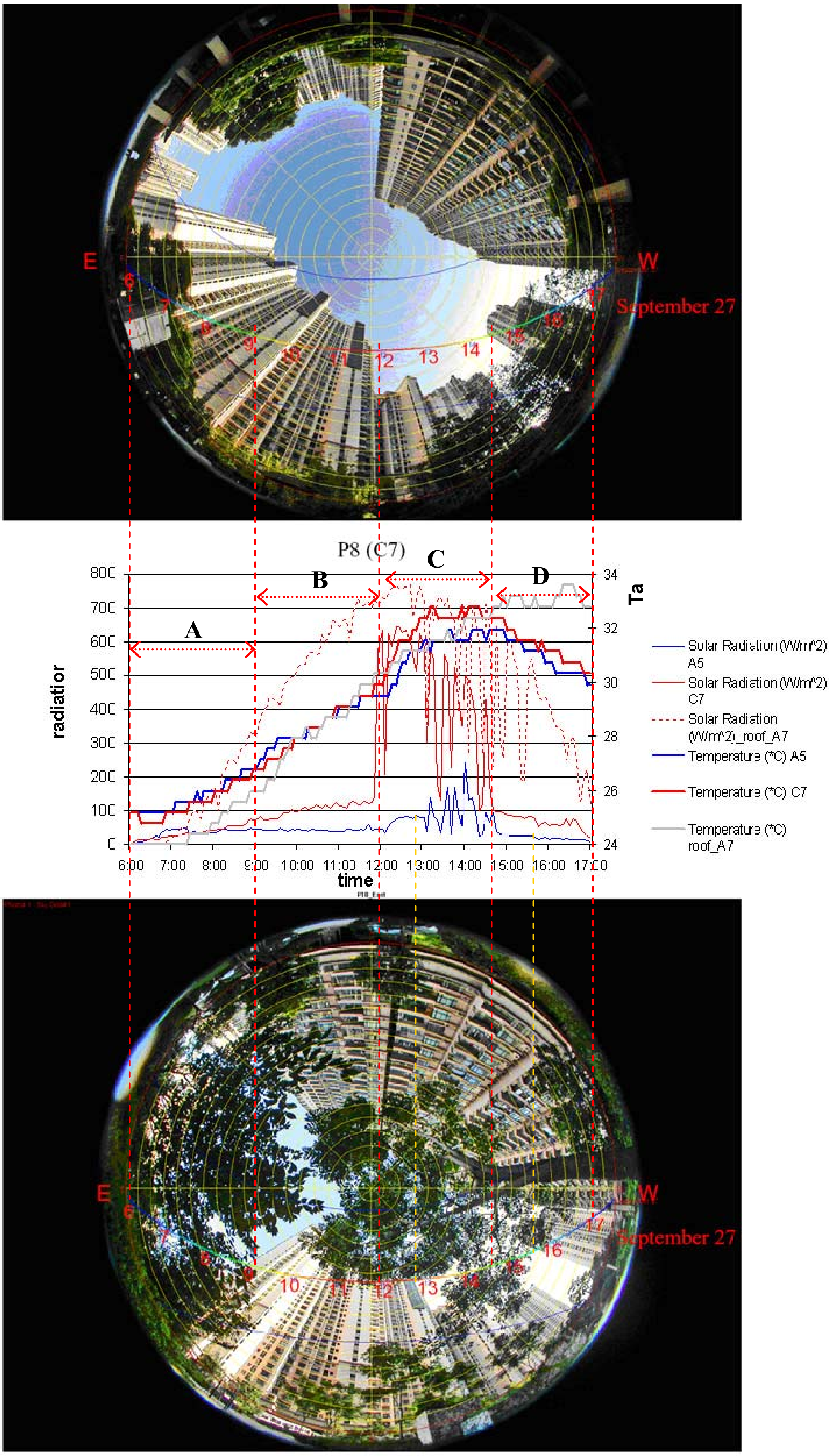
Other surface parameters being similar, the patterns of air temperature and globe radiation show significant variations due to different building and tree canopy densities (Figure 03):

6AM to 9AM (**Period A**): Temperatures show not much difference though T_9 is little higher (Max. 0.4^{o}C) than T_8 possibly because that shading by buildings blocks more solar radiation than tree canopies due to its porous nature.

9AM to 12AM (**Period B**): both points are shaded by buildings. T_8 grows up faster than T_9 and gradually outruns T9. This can be explained by the presence of tree canopies over P9: Although buildings intercept the same amount of direct radiation, tree canopies above P9 intercept a portion of reflected and diffused solar radiation (as can be seen from the Global radiation pattern), thus slowing its temperature increase.

12AM to 2PM (**Period C**): P8 is un-shaded and P9 is shaded by trees. The temperature shows significant differences (Max. 1.2^{o}C), as shaded P9 received much less radiation and thus are cooler than P8.

2AM to 5PM (**Period D**): both points are shaded by buildings. T_9 remains lower than T_8; the reason is the same with period B.



P9 (A5)

Figure 03: diagrammatic analysis combining sky view images and climatic patterns

Another comparison made at BCW yield similar findings. The above observation indicates tree canopy density as an important factor to lower air temperature, for its capability to intercept solar radiation, direct, reflected and diffused. Other greening factors such as grass cover and shrub cover seem not play an active role in environmental cooling. This is further discussed in the following section on regression analysis.

4.2 Multiple regression analysis

4.3.1 Daytime UHI in BCE: impact of greening variables

The first stage analysis focuses on each site, and regression was done using the six on-site design variables, in order to identify most significant combinations of variables. Because the main interest of study is on greening variables, the variable set containing three greening variables is used to build the base case model. (Because the R^2 of BCW model is quite low, only BCE model is presented in Table 05).

Table 05: Results of BCE regression analysis

	Coefficients					
	Model 1 (3 vars)	Model 2 (3 greening vars)	Model 3 (3 vars + SVF)	Model 4 (3 vars + AL)	Model 5 (3 vars + BVF)	Model 6 (all 6 vars)
Constant	*-1.135(.320)*	*2.595 (.000)*	*3.120 (.003)*	*3.564 (.000)*	*1.025 (.233)*	*-.586 (-.853)*
GCR	*.007 (.048)*	*.004 (.394)*	*.005 (.380)*	*.003 (.675)*	*.005 (.247)*	*.003 (.630)*
TVF	--	*-.025 (.101)*	*-.024 (.112)*	*-.028 (.053)*	*-.015 (.274)*	*-.010 (.550)*
LAI	--	*.225 (.264)*	*.151 (.499)*	*.309 (.117)*	*.103 (.567)*	*.196 (.349)*
BVF	*.041 (.006)*	--	--	--	*.023 (.061)*	*.036 (.173)*
SVF	*.023 (.111)*		*-.014 (.440)*	--	--	*.026 (.383)*
AL	--	--	--	*-3.909(.108)*	--	*-1.045(.716)*
R^2	.627	.385	.427	.546	.593	.674
F statistic	5.597	2.090	1.676	2.704	3.275	2.410
Case No.	14	14	14	14	14	14

Independent variable: UHI_{day}

Values in the parentheses are significant levels of variables.

As the first step stepwise regression is applied. The three most significant variables are BVF, SVF and GCR (Model 1). Secondly, regression analysis uses three variables representing variations in greening, i.e. GCR, TVF and LAI. The model generated explains 38.5% of variability in the dependent variable, and the F statistic is only 2.090, the model is not strong (Model 2). This suggests that variations in greening solely are not capable of explaining the majority of temperature variations. Based on this, the other three variables, SVF, AL and BVF were added to the model one at a time. It is found that, compared with Sky View Factor and Surface Albedo, the incorporation of Building View Factor significantly increase the R^2 (.593) and F statistic increases to 3.275. (Model 5) (In fact, in forward regression with sig. level set at 5%, only BVF is included in the model, with R^2=.379; F=7.330.) The model 5 suggests that an increase of 10% in Building View Factor increase UHI by 0.23%. As BVF indicates surrounding built density of the station, the finding shows the significance of including density parameters in study on greening in high rise built environments.

The magnitude of evapotranspiration (ET) of vegetation depends on the species of vegetation, local meteorological factors (solar radiation, temperature, air movement, humidity) and availability of moisture. In complex high rise building environment, ET of greening needs careful consideration. In all the five models in table 03, both coefficients of LAI and GCR show positive signs. This is possibly because that, for the outdoor area in Brilliant City, the ground is generally artificial surfaces with underground car parks. Unless regularly irrigated, the growing substrate for vegetation is usually shallow and unable to hold consistently enough water for one day period. During the survey, the author did not see any irrigating work in progress in the site. So insufficiency in moisture in soil could contribute to reduced ET of greening, and thus the cooling effect.

Further, as albedo tends to decrease with the increase of Green Cover Ratio and Leaf Area Index (Fig.04), so the stations with higher green cover and green biomass have higher net all-wave radiation, and thus more heat to dissipate (Grimmond et al. 1996). Since ET was suppressed as discussed above, the sensible heat fluxes were enhanced and so was higher the increase in air temperature.

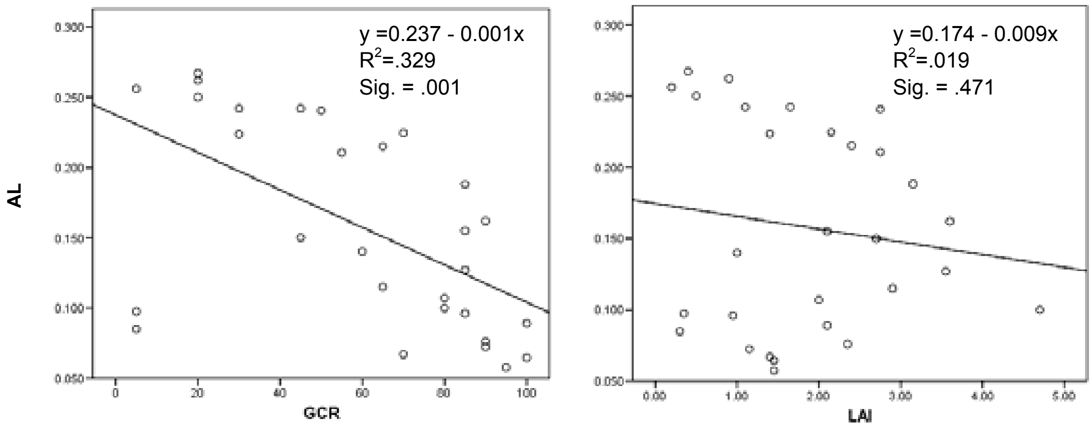


Figure 04: Albedo vs green cover ratio scatter plot (Up) and Albedo vs Leaf area index (down)

4.3.2 Daytime UHI in combined sites: impact of Building View Factor

Based on the findings from 4.3.1, the second phase regression analysis was carried out to test the hypothesis that high built density would dilute cooling performance of urban greening. All cases in two sites are included in the model, and natural variables WVD and SR are included. The results of regression models are presented in Table 06.

Table 06: Results of regression analysis with combined BCE and BCW

	Coefficients			
	Model 1: All cases (8 variables)	Model 2: All cases (4 variables)	Model 3: BVF<60% (4 variables)	Model 4: BVF>=60% (4 variables)
Constant	*-4.377 (.018)*	*-2.581 (.008)*	*-1.823 (.191)*	*-3.514 (.012)*
SR	*.013 (.000)*	*.014 (.000)*	*.013 (.006)*	*.017 (.000)*
TVF	*-.006 (.644)*	*-.018 (.047)*	*-.038 (.015)*	*-.007 (.551)*
LAI	*.110 (.447)*	*.129 (.209)*	*.467 (.025)*	*-.002 (.986)*
AL	*-1.162 (.515)*	*-1.377 (.312)*	*-3.650 (.114)*	*-.884 (.628)*
BVF	*.018 (.179)*	--	--	--
GCR	*.001 (.903)*	--	--	--
SVF	*.021 (.211)*	--	--	--
WVD	--[a]	--	--	--
R^2	0.667	0.631	0.745	0.768
F statistic	6.003	10.243	5.839	9.105
Case No.	29	29	13	16

Independent variable: UHI_{day}
Values in the parentheses are significant levels of variables.
Note: a. WVD is excluded from regression because of multicollinearity.

For linear fit estimation of each independent variable with the dependent variable, it is found the most significant variable is SR (R^2=0.525, F=29.827). The magnitude of SR in each site is the same, using the mean value from 1pm to 6pm. This finding suggests that despite variations in planning, building and greening descriptors, solar intensity still influences temperature pattern to a large extent. Secondly, stepwise regression was used to identify the variable set containing the most significant four variables. The four most significant variables are SR, TVF, LAI and AL (model 2 in Table 06). The model is totally different with model 1 in Table 05. This is because of the influences from the incorporation of SR and combination of cases of BCE and BCW.

As found in the previous sector, tree canopy cover intercepts solar radiation and helps lower air temperature. Therefore higher tree view factor should lead to lower UHI_{day}. In the BVF<60% model, the coefficient of TVF shows the right sign. While in BVF>60% model, although the sign remains negative, the coefficient is much smaller (-0.007 compared with -0.038) and the linear correlation is very weak (sig. = 0.551, compared with 0.015), it is therefore deduced that the higher building density, because of more radiation being blocked, introduces more uncertainty to shading and ET mechanism of vegetation at ground level, and is possible to dilute its cooling performance. Similar changes can be found in the impact of albedo. This is because in denser built surroundings, the cooling performance of high albedo surfaces is negated by enhanced multiple reflections between ground and vertical surfaces (Giridharan et al. 2004). But due to limited sample size in the models, further analysis with larger data sets is needed to confirm this finding.

6. Conclusion

1. Vegetation canopy above pedestrian level provides shade from solar radiation and reduce the increment of air temperature. A variable named Tree View Factor (TVF) used in this study is capable of quantifying vegetation canopies above pedestrian level at a certain point and it shows negative correlations with UHI in multiple regression models.

2. Green mass, quantified by Green Cover Ratio (GCR) and Leaf Area Index (LAI) are suppressed in evapotranspiration because of lack of water in substrate and high albedo in high rise residential developments in Shanghai. So they seem to have shown no cooling effect on outdoor air temperatures. But this still needs further study.

3. The combined impact of greening variables (TVF, GCR and LAI) cannot explain well the variations in UHI. Solar radiation has significant impact on UHI intensity. Building density is also found to have significant impact. In this study a variable named building view factor (BVF) is able to quantify the building density.

4. Higher building density blocks more radiation and introduces more uncertainty to shading and ET mechanism of vegetation at ground level, thus is possible to dilute its cooling performance. But further analysis with larger data sets is needed to confirm this finding.

7. Limitation and future study

Due to the logistic problem, this preliminary study measured only two sites with only one day period for each site. And the dates under measurement are not among the hottest days in Shanghai summer. These limitations could to some extent influence the data obtained and reliability of analysis. Despite all the limitations, the study yields reasonably good results, and testifies the method used in this study is reliable and applicable in larger scale data analysis. For future study, several issues should be addressed:

1. More extensive measurement is needed to be carried out in more sites with more diversified characteristics in building layout, surface material, green cover ratio etc. Each site is to be measured for a period of at least three days with similar weather conditions.

2. All wave radiation should be measured at each station, to calculate mean radiant temperature and other thermal index, in order to understand the impact of greening on human thermal comfort.

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EFFECTS OF INDOOR ENVIRONMENTAL QUALITY ON OCCUPANT COMFORT AND PERFORMANCE IN WORK ENVIRONMENTS

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Keywords: indoor environmental quality (IEQ), perceived IEQ, environmental comfort, comfort evaluation criteria, comfort indicators, psychological effects, work performance

Summary

This study attempts to examine how indoor environment influences occupant comfort and performance in work environments. As concern about environment and energy has been growing, indoor environmental quality (IEQ) has received considerable attention lately. However, there are gaps between actual measurements and perceived IEQ when evaluating environmental comfort. Understanding indoor environmental influences on occupants in buildings can be a way to achieve healthy environments as well as energy efficiency. Psychological factors such as natural light and personal control enable green or sustainable buildings to improve occupant comfort and performance, decreasing energy use. Human resources are the most expensive and the greatest resources of organisations, therefore, a small increase of employees' performance results in a great deal of benefit to organisations. This paper describes the IEQ factors affecting environmental comfort and work performance and develops a theoretical framework of environmental comfort-performance evaluation model. The comfort criteria is categorised into five areas: Thermal comfort, Indoor Air Quality (IAQ), Acoustic comfort, Visual comfort and Spatial comfort. The environmental comfort indicators for physical, physiological and psychological comfort are respectively proposed and the hypotheses based on the theoretical framework are also proposed in the present paper. A follow-up paper will report on detail studies of office buildings in Seoul, Korea.

1. Introduction

As concern about the environment and energy has been growing, indoor environmental quality (IEQ) has received considerable attention recently. Specific design features and technologies have developed to improve environmental comfort and energy efficiency such as advanced natural ventilation to help avoid air conditioning and glazing systems with better thermal and daylight performance (Cohen et al, 2001). However, research has focused on energy efficient and sustainable buildings rather than on occupant comfort because of the direct benefits to be made out of saving operational expenses in buildings. While the relationship between environmental comfort and employee performance is difficult to measure in comparison with more tangible benefits like energy savings, there is significant and growing evidence to support this link. Improved productivity and reduced absenteeism lead to potentially massive financial benefits when employees are physically and psychologically comfortable. Human resources are the most expensive and the greatest resources of organisations, therefore, a small increase of employees' performance results in a great deal of benefit (Becker, 1990, Becker and Pearce, 2003). Staff costs amount to 10-20 percent of a business total revenue. Given that 1 percent increase in staff performance can offset total energy costs, it is important that environmental conditions are conducive to productivity (Oseland, 1998). Green or sustainable buildings specially have potentials of the indirect benefits to be made out of increasing occupants' health, comfort and productivity because of psychological factors such as natural light and personal control. Therefore, a holistic approach to understanding the issues of environmental comfort and human performance should be required to find out the way how people feel or react in the work environment.

The primary aim of the present paper is to examine how indoor environment influences occupant comfort and performance in work environments based on literature. In order to achieve it, this paper describes the IEQ factors affecting environmental comfort and work performance and develops a theoretical framework of environmental comfort-performance evaluation model. The comfort criteria is categorised into five areas: Thermal comfort, Indoor Air Quality (IAQ), Acoustic comfort, Visual comfort and Spatial comfort. The environmental comfort indicators for physical, physiological and psychological comfort are respectively proposed and the hypotheses based on the theoretical framework are also proposed in the present paper.

2. Indoor Environmental Quality (IEQ)

Indoor Environmental Quality (IEQ) has received attention recently since people have been staying longer indoors. Indoor environment encompasses a range of components including temperature, humidity, IAQ, lighting, ventilation, noise and crowded work space (Clements-Croom and Baizhan, 2000). However, the early research of IEQ is more likely to focus on IAQ problems which come from the airtight buildings which were completed with the 1970's energy crisis. The buildings were designed to be sealed from outside air to save heating and cooling costs brought out the damage of environmental health. Therefore, guidelines and standards for acceptable air quality have set to resolve the IAQ problems. Furthermore, it has been found that the improvement of the indoor environment do not just include IAQ issue, other environmental factors, temperature, humidity, light, acoustic and even ergonomic factors, need to be considered to provide comfortable surroundings. The study of the indoor environment was initially approached from a technical or a medical point of view and the technical measurements in the indoor environment have typically been performed without taking the response of the occupants into account (Engvall et al.,2004). However, the measured and perceived conditions have been found to be different in field research (Leaman and Bordass, 1999) since there are some dominant components contributing to overall environment comfort and some combined effects between components.

The dominant components of IEQ are an important key to satisfy environmental comfort, allowing energy savings in a sustainable way. If an individual is comfortable with some components of their environments, they are more likely to forgive others (Bordass et al., 1995, Leaman and Bordass, 1999, Humphreys, 2005, Vischer, 2005). An attractive view from windows enables occupants not to complain of cool temperature or noise from outside. Clements-Croome (2000) stated that building users report most dissatisfaction with temperature and ventilation, while noise, lighting and smoking feature less strongly. It might be that temperature and ventilation can be affected by changes at all levels in the building hierarchy, and, most fundamentally, by changes to the shell and services. In comparison, noise, lighting and smoking are affected mainly by changes in internal layout and workstation arrangements, which can often be partly controlled by users. Recent studies show that temperature control and the provision of outdoor air are important considerations in energy efficient buildings in tropical climates (Sekhar et al., 2003, Tham, 2004). Thermal comfort and IAQ are two important aspects of IEQ that receive considerable attention by building designers and occupants (Humphreys, 2005, Huizenga et al., 2006). Satisfaction with air quality and thermal comfort is more important than satisfaction with the level of lighting or noise although the relative importance of the various aspects depends on personal preferences, types of tasks and climates (Humphreys, 2005). However, the satisfaction can be achieved by individual control such as personalized ventilation and individually controlled thermal environment, being compatible with energy efficiency and sustainability (Fanger, 2000). In addition, the combined effects of IEQ have been investigated by researchers, mainly focusing on the combined conditions of temperature and noise. Temperature and noise often interact in buildings since heating, ventilation and air-conditioning systems usually increase noise level to maintain thermal comfort requirements. Pellerin and Candas (2003, 2004) found that acoustic perception decreases when thermal environment is far from thermoneutrality. They concluded that interactions between environmental components do exist, right from perceptual level, and might explain some combined effects on cognitive performance in their studies.

Besides these physical components, psychological factors have an influence on the occupant perception in their environment. Occupant perception is the mediator of the relationships between objective measurements of distracting stimuli and subjective appraisals of social environment (Woo, 2008). Research has shown that numerous office workers considered their work environments to be thermally uncomfortable although measured conditions are within thermal comfort requirements. This occupants' evaluation demonstrates that the methodology of environmental comfort research need to include the discipline of environmental psychology in order to fully measure IEQ (de Dear, 2004). People who have greater control over their indoor environment are more tolerant of wider ranges of temperature (Leaman and Bordass, 1999). Therefore, the energy efficient way can be found without sacrificing environmental comfort; however, the combination of physical and psychological factors adds to the complexity of defining IEQ. The perception of different aspects of the indoor environment is of great importance since it influences both the behaviour and the comfort of the occupant. Moreover, perceptions and physiological symptoms are affected by psychological aspects as well as physical environment. Engvall et al. (2004) stress that perceptions and medical symptoms is not only related to the physical indoor environment, but also influenced by social and cultural impacts, organisational aspects, lifestyle, as well as personality aspects and other individual factors.

3. Environmental Comfort

3.1 Concept of environmental comfort

As the drive for energy efficient and sustainable buildings continues, there has been interest in a wider definition of comfort that might allow future energy savings. Comfort has been meaningful beyond physical relaxation across various disciplines. Occupational health studies define comfort as having some control over the psychological and the physical aspects of an environmental situation. Researchers have long argued that a key way to increase workers' psychological comfort is to provide them with some control over the space they occupy (Vischer, 2005). In the built environment context, the ASHRAE definition of comfort is "the condition of mind that expresses satisfaction with the thermal environment; it requires subjective evaluation". This clearly embraces factors beyond the physical and physiological, therefore, the physiological neutrality may be precondition of comfort (Auliciems and Szokolay, 1997). The term of environmental comfort can be defined as a concept experienced by human beings and developed in their daily interaction with the environment, which means a balanced state of physical, physiological and psychological comfort between a human being and the environment.

3.2 Environmental comfort indicators

The environmental comfort incorporates physical, physiological and psychological comfort. The physical comfort is an essential prerequisite of the environmental comfort and brings about physiological and psychological comfort (Vischer, 2005). Physical comfort is typically provided through codes, standards and norms for building safety and health and also includes building convenience such as access, service and maintenance. Traditionally, only few relevant standards of IEQ have been addressed such as ventilation (ASHRAE, 2003) and thermal comfort (ISO, 2003, ASHRAE, 2004). The standards and guidelines are based on average values for a large group occupant; however, field studies demonstrate that there are substantial numbers of dissatisfied people in many buildings, even though existing standards and guidelines meet the requirements. The reason is that the level of requirements specified in these standards are relatively low in comparison with occupant expectation (Fanger, 2000), or there could be individual differences and preferences (Melikov et al., 1994).

Physiological comfort is obtained by the human body's operating controls, however, people often feel unwell for no apparent reason when they are in a building. This symptoms can be explained as the term sick building syndrome (SBS), which is a situation in a building where more people than normal suffer from various symptoms. According to a World Health Organisation working group (WHO, 1983), the SBS is characterised by the following: eye, nose and throat irritation; a sensation of dry mucous membranes and skin; skin redness; mental fatigue; headache; a high frequency of airway infections and cough; hoarseness; wheezing, itching and non-specific symptoms such as: nasal dryness; nasal congestion (stuffy, blocked nose); nasal excretion (runny nose); pharyngeal symptoms; difficulty in concentration; and difficulty in breathing and tight chest (Seppanen et al., 1999). The symptoms tend to increase in severity with the time that people spend in the building and to improve or disappear when people are away from the building. The SBS symptoms are also associated with common illnesses and allergies, usually in a relatively mild form so that many sufferers may not see a doctor and may not take time off from work (Appleby, 1996). Therefore, the SBS symptoms can be the indicators for the measurement of physiological comfort in buildings.

Psychological comfort depends on privacy, control and crowding in the work environment. The definitions of privacy focused on a person's right to individual privacy, to be alone and away from other people in the early literature (Chapin, 1951, Bates, 1964) and then expanded beyond the definition to include a person's environment (Bellingar and Kupritz, 2006). Therefore, privacy can be defined as the regulation of interaction between individuals and/or their environmental stimuli with the ability to control it depending on the situation (Kupritz, 1998, Woo, 2008). Personal control can be one of important factors to achieve productive work environments in terms of energy savings and workers' productivity. It is vital to give occupants power of intervention to control their environment. Workers' control over the physical environment-both actual and perceived-can enhance physical health and offset the stressing effects of heavy workloads and fast work paces (Bellingar and Kupritz, 2006). Crowding is the experiential state, in which the restrictive aspects of limited space are perceived by the individuals exposed to them. Crowding appears to arise through the proximity of density with certain social and personal circumstances which sensitise the individual to the potential constraints of limited space. The particular form of one's response to crowding will be a function of the relative intensity of spatial, social and personal factors, and the degree to which they can be modified (Stokols, 1972).

4. Work Performance

The literature that attempts to link office environments and productivity largely addresses the physical environment. However, there appears to be no universally accepted means of measuring office productivity, it is a key issue how to measure productivity, especially for non-repetitive, knowledge work. As a result of this difficulty, research in office settings often resorts to a self-assessed measure of productivity which is better than no measure of productivity (Heerwagen, 2000, Haynes, 2007). The term "productivity" can be defined as the ratio of effectiveness (output) to the cost of achieving that level of effectiveness (input), on the other hand, performance is defined as behaviour with an evaluative component, thus in this study, the term "performance" is used as a broader meaning, focusing on human behaviour.

4.1 Physical environment and work performance

Research on physical environment with work performance can be categorised into two main topics: environmental comfort and office layout. However, the physical environment literature reviewed appears to lack theoretical framework even though it has shown sufficient empirical evidence. In general, studies of the IEQ in work environments including temperature, lighting, noise and existence of windows suggest that such elements of the physical environment influence employee attitudes, behaviours, satisfaction and performance (Crouch and Nimran, 1989, Veith and Gifford, 1996, Larsen et al., 1998). The improvement of IEQ results in the increase of employees' performance. Indoor environmental conditions may directly influence the performance of physical and mental work. An early study for the Westinghouse Furniture Systems Company in Buffalo, New York (BOSTI, 1982) suggests that the physical environment for office work may account for a 5-15 percent variation in employees' productivity (Clements-Croome, 2000). Recent studies constantly show that improvement of IEQ increases office productivity (Vischer, 1989, Sundstrom et al., 1994, Fisk and Rosenfeld, 1997, Veitch and Newsham, 1998, Heerwagen, 2000, Leaman and Bordass, 2001, Wyon, 2004, Aye et al., 2005) Therefore, the general conclusion could be that people do more work on average work day if they are physically comfortable (Clements-Croome, 2000).

In the early literature, two characteristics of the indoor environment influencing the performance seem dominated: thermal conditions and lighting (Sundstrom,1986, Lorsch and Abdou, 1993, Fisk and Rosenfeld, 1997). Bedford (1949) concluded that there was a close relationship between the external temperature and the output of workers: Decreasing performance is partially attributable to heat. Kamon (1978) shows that heat can cause lethargy which not only increase the rate of accidents but also seriously affect productivity. Lighting was another important factor in early work environments, specially in manufacturing industry, since it seems to affect directly the work output. Thus, the brightness of lighting was most concerned and any other than visibility was not questioned. Performance increases with added light, however, each increment in brightness of light brings less benefit and the benefits are smallest for the least difficult task (Sundstrom, 1986). However, the industrial structure has changed from manufacturing industry to service industry, and even further to knowledge based work with the exceptional development of the information technologies. Accordingly, the term “work” has also changed and the meaning of office worker can be defined as a person who performs their tasks using office information technologies, sharing their knowledge with their colleagues. Approximately 80 percent of all tasks performed in an office are visual task by using a wide range of visual display terminals. Therefore, the brightness of lighting has become a less important factor of IEQ, but overall visual comfort including light quality eliminating discomfort and natural light and view enhancing moods and reducing work stress, has been weighed instead.

Apart from the direct connection between worker performance and IEQ, there is also the evidence of association between ventilation rates, IAQ, SBS symptoms and employee performance. Researchers have shown that productivity in the office environment is sensitive to poor IAQ, and this is linked to SBS symptoms (Abdou and Lorsch, 1994, Holcomb and Pedelty, 1994). Furthermore, perceived air quality, SBS symptoms and performance of office work were studied in a real office space at three levels of air temperature and humidity and two levels of ventilation rate. Performance of office work was not significantly affected by indoor air temperature and humidity. However, several SBS symptoms were alleviated when the subjects worked at low levels of air temperature and humidity, which implies that a longer term exposure to low indoor air temperature and humidity might help to improve the performance of office work (Fang et al., 2004).

The literature relating to the office layout has been debated on open-plan verses private offices, mainly focusing on the matching of the office environment to the work processes. It could be argued that the open-plan office has led to cost reduction and communication increase, however, there are more distractions in open-plan offices than in conventional private closed offices (Brookes and Kaplan, 1972, Canter, 1972, Hedge, 1982). Noise is the major source of distraction for employees in relation to open-plan office debates. It was found that noise coming from telephones, conversations, ventilation system, and office equipments was related to distraction and openness. Also, the potential tension that can exist in the office environment between individual work and group work is established. If the office environment is to act as a conduit for knowledge creation, and knowledge transfer, then offices need to allow both collaborative work and individual work to coexist without causing conflict between the two (Haynes, 2007).

4.2 Psychological effects and work performance

The difficulty of research exists in this area because of the complexity of defining and measuring human performance in real-world environments. There are also many other factors influencing performance beyond the physical factors, specially naturalistic features such as daylight, views and natural or urban settings with trees can bring about positive effects on employee performance. The main benefits of natural light are psychological improvements such as increasing comfort levels and reducing stress. They have broad effects on physical health, mood, behaviour and productivity, regardless of an individual’s gender, position or task. Reduced stress and a great level of comfort affect both productivity and performance. A study of daylight in schools shows that students with the most daylight in their classrooms progressed 20 to 26 percent faster on math and reading tests and were found to have 7 to 18 percent higher scores than students in rooms with the least daylight (Heschong, 2002). There is also a sizeable and growing evidence to suggest that giving office workers a view outdoors, especially a view with natural elements, is beneficial. In Biophilia, Wilson (1984) suggests that natural views play such a powerful role in the well-being of humans since the human brain evolved in a natural setting, where many significant factors played into survival. Research has shown that employees with a natural view express less job pressure and more job satisfaction, and recover from stressful situations more quickly (Bouberiki et al., 1991, Ulrich et al., 1991, Heerwagen and Wise, 1998, Leather et al., 1998, Heerwagen, 2000). Leather et al. (1998) determined that external views of natural settings helped to buffer the negative impact of job stress. Further, Stone and Irvine (1993) found that the presence of windows did not affect performance but appeared to support job task demand.

5. Comfort-Performance Evaluation Model

The following environmental comfort-performance evaluation model can be proposed based on the relevant literature. People judge their environments with subjective averaging process in order to reach their overall assessment. In this process, people judge their indoor environments according to how they feel in their environments: whether the temperature is warm or the air is fresh, not according to measuring temperature or carbon dioxide(CO_2) levels.

The theoretical framework of the environmental comfort-performance evaluation model (Figure 1) is based on the theories of environmental psychology, specially derived from Lewin's equation (1951). In principle, B=f(PE); behaviour(B) was viewed as a joint function of personal factors(P) and the perceived environment(E). In this formula, the person and the environment are interdependent variables. In the comfort-performance evaluation process, the physical comfort affects directly overall comfort and work performance as well as physiological and psychological comfort. Brunswik's lens theory (1956) can be adopted in this process, it is describing individuals' perceptual processes when making judgement in response to the environment. Brunswik emphasized the importance of the subjective or perceived environment as a determinant of behaviour and argued that complex stimuli are focused into a single perception of the environment as though through a lens.

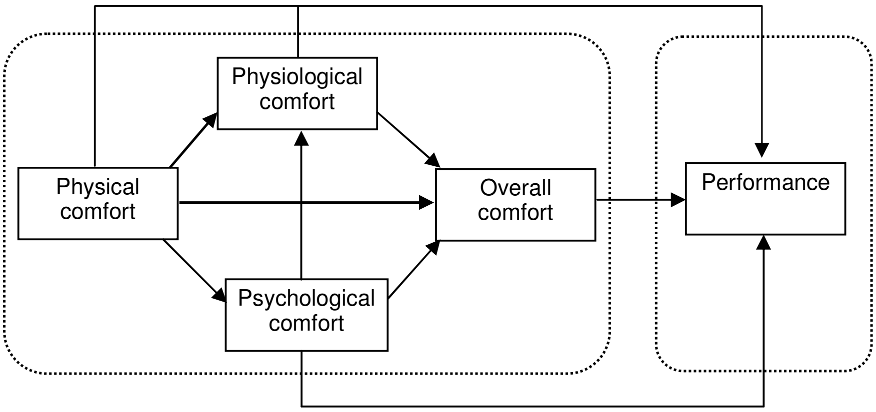

Figure 1 Comfort-Performance Evaluation Model: Theoretical Framework

Based on the literature and theoretical considerations, the following hypotheses are proposed:

H1: That thermal comfort and IAQ are dominant elements when occupants evaluate overall environmental comfort

H2: That the improvement of occupant comfort has positive effects on employees' performance

- That physical, physiological and overall environmental comfort influence employees' performance at individual level
- That psychological comfort affects employees' performance at interpersonal level

H3: That psychological factors have positive effects on occupant comfort, thus improving performance in sustainable or green buildings

6. Conclusion

In conclusion, this study attempts to examine the variables predicting environmental comfort and performance in work environments and develop the theoretical framework of the environmental comfort-performance evaluation model. The environmental comfort incorporates physical, physiological and psychological comfort, it is a concept experienced by human beings and developed in their daily interaction with the environment. Therefore, a holistic approach to understanding the issue of environmental comfort and human performance should be required to find out the way how people feel or react in the work environment. It can be an energy efficient way without sacrificing environmental comfort in buildings, thus increasing the indirect benefit from occupants' health, comfort and productivity.

Based on the literature, it could be hypothesised that there are dominant IEQ components such as thermal comfort and IAQ, thus these factors have stronger effects on overall environmental comfort than other factors. However, psychological comfort could influence occupants' comfort and performance, specially in green or sustainable buildings with more natural features. The present paper only presents a first step to evaluate buildings with post occupancy evaluation method which can be used to systematically examine building performance. Further research will be carried out to make a systematic tool based on the theoretical framework and test the validity of this comfort-performance evaluation model in field study.

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RESULTS OF A TRIAL OF URINE-SEPARATION AND DRY COMPOSTING TOILETS IN A SECONDARY SCHOOL

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Summary

The Victorian Smart Water Fund, the Department of Education and Early Childhood Development Victoria, GHD and other parties involved have funded a trial of 6 dry composting toilets and 2 waterless urinals at a new secondary school at Maryborough in Victoria. The installation was commissioned in April 2007 and results to date indicate a reasonable level of acceptance by students, good performance in terms of no odour, no fly nuisance, no operational difficulties (despite significant vandalism) and reasonably low energy use for ventilation. The paper presents data on ventilation, temperature records, energy use and quantities of residues that is difficult to find elsewhere.

To date usage has been lower than expected and quantities of urine and compost have been insufficient to undertake the proposed trial use of these materials in agriculture.

Whilst the installation cost (around 28 000 AUD/fixture in this case but potentially around 10 000 AUD/fixture) is considerably more than water flush toilets (around 4 000 AUD/fixture), it is concluded that the overall economics of dry sanitation will become favourable in a situation where water and fertiliser costs are likely to increase faster than other costs. Wider application of this sanitation approach is justified.

1. Previous Conclusions on the Feasibility of Urine-Separating Dry Composting Toilets

The UN has declared 2008 the International Year of Sanitation and there is an urgent need to assist the 2.6 billion people in the world today who lack adequate sanitation. With increasing population, declining rainfall in many areas and the need to reduce fossil fuel use, waterless sanitation systems that also recover nutrients offer a more ecologically sustainable solution than water-flushed toilets. Such systems are probably the only affordable option for those lacking sanitation and they have significant advantages in locations where there is already sewerage. Figure 1 shows the proportions of key components of domestic sewage that are contributed by each resident from the toilet. In the case of nitrogen and phosphorus, the majority of the contribution comes from urine.

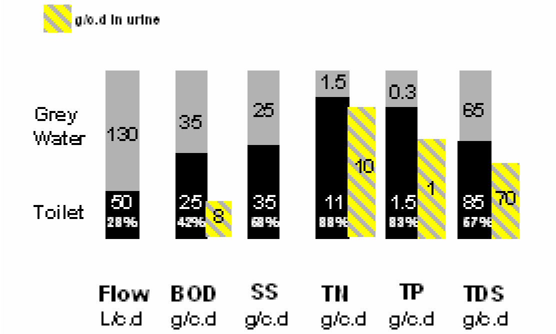

Figure 1 Load Components from Sewage & Grey Water.

There has been considerable research around the world into both urine separation and agricultural use and into composting toilets. A recent report for the Smart Water Fund (an initiative of the Victorian Government and the Victorian water industry supporting the development of innovative water conservation, water recycling and sustainable biosolids solutions) (GHD, 2003) reviewed much of this work and concluded that advantages of a dry sanitation system include:

- up to about 19% of an average household water usage (around 18 kL/c.yr saved out of 96 kL/c.yr currently used by the average Melbourne household) and up to about 28% of domestic sewage discharge would be avoided by eliminating toilet flushing.

- over 80% of the nitrogen, phosphorus and potassium, around 55% of the total salts and 25% of the BOD discharged by a household to sewer can be recovered in a transportable, stabilised and reusable form with low pathogen content.
- other technologies for reducing water use such as dual, low and vacuum flush toilets and the use of recycled grey water or roof water for flushing do not have the advantage of reducing pollutant, salt and nutrient loads to sewer.
- odour is generally not found in the toilet room because of the required ventilation of dry toilets and the overall health risks to householders and sanitation workers are assessed as being no higher than with conventional sewerage.

The report also concluded that the cost would be higher than providing water flush toilets (an additional 3 000 AUD to 6 000 AUD per fixture in an existing residential apartment block) due to the on-site equipment requirements and building construction that allows gravity fall of solids into the composters. These costs could be reduced to 1 500 AUD per fixture in new dense urban development by initially designing buildings for dry sanitation (GHD, 2003). However, the cost of dry sanitation were estimated to be comparable with conventional sanitation if overall community costs for the sewerage system were included, since dry on-site systems avoid (or reduce the size and treatment capacity required in) a municipal sewerage system.

Interest from parent representatives involved in the design of a new school in Maryborough, Victoria, spurred the Victorian Department of Education and Early Childhood Development to commission GHD to undertake a feasibility study of providing urine-separating composting toilets in schools (GHD, 2005).

This feasibility study included a comprehensive risk assessment, which concluded that only a small number of additional risks were identified for urine-separating composting toilets compared to water-flushed toilets. Of these, the health risks related to flies gaining access to the toilets were seen as potentially most significant, however there was insufficient information available to quantify this risk and monitoring of flies was identified as a key need for the trial. The risk assessment also addressed misuse and vandalism, concluding that whilst more significant for urine-separating composting toilets, these risks would be manageable. Overall it was concluded that the use of urine-separating composting toilets would not present a higher overall risk than having an on-site treatment system for conventional water-flushed toilets.

The feasibility study's final conclusion was that a trial was warranted, since there is limited data and experience from operating facilities that include both urine separation and composting of faecal matter and toilet paper. The Department of Education and Training agreed to a trial installation at the Maryborough Education Centre. A successful application was made to the Smart Water Fund for assistance with funding of this trial with other contributions coming from the Department, GHD, Oaten Stanistreet Architects and Environment Equipment Pty Ltd, the suppliers of Rotaloo® composting toilets.

2. Description of the Maryborough Education Centre Installation and Operating Experience

2.1 The Maryborough Education Centre

The secondary section of the new Maryborough Education Centre caters for about 1 000 students and contains five student toilet blocks plus staff toilets. .

Figure 2 The urine-separating dry composting toilet block and greenhouse enclosure.

Figure 3 From left: composters, leachate storage tank and urine tank.

Figure 4 One of the urine-separating pedestals.

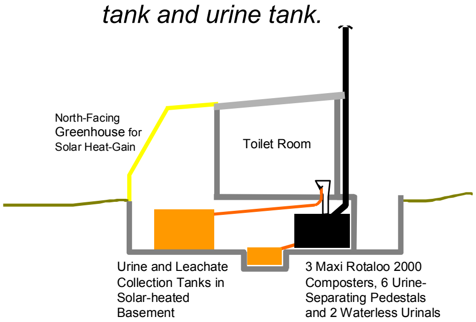

Figure 5 Cross section of the toilets.

Figure 2 shows the toilet block and its greenhouse-type west-facing structure. The three pipes pointing up from the ground on the right are from an in-ground biofilter, which removes odour from the urine and leachate tank vents. Figure 3 shows the basement below the toilet rooms with three composters on the left, the leachate tank to collect liquid from the composters in the centre (in the floor) and the edge of the separated urine tank on the far right. Figure 4 shows a urine separating pedestals. Figure 5 shows a cross section of the installation

2.2 Equipment and Capacity

The three Rotaloo® Maxi 2000 composting toilets were supplied by Environment Equipment Pty Ltd. Each has two ceramic urine-separating pedestals and eight 50 kg capacity HDPE compost bins on a carrousel within the HDPE composting container. The female toilet has four pedestals and the male toilet has two pedestals and two waterless urinals. Urine that is separated flows via PVC pipes to a 4.3 kL HDPE urine holding tank. Unseparated urine drains through the holes in the bottom of the composting bins on the carrousel, collects in the base of the composters and flows to a 2.7 kL leachate tank. The composters and tanks were sized based on the assumption that approximately 200 students over normal school hours and that, whilst at school, they would contribute 30 percent of published daily urine and faecal loads from adults. It was estimated it would take 0.5 to 1 year to fill the urine and leachate tanks and around 1 to 2 years to fill all 24 compost bins. Table 1 shows the estimated loads from this usage.

Table 1 Estimated Loads from 200 Users

Component	Yearly Loads kg/yr (based on 200 users on school days)			
	Compost	Clean Urine	Leachate	Total
Total Nitrogen	20	60	30	110
Total Phosphorus	10	10	0	20
Potasium	10	10	0	20
BOD	400	80	40	260
Organic Carbon	200	40	20	260
Total Salts	300	400	200	900
Calcium	10	0	0	10
Magnesium	0	0	1	1
Sodium"	10	20	10	40
Total Solids	500	400	200	1100
Water	200	7 400	3 500	11 100
Total Mass	700	7 800	3 700	12 200

These loads equate to 20 g of faecal matter and toilet paper per day and 320 mL of urine and leachate per day per user.

3. Experience and Quantitative Results to Date

3.1 Approvals

Current guidelines and regulations in Victoria are not established to address either urine separation or off-site use of residues on agricultural land surfaces. This meant the approval process for the installation involved several steps. Health risks were extensively researched and presented, along with details on the proposed agricultural trial and monitoring, to both the Victorian Environment Protection Authority (EPA) and the municipal council. The EPA advised that the composter type proposed was on its approved list, that this approval extended to use in schools and that it would have no objection to the trial, provided a number of conditions were met: the agricultural use of residues complied with published requirements for application of biosolids; the Chief Veterinary Officer of Department of Primary Industries had no objections; and the municipal council approved the installation and agricultural use on the nominated farm. Council required that a formal application and fee be submitted as for a septic tank permit application, although there are few similarities with a septic tank. Council also had concerns about the agricultural trial. The farmer who agreed to accept the residues for trial application was concerned about the effect on his ability to sell sheep, as farmers must complete a statutory declaration to confirm the sheep they are selling have not grazed on contaminated pastures (this largely relates to pesticide application rather than the materials from the trial).

Approvals from all stakeholders were eventually gained but the experience confirmed the feasibility study conclusion that regulation in Victoria will need modification to more appropriately regulate such installations.

3.2 Construction Costs

Table 2 sets out the estimated and actual costs for the installation and the capital cost per fixture, disregarding costs which are equivalent for composting and conventional toilets (eg toilet room, handwash basins). The actual costs do not include costs of monitoring equipment purchased purely for the trial and water metering to the hand-wash basins and to another toilet block in the school to allow comparison of water use (which added 27 000 AUD to the capital cost).

Table 2 Estimated and Actual Capital Costs (AUD)

	Urine-Separating Composting Toilets			Conventional Toilet Option (20 fixtures)
	Estimate (20 fixtures)	Actual (8 fixtures)	Estimated Minimum (20 fixtures)	
Total Capital Cost	318 000	226 000	211 000	81 400
Capital Cost per Fixture	15 900	28 000	10 600	4 000

Thus, prior to construction, it was estimated that the urine-separating composting toilets would cost around 12 000 AUD more per fixture than conventional water-flushed toilets but that, if the building arrangement had been different, this difference could reduce to around 6 600 AUD. The cost of the Rotaloos, pedestals and urinals is understood to have been only around 10 000 AUD of the 226 000 AUD actual cost.

The actual capital costs, which include an allowance of 10% for design and project management costs, were higher than estimated, 28 000 AUD/fixture or 24 000 AUD/fixture more than conventional toilets, for a number of reasons. First, the building was constructed as a slab-on-ground structure on rock. The cost of constructing and providing drainage to the basement for the composters and tanks was significant and could have been reduced if the building was constructed on sloping ground on piers, allowing sufficient under-floor space. This would have been feasible on the site but design of the buildings had progressed significantly before the trial was commissioned. Secondly, a contractor was engaged before the design was complete, which meant significant contract variations were required to complete the works. In addition, the urine and leachate tanks were custom-built by the contractor rather than using standard plastic tanks or bladders. Thirdly, the installation includes a significant number of items installed specifically for the trial, including hot and cold water hand-washing facilities in the basement, plumbing that allows later conversion to water-flush toilets if required, a natural gas supply in case supplementary heating is required and additional electrical supply for monitoring equipment. Experience to date is that the greenhouse could have been simplified and made smaller and a smaller basement could have been built if the urine and leachate tanks had been constructed below the ground outside the building. Overall, it is considered that the original estimate of the minimum capital cost or around 84 000 AUD for 7 fixtures should be achievable.

It is concluded that urine-separating composting toilets can be installed for an additional cost per fixture of somewhere between 6 000 AUD and 10 000 AUD per fixture over that of water flush toilets and possibly less in large installations with suitable building design.

3.3 User Training and Surveys

In February 2007, short information sessions were run for students and staff at the toilets during orientation tours of the new school buildings. The purpose of the information sessions and accompanying display was to explain the objectives of the trial, give insight into the installation and emphasise the importance of getting a significant level of use of the toilets. The need to keep toilet lids closed was also stressed.

Further training was undertaken with Year 8 students and staff to coincide with their Term 3 project focusing on "Sustainability in the Home". Feedback from this session was positive and the student responses indicated that a much better understanding of the urine-separating dry composting toilet installation had been gained. Additional presentations to most year levels were completed in June 2008.

User surveys have provided feedback about the level of knowledge of the trial and acceptance of the composting toilets and urine separation in general.

The first survey (distributed in March 2007 prior to any training or usage of the toilets) found that: (1) students did not have very good knowledge of and had rarely used composting toilets, urine separating systems or waterless urinals; (2) students were somewhat deterred or unsure if they would be deterred from using the facility once they knew the toilets were unconventional; and (3) staff had more knowledge and experience than students of composting toilets and waterless urinals and were generally more open to their use once they knew the toilets were unconventional.

The second survey (distributed in June 2008 after the further training had been conducted and the toilets had been in use for 15 months) found that: (1) usage of the toilets had been low, with key reasons for low usage identified as their remote location, inconsistency in being open and available for use and the fact that the toilets attract students who smoke; (2) students knew the toilets existed but did not feel they had been provided with enough information about them, although they were aware of the environmental benefits associated; and (3) students who had used the toilets found the experience to be surprisingly positive.

3.4 Operating History

The new school was opened and the installation was commissioned in April 2007 on the first day of the second school term. Since commissioning the male toilets have been open for a total of over 160 days and the female toilets for a total of over 125 days to July 2008.

There have been several periods when the toilets have been closed. A seven week closure of both male and female toilets occurred in November 2007, when heavy rain caused the leachate tank to float in the basement floor, necessitating repairs. Other closures have been in response to a few students smoking in the toilets and dropping cigarette butts and lighted paper down the toilet pedestals. Mostly, the lighted material has not caused any damage but on one occasion, the contents of a compost bin smoldered and generated significant smoke. This risk was not identified in the original risk assessment and has been exacerbated by the low use leading to drying out of the compost bin contents. Since identification of the risk, water is added daily to each of the six operating compost bins, in summer at a rate of 1.5 L/bin.day.

Throughout the trial to date there have been no complaints about flies and no complaints about odour during school hours. Regular checks and recoding have not observed flies in or emerging from the composters or pedestals or congregating in the toilet rooms. This was contrary to expectations since the author's experience is that development of Drisophila *melanogaster* (fruit flies) in compost is very common and larger flies are also attracted.

Users have not reported any toilet odour within the toilet rooms. The only toilet odour observed has been noted by the cleaners when timers controlling the ventilation fans have failed, leading to no ventilation flow in the period before school when the cleaners open the toilets. The urine and leachate tanks are sealed to prevent odour release. The urine tank inlet pipe and tank overflow pipes are equipped with a water seal. There are air vents from both tanks which discharge into the base of an odour control biofilter. Some odour has been noticed by the authors from the roof vents of the composters on cold mornings around the outside of the toilets but this has not been noted during school hours or led to complaints. There is minimal odour release when the composters are opened to inspect bins as the fans remove most of the odourous air. The urine and leachate in the holding tanks has a strong amine/ammonia odour but this is only noted when the inspection hatches are open, not when 50 mm caps are removed to take depth measurements.

Usage of the toilets has been much lower than the expected 200 students per day. The quantities of material collected (a total of around 500 L of urine and leachate and 22 kg of faecal matter and paper) have been insufficient to carry out the proposed agricultural trial of use of residues. Data on actual versus expected urine volume suggests that there has been an average only around seven uses per day (male and female combined). Data on the mass of faecal matter and paper collected suggests that there has also been an average of less than 3 uses per day. This is based on the number of days the toilets have been open and assumes that each urination contributes 0.3 L and each defecation contributes 50 g of semi-dry compost (including toilet paper) containing 30% moisture. Testing has yet to be completed to determine the actual water content of compost.

3.5 Useful Data Obtained

3.5.1 Air handling and odour control

Each composter has a 19 W mains-powered educt fan which exhausts air to a vent above the roof line. These three fans are controlled by time clocks to limit energy consumption and also to prevent drawing cold night air into the composters. Up to May 2008 they were switched on at 5 am and turned off at 6 pm with three 15 minute operations during the night. This was sufficient to prevent toilet odour within the toilet rooms but timer failures lead to some odour incidents so fans have been left on with no odour reported since.

The educt fans maintain a slight negative pressure within each composter, which draws air from an inlet as well as down through the pedestal when the lid is open. The latter air flow, the velocity of which has been measured to be around 0.2 m/s across the cross section at the level of the seat when the lid of one of the two pedestals is open, ensures that no odour from the composter is released into the toilet room. The volumetric flow of air down an open pan is approximately 0.02 m^3/s, which is around 50% to 60% of the 0.03 to 0.05 m^3/s of air flow induced by each composter educt fan. The remainder of the air flow into each composter comes from a duct system designed to draw warm air from the greenhouse roof. Some of this warmed air is transferred by a solar-powered fan and heating panel from the top of the greenhouse. This flow has been measured as up to 0.02 m^3/s or about 20% of the air total educt air flow from the three composters. The remainder of the air enters the composter via leaks and the pedestals. There is an additional mains-operated fan which draws air from the top of the greenhouse and discharges it close to the composters. This warmed air transfer fan is operated from around 8 am to 4:30 pm.

3.5.2 Monitoring program and temperature and relative humidity monitoring results to date

The following measurements are being taken as part of the project's ongoing monitoring program:

- compost, urine and leachate temperature,
- air temperature, relative humidity and velocity in various locations including each Rotaloo exhaust, air distribution box, greenhouse, solar heater inlet and outlet,
- volume and specific gravity of leachate and urine,
- mass of compost,
- water flow into the site, to the trial toilets and to a similar conventional toilet block.

Water use in the hand basins has averaged around 12 L per operating day, which suggests about 2 L/use. However there was a period of unusually high water use. The added water has amounted to a further 6 to 9 L/d. It should be noted that if flush toilets were used, the expected water usage would be of the order of 30 to 50 L/d at the current usage levels.

Figures 6 and 7 provide an example of the temperature and relative humidity results obtained from the ongoing monitoring to date covering an 8 month period. Figure 6 shows no evidence of heating due to aerobic composting. This confirms the observation that the material is desiccating rather than composting. Figure 7 shows the same diurnal temperature variations in air leaving a composter and also indicates that, even with the greenhouse in place, it is not possible to get the air temperature up to a desirable in winter to assist composting. Nor has it been possible to keep the stored urine and leachate at 20°C, which has been shown to provide rapid die off of pathogens. Trial of a heating system is now in progress.

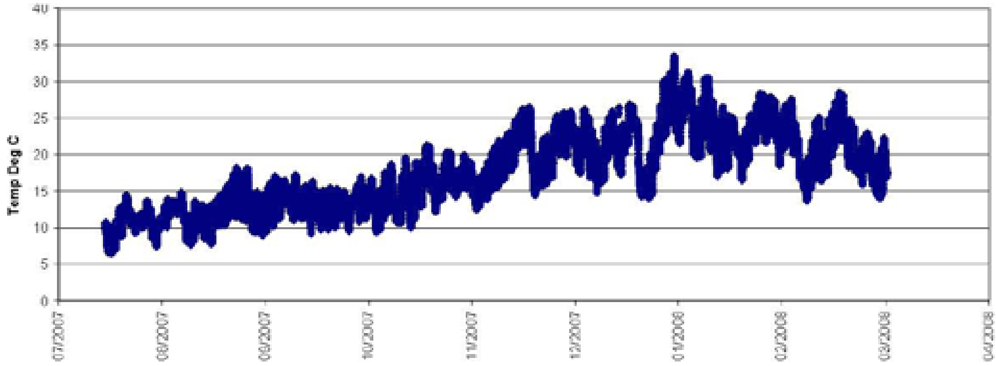

Fig 6 Compost Bin M Compost Temperature Deg C

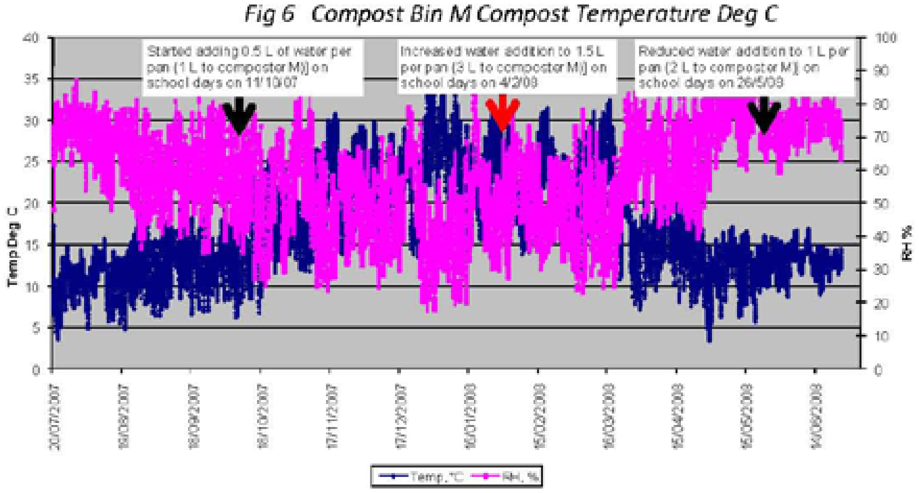

Figure 7 Male Rotaloo (M) Exit Air Temperature and Relative Humidity

3.6 Cleaning, Aesthetics, Acceptance

The operating and maintenance program was designed to ensure the toilets were pleasant and easy to keep clean. The cleaners, who also undertake some of the monitoring, keep the toilet pedestals and rooms very clean without adding water to the pedestals by using a 1:5 vinegar:water solution to wipe over seats and pedestal surfaces. The waterless urinals and other surfaces in the toilets are cleaned in a similar way. It has not yet been necessary to clean the drop pipes below the pedestals and these appear to remain clean. The cleanliness of the pedestals has been excellent with only occasional observation of faecal smears, no more and probably less than in public water-flushed toilets. This is an important factor in dry toilets, as inadequate design and inadequate cleaning results in unpleasant facilities and discourages use. However, the low usage to date means that this aspect has not been fully tested.

The architects were also requested to design the lighting so that it did not shine down the pedestals in such a way that the solids heap was visible. This objective was achieved successfully and it is difficult for users to see anything at the base of the composter drop ducts.

Further user surveys are necessary before reaching conclusions on acceptance. Reasons for low usage are not generally the fact that the toilets are non-conventional; however a minority of students have said that urine-separating composting toilets are unacceptable to them and they would not use them.

3.7 Health Risks

The low usage has delayed proposed testing of the compost, urine and leachate for indicators of pathogen presence. However, there has been no evidence of flies gaining access to the compost bins or of large fly numbers in the toilet rooms. To date, the conclusion from the risk assessment, that there was no significant risk to health, is supported by experience.

3.8 Student Behaviour

The toilet block is located at the end of a classroom pod and is hidden from view from most walkways and staffed office areas around the school. The nearest alternative toilet block has a tiled floor rather than the cheaper painted concrete in the trial toilets. The location is not ideal and there have been a number of instances of problem behavior. The only damage caused to the toilet equipment has been one broken seat and a fire that was started within one of the compost bins by dropping lit paper. It does not appear that dropping of cigarette butts into the toilets has caused the compost mass to burn. Further efforts are being made to encourage appropriate behavior and increased use of the toilets.

The conclusion from this experience is that location, design detailing, introduction of students to the toilets and ongoing discipline are major factors in the success of such a trial or permanent installation in a school environment.

4. Key Issues and Further Investigations Required

4.1 Composting versus Desiccation of Solids

The faecal matter and compost collected to date has shown no sign, either from appearance or temperature measurements, of composting. This is thought to be due to a combination of the low usage and drying by air flow. Urine separation does mean that the solid material will remain much drier than in standard composting toilets and it appears that there may be a need to add water to aid in composting. Addition of some water to maintain an non-flamable compost is desirable in any case. However, until usage increases it is not likely that the extent of composting can be fully investigated. Suppliers of continuous composters claim that the batch composting process such as that in the Rotaloo® leads to drying out of the solids once bins are moved away from below the pedestals. The indications from this trial is that in a school environment, the process may well be more desiccation of solids than composting.

4.2 Health and Aesthetic Issues with Residues

Once sufficient volume of urine, leachate and faecal matter/toilet paper is available, comprehensive physical, chemical and biological testing is planned. A key focus of this will be to check for faecal microorganism survival in both the solids and liquids and how this may vary with storage temperatures of the liquids and the storage/composting history of the solids. GHD (2003) reviewed the available literature on pathogen survival in separated urine and compost and concluded materials that could be safely used for surface application on agricultural land if the liquids were stored for 6 months or more at at least 20°C. Survival of pathogens in compost is dependent on temperature reached and since the data to date shows no elevation above air temperature, it must be concluded that pathogens are likely to have survived and the materials therefore will need further treatment before use on land.

4.3 Misuse

While the design of the facility has allowed it to operate despite some misuse, potential improvements have been identified: (1) toilets would ideally be located in areas of greater foot traffic, especially staff traffic, so they do not become a refuge for bad behaviour; (2) an automated wetting system in the compost bins using a simple garden watering spray system would be prudent, assuming that the desiccation that has been observed continues with increased usage. Alternatively or additionally, a smoke detector and spray system could be installed within each composter to guard against fire. Consideration was given to installing tobacco smoke detectors inside the toilets to detect smoker activity and alarm this locally and in a staff room. It was difficult to find suitable devices that would detect tobacco smoke; (3) the waterless urinals have a loose-fitting ceramic disk over the outlet. These discs have been occasionally been removed and dropped into the composters and clearly such loose items are undesirable; (4) signage needs to be largely out of reach and firmly attached; (5) solid padlocks are needed to resist vandalism and unauthorised entry to the equipment. Bad behavior by a few students can create an unpleasant and threatening environment in and around the toilets and that this contributes to low usage.

4.4 User Attitude and Acceptance

A further user survey will be carried out during the trial to gauge changes in attitudes and acceptance. The results of these surveys will be reported in the project report to the Smart Water Fund, which will be available on the Smart Water Fund website, probably during 2009.

4.5 Energy Use for Composting Toilets Compared to Conventional Sewerage

Conventional sewerage may be more energy-efficient than dry composting toilets installed with mains-powered ventilation fans (the current practice in most installations and the predominant method of ventilation at the Maryborough installation) (GHD, 2003). As such, energy use is being monitored during the trial and will be considered as part of an assessment of overall benefit. The need for supplementary heating in winter is being investigated and it is yet to be determined if composting (as against desiccation) ever takes place at the Maryborough installation. The need for supplementary heating in winter is being investigated and it is yet to be determined if composting (as against desiccation) ever takes place at the Maryborough installation.

Table 3 compares estimated energy use per capita of conventional sewerage with a composting toilet/grey water sewerage option for an urban area of a large city. The range for conventional sewerage relates to whether the sewage treatment plant generates some of its own energy demand from biogas or not. The range for composting toilets results from assumptions on supplemental heating and ventilation energy use.

Table 3 Estimates of Energy and Greenhouse Parameters for Sanitation Options

Energy or Greenhouse Measure	Conventional Sewerage (WC waste and flushing water)	Composting Toilets and Grey Water Sewerage
TOTAL MJ/capita.yr	248 - 540	171 - 529
Lifetime Emissions (50 years) tonnes CO_2e/capita	1.0 – 2.1	0.7 - 2.1

If mains-powered ventilation and supplementary heating is necessary to make the composting process and installation work effectively, composting toilet systems would use more energy than conventional sewerage with some energy generation from biogas at the sewage treatment plant. If ventilation fan energy is derived from solar power and if waste heat from the apartment or passive solar heat input is sufficient to keep the compost warm, then a sanitation system based on dry composting toilets with urine separation, trucking of residues up to 50 km (a 100 km round trip) and discharge of grey water to sewer will use less mains and non-renewable energy overall than a conventional system where the sewage treatment plant does not generate any of its own energy. This situation is typical of outlying areas with their own treatment plants. Further, the evaluation of energy use makes allowance for embodied energy in fertiliser saved by use of compost and urine on land.

The 19 W Rotaloo educt vent fans used on each of the composters at Maryborough were operated for 13.75 hrs per day, which was sufficient. There is one additional fan operated for 8.5 hours per day, which is used to move warm air from the top of the greenhouse down to the composter space. Thus total energy use for fans is estimated to be 290 kW.hr/yr (assuming 365 days of operation per year). If the units were installed in residential apartments they could service a population of 20 to 30 persons so the estimated annual energy use for the fans at Maryborough would be of the order of 10 kW.hr/capita.yr or 36 MJ/capita.yr which is within the assumptions used in Table 3. A solar-powered fan is used to force warmed air from the greenhouse via a heating chamber into the air distribution box for the three Rotaloos. If similar solar powered fans were used on the educt vents then fan energy use could be reduced significantly although in a normal residential situation some overnight operation would be required to control indoor odour.

5. Conclusions

Urine-separating composting toilets can easily be kept clean and properly controlled ventilation should eliminate smell from the toilet room. A biofilter on vents from urine/leachate holding tanks is recommended to remove all odour from this source. Bladders instead of tanks would avoid the need for vents.

It is feasible to turn ventilation fans off overnight if toilets are not open all the time, provided they are turned on at least 2 to 3 hours before the first use.

Trial in a residential situation would be desirable as the intermittent and low use experienced in a school limits the information that can be obtained and presents some additional challenges related to misuse.

The estimates of compost and urine/leachate volumes used in the design are probably more than adequate.

It is probable that use of rotary type batch composters coupled with urine separation will mean that desiccation rather than composting is the main mode of operation and, if so, the survival of pathogens in desiccated solids will need further investigation. An alternative may be to automatically add water to maintain moisture content in the solids closer to the optimum for composting.

For a greenhouse to effectively capture heat and keep the composters and storage tanks above the target of 20°C, it would be necessary to insulate the walls of the building (but still allow sun penetration), seal doors and other gaps to minimise drafts, and probably insulate the composters themselves. In addition, it may be necessary to reduce ventilation rates, particularly when temperature of the inlet air is less than 20°C. If desiccation is the mode of operation there would be no need for a greenhouse structure.

Urine-separating composting or desiccating toilets offer a more ecologically sustainable sanitation option than water-flush toilets and can be successfully used in schools.

Whilst the capital cost of this trial installation was very high compared to conventional water-flush toilets (an additional 24 000 AUD/fixture), a previous conclusion that urine-separating dry composting toilets can be installed for under 10 000 AUD/fixture is probably still valid. In order to minimise facility cost, the building should preferably be on sloping land and on piers or if slab on ground, with a basement design that minimises cost and uses tanks for urine and leachate that can be buried adjacent to the building.

With increasing costs of water and fertiliser, there should be no cost disadvantage. There may be cost advantages if wide-scale use of such toilets is adopted in future in school, public facility, commercial and residential settings. Such toilets already are seeing wide application in developing countries that do not have existing water-borne sewerage systems.

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SMART AND BIOCLIMATIC DESIGN: AN EFFECTIVE APPROACH TO THE SUSTAINABLE USE OF RESOURCES AND DEPLOYMENT OF LOCAL QUALITIES

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Summary

The seeming abundance of high-quality energy resources and easy access to inexpensive products and labour from anywhere have made many parts in the world dependent on regions elsewhere. The ecological footprint of richer countries demonstrates how severely this process has developed. As a result of this and of economic prosperity, man has often lost the ingenuity to make optimal use of features of the local environment.

Smart and bioclimatic design encompasses an approach that deploys local characteristics into the design of buildings and urban plans. These local characteristics refer to natural circumstances (the climate, seasonal changes, variation in the weather, diurnal differences, geomorphology, etc.) yet also to man-made interventions (such as the landscape, cultural, historical and technical features, and the built surroundings). Especially, a thorough analysis of climatic conditions and the intended use of a building or urban area can lay the foundation for a smart and bioclimatic design that uses much less energy and satisfies better the needs of users.

The paper will discuss the different definitions and theory of smart design and bioclimatic design. It will present a step-by-step approach to smart and bioclimatic urban environments and buildings. This is based on years of study and teaching to students of architecture, urbanism and building technology. Moreover, the students themselves have contributed to this knowledge through an academic subject, for which they were asked to write a designer's manual on smart and bioclimatic design in general or on a specific part of it.

1. Introduction

1.1 Globalism and interdependence

There once was a time when individuals and communities had to take care of themselves on the basis of locally available or locally grown resources. Trade, first with neighbouring communities, later with settlements farther off or indirectly, through intermediate merchants, enabled growth in wealth and luxury and substitution of local provision by supply from elsewhere. This made it possible for essential resources to rely on other regions whilst providing these regions with resources they lacked. Through the centuries this has brought mankind to a thriving global economy. However, it has also given rich countries an ecological footprint many times their own area, imposed on developing regions that thereby fall behind.

Since the industrial revolution the development as described in particular affected industrial products and the fossil fuels needed for them. The world has become increasingly dependent on high-quality energy resources: natural oil and gas, coal and nuclear power. With certain reserves in depletion man is putting a lot of effort to, firstly, reduce the demand for energy and, secondly, prolongation of the provision of finite energy resources. How successful this strategy may be, it will eventually prove to be the stay of inevitable execution.

And we should not forget that the development described, supported by ineffective movements of goods across the world, has been facilitated by economic prosperity on the side of rich countries. The downfall of this prosperity would demonstrate the mutual dependence of various regions in the world and it would necessitate severe measures.

1.2 The Titanic strategy or a reconsideration of local potentials

We are at the crossroads of a principal choice. Are we going to prolong our current system, confident of new technology to win the very last reserves, until we eventually are stuck with fossil fuel quantities insufficient to produce the equipment and infrastructure for sustainable energy (the "the orchestra plays on while the Titanic sinks" strategy), or are we going to head in a different direction? Regardless of the impact on the energy market and global climate, the Titanic strategy will lead to unavailability of oil for the production of irreplaceable synthetics and other valuable purposes.

Shortage often encourages ingenuity to provide oneself with limited resources. Apart from interdependence, prosperity has made many people lose the ingenuity to make optimal use of local features. Facing the problems of fossil energy depletion, a different strategy therefore would be a reconsideration of the potentials of the regional and local environment before a demand from sources from elsewhere. This approach can be applied to different scales, of which the building scale can be described by smart and bioclimatic design.

1.3 Smart and bioclimatic design, definitions

Smart and bioclimatic design encompasses an approach that deploys local characteristics into the design of buildings and urban plans.

The *climate design* of buildings encompasses the realisation of a comfortable environment inside and outside the building, regardless of the design, engineering and technology applied. *Sustainable climate design* aims at doing this by minimal consumption of energy and mitigated environmental effects. It is an expertise that integrates the basic knowledge of building physics and building services into the area of architectural design, with a focus on sustainable solutions for energy en comfort. Due to depleting energy resources and the demand for healthier indoor and outdoor environments, there is a growing need for a more sustainable climate design. There are several approaches to this, among which smart design and bioclimatic design.

Smart design is a vague term that is perceived differently in different countries. Related to 'intelligent' (Latin: 'intelligens' = distinctive, selective) it can refer to natural or artificial intelligence (Timmeren 2001). Natural intelligence is a natural generic cognitive ability to reason underlying processes in a conventional way. Artificial intelligence is the theoretical stream in informatics and psychology that is aiming at a perfect imitation of intelligent human behaviour by a computer. In terms of building, building management systems attempt to match this cognitive reacting: through specific programming input is processed (via sensors) to a desired output (Timmeren 2001). Over the latest decades in Western Europe the meaning of smart design and specifically *smart architecture* (Hinte et al. 2003) has shifted towards sustainable designs that intelligently interact with the environment.

Bioclimatic design has a more tangible meaning. Practised through hundreds of years but introduced as a common term by the Malaysian architect Ken Yeang, it is defined as "the passive low-energy design approach that makes use of the ambient energies of the climate of the locality (including the latitude and the ecosystem, through siting, orientation, layout and construction) to create conditions of comfort for the users of the building" (Yeang 1999).

The combination of both terms – *smart and bioclimatic design* (S&BCD) – encompasses a design approach that deploys local characteristics intelligently into the sustainable design of buildings and urban plans. These local characteristics refer to natural circumstances (the climate, seasonal changes, variety of the weather, diurnal differences, geomorphology, etc.) yet also to man-made interventions (such as the landscape, cultural, historical and technical features, and the built surroundings). In particular, a thorough analysis of climatic conditions and the intended use of a building or urban area can lay the foundation for a smart and bioclimatic design that uses much less energy and satisfies the needs of users better.

1.3 An incremental approach

Smart and bioclimatic design requires an incremental approach of three basic steps, preceded by a declaration of the basic indoor requirements.

It starts with a profound study of the natural circumstances of environment of the building in question. Natural circumstances involve climate, underground and man-made interventions. Each of the circumstances define the natural potential of the building site and therefore should be studied first if one wants to make the most of an energy-efficient building design.

The second step is the synthesis of the basic knowledge acquired to starting-points and boundary conditions for the energy-efficient urban plan and building design.

In the following sections, the steps toward smart and bioclimatic design will be exemplified by the case study of the new Dutch chancellery in Canberra, Australia (Dobbelsteen et al. 2008).

2. The start: basic declaration of the indoor climate

2.1 Fanger

The demand for energy in buildings originates in the indoor environment. Since the 1970s, comfort in buildings is based on findings by Fanger (e.g. 2002), who determined deviations from a mean comfort temperature (reference score: 0) in the indoor environment by scores from minus 3 to plus 3. The comfort temperature turned out to follow a slightly increasing outdoor temperature. Temperature transgression norms have been operated for decades on the basis of Fanger's work.

2.2 Adaptive thermal comfort

Recent investigations by Linden et al. (2006) supported Fanger's findings for entirely mechanically ventilated or air-conditioned buildings ('beta buildings'). However, for cases of high outdoor temperatures, there were discrepancies with partly naturally ventilated buildings (or with mechanical exhaust air extraction, 'alpha buildings'). Linden et al. found that building occupants accept higher indoor temperatures from certain outdoor temperatures, and hence that building services could be designed for higher indoor temperatures in summer (figure 1).

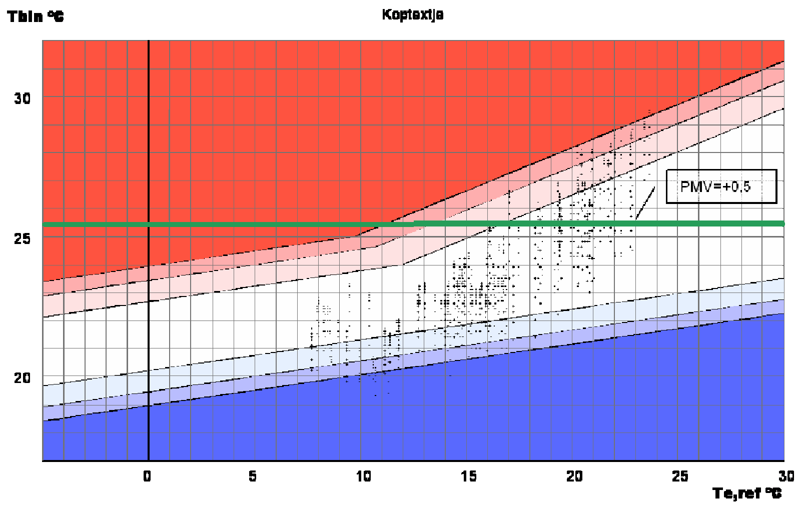

Figure 1 Comfort temperature (Tbin) at different external temperatures (Te,ref): high outdoor temperatures allow greater margins of indoor temperatures than initially perceived (Linden et al. 2006).

2.3 The importance to energy saving

Findings by Linden et al. enable less energy consuming buildings, in terms of reduced cooling demands in summer. In addition, the central climate utility in a building can be managed in such a way, that it provides with temperatures that are close to the under-margin of figure 1 in winter, and close to the upper margin in summertime, under the condition of local, individual adjustment. In this case, an optimal energy usage will be established. Moreover, occupants will not adjust temperatures contrary to the system (e.g. additional cooling when the system is heating up). This saves a lot of energy.

3. Analysis of climate, underground and surroundings

3.1 Introduction

Starting with the indoor environment and the way it needs to be managed, the demand for heat and cold in buildings is defined by the local climate. Therefore, good foundation for energy-efficient design is to be found in a thorough analysis of the local climate. The climate relates to seasonal changes, variations in the weather and diurnal differences of e.g. temperature, sun and wind. This section will mainly focus on a discussion of the analysis of climatic features.

The underground concerns the geomorphology, soil types and ground and open water. These are important as buildings connect to the underground and direct surroundings. They make storage or exchange of energy possible or impossible and they define water management features.

Many architects design as if their building could be placed anywhere, ignoring the inconvenient surroundings constituting the landscape, as well as natural, cultural, historical and technical environmental features. In contradiction, a smart and bioclimatic building can never ignore its surroundings, it should respond to them and utilise the potentials they offer to the building site.

3.2 Climatic zones, temperatures and humidity

According to Koeppen, the earth can be divided into basic climate classes (figure 2). These classes define the approach required for the energy-efficient climate design of buildings. There is no generic design for buildings: they should be based on the local features of temperatures and humidity.

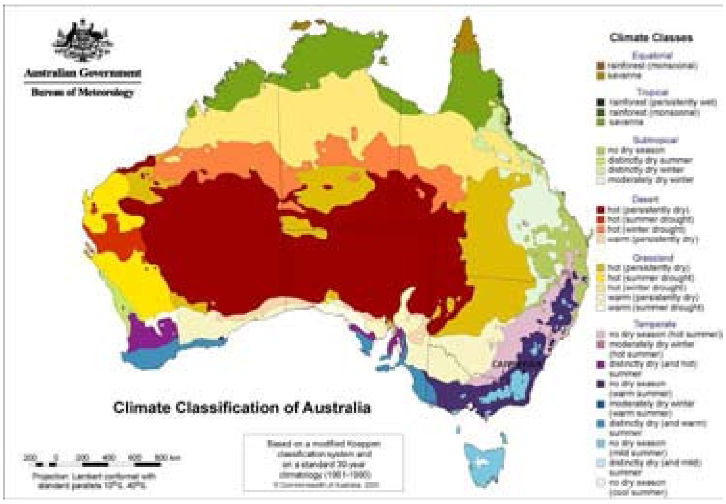

Figure 2 Climate classes according to Koeppen, period of 1961-1990 (Bureau of Meteorology 2005).

For the case study of the Dutch embassy, to Australian standards Canberra lies in a very particular zone: a temperate climate with no dry season and a mild to hot summer. The mean temperature is temperate (13 ^{o}C, relatively cool for Australia) but show relatively large seasonal and diurnal differences (table 1). This is an important feature that will influence the recommended building design.

Rainfall figures are moderate (relatively wet to Australian standards) but show a decrease over the last decades. This emphasises the importance to retain and make use of any form precipitation in the design of new buildings.

Table 1 Temperature, rainfall and solar statistics of Canberra

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean maximum temperature (°C)	27.9	27.1	24.5	20.0	15.5	12.2	11.3	13.0	16.1	19.4	22.6	26.1	19.6
Mean minimum temperature (°C)	13.1	13.1	10.7	6.7	3.2	0.9	-0.1	1.0	3.2	6.0	8.7	11.3	6.5
Mean rainfall (mm)	59.5	56.0	51.1	46.4	45.1	41.1	41.3	46.6	52.3	62.7	64.2	52.5	618.7
Mean daily solar exposure (MJ/m^2)	26.4	23.8	19.8	15.4	11.2	8.2	8.8	11.2	15.1	20.4	23.7	25.8	17.5

3.3 The sun: north arrow and course of the sun

Table 1 also depicts the mean daily solar exposure, in energy terms. This of course is important for the yield of solar energy when making use of solar panels, solar collectors or passive solar energy.

A first simple step to smart design of buildings is putting the north arrow on every plan that is drawn. It sounds stupid but there are numerous architects who fail to acknowledge the north in their drawings, and who thereby ignore the most important energy source on our planet. No explanation needed that their buildings will not save the planet.

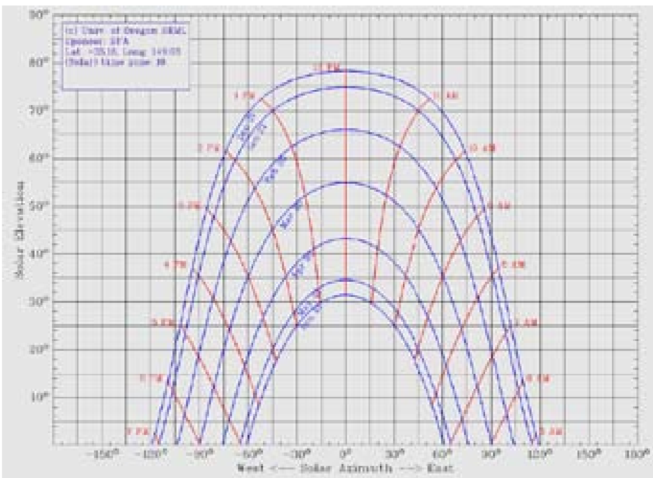

Figure 3 Solar chart for Canberra, showing the solar azimuth and elevation (University of Oregon 2007).

The designer who understands the climate features and acknowledges the course of the sun throughout the months of the year (figure 3) will be able to take appropriate measures in the envelope of the building. Table 2 for instance depicts solar properties for eight façade elevations during four typical dates of the year, at three hours of the day: the start (8 AM) and end (6 PM) of office hours and the time of the solar summit (12:04 AM in wintertime, 01:04 PM in summertime). If these data are connected to the simultaneously occurring temperatures, some indication will be gained about which solar angles to be obstructed to avoid unnecessary cooling inside the building.

Table 2 Analysis of solar characteristics on different elevations in Canberra

elevation	date	08:00 solar time			12:00 solar time			18:00 solar time		
		clock	height	azimuth	clock	height	azimuth	clock	height	azimuth
N	21/03	08:04	25	71	12:04	55	0	18:04	0	-45
	21/06	00:04	8	53	12:04	29	0	10:04	-	-
	23/09	09:04	25	71	13:04	55	0	19:04	0	-45
	22/12	09:04	42	95	13:04	79	0	19:04	13	-110
NE	21/03	08:04	25	71	12:04	55	0	18:04	0	-45
	21/06	00:04	8	53	12:04	29	0	10:04	-	-
	23/09	09:04	25	71	13:04	55	0	19:04	0	-45
	22/12	09:04	42	95	13:04	79	0	19:04	-	-110
E	21/03	08:04	25	71	12:04	55	0	18:04	-	-45
	21/06	08:04	8	53	12:04	29	0	18:04	-	-
	23/09	09:04	25	71	13:04	55	0	19:04	-	-45
	22/12	09:04	42	95	13:04	79	0	19:04	-	-110
SE	21/03	08:04	25	71	12:04	-	0	18:04	-	-45
	21/06	08:04	8	53	12:04	-	0	18:04	-	-
	23/09	09:04	25	71	13:04	-	0	19:04	-	-45
	22/12	09:04	42	95	13:04	-	0	19:04	-	-110
S	21/03	00:04	-	71	12:04	-	0	10:04	-	-45
	21/06	08:04	-	53	12:04	-	0	18:04	-	-
	23/09	09:04	-	71	13:04	-	0	19:04	-	-45
	22/12	09:04	42	95	13:04	-	0	19:04	13	-110
SW	21/03	00:04	-	71	12:04	-	0	10:04	0	-45
	21/06	00:04	-	53	12:04	-	0	10:04	-	-
	23/09	09:04	-	71	13:04	-	0	19:04	0	-45
	22/12	09:04	-	95	13:04	-	0	19:04	13	-110
W	21/3	08:04	-	71	12:04	55	0	18:04	0	-45
	21/6	00:04	-	53	12:04	29	0	10:04	-	-
	23/9	09:04	-	71	13:04	55	0	19:04	0	-45
	22/12	09:04	-	95	13:04	79	0	19:04	13	-110
NW	21/3	08:04	25	71	12:04	55	0	18:04	0	-45
	21/6	08:04	8	53	12:04	29	0	18:04	-	-
	23/9	09:04	25	71	13:04	55	0	19:04	0	-45
	22/12	09:04	42	95	13:04	79	0	19:04	13	-110

3.4 Wind: strength and direction

Next important aspect of climate is wind. Wind characteristics (strength and predominant directions) per season and with diurnal differences, combined again with temperature and humidity features, define the desired or undesired access or deployment of wind in the climate design of a building.

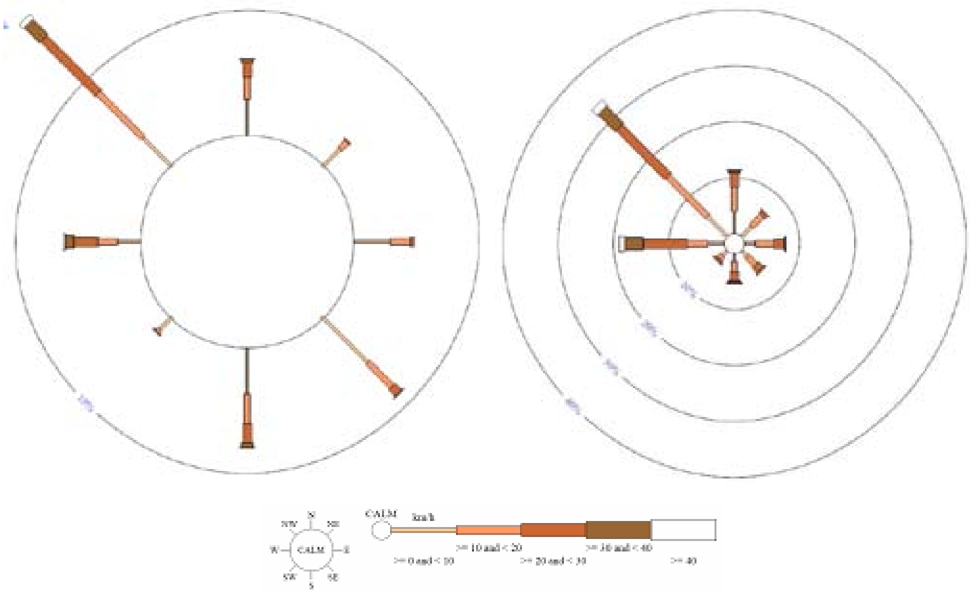

Figure 4 Wind roses for Canberra, at 9 AM (left) and 3 PM (right) (Bureau of Meteorology 2008)

Figure 4 gives average wind roses for Canberra at two times of the day. The morning is relatively still, whereas the afternoon shows a predominant north-western wind, which comes from the desert, implying hot winds in summer and cold winds in wintertime, both undesirable and hence, projecting boundary conditions for the orientation of a building.

4. Synthesis: starting-points and boundary conditions

4.1 Urban boundary conditions

The climatic analysis as discussed previously, as well as requirements imposed on the plan by authorities, can be translated into a map of the building site. Figure 5 presents the basic urban boundary conditions for the Dutch embassy in Canberra. Present trees are actually on the wrong side of the plot, considering the north sun and prevailing demand for cooling. The undesired wind from the north-west is to be obstructed or turned into an advantage since they are the only winds of any mention.

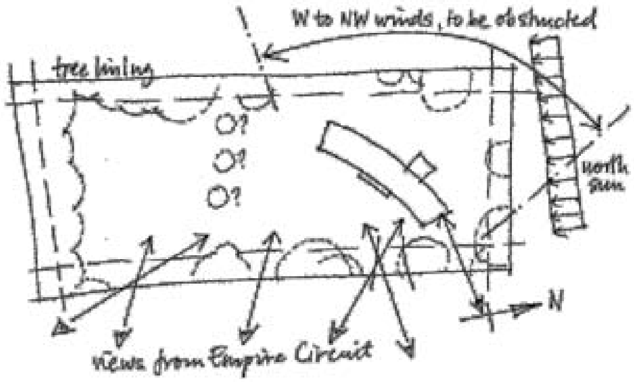

Figure 5 Urban boundary conditions for the new Dutch embassy in Canberra.

4.2 Boundary conditions for the building design

Analogue to boundary conditions for the urban setting, requirements can be made for the building design. It starts with the orientation, internal zoning, layout, and the general building shape, which in the case of Canberra would respond to the solar course by avoiding insolation from the north – which is easy, considering the high solar elevation, easily obstructed by canopies and blinds – and reducing the area of east and west facades – which are difficult, due to the low solar angles, demanding for full shading devices.

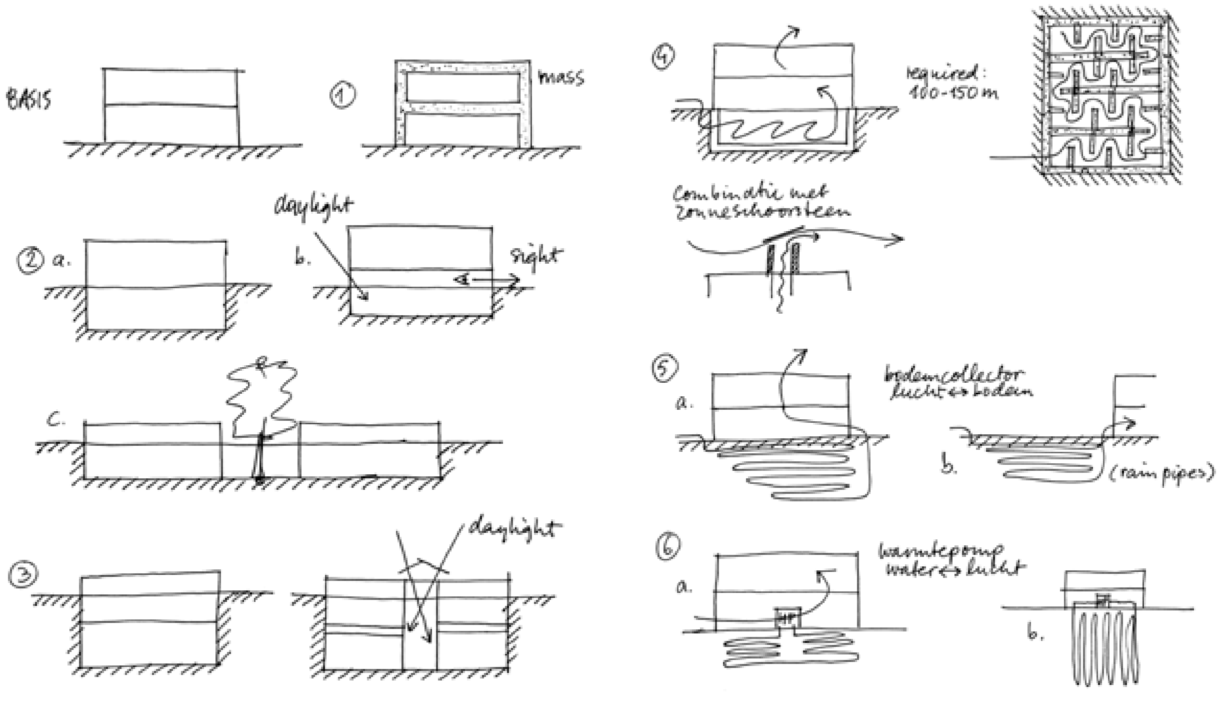

Figure 6 Possibilities to stabilise or temper the indoor climate: 1: more building mass, 2: building one layer into the ground, 3: building two layers underground, 4: using a cellar for direct cooling of fresh air, 5: using underground ducts for direct cooling of fresh air, 6: indirectly cooling the building through a soil collector and heat pump.

Within the climatic circumstances of Canberra, especially the temperature differences between night and day, winter and summer, some dimming measures are welcome. Dimming of extremes is established through mass, inside or outside the building. As the mean annual temperature is 13°C, a nearly infinite mass and the soil approximately 1.5 m below surface will reflect this average from. This means that free pre-cooling and pre-heating can be gained from the soil in summer and winter respectively. Figure 6 depicts some principal solutions – directly and indirectly – that deploy the soil in stabilising the climate inside the building.

4.3 Boundary conditions for the building envelope

The forceful solar radiation and high summer elevation of the sun in Canberra urge measures in the roof of the building. A tropical roof, an elevated light-weight roof under which the air flow can cool the building, can be an apt solution (figure 7). An upside-down wing-shaped hat can additionally provide under-pressure beneath this roof, enabling passive extraction of exhaust air from the building. This is also possible in combination with a solar chimney.

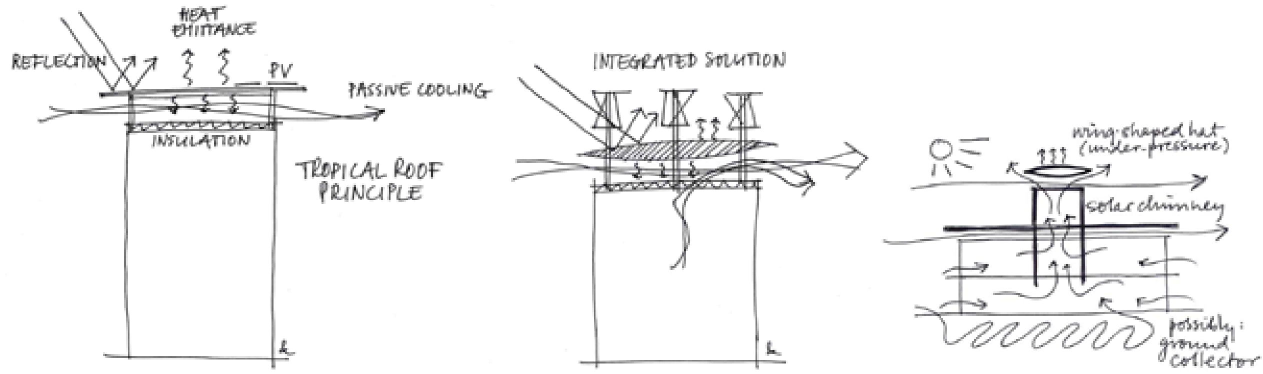

Figure 7 Tropical roof principles: the normal solution (left), an upside-down wing-shaped tropical roof (centre) and an upside down wing-shaped hat on a solar chimney (right).

Furthermore, the solar properties of table 2 can be translated to design principles for the facade, which needs to be approached differently for every orientation. Figure 8 shows three of the six elevations and their basic measures to avoid insolation.

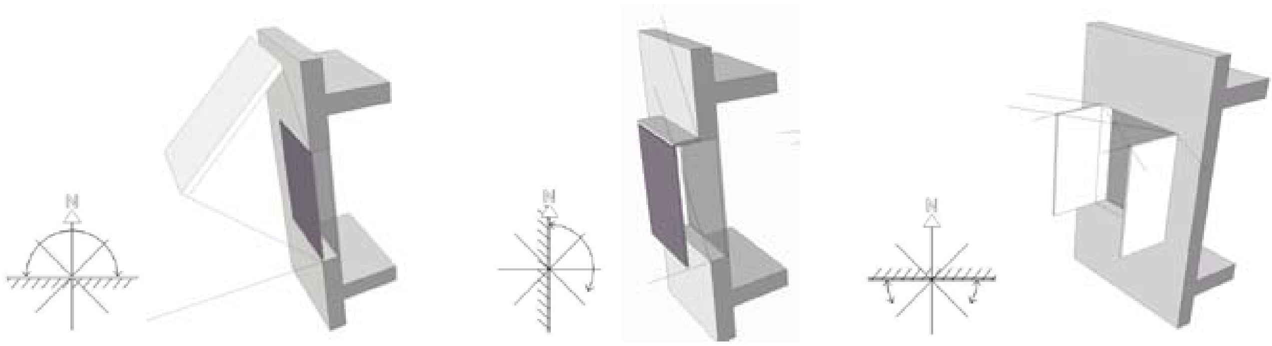

Figure 8 Solutions to avoid insolation from defined solar angles on different elevations.

5. Design proposals

A final step towards smart and bioclimatic design can be made through the elaboration of boundary conditions and design principles into an actual crude design. Creative design is a delicate process, so it should not be bound too much to restrictions, but a set of boundary conditions and principles that still allow architectural freedom can be a profound basis for sustainable architecture.

Figure 9 gives an example of just one design proposal for the chancellery in Canberra, without any architectural intention. In this sketch the old chancellery building from the 1950s is preserved (against the desire of the Ministry of Foreign Affairs and the selected architect), using it as a wind screen, open-air gallery and hosting a solar chimney that passively ventilates the new pavilion. Fresh air is let in through a ground collector beneath the new pavilion, which can basically be of any architectural expression

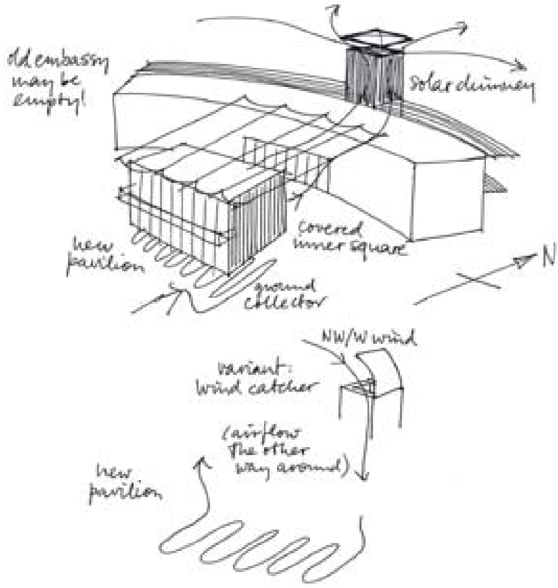

Figure 9 *Sketch of a possible solution for the new Dutch embassy in Canberra, based on bioclimatic principles and preserving the old chancellery.*

6. Conclusions and discussion

6.1 Conclusions

Despite the character of an intangible process, smart and bioclimatic design is supported by a well-structured investigation of aspects that will influence the energy performance of a building. The structured approach discussed in this paper can provide the basis for such a design that better utilises the implicit local energy potentials.

6.2 Discussion

The case study exemplifying this paper was seriously meant as a starting-point for three architects who would compete for the design of the chancellery of the Dutch embassy in Australia. Due to tight time-planning issues the Dutch ministry of Foreign Affairs however selected one architect in an early stage. This architect commenced design work while the preparative research was still ongoing. This led to suboptimal tuning of research findings and decisions on the crude design.

This demonstrated the necessity of patience in an ambitious project aiming at optimal energetic performance.

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SIGNIFICANCE OF BUILDING PERFORMANCE, USABILITY AND SERVICEABILITY IN TERMS OF SUSTAINABLE BUILDING

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Summary

Vision for a Sustainable and Competitive Construction Sector by the European Construction Technology Platform states that "In the year 2030, Europe's built environment is designed, built and maintained by a successful knowledge- and demand driven sector, well known for its ability to satisfy all needs of its clients and society, providing a high quality of life and demonstrating its long-term responsibility to the mankind's environment." To achieve this, there are two main challenges: Meeting client requirements and reaching sustainability. Sustainable building is a comprehensive process which is able to understand user needs and requirements, to create a design that fulfils these requirements while minimising environmental impacts and life cycle costs. Understanding user needs is essential in sustainable building. However, several case studies have shown that there may be significant problems in understanding the user needs and achieving the desired usability. Systematics that support identifying user needs and requirement setting are missing; many of the existing methods rather support subsequent assessment of user satisfaction.

The paper discusses the meaning of building performance and usability as aspects of sustainable building, and gives recommendations for the development of methods that support the identification and understanding of user needs.

1 Introduction

The principles of sustainable development define the ecological, economic, social and cultural framework for the activities of communities, enterprises and individual citizens. Vision for a Sustainable and Competitive Construction Sector by the European Construction Technology Platform states (ECTP 2006) that "In the year 2030, Europe's built environment is designed, built and maintained by a successful knowledge- and demand driven sector, well known for its ability to satisfy all needs of its clients and society, providing a high quality of life and demonstrating its long-term responsibility to the mankind's environment. …In order to meet this vision, objectives and research targets are specified for two key aspects of construction: Meeting client requirements and reaching sustainability."

This paper discusses the different aspects of sustainable building. The specific focus is to try to define the significance and importance of building performance and usability as aspects of sustainable building. The specific scope of this paper is buildings as places to work.

There is a wide consensus that sustainable building is a comprehensive process which is able to understand user needs and requirements, to create design options that fulfil these requirements while minimising environmental impacts and life cycle costs. ISO TS 21929 defines that sustainable building brings about the required performance with the least unfavourable environmental impact, while encouraging economic, social and cultural improvement at a local, regional and global level.

The three main types of benefits associated with sustainable construction are environmental, economic and health and community benefits. Environmental benefits include improved air and water quality, reduced energy and water consumption and reduced waste disposal. Economic benefits include reduced operational costs, reduced maintenance costs and increase revenue (sale price or rent). Health and community benefits include enhanced occupant comfort and health, reduced absenteeism and turnover rate, and reduced liabilities (Andrews et al. 2006).

According to Cole (2005) assessment methods of buildings have overtaken other approaches for the management of sustainable building within building industry. Those methods are increasingly considered as the most potential mechanisms for affecting change while the initial intention was to ensure a specific assessment role to avoid problems from unverified claims on environmental performance. The majority of the existing assessment methods evaluate environmental performance of buildings relative to explicitly declared or implicit benchmarks. The point of view has gradually widened from sole environmental assessment to overall assessment of sustainability aspects of buildings. Existing systems are several; for example the following: BREEAM (2008) (UK BRE), LEED (2008) (US Green Building Council), Green Star (2008) (Australia), PromisE (2008) (Finland Motiva). These systems are useful not only when rating buildings but also in setting requirements. The strengths of the systems include that those are easy to use, they cover a wide range of sustainability aspects, support target setting, provide a common set of criteria. Weaknesses - on the other hand - include that the true meaning of the selected indicators is not defined, indicators may be overlapping, indicators may depend on each other and the relationship between indicators is not clearly defined. Typically, indicators concerns not only environmental performance of buildings but also functional and social performance of buildings.

Building performance is paid stronger consideration within the building sector's ongoing activities in the field of sustainable building. Performance based building and sustainable building are complementary (Sjöström and Holmgren 2005). There is a growing interest in both the public and private sectors for more sustainable approaches to buildings. Influencing factors are the need to reduce energy use, and greenhouse gases output. However, even more important than mitigating these adverse impacts may be the potential of amplifying the positive impacts of occupant satisfaction and performance (Andrews et al. 2006). Understanding and considering user needs is essential in sustainable building discussed for example in Häkkinen (2007). An integrated design approach may be a basic reason for successfulness of sustainable construction projects (Riley et al. 2004). There is a need to develop methods that support the identification and understanding of user needs, and the interpretation of these needs as requirements for building performance and spaces of building.

2 Definitions

The concepts of sustainable building have been defined variously. This section presents a summary of definitions given for sustainable building and its main aspects.

IS0 15932-2 General Principles and ISO TS 21929 define a framework for sustainable building and sustainability indicators of buildings. Environmental indicators address environmental aspects in terms of environmental loadings or impacts assessed on the basis of life cycle inventory or assessment. Environmental loadings are the use of resources and the production of waste, odours, noise and harmful emissions to land, water and air. Consequential environmental indicators express environmental impacts in terms of building performance or location either quantitatively or qualitatively.

The economic indicators indicate monetary flows connected to the building life cycle. Social indicators of buildings are used to describe how buildings interact with issues of concern related to sustainability at the community level. Community level issues that may be relevant are for example urban sprawl, mixed land use, development of brown-fields, safety, and noise and air quality. Social aspects can also be addressed on the building level like for example (ISO 2006): quality of buildings as a place to live and work, building-related effects on health and safety of users, barrier-free use of buildings, access to services needed by users of a building, user satisfaction, architectural quality of buildings and protection of cultural heritage.

The three main functions of indicators are quantification, simplification and communication. Changes over time and the development of changes in relation to stated objectives can be monitored with the help of indicators. One of the important functions of an indicator with reference to decision-making is its potential to show a trend, Indicators should be objective and the results should be repeatable. When developing and selecting indicators the starting point is the identification of the main users and user needs (Häkkinen et al. 2002).

ISO 6707-1 provides definitions for performance, performance requirement and serviceability:

- Performance - ability of a product to fulfil required functions under intended use conditions or behaviour when in use
- Performance requirement - minimum acceptable level of a critical property
- Serviceability - ability to meet or exceed relevant performance requirements

According to ISO 9241-11 usability is the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.

CIB W111 (CIB) focuses on the concept of usability of workplaces including commercial buildings and buildings for healthcare and education. Usability, with focus on the user perspective, is often a neglected aspect of building performance, but the importance is increasing as organisations seek new and more effective ways of working. Several aspects influence a building's usability. According to Nylåna (2005) usability, or functionality in use, is concerning the buildings ability to support the user organisation's economical and professional objectives. The quality of use for a building means that it is efficient in use (use of resources, productivity, effectiveness, rationality), offers the desired effect in use (increasing the value), and/or offers the desired quality in use (user satisfaction). Usability focuses on user perceptions of the ease and efficiency with which they can use the building. Serviceability, on the other hand, describes the capability of a building to provide a range of performances for which it is designed, used or required to be used, over time. While usability states a demand perspective, serviceability states a supply perspective. The CIB W060 (CIB) focuses on performance based briefing in relation to client requirements and performance indicators and in relation to sustainable building.

ISO 9001 specifies quality system requirements for achieving customer satisfaction by preventing non-conformity. ISO 9001 concerns usability because improving usability of a product is essential to quality. True quality of product design is a result of a usability process that includes measuring and improving usability (Dick 1999).

According to CIB report 'Working with the performance approach of building' (1982) performance approach is concerned with what the building is required to do, and not with describing the technical solutions i.e. how it is constructed. A prescriptive approach describes an acceptable solution while a performance approach describes the required performance. Essentially, the performance approach is the practice of thinking and working in terms of ends rather than means. Performance requirements do not say anything about the ways and means of buildings, e.g. the type of materials, the thickness, dimensions, and size of building parts, or the method of construction, but they state the required end result.

The performance approach is dual in a sense that first there is a need to identify and quantify two types of constraining sets: i) basic and intrinsic aims that the end product is expected to satisfy, ii) restraining general forces and environmental conditions (Becker 1999). It is essential to distinguish performance issues between i) design features and ii) management, operation and process issues (Cole 2000).

With reference to building performance Prior and Szigeti (2003) make a distinction between demand and supply: Demand includes descriptions of functionality needs of owners and users; Supply includes indicators of serviceability describing the performance of materials, components and structures as features of the whole asset. Based on such information it is possible to address the quality of fit, matching performance with need and analyse suitability of a building or other constructed asset to meet the required functionality of the users.

Lützkendorf et al. (2005) deal with performance as a major concept which is divided into categories including functional, technical, environmental, economic, social and process performance. Functional performance describes the suitability with planned use and it also covers aspects of accessibility and adaptability. It is closely related to the needs of the building users. Social performance refers to the health, comfort and safety of building users. Building regulations provide a base for these aspects but clients often choose to demand more.

This paper refers to the last mentioned definitions and from this point onwards uses the terms functional and social performance. This paper discusses the meaning of functional and social performance on the basis of the following definition for sustainable building: sustainable building brings about the required performance with the least unfavourable environmental impact, while encouraging economic, social and cultural improvement at a local, regional and global level.

3 Functional and social performance as a unit of reference in assessing environmental impacts

The notion of life cycle assessment (LCA) has been generally accepted within the environmental research community as the only legitimate basis on which to compare the environmental impacts of alternative products and services (Cole 2005). The approach is firmly adopted for the European environmental assessment tools. It also seems that there is a tendency to adopt the LCA approach to the sustainability assessment systems of buildings to deal with the environmental impacts of buildings. This approach has been chosen for example to the German (Schminke 2008), Australian (Green Star 2008) and Finnish systems (PromisE 2008).

LCA theory and related standards (ISO) point out the quantified performance of a product system for use as a reference unit. Within an LCA, environmental impact is always looked at in relation to the functional unit (FU) in terms of quantified performance. According Heijungs et al. (1992) the FU should be defined with the end-user in mind. Whenever possible the FU unit should be defined as a service to the user or to the process. A definition of a product is that it is of benefit to the user; it provides a service. Wenzel et al. (1997) point out that the service, the response to the user's needs, is the reason for the product's existence, and therefore the environmental impact caused by the product should be ascribed with reference to this service. To ensure that the different ways of providing a service are comparable, the service must be defined and quantified.

The service that is provided by a building or construction can be described with help of its (functional and social) performance. To fulfil the required functional and social performance (suitability for planned use including aspects of accessibility, adaptability, health, comfort and safety) there may be several alternative technical solutions. Sustainable construction should be able to choose the one that causes the minimal adverse environmental impacts. To be used as the basis of comparison, we should be able to define and quantify the performance; or if not absolutely quantify it, at least classify it so that the required service can be expressed in terms of performance classes.

World Business Council for Sustainable Development (WBCSD) first introduced the concept of eco-efficiency in its report for the UN conference on sustainable development in 1992. The meaning of eco-efficiency concept has been widely discussed ever since. The OECD (1998) has defined the term in such a way that "Eco-efficiency expresses the efficiency with which ecological resources are used to meet human needs". According to the OECD report, eco-efficiency can also be defined as a ratio of output and input so that the output represents the value of the products or services that a company produces and the input is the sum of environmental pressures caused by the production. The approach is close to life-cycle assessment approach.

By expressing the value of products or services in terms of functional and social performance, we can define that the eco-efficiency of a building expresses the efficiency with which ecological resources (and economic resources) are used to meet the user requirements concerning usability in terms of functional performance and indoor conditions. Theoretically, we can undestand eco-efficiency as a ratio of two parameters; the ratio can be improved both by increasing the numerator or decreasing the denominator.

However, at the current state of development, the ISO standards do not indicate how to derive values for building performance. According to Trinius and Sjöström (2005) the discussion of the link between performance aspects and sustainability aspects reflects the relative vagueness of the term sustainable building. The term does not relate to the establishment of a benchmark for a sustainable building, but rather to the process considering sustainability aspects during the design and operation of buildings. Watson (2005) has analysed the existing sustainable building tools in terms of their ability to support design for sustainability. Among other things Watson concludes that tools cover a wide range of issues, but do not provide a clear and consistent means of organising these.

Building regulations may provide a basis for using technical performance and basic aspects of social performance as a reference unit when comparing alternative design options in terms of environmental impacts. However, we are far from being able to quantify the overall functional and social performance. There are attempts going on and for example the Nordic CREDIT project may bring some solutions for these questions. CREDIT (2008) aims - among other things - to identify performance indicators that can be used to support clients to express user needs and that indicate the value of real estate. On the other hand, we can question the possibility - and even the meaningfulness - to define functional and social performance in such a way that it could be used and determined generally as quantified reference unit. This is because the functional and social performance (especially the suitability for planned use and comfort) depends significantly on user-specific views. In the end, it is the user who is able to prioritize and quantify. Thus the development of methods for the investigation of user views and user satisfaction might offer case specific solutions for the problem.

Whether to use functional performance as an indicator simultaneously with environmental indicators or as a reference unit for environmental assessment is problematic from the view point of current sustainable building rating systems. The majority of the systems of sustainable building indicators deal with distinct environmental parameters (like harmful emissions and the use of resources) as well as with performance aspects (like air quality, comfort and flexibility). These approaches do not define the building performance as the reference unit, but use performance aspects as indicators of environmental performance in addition to the environmental pressure indicators.

4 Functional and social performance as targets of user requirement

Sustainable building fulfils the required performance and at the same time causes the most favourable environmental impacts while encouraging economic, social and cultural improvement. On the basis of this definition, functional and social performance belongs to aspects of sustainable building, because those are essential targets of user requirements and because the user satisfaction mainly depends on functional and social performance. According to Trinius (2005) performance approach is a key element in sustainable construction: as the performance approach starts off with an expression of what is expected from a building in terms of functionality, the identification of performance requirements can perform as an anchor in other elements of sustainable construction.

In addition, functional and social performance may also be seen as aspects of sustainable building, because those have an effect on the potentiality of buildings and built environment to encourage economic, social and cultural improvement and sustainable development on the whole. Built environment and buildings may be linked to sustainable development through their ability to support work towards sustainability. Sustainable development requires changes compared to the current situation; sustainable development can be defined as an innovation process. There are different strategies to proceed towards sustainable development, but in each case innovations are needed (Gerlach 2000). Work spaces and built environment should be able to support organisations' activities in the innovation process. The meaning of functional performance from the view point of user satisfaction and productivity is more dealt with in Section 6.

5 Functional and social performance as potential means of saving resources

It can also be presented as a self-evident conclusion that the better the building corresponds to the requirements of the owner and the needs of the users and the better the coming needs have been able to foresee the longer the building can be used (after new building or refurbishment) by its users before any needs for making changes and thus needs for demolishing and rebuilding. Thus good functional, technical and social performance probably saves both economical and environmental resources and environmental loadings. This can be taken as one of the reasons for defining functional and social performance as aspects of sustainable building.

6 Functional and social performance as a compensating element for space efficiency

Organisations seek new solutions for office buildings and efficient space use in order to achieve direct benefits such as savings in energy use and costs. The development has proceeded from closed to open spaces, from personal to shared workstations, and towards telework enabled by advanced ICT. It is also possible that the threat of climate change forces the building sector to seek these solutions not only in order to save energy and costs but also primarily to save environmental impacts. In addition, if the building sector will be forced to make significant improvements, such indicators as CO_2 per square meter might not be adequate but indicators like CO_2 per employee and/or organisation or CO_2 per occupant might be more effective.

In this kind of situation functional and social performance becomes an important issue of sustainable building because it can offer compensation and potential for increasing space efficiency. Improved functional performance may enable improved efficiency in space use (and thus savings in CO_2) without impairing the quality of building.

There are a number of studies on new work space solutions and their abilities to support satisfaction and productivity (see for example the literature surveys by Häkkinen and Nuutinen 2007 and Reunanen et al. 2006). For example Haynes and Price (2004) found that the most important factors that affect productivity of work include the quality of indoor conditions, workspace structure, comfort of work spaces, flexibility, and interaction and disturbances. Similar aspects affect work satisfaction: possibilities for undisturbed work and spontaneous interaction, comfort, ergonomics, space for storing the needed equipments and documents, possibilities for chatting and good spaces for break; accessibility to needed technology, indoor conditions and possibilities to adjust (Olson 2002, Veitch et al. 2003, Charles and Veitch 2002). With regard to workspace structure, there is a general opinion that individual working rooms and individual workstations create satisfaction, while lack of those can be compensated with help of good architectural design and high quality ICT (Voordt 2004).

7 Management of functional and social performance

Functional and social performance is an important element of sustainable building and construction. Thus we need approaches and tools that enable the determination, quantification and management of functional and social performance. As already dealt with in section 3, it is doubtful, whether overall functional and social performance can be quantified in general terms, because the suitability for planned use depends on subjective views. However, improved consideration and management would be possible by developing methods and tools for identification and understanding user needs.

Different kinds of methods and standards have been developed for the management of user needs especially in terms of minimum performance levels and technical requirements. The major purpose of legislation in this field is to ensure the health and safety issues of buildings. However, many buildings are still suffering from failures and weaknesses and there is a potential for improvements. This shows that good usability cannot be ensured with help of minimum levels stated by building codes, but a better understanding is needed to improve the understanding of usability (Nylåna 2005).

Case studies have also shown (for example Häkkinen and Nuutinen 2007) that in spite of careful preparation there may be significant problems in understanding and identifying the user needs. Systematics that support requirement setting and identifying user needs in terms of functional performance and consistence with the strategic working models are missing. The existing methods mainly support subsequent assessment of user satisfaction.

Space planning is the process of optimizing the layout of a building to suit a business's needs; ideally this is done in the context of the business plan and facility management plan (Muir 2003). Conceptually the process is simple; the needs of the business and those of the employees are gathered, analysed and translated into a space plan through a design process. The success or a failure of the space planning solution can be assessed using various indicators and methods. Different kinds of user satisfaction survey instruments exist. These link user satisfaction and self-assessed productivity to the environmental factors of thermal, lighting, acoustic and spatial comfort and privacy and other issues (Wilkinson and Leifert 2003). The outlines of these kinds of surveys can also be made use of in the process of understanding user needs.

The premise is that especially the following three types of methods can be used to support the understanding of users' needs: 1) outlining functional and social performance, 2) interviews, and 3) visualisation tools. Structured outlines of functional and social performance support owners and users to express their needs. Also visualisation tools should be developed and made use of in the process of requirement management. The nature of user activities and the practical meaning of the stated strategic goals of an organisation should be understood in the early stages of project. At present, the building process lacks systematics for identification and understanding user needs from the view point of

- the consistence of workspaces with user's strategy, activities and desired ways of working,
- suitability for daily user needs and activities,
- special requirements based on specific characteristics of work,
- user's tolerance with regard to risks of non-conformity,
- compatibility with desired imago.

Section 2 introduces definitions given for usability, serviceability and building performance. We lack detailed outlining which could be made use of when investigating user needs. However, there are approaches which offer a good starting point. For example, there are building-level tools for requirement setting for building performance; these include the Finnish tool EcoProP (Huovila 2005). These methods and tools should be further developed to support the identification of space and activity specific needs. At present, the main headings of the EcoProP tool are as follows:

- Conformity: Location, Spaces, Services
- Performance: Safety, Indoor conditions, Accessibility, Adaptability; Usability; Comfort.

Usability is not divided into subheadings. REKOS (Häkkinen et al. 2002) project defined that the usability is about building spaces and their relations, ability to orientate, and the easiness to use the spaces. The connections of different kinds of spaces are essential from the view point of usability, for example the location of kitchen spaces with regard to meeting rooms, and location of corridors with regard to office rooms. The easiness to use the spaces is also important. This may depend for example on the possibilities to adjust indoor conditions, easiness to clean and operate spaces, and easiness to maintain and repair spaces. Flexibility or adaptability might also be seen as one part of usability. REKOS defined flexibility with regard to residential buildings and divided the term into the following sub headings: Usability of spaces for different kinds of use purposes (from the view point of electricity, ICT and other installations); Flexibility with regard to furnishing (ability to place furniture variedly); Ability to make changes in the image of spaces; Ability to make changes in the dimensions of spaces. Correspondingly, we can define that in addition to connections of different kinds of spaces, also the standard of installations, image, and furnishing options are of importance.

In an early design phase, the architect typically visualises various design concepts by hand sketching, or by making draft layouts and illustrations with an image processing or design tool. The visualisation is needed in order to negotiate and decide over aesthetical, functional, and technical issues. The process includes typically several iterations, which eventually converge to an optimal or widely accepted solution. An ideal support tool might be a system combining the ease of hand sketching with the accuracy and realism of a computer based system. In principle, architectural 3D models would work fine in visualisation purposes for the requirements capture. However, in spite of the obvious progress that has been made, the current design tools are not easy enough to be used for real-time conceptual visualisation and requirements capture.

In spite of the obvious progress that has been made, current CAD/3D tools are not easy enough to be use for real-time conceptual visualisation and requirements capture. However, some advances to this direction have been reported in literature. A notable work is reported in Oh et al. (2005). There the starting point for the 3D design is a 2D layout, in which an interface is provided to extrude and edit (resize, move, rotate or remove) 3D space structures. Another approach is to enable compilation of a conceptual design from a set of 3D primitive objects (basic forms), as e.g. in Virtual Lego (Oh 2004).

In principle, a specific concept description language could be developed, based e.g. on the use of a set of basic geometric patterns and graphs. Typically, 3D models are specific text files, e.g. variants of XML. Independent whether the input is textual, graphical or model based, the result needs to be converted into textual format. This needs a specific language convention to be used including a well defined vocabulary (semantics). By using specific semantics, connections and associations between spatial objects and various captured parameters, the design data can be made and stored into a database for further use. A problem is that language and its semantics depend on the user and on the purpose of use. The importance and priority of the requirements also vary and are many times both difficult to measure or quantify, and controversial with each other. The system should therefore support optimisation of the captured set of requirements according to a chosen set of cost functions (price, space, distance, functionality, etc.).

In addition to the drafting for visualisation purposes, the system should also support the storage and follow-up of the captured requirements in order to avoid the known problem of gradually drifting away from the original user requirements during various design and implementation phases (Kiviniemi 2005).

A novel possibility - especially useful for 3D visualisation in existing buildings or environments - is the use of Augmented Reality, which enables visualisation of virtual objects in physical environment. An example of an AR tool for renovation visualisation is described by Pinto et al. (2007). Augmented Reality, or more generally Mixed Reality, means computer visualisation which combines physical scenes with virtual objects. This option is particularly applicable for showing designed 3D structures in existing buildings and environments. Several other examples of using Mixed Reality in building and construction applications are given by Woodward et al. (2007).

A useful functionality in 3D visualisation is the possibility to position an animated human avatar to give realism, as well as an indication of the real scale of the 3D environment. This avatar can also be animated, and made to move according to physical rules (collision detection etc.). Animation is commonly used in computer games where even the human behaviour can been modelled. A corresponding example in Mixed Reality is to place a motioning real human into 3D environment, e.g. an architect to walk inside the 3D building model, explaining his/her reasoning behind specific architectural choices.

8 Conclusions

Functional performance and social performance are becoming more and more important aspects of sustainable building. There are several reasons for this:

1) Minimising and optimising the environmental impacts of building happens with help of comparing alternative design options. In order to compare we have to be able to define a functional unit against which the comparison takes place.

2) Functional and social performance is an essential element of sustainable building because that is a target of user requirements and because the user satisfaction mainly depends on functional and social performance. Even more extensively, we can say that the functional and social performance of buildings and the built environment affects how well the built environment (among other factors) is able to support the general innovation process that is needed in order to solve the challenges of sustainable development.

3) Good functional and social performance and conformity with users' needs probably reduces the needs to make changes and rebuild. Thus it also saves both ecological and economic resources.

4) The threats concerning the climate change will mean increasing requirements for building sector to diminish Green House Gases. This will probably mean that decreasing carbon dioxide emissions in terms of CO_2 per building volume will not be an adequate goal but absolute decreasing in terms of overall quantities is needed. This kind of development is already happening with regard to office buildings as companies seek overall savings in energy and costs with help of open space offices and effective space use. In order to remain and improve the quality of buildings as places to work and live focus has to be directed not only on decreasing environmental impact but also improving the functional performance of buildings and spaces.

Functional and social performance is an important element of sustainable building and construction; thus we need methods that enable the management of functional and social performance. It is doubtful whether the overall functional and social performance could or should be quantified in general terms, because the suitability for planned use depends on subjective views. However, improved consideration and management of functional and social performance is possible by developing methods for identification and understanding user needs. The premise is that especially the development of structured outlines for functional and social performance and visualisation tools would support understanding and consideration of user needs.

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STRATEGIES FOR THE REFURBISHMENT OF OFFICE FAÇADES – A CASE STUDY

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Summary

Two thirds of the office-stock in Western Europe is older than 30 years (Russig 1999). At this age façades and technical installations reach the end of their technical life-span and buildings show a bad performance in terms of user comfort and energy consumption. This situation has led to a high demand for refurbishment of office buildings constructed between 1950 and 1980.

This paper shows the four different possibilities for the refurbishment of façades and technical installations of office buildings: A simple upgrade of the façade to current needs, the application of an additional glass façade, the replacement by a façade with integrated building services, and an option in which the entire building geometry is changed. To elaborate and compare strengths, weaknesses, restrictions and opportunities of the different strategies, they have been applied to a case study of a typical German office building from the 1970s.

The results show that all different strategies generally function for the presented case study. Nevertheless they impose different restrictions to the construction process and future use of the building. By taking running costs and the interference with ongoing work into account, one can see that an appropriate refurbishment strategy creates up-to-date buildings at reasonable expenses that pay off well within the technical life-span of façade and installation-components.

1. A Case Study for Refurbishment

The assessment of case studies forms an integral part of the research project "Façade Refurbishment for Office Buildings" which is being conducted at the Faculty of Architecture at Delft Technical University. In 2007 we carried out a feasibility study for the refurbishment of the university campus building in Bielefeld, Germany. The building owner needed an overview and comparison of possible refurbishment strategies. As this building is representative of a common construction of its period, this project provided us with the opportunity to apply different refurbishment strategies developed within the research-project and evaluate them in terms of practicability, energy saving potential, and economic feasibility.

Figure 1 Aerial view of the case study project

The campus building was erected in the 1970s and contains a GFA of roughly 300 000 m². The load bearing structure is based on a grid of 7.20 m and is built of steel columns and beams. Floor slabs are made of on-site concrete and take in the structural function of horizontal stiffening. Further stiffening is realized by the staircases and elevator shafts between the actual office buildings. The major structural problems for refurbishment planning lie in the very limited load-bearing capacity of the steel skeleton and in the structural importance of the floor slabs that does not allow openings to be cut out.

The façade construction consists of pre-fabricated concrete balustrade elements that span 7.20 m and are supported by only one connection at each end. These elements carry the window frames and sun blinds. The balustrades are made of light weight concrete and are not equipped with additional insulation. The windows contain insulated glass dating from the 1970s. Hence, the façade does not comply with current energy-performance regulations. In addition to this lack of insulation, the façade shows both wind and water leaks.

A major restriction for the refurbishment process is that the concrete balustrades are difficult to remove. They were placed successively during the construction process. Today the building forms inner courtyards that are closed on all sides. Balustrades in these zones could only be reached by special cranes and would have to be lifted over building parts that are supposed to be kept in use during the refurbishment.

2 The Application of Strategies

This chapter presents four different refurbishment strategies and their adaptation for the presented building project. These range from a “minimal solution” to different approaches that aim to generate additional advantages from the refurbishment project. The evaluation and comparison of these strategies is presented in Chapter 3.

2.1 The Necessary Renovation – Ventilated Cladding

The first solution presents the necessary renovation that has to be done in order to allow the future use of the building. The aim of this ‘minimal solution’ is to achieve a proper building physical performance of the façade at minimal expenses.

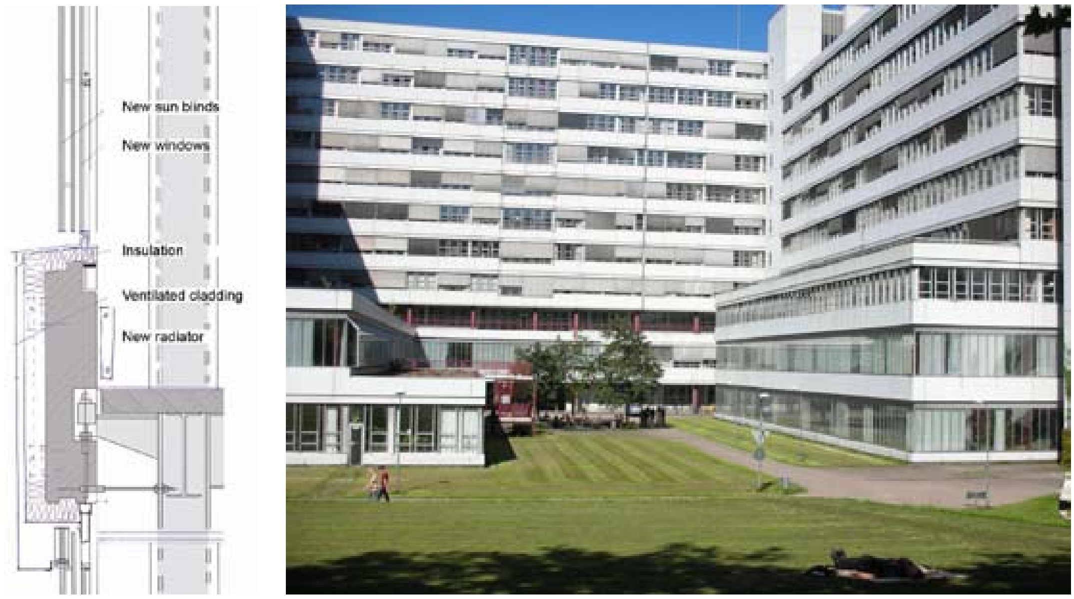

Figure 2 Principle Section of the ‘Ventilated Cladding’; Impression of the current façade

Additional insulation material is added to the outside of the balustrades in order to improve the insulation level. A ventilated metal cladding protects the insulation from weather conditions. Furthermore, the windows are replaced with new façades that provide proper wind tightness and insulation. New sun blinds reduce solar irradiation and thus cooling loads.

This concept provides a fast, easy to apply, and safe solution for the major problems of the building. It improves insulation and energy performance and includes the least construction costs. In this particular project the main restriction results from the very limited load bearing capacity of the existing balustrades, which do not allow a heavy cladding or big eccentric loads. Following this restriction we developed another solution in which at least the wind-loads on the balustrade are reduced compared to the current situation.

2.2 Twin Face Façade

It can be argued if 'Twin Face Façades' or 'Double Façades' are intelligent solutions or if they cause more problems than they solve. Nevertheless, for the task of refurbishment it is an interesting option to add a second façade layer to the outside of an existing building that prevents all weather impact to the old structure. Furthermore, the disturbance to the interior is reduced, if the existing façade is kept and all connections to dividing walls and floors do not need to be changed.

The aim for this refurbishment task is to conserve as much of the existing façade as possible, reduce the wind loads on the balustrade elements, and develop a new, energy efficient climate concept for the office rooms. In order to do so it is proposed to place a single glass screen in front of the old façade. The load bearing structure of the additional façade is suspended from new beams on top of the building that bring the loads into the main supporting columns.

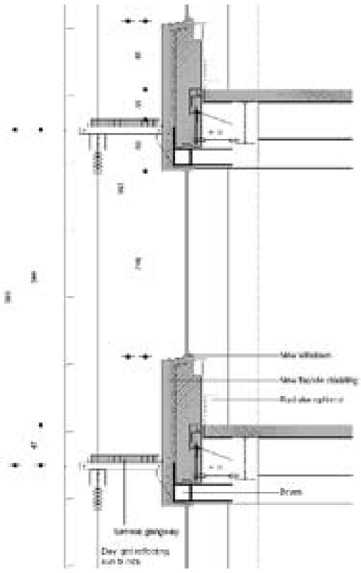

Figure 3 Principle of the 'Twin Face Façade'

The climate concept proposes using pre-conditioned air from the cavity in winter season as inlet air for the workspaces. Exhaust air needs to be let out through the central corridors and air shafts. In the summer situation the direction of the air flow is reversed. A natural updraft in the façade-cavity is used to extract exit air from the rooms. Fresh air is brought in through shafts and ducts within the building. All these technical installations have to be built, as the buildings currently are not equipped with any mechanical ventilation.

In winter the air in the façade cavity can reach very low temperatures because the cavity is used to bring in outside air to the rooms. To prevent cold bridges, condensation and heat loss, we need to improve the insulation of the inner (old) façade layer. This has to be done by new windows and additional insulation of the balustrade elements. All these efforts lead to a very complicated and expensive façade which can provide a high level of insulation and an efficient ventilation concept. But on the contrary it causes structural problems and difficulties controlling the temperature within the cavity. A bigger air volume in the cavity would reduce the range between high and low temperatures.

2.3 Winter Gardens

The shape of the existing building forms a series of courtyards and inner atria. Currently these are outdoor spaces surrounded by huge façade surfaces. By closing the courtyards and atria we can create covered spaces or 'Winter gardens' and thus reduce the façade surface of the building from 110 000 m² to 70 000 m² (including atria roofs).

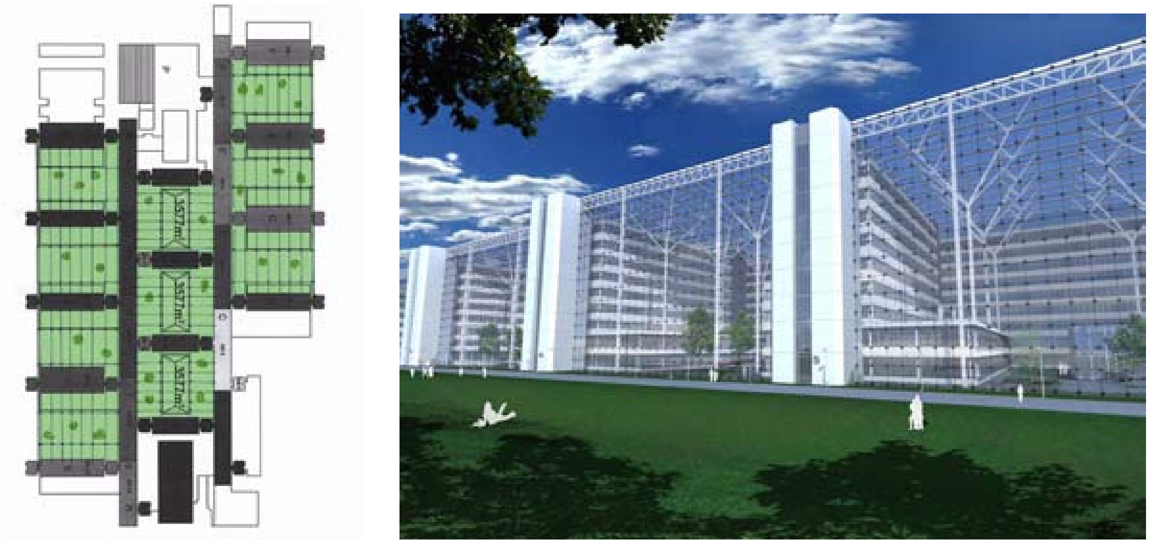

Figure 4 Principle of the 'Winter Garden' solution

The main aim of this concept is to create a buffer climate in which the air is pre-conditioned by solar radiation. Due to the big volume of the atria the air temperature will always stay above a level for which the existing façades provide enough insulation without further treatment. All office rooms get fresh air directly from the atria. The air intake for the central areas, such as libraries and auditoria, is also located in the courtyards and thus supplied with pre-conditioned air. In summer the covered atria need to be well-ventilated in order to discharge excess heat.

This concept achieves a good insulation level and a user-friendly ventilation concept in which the leaks of the old façade can be ignored. Additionally the winter gardens provide extra covered space that can be occupied by university functions. The particular problems of this concept lie in the need for new roof structures and façades for the courtyards that demand additional foundations and connections to the existing building. The ventilation concept of the atria demands special planning in order to prevent overheating in summer.

2.4 Modular Façade

So far all strategies followed the restriction of preserving the existing façade. Additionally we developed a model in which the windows and balustrade elements are removed. By removing an existing non-load-bearing façade the planner ends up with a kind of "tabula rasa" situation that allows almost any new curtain wall solution.

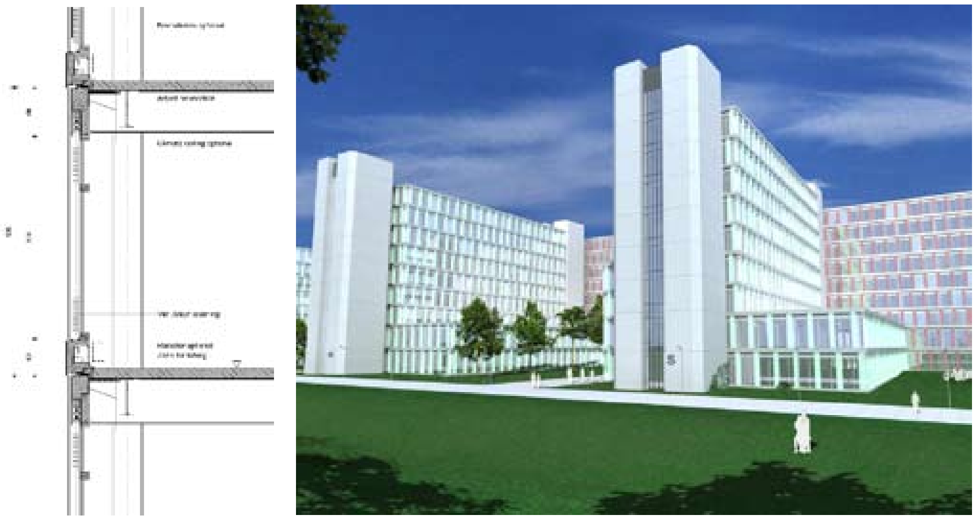

Figure 5 Principle of the 'Modular Façade'

For the university building we have created an adjustable and upgradeable concept that includes building services in the actual façade construction. This concept is based on the idea that different rooms have different demands for heating, ventilation and air conditioning depending on their use or location within a building. For example, an office room on a northern side does not need air conditioning at all, while a meeting room on the southern side does need it in summer, and a server room needs it all year round. Particularly at universities, the functions of rooms tend to be altered quite frequently.

Following this idea, we propose an element façade that provides the basic tubing for any kind of building services. In place of fixed climate components the façade supplies installation space in which different standardized components can be built in. The concept proposes that the user of a room can order his or her personal level of installation, which then can easily be installed (and billed individually). Figure 6 shows some possible HVAC concepts in sketch-form.

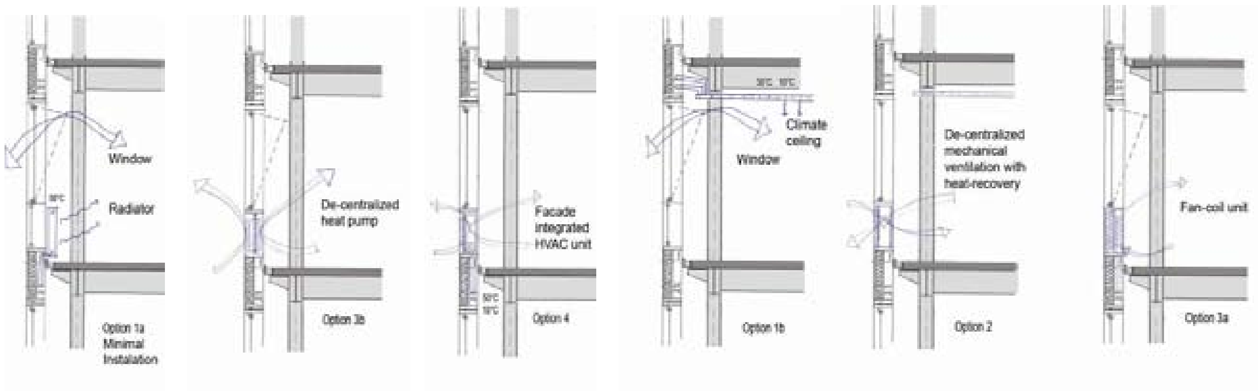

Figure 6 Different possible HVAC concepts

On the one hand, this concept provides the desired level of building services and comfort for each room. On the other hand only the absolutely necessary number of components needs to be produced and purchased. This reduces the demand of energy both in production as well as in use and allows perfect cost control. Nevertheless, this concept creates two major complications. The existing façade elements have to be removed, which is easy in the accessible outer courtyards but complicated and expensive for those courtyards that are fully surrounded by buildings. When the building is in use, this concept demands a good cooperation between building owner, user and facility manager.

3 Comparison of the different strategies

So far we have seen the description of different refurbishment concepts that show a broad variety of solutions with different levels of effort and impact. This chapter compares the four different refurbishment strategies in terms of construction cost, energy saving and life cycle cost, finally giving an impression of the possible repayment period of these concepts.

3.1 Construction Cost

To compare the investment for the different solutions, we have roughly estimated the cost for the construction of the façade and for the building services. In order to get comparable figures we estimated the costs and divided them by the square meters of the existing façade. The installation cost for building services are calculated per GFA. Table 1 shows the costs for all four solutions:

Table 1 Estimated Construction Costs

	Ventilated Cladding	Twin Face Facade	Winter Garden	Modular Facade
Façade (€ / m² Façade)	510	1130	950	890
HVAC (€/m² GFA)	60	115	95	105

The 'Ventilated Cladding' is the cheapest solution as it provides only the most necessary refurbishment. Installation costs are very low because they only cover the replacement of old radiator heating. The high investment cost for the 'Twin Face Façade' results from the complicated load bearing structure and the necessary treatment of the old façade layer. Installation costs are very high in this option, because a new ventilation system has to be installed. It is very interesting to see that the 'Winter Garden' solution is comparable to the other options. This is due to the fact that the façade surface is reduced and the existing façade needs no treatment. Installation costs in this case cover the replacement of the heating system in the rooms and the ventilation for the atria. The Construction cost for the 'Modular Façade' also covers the installation space for building services. For the installation-costs we estimated ¼ of the GFA to be fully air conditioned, while the rest is equipped with heating only.

3.2 Energy Demand

In order to determine data on the energy demand after refurbishment, we assessed one floor of the building with a thermo-dynamic simulation tool. Figure 7 shows the energy demand for heating, cooling, electric lighting and operating power in kWh per m² GFA and year. Column 'B' gives the reference data for the existing situation.

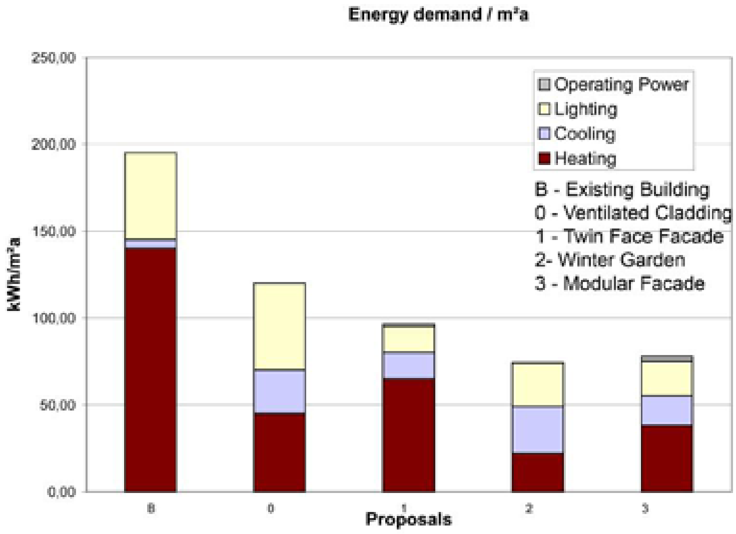

Figure 7 Energy Demand [kWh / m²$_{GFA}$ a]

Obviously the smallest refurbishment achieves the least energy saving. Nevertheless, the 'Ventilated Cladding' saves around 40% in comparison to the existing situation. The twin face façade causes a high demand for heating because the ventilation concept, based on operable windows, is difficult to control. Decentralized mechanical ventilation with heat recovery would provide a better performance, but also cause higher installation and maintenance costs. The reduction of electric lighting is achieved by daylight-reflecting sun blinds, installed in the cavity. The winter garden solution delivered interesting results: Although the old façade has not been upgraded, this solution demands the least heating energy. This shows the effect of the solar pre-conditioned climate in the atria which reduces the effect of the lack of insulation and the leaks in the old façade. A higher demand for lighting energy is caused by the shading of the roof. The Modular façade allows creating the optimal contemporary standards. By applying controlled ventilation to more than the calculated ¼ of the space, the heating demand could be reduced even further.

3.3 Running Costs

Running costs cover not only the costs for heating, cooling, electric lighting and operation of building services, but also the costs for maintaining the façade and building services, as well as window-cleaning. In the existing situation the costs for maintenance are particularly high, as it is expected that both façade and technical installations, being more than 30 years of age, demand a lot of attention. The impact of façade cleaning on the running costs becomes clear for the twin face façade. Electric lighting is an important factor for the minimal solution as this is not equipped with presence control, which on the contrary has been applied for the other proposals.

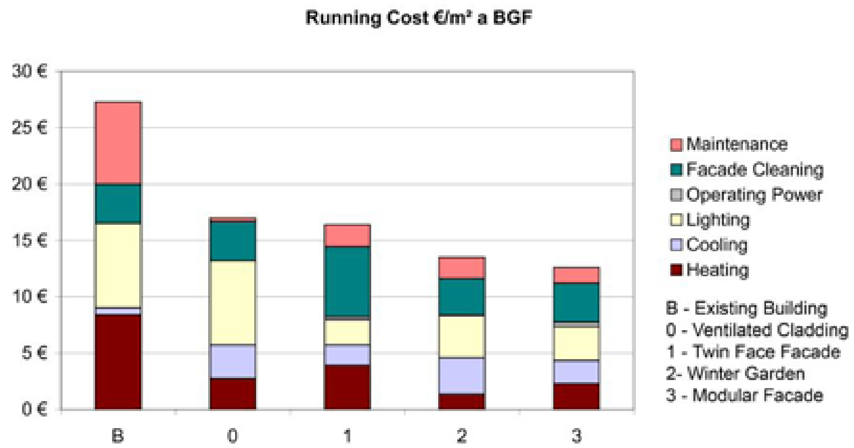

Figure 8 Running cost [Euro / m²$_{GFA}$ a]

3.4 Life Cycle Cost

Life cycle costs include the construction cost and the running costs presented before. To evaluate the future development we estimated, an increase of energy costs of 10% per year (destatis 2008). All other costs are expected to rise by 2% per year. Figure 9 shows the life cycle costs per m²$_{GFA}$.

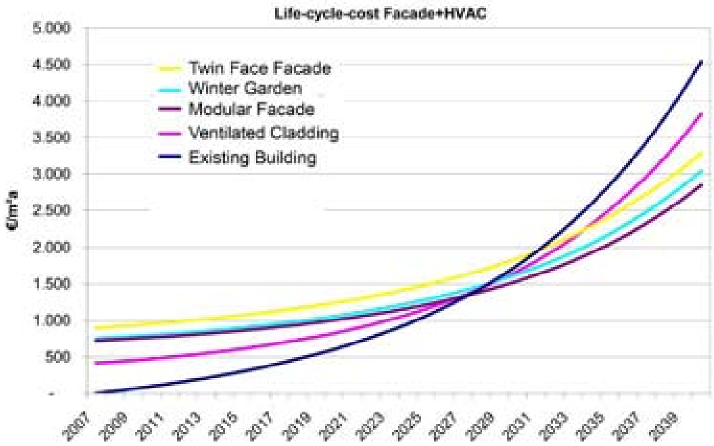

Figure 9 Life Cycle Costs [Euro / m²GFA]

All presented refurbishment strategies provide significantly lower running costs than the current situation. The graphs of all the different strategies intersect the line of the existing situation within the next 25 years. This means that any refurbishment proposal can pay off on the saving of running costs within the expected technical lifespan of façade and HVAC-components of 30 years. Under the given circumstances, the 'Ventilated Cladding' is the cheapest solution in the beginning. But, after 20 years the better performances of both the 'Modular Façade' and the 'Winter Garden' become evident. The 'Twin Face Façade' takes the longest time to pay off. A very interesting result is that the replaced 'Modular Façade' and the 'Winter Garden' are very close to each other, both in terms of construction costs as well as running costs. Keeping in mind that the 'Winter Garden' concept creates additional useable space, it is an option worth considering.

4 Applicability of the Refurbishment Concepts

The presented case study gave the opportunity to test and evaluate different refurbishment strategies. From the results generated here we have been able to conclude general results for the applicability of the different refurbishment concepts.

4.1 Ventilated Cladding

Ventilated cladding is a very common solution for the refurbishment of façades. It usually achieves a technically safe and long-lasting solution at reasonable expenses. As this kind of refurbishment is so frequently applied, it is also often criticized for the risk that buildings after renovation can lose their architectonic identity. It is the architects' task to create the best combination of good performance and appropriate appearance. A ventilated cladding always demands a sub-structure that can support new windows, insulation and the cladding. Therefore, it is mainly suitable for load bearing façades, such as massive walls with windows, or buildings with structural balustrades.

4.2 Twin Face Façade

Twin face façades can create an intelligent solution when they form an integral part of the climate concept of the building. The new cavity provides space for installation components and can make it possible to refurbish façade and building services without disturbing the interior. The load of the additional façade layer often causes structural problems. The necessary improvement of insulation and vapour tightness of the old façade layer leads to higher costs than a single façade layer. Therefore the application of an additional façade is most interesting in those special cases where the interior may not be altered, when the building has to stay in use, where the façade was originally equipped with structural service gangways, or when the HVAC-concept was based on de-centralized ventilation in the façade.

4.3 Winter Gardens

The covering of atria reduces the surface of a building, prevents weather impact on the old façade and creates a buffer climate that may make a treatment of the latter redundant. Additional values such a gain of space are further advantages. The main problems are the construction of wide-spanning roofs and the ventilation concept for the atria. This concept is particularly suitable for buildings with a convenient geometry, such as those with courtyards or feather-shaped layouts.

4.4 Modular Façade

The modular façade concept is interesting for both new and refurbishment projects. It reduces the need for HVAC equipment and allows for easy upgrades and changes in the future. Therefore it demands a complete refurbishment of façade and building services and is thus suitable for buildings that are supposed to undergo a complete retrofitting. To be successful, this HVAC-concept requires an intensive dialog between building owner, user and facility manager.

5 Conclusion

The façade is one of the most important and complex parts in construction. It creates the outer looks of a building, is the 'user-interface' between inside and outside, and it is the most important factor for the energy performance of a building. Most of the existing office buildings in Europe are older than 30 years and thus in need for refurbishment. Many interesting strategies can be considered for this task.

But, as every building is different and any refurbishment project provides different demands, no one strategy can be applied to every building type. The planner has to know the variety of possibilities. This report has shown a collection of promising solutions. It has been generated within a PhD-project that aims to provide a more comprehensive overview of refurbishment strategies, their advantages, problems and their applicability on the most common building typologies.

The presented case study shows that refurbishment design has to take into account the complete project. The integral planning of façades and building services achieves the best performance. Not only is the investment for construction important for the estimation of feasibility, but the future costs of using the building as well. This demands planners from different fields to work together with the ones, who own, use and run the building now and in the future. When all these parties collaborate, they will be able to find synergy effects that help to achieve energy and economic advantages, and they can further create a new architectural image to an old building. Refurbishment of offices makes sense and is an economically and ecologically feasible investment.

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CITY LIMITS: PUSHING BOUNDARIES IN URBAN INFILL DEVELOPMENTS

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Summary

There is increasing recognition that current 'best practice' in the design, construction and management of the built environment is not enough to ensure a sustainable future. Our built environment contributes to some of Australia's most pressing environmental problems. In response, we need to push the limits and move far beyond our current conceptions of best practice. This paper puts forward a principles-based approach to sustainable design in the development industry that incorporates the concepts of ecological limits, systems thinking and responsibility for impacts. In addition, a new framework for setting targets and actions for 'restorative' developments is presented. This paper focuses on the opportunities associated with urban infill projects, examining the kind of targets required to achieve truly 'sustainable' and even 'restorative' development and the principles all developments and retrofits of the future need to embody. This analysis is done in the context of a changing regulatory and economic environment, using examples from precinct-scale Sydney developments that are currently being designed.

1. Background

The built environment contributes to some of Australia's most pressing environmental issues, such as climate change, biodiversity loss, resource depletion, pollution and social inequity. As a nation, Australia is exceeding its ecological footprint, which at 8.1 hectares per capita is 3 times the global average and far greater than the estimated sustainable footprint (1.7 hectares for every person in the world) (Commonwealth of Australia, 2005). This places Australia in the top 5 of consuming nations in the world (GFN et al., 2005) and illustrates the extent of reductions required in order to achieve a sustainable level of resource consumption. Greenhouse gas emissions (GHGE) and material consumption rates in Australia are the highest per capita in the world at 27 and 180 tonnes per capita per year, respectively. Domestic waste production is second only to the United States at 620 kilograms per capita per year. The construction industry contributes to these high statistics as construction and demolition waste is 430 kilograms per capita per year; which constitutes 40% of all solid waste disposed of to landfill (Commonwealth of Australia, 2005).

Currently, average water consumption across Australian cities is 154 kilolitres per capita per year (kL/cap/year) (Beeton et al., 2006), which is the highest national average in the world, with the U.S. falling just below this average (Commonwealth of Australia, 2005). Australia's performance in these indicators shows that vast improvements must be made to secure a sustainable future. An immediate and fundamental shift in thinking and practice is needed. In many of Australia's urban areas, energy supply, water supply and sewage disposal infrastructure is highly centralised, ageing and/or close to its capacity. These centralised systems were designed and built within a paradigm that segregated infrastructure types (e.g. energy and water) and elements within those types (e.g. water separate from wastewater). The unintended result of such systems is unwanted environmental impacts and increased costs. A different way of thinking about our infrastructure is needed, in part because infrastructure has such long life times - of the order of 20-100 years, and in part because infrastructure determines the material intensity of our lifestyles.

Current 'best practice' targets used for design and construction of the built environment have brought some progress towards the goal of sustainability; however, much greater steps need to be taken if we are to address some of the critical issues affecting our urban environment and move towards attaining the ultimate goal of sustainable development. As a highly urbanised nation, the greatest opportunity for Australia to reduce its environmental impact lies in its cities. Two thirds of Australia's population lives in cities and population growth is increasingly concentrated in urban areas. The rapid growth occurring in the inner urban areas of Australia's major cities, notably in Sydney, Melbourne and Perth (Commonwealth of Australia, 2005), presents significant challenges – and significant opportunities – for the sustainability of the built environment. Precinct-scale developments offer a particularly effective opportunity to create change in our built form and infrastructure.

This paper argues that it is time for a paradigm shift in thinking and practice, and that a principles-based approach provides an appropriate framework for this next stage in the development industry's evolution. We draw on principles for sustainability learning, because a deeper level of awareness and knowledge will be fundamental to this paradigm shift. If we are serious about a sustainable future, we need to engage more explicitly with principles such as responsibility, ecological limits and systems thinking.

2. A New Principles-Based Approach in the Development Industry

The Australian development industry has seen a considerable shift towards sustainability over the last decade. Regulatory requirements and the introduction of building rating tools have transformed mainstream awareness and have in turn resulted in changes within the building industry's supply chain. Despite this, even current leading edge practice falls short of what is needed to ensure a sustainable future. In light of the broader context outlined above, it is clear that significant changes need to be made in order to improve sustainability outcomes. The focus on harm minimisation in the development industry needs to be shifted to focus on creating sustainable and even restorative development. Concurrently, there needs to be a greater level of accountability in the way we describe development, as to date it has been common practice to describe a development as 'sustainable' when it features just a few green elements. This shift might be achieved by focusing on the principles behind sustainability and by using those principles to guide the design process.

A principles framework provides a reference point for sustainability in the development industry, ensuring industry progress towards (and beyond) sustainability is in alignment with the broader national and global picture. It reminds us of ecological limits and how we must stay within them, as well as encouraging a systems approach that will take development to a new level of synergy. A principles framework also opens up possibilities for innovation. It provides context and structure to the discourse about development of the future, whilst allowing sufficient flexibility for lateral thinking and creativity. Importantly, it supports learning for sustainability in the development industry. A deep, transdisciplinary, transformative learning approach to principles-based understanding of sustainability (e.g. Meppem and Gill 1998) empowers industry practitioners to recognise the principles that underpin truly sustainable development and apply them in new and creative ways, rather than 'following the recipe'. This is highly important for the development industry's evolution, and for reaching the long term goal of sustainability.

2.1 Principles for Sustainability Learning

This paper draws on previous research into appropriate principles for sustainability learning. The principles set out below have been drawn from many different fields of sustainability learning (Carew and Mitchell 2001) and adapted for the building and construction industry. The principles are divided into interdependence principles (systems thinking, limits and elasticity, impacts, and uncertainty and complexity) and ethical principles (responsibility, awareness and fairness) (see Figure 1). At the core of relevance to the building and construction industry are understanding limits, systems thinking, and responsibility. These are the focus of this paper.

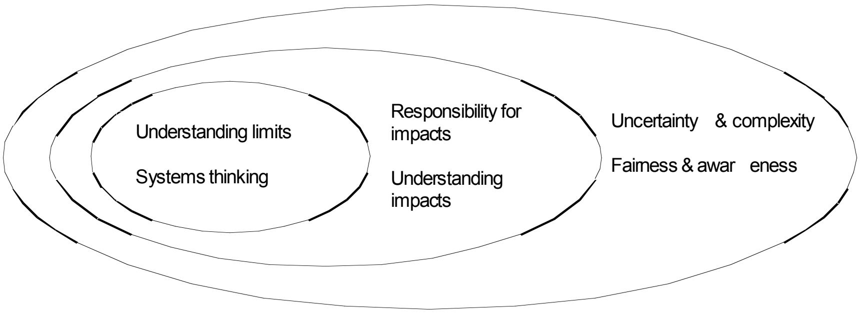


Figure 1: Principles for sustainability learning in the development industry

In the sections that follow, we first outline the principles, then demonstrate their application in various precinct scale developments in Sydney.

2.1.1 Limits

The idea of limits refers to the simple fact that all biophysical resources are limited. The planet has certain amounts of each fundamental building block - the elements - and a finite supply of energy from the sun to drive the processes that change the way those elements are combined in a myriad of ways to produce the biophysical world around us. These natural resources are all we have as potential starting materials for everything we manufacture, construct, use, and dispose. There are physical limits to the scale of these resources, ecological limits to the assimilation potential of the environment, and thermodynamic limits to the rates at which things happen. These limits and the way in which they interact are fundamental to the concept of resilience, which itself is fundamental to sustainability.

As noted earlier, we have already exceeded limits from many perspectives, and from other perspectives are close to it. Our actions have already increased atmospheric concentrations of greenhouse gases, and scientists believe we can only avoid dangerous climate change by urgently making 'deep cuts' in our greenhouse gas emissions. In water, there is a growing call to rehydrate the landscape - to return water to the catchment and source (surface or ground) from whence it was taken (Nelson 2008).

As we can see from the principles above, respecting limits is embodied in the concept of sustainability. Therefore to be considered sustainable, urban development must mirror this principle. It must itself perform within ecological limits. This may be easier to do and measure from some perspectives, such as greenhouse emissions from operational energy use, than from others, such as material intensity. However, the principle of performing within limits needs to be the goal of any sustainable development. Taking climate change as an example, urban development must deliver similar deep cuts in greenhouse emissions to those needed economy-wide to stabilise atmospheric emissions. Whilst sustainable development respects limits from a number of different perspectives, such as resource use, land disturbance and emissions, it also requires systems thinking to explore and optimise the connections between these different areas of ecological impact.

2.1.2 Systems thinking

Systems thinking is embodied in the concept of sustainability (Mitchell, 2000), and recognises we live in a highly interconnected and complex world. It considers the whole and the interrelationship of the many parts, taking into account context and multiple influences and relationships. It also creates awareness of the boundaries and assumptions used to define issues, recognises the influence of world views and perceptions, and embraces uncertainty and complexity. There are myriad examples of systems thinking in nature, yet few in the built environment. Even our approach to green development, perhaps partly as a consequence of traditional disciplinary divisions, tends to focus on one goal at the expense of another, leading to unintended perverse outcomes.

Systems thinking is not reflected in our traditional infrastructure design. Our tendency is to do what we are familiar with, which means that when an existing system is reaching its limits, we augment it with something similar. The economies of scale argument in industrialised systems makes the marginal cost of supplying one more customer look very small. However, a systems understanding of this cost that takes account of their proportion of the large scale infrastructure gives a quite different picture (Mitchell et al., 2007). The extensive economic and environmental advantages of small energy systems (Lovins et al., 2002) and small wastewater systems (Pinkham et al., 2004) are now well documented. The lack of a systems approach in engineering design has also been recently documented in wastewater systems in the USA (Etnier et al., 2007). A systems approach will lead to smaller, distributed infrastructure arrangements, focused on treatment rather than transport of commodities and capturing synergies between infrastructure systems.

Sustainability rating tools for building have played an important role in the 'mainstreaming' of green building, however they can constrain innovation at the cutting edge because they cannot adequately address systems thinking, an inherent limitation of any prescriptive tool. They prompt users to 'follow the formula' (as robust as that formula may be) instead of encouraging broader exploration. Systems thinking encourages creative new connections that allow us to do radically more with less. Emerging interest in the application of 'biomimicry' to buildings is also a recognition of the value of systems thinking. Systems thinking is key to the next paradigm shift in urban development and needs to be built into design and assessment processes.

2.1.3 Responsibility

Whilst the previous two principles are interdependence principles, responsibility is an ethical principle. Business as usual clearly has unacceptable consequences for the future, and in line with this principle all industry sectors, including the development industry, must take responsibility for its actions and accept a greater level of accountability throughout its operations.

For development industry stakeholders and practitioners, responsibility requires a shift in the level of engagement with sustainability principles and with others involved in the process. It means extending the boundaries of responsibility, similar to Covey (1990), by expanding one's area of control as well as taking action within one's influence. The Australian development industry has made significant progress in this regard e.g. It is common for developers to set up partnerships with those who will operate, manage and tenant their developments. However, there is potential for stronger and more extensive connections to be made. New institutional arrangements that facilitate these kinds of relationships will be key (Martin & Verbeek, 2006), particularly through harnessing market capital.

We need to hold ourselves accountable with respect to staying within limits. Some ecological impacts are easier to benchmark and measure than others, allowing us to more easily assess outcomes in relation to limits. For the impacts that are easier to benchmark and measure, targets can be applied as an accountability mechanism e.g. targets for greenhouse gas emission reductions or water use and effluent reductions. We also need to hold ourselves accountable with respect to systems thinking. In this regard, the quality of the outcomes achieved is largely determined by the quality of the process. It is increasingly recognised that traditional design and decision-making processes are no longer appropriate, or the traditional disciplinary roles and divisions. Integrated decision making and implementation processes are now often cited as an important way to optimise outcomes for sustainability. Therefore, it's possible to use process principles as an accountability mechanism for systems thinking.

Building rating tools such as Greenstar and the Australian Building Greenhouse Rating (ABGR) serve as our current accountability mechanism, and have made significant progress in shifting mainstream practice (Davis Langdon, 2008). However, to support the next shift, tools like these will need to be used within a broader principles-based framework that takes limits and systems thinking into account. In a similar vein, sustainability science scholars note the need for transdisciplinary thinking to deal with the issues of our time (Meppem and Gill 1998).

As it is not possible to know 'the right answers' in advance, we must move to the concept of learning, and particularly learning in new, transdisciplinary ways, as key in our planning and accountability mechanisms for sustainability.

3. Towards 'Restorative' Development In Urban Australia

To be truly sustainable, development needs to embody the principles described above. It must stay within ecological limits, and to do this from multiple perspectives a systems approach is required. This definition of sustainability is about a kind of equilibrium – development that uses only its 'sustainable' share of resources and creates only its 'sustainable' share of impacts (such as emissions, waste, effluent, etc). This is the principle of staying within limits. If all our building stock performed like this, we would have an sustainable built environment. However, performance of our existing building stock falls far short of this, and to compensate future development must aim for outcomes that go well beyond sustainability.

This is where the concept of 'restorative' development comes in. Restorative development contributes to the sustainability of the wider area, by using much less than its sustainable share of resources and creating much less than its sustainable share of outputs, or by achieving sustainability 'equilibrium' on the site and reducing the environmental impact of existing development beyond the site through, for example, export of energy with low greenhouse intensity or recycled water.

3.1. The Potential for Precinct Scale Urban Development to Lead in Restoration

Urban redevelopment provides the ideal opportunity for achieving restorative outcomes, particularly precinct scale development that, by nature of its scale and complexity, supports innovation in infrastructure design. This scale lends itself to the cost effective application of decentralised technologies for energy and water that help to minimise environmental impact and maximise efficiency and synergy. Examples include the use of trigeneration for electricity supply, heating and cooling on site, the conversion of organic waste to biogas for use on site, the use of urine separating or vacuum toilets to drastically reduce water use in conveying wastes and energy use in treatment, and improve the local nutrient and energy recovery potential. Use of these decentralised technologies helps a development to meet 'restorative' targets for minimising energy and water use, greenhouse gas emissions and effluent discharge – the principle of staying well within limits. These developments can greatly reduce their reliance on the city's ageing infrastructure, and in some cases be self sufficient and even support other development beyond the site boundaries.

Precinct scale urban development also lends itself well to a systems approach, which is key to restorative development. Developments of this scale are essentially microcosms, with the same spectrum of needs as a normal city, with residential, commercial, retail and community spaces as well as a connecting biological environment. Opportunities exist to apply systems thinking by maximising synergies between the different land and building uses. Buildings can be clustered to maximise symbiotic relationships between them and allow optimal sizing, design and staging of infrastructure.

Development of this scale and complexity provides opportunities to integrate a broader range of issues compared to single building developments, including issues related to transport, connectivity, social access and inclusion as well as the economic aspects of sustainability. This scale of development will naturally involve a larger range and number of stakeholders, meaning that multiple different perspectives and objectives need to be taken into account.

In terms of cost, precinct scale development lends itself to 'doing more with less', through the inherent economies of scale and the ability to optimise infrastructure design. This scale provides ability to bulk-purchase the most efficient products and materials (e.g. "Solaire" in New York). When there is a variety of building types and more uses (commercial, residential, retail), some infrastructure can be designed to better match supply with demand. This is certainly the case with energy, where demand profiles for heat, cooling and electricity can be better matched to supply profiles, effectively reducing the peaks in energy demand (and therefore the need to oversize infrastructure).

In terms of water, precinct scale has advantages over both highly centralised and highly decentralised - the economies of scale in treatment are realised, and the diseconomies of scale in transport are avoided (Pinkham et al 2004). Precinct scale allows potentially more cost effective integration of water cycle elements. Water is heavy, and pumping it around incurs significant energy costs. Therefore local capture, treatment and reuse at a 'cluster' scale is emerging as the means for delivering environmentally, economically, and socially preferable outcomes (Nelson 2008). Precinct scale also offers opportunities to connect effectively to other infrastructure realms. For example, shifting to a resource view of wastewater and collecting the organics in waste and wastewater and recycling those to local energy production. In the future, nutrient recovery will drive wastewater treatment processes, and this is also benefited by a precinct scale approach in terms of collection, storage, avoiding contamination and later transport.

3.2 Creating Restorative Development

In order to create a restorative development, the principles of sustainability need to be translated into specific targets for each aspect of a development, including: water, energy, waste, materials, transport and community. However, the key to restorative development is to meet individual targets and to maximise integration between systems in the built and natural environments. It is often the case that specific targets can be more easily met through synergies between systems and that these synergies can provide the means to "tunnel through the cost barrier".

3.2.1 Staying within limits – sustainable and restorative targets
Defining targets for some development aspects such as energy or water can be easier than for others, such as material intensity and community. For example, the reductions in energy use and greenhouse gas emissions (GHGE) that are required to stay within ecological limits are widely understood and universally applicable. The IPCC 4th Assessment Working Group III report argues that to achieve stabilisation of carbon dioxide at 450ppm CO2-eq, developed countries such as Australia, must reduce GHGE by 25-40% below 1990 levels by 2020 and by 80-95% below 1990 levels by 2050 (IPCC, 2007). As one of the highest per capita emitters of GHGE (WRI, 2008), Australia should arguably be aiming for the upper limit of this range and for meeting it earlier. Consequently, these society wide targets have been translated into specific targets for the building sector as shown in Table 1 below, in relation to the sustainable – restorative framework.

The sustainable level in Table 1 has been defined as meeting interim targets upfront and building in the flexibility to achieve longer-term targets. This target is derived by assuming that the upper bound of the

IPCC's 2020 target (i.e. a 40% reduction from 1990 levels) needs to be achieved upfront in new developments and that a further reduction of 10% is appropriate to account for the low cost of abatement opportunities in the building sector (Enkvist et al., 2008). The 50% reduction target is then adjusted taking into account growth in energy use in the commercial and residential sectors between 1990 and 2005 to establish reductions from 2005 (current) emissions levels. Table 1 represents an example of sustainable / restorative outcomes for greenhouse gas reductions targets for a mixed use urban renewal precinct, where targets are shown in line with their corresponding ratings in BASIX[1] and ABGR[2] as well as the measures and infrastructure required to meet these targets. Sustainable and restorative outcomes are compared with what is currently viewed within industry circles as best practice.

Table 1 – Example of Sustainable and Restorative targets for GHGE reductions and likely infrastructure requirements at a mixed use urban renewal site

Rating Tool	**Current 'best practice'**	**Sustainable Case**	**Restorative Case**
Target		40% reduction in GHGE from 1990 levels whole of society = 64% reduction in GHGE from 2005 levels for the building sector	Substantially greater than 64% reduction in GHGE
BASIX (residential)	25% BASIX score	60% BASIX score	substantially > 60% BASIX score
ABGR (commercial)	4.5 star	5 star + 40% additional CO_2-eq reductions	5 star + substantially > 40% additional CO_2-eq reductions
Measures / Infrastructure	1. Energy efficiency initiatives - average market practice in Australia, and 2. Solar hot water for residential buildings	1. Best practice energy efficiency, with some leading edge efficiency initiatives 2. Life-cycle embodied energy reductions and – Trigeneration or – Large-scale solar hot water system, – Geothermal heat exchange for space heating and cooling, and – Some on-site renewable energy	1. As for sustainable case (either path) with leading edge energy efficiency 2. Larger contribution from on-site renewable energy 3. Off-site greenhouse gas reduction initiatives

Adhering to ecological limits in the water cycle relates to the use of a sustainable yield of water that can be readily replenished locally as well as mitigating the impacts of stormwater runoff on downstream environments. Sustainability targets set for potable water substitution and stormwater management in general need to be site specific, to take into consideration the physical attributes of the site and surrounding catchment. The ecological limits concept in water extends to considering the resources in the wastewater stream - in particular, phosphorus. Phosphorus is an essential nutrient for all growth, and is currently supplied by mineral deposits that will be depleted in approximately 50-80 years. We need to move from a linear to cyclical approach to phosphorous use, by taking advantage of urine as a concentrated 'source' of phosphorus. The leading water research laboratories in Switzerland recently released a compilation of their technical, social, and economic work in this area (EAWAG 2007), and a trial of 20 urine-separating toilets is underway in Queensland (Beal et al 2008).

With respect to stormwater quality improvements, targets to create a restorative development need to reflect the sensitivities of the receiving environments downstream of the development (Barter, 2005). Natural runoff loads of phosphorous and nitrogen vary from catchment to catchment, as the natural uptake of these nutrients also varies depending on the downstream ecosystem and its condition. The most effective method to reduce adverse impacts on the downstream ecosystem is to design the development's landscape to mimic the natural environment, so that stormwater runoff is slowed and filtered to stay within natural limits of pollutant loads and flow frequency. The Sydney Metropolitan Catchment Management Authority is now recommending that the impervious area in a catchment that is directly connected to a stream by a stormwater drain be less than 2-5% of the catchment, in addition to ensuring that downstream waterways are not affected by erosion or excessive nutrients (SMCMA, 2007). This has significant implications for precinct developments and the integration of water sensitive features into landscape design. Reducing overall site imperviousness will mean an increase in green areas, including green roofs. Minimising the area of hard surfaces directly connected to drainage will mean that all hard surfaces must drain through buffer strips, grassed swales and other water sensitive landscape elements.

3.2.2 Systems thinking – a key attribute of restorative development

Ecological limits need to be respected within a development but also for the surrounding community, as for example, meeting potable water reduction targets at the expense of greater energy use in the community is not a sustainable outcome. This is where the application of the 'systems thinking' principle becomes important. Not only is it important to consider the overall balance of impacts across the different aspects of the development, but in order to make greater advances in sustainability it is vital to assess the potential for

[1] BASIX is the Building Sustainability Index tool used in NSW http://www.basix.nsw.gov.au/information/index.jsp
[2] ABGR is the Australian Building Greenhouse Rating tool http://www.abgr.com.au/

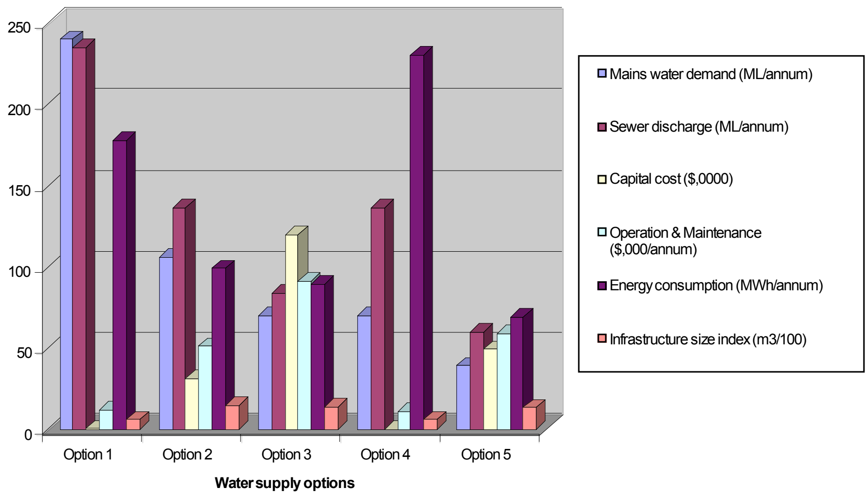
synergies between different parts of the overall system. For example, rainwater can be collected and used to cool an on-site cogeneration or trigeneration plant, which in itself reduces the site's greenhouse gas emissions; but in conjunction, the heat transferred to the rainwater produces a suitable hot water supply source for the development. Further examples of synergies between systems include: recycling biosolids and organic waste in a development for digestion and use as biogas, recycling biosolids/organics for soil conditioner, collecting urine from urine diverting toilets to recover nutrients for use as fertiliser and the use of green roofs to compensate for reduced green areas, improve water quality and provide thermal mass for a building. In this way, available resources can be used more effectively by maximising synergies.

One approach to maximising synergies between systems in a development is to use the principles of biomimicry. Biomimicry takes design inspiration from nature and encourages the incorporation of natural processes into the design of systems in the built environment (Benyus, 2002). Council House 2 is the first Australian urban building to be designed based on the principles of biomimicry (Morris-Nunn, 2007). Features of CH2 include: external sun shades made of recycled timber that pivot in response to the angle of the sun, extraction of warm air through ceiling exhaust and wind powered turbines, shower towers that use falling air and water to cool the lower levels of the building, plantings on the north façade and roof to provide shade, thermal mass in between floors to absorb excess heat as well as solar hot water, photovoltaic cells and a gas-fired co-generation plant to provide electricity (City of Melbourne, 2006).

In Berlin, UFA FABRIK and the Institute of Physics building at the Technical University of Berlin at Adlershof (Schmidt 2005) go further in connecting water and energy cycles with biological systems. Schmidt is interested in the direct connections between rainfall and energy absorption. He suggests that the lack of vegetation in our urban landscape is an insufficiently explored factor in the climate change equation that significantly shifts two variables: the nature of reflected radiation, resulting in shifts in the quantum of energy absorption potential in the atmosphere, and water and energy absorption patterns, significantly impacting heat island effects and thermal performance of buildings. The evaporation of water provides significant cooling potential - up to a theoretical maximum of 680kWh per cubic metre of water. Operational measurements are showing average figures of around 300 kWh/m2.a (Schmidt 2005).

The overall balance of sustainability outcomes is highly important when assessing options for a development. In the graph in Figure 2 below, the characteristics of a number of water demand/supply options that have been developed in accordance with the sustainable-restorative framework have been graphed for comparison. The water savings measures used in each option are explained in the key to the right of Figure 2. From left to right, each option provides a greater reduction in potable water demand; however, the associated sewer discharges and energy consumption do not uniformly decrease. In particular, the energy required for treatment and pumping of the externally sourced recycled water in option 4 is much greater than for option 3, which offers similar reductions in potable water use. The capital, operation and maintenance costs of each system and the relative size of the required infrastructure are also shown on this graph (note that capital and operating costs were unavailable for Options 1 and 4). In Option 4, mains water consumption is similar to option 3, however, energy consumption is high and in reality, the cost of this system to the community is likely to be much higher. It is clear from this graph that option 5, which maximizes efficiency, reuse of water, nutrients and biosolids and consequently incorporates synergies with natural systems, provides a more even reduction between potable water use, sewer discharge and energy consumption. This example shows very clearly that the entire system must be considered in order to achieve a balance between environmental impacts. It also shows that appropriate costing of infrastructure needs to be undertaken to reflect the real cost to the community of various options (Mitchell et al., 2007).

Figure 2 – Comparison of water demand-supply options for a precinct scale development



Option 1 - Australian best practice efficiency

Option 2 – Efficiency + rainwater + harvested stormwater

Option 3 – Efficiency + rainwater + on-site wastewater recycled

Option 4 – Efficiency + rainwater + externally sourced recycled water

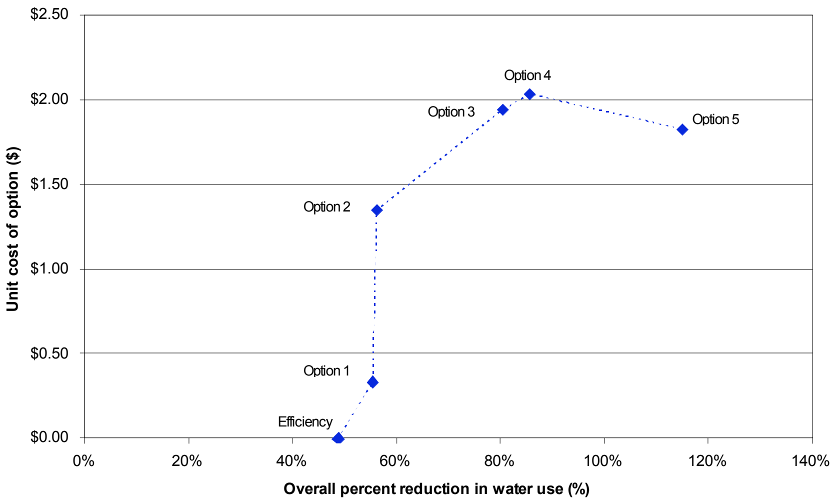
Option 5 – Greater efficiency + rainwater + greywater + collection of urine and biosolids

The graph in Figure 3 presents an example of the unit costs associated with different water demand-supply options for a precinct development. The infrastructure proposed for each option is explained in the key to the right of the graph. Options 1 to 4 illustrate the rising unit cost associated with increased water savings, however, option 5 is an example where the unit cost of water savings has reduced due to an economy of scale. This is an example of how innovative strategies and effective sizing can help to "tunnel through the cost barrier".

In practice, to ensure sustainable outcomes for a development, these sustainability principles (limits, systems thinking, responsibility) must be embedded in the design process. Collaboration between designers, planners and engineers is crucial to ensure that synergies between systems that may be simple to adopt are not overlooked. The application of explicit principles for process in urban development will help to encourage systems thinking and ensure synergies are captured. Figure 4 shows principles that have been developed specifically to guide precinct-scale urban redevelopment. The overarching principle governs outcomes – a development that is at least sustainable and ideally restorative. The other principles govern process and are in place to ensure the first principle is achieved, and in the most effective way. Using these process principles would support restorative outcomes and preclude the choice of design options such as Option 4 in Figure 2.

The examples used in this section of the paper focus on operational impacts that have been modeled for upcoming urban redevelopments in Sydney, however as the development industry moves further towards a systems approach, new concepts will be need to be assimilated. One of the emerging frontiers is the 'embodied impacts' of the materials used. These can be far ranging, and include impacts on climate change, biodiversity and other ecological health factors as well as energy and water use.

Figure 3 – Unit costs associated with water savings options for a precinct development



Efficiency - Australian Best Practice efficiency

Option 1 – Rainwater (cooling towers)

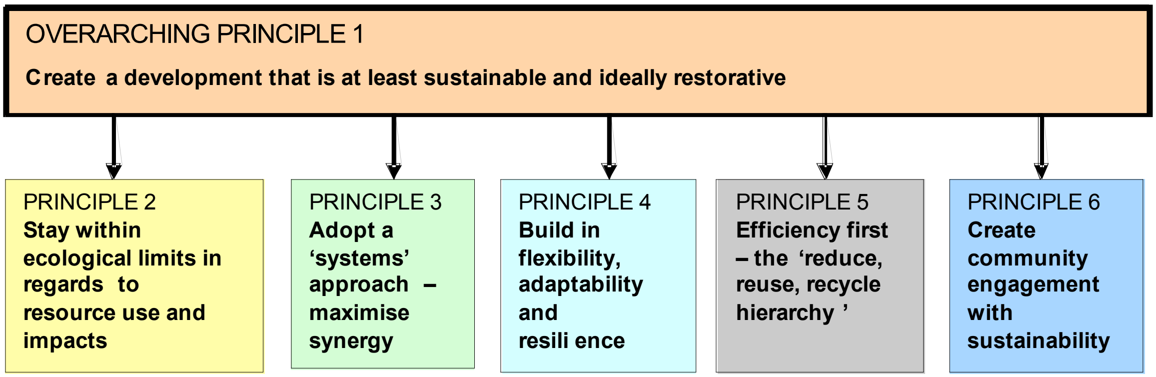
Option 2 – Rainwater (reticulated)

Option 3 – Rainwater & stormwater (reticulated)

Option 4 – Rainwater & on-site wastewater recycled

Option 5 – Rainwater & recycled wastewater from sewer main

Figure 4 – Sustainability process principles for design of precinct scale developments



4. Conclusion

Despite the increasing popularity of building sustainability rating schemes and the shifts that have been occurring in the building industry, greater changes need to occur in order for developments to become sustainable and respond to the pressing issues of climate change, material waste and water scarcity. Business as usual in the development industry and even current 'best practice' is not sufficient to address these problems. It is important that planners, designers and engineers in the industry look beyond current notions of 'best practice' and seek to create development that has a net positive impact on the environment and society. By using an overarching principles based framework, all practitioners involved in designing the built environment may be able to rethink their approach and collectively create development worthy of sustainable and even 'restorative' status, where the development has a positive impact on its environment. This paper sets out a principles framework that may be used to guide the process and outcomes of 'restorative' developments. The sustainable-restorative framework provides a means for identifying the most appropriate option in each development situation. Urban renewal sites present an excellent opportunity to apply this framework, due to the potential to create synergies between systems and the benefits gained from economies of scale. The creation of restorative developments in Australia will have a significant impact on reducing the ecological impact of urban areas, while still accommodating growth.

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CALCULATING BUILDINGS' GREENHOUSE GAS EMISSIONS

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Summary (*11-point Arial, bold, flush left, 11-point line spacing, style name "Heading 1*")

Increased concern about climate change has led many building designers throughout the world to focus on reducing energy use in buildings. It is often assumed that energy use is more or predictive of greenhouse gas GHG) emissions However, there are numerous time-dependent variations in building energy use and electric grid operation that result in important differences between the quantity of energy used and the related GHG emissions. These differences are not generally considered or even recognized by most designers or even regulators and others who are now striving to develop a carbon neutral economy. Efforts have begun to recognize the important factors that determine a building's GHG emissions based on its energy use, but these efforts are still in the preliminary stages. This paper identifies some of the important factors that affect the estimation of GHG emissions based on energy use data from simulations during design or from actual energy meters or purchases. These differences are being considered in a new effort to develop a tool that will more accurately predict building GHG emissions based on design alternatives, thus allowing design professionals to improve the GHG emission performance of their buildings.

Keywords: Greenhouse gas, climate change, GHG emissions, energy, design

1. Introduction

Buildings are responsible for a significant fraction (~40%) of fossil fuel consumption and related greenhouse gas (GHG) emissions globally. In the United States, buildings are responsible for 70% of total electricity use. While these factors vary from country to country and even among regions within countries, the numbers reflect the relative magnitude of building energy consumption in most of the developed world. In the developing world, the percentages are different with a shift toward combustion of biomass and less electricity use. However, the human contribution to GHG emissions is still significant and growing as developing countries gain access to modern energy-consuming technology, electricity, and a more mobile life style.

Growing concern about climate change and the human contribution to it through emissions of greenhouse gases (GHG) has led to increasing focus on reduction of GHG usually referred to as carbon dioxide equivalents (CO_2eq) using United Nations Framework Convention on Climate Change factors for global warming potentials of various atmospheric emissions. Efforts to reduce building's contributions to climate change focus on reduction of emissions of GHGs. Calculation of GHG emissions is usually done with simple conversion factors that translate fuel consumption and electricity use to GHG emissions. However, these conversion factors may not reliable inform design or building operational decisions due to potentially large influences of time and weather on actual GHG emissions compared with annual averages.

In the paper we describe the approach to GHG calculation commonly used today, some of the challenges facing those who are developing more reliable tools for such calculations, and some of the sources of uncertainty in any method for estimating GHG emissions from buildings.

1.1 Background: Global Greenhouse Gas Emissions

Emissions of GHGs have increased since the industrial revolution. The dramatic increase that began after World War II has resulted in an average annual increase in atmospheric CO_2 of 2 ppm to the present level of 383 ppm. The rate of increase has also increased in recent years. It is forecast that GHG emissions will increase by 50 percent by 2025. Emissions in developing countries are growing and are expected to continue to grow the fastest. To avoid dangerous climate change requires slowing this trend in the short term and eventually and reversing it over the coming decades.

While CO_2 comprises the majority of GHG emissions, at about 77 percent of the worldwide total (measured in global warming potentials). Methane (CH_4) and nitrous oxide (N_2O) are the next most important GHG, and methane's short term impact is dramatically larger than its longer term impact, the usual basis for comparison of global warming potentials (GWP) among the various GHGs. Fluorinated gases (SF_6, PFCs, and HFCs) have a small share of the remaining important GHGs.

In developing countries, the contributions of CH_4 and N_2O are significantly larger in and in some cases exceed those of energy-related CO_2 emissions.

GHG emissions come from almost every human activity. Because of their large contributions, key policy targets are electricity and heat, transport, buildings, industry, land-use change and forestry, and agriculture. In terms of future growth the electricity and transport sectors are particularly important sectors. In terms of potential for short-term and cost-effective reductions, buildings and transport both figure prominently.

Global emissions are dominated by a small number of countries producing the majority of global GHG emissions. Most of these are among the most populous countries and have the largest economies. However, the major emitters are comprised almost equally of developed and developing countries and some transition economies of the former Soviet Union.

Projection of emission by nations is highly uncertain, especially among developing country economies due to their volatility and vulnerability to external shocks.

Not surprisingly, most large current emitters are among the largest historic emitters.

Coal is the highest carbon fuel and it plays a dominant role in electric power generation throughout the world. Its future growth is expected to be significant. Many leaders in the building and environmental communities advocate reducing or eliminating emissions from coal-fired power plants either be carbon sequestration or by eliminating the plants altogether and stopping construction of new plants.

Avoiding dangerous climate change will require reduced coal use or geologic sequestration of coal-related emissions. Similarly, major emitting countries will need to reduce their dependence on oil, particularly in the transport sector where it has near monopoly status.

1.2 Buildings' Share of Global GHG Emissions

The proportion of total national emissions attributable to buildings ranges widely depending on the definition of building-related emissions, the accounting method used, and, of course, the level of development and energy efficiency of the national building stock. The major drivers of buildings energy demand are population growth, economic development, diffusion level of energy use equipment, size of households, square meters of buildings areas, and behavioral factors" (de la Rue du Can and Price, 2008).

In developed countries, buildings' share is relatively similar at around 25% to 35% of total national GHG emissions according to the World Resources Institute. In contrast, there is great diversity in buildings' share among developing countries ranging from around 10% (Brazil) to 40% (Poland) (Baumert et al, 2005). Where air-conditioning is common and widespread, electricity consumption will increase in non-residential buildings. In the U.S. the fraction of air conditioned homes (~70%) and commercial buildings is extremely high while in most other developed countries it is increasing in commercial buildings while in residences the penetration is strongly dependent on climate and other factors. Furthermore, the overall distribution of energy sources and the carbon intensity of the combustion fuels and electricity will be reflected in the national share of carbon emissions attributable to buildings.

"The residential sector is characterized by a striking contrast in fuel use between developed and developing countries. More than half the world's population lives in rural areas, of which more than 90% are in developing countries. The vast majority of this population is dependent upon traditional wood fuel to serve the basic need of cooking and water heating. Hence the share of biomass in the global residential final consumption represents more than 40% in 2004. In developed countries, natural gas and electricity are the most used fuel in residential buildings. While energy demand growth in residential sector was 1.4% over the period 1971–2000, growth in the commercial sector was 2.4%. Three quarters of the energy use in the commercial sector is currently consumed in developed countries. The commercial sector is characterized by a high level of electricity consumption, representing almost half of the total energy use (48%) in 2004." (de la Rue du Can and Price, 2008).

In the mid-1990s very different calculations done by the present author for buildings in the U.S. (Levin, Boerstra, and Ray, 1995) and by the World Resources Institute for buildings worldwide estimated buildings' share of total national carbon emissions at approximately 40% to 45% of total national energy consumption and a similar value for carbon emissions. Some authorities currently claim that buildings' share is even higher in the U.S. (e.g., 48% by Ed Mazria) (2008). The Levin et al estimate included building materials manufacturing, construction, operation, maintenance, renovation, and end-of-life disposal of buildings in this total. However, it should be noted that approximately 20 to 25% of building energy use is for "plug loads," that is energy used for appliances, electronics, and other devices that are not part of the building itself but that derive their energy from the same electrical source as the whole building. Therefore, their electrical consumption is measured at the electric meter and large scale data analysis and reporting often does not separate the building-related and the within-building-but-not-building-related energy uses. There remains a question as to whether devices like refrigerators, cookstoves, and plug-in lamps should be included in building-related energy uses for purposes of attribution and carbon emissions estimation

Table 1. Greenhouse gas emissions in 2004 by sector excluding land use change and forestry (source: adapted from Climate Analysis Indicators Tool (CAIT) Version 5.0. (Washington, DC: World Resources Institute, 2008).

Sector	**World %**	**United States %**	**European Union %**	**Asia %**
Energy	96.3	99.1	97.1	93.0
Electricity & Heat	45.3	45.8	39.4	46.5
Manufacturing & Construction	18.8	11.5	16.3	24.8
Transportation	19.1	30.5	23.1	10.9
Other Fuel Combustion	12.6	10.9	18.2	10.7
Fugitive Emissions	0.6	0.4	0.1	0.1
Industrial Processes	3.7	0.9	2.9	7.0
Total ($MtCO_2$)	**29,319.4%**	**5.873.8**	**4,013.1**	**9,968.1**

As can be seen in Table 1, the dominant source of human GHG emissions throughout the world is energy consumption with somewhere between 40 and 50% attributable to buildings. If construction and demolition are added to the total, buildings share is well over half. However, much of the electricity used in buildings is not to operate the building itself but is attributable to "plug loads' including appliances, electronics, etc. Nevertheless, building services uses of energy are approaching half of total energy use in developing countries.

Of course there are many ways of classifying the users of energy and of doing the accounting. According to the World Resources Institute (see Table 1), buildings account for only 15% of global GHGs. Of that amount, 65% is residential, 35% commercial. Within the residential sector, public electricity is 43%, District heat is 12%, and direct fuel combustion is 45%. In the commercial building sector, 65% is electricity, 4% is district heat, and 31% is direct fuel combustion. It is not clear whether the

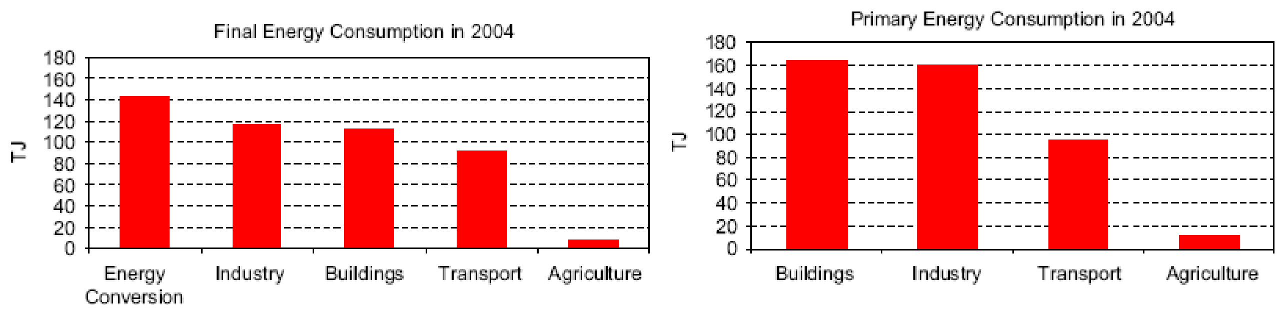

Figure 1. Final and Primary Energy Consumption by Sector in 2004 (source: de la Rue du Can and Price, 2008).

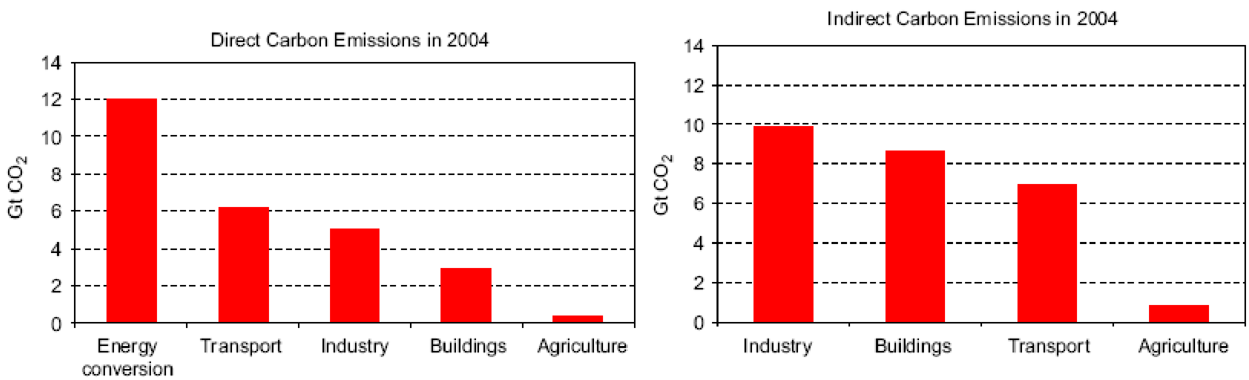

Figure 2. Direct and Indirect Carbon Dioxide Emissions in 2004 (source: de la Rue du Can and Price, 2008).

Regardless of the precise quantity of its share of global GHG emissions, it is clear that buildings are important sources of GHG emissions. It is also important to note that the range of building energy efficiencies and of potential sources of energy for buildings major consumption categories suggest that buildings can be far more energy efficient and emit far less GHGs. It may also be true that careful selection of energy efficiency measures can ensure optimization of both energy conservation goals as well as GHG emission reduction goals. However, since there is not a one-to-one relationship between energy use and GHG emissions, it is important to understand the GHG emissions implications of various alternative technologies to reduce energy use. For example, electricity from coal-fired power plants is associated with roughly twice the GHG emissions as that from natural gas-fired plants. Hydroelectric and wind electric energy plants are responsible for far less GHG emissions, although their construction, operation, and ultimate disposal do have GHG emission implications as does the transmission of electricity from any plant to the site where it is used. Large-scale concentrating solar electricity generation is viewed as one of the potentially viable renewable sources of future electricity, but it too has GHG emissions associated with its construction, operation, and electricity distribution. On site photovoltaic electric generation eliminates the transmission losses but does have a several-year payback for the energy required to manufacture and install the system. Even passive solar heating and cooling where high performance glass, shading, thermal storage, and other components are included in order to improve system performance still must be accounted for in total GHG emissions required to install and "operate" for their entire life cycles.

Conversion of building energy use data to GHG emissions

Following are definitions of some basic terms and some background information on greenhouse gases that are useful for those calculating greenhouse gas emissions.

Carbon sequestration: The fixation of atmospheric carbon dioxide in a carbon sink through biological or physical processes.

Carbon sink: A reservoir that absorbs or takes up released carbon from another part of the carbon cycle. The four sinks, which are regions of the Earth within which carbon behaves in a systematic manner, are the atmosphere, terrestrial biosphere (usually including freshwater systems), oceans, and sediments (including fossil fuels).

Global warming potential (GWP): An index used to compare the relative radiative forcing of different gases without directly calculating the changes in atmospheric concentrations. GWPs are calculated as the ratio of the radiative forcing that would result from the emission of one kilogram of a greenhouse gas to that from the emission of one kilogram of carbon dioxide over a fixed period of time, such as 100 years.

Greenhouse gases: Those gases, such as water vapor, carbon dioxide, nitrous oxide, methane, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride, that are transparent to solar (short-wave) radiation but opaque to long-wave (infrared) radiation, thus preventing long-wave radiant energy from leaving the Earth's atmosphere. The net effect is a trapping of absorbed radiation and a tendency to warm the planet's surface.

Greenhouse effect: The result of water vapor, carbon dioxide, and other atmospheric gases trapping radiant (infrared) energy, thereby keeping the earth's surface warmer than it would otherwise be. Greenhouse gases within the lower levels of the atmosphere trap this radiation, which would otherwise escape into space, and subsequent re-radiation of some of this energy back to the Earth maintains higher surface temperatures than would occur if the gases were absent. See Greenhouse gases.

Radiative forcing: a measure of how the energy balance of the Earth-atmosphere system is influenced when factors that affect climate are altered. The word radiative arises because these factors change the balance between incoming solar radiation and outgoing infrared radiation within the Earth's atmosphere. This radiative balance controls the Earth's surface temperature. The term forcing is used to indicate that Earth's radiative balance is being pushed away from its normal state.

The principal greenhouse gases are shown in Table 2. From the table it is possible to see the growth in concentrations between pre-industrial atmospheric concentrations and those observed in 1998. Note that the atmospheric lifetimes of these gases vary greatly and are part of the reason that the time required for stabilizing climate and eventually reversing climate change through control of the concentrations of releases of these gases.

Table 2. Global atmospheric concentration (ppm unless otherwise specified), rate of concentration change (ppb/year) and atmospheric lifetime (years) of selected greenhouse gases

Atmospheric Variable	CO_2	CH_4	N_2O	SF_6 [a]	CF_4 [a]
Pre-industrial atmospheric concentration	278	0.700	0.270	0	40
Atmospheric concentration (1998)	365	1.745	0.314	4.2	80
Rate of concentration change[b]	1.5c	0.007[c]	0.0008	0.24	1.0
Atmospheric Lifetime	50-200[d]	12[e]	114[e]	3,200	>50,000

[a] Concentrations in parts per trillion (ppt) and rate of concentration change in ppt/year.

[b] Rate is calculated over the period 1990 to 1999.

[c] Rate has fluctuated between 0.9 and 2.8 ppm per year for CO_2 and between 0 and 0.013 ppm per year for CH_4 over the period 1990 to 1999

[d] No single lifetime can be defined for CO_2 because of the different rates of uptake by different removal process removal processes.

[e] This lifetime has been defined as an "adjustment time" that takes into account the indirect effect of the gas on its own residence time.

1.2. Basics of GHG Emission Calculations

It is common practice in most developed countries to use annual average conversion factors for calculating GHG emissions based on electricity consumption. These factors may vary greatly within and among countries due to differences in the composition or inventory of electricity generating plants. There is a substantial range of emissions depending on the combustion fuel used or other source of energy to produce electricity. For example, electricity produced in coal-fired power plants result in approximately twice the CO_2 emissions compared with natural gas fired electric power plants.

A general practice is to calculate a building's greenhouse gas emissions relatively simply. This involves using readily available conversion factors for each form of energy used annually. An alternative that may be somewhat more accurate is to modify fuel use data by the efficiency of the device consuming the fuel and other factors to convert the fuel consumption to emissions of each to the mass of the greenhouse gases. Then, using global warming potentials (GWP) of each pollutant emitted, the total GWP is given in carbon dioxide equivalents (CO_2e).

Currently, building design professionals estimate the annual energy consumption (e.g. kWh) that will be required to operate the building, and then apply actual average annual carbon emission factors (e.g., tons of CO_2 per kWh or per therm) to those estimates in order to estimate the annual carbon emissions associated with the building's operation (e.g. tons of CO_2 = kWh * tons of CO_2/kWh). The carbon emission factors applied to electricity to be purchased from the grid are based upon various sources within the building design professions today. There is not standard practice for selecting and applying carbon emission factors applied to electricity whether purchased from a utility or produced on-site. Combustion on-site is more reliably converted to emissions using standard factors although inclusion of 'embodied' emissions related to use of the fuel is not common.

Limitations of current methods for estimating GHG emissions

There are at least four aspects of the current method that may lead to less than sufficiently accurate estimates of carbon emissions associated with buildings.

Limited scope

The current emission factors for the carbon emissions associated with the generation of electricity, i.e., predominantly from the emissions from combustion of a fuel to produce electricity, do not reflect the emissions associated with the extraction and transportation of the fuels used to generate that electricity. It is also possible that these factors have not been fully adjusted to reflect the energy losses on the transmission and distribution grid between the point of generation and the point of consumption, i.e., the building. Similarly, emission factors for on-site combustion do not include the so-called 'embodied' emissions associated with extraction, transportation, and storage of the fuels.

No differentiation by time period

Annual average emission factors for electricity purchased from the grid can mask significant variations in emissions by time of day, day of the week and/or season, and therefore may not produce a sufficiently accurate estimate. This is a major reason for this project. Energy consumption and GHG emissions do not map one-to-one due to the diversity of electricity generation on the grid and its geographical and temporal variations. The question then is whether the estimate of carbon emissions would be materially improved if building design professionals could evaluate the time-dependent energy consumption at the site using emission factors based upon the corresponding time-dependent output of the electric grid providing electricity to that that site.

No differentiation by weather

There are two potential concerns in this regard. The first is similar to, if not the same as, the lack of time differentiation. Annual average emission factors for electricity purchased from the grid can mask significant variations in emissions within the year due to variations in weather conditions. In other words, electricity generation emissions under extreme weather conditions such as heat waves and cold waves are different from emissions under annual average weather. The second relates to potential mismatches between the weather assumptions underlying the estimates of building energy consumption and the weather assumptions underlying the carbon emission factors. Building energy simulations are performed using average annual weather data (Typical Meteorological Year – TMY). Therefore the estimates of energy consumption produced by those simulations reflect that weather assumption. In contrast, actual carbon emission factors for grid electricity reflect actual weather in the relevant year while projected carbon emission factors reflect the weather assumptions used in the simulation of the electric grid. Thus, there is a possibility of a mismatch between the estimates of energy consumption and the carbon emission factors being applied to those estimates.

Actual versus projected emission factors

The current emission factors for electricity purchased from the grid are based upon emissions associated with actual generation of electricity in a recent year. The concern here is whether those factors provide a sufficiently accurate estimate of the emissions that will be associated with the future mix of generation over the life of the building.

In addition to evaluating the accuracy implications of each of those aspects of the current carbon estimation methodology, the accuracy of the energy use estimates to which those factors are being applied must be considered. Research indicates that the actual levels and patterns of building energy use can be very different from the estimates of use from simulation models made during the design process. These differences between estimated and actual building energy use arise because building energy simulations rely upon assumptions about key factors such as building occupancy, use, and operation. Actual occupancy, usage and operation of the building are often very different from those assumptions.

ASHRAE's Carbon Tool Development Project

The American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) has embarked on a project to development a more robust and accurate tool for estimating building's carbon emissions to enable designers, building operators, and others to make decisions that will improve the carbon emissions performance of a building and to account for the emissions that have occurred in an existing building. The tool will weigh the accuracy of the building energy use estimates when considering the value of developing more accurate estimates of carbon emissions to be applied to those energy estimates.

While the uncertainties are very large in any prospective estimate of carbon emissions based on forecasts and historical data as well as building simulations, by identifying and characterizing the sources of uncertainty and incorporating means to reflect them in an estimating tool will provide "realistic" data as an improved basis for design and operation.

Discussion and Conclusion

The present inaccurate methods of estimating buildings' carbon emissions leave building design and operational professionals with inadequate information to make decisions that actually result in lower greenhouse gas emissions. The assumption that a decision resulting in less energy use is always the lower GHG emission strategy is potentially costly both to the building operator as well as to the global climate. It is important to improve on currently available estimation tools and reduce the uncertainty in decision-making around a building's carbon footprint. While the data available currently is a major constraint on the development of accurate tools, investigation and improvement of the performance of current tools can help identify the most important data needs and the value in improving data quality. ASHRAE's current efforts are unique as far as is known by the author, and they are certain to create increased awareness of the problems and means of addressing them. It is hoped that the tool itself will be a major step toward broader recognition of the most important factors related to buildings' GHG emissions and that this recognition will enable more rapid progress toward net zero GHG emission buildings.

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Appendix

The data in this appendix are provided for more readers interested in more detailed quantification of greenhouse gases.

Table A1: Global Warming Potentials (GWP) (Relative to Carbon dioxide = 1) and Atmospheric Lifetimes (Years) IPCC 1996 values.

Gas	Atmospheric Lifetime	100-year GWPa	20-year GWP	500-year GWP
Methane (CH_4)b	12.3	21	56	6.5
Nitrous oxide (N_2O)	120	310	280	170
HFC-23	264	11,700	9,100	9,800
HFC-125	32.6	2,800	4,600	920
HFC-134a	14.6	1,300	3,400	420
HFC-143a	48.3	3,800	5,000	1,400
HFC-152a	1.5	140	460	42
HFC-227ea	36.5	2,900	4,300	950
HFC-236fa	209	6,300	5,100	4,700
HFC-4310mee	17.1	1,300	3,000	400
CF4	50,000	6,500	4,400	10,000
C2F6	10,000	9,200	6,200	14,000
C4F10	2,600	7,000	4,800	10,100
C6F14	3,200	7,400	5,000	10,700
SF6	3,200	23,900	16,300	34,900

These values were modified for the IPCC's Third Assessment Report (TAR) released in 2001 as shown in Table A2.

Table A2. Conversion Factors for Global Warming Potentials (source: 2001 IPCC GWP)

Gas	2001 IPCC GWP
Carbon Dioxide	1
Methane	23
Nitrous Oxide	296
HFC-23	12,000
HFC-125	3,400
HFC-134a	1,300
HFC-143a	4,300
HFC-152a	120
HFC-227	3,500
HFC-236	9,400
Perfluoromethane (CF_4)	5,700
Perfluoromethane (C_2F_6)	11,900
Sulfur Hexafluoride (SF_6)	22,200

Table A3 from L2, Approved document L2A emissions factors (source: UK, 2006)

Fuel	**CO_2 emission factor $kgCO_2/kWh$**
	UK
Natural gas	0.194
LPG	0.234
Biogas	0.025
Oil	0.265
Coal	0.291
Anthracite	0.317
Smokeless fuel (including coke)	0.392
Dual fuel appliances (mineral and wood)	0.187
Biomass	0.025
Grid supplied electricity	0.422
Grid displaced electricity[1]	0.568
Waste heat[2]	0.018

Notes:

1. Grid displaced electricity comprises all electricity generated in or on the building premises by, for instance, PV panels, wind-powered generators, combined heat and power (CHP), etc. The associated CO_2 emissions are deducted from the total CO_2 emissions for the building before determining the BER. CO_2 emissions arising from fuels used by the building's power generation system (.e.g., to power CHP engine) must be included in the building CO_2 emissions calculations.
2. This includes waste heat from industrial processes and power stations rated at more than 10 MWe and with a power efficiency > 35%.

ACCURACY OF SOME EPBD IMPLEMENTED THERMAL PERFORMANCE CALCULATION PROCEDURES

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Keywords: energy, simulations, regulations, EPBD

Summary

The driving force of the thermal regulations revision in the European Union (EU) was the European Directive for the Energy Performance of Buildings – EPBD (European Commission, 2003). The main objectives of the EPBD are the harmonization of all thermal regulations in the EU and the optimization of buildings energy performance, taking into account the climatic conditions, indoor comfort conditions and economic viability, for both new and existing buildings.

In order to be efficient and effective, the thermal regulations must lead to an accurate estimation of the energy performance of buildings allowing the energy certification to become a useful tool to compare results obtained in different countries. Having this fact in mind, the results obtained with the Portuguese calculation methodology, together with the results obtained with the methodologies used in two other countries (UK and Belgium), will be put side by side and also compared with the results obtained with a dynamic simulation tool for the energy performance estimation - VisualDOE.

This case study will be based on the heating and cooling needs estimation of some Test Cells built in the School of Engineering of the University of Minho. The simulated results obtained using the simplified calculation models established in the mentioned three countries thermal regulations and by VisualDOE.

1. Introduction

One of the main challenges that nowadays humankind has to face is the climatic changes and environmental depletion. It is known that these challenges are closely related to the energy consumption. In the EU 15, there are about 164 million buildings, responsible for 40% of the final energy demand and 1/3 of the greenhouse gas emissions. So, in order to promote the reduction of energy consumption, it is fundamental to apply sustainable development principles in the construction sector (Tzikopoulos et al, 2005; Eyckmans and Cornillie, 2002).

There are several measures that can be applied in order to reduce the buildings energy consumption, since the appeal of the consumers' consciousness to environmental problems, to the development of new construction solutions, more energy efficient.

One of the larger impact measures is the implementation of more restrictive thermal regulations. One of the new Portuguese thermal regulations, the RCCTE 2006, is applied to residential buildings and imposes a higher quality of the envelope, promotes the use of renewable energy and supports the use of certified materials.

The driving force of the thermal regulation revision was the European Energy Performance of Buildings Directive (European Commission, 2003). The main objectives of the EPBD are the harmonization of all thermal regulations in the European Union and the increase of buildings energy performance, taking into account the climatic conditions, indoor comfort and economic viability, for both new and existing buildings.

All the EU thermal regulations have methodologies that can, effectively, estimate the energy performance of standard buildings allowing a much more energy efficient design and thus an effective reduction of the energy consumption. The harmonization of methodologies and the subsequent building energy certification can allow comparing the European building stock in a more effective way.

The goal of this paper is to assess and compare different European thermal regulation methodologies, based on the EPBD. Three methodologies were applied to estimate the heating and cooling needs of a case study: the Portuguese (RCCTE, 2006), United Kingdom (SBEM, 2007) and Belgium – Walloon Region

(CWATUPE, 2007) thermal regulations. The heating and cooling needs were also determined by means of a dynamic simulation tool – VisualDOE – in each climate (Portugal, United Kingdom and Belgium). The case study used was the Test Cells built in the School of Engineering of the University of Minho, Portugal.

2. Building description

The Test Cells used in this study have three compartments: a Sustainable Test Cell (STC), a Conventional Test Cell (CTC) and a Passys Test Cell (PTC). However, this study focuses only the STC and the CTC, in order to guarantee that the Portuguese, the Belgium and the United Kingdom thermal regulations calculation methodologies can estimate with good accuracy the thermal behaviour of both conventional and non-conventional solutions.

2.1 Sustainable Test Cell

The Sustainable Test Cell (STC) contains two rooms (Figure1):

- Room 1 (simulates a bedroom) – It has a massive envelope with compacted earth walls (Goodhew & Griffiths, 2005) and an opening in the south façade. The high thermal inertia combined with an opening equipped with exterior horizontal and vertical shading devices - in order to avoid overheating in summer - is a passive solar technique. To improve the sustainability of the solution, the room' exterior walls were built with a locally available material - earth;
- Room 2 (simulates an office) – It is an insulated lightweight construction with a large opening in the north façade in order to promote the daylighting and thus reduce the energy consumption in lighting.

Between the two rooms of this Test Cell there is a movable partition that allows testing the performance of the whole Test Cell space or of the two distinct rooms (Silva, 2006).

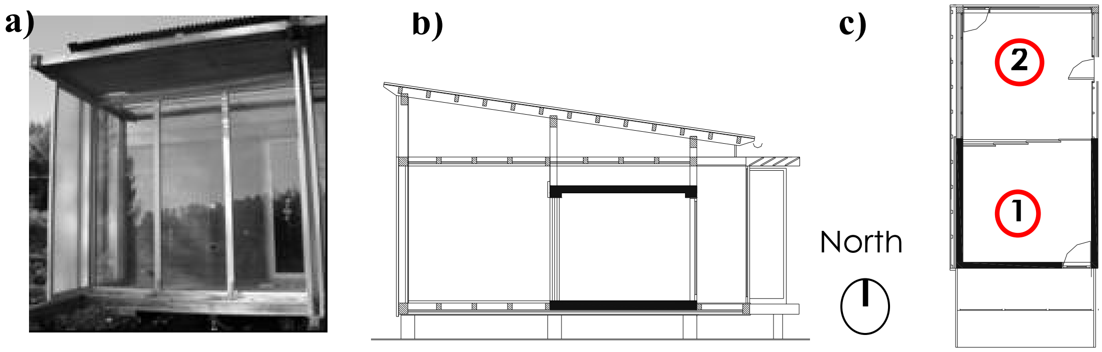

Figure 1 Sustainable Test Cell: a) Photo; b) lateral view; c) plan view

2.2 Conventional Test Cell

The Conventional Test Cell (CTC), shown in Figure 2, contains three rooms: the room 1 simulates a bedroom; room 2 simulates a bathroom; room 3 simulates a hall. The CTC was built with a double pane hollow brick wall with extruded expanded polystyrene in the air gap. This Test Cell is representative of the conventional Portuguese Construction (Mendonça, 2003).

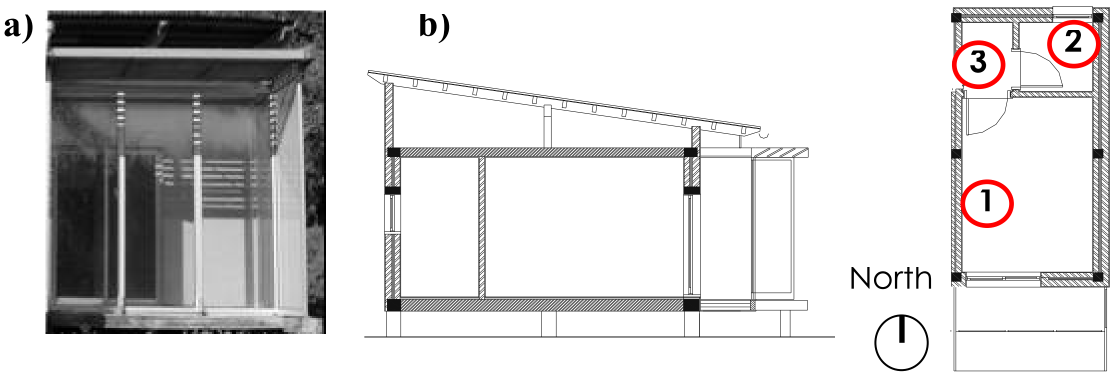

Figure 2 Conventional Test Cell: a) Photo; b) lateral view; c) plan view

3. Estimation methods

3.1 Portuguese thermal regulation - RCCTE

RCCTE is the Portuguese thermal regulation targeted to residential buildings and office buildings without HVAC systems. The objectives of this regulation are: guarantee that the heating and cooling requirements for thermal comfort, the ventilation requirements for indoor air quality and the hot water requirements are satisfied without an excessive energy consumption; Minimize the pathologies in the construction elements due to condensation.

This regulation defines values for the heating needs (N_{ic}) and cooling needs (N_{vc}). The N_{ic} and N_{vc} are obtained using the following equations:

$$N_{ic} = \frac{0{,}024.GD.(U.A_e + U.A_i.\ \tau + \sum \Psi B_s + \sum \Psi B_j + (0{,}34 * Rph + Ap * Pd) - \eta_H (qi.M.Ap\ 0{,}720 + G_{Sul} \sum_j [X_j \sum_n A_{snj}].M)}{A_p} \quad (1)$$

$$N_{vc} = \frac{(1-\eta_C)\left[\left[2{,}928\ U.A.(\theta_m - \theta_i) + U.A.(\frac{\alpha.Ir}{h_e})\right] + \sum_j \left[Ir_j \sum_n A_{snj}\right] + \left[2{,}928\,(0{,}34.Rph.Ap\,Pd)\right] + 2{,}928\,qi.Ap\right]}{A_p} \quad (2)$$

Where: A_p is the useful floor area; GD is the number of degree-day of heating for a 20ºC base; U is the thermal transmittance (U-value, e - for elements of the external envelope and i – for elements of the internal envelope); A_e is the area of the elements of the external envelope; A_i is the area of the elements of the internal envelope; τ is the coefficient of reduction of the thermal losses to non-heated spaces; Ψ_s is the linear thermal transmittance of the elements in contact with the soil; B_s is the length of the elements in contact with the soil; Ψ_j is the linear thermal transmittance of the linear thermal bridge; B_j is the length of linear thermal bridges; R_{ph} are the hourly air flow rate; P_d is the ceiling height; η_H is the dimensionless gain utilisation factor; η_C is the dimensionless utilisation factor for heat losses; qi are the internal heat gains (4 W/m^2 for residential buildings); M is the duration of heating period; G_{Sul} is the average mensal value of the solar energy hitting on a vertical surface south oriented of a unitary area during the heating season; X_j is the orientation factor; A_{snj} is the effective collecting area of the solar radiation (n – surface; j – orientation); θ_m is the average external air temperature for the cooling season; θ_i is the internal air temperature; α is the coefficient of absorption of solar radiation of the outside surface of the element; I_r is the average Intensity of the total solar energy hitting on the surfaces, per orientation, for all the cooling season; h_e is the external thermal superficial conductance of the envelope element (25 W/m^2.ºC).

3.2 United kingdom thermal regulation

In the United Kingdom the Energy Heating Needs are defined:

$$Q_{NH} = \sum\left[(\sum_i A_i U_i + \sum_k l_k \Psi_k).(\theta_i - \theta_{e,k})\right].t.\mathrm{f} + \rho_a.\mathrm{C_a}.\mathrm{U_{v\text{-}heat}}.A.(\theta_i - \theta_e).n.0.0864$$
$$-\eta_{\mathrm{G,H}} \cdot \left[Q_i + \sum_j (q_{sun,j}.\mathrm{f}_{sh,j}.\mathrm{f}_{sun,j}.g_j.\mathrm{f_f}) + \sum_j (\mathrm{f}_{ab}.q_{sun,j}.U_{c,j}.A_{\mathrm{c,j}})\right] \quad (3)$$

And the Energy Cooling Needs are obtained:

$$Q_{NC} = \sum\left[(\sum_i A_i U_i + \sum_k l_k \Psi_k).(\theta_i - \theta_{e,k})\right].t.\mathrm{f} + \rho_a.\mathrm{C_a}.\mathrm{U_{V\text{-}Cool}}.A.(\theta_i - \theta_e^{'}).n.0.0864$$
$$-\eta_{\mathrm{L,C}} \cdot \left[Q_i + \sum_j (q_{sun,j}.\mathrm{f}_{sh,j}.\mathrm{f}_{sun,j}.g_j.\mathrm{f_f}) + \sum_j (\mathrm{f}_{ab}.q_{sun,j}.U_{c,j}.A_{\mathrm{c,j}})\right] \quad (4)$$

Where: A_i is the area of the element i of the building envelope; U_i is the thermal transmittance (U-value) of the element i of the building envelope; l_k is the length of the linear thermal bridge k; Ψ_k is the linear thermal transmittance of the linear thermal bridge k; θ_i is the internal temperature of the building zone (heating set point); $\theta_{e,k}$ is the external temperature (the monthly average temperature) of element k; t is the duration of the calculation period; f is a factor for conversion from Wh to MJ; ρ_a . C_a is the specific air heat capacity (1.2 kJ/m^3); $U_{v\text{-}heat}$ is the air flow rate through the conditioned space, for heating; $U_{v\text{-}cool}$ is the air flow rate through the conditioned space, for cooling; A is the zone floor area; θ_i is the internal temperature of the building zone (heating set point); θ_e is the external temperature (the monthly average temperature); θ'_e is the modified external air temperature; n is the number of days within a month; $\eta_{G,H}$ is the dimensionless gain utilisation factor; $\eta_{L,C}$ is the dimensionless utilisation factor for heat losses; Q_i is the sum of internal heat sources (occupants, appliances and lighting) over a given period; $q_{sun,j}$ is the quantity of solar radiation per month on the plane, for weather location an orientation of window j; $f_{sh,j}$ is the shading correction factor of the window j; $f_{sun,j}$ is the reduction factor for moveable solar protection for window j; g_j is the total solar energy transmittance, for window j; $A_{r,j}$ is the area of window j, including the frame; $\mathrm{f_f}$ is the computation value for the frame factor (taken as 0.75); $\mathrm{f_{ab}}$ is the dimensionless absorption coefficient for solar radiation of the opaque construction multiplied by the external surface heat resistance (0.9X0.05= 0.045); $q_{sun,j}$ is the quantity of solar radiation per month on the plane, for weather location and orientation of construction part j; $U_{c,j}$ is the thermal transmittance of construction part j; $A_{c,j}$ is the area of construction part j.

3.3 Belgium, Walloon thermal regulation

The Belgium Walloon region regulation also defines the heating and cooling needs, as presented in the following expressions:

$$Q_{heat,\ final,\ m} = \frac{Q_{heat,\ gross,\ m}}{\eta_{ger,\ heat}} \quad (5)$$

$$Q_{heat,\ gross,\ m} = \frac{A_T \cdot K_S \cdot (18-\theta_{e,m}) \cdot t_m + H_{V,heati} \cdot (18-\theta_{e,m}) \cdot t_m + \eta_{util,heat,m} \cdot (Qi + 0.95 . g_j . A_{g,j} . I_{s,m,j,shad})}{\eta_{sys,\ heat,\ m}} \quad (6)$$

The cooling needs are obtained:

$$Q_{cool,\ final,\ m} = \frac{\max\left\{0, \min\left(\frac{I2-I1}{I3-I1}, 1\right)\right\} \cdot Q_{excess,cool,m}}{8.1} \quad (7)$$

Where: $\eta_{ger,heat}$ is the efficiency of the mensal energy production for heating; $\eta_{sys,heat,m}$ is the efficiency of the heating system; A_T is the total envelope area; K_S is the average thermal transmittance (average U-value); $\theta_{e,m}$ is the mensal external average temperature; t_m- is the duration of the heating period; $H_{v,heat}$ are the thermal losses due to ventilation and infiltration; Q_i is the sum of internal heat sources (occupants, appliances and lighting); g is the solar factor; Window area; $I_{s,m,j,shad}$ is the incident solar radiation having in account the effect of the fixed obstacles; $\eta_{util,heat,m}$ is the thermal gains utilization factor; I_1, I_2 and I_3 can be obtained from Figure 3; $Q_{excess.cool.m}$ are the excessive heat gains comparatively to the comfort temperature (23ºC).

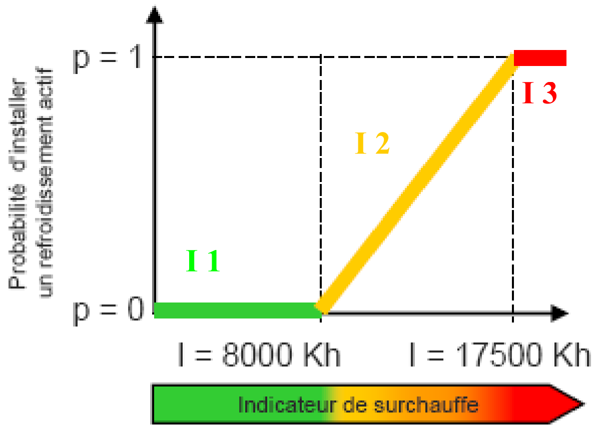

Figure 3 Probability of installing an active, conventional cooling system

3.4 VisualDOE

VisualDOE is a WindowsTM application that can estimate the buildings energy performance. The calculation engine used in this tool is the very well known and tested DOE2.1E. However, only the 3rd version of this tool (VisualDOE 3.1) can be considered as a Graphical User Interface of the DOE engine, as it allows a good control of the introduction of geometrical elements, in real-time, through the pictures of the model produced by the tool and it has the possibility of editing the model simply by clicking with the mouse in an element. This tool can be used without any knowledge of the source engine (Green Design Tools, 2001).

To estimate the buildings energy performance with VisualDOE it is necessary to follow 3 steps:

- Project data introduction;
- Execution of the simulation;
- Results analysis.

The project data introduction begins with the definition of all the VisualDOE databases containing the elements applied into the building – Glazing, Openings, Materials, Constructions, Occupancy, Schedules and Utility rates – and afterwards with the introduction of the model and project data that is formed by 6 folders – Project, Blocks, Rooms, Façade, Systems, Zones. As VisualDOE was created for the WindowsTM platform, the databases are easily updated with new materials and constructions through a graphical interface, as shown in Figure 4.

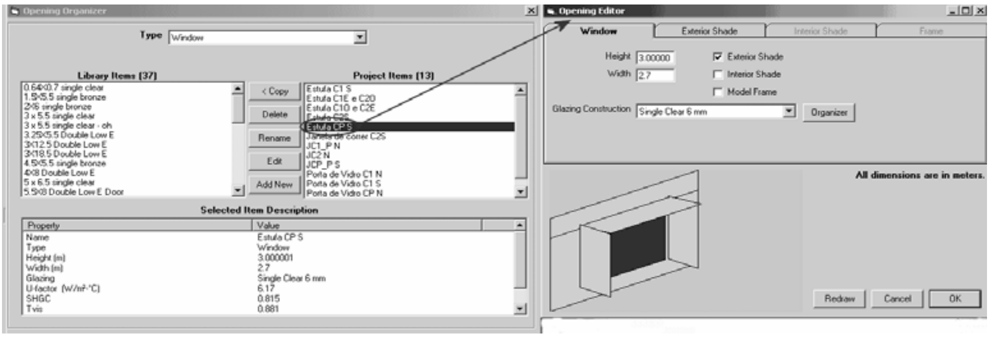

Figure 4 Openings definition in VisualDOE databases

In the 2nd step there will be present three folders – Simulation, Standard DOE-2 Reports and Hourly Reports – where we can define the base case, the alternatives (if necessary) and all the reports needed (hourly, daily, monthly or yearly results) for each specific study.

For the results analysis there are two main groups of data – the VisualDOE graphs and reports and the DOE-2 reports. The main difference between these sets of result is that the ones obtained with VisualDOE follow the WindowsTM platform (allows exporting results to other tools) while the DOE-2 reports follow a DOS platform.

The Test Cells were modelled and calibrated following the procedure shown in Silva *et al* (2006) in order to apply the model to VisualDOE. The final model is shown in Figure 5.

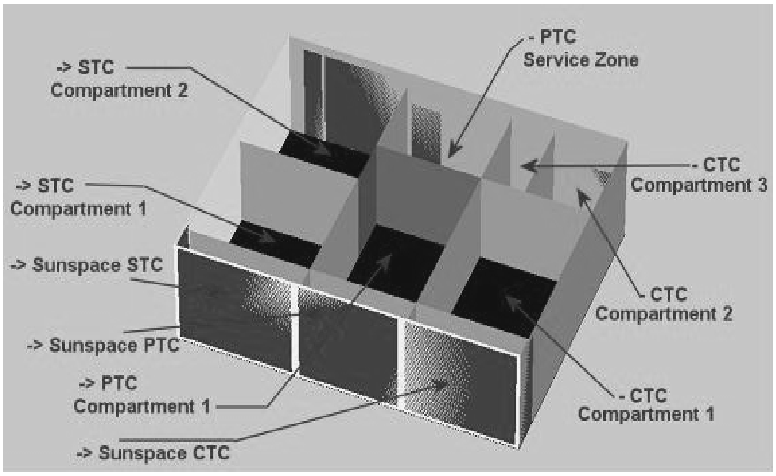

Figure 5 Model of the Test Cells

4. Simulations

This study was executed following three building energy performance calculation methodologies, all based on the EPBD (Energy Performance of Buildings Directive):

- The Portuguese methodology – RCCTE – Regulation of the Thermal Behaviour of Buildings;
- The Belgium methodology (Walloon region) – CWATUPE – Walloon Code of the Territory Development, Urban Planning, Heritage and Energy;
- The UK methodology – NCM – National Calculation Methodology;

Since the different methodologies enclose different input data, like the climatic data, heating and cooling set points and others, they can not be compared directly. Then, it was applied a dynamic simulation tool – VisualDOE – in order to put side by side with all the methodologies, in each case with the same input data.

4.1 Portuguese thermal regulation - RCCTE

The Portuguese regulation was assessed using the calculation model of the RCCTE to obtain the energy needs of the case study, with the following input data:

- City: Guimarães (41º27'N, 8º17'W));
- Heating set point: 20ºC;
- Cooling set point: 25ºC.

The results obtained with RCCTE and VisualDOE are expressed in Table 1.

Table 1 Heating and Cooling needs from RCCTE and VisualDOE

Test Cells		Heating Needs (kwh/m^2.year)		Cooling Needs (kwh/m^2.year)		Total Needs (kwh/m^2.year)	
		RCCTE	VisualDOE	RCCTE	VisualDOE	RCCTE	VisualDOE
With Sunspace	STC	127.7	124.7	49.5	41.9	177.2	166.6
	CTC	100.9	120.5	13.8	13.6	114.7	134.1
Without Sunspace	STC	139.8	135.2	51.3	42.5	191.1	177.7
	CTC	129.4	149.8	30.3	32.3	159.7	182.1

4.2 United Kingdom thermal regulation - NCM

In the case of the UK regulation, it was applied the basic user interface iSBEM Version 3.0 (Simplified Building Energy Model) in order to obtain the case study energy needs, with the following input data:

- City: London (51º30'N, 0º7'W);
- Heating set point: 18ºC;
- Cooling set point: 25ºC.

The results obtained with NCM and VisualDOE are expressed in Table 2.

Table 2 Heating and Cooling needs from NCM and VisualDOE

Test Cells		Heating Needs (kwh/m^2.year)		Cooling Needs (kwh/m^2.year)		Total Needs (kwh/m^2.year)	
		SBEM	VisualDOE	SBEM	VisualDOE	SBEM	VisualDOE
With Sunspace	STC	346.41	366.2	17.6	6.4	364.0	372.6
	CTC	355.2	359.1	10.0	1.2	365.2	360.3
Without Sunspace	STC	384.12	383.2	27.2	5.4	411.3	388.6
	CTC	403.04	383.5	37.5	4.8	440.6	388.3

4.3 Belgium, Walloon region thermal regulation - CWATUPE

For the Belgian regulation (Walloon region) it was applied the tool CALE Version 1.3 (Built with the Energy – Construire Avec L'Energie) in order to obtain the case study energy needs, with the following input data:

- City: Saint Hubert (50º1'N, 5º22'E);
- Heating set point: 18ºC;
- Cooling set point: 23ºC.

The results obtained with CWATUPE and VisualDOE are expressed in Table 3.

Table 3 Heating and Cooling needs from CWATUPE and VisualDOE

Test Cells		Heating Needs (kwh/m^2.year)		Cooling Needs (kwh/m^2.year)		Total Needs (kwh/m^2.year)	
		CWATUPE	VisualDOE	CWATUPE	VisualDOE	CWATUPE	VisualDOE
With Sunspace	STC	402.8	405.7	10.7	1.5	413.5	407.2
	CTC	379.4	379.4	10.8	0.0	390.2	379.4
Without Sunspace	STC	402.8	426.7	10.7	1.6	413.5	428.3
	CTC	435.0	479.0	10.0	1.1	445.0	480.1

5 Results

With the energy needs estimated following each of the Energy Performance Regulations presented before, and with the simulations performed with VisualDOE using, in each case, a similar input data, it is now possible to compare the performance of the different regulations. However, it is necessary to have in mind that the Portuguese model should have a more efficient calibration, as the climatic input data used for the

RCCTE calculation was retrieved from the "*in-situ*" Climatic File, obtained as shown in Silva *et al* (2006), applied in VisualDOE. Although, the rest of the model calibration, like the U values, is similar in all the models.

5.1 RCCTE Vs VisualDOE

The results of the RCCTE calculation methodology were compared with the ones obtained with VisualDOE. The variation between the two estimation methods is presented in Table 4.

Table 4 Differences between RCCTE and VisualDOE estimation

Test Cells		Heating Needs	Cooling Needs (kwh/m^2.year) (%)	Total Needs
Guimarães, Portugal				
With Sunspace	STC	3.0 (2.3%)	7.6 (15.4%)	10.6 (6.0%)
	CTC	19.6 (16.3%)	0.2 (1.4%)	19.4 (14.5%)
Without Sunspace	STC	4.6 (3.3%)	8.8 (17.2%)	13.4 (7.0%)
	CTC	20.4 (13.6%)	2.0 (6.2%)	22.4 (12.3%)
Total error in the average energy needs estimation of all models				**13.1 (2.7%)**

From Table 4 it can be concluded that there is a good approximation between the STC total needs estimated with RCCTE and with VisualDOE, with only an average errpr of 6.5% in the total needs (average between STC with and without sunspace). This fact should be due to a good calculation methodology from the RCCTE associated to a good calibration of the models. The higher variation in the estimation of CTC total needs, 13.4% (average between CTC with and without sunspace), is due to the heating needs contribution. This fact can be explained by a higher south oriented glazing area in this Test Cell that can lead to very high solar gains. This could have led to an overestimation of the thermal gains in the RCCTE methodology.

4.7 NCM Vs VisualDOE

The results of the NCM methodology were compared with the ones obtained with VisualDOE. The variation between the two estimation methods is presented in Table 5.

Table 5 Differences between NCM and VisualDOE estimation

Test Cells		Heating Needs	Cooling Needs (kwh/m^2.year) (%)	Total Needs
London, United Kingdom				
With Sunspace	STC	19.8 (5.4%)	11.2 (63.6%)	8.5 (6.0%)
	CTC	3.9 (1.1%)	8.8 (88.0%)	4.9 (1.3%)
Without Sunspace	STC	1.0 (0.2%)	21.8 (80.1%)	22.8 (5.5%)
	CTC	19.5 (4.8%)	32.7 (87.2%)	52.2 (11.9%)
Total error in the average energy needs estimation of all models				**22.1 (4.5%)**

As Table 5 shows there is a high approximation between the CTC with sunspace and STC without sunspace heating needs estimated with NCM and with VisualDOE. It can be observed that the heating needs have a very good approximation between both the estimation methods, however the cooling needs appears to be overestimated by the NCM methodology.

5.3 CWATUPE Vs VisualDOE

The results of the CWATUPE methodology were compared with the ones obtained with VisualDOE. The variation between the two estimation methods is presented in Table 6.

Table 6 Differences between CWATUPE and VisualDOE estimation

Test Cells		Heating Needs	Cooling Needs (kwh/m^2.year) (%)	Total Needs
Saint Hubert, Belgium				
With Sunspace	STC	2.9 (0.7%)	9.2 (86.0%)	6.2 (1.5%)
	CTC	0.01 (0.0%)	10.8 (100%)	10.8 (2.8%)
Without Sunspace	STC	23.9 (5.6%)	9.1 (85.0%)	14.8 (3.5%)
	CTC	44.0 (9.2%)	9.1 (89.0%)	35.1 (7.3%)
Total error in the average energy needs estimation of all models				**16.7 (1.9%)**

From Table 6 it can be concluded that there is a very high approximation between the CTC, with sunspace, heating needs estimated with CALE and with VisualDOE. It can be observed that the heating needs have a very good approximation between both the estimation methods, however the cooling needs appears also to be overestimated by the NCM methodology.

6. Conclusions

The objective of this study was to evaluate and compare the precision of the Portuguese thermal regulation calculation methodology and some other countries calculation models. Therefore, the RCCTE, CWATUPE and NCM heating and cooling needs estimation methodologies were put side by side with the ones calculated with the dynamic simulation tool VisualDOE.

From this evaluation it can be said that all the calculation methodologies have a good precision, better than one could expect, as they are simple steady state methods. All the methods just appear to have a higher difficulty in estimating accurately the heating needs of buildings with large openings. Also, the Belgium and UK methodology have problems in the cooling needs estimation, overestimating them.

The three methodologies show similar errors, being the Belgium one the most accurate and the UK methodology the least accurate.

Then, it can be said that all the studied thermal codes can produce good results in what concerns energy needs. Thus, as they correctly foresee the energy performance of buildings, the buildings energy certification will allow that the comparisons of the certified building stock of each country can be more meaningful.

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THE A,B,C'S OF SUSTAINABLE SCHOOLS

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Summary

This paper focuses on the A, B, C's of creating and operating a sustainable educational facility, based on the examples of schools in the United States of America. These schools include public and private schools, from elementary schools, to high schools, day-only to shared community-use facilities. The paper firstly covers the "A" or attributes of a sustainable school, with an emphasis on the characteristics of the learning and working environment. The paper then identifies the "B" or benefits of sustainable schools, including the pedagogical opportunities. The "C" or challenges associated with designing, constructing and operating a sustainable school are also then discussed. Drawing from lessons learnt from the various schools, the paper identifies the essential steps in adopting sustainability goals for schools, and concludes with a focus on the educational opportunity this presents for our current generation.

Fig. 1 Classroom at Willow School
(Image courtesy of Willow School)

Fig. 2 Courtyard at Clackamas High School
(Image courtesy of Boora Architects)

1. "A" is for Attributes

Sustainable schools can be defined as "high performance" schools, where the buildings and site have been designed and constructed to create optimal, healthy learning environments; while consuming a minimum of resources and producing a minimum of waste. The attributes of a sustainable school can be succinctly described as follows:

- Provides Healthy and Productive Environments
  - Learning and working spaces are designed to have high levels of thermal, visual and acoustical comfort
  - Superior indoor environment throughout, with high quality air and natural daylight

- Operates in a Cost-Effective Manner
  - Energy performance is optimized and a life-cycle cost approach is adopted for decision making
  - Building commissioning and re-commissioning is standard practice

- Conforms to Sustainable Design and Operations
  - Efficient and effective use of resources (energy, water, materials) during the creation and operations of the school
  - Environmentally responsive site activities and landscape
  - The building is a teaching tool featuring examples of sustainable strategies

Until the late 1990's, the notion of a sustainable school was open to interpretation and there was no common metric in place to validate the claims of a sustainable school. Several sustainable frameworks have since been developed in the United States to address the design, construction and operations of sustainable educational facilities in a holistic manner. The US Green Building Council created the LEED (Leadership in Energy and Environmental Design) rating system in 2001, as a third-party certification program, and a school specific program, LEED for Schools, was launched in 2007. The Collaborative of High Performance Schools (CHPS) introduced their program in 2002, with a focus on the California school market, but is now being adopted by various other states. The CHPS program started as a self-certifying program, but in 2007 introduced a third-party certification option.

The rating system or framework establishes a defined standard for what a sustainable school should be like. It is a valuable tool for guiding the design team on sustainable decision making, dictates how the construction practices will happen, and informs the operational policies and practices of the school. Similar to an academic program, the process of certification itself provides rigor to the design process and construction practices, and enables a greater level of accountability between all players. It provides a common language and reference point for all, as well as facilitates the integrated design process. For example, sustainable strategies such as rainwater harvesting for irrigation and waste conveyance will necessitate the early involvement of the architect, the plumbing engineer, the landscape designer and civil engineer; with each working towards a common goal.

2. "B" is for Benefits

A sustainable school can result in significant benefits in terms of the performance and operations of the building. These benefits include both tangible and intangible benefits, including:

2.1 Optimized Learning and Working Environments

2.1.1 Thermal, Visual and Acoustical Comfort

Studies have shown that the student learning performance can be enhanced by the physical learning environment itself. The effects from the introduction of controlled natural daylight to classrooms, along with allowing views to the outdoors, were analyzed in the 'Daylighting in Schools' and 'Windows and Classrooms' studies (1999, 2003) conducted by the Heschong Mahone Group. The study showed an increase in student achievement by up to 26%, compared with statistical control groups. Other studies indicate that daylight in classrooms can have an impact on reducing illness and absenteeism, and in improving student behavior.

The ability to have environmental controls to adjust the comfort levels of the classroom or offices are also crucial components in an optimized environment. Studies indicate that teachers have a basic expectation of being able to dictate light levels, mitigate sun penetration and adjust for audio visual needs, regulate the temperature and ventilation in their classrooms.

The optimized environments will positively improve satisfaction and morale at sustainable schools, especially among the teaching staff, leading to direct benefits in improved teaching performance, as well as retaining and recruiting teachers.

Fig.3 Classroom at Third Creek Elementary School
(Image courtesy of Moseley Architects)

Fig.4 Gymnasium at Clackamas High School
(Image courtesy of Boora Architects)

2.1.2 Indoor Air Quality

Improved indoor air quality has also been found to contribute to student performance and health. With a sharp increase of asthma in school-aged children today, the need for good indoor air quality is critical. Poor indoor air quality will result in sickness and absenteeism. Clearly, if kids are sick or not in school, they will not learn or perform as well as those who are attentive, well and present on a regular basis.

Similarly, schools designed for good indoor air quality provide benefits to the staff, and demonstrates that the school administrative body is vested in the health and well-being of all employees and students. This fosters staff retention, and creates a positive image in the community as a responsible employee.

Indoor air quality is an issue that needs continual attention, and starts with good design followed by on-going indoor air quality management measures. The adoption of a green cleaning policy and practices, along with an integrated pest management policy, can further ensure good indoor air quality (in the interior and exterior) is maintained during the operations and maintenance of the building.

2.2 Financial Benefits

2.2.1 Design and Construction Cost

While sustainable schools can incur a premium in design and construction cost, there can also be opportunities for cost savings when innovative approaches are taken to systems and materials. For example, at Clackamas High School (Portland, Oregon), the chiller system was down-sized, as the school recognized that based on the scheduling of events, the auditorium and gymnasium would not typically be used concurrently. The chiller was then designed to serve one of the spaces, and could switch to serve the other space as needed. In the Londonderry School (Harrisburg, Pennsylvania), a low-cost heating and cooling system was selected using a baseboard heat system with basic controls located in each classroom, along with the use of natural ventilation (via operable windows). This also reduced the amount of resources used in terms of materials, by omitting heating and cooling mechanical equipment and ductwork.

The reduction of finish materials can also result in cost savings, with block walls left unpainted or concrete floors sealed without needing a top layer floor finish. The exterior walls of The Dalles Middle School (The Dalles, Oregon) were stained concrete tilt-up slabs, which were efficient to construct, and reduced the need for costly maintenance such as repainting. Cost saving were also achieved with the extensive use of salvaged materials for the Willow School (Gladstone, New Jersey). Salvaged timber frames were used for the structure, pickle barrels were used for window trim, and felled trees on-site were used for the furniture.

Fig.5 Exterior of The Dalles Middle School

Fig.6 Furniture at Willow School
(Image courtesy of Willow School)

2.2.2 Operating Cost

One of the most significant benefits of a sustainable school is the resultant operating cost reductions, particularly in the areas of energy and water use. The adoption of passive systems, coupled with energy efficient systems, result in a reduction in electrical and gas consumption, along with the associated cost savings. Similarly, the use of water efficient plumbing fixtures and efficient irrigation strategies or xeriscaping provides further cost savings. The water savings for plumbing can be accounted for both in terms of water supplied and also in terms of a reduction in sewage conveyance charges. Managing the stormwater on-site could also result in a reduction of stormwater charges, and adopting waste recycling practices can also reduce the waste utility charges as well.

At Third Creek Elementary School (Raleigh, North Carolina), the projected energy savings based on the energy model was $25,600 or 22.89% compared to the baseline case. Over a period of five years, the building has in fact achieved a total savings of $171,400, based on normalized energy rates, which exceeds the projected amount. In terms of water, the calculated per student use is about 27% less compared to other schools in the school district, and was achieved through the use of waterless urinals and low-flow faucets.

2.3 Community and Cultural Alignment

2.3.2 Expression of the Cultural Values

The concept of a sustainable school is often aligned with the cultural values of the community. The Baca/Dlo'ay Community School (Prewitt, New Mexico) is a Native American school that embraced sustainable design and construction as an outward expression of their values in terms of respect for the land. The Punahou School's new Kindergarten-First Grade School (Honolulu, Hawaii) is currently in the design phase, and borrows sustainable ideas from the "ahupua'a", which describes the manner within which the native Hawaiians lived, and represented land divisions that were complete ecological and economic production systems. The project is expected to have an on-site photovoltaic system that will off-set over 50% of its electrical needs. There will also be rainwater harvesting and stormwater swales, to manage the water resources on the site. These measures allow the new school to be partially self-sustaining, similar in concept to the "ahupua'a".

2.3.2 Responsibility to the Community

A sustainable approach to schools will show the community that school districts are putting the best efforts possible into improving the facilities where their kids spend so much of their formative years. The reduction in operating costs is also a visible demonstration of a school district's efforts to conserve financial resources. This focus will reflect favorably on school districts and will help it to achieve national recognition as a leader in sustainable schools.

A sustainable school also manages its resources wisely, to ensure it does not drain the local resources. A school district is often one of the largest local users of energy and water, and generates a significant amount of waste. In some cases, the school itself can service the community with the introduction of a recycling center on its campus, or convert cooking oil into biodiesel for community use. A photo-voltaic system on a school can generate electrical back to the grid during the summer months when school is out. The use of local materials and resources for the school can also help generate a healthy local economy.

In partnership with the community, shared use educational facilities can reduce the need for additional new buildings, while maximizing the use of the school and its associated spaces. The Langston-Brown High School Continuation and Community Center (Arlington, Virginia) consist of a continuing education high school, a community recreation center, and an early education center. This school has successfully become the new community hub, and effectively reduced the need for further new construction and infrastructure based on centralizing the three uses. Similarly, the Rosa Parks School (Portland, Oregon) houses both an elementary school and an after-school Boys and Girls Club program, drawings kids from the community, while showcasing sustainable strategies.

2.4 Pedagogical Opportunities

2.4.1 Using the Building as a Teaching Tool

The integration of visible sustainable elements can provide an interactive and experiential learning environment for the students and the community. Elements such as on-site stormwater management systems, native landscaping and xeriscaping, wind turbines, photovoltaic systems, shading devices, or green roofs; can be designed to be highly visible and accessible for the students, staff and the community. The use of signage or data on the school's website can further be used to educate the students, staff and the community about sustainability.

The Twenhofel Middle School (Independence, Kentucky) installed a large plasma screen information center in the building lobby to monitor the energy efficient systems. The data includes information about the energy use of different classroom wings, the amount of rainwater stored in the cistern, and details about the performance of the on-site photovoltaic system. Using the data for the different classroom wings, the energy efficiency efforts can also be recognized and rewarded via a friendly competition between the wings. This encourages each classroom to be mindful of their daily energy usage. The data, which has been named 'Vital Signs', is also available on their website (www.twhvac.kenton.kyschools.us), and through this means, has the potential to educate an extensive global audience.

At Rosa Parks School (Portland, Oregon), a monitoring system offers students real-time data on the building's photovoltaic panel's energy generation and several bioswales around the building teach kids about on-site stormwater treatment. At Roy Lee Walker Elementary School (McKinney, Texas), the wind turbine and rainwater cisterns are clearly visible sustainable elements, and act in conjunction with each other, to supply the irrigation needs for the site.

Fig.7 Bioswale at Rosa Parks School
(Image courtesy of Dull Olsen Weekes Architects)

Fig.8 Wind turbine and cistern at Roy Lee Walker Elementary School
(Image courtesy of SHW Group)

2.4.2. Integration into the Curriculum

The various elements of a sustainable school can be featured as part of the educational curriculum. For example, statistical data from the on-site photovoltaic system can be used for a mathematics exercise, or data about the sun movement can be incorporated into the science lesson. These bring home the message in a direct and effective manner.

At Kersey Creek Elementary School (Hanover County, Virginia), the project architects, Moseley Architects, worked together with the school faculty to write curriculum about project strategies that promote environmental responsibility. Lessons might feature an assignment on how the building materials were made using recycled products, or students may perform measurements on the temperature differences between black asphalt surfaces, white concrete surfaces, and shaded vegetated surfaces. At Case Middle School, part of Punahou School (Honolulu, Hawaii), students do a research project on the three ice-making plants that are a part of the air-conditioning system, and learn about the photovoltaic system on the roof.

3. "C" is for Challenges

While the benefits of sustainable schools are compelling, most schools face some challenges in the process of adopting and applying their sustainable goals, both in the design phase and in the operations of the building. Some schools have been designed to meet a high level of green certification, with significant design effort and analysis performed to ensure a high performance building is built. However, once the building is occupied and in operation, the projected energy savings are not realized, and the building does not perform in a sustainable manner. Some of the challenges associated with designing, constructing and operating a sustainable school include:

3.1 Juxtaposition of Goals

3.1.1 Conflicts in Performance

Many sustainable schools aspire to have a natural ventilated building, and provide operable windows in the classrooms and offices. The desire however to have a high level of acoustical performance in the same space can be minimized when the windows are open. Careful analysis of the exterior noise level and consideration of the natural ventilation methods should be taken into account early in the design stage to mitigate this conflict. At Baker Prairie Middle School (Canby, Oregon) and Clackamas High School (Portland, Oregon), ventilation louvers located below the windows in the exterior wall, are tempered with acoustical baffles, and allow natural ventilation without significant exterior noise transfer.

Teaching methods and equipment needs are also evolving over time, and the use of computers and audio visual equipment has significantly increased. The lighting levels required for this can at times be in conflict with the provision of a day-lit classroom. The use of blinds can allow for controlled daylight levels, and as needed, be supplemented by electrical lighting.

3.1.2 Code Constraints

At times, the local code requirements can be at odds with the sustainable goals of a project. For example, in certain states in the United States, plumbing and water codes limit or prohibit the use of captured rainwater for flushing toilets or limit the use of certain types of plumbing fixtures, such as waterless urinals. Restrictions on height limits can at times result in a larger building footprint with more site impacts, or may preclude the use of wind turbines. Green roofs or the use of photovoltaic panels may be prohibited in certain neighborhoods with defined code requirements for aesthetics and regulated material use. The application for special use permits or exemptions takes time and expense, but it may be possible to partner with the local authorities to use the school as a demonstration or case study for new technology or strategies.

3.2 Financial Constraints

3.2.1 Capital Budget versus Operations Budget

A common challenge for schools is the segregation of the capital budget versus the operations budget. These budgets can constraint the opportunities up-front for selecting efficient mechanical systems, which can be more expensive, even though there are apparent long-term operations savings. For some public and private projects, the budget is determined several years before the final construction occurs, as the bond approval process or fund raising efforts can take a long time. When the project is finally bid, the budget may then be inadequate for the project, and often sustainable strategies are the first items to be eliminated in a cost cutting exercise. However, carefully considered design will integrate sustainable elements to ensure that these elements are integral to the success of the building, and are less likely to be eliminated.

During the operations of a school, cost constraints can again be a factor in limiting the manner in which a school performs. The availability of skilled staff and time may preclude appropriate monitoring of a building, and preventative measures may be overlooked as a consequence.

To fund the up-front cost of some sustainable strategies, schools in the United States can seek out various funding opportunities and grant partnerships that could be pursued to assist with off-setting the cost of specific sustainable strategies. Some states have energy efficiency incentives, or special funding for projects pursuing LEED or CHPS certification. Shared-use educational facilities are also likely to trigger other funding sources, with potential collaboration between the school, the community and local businesses. The additional funding could be directed towards sustainable elements that directly educate or benefit the community, such as a photovoltaic system or a rainwater harvesting cistern.

3.2.2 Perceived Costs

For many schools incorporating sustainability for the first time, there can be a fear associated with the cost of building a sustainable school, and this perceived cost may deter them from pursuing a sustainable school. This fear is often not founded on factual information or is a misunderstanding of building costs. For example, some may consider the full cost of a high performance glazing system as associated with this sustainable strategy, instead of the incremental cost over a conventional glazing system.

Having a clear understanding of cost is vital and where possible, life cycle cost should also be factored into the decision making. There often is a cost premium in building a sustainable school, in part due to the soft cost of additional design and analysis, as well as the selection of efficient equipment and fixtures. The study completed by Capital E's Gregory Kats, "Greening America's Schools – Cost and Benefits" (2006) noted cost premiums were typically less than 2%, but in some cases, sustainable schools cost less than a conventional design. When project budgets are determined, consideration must be given to ensure that both cost escalation and the potential premium in building a sustainable school is accounted for.

Taking consideration of the long-term benefits of sustainable schools, Ohio Schools Facilities Commission (OSFC) mandated that all new schools must meet a minimum LEED for Schools rating of Silver certification and should be targeting the Gold level. At least 250 buildings will meet these requirements over the next two years, with an estimated $1.4 billion return on investment over 40 years for the state.

3.3 Knowledge Base and Knowledge Transfer

3.3.1 Receptiveness to Sustainability

The idea of building and operating a sustainable school can be a new concept for some of the school's stakeholders, as this may new or unfamiliar territory. The design team may not be as familiar with designing and implementing sustainable concepts and strategies, or the contractor may be reluctant to install certain types of new products, if they have not used them before. The facilities department may be comfortable with the use of certain controls, mechanical systems or materials, and may resist changing out to new options, even if it is more efficient or sustainable. There may be concerns over the need to hire a specialist (possibly at considerable expense) when the mechanical system needs maintenance, or replacement parts may not be available locally or in a timely manner. There may also be concerns over adopting new technologies that may not have been tested and proven in applications like schools, and are "bleeding edge" rather than "leading edge". There can also be concerns about the desired occupant comfort levels versus the use of passive systems, which typically result in less control over the comfort levels.

In order to overcome these barriers, it is vital to engage all key stakeholders early in the design process, and often an "eco-charrette' is a great way to get everyone involved. This facilitated brainstorming event can generate sustainable goals and identify strategies for the project, with the input from everyone involved. In terms of implementing sustainable measures in the operations of schools, one successful approach in changing the mind-set of those "nay-sayers" is to firstly evaluate current policies and practices, and identifying what is already being done. In many instances, the school may already have adopted sustainable practices, and with minor modifications, will be well on their way towards operating a more efficient, environmentally responsive school.

3.3.2 On-going Performance Monitoring

A high performance building needs to be operated and maintained well to ensure on-going performance. The knowledge of how the building works needs to transfer between one facility manager to another. This can be challenging as there may not be overlapping time between the transition of the managers, or the operations manuals or policies may not be in place to provide the appropriate record and guidance on how to successfully operate the school. It may also be that the facility manager is not tasked with tracking and monitoring the performance of the building, but rather is focused on maintenance issues instead. In some cases, unskilled staff may be responsible for managing a sophisticated control and mechanical system, without clear instructions or knowledge on how to optimize the systems. A well designed high performance building can suffer from poor performance if there is no one at the helm guiding the efficiency efforts.

Commissioning new schools and re-commissioning existing schools on a periodic basis are excellent ways to identify any issues, course correct defects, and enhance the performance of the building. These services can be performed by in-house experts, or external consultants can be engaged to complete the work. While there is cost associated with this work, any improvements to the efficiency of the system are likely to generate energy savings, which can off-set the cost for performing this work.

In order to facilitate the adoption of sustainable strategies, it is beneficial to have a sustainable "champion" on board. In Montgomery County Public Schools, the in-house sustainable champion is known as the Green Building Manager, and is a part of the Division of Construction. The Green Building Manager facilitates the sustainable task force, with representatives from each division, such as building maintenance, transportation, and finance. Each brings their own unique concerns to the forefront, and collectively common policies and practices can be established. Other school districts or schools may have a resource conservation manager or an energy manager in-house, who can be vital in guiding the sustainability efforts for the district or school.

3.4 Occupant Patterns of Use

3.4.1 "Old Habits Die Hard "

Many sustainable schools are designed to achieve good daylight, augmented with electrical lighting, and use natural ventilation, supplemented by mechanical ventilation and heating. The best designed schools will however not perform well if the occupants are not mindful of their responsibilities in ensuring the building operates the way it is intended. For example, in many schools, the lights are turned on when one enters the classroom, even if the daylight levels are adequate without artificial lighting. The lights may be left on even when the classroom is empty, or every lighting zone may be turned on even if only part of the classroom needs the artificial lighting or is in use. The blinds on the windows may be lowered for an audio visual presentation, and not raised after the presentation, so daylight is blocked out of the classroom, resulting in the need for artificial lighting. Windows may be open when the weather is not conducive for natural ventilation, or the window ledge may be used as book shelves, and as such, the windows cannot be opened.

There are automatic controls that can be installed to mitigate some of these scenarios, but it is important to have simple instructions available on how to operate the classroom as intended. When The Dalles Middle School was first opened, the design team conducted a training session on how to maximize the use of daylight and natural ventilation in the classrooms. An instruction sheet was included in each classroom for reference, and would then inform future occupants of how to operate the classroom. At the Londonderry School, classrooms are equipped with a red/green light to indicate when the climatic conditions are optimum for opening the windows.

3.4.2 Expectations of Occupants

The expectations of the occupants can eliminate sustainable strategies from the design concept of a sustainable school. The desire to have air conditioned spaces in lieu of natural ventilation and passive cooling is often a major point of discussion in schools, even in more temperate climates. If another existing school has an air conditioning system, the future occupants of the new school will often want a comparable system, even if the climatic conditions are suitable for passive cooling. In one school district, the idea of installing skylights in the upper level classrooms was omitted as the school felt they needed to create equitable spaces on all levels, and variations in daylight levels could be misconstrued as a demonstration of favoritism.

Different spaces may also have different comfort needs based on the activities of the space, and a "one size fits all" concept may not be appropriate in terms of heating, cooling and ventilation. These unique needs should be identified early in the design phase, to both manage the expectations for comfort, and also to ensure that appropriate systems are selected to meet these demands.

4. Getting from "A" to "Z"

Based on the experiences and lessons learned from several sustainable schools, the following steps were identified as being crucial in the adoption and implementation of sustainable design, construction and operations strategies:

- Aim High, Start Early
    - Aspire for great things, with clear, mutual goals
    - Identify a champion to keep the sustainable goals in the forefront
    - Bring all players to the table early
- Setting The Passing Mark
    - Determine the priorities for the project
    - Establish the standards
        - Create design and construction guidelines, and use an established framework
        - Implement sustainable operating protocols
    - For new construction and renovations, select the right design and construction team
    - Test out ideas with a prototype building before adopting the strategies for all projects
- Use Lessons from History
    - Learn from the occupants of existing schools in the district with post occupancy evaluations
    - Indentify what works and what doesn't work with existing schools
    - Evaluate comparable sustainable schools, and identify strategies to adopt
- Do the Math
    - Establish realistic budgets and timeframes
    - Consider cost holistically – upfront expenses can result in long terms savings
    - Value the intangible – staff retention and attraction, student well-being and test scores, can all have indirect financial impacts
    - Seek out funding sources, and get buy-in early

- Excel in Geography and Science
  - Design and construct appropriate to the context – consider climatic conditions and site
  - Think Global, Act Local – seek out local partnership opportunities, use local resources wisely, and mitigate impacts on the local infrastructure

- Establish the Curriculum
  - Use the school to educate not just the students, but all occupants and the community at large
  - Establish clear protocols for knowledge transfer to ensure smooth operations of a sustainable school

Fig.9 Students at Baca/Dlo'ay Community School
(Image courtesy of Baca/Dlo'ay Community School))

Fig.10 Students at Willow School
(Image courtesy of Willow School)

5. Conclusions

Schools are educational facilities, centered on educating the children of their respective communities. A sustainable school is also an opportunity to educate and inform not just the students, but also the staff, parents, and the community, about sustainable design, construction and operations.

A sustainable school takes consideration of sustainability as defined by the World Commission on Environment and Development (Bruntland Commission) in 1987 as "Development that meets the needs of the present without compromising the ability of future generations to meet their needs." Sustainable schools play a critical role in educating and equipping our future leaders with the awareness, expectation, knowledge, and skills to help mould a sustainable future for all.

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Energy and environmental analysis of a mono-familiar Mediterranean house

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Summary

The path to sustainable cities goes trough detailed studies concerning the energy and the environmental performances of buildings. In particular, the buildings should be analyzed following a life-cycle approach, including the energy flows and the environmental burdens that arise during all the life cycle steps.
The paper presents a Life Cycle Assessment of an Italian mono-familiar house in the Mediterranean area. All the main stages of the building useful life have been investigated including: design, production of raw materials and building components, energy and materials supply, construction and installations, maintenance, demolition and debris disposal.
The aim of the study is to locate the building components that are responsible of the higher burdens and to state the incidence of each component and phase. The assessment showed that the largest impacts are located in the use stage, but significant environmental impacts are due to manufacture and transport of materials. It resulted that the studied building had low impacts compared to other case-studies in the central and Northern Europe. Energy for winter air conditioning is significant but not dominant; the contribution of the electricity utilized for households and other equipments resulted, instead, very significant.
The study is a part of the Italian research project “Genius Loci” about the role of the building sector on the climate changes.

1. Introduction

Traditional environmental analyses generally focus on a restricted number of life cycle steps according to the contest of the investigation. In the building sector, for example, a household or plant producer generally focuses the attention on the products use stage, aiming to give to the consumer information about final energy consumption and other consumables.

Furthermore, analysts often focus their attention on direct environmental impacts more than external and indirect impacts due to suppliers, retailers and consumers activities.

The Life Cycle Assessment (LCA) is a methodology voted to analyze and assess the environmental impact of materials, products or services throughout their entire life cycle, from the origin of raw materials to their disposal. The LCA can be applied to every typology of good or service defining their eco-profile. This approach allows to perform a scientific environmental balance between the benefits and the drawbacks related to the product’s use. In comparison to traditional environmental analyses, the LCA allows to avoid partial or wrong assessments concerning the products environmental performances.

Besides information regarding the environmental impacts due to manufacturing of construction materials, maintenance or disposal of the buildings are generally not sufficiently investigated or even neglected.

Dealing with the building sector (Council Directive 89/106/EEC) several Member States have set and developed approaches aimed to integrate the environmental criteria in the design and construction of buildings. The LCA could therefore become a support methodology for designers and decision makers into the defining and the realisation of strategies and solutions for ecological buildings with high energy and environmental performances.

Finally we underline the role of LCA of buildings into the definition of environmental certification of buildings. In particular, the European Commission is debating about the possibility to extend the European Ecolabel (European Commission, 2000) to buildings. LCA studies on exemplary case studies could address the work of decision makers into the definition of environmental criteria for the certification of constructions.

1.1 Life Cycle Assessment of a building

There are many benefits for businesses activities adopting the LCA approach to the evaluation of buildings, including:

- Assessing, on the basis of a internationally agreed scientific procedure, the components and the life cycle steps that are responsible of the most significant environmental impacts;
- Identifying the most efficient and cost effective options to increase the environmental performance of the building, more desirable to consumers;
- Assessing the company's operations and production processes to identify opportunities for efficiency improvements, while reducing financial costs;
- Reducing greenhouse emissions and other environmental burdens throughout every life-cycle step, in accordance with national and international laws and agreements;
- Utilising the LCA results as the basis to develop an Environmental Management System (EMS) or to obtain environmental label and product certifications;
- Comparing the performances of replaceable products in terms of environmental performances or life cycle costs.

The LCA of a building should be developed according to the following scheme:

1. <u>Qualitative and quantitative analysis of building components</u> including the main construction materials and the main equipments;
2. <u>Analysis of the construction phase</u> including material origin and transport, the use of construction machineries, installation steps, environmental impacts due to the construction (as land use, soil removal, air and water emissions, wastes, noise levels), etc.;
3. <u>Reference analysis</u> to collect information regarding the construction materials and plant's components. When available, it is generally suggested to refer to local producers; otherwise the analyst could refer to national or international data and statistics;
4. <u>Detailed analysis of the use phase</u>, computing the yearly energy employed for lighting, air conditioning, sanitary water heating, food cooking, etc.;
5. <u>Analysis of maintenance operations</u>. For new buildings the analyst could refer to experiences of previous buildings or to local and national statistics. This step should include the qualitative and quantitative analysis of utilised materials and environmental impacts due to the maintenance (following a similar approach as that performed for the building construction analysis);
6. <u>Analysis of disposal phase</u>. That should include the energy and the environmental impacts related to the building demolition (energy employed by machineries, air and water emissions, etc.) and the exhausted materials disposal or recovery. Being generally not possible to exactly foresee and describe the disposal phase before accomplishing it, the analysis should be based on different disposal scenarios. These scenarios have to describe different disposal assumptions and technologies (i.e. material totally moved to landfill or partially reused and recycled, energy recovery, etc.);
7. <u>Data regarding each life cycle step have to be processed</u> in order to obtain global environmental indexes that synthesize the environmental performances of the building;

8. Analysis of all the previous steps to locate hot spots (components of the system with the higher environmental burdens) that are further investigated in order to reach the desired level of precision and reliability of the results. Assumptions concerning hot spot have to be discussed in a sensitivity analysis.

1.2 Global environmental impacts of building

Several studies have been performed worldwide concerning the LCA of buildings and construction.

An interesting Swiss study was performed to assess the energy consumption of the construction sector (Wüest&Partner, 1994; Zimmermann et. al., 2005). It was estimated that the construction sector is responsible of the consumption of about 50% of the primary energy in Swiss. Specific average energy consumption for different building typologies are: mono-familiar houses resulted the most energy consuming (1.5 $\frac{GJ}{m^2 year}$), followed by multi-familiar houses (1.15 $\frac{GJ}{m^2 year}$) and offices (0.82 $\frac{GJ}{m^2 year}$). Such consumption are mainly related to the indoor air-conditioning and sanitary warm water demand (50% - 70% of the global consumption), and to the production of building materials (10% - 20%).

Another interesting comparative study among different residential buildings has been presented by the European Commission (2003). Sixth semi-detached house typologies commonly employed in the central Europe, with a living surface are from 176 m^2 to 185 m^2, have been analysed, supposing an average useful life of 80 years. The study shows that respect to a common reference building, the adoption of high efficiency design solutions (with better insulations, high efficiency plants, low energy materials, etc.) sensibly decrease the global energy demands. Global primary energy consumption can sensibly vary from $6 \cdot 10^3$ GJ to $12 \cdot 10^3$ GJ. Worse performances are generally related to bad insulated construction or to the use of electricity for the building heating.

A component detail of the LCA of a building is presented by Thormark (2003). The analysis regarded a "good performing" residential building in Sweden and it includes energy for material's production, building installation and maintenance and replacement. The Energy requirement for heating has been estimated to be 45 kWh/m^2. The author shows that the energy consumption due to embodied energy of materials could be sensible decreased by employing recycled materials and about 35 - 40 % of the building embodied energy can be saved through the recycling. The global energy consumption during the use phase amounts to about *8.2* GJ/m^2; the consumption for other life-cycle steps (materials manufacture, transports, construction, maintenance, and demolition) amounts to *7* GJ/m^2. It shows that, concerning a "*low energy*" building with good performance, the energy consumption for plants is approximately comparable to the consumptions during the other phases. On the other side, in bad performing building energy consumption for the plants could represent till up the 90% of the consumption. The author finally shows the great importance of the *design for recycling* and *design for disassembly*: it is expected that the reuse/recycle of material could allow to save up to 30% - 40% of the energy used to manufacture building materials and components.

2. Application of the LCA methodology to an exemplary construction: an Italian case study

In the following paragraphs a study of LCA applied to an Italian exemplary mono-familiar house is presented. The house can be considered as a representative Italian construction of the Mediterranean area (Figure 1). The house is occupied by a three member family.

The studied area is characterized by a temperate climate, with mild winters and hot summers. Such conditions influence significantly the energy performances of the building. In fact, compared to Northern case study, the energy consumptions for air-conditioning are reduced during the winter time, while sensibly increased are the consumptions for the indoor cooling in the hot seasons. The house is isolated and no neighbouring constructions modify the direct sun radiation.

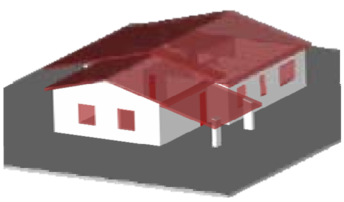


Figure 1 Structural layer of the case-study building

The structure has been realized with reinforced concrete pillars and body bolsters; external walls include 20 cm bricks with a 9 cm cavity filled with insulating expanded vermiculite; the building is equipped with wooden double-glazed insulated windows; floors are 20 cm width, including perforated brick and prefabricated reinforced concrete rafters. Roof is constituted by a wooden structure with composite materials and clay roof tiles cover. The basement rests on a reinforced concrete structure and a layer of cave crushed stones. Bitumen sheets are used as water proof barriers.

The heating system consists of a Liquid Petroleum Gas boiler, steel radiant radiators and insulated steel pipes. The boiler provides also warm water for sanitary demand. Gas is purchased by local companies, transported in small trucks and stored in an autonomous 1000 litres tank. Summer air conditioning is granted by electrical heat pumps installed into main rooms.

The house is equipped with normal electrical and sanitary water lines.

2.1 LCA phases: Goal and scope definition

The Functional Unit is a single level structure with of an overall surface of 108 m^2, located in the municipality of Palermo. The house has been built in the last decade. The aim of the research is to evaluate the global environmental impacts of an exemplary mono-familiar house of the Mediterranean area. The scopes are:

- to locate components that are responsible of largest impacts (key issues);
- to assess incidence of each life-cycle steps and, in particular of phases generally not adequately investigated (incidence on the global environmental balance of construction materials, maintenance cycles, transports, etc.);
- to focus the attention on components that are responsible of significant impacts in a prospective of an environmental design of the residential buildings.

Results can represent a scientific basis useful for the definition of criteria concerning the energy and the environmental certification (Ecolabel) of buildings.

2.2 LCA phases: Inventory phase

Data collection has been structured as following;

- Analysis of design plans: collection of structural information and calculation and assessment of the quantity of used construction materials;
- Analysis of building components: technical sheet of building components (windows, plants, pipe lines, etc.) have been analysed in order to detail their composition and performances;
- Reference survey: LCA databases (Boustead, 2001; PE International 2006; Pré-Consultants, 2006) have been consulted in order to acquire information regarding the eco-profile of construction materials, components and plants;
- Inventory of construction phase: at the time of the study, being the case-study house already existing, it was not possible to compute impacts during the construction. A similar mono familiar house in construction has been studied, in order to estimate main impacts due to construction machines and transports;
- Use phase: electricity, LPG and water consumptions of the case-study house have been monthly monitored for two years.
- Maintenance: the consumptions due to the renovation of plants and house components have been calculated on the basis of information of the owners concerning the house life. Further information have been asked to the building company, concerning their experience on the buildings maintenance cycles;
- Demolition and Disposal: the life-time of the building is supposed to be 50 years. The end-life scenario of the house has been assessed jointly with the construction company. Exhausted inert materials are supposed to be addressed to a sorting plant, wood and plastic components to incinerators, steel to recycling. Secondary components are disposed in landfills.

Details of main building materials and components utilized during construction (Table 1) and of average consumptions during the use (Table 2) is following shown.

Table 1 Detail of main construction materials and components

Material	Unit	
Concrete	[10^3 kg]	276,5
Clay bricks	[10^3 kg]	33,0
Roof tiles	[10^3 kg]	13,6
Ceramic tiles	[10^3 kg]	6,5
Plaster	[10^3 kg]	4,7
Wood boards	[10^3 kg]	4,6
Steel	[10^3 kg]	4,0
Composite membrane	[10^3 kg]	1,0
Galvanized steel	[10 kg]	221
Sanitary ceramics	[10 kg]	151
Glass	[10 kg]	115
PVC	[10 kg]	23
Copper wires	[10 kg]	10

Table 2 Average yearly consumption during the use phase

Consumption	Unit	
Electricity	[kWh]	3,944
LPG	[MJ]	22,122
Water	[m^3]	318

2.3 LCA phases: Impact assessment

The energy and the environmental impacts have been assessed on the basis of declaration scheme and characterization factors utilized in the EPD system (Swedish Environmental Management Council, 2000). Results are showed in Table 3 and figure 2.

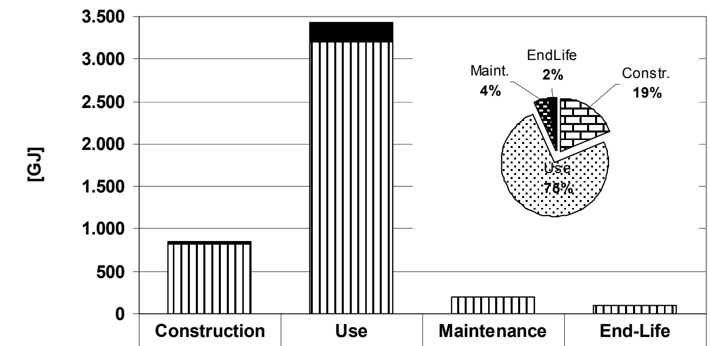
Table 3 Life-cycle Impacts

Impact Category		Total
Global Warming Potential (GWP)	[kg $CO_{2\ eq}$]	327.406
Ozone Depletion Potential (ODP)	[kg $CFC_{11\ eq}$]	0,05
Photochemical Ozone Creation Potential (POCP)	[kg C_2H_4]	68
Acidification Potential (AP)	[kg $SO_{2\ eq}$]	1.551
Nutrification Potential (NP)	[kg $PO_{4---\ eq}$]	145

It is possible to observe that:

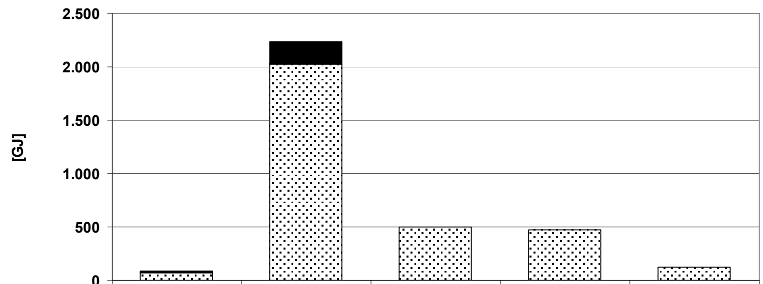
- The GER amounts to about 4.58 $\cdot 10^3$ GJ of primary energy. Yearly specific consumption per unit of area is 0.63 $\frac{GJ}{m^2 year}$. Such values are lower than reference values reported in the previous paragraphs. This is mainly due to good energy performances of the house but also to mild climate conditions (that decrease sensibly the consumptions for winter air conditioning) and the particular care of users to the energy save;
- Concerning ODP, impacts are almost negligible. The highest incidence is related to the production and transport of construction materials;
- As expected, the usage is the phase that causes the largest impacts (Figure 2). It is responsible, for each environmental index, of about 50-70% of the global impacts.
- The incidence of the construction phase is considerable, moving from 20% (GER) to 30% (NP);
- Other phases are responsible of about 6% of the GER. Higher percentage have been observed considering the other indexes, till up a weight of 20% in the NP index;

- The GER consumption is mostly represented by non renewable energy sources. Small quantity of renewable energy are related to the use of electricity, following Italian power energy generation mix, and to the utilization of renewable materials into the construction components;
- A detail of the use phase (Figure 3) shows that the largest impacts are due to the use of electricity. The consumptions for the winter heating and for the sanitary warm water demand are almost the same.



	Construction	Use	Maintenance	End-Life
■ Renewable (GJ)	30	228	12	2
□ Non renewable (GJ)	826	3.198	193	94

Figure 2 Details of Global Energy Requirements (GER)



	Water supply	Electricity	LPG (heating)	LPG (sanitary warm water)	LPG (cooking)
■ Renewable (GJ)	19	209	0	0	0
□ Non renewable (GJ)	73	2.029	500	478	118

Figure 3 Detail of energy life-cycle consumption during the use phase

From a more detailed analysis, it resulted that the energy consumption for summer air conditioning is about 20% of global summer electricity input, corresponding to about 7% of the yearly consumption, as about 157 GJ of primary energy consumption during the life-cycle of the building.

It's interesting to note that energy consumption due to air conditioning are relevant but not dominant, as shown by other authors concerning case-studies in the central and northern Europe. The summer air conditioning is also significant but comparable to the energy consumption for the cooking. Very relevant are other consumption almost equally distributed along the year, as energy for water heating and electricity for households. This last component is responsible of about 45% of the GER during the entire house life-cycle. It means that the application of good practises in the household use and the purchase of high energy performing devices could reduce sensibly the energy consumptions and the related environmental impacts.

2.4 LCA phases: Life cycle interpretation

The previous paragraphs showed that the use phase is critical in the global environmental analysis of the case-study house. Therefore attention has been focused on such life-cycle step.

First of all, being electricity a dominant factor, it has been carried out a sensitivity analysis by changing the eco-profile of power energy production mix. The previous assessment, based on Ecoinvent energy data (Swiss Centre for Life Cycle Inventories, 2000), has been modified supposing to use data from ETH concerning the national average energy mix (Frischknecht, 1996). As result, we observed little modifies on the GER index (less than 1%) due to the ETH data, with a small increase of the incidence of renewable energy use in the global energy balance. Higher modifies (from 10 to 30%) has been observed in the GWP and NP indexes. ODP index is totally modified: considering input data form ETH, ODP resulted about ten times higher. These large variations are ascribable to different air emissions included in the inventory phase. We underline that those data are quite aged, especially data from ETH that referred to the last decade, and their quality is therefore low. A further analysis should be performed with updated eco-profile and, possibly, using data related to the regional context with a higher geographical representativeness.

The next step in the analysis was the house simulation of the energy consumptions by means of specialist software. Such analysis is described in the following paragraph. Finally, we observe that a large part of the energy consumptions are due to the use of households and to the behaviors of the house habitants. That represents a limit of such typology of analysis, being the results strictly dependent of the case-study peculiarities and not plenty transferable to a more general context.

2.4.1 Energy simulation of the building

The energy simulation of the house has been performed with the *TRaNsient SYstem Simulation Program - TRNSYS* (Klein et al., 1976). The software has been applied to the case study building. Input data to the model included: building input description (structural components, material thermal performances, orientation, internal thermal loads), characteristics of system components (plants, windows and other transparent modules) and manner in which components are interconnected and local weather data (temperatures, humidity, wind and solar radiation).

Simulations have been performed with a 1 hour time-step. Design assumptions were: internal temperature enclosed in the range 20-26 °C and humidity in the range 40-60%. The aim of the simulation has been:

- to assess the energy winter and summer loads, and to compare results with monitored data;
- to assess the variability of results on the basis of initial assumption.

As example of simulations, Figures 4 shows the yearly trends of the sensible heat loads of the building. However, the estimated results have been very different from monitored consumptions, showing even in this case a discrepancy between assumptions and real users' behaviors

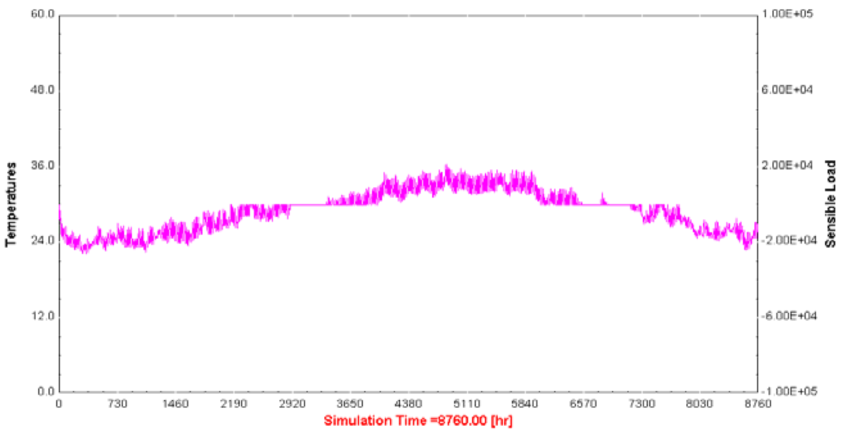


Figure 4 Yearly trends of sensible heat load

3. Conclusions

The paper presented a Life Cycle Assessment study of a mono-familiar house in Italy. The construction can be assumed as representative case-study building of the Italian Mediterranean area. The study is a part of the Italian research project "Genius Loci" about the role of the building sector on the climate changes. It is expected that the results could be employed for the definition of criteria for the energy and environmental certification scheme of the building.

The analysis was performed collecting and estimating data from each life-cycle step of the building including: design phase, production of construction materials and components, energy and water supply, construction and installation of plant, use, maintenance and management of the building end-life. Data concerning the building have been directly measured or estimated in collaboration with the construction company. Data regarding the eco-profile of construction materials, plants and energy sources have been referred to international LCA databases.

The results showed the large incidence of the use phase in almost all the considered energy and environmental indexes. In particular, concerning the primary energy consumptions, the use phase is responsible of about 75% of the GER index. Other phases, as in particular the use of construction materials and components, have a significant incidence (from 20% to 40%).

A more detailed analysis of the use phase showed that the utilization of electricity is dominant, followed by the use of LPG for house winter heating, warm water demand and cooking.

The global and specific energy indexes of the studied building are, however, lower than reference data related to other case-studies in the central and northern Europe. Energy consumption for air conditioning, in fact, is low due to both mild winter weather conditions and an energy saving behaviours of the building users. On the other side, a large part of the consumptions are related to the use of households and other electrical equipments. It means that the eco-profile of a house is strictly depending on the activities of families and the conductions of plants.

A sensitivity analysis was performed on the incidence of electricity eco-profile, showing significant variations especially on non-energy indexes. Finally it has been performed an energy simulation of the building with the TRNSYS software, supposing to maintain in the rooms the indoor comfort values of the thermal parameters. The results have been however very different from monitored consumptions, showing even in this case a discrepancy between assumptions and real users behaviours.

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STUDIES CONCERNING 'THE STATUS OF UTILIZING CASBEE EVALUATION' AND 'THE PREVALENCE OF ASSESSMENT TOOL' IN DESIGN DIVISIONS WITHIN LARGE CONTRACTORS IN JAPAN

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Key words: BCS, CASBEE, building, assessment, questionnaire, survey, results, outlook

Summary

Every year since 2004, the Building Contractors Society (BCS), an industry organization (public service corporation) of general contractors working in building construction throughout Japan, has conducted a questionnaire survey of 23 member companies having in-house architectural design divisions with regard to the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE). The questionnaire covers a wide range of topics, including the projects subject to assessment, reasons for introducing CASBEE, in-house education, targets if any, numbers of buildings evaluated, assessment results, opinions concerning positive and negative aspects of CASBEE, time spent on assessment work, and the future outlook. Through these surveys, we have learned that many companies are actively introducing CASBEE, and that some are using CASBEE to evaluate all of the buildings they design. The unstructured comments from survey respondents are taken into consideration when deciding how to further promote the use of this assessment tool in the future.

1. About CASBEE

CASBEE• Comprehensive Assessment System for Building Environmental Efficiency•• has been developed since 2001 in Japan with the support by Ministry of Land, Infrastructure and Transport. CASBEE distinguishes environmental load (L) and quality of building performance (Q) as the major assessment targets, and applied the concept of eco-efficiency as BEE (Building Environmental Efficiency). Give L and Q, BEE is defined as Q/L to indicate the overall result of environmental assessment of buildings.

2. About BCS

2.1 Building Contractors Society (BCS) and its design and construction activities

The Building Contractors Society (BCS) is an industry organization (public service corporation) of general contractors working in building construction throughout Japan. It has 69 member companies (as of March 2008), which employ a total of about 122,000 employees (as of July 2007) and handle approximately ¥14,660.068 billion in construction orders (FY 2006, including civil engineering projects), about three-quarters of which consists of building construction orders (approximately ¥10,853.015 billion).

One important characteristic of Japan's large-scale construction companies is that they include in-house architectural design divisions. With this kind of corporate organization, they can provide design and construction in so-called "full turnkey" services according to the client's preferences. The architectural design divisions of BCS member companies are involved in the design of 44% of all of the building construction orders they handle. The buildings designed by BCS member companies include some architecturally and technologically outstanding buildings which have won a variety of awards. For example, about 17% of the buildings in "Selected Architectural Design 2007" by the Architectural Institute of Japan (AIJ) were designed and built by leading companies which are members of BCS.

2.2 Promotion by BCS of environmental responsibility throughout a building's life cycle

BCS has adopted an action plan indicating its goals and the role of its activities with regard to society; and is implementing this plan in collaboration with member companies. The second of five goals under the BCS action plan is "to contribute to the global environment through sustainable architecture." To protect the global environment, it is essential to implement environmental measures throughout a building's life cycle. Because BCS is involved not only in construction, but also in planning, design, and operation after a building is completed, it is taking the following three specific actions to achieve this goal: promoting environmentally friendly planning, programming, and design; pursuing environmentally friendly construction processes; and promoting improved environmental performance at the operational stage. Many BCS member companies have in-house architectural design divisions and are capable of involvement for the sake of environmental responsibility at all stages, having organizations that facilitate the effective application of lessons learned through experiences and information at each stage.

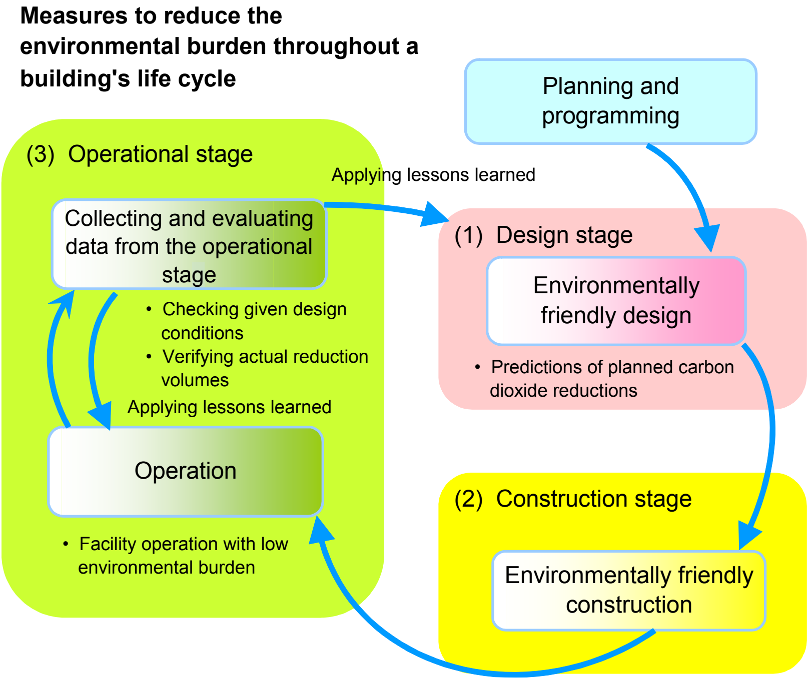


Figure 1. Measures to reduce the environmental burden throughout a building's life cycle

2.3 Survey of BCS companies regarding CASBEE utilization

Considering the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) to be an effective tool for promoting environmentally friendly planning, programming, and design, BCS believes that the widespread adoption of CASBEE is important, not only among its member companies but also in society at large. Therefore, every year since 2004, BCS has used questionnaires to survey 23 of its member companies with regard to CASBEE. The 23 surveyed firms have active in-house architectural design divisions. The volume of building design and construction orders taken by these 23 companies accounts for over 90% of the total handled by these BCS member companies.

The questionnaire covers a wide range of topics, including the projects subject to assessment (voluntary decision or based on administrative guidance), reasons for introducing this assessment system, acquisition of evaluator qualifications, in-house training, targets, the evaluated properties (about 500 buildings) categorized by purpose of use and assessment results, opinions concerning positive and negative aspects of CASBEE, time spent on assessment work, increases in assessment staffing, and future expectations.

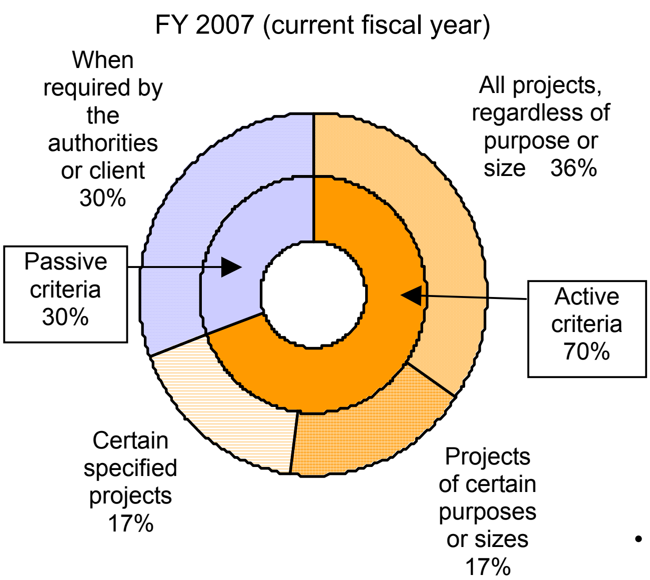
Here, we report the findings from surveys conducted over the past four years. When no fiscal year is specified, the results from the FY 2006 survey are indicated.

3. Survey results

The survey results are reported in four categories: situation of CASBEE use, analysis of past assessment records, opinions concerning the assessment system, and unstructured comments.

3.1 Situation of CASBEE use

Several local governments in Japan (12 local governments as of January 2008) require CASBEE evaluations for construction projects above a certain size; and some clients specify the use of CASBEE. In addition, 16 of the 23 surveyed companies (70%) actively utilize CASBEE based on their own criteria, even without these external factors. These companies have established a wide variety of criteria, including the use of CASBEE for certain specified projects (e.g., based on annual target numbers of projects), or for projects of certain purposes or sizes (e.g., at least 5,000 square meters of total floor area). Also, four companies stated that they use CASBEE for all their projects. (Figure 2)



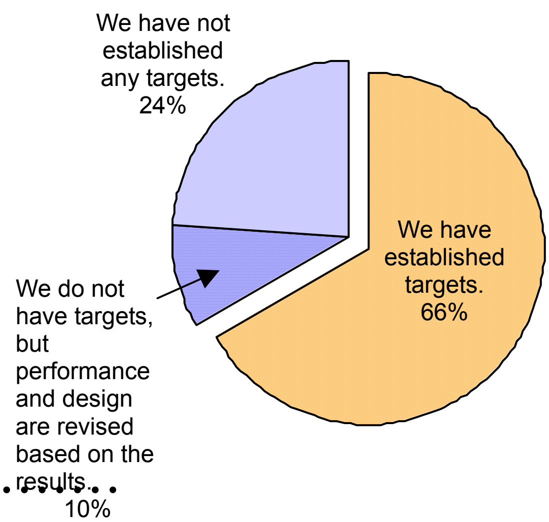


Figure 2. Criteria for conducting CASBEE evaluations *Figure 3. Targets for assessment results*

14 companies (66%) have established targets regarding CASBEE evaluation results. Seven companies have no targets, but two of these companies revise performance and design in some cases according to the results obtained. This means that the companies conduct design with an awareness of CASBEE evaluations. Eight companies have selected targets of a certain rank (at least B+, or BEE scores of at least 1.0, etc.), and four companies establish targets according to the project. (Figure 3)

Concerning internal measures for the implementation of CASBEE evaluations, 18 companies recommend or encourage the acquisition of evaluator qualifications; 12 companies participate in external training sessions; nine companies incorporate this into internal programs such as ISO 14001; and nine companies hold in-house training sessions.

22 of the 23 companies surveyed have environmentally friendly design tools and include them in ISO 14001 documentation. Ten companies correlate these environmentally friendly design tools with CASBEE or plan to do so in the future; and eight of these companies use the simplified edition of CASBEE as is.

3.2 Analysis of past CASBEE evaluation records

Figure 4 shows trends in the numbers of properties evaluated using CASBEE by the surveyed companies since CASBEE was first published. There were 591 properties in FY 2006, bringing the cumulative total up to 1,090 properties. About 1.5 times as many properties were evaluated using CASBEE in FY 2006 as in FY 2005.

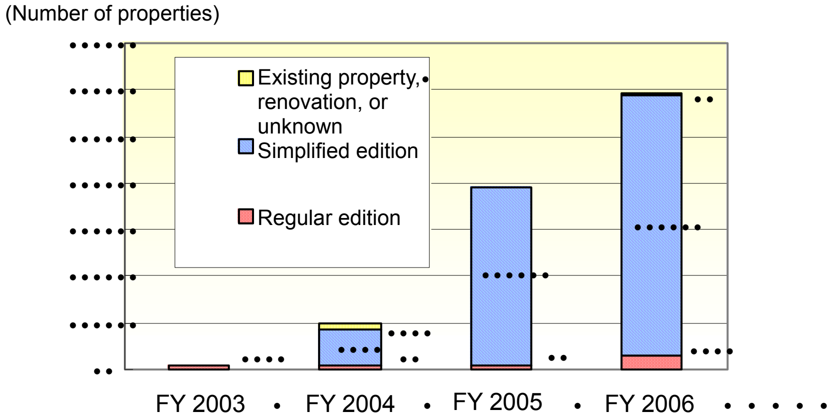


Figure 4. Trends in numbers of assessments by year

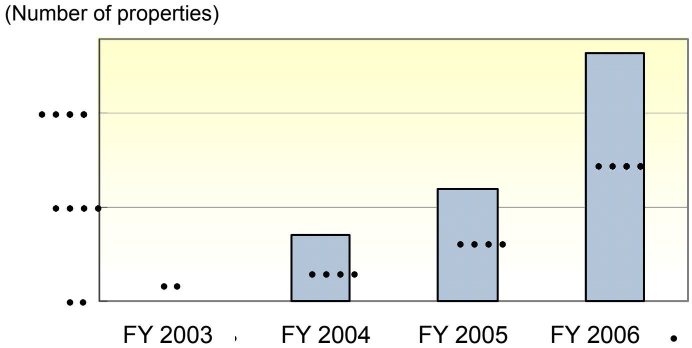


Figure 5. Trends in numbers of assessments submitted to local governments

Figure 5 shows annual trends in the numbers of assessments submitted to local governments. Reflecting the increasing number of local governments that have adopted environmentally friendly programs using CASBEE, twice as many assessments were submitted to local governments in FY 2006 as in FY 2005.

Figure 6 shows past CASBEE evaluations by rank. The most frequent rank has been B+ at over 40%, and nearly as many properties have been ranked A. Ranks of B+ or higher account for about 90% of the total.

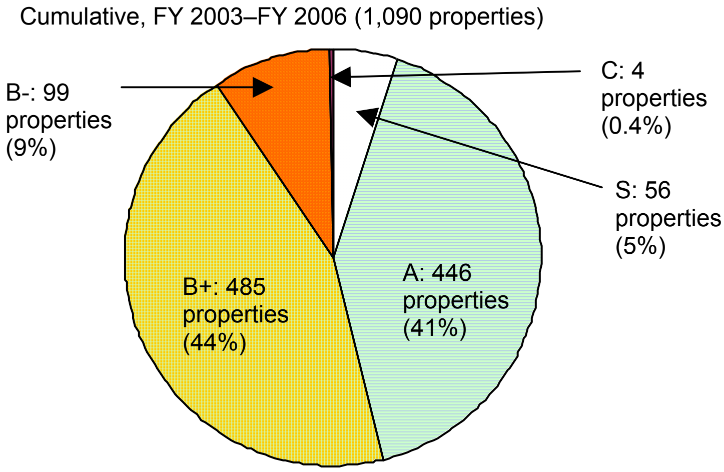


Figure 6. Breakdown of evaluated result by rank

Figure 7 is a scatter plot of environmental efficiency rates (Q/L) in FY 2006. Most (87%) earned a rank of A or B+, and about 4% were ranked S. About 9% were ranked B-, and practically none were ranked C. The number of points plotted rises sharply for environmental efficiency rates (Q/L) of 1.0 and higher, implying efforts at the design stage to meet a standard of at least 1.0.

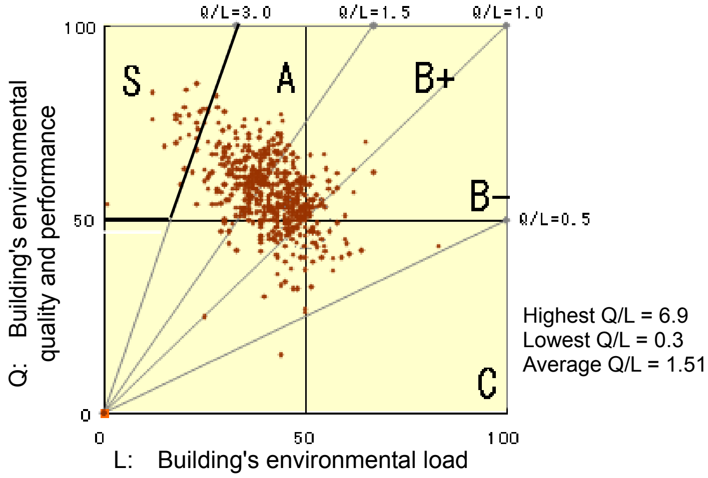


Figure 7. Q/L scatter plot

Figure 8 shows the assessment results of the past four years classified by the building's purpose of use. Schools and assembly halls have tended to earn high CASBEE scores. Apartment buildings and factories account for the largest numbers of projects, but fewer than half of them earned scores of A or higher, a lower proportion than other purposes of use. This could be attributed to the greater difficulty of obtaining a high score in these purposes of use; nevertheless, further improvement is needed in the environmental performance of buildings for these purposes of use in the future.

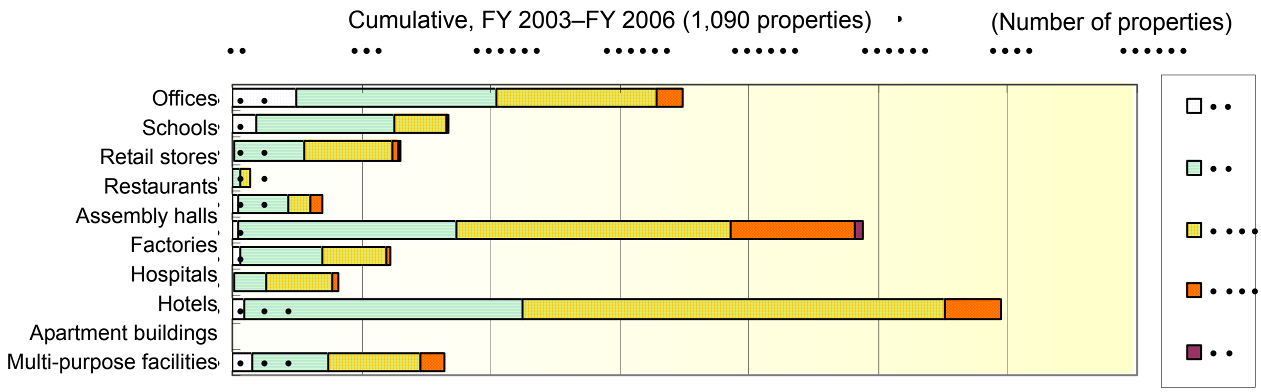


Figure 8. Assessment results by purpose of use

Figure 9 shows the assessment results of the past four years classified by the building's total floor area. Larger-size buildings have tended to achieve better assessment results, with a higher proportion of S and A ranks. Some companies use 2,000 square meters as the cutoff point for deciding whether to perform a CASBEE evaluation. There is a trend toward lower ranks among buildings of less than 2,000 square meters.

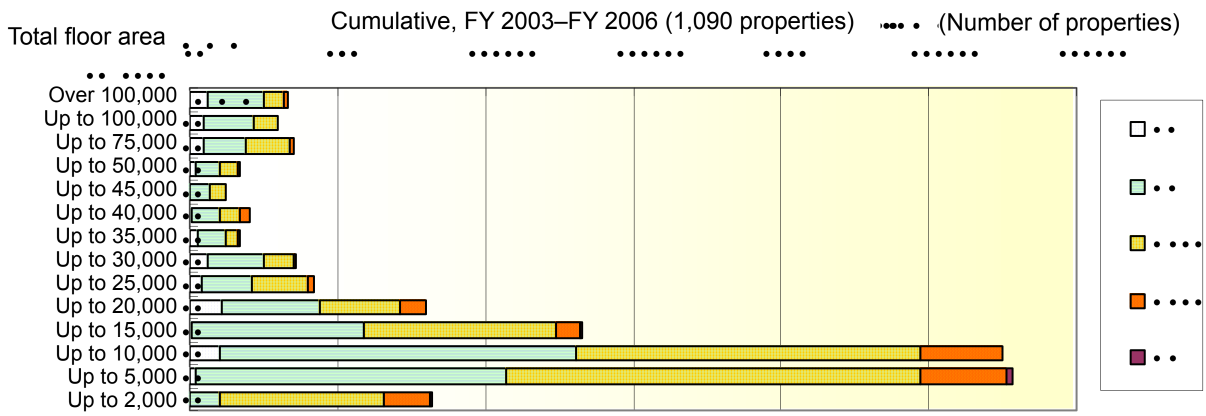


Figure 9. Assessment results by size

3.3 Opinions concerning the CASBEE evaluation system

Among the 16 companies which have actively incorporated CASBEE evaluation, 11 firms said the most important reason was that they consider CASBEE to be an effective tool for promoting environmentally friendly design.

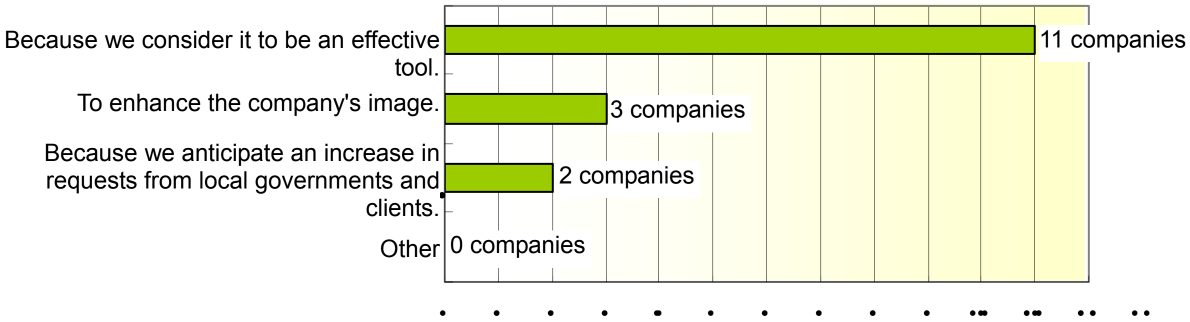


Figure 10. Reasons for actively incorporating CASBEE evaluation

Figure 11 shows the positive aspects of CASBEE evaluations, with the greatest number of respondents indicating the fact that results of environmentally friendly design can be expressed in numerical terms, followed by the facts that it helps to educate architects with regard to environmentally friendly design, and that the evaluation is relatively simple.

Figure 12 shows the negative aspects of CASBEE evaluations, with the greatest number of respondents indicating the difficulty of subjective evaluation judgments, followed by the burden on architects, and the lack of quantification of the reduction in carbon dioxide emissions.

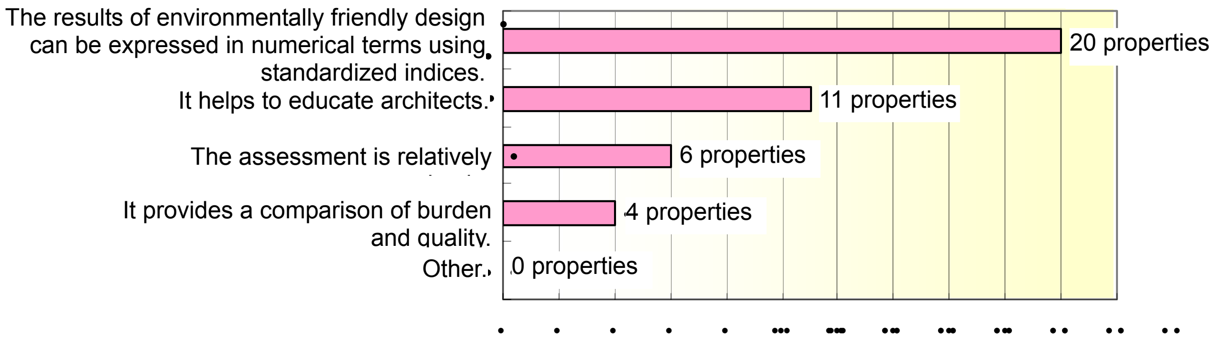


Figure 11. Positive aspects of CASBEE evaluations

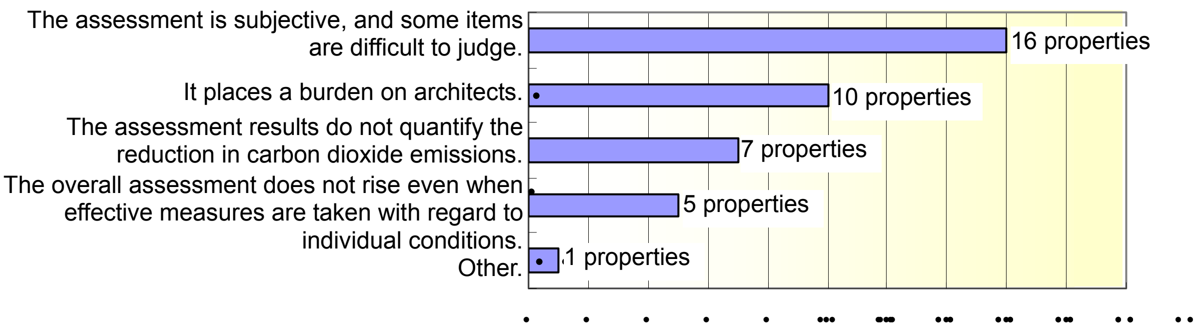


Figure 12. Negative aspects of CASBEE evaluations

Figure 13 indicates the approximate working hours required for CASBEE evaluations (assuming that PAL and CEC data are already in place at the time of CASBEE evaluation work). The simplified edition is indicated as requiring about two hours, but in fact, 60% spent half a day and 20% spent an entire day, while only about 10% completed it within about two hours (no non-responders). Among the eight companies responding that they spent either about eight hours or more than eight hours, the most time-consuming tasks were understanding the manual and gathering back data. Under "other," responses included document preparation, coordination with the architectural and M&E divisions, discussions and guidance from the authorities concerning documents to be submitted and the resulting additional document preparation time, and coordination regarding the views of government authorities.

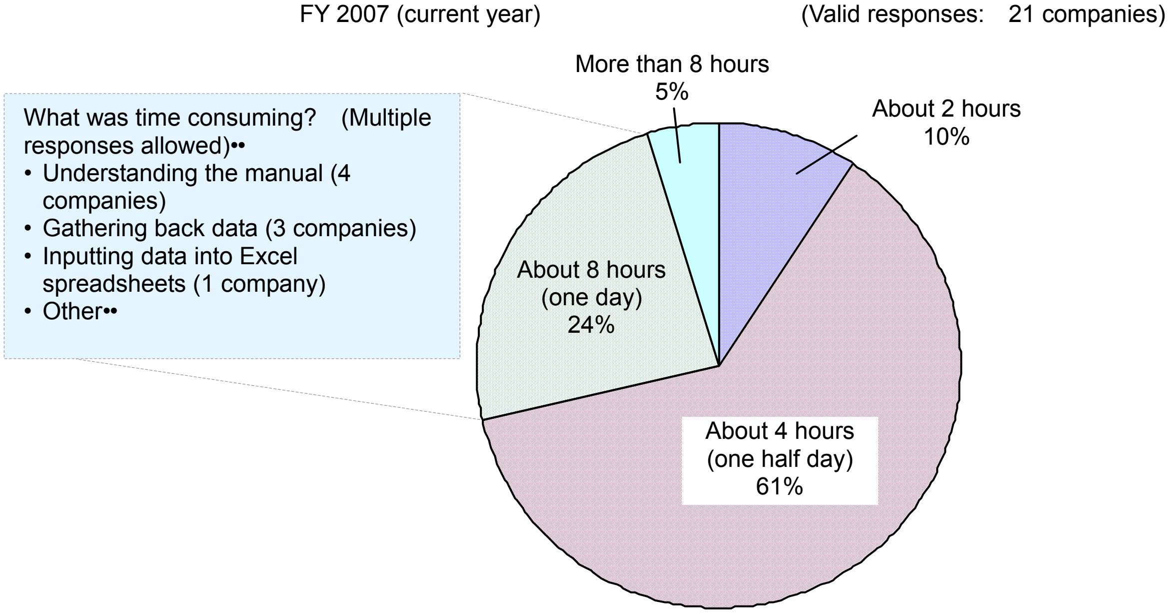


Figure 13. Working hours for "CASBEE, New Construction: Simplified Edition"

3.4 Unstructured comments concerning CASBEE

Table 1 shows the unstructured comments of 23 companies in the BCS design subcommittee regarding CASBEE this fiscal year, by category. The following were the most frequent types of responses:

[1] The CASBEE evaluation system should clarify the effects with regard to reducing carbon dioxide emissions, etc.

[2] Efforts should be made to promote dissemination among a wide range of interested parties including clients, managers, and financial institutions.

[3] Building facility engineers should also be permitted to take the CASBEE evaluator examination.

[4] The local government editions of CASBEE should use the same tools in order to allow the work to be standardized, from the applicant's standpoint.

Regarding item [1], the developer of CASBEE (Japan Sustainable Building Consortium) published "CASBEE, New Construction" (FY 2007 Provisional Edition) in September 2007, clearly indicating evaluation items for the prevention of global warming and incorporating a standard method for calculating life-cycle carbon dioxide emissions. The official edition is scheduled to appear in July 2008.

Many CASBEE users within BCS would agree with items [2] and [3]. Item [4] reflects some level of apprehension regarding the differences in CASBEE content among different local governments which require these assessments.

Table 1

<u>Wishes regarding the CASBEE evaluation system:</u> • The assessment does not clearly indicate the extent of effects regarding the prevention of global warming. A clear indication is desirable, such as stating the amount of reduction in carbon dioxide emissions resulting from a certain assessment rank. • The layout and composition of the evaluation sheet should be improved to allow the input work to be handled mechanically. • Some items, such as consideration for scenic aesthetics, are subjective and difficult to evaluate, and this should be improved if possible.

<u>Wishes regarding promotion and dissemination:</u>

- Although CASBEE is becoming more prevalent in the building industry, most clients still do not understand CASBEE evaluations. Measures should be taken to provide benefits to clients, in addition to encouraging local governments to adopt CASBEE.
- Widespread adoption and utilization of CASBEE should be promoted not only among government authorities and the building industry (design, construction, and manufacturing), but also among clients, end users, maintenance and management providers, and financial institutions.
- Eligibility for CASBEE evaluator testing is limited to first class architects, but it should be opened to building facility engineers as well.

<u>Wishes regarding local governments:</u>

- Different local governments use different standards regarding the size of buildings to be evaluated. The trend toward widely varying approaches among local governments is problematic in terms of the reputation of CASBEE.

<u>Other</u>

- Environmentally friendly design should be actively promoted in competitions for energy efficient and environmentally friendly buildings, based on assessment results.

4. Future outlook

No other organization in Japan conducts a survey that rivals the BCS survey regarding CASBEE, excluding certain local governments. In this survey, the third annual survey since its full-scale launch, we see that CASBEE is becoming increasingly prevalent among BCS member companies. The number of buildings evaluated has also increased to nearly 600 per year, including many certified buildings and buildings published by local governments. It is becoming possible to measure progress in the prevalence of CASBEE by means of these large numbers of cases and assessment results.

This survey has been discussed at symposia held by the CASBEE development committee, and it is also noted by the Ministry of Land, Infrastructure and Transport, financial institutions, and real estate appraisal organizations. BCS will continue to actively communicate these findings to all types of stakeholders (CASBEE development committee, local governments, builders, financial institutions, real estate appraisal organizations, end users, etc.) and listen to their reactions.

Some of the future issues are included under the summary of unstructured responses. Another important future issue is to increase assessments of existing buildings.

Today, there is growing demand for truly effective performance from buildings that are planned with an eye to preventing global warming. In other words, it is becoming imperative to measure energy consumption in completed buildings, publish these figures, and promote further reductions.This suggests the importance of assessments under the "CASBEE, Existing Buildings" edition. It is important for BCS to increase the number of properties evaluated in this way. Meanwhile, it is also important for CASBEE tools to include ways to evaluate the performance of existing buildings.

5. Acknowledgment

This article is based on the BCS's research conducted by a committee of BCS. We are grateful to the following members for their efforts."Working Panel for Environment Issues" in Design Committee of BCS -Panel Chair: Kenichi KAJIMOTO(Maeda Corporation), Vice-Chair: Tadayuki SUZUKI(Toda Corporation), Members: Yasuhiro IMAI(Obayashi Corporation), Kunihiko KAGAWA(Kumagai Gumi), Masaru KIKUIRI(Tokyu Construction), Tomonori MIYAZAKI(Tekken Corporation), Hiroshi MIYAHARA(Sumitomo Mitsui Construction), Hisayoshi SAKUMA(Taisei Corporation), Hiroaki TAKAI(Takenaka Corporation), Masaki TAKEUCHI(Shimizu Corporation), Akira TOKESHI(Hazama Corporation)

INTEGRATED SUSTAINABILITY ASSESSMENT OF URBAN DEVELOPMENT AND INFRASTRUCTURE: COMPLEMENTARITIES AND CONTRADICTIONS

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Keywords: urban sustainability, infrastructure, urban development, integrated assessment, allocative efficiency, resource productivity, social preferences.

Summary

The context of this paper is the Green Growth agenda of the United Nations which has highlighted the challenge of the developing world to achieve economic growth but with less resource use and lower social and environmental impacts compared with Western nations. Urban infrastructure systems, including transport, water, energy, education, health and housing, and associated land use patterns, are important elements of achieving Green Growth as they consume significant resources, establish consumption patterns for decades and have major socio-economic impacts.

As part of a longer term project to develop a model for the integrated assessment of urban sustainability, this concept paper discusses various theories and approaches from economic, social and environmental sustainability perspectives, exploring opportunities for integration. Using a case study of a proposed transit-oriented development in a growing urban centre near Adelaide, South Australia, it examines how more compact and dense urban development may be planned and assessed from an integrated sustainability viewpoint. It is intended that the results of this work will inform policy and urban development and infrastructure decisions across a wide range of urban locations, including rapidly growing urban areas within the Asia-Pacific.

1. Introduction

The world's high rate of urbanization has potentially catastrophic consequences for the planet, in terms of consumption of resources, degradation of the natural environment, the waste and emissions generated, and effect upon human health. Some have claimed it is the most important cause of greenhouse gas emissions and climate change, coupled with increases in ecological footprint (Von Weizsacker 2007). Urban societies have footprints of around 7-10 global hectares per inhabitant, compared with a world average of about 2.2, and a biological carrying capacity of 1.7 available worldwide (WWF International 2006; Rees & Wackernagel 1996). In addition, whilst urbanization brings increased wealth for some, it can be characterized by inequalities, severe poverty and social problems. Thus, the challenge is to achieve urban development that is not only environmentally sustainable, but also economically and socially advantageous, to meet the UN Millennium Development Goals and the UN 'Green Growth' agenda (ESCAP 2006).

It is therefore imperative that a way is found for the urban areas of developing nations to grow in a more sustainable manner, avoiding the high consumption patterns of western cities. Moreover, it is incumbent on cities of the west to reduce dramatically their own consumption of scarce resources and develop new more sustainable modes of growth, which may be emulated by cities in developing nations.

The paper firstly outlines the challenge to develop rapidly growing urban areas in a more sustainable manner, introducing the concept of transit oriented urban development (TOD), and highlighting the need to consider the relative merits of compact, more dense configurations of development (such as TODs) and more dispersed, lower density patterns.

Various efficiency-related principles from the economic, social and environmental disciplines are examined, including allocative and resource efficiency, with opportunities for integrated thinking being explored.

The literature on urban sustainability assessment is then reviewed, firstly from the economic, environmental, and social perspectives of sustainability and, secondly, in terms of the intersections and associated contradictions and complementarities.

Reference is then made to a planned case study of an urban centre to the south of Adelaide, with some preliminary thoughts on new patterns of integrated and sustainable urban development. More dense and compact patterns are compared with lower density, dispersed modes, based upon the current state of knowledge. Means of integrated assessment of urban sustainability are also examined.

Finally, some indication is given of how the principles and techniques being trialed in Adelaide may be adapted and extended to cities in developing countries.

2. The challenges

2.1 Sustainable urban development and infrastructure

The provision of engineering and social infrastructure to provide increased services for rapidly increasing urban populations is a challenge faced by urban planners and developers in most Australian cities and elsewhere. Engineering infrastructure includes transport, energy and water services, whilst social infrastructure includes health, education and other government services, including public housing.

Recognising the substantial contribution of infrastructure and associated urban developments to greenhouse gas emissions and ecological footprint (Ness 2007), especially given its long life, increased attention has been given to its sustainability. At a recent UN Expert Group Meeting, a sustainable infrastructure system was seen as one that facilitates the delivery of transport, energy, water and other services to support social and economic development in an integrated, resource efficient and socially inclusive manner. It was recognized that infrastructure systems are central to economic and social development, as they support economic growth and deliver services to communities, and are also critical determinants of environmental impacts as they lock in consumption patterns for decades. Infrastructure was seen as not only very costly and having a long life, but also as very intensive in resource use, including energy, water, materials and land (ESCAP 2007).

Within Australia, state and local planning authorities are increasingly favouring urban developments characterised by mixed use, higher density and proximity to existing or new public transport systems as a way of reducing the consumption of scarce resources and environmental impacts. The current interest in Transit Oriented Developments (TODs) by the South Australian Government is a case in point. Such compact developments can be considered to be manifestations of 'new urbanism', a planning theory which suggests that urban sprawl might be contained by rebuilding inner cities around attractive streetscapes, walkable town centres and public transport hubs (Scheurer 2004). 'New urbanist' developments typically have higher population densities than in suburban localities. For example, Gordon and Vipond's (2005) study of a new urbanist development in Markham, Ontario suggests gross densities twice that of traditional suburbs might be achieved.

Some planners have previously expressed simplistic arguments in favour of more densification in urban development. However, these need to be balanced with what is achievable in the existing urban structure and with regard to social preferences.

2.2 The need for tools

Our ability to assess the sustainability of forms of urban development as described above is limited and the tools to do so have yet to be coherently brought together, with many existing tools and approaches being uni-dimensional. Tools are required to undertake a more integrated analysis than is currently available (Rotmans 2006; Davidson 2007) and to evaluate and guide development and infrastructure decisions. These tools should have the capacity to assess alternative development proposals and compare them on the basis of their sustainability, in addition to the normal financial feasibility assessments.

In addition, interdisciplinary research is required, in recognition of the complexities of urban systems, and to draw together diverse lines of enquiry to form coherent, integrated theory and practice.

3. Literature review

3.1 Economic welfare/well-being

Economists propose goods, services and outcomes that society most prefer/want/need, delivered with the best/most appropriate use of resources. The former is known as 'allocative efficiency', sometimes called '*doing the right things*', whilst the latter is known as 'productive efficiency', sometimes called '*doing things right*'.

The economic concept of 'allocative efficiency' aligns with the needs and preferences of urban dwellers for space, privacy, housing type, appropriate noise levels, to name a few. In Australian society, the market plays a key role in delivering those needs, but government can also play an important role in identifying market failures (e.g. inequitable outcomes, unsafe construction, etc) and considering options for overcoming those failures.

In relation to the related concept of 'productive efficiency', economists look for the cost minimising mix of resource use to deliver any given outcomes – this should include full costing of resources, including environmental and social costs. This means minimising negative impacts but, of course, positive impacts are very welcome.

'Tradeoffs' are a core issue in the dialogue about sustainability (SA Government 2005). In discussing trade-offs, the concepts of 'weak' and 'strong' sustainability can be helpful (see Neumayer 2003). These concepts relate to the substitutability or trade-off between economic and environmental capital. Strong sustainability requires that economic capital should only be increased provided there is no reduction in environmental capital. On the other hand, weak sustainability allows for environmental capital to be decreased whilst economic capital is increased, provided the gain in economic capital is greater than the loss of environmental capital. In an ideal world, sustainability would involve no trade-offs i.e. strong sustainability. However, the real world consists of many situations involving tradeoffs, where weak sustainability can play a role. In this regard, Rotmans (2006) acknowledges the unavoidable conflicts and tradeoffs that are required for a sustainable future.

3.2 Environmental sustainability and urban density

A transition to higher levels of residential density within cities is seen as a means of achieving a number of key environmental objectives. According to Newton (2006), 'medium density housing has approximately two thirds the material intensity of detached single family housing'. Similarly, Schiller noted 'a strong correlation between material consumption and building density', concluding that the parameter 'cost efficiency' is an argument for more dense and less resource-intensive settlement structures (Schiller 2007). Newton (2006) acknowledges that more compact styles of development are the subject of debate in respect of the perceived benefits in areas other than resource consumption – namely neighbourhood character and amenity. Other aspects of consumer preference could be added to this list, such as preference for private space and privacy.

Salat (2007) has called for action on more efficient engineering infrastructure complemented by more compact forms of urban development, with a focus on the relationship between energy and density. In this regard, the mapping of energy consumption in the urban environment offers the potential for determining more energy efficient urban forms, monitoring energy efficiency improvements and complying with targets for greenhouse gas emissions (Troy & Smith 2000; Jones et al. 2001; Gupta 2005; Matsumoto et al. 2006). The life cycle energy consumption of the built environment includes a number of components including the embodied energy of the materials from which buildings are constructed as well as the operational energy for running buildings. Research is being carried out to depict both the embodied energy of residential buildings in the Adelaide metropolitan area in a spatial format (Pullen 2007) and the operational energy used in specific areas (Hamilton et al. 2008).

The model for spatially representing the embodied energy consumption of residential areas has three components - embodied energy theory, property register data and geographical information software (GIS) – that can be integrated to provide maps (Pullen 2007). The advantage of using GIS as the mapping medium is that ultimately other forms of energy consumption in the urban environment can be overlayed and accumulated to allow a more comprehensive representation of urban energy usage.

In this regard, the consumption of energy and other resources (land, materials and water) can be considered not only in relation to residential areas, but also associated with engineering infrastructure for transport and utilities and social infrastructure for government services. Sharing and co-location of infrastructure and facilities, for example, can lead to higher resource productivity – delivering more services with less use of embodied and operational (fossil fuel) energy and other scarce resources, less environmental impact and less cost. An example is the use of a road corridor for water collection and harvesting and as a linear solar energy source to serve adjacent housing (Ness 2007, 2008).

The modelling and measurement of energy consumption, which takes into account embodied energy, can also provide a means for valuing the existing built form and accounting for saved energy in the re-use or recycling of construction materials in the redevelopment of existing urban areas (Pullen 2007). This provides a more holistic analysis of energy consumption and indicates the significance of the embodied energy component of overall life cycle energy consumption. The analysis of operational energy demonstrates that different forms of residential development at different densities display differing energy profiles (Perkins & Hamnett 2005; Perkins et al. 2007). These spill over into transport energy, since density is often related to location and proximity to services. Therefore, even within a discrete area of study such as urban energy demand, we can identify relationships which need to be made explicit in any analysis of the sustainability of urban form.

3.3 Social sustainability and urban density

Despite the interest in transit oriented developments in Australia, Crabtree (2005: 333) notes that 'we seem to know what needs doing to move towards sustainability' but the uptake of new urbanist projects has been slow. Crabtree (2005) lays the blame for this on a neo-liberal planning agenda, which avoids what she terms the substantial challenges of 'ecocity design and community based enterprise'. Whilst she argues there is a demand for such developments, her case study of the Pinakarri co-housing community in Perth suggests local resistance to urban designs of this nature might arise when such developments are imposed on communities by housing authorities.

Much of the thinking on urban intensification in Australia as in other parts of the world seems to focus on the notion that residents can be induced into choosing higher density living options in preference to low density suburban locations (Skaburkis 2006). It assumes that consumers will accept giving up backyards and using public transport in place of cars to access work and shopping because it will create 'socially sustainable communities'.

It is almost forty years since Arnstein (1969) drew attention to the relationship between inclusive, resilient communities and the degree of control local people have over institutional decisions that affect their lives. If we accept Arnstein's argument it is clear that the degree to which residents are able to address their preferences for the style of housing they wish to live in and the choices they have in relation to the location of their homes have implications for the sustainability of a community. That is, urban developments are more likely to be sustainable if residents are satisfied with the design of their housing, the density of their local area and the accessibility of work, shopping and social institutions. Hence a model that wishes to measure the sustainability of urban developments should consider not only the types of housing and relative urban densities that might be supplied but public demand for such developments. We might begin by asking if actors in the housing market will increasingly accept compact city living in mixed use, higher density communities as assumed by many policy makers and planners.

The planning literature on consumer preferences for new urbanist living is limited but a recent British study by Senior et al. (2006) examined the acceptability to relocating households of higher density living in mixed land use land areas in redeveloped dockland, inner urban and city centre locations. Relocation has been encouraged in the UK by policies to address social exclusion through the creation of sustainable, mixed income communities (Silverman et al. 2005). Senior et al. (2006) surveyed the housing preferences of owner occupier residents of Cardiff, Wales who were selling or had sold their homes to relocate. Their study found a continuing preference for detached properties in suburban locations rather than in higher density, inner city locations. Such preferences were strong among families with children of pre-school age. Those of retirement age were even less likely to opt for inner urban locations. Senior et al. (2006) noted a significant general aversion to living in areas where residents were perceived to be of lower socio-economic status. Their respondents also expressed an aversion to neighbourhoods where residents were considered to be of a higher social status than themselves. First time home buyers with financial constraints indicated they would look at affordable options in the inner city. However, once on the housing ownership ladder, most first home buyers said they would prefer to move to suburban locations and detached housing once they had established some equity. Most respondents expressed a preference for socially homogenous communities where they might live among people similar to themselves.

A similar survey by Skaburkis (2006) of residents of a new urbanist development in Cornell, Ontario tends to support the findings of Senior et al. (2006). At the time of Skaburkis' study, 37 percent of homes in Cornell were detached houses with the rest a mix of units and townhouses. While almost all of Cornell residents expressed satisfaction with their housing and their community, 88.6 percent said they would move to a detached house if they could. Skaburkis noted that while housing density in Cornell was twice as high as in surrounding suburbs, many residents were beginning their housing careers in relatively cheap, attached housing and were likely to move to detached housing when it became affordable to them. Skaburkis (2006) did find that residents who wished to move from attached to detached housing were keen to retain a new urbanist lifestyle and would accept living on smaller blocks if that lifestyle could be maintained. Nevertheless, the net effect on urban density of developments such as Cornell might be much less than crude measures of gross density suggest.

4. Towards integrated concepts and assessment

4.1 Integrated concepts

The need for at least a Factor 4 improvement in resource productivity, doubling wealth whilst halving resource use, has been highlighted by authors such as von Weizsacker et al. (1998). In addition, the UN (ESCAP 2006), the Wuppertal Institute (Rithoff et al. 2002) and the WBCSD (2000) have promoted the concepts of eco or resource efficiency. As discussed at the aforementioned UN meeting on sustainable infrastructure development (ESCAP 2007), eco-efficient and sustainable infrastructure systems should, among other objectives, deliver economically viable goods and services, be financially viable, be socially inclusive, and minimize resource use and ecological impacts throughout the life cycle.

To date, however, a strong link has not been made between 'eco-efficiency' and related 'efficiency' concepts in the economic field. The economic concept of allocative efficiency, or doing the right things, aligns closely with the preferences of urban dwellers that receive the attention of social planners. On the other hand, the concept of productive efficiency, or doing things right, is closely related to resource efficiency.

Thus, the notion of providing more services with less resource use, less environmental impact and less cost may be expressed in economic, social and environmental terms, namely: more services and outcomes that people prefer/want/need, with improved/best use of all resources (land, materials, energy and water, labour, capital), leading to reduced negative, and increased positive economic, social and environmental impacts.

4.2 Integrated assessment

The challenge here is to develop a framework tool that is capable of assessing sustainability using reliable and widely accepted measures across a broad spectrum ranging from physical inputs of concrete, steel and energy, through environmental factors such as water quality, biodiversity and habitat protection to social cohesion, service delivery, quality of life, and the preferences of residents and the community.

The UK government's sustainability indicators suite provides one such attempt. Developmental work on formal techniques of Sustainability Appraisal and Integrated Assessment also provide useful starting points. There remains a significant intellectual challenge, in both identifying the key indicators and building a robust framework tool which, crucially, includes suitable trade offs between social, economic and environmental factors.

A model that seeks to assess new urban developments in terms of their capacity to reduce consumption of material resources and energy without having differential impacts on the sustainability of communities should, at a minimum, incorporate a mechanism to assess consumer preferences in terms of housing (e.g. style and location) and mode of transport and hence relative demand. A mechanism is required that has the capacity to unpack the housing and other preferences of residents and the implications of these preferences for the nature and sustainability of the local communities that will form around new developments. The mechanism might be integrated with tools to measure resource efficiency so that an assessment of the relative environmental impacts can be considered in relation to the social sustainability of new developments and with economic measures to evaluate economic allocative efficiency as well.

Resource efficiency can be measured in terms of Material Input Per Service unit (MIPS or MI/S), a concept developed by Schmidt-Bleek (1993) that has a strong relationship to Factor 4. The reciprocal of MIPS (i.e. S/MI) is known as 'resource productivity'. Although the MIPS concept has been mainly applied to measuring resource efficiency at a product or company level it is, potentially, a very useful indicator of the relative resource efficiency of various patterns of infrastructure development (Ritthoff et al. 2002).

Wallbaum and Buerkin (2003) have noted that resource efficiency is only one important path towards sustainability. In the broader context of sustainable development there are also economic targets, environmental targets and social targets (e.g. employee satisfaction over low unemployment rate, overall stability in society) that have to be addressed.

Consideration could be given to extending the MIPS concept to include not only material input, but also social, environmental and economic outputs per unit of service. Thus, it may be possible to assess various configurations of infrastructure and associated urban development not only in terms of their ability to meet service demands with greater resource efficiency and with recognition to the key issues of public acceptability and social performance. Thus, urban areas may be sustainable and efficient in terms of 'allocative efficiency' and 'productive efficiency', including resource efficiency.

5. Exploration and application of theoretical concepts using a case study

5.1 Aims

Our aim is to examine the intersections between environmental, social and economic sustainability, and how these may influence forms of urban development and infrastructure provision, through a case study of an urban centre near Adelaide. The study of single exemplars has been rigorously supported by Flyvberg (2004) as a valid approach for undertaking qualitative research.

The study comprises the first phase of a proposed longer-term research programme, leading to the development of an integrated model for the assessment of urban sustainability, aimed at the level of new urban Master Planned communities.

TODs and similar developments are normally considered in terms of integrating land use and transport (Cervero 2005). This study and research seeks to extend the analysis, considering the inter-relationship of various forms of 'economic' infrastructure systems and services, including transport, energy, water, and the 'social' infrastructure of affordable housing, education, health and welfare.

The study/research seeks to answer questions including the following:

- How do compact, dense and 'urbanised' patterns of infrastructure development (including TODs) perform in terms of cost, resource efficiency and allocative efficiency, compared with more dispersed 'suburbanised' patterns?
- Can they deliver community well being and social sustainability in comparison with dispersed 'suburbanised' developments?
- How can we assess the relative social, economic and environmental impact of urbanised and suburbanised developments?

5.2 Noarlunga regional centre

This regional centre (see Figure 1) is projected to grow significantly in future, in accordance with South Australia's population policy (Department of Premier and Cabinet 2004).

However, this needs to occur in much more environmentally sustainable manner, with more efficient use of resources e.g. water, energy, land and materials plus less emissions and waste. In addition, the pattern of development must recognise social preferences and address housing affordability. Land within the area is poorly utilised at present, and includes a shopping centre with extensive car parking, underutilised government land, a transport interchange, and disconnected facilities such as a hospital, technical and further education centre (TAFE), technical college, public high school and private school, sports centre, cinema, offices, and police station and courthouse.

At present, the centre is surrounded by low density public and private housing, with no residences within the centre itself. In this regard, the SA Government and the local council envisage that the centre should accommodate 6000 residents by 2050, adding to its current 7000 working population.

In terms of its demographic characteristics, 30 per cent of the existing households in the vicinity are single parent, with relatively low incomes and declining affordability of houses. Car ownership is low compared with other parts of South Australia, with 50 per cent of residents having none or one car. The aged proportion of the population is increasing.

Figure 1 Noarlunga Regional Centre

The government/council vision for the Noarlunga Centre is of a vibrant, dense community focused on the transit interchange and with connected and integrated land uses. Housing densities of up to 40-50 dwellings per hectare are envisaged, with at least 15 per cent of housing being 'affordable housing', including 5 per cent 'high needs'. At least 12.5 per cent open space is required as part of new development. The area has targets for water conservation and reuse, for reducing emissions (the state target being to reduce emissions by 60 per cent by 2050), for reducing its ecological footprint (by 30 per cent by 2050) and for biodiversity.

5.3 Possible scenarios: complementarities and contradictions

The area is currently the subject of a consultant study, with the aim of developing a 'structure plan' and guidelines to accelerate transit-oriented urban development'. Whilst this study is yet to be completed, it is clear that a residential population of over 5000 can be accommodated within the centre confines, at densities ranging from 30 to 55 dwellings per hectare and with a choice of housing types. Lower densities are likely to be more affordable.

A market study by the consultants indicated that residents for higher density forms of housing would need to be attracted from outside the area. However, this could be viable, given the present scarcity of this form of housing in the southern part of Adelaide and the availability of shopping, government services and retail development.

One option is for higher density residential development to be clustered around the transport nodes, including the interchange, surrounded by the lower density development. Currently dispersed car parking could be consolidated into compact, multi-deck structures, enabling the land to be used more efficiently e.g. urbanised built form of several stories could be constructed along new shopping streets, with retail at street level and offices and residential uses above.

However, whilst there may be savings in energy, materials and cost deriving from higher densities, this may imply problems of privacy, access to open space or excessive levels of noise in the urban environment leading to social stress.

In the Noarlunga example, the land adjacent the transport nodes and with increased access to services is likely to be more expensive. This poses a problem for the 50 per cent of the current population in the area who have access to one or no car, or who are single parent households, many of whom are struggling to pay their rent or mortgages. Similarly, the aged and infirm, who require access to services and transport, will need to be located at or near ground level – otherwise lifts will be required which will detract from the affordability of housing for the aged, low income population. Such contradications represent 'weak sustainability' and will require tradeoffs.

On the other hand, there are examples of possible complementarities and synergies that represent 'strong sustainability' ('win-win' situations). Various government services will need to expand to meet projected population growth, and facilities could be shared and co-located, leading not only to improved services but also to reduced ecological footprint and emissions. For example, educational services (e.g. high school, technical and further education) could share additional teaching space, accompanied by more efficient use of existing facilities through connectivity. Community health care, with general practitioners and health promotion, could be co-located with family and community support services related to housing, disability, financial support/advice and the like, all in close proximity to transport, retail and commercial hubs. Similarly, landscaped open space penetrating the centre may be used for water detention and treatment, recreation, walking and cycling routes, food cultivation, and promotion of biodiversity. Thus, application of 'systems thinking' enables connections and synergies between various elements of the urban system to be explored and optimised, resulting in provision of more services but in a resource efficient manner.

The above case study of the Noarlunga Regional Centre has revealed that, while some examples of strong sustainability can be identified, others represent 'weak sustainability' and will require tradeoffs between economic, social and environmental factors.

6. Application to urban areas in developing countries

It is incumbent on developed nations such as Australia to demonstrate how urban areas may grow in an environmentally sustainable manner and, at the same time, address social disadvantage and differing cultural and other preferences. This could require major shifts in western patterns of consumption of scarce resources and forms of urban development.

Whilst the Australian case study context is vastly different from urban areas in developing countries, it is expected that the broad principles and methodology for integrated sustainability assessment will be transferable, with appropriate adaptation to particular cultural and other circumstances. The methodology will require testing in a developing country urban context, after the model has been constructed, with comparisons to Australian applications and findings.

7. Closing remarks

This 'concept paper' has indicated a direction towards urban sustainability, integrating the economic, environmental and social dimensions and recognising the intersections and tensions. Decisions on urban sustainability will usually require tradeoffs.

It has also highlighted the relationship between allocative efficiency and social preferences, and between productive efficiency and resource efficiency.

Whilst compact, more dense forms of urban development such as TODs may be more resource efficient, this will need to be balanced against possible disadvantages in terms of allocative efficiency. The achievement of overall sustainability, balancing the economic, environmental and social dimensions, is a complex process that may have been over-simplified in the past. This requires a multi-disciplinary team approach such as represented by the authors of this paper.

The findings are indicative only, and more in depth research is required to develop the integrated model and to test this in practice using Noarlunga and other 'small area' case studies.

Whilst based on an Australian case study, the methodology we are developing is intended to be broadly applicable in different cultural settings, with appropriate adaptation.

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THE SUSTAINABLE BUILDING ASSESSMENT TOOL: INTEGRATING SUSTAINABILITY INTO CURRENT DESIGN AND BUILDING PROCESSES

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Summary

The Sustainable Building Assessment Tool (SBAT) was developed to ascertain the performance of buildings in terms of their contribution to sustainable development. In particular, the tool focuses on a developing country context and includes social and economic criteria as well as environmental indicators. The paper reviews definitions of sustainable development and current measures of global and national sustainability performance and compares this to criteria used in the SBAT. It shows that the SBAT is reasonably well aligned with these definitions and measures and identifies a number of areas where alignment could be improved.

The paper suggests that the tool is reflects progress within the wider field of sustainability performance measurement. Here, environmental sustainability performance measurement is now well defined and can be ascertained in objective and detailed ways through ecological footprints and carbon emissions measurement and calculations. Social and economic sustainability measurement however is still difficult to measure and there are a range of competing systems such as the Human Development Index (HDI) and the Genuine Progress Indicator (GPI).

While there is no general consensus and appropriate measurement system for social and economic sustainability at global or national scale it will be difficult to finalize these aspects in assessment tools that aim to measure sustainability in buildings. The paper argues however that this should not be an excuse to leave out social and economic indicators in building sustainability assessment tools. It suggests instead that these criteria are important and should be developed, particularly in developing countries, as buildings and construction can make substantial contributions to local economic and social sustainable development.

1. Sustainable Development

What is sustainable development? There are many definitions of sustainable development. These generally describe a 'state' to be aspired to, and a recommended route to this. This state is defined in terms of its ability 'to maintain services and quality of natural resources', 'to live within carrying capacities of supporting ecosystems', 'to meet future generations needs and aspirations'. The recommended route to this state in these definitions expresses a concern about current populations and aims to ensure that 'current needs' are met, and the 'net benefits of economic benefit are maximised' and the 'quality of human life is improved'. Examples of definitions that reflect this are outlined below.

…development that meets the needs of current generations without compromising the ability of future generations to meet their needs and aspirations. (World Commission on the Environment and Development 1987)

…maximising the net benefits of economic development, subject to maintaining the services and quality of natural resources over time. (Pearce and Turner 1990)

…. development that improves the quality of human life while living within the carrying capacity of supporting ecosystems. (International Union for Conservation of Nature 1991)

These definitions focus on what Wackernagel and Yount call the "socio-economic" and "ecological imperatives" of sustainability (Wackernagel et al, 2000). Measuring progress towards sustainability therefore requires accounting tools that measure progress in terms of the socio-economic and ecological imperatives. Two well known tools for measuring progress in these areas are the Human Development Index (socio-economic) and Ecological Footprints (ecological)

1.1 The Human Development Index

The Human Development Index was developed as an alternative to economic progress indicators and aimed to provide a broader measure that defined human development as a process of enlarging people's choices and enhancing human capabilities. The measure is based on

- A long healthy life, measured by life expectancy at birth

- Knowledge, measured by the adult literacy rate and combined primary, secondary, and tertiary gross enrolment ratio
- A decent standard of living, as measure by the GDP per capital in purchasing power parity (PPP) in terms of US dollars

1.2 Ecological Footprint

An Ecological Footprint is an estimate of the amount of biologically productive land and sea required to provide the resources a human population consumes and absorb the corresponding waste. These estimates are based on consumption and production of waste in the following areas:

- Food, measured in type and amount of food consumed
- Shelter, measured in size, utilization and energy consumption
- Mobility, measured in type of transport used and distances traveled
- Goods, measured in type and quantity consumed
- Services, measured in type and quantity consumed

Figures from these measures have been combined in graph developed by the World Wildlife Fund (WWF), shown below. This shows that countries in Europe and North America tend to have very high ecological footprints and acceptable human development indexes (above 0.8), while countries in Asia and Africa tend to have unacceptably low human development indexes (below 0.8) but have ecological footprints within the biosphere's average capacity per person.

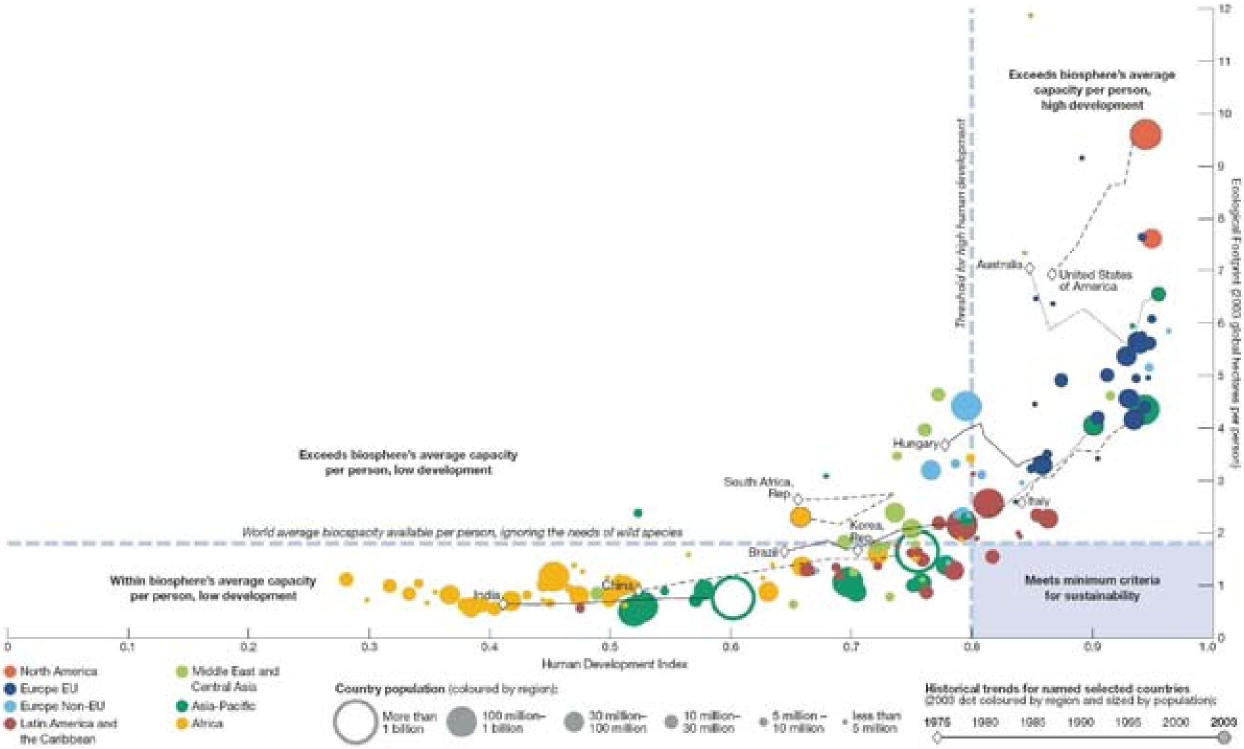


Figure 1 Human development and ecological footprints 2003 (from the Living Planet Report)

The figure is interesting in that it suggest that only one country (in Latin America and the Caribbean) meets the minimum criteria for sustainability. The clustering of countries from Latin America and the Caribbean (brown dots) around the minimum sustainability criteria for sustainability box suggests that these countries have development models that should be emulated.

2. Implications for buildings

The definitions of sustainable development described above have implications for the planning, design and management of the built environment. In particular, they suggest that the built environment should contribute to the socio-economic and ecological imperatives of sustainability. Assessment systems designed to measure a building's performance in terms of sustainability therefore must measure performance in terms of the extent to which a building contributes to these socio-economic and ecological imperatives.

Most building environmental impact assessments have focused on the shelter and, to a less extent, the mobility aspects described above. The Sustainable Building Assessment Tool has had a broader focus and aims to capture social and economic impacts of the built environment

3. The Sustainable Building Assessment Tool

The Sustainable Building Assessment Tool (SBAT) measures sustainability performance in the built environment against 15 social, economic and environmental criteria, as outlined below.

3. 1 Social

- SO1: Occupant comfort
- SO2: Inclusive environments
- SO3: Access to facilities
- S04: Participation and control
- S05: Education, health and safety

Economic

- EC1: Local economy
- EC2: Efficiency
- EC3: Adaptability
- EC4: Ongoing costs
- EC5: Capital costs

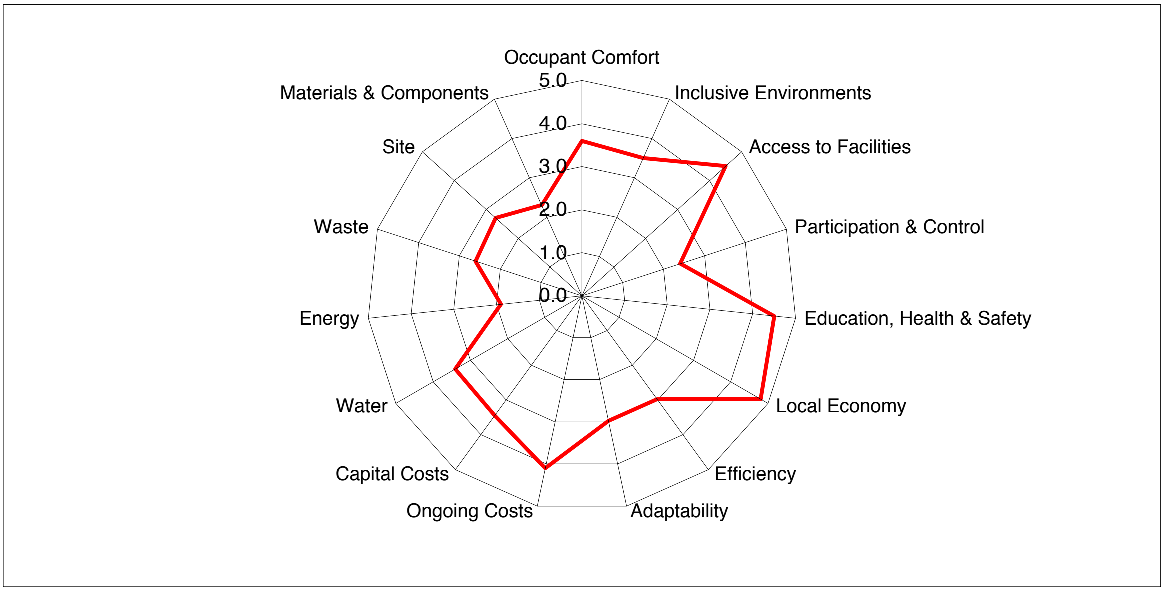
Environmental

- EN1: Water
- EN2: Energy
- EN3: Waste
- EN4: Site
- EN5: Materials and components

Performance in each of these areas is measured out of 5 and presented on a radar diagram, see below. This enables performance in the different areas to be 'read' quickly and the 'balance' of the approach between social, economic and environmental performance to be ascertained.

SUSTAINABLE BUILDING ASSESSMENT TOOL (SBAT- P) V1

PROJECT	ASSESSMENT	
Project title:	Date:	
Location:	Undertaken by:	
Building type:	Company / organisation:	
Internal area (m2):	Telephone:	Fax:
Number of users:	Email:	



Social	3.7	Economic	3.7	Environmental	2.6
Overall	3.3	Classification	GOOD		

Figure 2 SBAT report

SBAT criteria were developed through a process of describing, and understanding, buildings in terms of their relationship to social, economic and environmental systems Gibberd (2001). Different environmental and economic and social systems have different levels of sustainability and the approach used to develop the

SBAT aimed to assess not only the performance of buildings in terms of sustainability but also assess the extent of the building's contribution to supporting and developing more sustainable systems around it.

This aspect can be illustrated through the example of the **Local Economy** set of criteria in the Tool. This suggests that a strong and diversified local economy is important for sustainability. A local emphasis supports sustainability in a very simple way by reducing the need for transportation and therefore limits the consumption of non-renewable resources and pollution. A more subtle aspect of this concept is the way it draws on the connections between people and their environments. The local emphasis encourages people to adopt more sustainable practices by ensuring that people experience, and suffer the negative consequences of their actions (Ekins 1992). Buildings can also have a positive impact on the economy of an area by being designed, constructed and managed to stimulate, and support, a local, diversified economy and create local employment. In order to establish the extent and type of impact a building makes on the local economy the SBAT uses the following measures.

- **Local Contractors:** The extent to which local contractors and labour is used to construct the building
- **Local Building Material Supply**: the extent to which local materials is used in the building
- **Local Components, Fittings and Furniture:** The extent to which local components, fittings and furniture are used for the building
- **Small Business Support:** The extent to which small business such as contractors, manufacturers or retailers are supported through the construction process (i.e. through construction and business administration training) or in the completed building (i.e. through outsourcing, low or no cost access to space and facilities).
- **Maintenance:** The extent to which the building and its system is maintained locally.

4. Discussion

A review of sustainable development definitions and measures raise a number of questions for the development of tools that aim to measure sustainability performance in the built environment. These questions include:

A. Does the sustainable building assessment tool measure aspects related to human development or quality of life (as measured for instance by the Human Development Index)?
B. Does the tool measure the key factors related carrying capacity and ecological footprint?
C. What should be the balance of weighting **between** 'human development' measures and 'ecological foot print' criteria?
D. What should be the balance of weighting **within** the 'human development' and 'ecological footprint criteria'?

Applying the first two questions to the SBAT reveals a number of interesting findings. It shows that for each of the Human Development Index (HDI) criteria there, there are at least two relevant SBAT criteria. The SBAT criteria however are not directly related to the HDI criteria. Where the built environment was being used as mechanism to support human development, it could be argued that these measures should be more closely aligned. For instance, SBAT criteria could measure the labour intensity of building operation as well as labour intensity in construction (measured as person years of employment created per R million construction costs) and check that remuneration provided enabled a reasonable quality of life in terms of Purchasing Power Parity (PPP). The HDI measures with relevant SBAT criteria are shown.

Table 1 Alignment between HDI measures and SBAT criteria

HDI sustainability measure	**SBAT criteria**
A long and healthy life	SO1, SO5
Knowledge	SO3, SO4
A decent standard of living	EC1, SO3

Checking alignment of SBAT criteria with Ecological Footprint measures reveals an expected strong alignment for the Shelter measure. It also reveals weak alignment with the Services measure and no alignment with the Food measure, as indicated below.

Table 2 Alignment between Ecological Footprint measures and SBAT critiera

Ecological foot print Sustainability measure	**SBAT criteria**
Food	
Shelter	EN1, EN2, EN5 EN4, EN5, EC3, EC4, EC5
Mobility	EN2, SO3, EC3
Goods	EC1, EC2, EN5
Services	EC

The weak alignment for the Food and Services criteria is a result of the SBAT's focus on design rather than operational issues. To strengthen alignment there should be a stronger emphasis on operational issues. Specifically, criteria on the availability of 'low ecological footprint food' such as vegetarian meals in buildings as well as criteria that aim to minimize the ecological footprint of goods consumed and services used in buildings should be included.

The SBAT addresses the problem of weighting (Question C) by encouraging a responsive approach in which environmental, social and economic performance targets of the building relate to the building type, the owner of the building and the local context in terms local needs and opportunities. The Sustainable Building Lifecycle (SBL), the process by which the SBAT is used to integrate sustainability into buildings therefore recommends that background research is carried out of the local area at an early stage of the development of the building in order to ensure that this informs the development of the building. Thus, if this research revealed that there was high unemployment and an unreliable water supply in the area, targets within the Local economy and Water SBAT criteria should be challenging. This process can work well, for instance in the Thuba Makote project, however in many cases owners and professional teams are not willing to make the required investment in time to carry out these early studies and do not see local economic and social impact as part of their remit (Gibberd 2005).

The weighting of indicators within the social, economic and environment relate to the 'internal' performance and impact of buildings. The review (Question D) suggests that perhaps the weighting should reflect the balance found in the human development index and ecological footprint measures. Thus the weighting distributed to 'health', 'knowledge' and 'standard of living' in the Human Development Index should be reflected in the weighting of indicators supporting these measures in the SBAT.

5. Recommendations

Assessment tools that measure sustainability performance of buildings need to be aligned more closely to internationally accepted sustainability performance measures such as the Human Development Index and Ecological footprint. In order to do this the design and development of assessment tools should aim to incorporate the following issues:

- **Context responsive:** The design of tools and procedures used to apply assessment should take into account the local context. Where the ecological footprint of the country is well above 2 global hectares per person, the tool should have a strong weighting on criteria that measure environment impact. If however, the human development index of the country is well below 0.8 there should be a strong weighting on social and economic criteria in buildings that support human development.
- **Building-human interface**: An understanding of how the built environment can influence and structure human behavior should inform the design of assessment tools. For instance, easy access to 'low ecological' footprint food such as vegetarian meals and to facilities that support education and health could play a significant role in supporting sustainable development and should be included as measured criteria.
- **Operational issues:** Design of assessment tools should have a strong focus on operational issues. In particular, criteria measuring the ongoing contribution of buildings to human development and to reducing ecological footprints should be set and measured.

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STUDY ON DYNAMIC EVALUATION SYSTEM OF GREEN-EFFICIENCY OF RURAL COMMUNITIES IN CHINA

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Keywords: rural green community; green-efficiency; evaluation; system dynamics; simulation

Summary

The traditional high-energy approach of community construction and operation has resulted in serious problems in fields of economy, environment and society. The purpose of this paper is to discuss a new way to evaluate green-efficiency of rural community construction and operation by system dynamics. The approach followed in the paper is a comparative study on characteristics between rural and urban community, and dynamic feedback loops and quantitative relationships in rural community, extended by a case study. Findings are that ecological environment is still fragile in rural community though the initial environment is excellent, and emissions of domestic sewage and refuse is the most important environmental issue, also, the value of green-efficiency of rural community should maintain at a certain level instead of a initial one. Further research should concentrate on the detailed analysis of factors. Practical implications are an increased embedding of system dynamics in rural community development. The originality of the paper lies in its focus and discussion of a new approach of green-efficiency assessment.

1. Introduction

1.1 Development and Problems of Green Community and Rural Community

Human society, developing from the hunting civilization to the agricultural civilization, then to the industrial civilization, has accumulated a great deal of wealth and a highly developed spirit and culture. On the other hand, the rapid economic development with growing world's population and accelerating urbanization process, especially in the industrial civilization drives more people to settle down in community which speeds up the process of urbanization in the end. It leads to (1) high density of human settlement, pollution of domestic refuses and sewage, emissions from large industrial enterprises in terms of various pollutants and serious damage to the environment and ecosystem eventually; (2) that management of sewage treatment and the facilities in city are lagged behind compared to the rapid increase of urban population when people swarm into cities who are lack of attribution to the city identity and often damage the urban environment and ecosystem; (3) and that family structure, educational background, cultural qualities, living habits, nature of the work and the economic situation for the people living in cities are totally changed, which inevitably results in imbalances and conflicts. And in China, nearly half of the 1.3 billion people are still living in rural communities and the construction and operation in rural areas should not be taken the pattern as that of the old days. How to build rural green communities and improve the living environment and conditions of farmers becomes one of the major problems in the community construction in China.

In recent years, the implementation of sustainable development of communities has been the focus all over the world. Green Community, also known as sustainable community or ecological community, refers to the community which has the facilities meeting the requirements of environmental protection and establishes and maintains long-term community environmental management system and public participation in environmental protection mechanism. (State Environmental Protection Administration of China 2005). Western scholars propose that Green Community, as a non-profit, community-based organization, functions to advocate environmental actions, changes environmental activities, and promotes green products and green services. Each Green Community has its own board of directors, budget and professionals. Furthermore, Green Community construction has become an important and effective form for the strategy of sustainable development and environmental protection in western countries (Li Jiusheng *et al*. 2003). The contents of Green Community basically relates to three themes: firstly, reducing the load and passive impact onto the resources and environment; secondly, creating a healthy and comfortable living environment; thirdly, promoting the renewal of the existing patterns to live, produce and consume according to the natural environment (Zhang Linying *et al.* 2006). The goal for building urban Green Community is to strengthen the functions of community as the human survival and development base by enhancing the community's self-organization, self-regulation and self-control ability to use material, energy and information rationally and efficiently and improving the environmental standards of life quality to fully adapt to the social development needs, so as to ultimately create the optimal residential place for human beings that fully integrates technology and natural environment from both the aspects of natural ecology and social psychology (Shi Wenxin *et al.* 2002).

Rural Community is the regional social life community consisting of farmers mainly engaging in agricultural activities. With the overall environmental changes, Rural Community has been put forward in the direction of "quasi-city", which forces us to consider the carrying capacity of environment while exploring the economic development in communities. Through systematic observing and analyzing, we can form the inner function of Rural Community by five aspects namely, community land utilization, community life characteristics, community environmental resources, community culture and community tourism, and deduce the dialectical functional relationship based on sustainable development model (Weng Zhengkai *et al.* 2007).

1.2 Evaluation of Green-efficiency of Community

Green-efficiency analysis, also called eco-efficiency analysis, emerges as a valuable tool towards the target of sustainable development. The World Business Council for Sustainable Development defined that "Eco-efficiency is reached by the delivery of competitively priced goods and services that satisfy human needs and bring life quality, while progressively reducing the impacts to environment and resource intensity throughout the life cycle to a level at least in line with the earth's estimated carrying capacity" (NRTEE 2001; E. Syrrakou 2006). Since its original academic development, the approach has been refined during the last decade and applied to a multitude of projects (Andreas Kicherer *et al.* 2008) and there are some new approaches (Landsiedel R. *et al.* 2002; Zhongsheng Hua *et al.* 2007; J. Quariguasi Frota Neto *et al.* 2008; Pil-Ju Park *et al.* 2008).

In the field of evaluation of green-efficiency of community, eco-efficiency and industrial symbiosis method have been used to analyze the development of a mining community (Olli Salmi 2007). In the business community, people pay more attention to promote sustainable consumption in the way of improving eco-efficiency (L. Michaelis 2003), and the Model Sustainable Agricultural Complex (MSAC) is applied in experimental farm to monitor and manage resource efficiency so as to promote long-term environmental improvement (Charles C. Reith 2003). Several testing criteria of Green Community have been put forward in the mid-1990s in China, including "National commendation and assessment criteria for the Green Community (2005)" by State Environmental Protection Administration and various local criteria, such as Commendation and assessment criteria for the Green Community in Hubei province, which is calculated by scores to promote the construction and development of urban green communities. However, the construction standards of Green Community do not reach a complete and accurate conclusion and China's Ministry of Construction and Housing Industry Promotion Centre in 2001 introduced "Construction key points and technical guidelines for Green Community (for trial implementation) ", giving nine subsystems proposed to design indexes of energy, water, gas, sound, light, heat, virescence, waste treatment and management of green construction materials, and offered as the technical criteria to help China's development of green eco-community system. So far, this guideline is still the only official, authoritative and comprehensive technology index system to guide construction of green communities (Zhang Linying *et al.* 2006).

At the same time, assessment criteria for rural green communities are not involved, and evaluation criteria classified by scores is not fit for rural Green Community which has its own characteristics.

1.3 Evaluation of Green-efficiency of Rural Community with a System Dynamics Approach

The construction of rural Green community is affected by many factors related to social, economic, environmental factors and local development level of technology and so on. These factors are complicated, involving not only the Green Community itself, but also affecting the external environment. The combined effects of various elements will influence the effectiveness of Green Community construction in the end. There will be a large number of unpredictable factors during the construction of Green Community, the interaction of these factors leads to different results, which may be far from that of comparing with these factors alone and ultimately affect projects' objectives. It is precisely because the characteristics of complex nonlinear and feedback loops in community construction, the evaluation of green-efficiency of community can not be decided by scores or linear indexes simply. Therefore, we introduce system dynamics methodology to evaluate the green-efficiency of rural community in order to solve the complex and dynamics in the process of rural community construction (Wang Yang *et al*. 2007).

2. Dynamic Evaluation System Model of Green-efficiency of Rural Community

2.1 Subsystems of Rural Green Community and Their Interaction

There are two basic sources of the dynamics that impinge upon a project system: planned activities and uncertainties. Planned activities, namely attended dynamic, include established operational programmes, arranged daily duties and planned material and plant operations and so on. These activities are designed to initiate the progress of construction while the characteristics of unattended dynamics are represented by unexpected events or uncertainties causing changes to a project system which potentially affect the overall performance of the system (P.E.D. Lovea *et al.* 2002). Within each subsystem, the internal factors will change as time changes and these changes call for the policy-makers of projects to make quick and effective responses. Such responses should be appropriate, strategy adjusted to achieve the original targets by reducing the loss of the unpredictable events. Generally speaking, these factors will have either positive correlation or negative correlation effects on the target system as a whole. For those leading to the strengthening influences onto the system, we call as positive correlation effects and negative correlation effects for dwindling influences. Figure 1 below shows the project dynamic system (P.E.D. Lovea *et al.* 2002). Taking the project as a system, apart from its own changes after the influence, the impact of changes in system 1 will be transmitted to the system 2, which will affect both of the two systems eventually. Furthermore, the impact of changes in system 2 will be transmitted to system i in turn and such cycle.

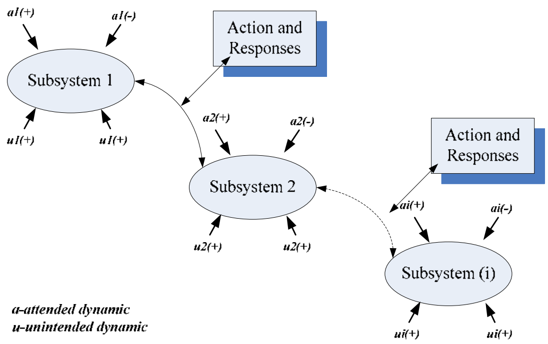

Figure 1 Dynamics of the project management system

Turning our focuses onto the Green Community, from the viewpoint of system theory, rural green community can also be divided into several sub-systems, such as economic, social, environmental and construction systems. These subsystems are relatively independent on each other while each evolves according to its own characteristics. And relative factors known and unknown affect the changes and development. Meanwhile, there are various interactions among the subsystems, as the changes in a subsystem may influence the others and bring the impacts like the domino effect.

2.2 Analysis of Feedback Loops of Dynamic Evaluation System of Green Rural Community

Compared with the green urban community, the green rural community in China has its own characteristics.

Firstly, in regard to the environment, the green rural community maintains a good condition compared with that of urban areas. The green rural community has better environmental capacity, better recoverability of environment and the pollution index is relatively low because it rarely or little, if ever, involves industrial production with damages to the environment at a lower level.

Secondly, compared with the urban green community, the economic structure of rural Green Community is still underdeveloped and the economic level relatively low as the income sources of rural households mainly rely on family-based farming and aquaculture. Housing is not only for the residential life but also for the production and the economic conditions form a strong contrast between rural community and urban community. Therefore, a common kind of farm tourism that people living in cities go to the rural communities for tourism and relax has been developed for the past decades. And this phenomenon becomes more and more popular and such kind of tourism takes an important part in the economic system of rural community.

Finally, after a relatively long period of growth of population in rural communities, the increase and decrease of it are close to a balance, which causes the population in rural community now to be in a stable way. So we can suppose that the increase of housing area is nearly all because of the growing tourism demands.

As the above-mentioned characteristics, we suppose that construction and operational system of rural community in China consists of three reinforcing feedback causal loops and another three balancing feedback causal loops as shown in Figure 2.

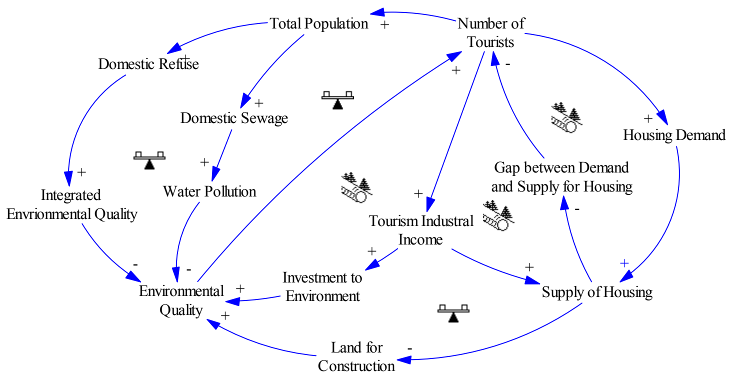

Figure 2 Feedback loop diagram of green rural community construction and operational system

There is the interaction between environmental subsystem and economic subsystem. With the development of tourism in rural community, the incomes from tourism industry increase which leads the increase of the investment to environment. The related facilities for domestic refuse classification, transportation and treatment, and establishment of domestic sewage will be built to improve the environmental quality in rural community eventually, so that the community becomes more attractive to tourists. This reinforcing feedback causal loop is shown in Figure 3 (the left one).

The middle one in Figure 3 is for the interaction between economic subsystem and construction subsystem As the number of tourists increases while the population in local community is relatively stable, the housing demands from tourism industry will increases which will lead to the increase of supply of housing by greater numbers of housing construction. Then the gap between the demand and supply will be narrowed which pushes on the increase of tourists as shown in Figure 3 (the middle one).

And the right one in Figure 3 is also for the interaction between economic subsystem and construction subsystem. The increase of tourists drives the increase of income from the tourism industry and new housing construction as well, and the gap between housing demand and supply is releasing, also leading to the growth of tourists. These three causal loops are shown the reinforcing strength to the entire construction and operational system of rural Green Community.

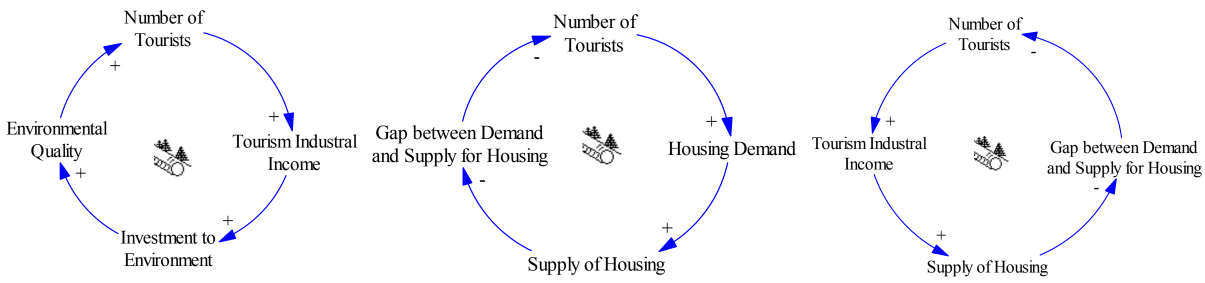

Figure 3 Diagram of reinforcing feedback causal loops in the green rural community construction and operational system

There is not only reinforcing feedback causal loops but also balancing ones in the construction and operational system of rural Green Community, shown in Figure 4. Some tangible limits in the model causes the feedback loops balancing and they were what we now call "environmental": limited natural resources, limited agricultural land, limited pollution absorption (Jorgen Randers 2000). The growth of tourists pushes up the demand and actual increase of new housing construction, which leads to decrease of land for construction and the environmental carrying capability. And the environmental deterioration will relatively restrain the growth of tourists because the environment then is out of attractiveness, the dynamics as shown in Figure 4 (the left one). The increase of number of tourists which are part of the total population in the community, given that the per capita of domestic sewage and refuse is constant, will increase the domestic sewage and refuse in the community and the environmental quality gets worse which inhibits the growth of tourists, as shown in Figure 4 (the middle and right one in respective). And these latter two dynamics is the most significant environmental menace in the rural communities.

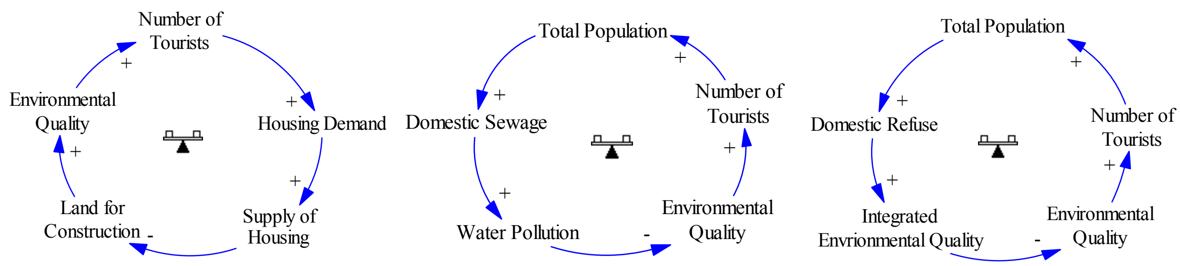

Figure 4 Diagram of balancing feedback loops in the green rural community construction and operational system

3. Modeling and Case Study

3.1 Assumptions

There is certainly a certain distance between the reality and the mathematical model of the construction and operational system of rural Green Community, which should include systematic timing delay and other factors which cannot be quantified. And for easy analysis, we put forward the modeling assumptions as follows:

(1) Not every rural community has developed an economic part of tourism, but in view of its popularization and good trends in China, we assume that there is tourism development in the model.

(2) We suppose that the environmental impact onto travel time stays can be shown immediately, that is to say, the travel time could be decided to prolong or shorten without difficulties during the trip. Meanwhile, the average consumption of tourist is a constant neglecting the effect of environmental impact.

(3) There are of course, various factors affecting the quality of rural community and in this model we only choose the domestic refuse and sewage which is the most representative and sensitive kind with the stock at the very beginning is set to be zero.

(4) Disposable income is largely from the industry or tourism and it is assumed in the model that the income of farmers from scattered farming and production is just to meet their needs and the tourism income is all of the disposable income we will calculate for the growth in rural community at this stage.

3.2 Case Introduction

Yanhe Village is located in the north of Hubei province, a typical representative of hilly type rural communities in the central China and its environmental condition is very excellent. The area of Yanhe Village is about 1.2 square kilometers and there are 222 families with 840 residents. The average income of farmers there reaches 3400 yuan per person in the year of 2005 and the total revenue of the village is about 5 million yuan. There are 440,000 m^2 of housing, and the land for construction purpose is about one square kilometers.

3.3 Simulation Analysis

3.3.1 Environmental Subsystem Simulation and Evaluation Analysis

As shown in Figure 5 below, the assumptive initial stock value of domestic sewage is zero and for the first three years, the stock of domestic sewage will peak up at a high level quickly. But after the period of approximate three years, the stock value will be slightly adjusted declining and ultimately reaches balanced at about 2200 tons while the stock of domestic refuse has been with a nonlinear increase to reach about the balance till the year 2020.

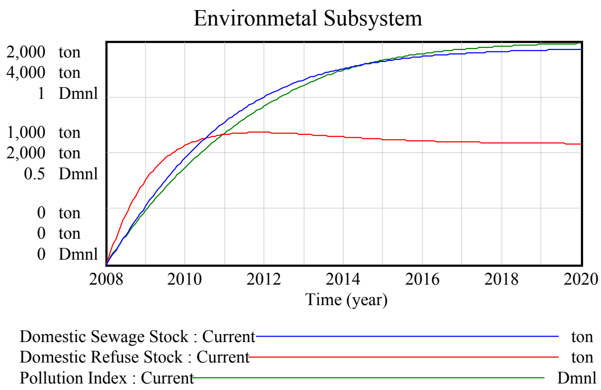

Figure 5 Simulation results of environmental subsystem

For the pollution index, we have selected the more sensitive one in rural community between domestic sewage index and refuse index as its value. That's to say, if the domestic sewage or refuse exceeds its environmental capability in the case of the worse of the environment quality, we choose the one which is greater as the value of the pollution index and there is the formula:

$$\text{Pollution Index} = \frac{\text{Max (Domestic refuse index, Domestic sewage index)}}{\text{Environmental carrying capacity} \times \text{Impact of the land area reduction}} \quad (1)$$

Of which:

$$\text{Domestic Sewage Index} = \frac{\text{Domestic Sewage Stock}}{\text{Total Population} \times \text{Per Capita Domestic Sewage Carrying Capacity}} \quad (2)$$

$$\text{Domestic Refuse Index} = \frac{\text{Domestic Refuse Stock}}{\text{Total Population} \times \text{Per Capita Domestic Refuse Carrying Capacity}} \quad (3)$$

As Figure 5 shows that the pollution index is much more related to domestic refuse index, which indicates that the emissions of domestic refuse have greater impact on the environment of community and are more sensitive. Meanwhile, the pollution index is not entirely consistent with the domestic refuse index and that's because the decrease of the community land for construction purpose mitigates the pollution so that the environmental pollution is getting worse.

3.3.2 Economic Subsystem Simulation and Evaluation Analysis

As shown in Figure 6, development of the tourism in rural community promotes the development of economy so that the disposable income of farmers can be substantially increased. After a period of about six years, the income peaks to achieve a smooth level and this is because that the environmental and housing conditions are considered to be growing in accordance with the number of tourists reaching to a certain level of balance. The model assumes that the ratios of the capital input to the treatment of domestic sewage, refuse pollution and housing construction in the community are all constants respectively. And we can see that the behaviors of capital input to the integrated environment (domestic refuse), water environment and the housing construction are as well as that of income of industry or tourism.

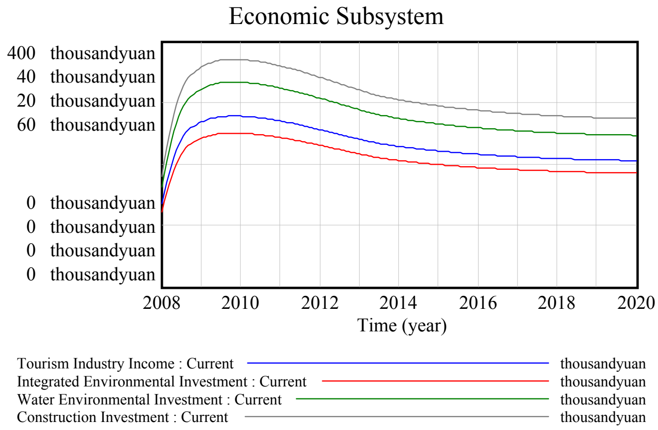

Figure 6 Simulation results of economic subsystem

3.3.3 Construction Subsystem Simulation and Evaluation Analysis

As shown in Figure 7, the construction of housing will reach a peak during the development of tourism industry in the first six or seven years and slightly downwards to a balanced level and the amount of land available for new housing construction will drop down. Conversely the area of housing in community is increasing from the original 44,000 m^2 to about 45000 m^2 and the situation is similar to the investigation we have done in the case area before.

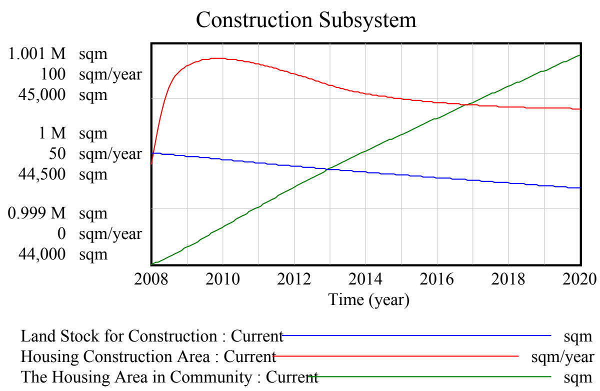

Figure 7 Performance simulation results of construction subsystem

3.3.4 Simulation and Evaluation Analysis of Green-efficiency

Green-efficiency, also the eco-efficiency as we said before, means using fewer natural resources and less environmental impact to create greater economic value (Dicksen Tanzil *et al.* 2006). In this paper, green-efficiency in the model is defined as the ratio of economic value to environmental costs as:

$$\text{Green-efficiency} = \text{Industry Income} / \text{Environmental Degradation Index} \quad (4)$$

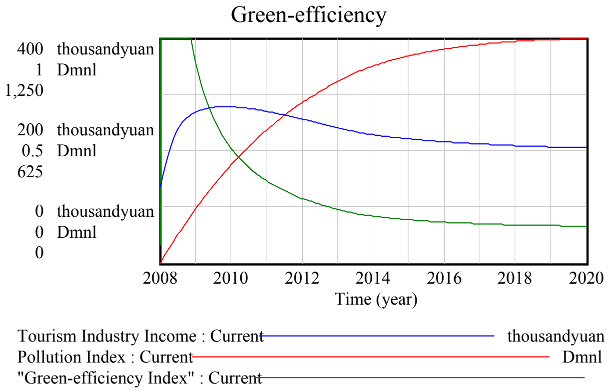

Figure 8 Simulation results of green-efficiency

As shown in Figure 8, the high development of tourism industry greatly enhances disposable income, but with the further increase of the pressure on the environment, deterioration of the environment is getting worse and green-efficiency of economy and environment is declining seriously. The deterioration of the environment doesn't reach to a balance until the industry income is stable and the trend of green-efficiency is from getting down to a balance in the end.

4. Conclusions and Following Research

(1) The ecological environment is still fragile in rural community in China, though the original condition is excellent. The solution to damage and impact from people to the environment relying solely on its own recoverability is not far from enough and financial and technological efforts are strongly needed so that part of economic inputs can monish the environmental impact.

(2) The emissions of domestic sewage and refuse in rural community in China is the most important environmental issue and we should try to change people's customs to decrease the amount of per capita emission and use technical means to reduce the impact, especially those from domestic sewage and refuse.

(3) As shown in the model, environmental degradation index is zero without development and green-efficiency is infinite, which is the idealism what we want. While in the process of development, green-efficiency is inevitably gradual declining. For a rural community in China, an area with relatively backward economic conditions, we should get the economic development at the cost of part of the quality of environment and we should consider the issue in a correct view. While eco-efficiency is certainly an important element of sustainability, it is by no means a representation of the whole picture. (Dicksen Tanzil *et al.* 2006).

We cannot ignore that kind of trade-off. Almost every step of development will bring the decline of the quality of the environment and how to make the balance between development and the quality of environment is always a worthwhile research topic. As formulated above, how to accurate the table functions from technology and fund to environment is the following issue of our research. Meanwhile, in the field of green-efficiency evaluation, how to measure and choose a proper initial value of green-efficiency may be a vital path to establish the evaluation system and method of green-efficiency to assess sustainability of economic and social development accurately and objectively.

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SUSTAINABILITY ASSESSMENT AND RATING OF PORTUGUESE BUILDINGS

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Summary

Building sustainability assessment involves various relations between built, natural and social systems. Therefore it comprises hundreds of parameters, most of them interrelated and partly contradictory. To cope with this complexity and to support the sustainable building design, a systematic, holistic and practical approach is proposed in this paper.

The main goal of this paper is to present a methodology for the sustainability assessment of new, built or renovated buildings that is adapted to the Portuguese context. This paper contributes to the evolution of generic methodology and international understanding by introducing an approach to take the traditions and social aspects into account. It is expected that the methodology to assess the weight of the social parameters will contribute for a more consensual and objective distribution of social weights. The presented methodology assesses the performance of a building within the three dimensions of the sustainable development (environment, society and economy).

1. Introduction

Construction and real estate sector affects each three dimensions (environment, societal and economy) of sustainable development. In a sustainable building, each bottom line dimension is considered as well as the interaction with its surroundings. In common, the sustainability issues cope with reducing use of non-renewable energy, materials and water as well as production of emissions, waste and pollutants. The following goals can be found in several agendas: optimization of site potential, preservation of regional and cultural identity, minimization of energy consumption, protection and conservation of water resources, use of environmentally friendly materials and products, healthy and convenient indoor climate and optimized operational and maintenance practices.

The purpose of a sustainability assessment is to gather and report information for decision-making during different phases of construction, design and use of a building. The sustainability scores or profiles based on indicators result from a process in which the relevant phenomena are identified, analyzed and valued. Following a life-cycle-analysis or performance analysis of chosen indicators, a building can be rated and certified. The benefits of rating tools are that various kinds of sustainability and performance issues can be included in the assessment criteria and their use is in common user-friendly, to the extent that self-evaluation tools are available in the Internet.

A variety of sustainability assessment tools is available on the construction market, and they are widely used as a basis for environmental product declarations. The majority of tools for building level assessment has then been developed by summing up results of building materials and components to a building. When the environmental impacts are considered, this approach can be regarded as justified as a starting point and providing that the interface issues of a system are taken into account. When an assessment includes functionalities of the whole building including energy demand, this approach has been criticised by several researches (Kohler 1997, Erlandsson & Borg 2003). There are LCA-based tools available that are especially developed to address the building as whole, like e.g. Eco-Quantum (Netherlands), EcoEffect (Sweden), ENVEST (U.K.), BEES (U.S.), ATHENA (Canada) and LCA House (Finland). A comparison of contextual and methodological aspects of tools has been made e.g. by Forsberg and Malmborg (2004).

Three major building rating and certification systems are providing the basis for the other applications throughout the world. They are Building Research Establishment Environmental Assessment Method

BREEAM, developed in U.K.; Sustainable Building Challenge Framework SBTool, developed by the collaborative work of the international initiative for Sustainable Building iiSBE; and Leadership in Energy and Environmental design LEED, developed in U.S.A.

In the Sustainable Building Tool (SBTool) the approach is to weight different criteria, considering weighting factors that are fixed at national level. Each "score" results from the comparison between the studied building and national reference. This scheme allows an international comparison of buildings from different countries. Other tools, like for instance BREEAM and LEED, are based upon credits. The maximum number of credits available for each indicator it is related to its weight in the overall score, that is expressed by a rating (e.g. from Pass to Excellent in BREEAM).

The problems of the sustainability rating tools are similar with those of the sustainability assessment methods: At first, they embrace and compromise tens of parameters which turn implementation very time consuming. Secondly, the subjective qualitative evaluation turns the reliability of the results very limited.

This paper presents a novel approach to develop building sustainability assessment and rating. The main objective of a systematic methodology is to support building design that achieves the most appropriate balance between the different sustainability dimensions, and that is at the same time practical, transparent and flexible enough to be easily adapted to different kinds of buildings and to technology. This new approach can be used in the assessment of new, built and renovated residential buildings.

2. Scope and objectives of a new Building Sustainability Assessment

The scope of the research work performed in the University of Minho, Portugal, was to develop and propose a generic methodology to assess the sustainability of existing, new and renovated buildings in the urban areas and especially in the Portuguese context. It is intended to foster the awareness of the Portuguese construction market stakeholders and to allow adequate policy implementation on sustainable construction.

The objectives of the research work were to analyze the applicability of various generic methods to actual building projects and to develop methods to incorporate the influences of local regulations, technologies and traditions to the building sustainability assessment.

As a first step, a methodology to assess the sustainability of residential buildings has been developed. Reasoning for this priority is due to the fact that most of the impacts related to the construction sector are related to the housing sector. The acronym of the methodology is MARS-H (from the Portuguese name *"Metodologia de Avaliação Relativa da Sustentabilidade de Edifícios de Habitação"*).

The following priorities were stated in the development of the MARS-H:

- List of parameters wide enough to be meaningful and to comprise the most relevant building impacts and at the same time limited enough to be practical (fifty parameters at maximum);
- Building-level assessment, based upon the state-of-the-art of methodologies and considering ongoing standardization;
- Balancing between all different dimensions of sustainable development (environment, societal and economics);
- Limitation or exclusion of subjective and/or qualitative criteria that is hard to validate (e.g. aesthetics and technical innovation);
- Improved reliability through the use of accepted LCA methods for environmental performance;
- Assessment output and certification label that is easy for building users to interpret and understand but is also one which clients and designers can work with.
- Validation of the work by the development of a prototype tool and test it on case study buildings.

As a result of the research work, the MARS-H is based in the SBTool approach and is harmonized with the CEN/TC350 draft standards "Sustainability of Construction Works – Assessment of Environmental Performance of Buildings". This methodology allows future rating and labelling of buildings, in analogy with the Energy Performance of Buildings Directive.

Although the interaction between a building and its surroundings is of importance for sustainability (e.g. energy performance, social indicators) it was decided to exclude this aspect. The main reason was that in an urban environment, the decisions concerning the surroundings and networks of a site are mostly made by the local and regional authorities. However, some publications have concluded that restricted scales of study (corresponding for a single building for example) are too limited to take into account sustainable development objectives correctly (Bussemey-Buhe, 1997).

3. Development of the Building Sustainability Assessment

3.1 General

The research and development project on the new Building Sustainability Assessment methodology was undertaken by literature survey of the state-of-the-art, development and feasibility studies of indicators and weighting factors as well as case-studies and interviews of stake-holders.

Due to the scope and objectives of the research work, the focus of the studies was in the development of weighting factors that would take into account the local environmental, socio-economic and legal reality as well as the type of building.

The system boundaries were chosen to include the building itself with all structures and the building site. The impacts of the building to the surroundings and in urban environment won't be assessed. This way, the methodology excludes construction works outside of the site location and construction of the different networks for communication, energy and transportation outside of the site location.

The time boundary should represent the whole life cycle stages of the building. In a new building it will consider all life-cycle stages, from construction to final disposal and in existing buildings the time boundary will start from the moment of the intervention to the final disposal.

After defining the methodology's time and physical boundaries the next step is to choose the categories, indicators and related parameters within the three sustainable development dimensions that are going to be used to assess the objectives of a project. According to Kurtz et al (2001) a parameters is a sign or a signal that relay a complex message, from potentially numerous sources, in a simple and useful manner. Therefore the main three objectives of the parameters are: simplification, quantification and communication (Geissler, 2001). Indicators and related parameters are the basis of the methodology, since objectives and results will be conditioned by them.

After selecting the parameters it is necessary to proceed with their quantification. Quantification means linking the environmental information to the actual designs of a building. The quantification method should be anticipated. There are several quantification methods: previous studies results, simulation and other software tools, expert's opinions, databases processing, etc. (Cherqui, 2004). At the level of the quantification of the environmental parameters, there are some aspects to overcome, mainly regarding to the availability of local data for the life-cycle inventory (LCI).

There is a growing number of voluntary Environmental Product Declarations (EPD), and their information can be used in quantification. The Environmental Product Declarations are based in the product categories rules (PCR) which established the rules for developing the environmental data and predetermined parameters for that product category, in compliance with the ISO standards ISO DIS 21930, ISO FDIS 14025 and ISO 14040. The EPD presents data that has been aggregated over the life cycle stages "Product stage", "Building stage" and "End of life stage" or relevant portions of it.

3.2 Categories, Indicators and Parameters

Figure 1 presents the categories and indicators considered in the MARS-H methodology. There are 9 categories, 35 indicators and 44 parameters. The complete list of categories, indicators and parameters can be found in the iiSBE Portugal webpage (www.iiSBEPortugal.org).

In the evaluation of the environmental performance, the commonly accepted LCA methodologies were adopted. Analysing the different LCA methodologies it was possible to observe that the number of environmental categories undertaken to access the embodied impacts of the building materials usually varies from 8 to 10. To access the embodied impacts related to the building materials, MARS-H uses the same environmental parameters declared in the Environmental Product Declarations. The list of environmental categories and environmental parameters was extended in order that, in a holistic approach, would be possible to access the other life-cycle environmental impacts related to the operation phase of the building, according to the national priorities.

In societal performance assessment, only the parameters related to the health and comfort were chosen, and they were assessed especially during the use and operation of a building. The methodology doesn't consider parameters that could raise some kind of complexity and subjectivity in the assessment, in order to facilitate its use by all Portuguese construction market's actors. The list of societal parameters presented in Figure 2 reflects the functional requirements of a residential building, according to national building codes.

The economic performance indicators were defined in order to include all costs related to building's life-cycle, from cradle to grave. This performance also considers the possibility to adapt, in the future, the building for other types of uses, factor that increases its value.

3.3 Quantification of Parameters

In order to potentiate their use, MARS-H uses the same parameters that are declared in the Environmental Product Declarations. At the moment, there are limitations with this approach due to the small number of EPD's.

Other solution is to import the results that come from the use of external LCA tools and methods (e.g. SimaPro tool and CML2 baseline 2000 method to assess the *Mid Point* impact categories and the Cumulative Energy Demand method for the embodied primary energy). One important drawback of this method is that LCA procedures are very time consuming and complex and therefore, in most times, limited to experts and academics.

The best way is to develop and use databases with the environmental data of the most used building technologies. In order to facilitate the quantification of the environmental parameters, a database that gathers the same parameters declared in the EPD is being developed. This database will cover the most used building technologies for each building element (walls, floors, windows, doors, etc.) and will be built-in the MARS-H methodology. The database covers the parameters presented in Table 1. The values of the parameters are presented for two life-cycle stages: “cradle to gate” and “demolition/disposal”.

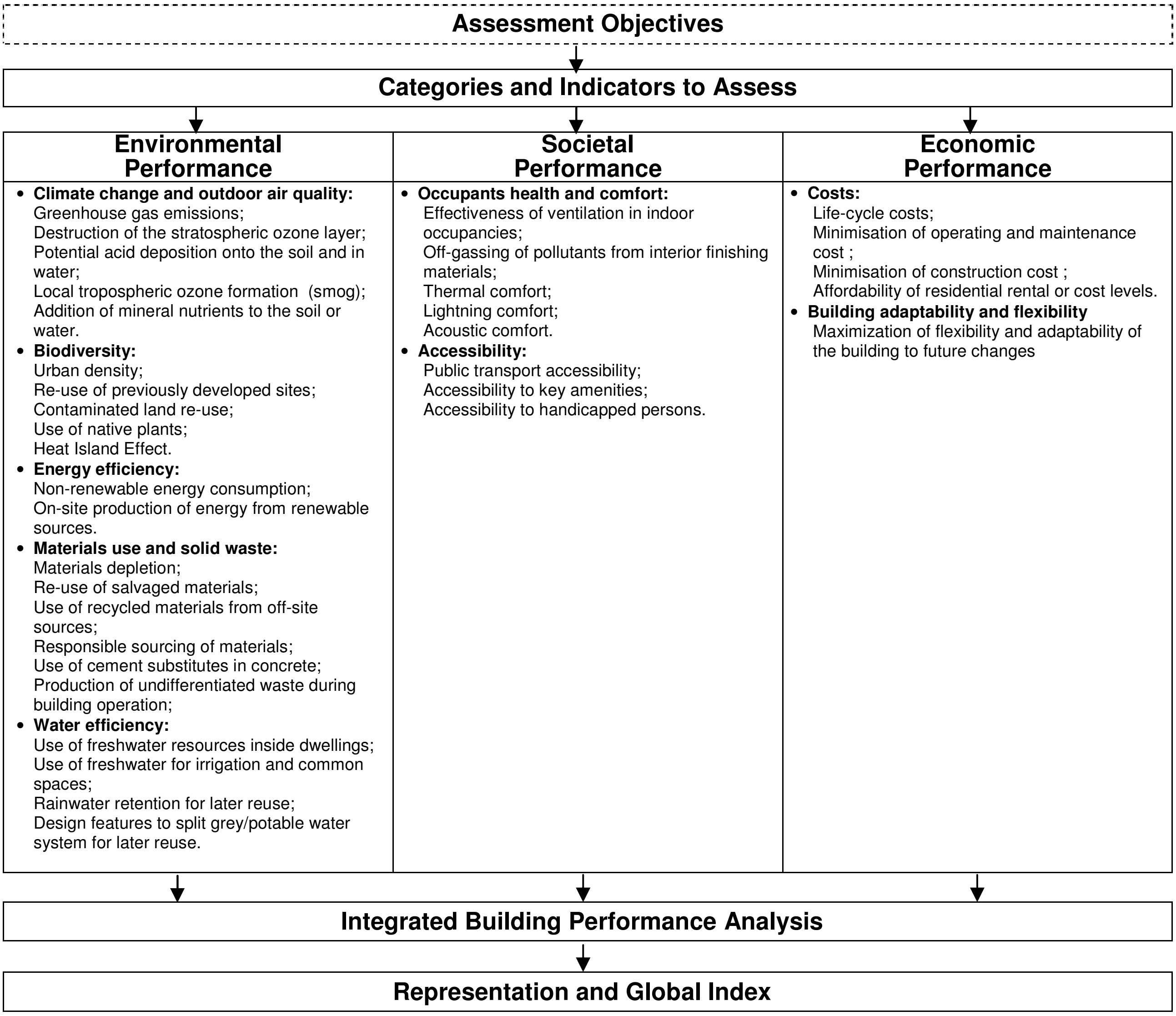

Figure 2 Indicators and related parameters considered in the MARS-H methodology.

At the level of the societal performance, it is possible to use one of the available analytical methods to quantify the parameters. If the object of assessment is a built building one can use the results of the experimental monitoring of it to evaluate the performance.

Measuring the economic performance of a building is more straightforward than measuring the environmental performance. Standardized methodologies and quantitative published data are readily available for the Portuguese context. The biggest problem is to foresee the maintenance costs, since the durability of the finishing and building solutions are quite dependable on external factors, like for instance, climatic conditions.

3.4 Normalization, Aggregation and Weights

The objective of the normalization of parameters is to avoid the scale effects in the aggregation of parameters inside each indicator and to solve the problem that some parameters are of the type “higher is better” and others “lower is better”. Normalization is done using the Diaz-Balteiro *et al.* (2004) Equation 1.

$$\overline{P_i} = \frac{P_i - P_{*i}}{P_i^* - P_{*i}} \forall_i \quad (1)$$

In this equation, P_i is the value of i^{th} parameter. P^*_i and P_{*i} are the best and worst value of the i^{th} sustainable parameter. The best value of a parameter represents the best practice available and the worst value represents the standard practice or the minimum legal requirement.

Table 1 Parameters declared in the built-in LCA database for building technologies

Parameter	Unit/declared unit	Source
Depletion of abiotic resources	[kg Sb equiv.]	CML 2 baseline 2000
Global warming potential (GWP)	[Kg CO_2 equiv.]	IPCC 2001 GWP 100a
Destruction of atmospheric ozone (ODP)	[Kg CFC-11 equiv.]	CML 2 baseline 2000
Acidification potential (AP)	[Kg SO_2 equiv.]	CML 2 baseline 2000
Eutrophication potential (NP)	[Kg PO_4 equiv.]	CML 2 baseline 2000
Photochemical Ozone Creation (POCP)	[Kg C_2H_4 equiv.]	CML 2 baseline 2000
Non-renewable primary energy	[MJ equiv.]	Cumulative Energy Demand
Renewable primary energy	[MJ equiv.]	Cumulative Energy Demand

Normalization in addition to turning dimensionless the value of the parameters considered in the assessment, converts the values between best and conventional/reference practices into a scale bounded between 0 (worst value) and 1 (best value). Excellent practices will have a score above 1 and performances bellow the reference will have a negative normalized value. This equation is valid for both situations: “higher is better” and “lower is better”.

For example, the normalization of the primary energy used for heating (hot water heating included) is done as presented in Table 2 and Equation 2.

Table 2 Example of benchmarking for normalization

Parameter	Primary energy used for heating (hot water heating include)
Notation	Eh
Unit	kWh/m²/year
Value	100
Reference value	140
Best practice	35

$$\overline{Eh} = \frac{Eh - Eh_*}{Eh^* - Eh_*} = \frac{100 - 140}{35 - 140} = 0{,}38 \quad (2)$$

In order to facilitate the interpretation of results, the normalized values of each parameter are converted in a graded scale, as presented in Table 3.

Table 3 Conversion of the quantitative normalized parameters into a qualitative graded scale

Grade	Values
A+ (Above best practice)	$\overline{P_i} > 1{,}00$
A	$0{,}90 < \overline{P_i} \leq 1{,}00$
B	$0{,}70 < \overline{P_i} \leq 0{,}90$
C	$0{,}50 < \overline{P_i} \leq 0{,}70$
D	$0{,}30 < \overline{P_i} \leq 0{,}50$
E	$0{,}10 < \overline{P_i} \leq 0{,}30$
F (Reference practice)	$0{,}00 < \overline{P_i} \leq 0{,}10$
G (Bellow reference)	$\overline{P_i} \leq 0{,}00$

Although building sustainability assessment across different fields and involves the use of numerous indicators and tens of parameters, a long list of parameters with its associated values won’t be useful to assess a solution. The best way is to combine parameters with each other inside each dimension in order to obtain the performance of the solution in each indicator (Allard, 2004).

The methodology uses a complete aggregation method for each indicator, according to Equation 3.

$$I_j = \sum_{i=1}^{n} w_i . \overline{P_i} \tag{3}$$

The indicator I_j is the result of the weighting average of all the normalized parameters $\overline{P_i}$.

w_i is the weight of the i^{th} parameter. The sum of all weights must be equal to 1.

Difficulties in this method lie in setting the weight of each parameter and in the possible compensation between parameters. Since weights are strongly linked to the objectives of the project and to the relative importance of each parameter in the assessment of each indicator, higher weights must be adopted for parameters of major importance in the project.

In what concerns to the weights of the environmental parameters, there aren't national impacts scores for each environmental parameter, according to its relative importance to overall performance. Additionally, European Environment Agency doesn't studied it yet. However, there are some international accepted studies that allow an almost clear definition of it. Two of the most consensual lists of values are based on the US Environmental Protection Agency's Science Advisory Board study (TRACI) and a Harvard University study (Norberg-Bohm, 1992). MARS-H uses the TRACI approach, allocating the considered environmental parameters in the impact categories of that method. Table 4 presents the relative importance of each impact category, according to the US EPA's Science Advisory Board study.

Table 4 Relative importance weight (%) of each impact category according to TRACI method (EPA, 2000)

Impact category	Relative importance weight (%) 8 impacts	12 impacts
Global warming	24	16
Acidification	8	5
Eutrophication	8	5
Fossil fuel depletion	8	5
Indoor air quality	16	11
Habitat alteration	24	16
Water intake	4	3
Criteria air pollutants		6
Smog		6
Ecological toxicity		11
Ozone depletion		5
Human health		11

In spite of being easy to quantify the functional parameters, the way as each parameter influences the functional performance and therefore the sustainability isn't consensual. This assessment involves subjective rating and depends, above all, on the type of solution and on the valuator's social-cultural and economic status. Several building sustainability assessment methodologies consider an empirical distribution of weights to assess the social performance. In order to overcome this situation a scientific-based methodology was developed in order to study the relative importance (w_i) of the most important comfort stressors - thermal environment (P_{tc}), acoustics (P_{ac}), air quality (P_{aq}) and visual comfort (P_{vc}) - in the perceived global comfort (G_c), as presented in Equation 4.

$$G_c = P_{tc}.w_{tc} + P_{ac}.w_{ac} + P_{aq}.w_{aq} + P_{vc}.w_{vc} \tag{4}$$

The methodology involves subjective evaluation (questionnaires to building users) and parallel experimental evaluations. During the experimental evaluations, the method assesses four parameters: resultant temperature (T_r), average illuminace (lx), CO_2 concentration (ppm) and weight A equivalent continuous noise level (L_{eq}). Collected data is processed using a multivariable linear regression and an artificial neural network method. Results, so far, show the distribution of weights presented in Table 5.

Table 5 Relative importance weight (%) of health and comfort impact categories considered in MARS-H

Category	Weight (%)
Thermal comfort	38
Visual comfort	27
Indoor air quality	22
Acoustic comfort	13

3.5 Representation and global assessment of a project

Normally, the majority of the stakeholders would like to see a single, graded scale measure representing the overall building score. Such score should be easily for building occupants to understand and interpret but also one which clients, designers and other stakeholders can work with.

Having this in mind, in MARS-H the overall performance of the building is represented by a single score in a graded scale. The methodology adopted a similar approach to the one used in the existing labeling schemes such as the EU energy labeling scheme for white goods and the European DisplayTM Campaign posters. However, due to the possible compensation between categories, the global performance of a building is not communicated using only the overall score. This way, the performance of a building is measured against each category, sustainable dimension and global score (sustainable score) and will be ranked on a scale from A to G. Figures 3 e 4 represents the outputs of the MARS-H methodology for a hypothetical case study.

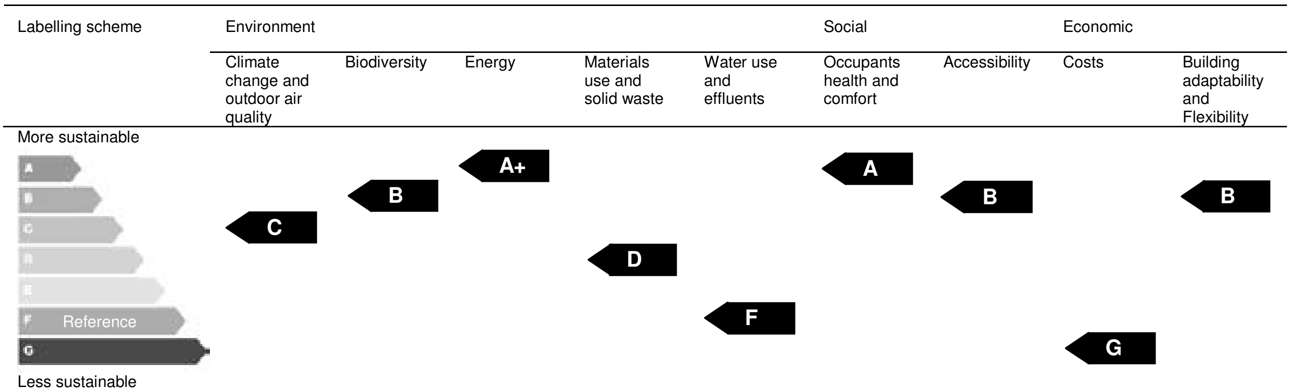

Figure 3 MARS-H output for a hypothetical building - performance of the solution presented at the level of the different categories.

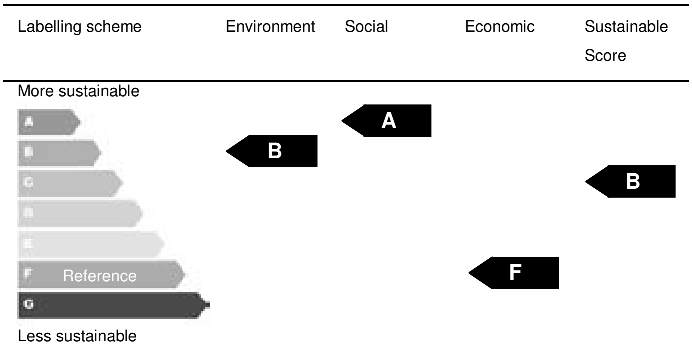

Figure 4 MARS-H output for a hypothetical building - performance of the solution presented at the level of the three sustainable dimensions and sustainable score.

From the outputs of this building sustainability assessment method it is possible to monitor and compare the performance of the solution in study with the reference solution (F grade). Nearest to the grade A is the performance of the solution, more sustainable it is. If the solution has a grade G at one parameter or category it means that special attention should be given to that issue, since it has a worst performance that the reference solution at that level.

The assessment of a project will not come only from the sustainable score grade, but mainly from the visualization of all categories. Analysing Figure 4 it is possible to verify that the analysed solution is more sustainable than the reference one. Nevertheless it is only possible to see what are the advantages and disadvantages of the solution when the performance at the level of each category is analysed (Figure 3). According to Figure 3, although the solution has higher performance in the major part of the categories, it has a lower performance in the costs category. In order to improve the overall performance the design team will have to check and try to improve the parameters that are negatively influencing the cost category.

4. Conclusions

Sustainable design, construction and use of buildings are based on the evaluation of the environmental pressure (related to the environmental impacts), social aspects (related to the users comfort and other social benefits) and economic aspects (related to the life-cycle costs). The sustainable design searches for higher compatibility between the artificial and the natural environments without compromising the functional requirements of the buildings and the associated costs.

Despite of numerous studies about the building sustainability assessment, there is a lack of a commonly accepted methodology to assist the architects and engineers in the design, production and refurbishing stages of a building. Nevertheless, in spite of the limitations of different methods, the widespread of assessment methods is having several direct and indirect impacts in the sustainable building design. The actual LCA methods and building rating tools have a positive contribution in the fulfilment of sustainable developing aims.

Many countries are either having or being in the process of developing domestic assessment methods, and therefore the international exchanges and coordination is increasingly needed. This paper contributes to the evolution of generic methodology and international understanding by introducing an approach to take the traditions and social aspects into account. It is expected that the methodology to assess the weight of the social parameters will contribute for a more consensual and objective distribution of social weights.

The building assessment and rating tool that is being developed in Portugal supports steps toward the sustainable design and construction, through the definition of a list of objectives that are easily understandable by all intervenient in construction market and compatible with the Portuguese construction technology background. Although the list of indicators and parameters is partially based on the framework for assessment of integrated building performance (CEN/TC 350), further work includes its validation in Portugal through its application to case studies.

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SMART VERNACULAR PLANNING: SUSTAINABLE REGIONAL DESIGN BASED ON LOCAL POTENTIALS AND OPTIMAL DEPLOYMENT OF THE ENERGY CHAIN

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Keywords: climate change, vernacular planning, backtracking, energy potential mapping, low-exergy design, heat cascading

Summary

Energy depletion and climate change require an approach to spatial planning that is radically different from what we are used to. For developed countries, with an ecological footprint exceeding their national territory, it is a moral question to not just depend on supply of energy from elsewhere. For developing countries an economy relying mainly on smart deployment of local qualities will enable sustainable growth without the changeable support of richer countries.

The principle of smart vernacular planning is based on a thorough analysis of local characteristics that can be used in the management of energy, water and other resources. These features can be translated to potential maps depicting, for instance, the opportunities to generate power from local resources.

Furthermore, the depletion of fossil energy requires optimal management of the energy chain: use of sustainable resources (supply) and low-exergy design (demand). At present much waste energy (mainly heat) is emitted unused into the air, water and soil. In addition, high-quality energy is now used for low-grade purposes for which waste energy of a lower quality would suffice. Cascading spatial functions that tune supply and demand would satisfy the principle of effectiveness, creating greater effect than energy efficiency.

A next creative step in smart vernacular planning is the translation of the information gained into interventions in an already existing built, or unbuilt, environment. This process requires ingenuity, knowledge of planning process and, above all, political courage. It is the only way towards a sustainable future within shifting boundary conditions of climate and available resources.

In the paper we will elaborate on the methods of energy potential mapping and matching, energy cascading and climate- and energy-inclusive planning, all of which form the building blocks of smart vernacular planning. We will discuss recent studies that applied this principle.

1. Introduction

1.1 Need for a different approach to energy

While dramatic changes are taking place to our climate, one of its probable causes, consumption of fossil fuel is becoming an uncertain asset in the near future. Natural oil and gas reserves are depleting, or their extraction is becoming complex and expensive. This will make the availability of energy uncertain and very expensive, which will probably affect developing countries the hardest.

The tendency to widely use coal again for the generation of electricity – for instance in China and the Western world – will have a devastating impact on greenhouse emissions and pollutions that seemed to have been banished. Many countries now seek refuge to nuclear power but uranium is also depleting. Meanwhile, sustainable energy may be expensive yet abundant: based on the potential for energy from the sun, wind and water, Jong et al. (2004) calculated that the Netherlands alone could already sufficiently provide the global economy with energy. However, at this instant local potentials are not effectively seized.

1.2 Sustainable development

Paradoxically, the threats of climate change and energy depletion can be used as a catalyst for sustainable redevelopment. A new paradigm can be found in responding to the inevitable changes in climate rather than fighting them. Spatial planning can be based on local energy potentials and in accordance with an optimal usage of the energy cycle by means of the low-exergy principle. The local potentials for energy generation can be investigated by means of analyses of climatic conditions, landscape and land use typology, local natural, cultural and technical features, and existing 'hotspots' of energy and heat generation.

This new approach to sustainable regional planning leads to 'energy potential maps', depicting the local potentials for energy provision. These can be combined to a map of interventions proposed from an energetic point of view.

1.3 Need for a different approach to energy

Energy depletion and climate change require an approach to spatial planning that is radically different from what we are used to. For developed countries, with an ecological footprint exceeding their national territory, it is a moral question to not just depend on supply of energy from elsewhere. For developing countries an economy relying mainly on smart deployment of local qualities will enable sustainable growth without the changeable support of richer countries. Local strengths therefore should be better used, and vernacular solutions were primarily based on the deployment of these local characteristics, so they will be most helpful.

In addition, we need to acknowledge that many of the current energy systems are close to 100% energy efficiency. Nevertheless, we still seem far off from the desired sustainable development. Energy efficiency, as it seems, is not the solution for a sustainable society. This can be made understandable by the exergy concept, which is rather about effectiveness than efficiency and which will be discussed further on.

2. Smart vernacular planning

2.1 Backtracking, revaluating vernacular solutions in a traditional sense

In order to set the path for future sustainable developments, there are different time-based approaches (figure 1, Dobbelsteen et al. 2006).

- *Forecasting* is needed when we want to estimate the consequences of current developments and our own intervention on long-term effects, such as the issues of climate change and depletion of resources.
- *Backcasting* involves the description of a desired future state (sustainable and based on the needs that need to be met), translating this state back to strategies and measures we need to develop now.
- By means of *backtracking*, solutions are based on historical circumstances at the time when there still was a sustainable equilibrium. This sustainable past may be an instance for planning directions, for which perhaps certain valuable historical, natural or cultural features or circumstances can be brought back to new design.

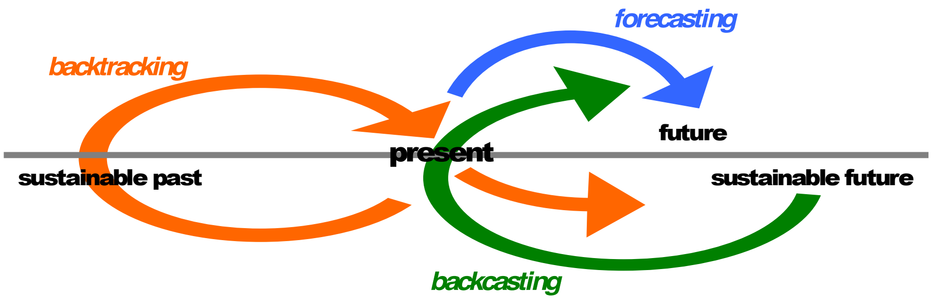

Figure 1 Graphical explanation of the forecasting, backcasting and backtracking methods.

Forecasting is useful to predict trends that have developed over some time already, but is not very effective to establish a great leap toward a sustainable future. A better, more effective method for substantial change is backcasting, but one could consider this method rather detached from real life and how it evolved throughout the centuries. Therefore, backtracking can be used to link the present to qualities of the past, embodied by vernacular principles. Backtracking would revaluate vernacular solutions that in itself sustained a way of living in equilibrium with the environs.

None of the methods presented should be applied alone. We found that the simultaneous use of all three of them means synergy, picking the best solutions from history, the present, and the imagined and desirable future.

2.2 Incremental approach to new vernacular principles

Apart from local historical principles, smart vernacular planning needs to be based on a profound analysis of local characteristics that can be used in the management of energy, water and other resources. Therefore, basic information is collected of climate, historical developments, topography, soil and underground, landscape, land use and infrastructure. For instance, the local climate is essential for the determination of potentials of solar and wind energy, and land use gives a clue to the possibilities of biomass.

This basic information then is translated to energy potential maps for fuel, electricity, heat and cold, and CO_2 capture. These maps evolve through a process of deduction, association and creativity. The depletion of fossil energy requires optimal management of the energy chain: use of sustainable resources (supply) and low-exergy design (demand). At present waste energy (mainly heat) is usually emitted unused into the air, water and soil. In addition, high-quality energy is now used for low-grade purposes for which waste energy of a lower quality would suffice. Cascading spatial functions that tune supply and demand would satisfy the principle of effectiveness, creating greater effect than energy efficiency.

A next creative step in smart vernacular planning is the translation of the information gained into interventions in an already existing built, or unbuilt, environment. This process requires ingenuity, knowledge of the planning process and, above all, political courage. It is the only way towards a sustainable future within shifting boundary conditions of climate and available resources.

Figure 2 depicts this generic methodology for charting energy potentials and interventions therefrom.

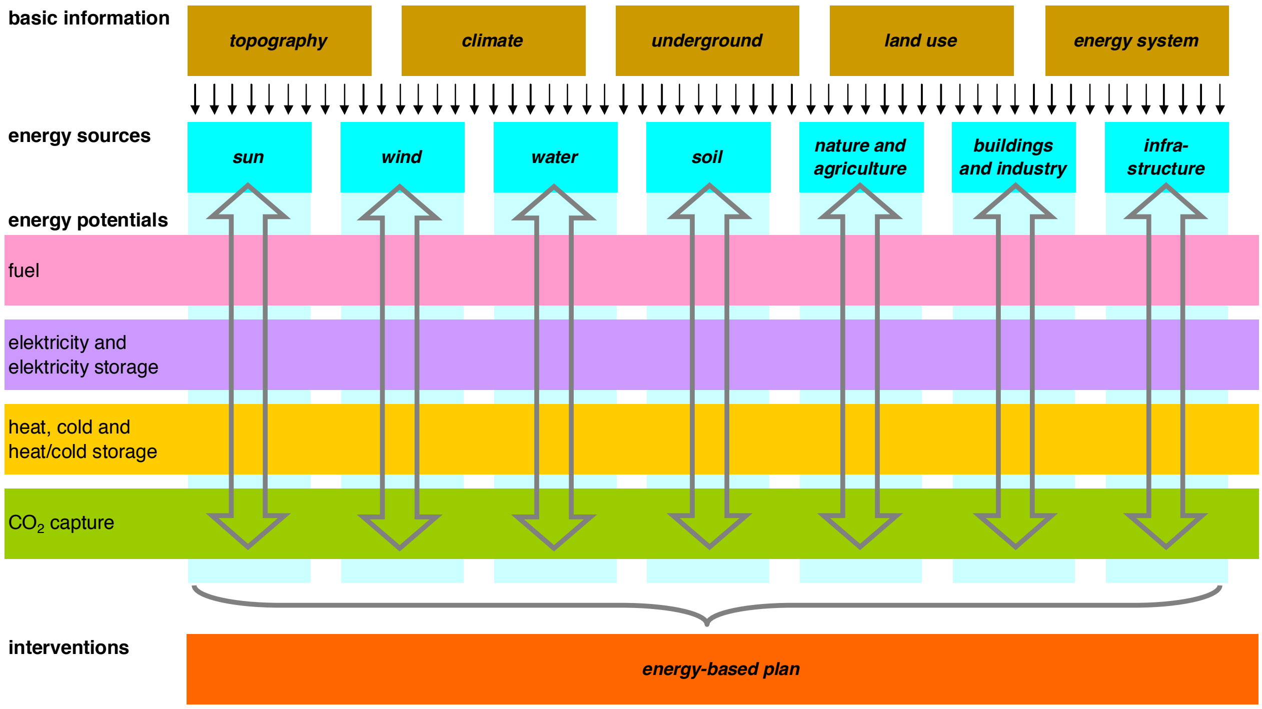

Figure 2 Methodology of the energy potential mapping.

3 Heat cascading

3.1 Exergy

The First Law of Thermodynamics states that energy is never lost, whereas the Second Law describes that processes develop towards a state of increasing entropy. Hence, entropy embodies the non-useful waste energy evolving during processes. Exergy is the useful part, the part that can perform work. It is a measure of energy quality.

As already stated, processes can be energy-efficient but in terms of exergy this efficiency can be totally different if the initial exergy level is predominantly converted to entropy. For instance, a contemporary boiler may have an energetic efficiency of 95%, but considering the gas flame of 1500^{o}C, a lot more can be done with it than just heating up houses to 20^{o}C. The exergetic efficiency is approximately 10%. If the gas flame heat were used in the metal industry, the exergetic efficiency would approximate 100%. Therefore, energy of a high-quality level should be used for high-grade functions before it transforms into a lower-quality state, which can still be useful to low-grade functions.

3.2 The low-ex approach

The current energy system of a region (figure 3, left) is characterised by an influx of primary energy – fossil fuel – into every function present in the area. A power plant, which is also fuelled by fossil energy, generates electricity and every function produces waste and waste heat. The latter is emitted into the air and water. In this system each step requires high-quality input of exergy.

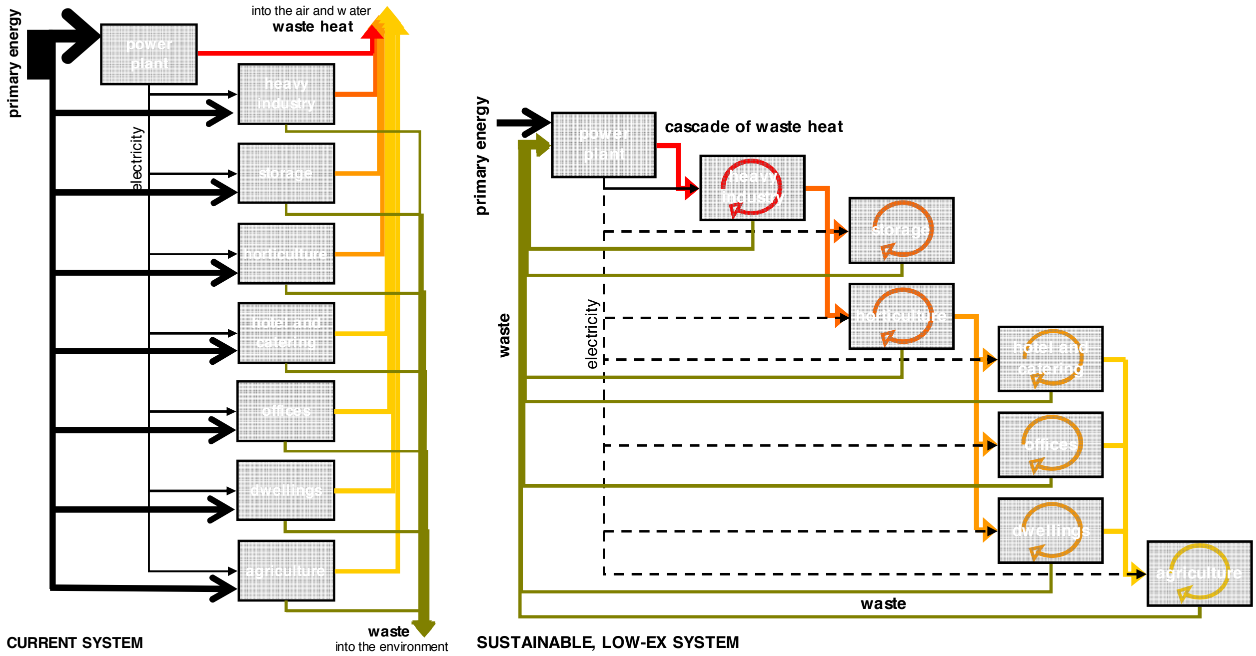

Figure 3 Graphical example of energy provision in the current system (left) and in a more sustainable, low-exergy system that uses heat cascading (right).

The low-exergy (low-ex) approach (figure 3, right) limits exergy losses between and during process steps. This would imply feeding an exergy quality close to the demanded level, losing little exergy during the process and finding a secondary function that can make use of the output level. High temperatures would only be used in heavy industrial processes, of which waste heat could be used in lower-grade functions such as manufacturing processes, horticulture, and subsequently for residential heating. Residences and agriculture can eventually again 'feed' the power plant with biomass and waste.

Thus, four to seven instead of just one purpose would be served by the same amount of primary energy.

3.3 An uncommon inventory

In order to get the full picture of heat cascading potentials, a survey needs to be executed of all regional functions, their exact location, temperature levels required for their processes, the demand of energy and the supply of waste energy and other products. In order to make the inventory feasible, for some of these functions – e.g. housing and offices – one may use generic values of energy demand and supply. Specific industrial functions however require individual study of internal processes and energy characteristics. Not every company is willing to give this information, but regional administrations often need the same data for environmental licences, and one can use these in the energy survey.

After the collection of data, the exact location of heat and cold supply and demand can be charted. This will visualise areas with excess and lack of energy, and evoke measures to be taken for closing the heat chain.

3.4 Right form, right place, right time

In order to make heat cascading possible, there is a question of the right energy form needing to be in the right place at the right time (Gommans & Dobbelsteen 2007).

3.4.1 The right energy form

For the mapping of (waste) energy potentials it is necessary to know which forms of (waste) energy can be harvested and for which use. The energy required for certain processes is not always available in the desired form, in which case conversion is necessary. Practical expertise is necessary of this conversion process, including knowledge of efficiency, costs and space requirements. This sometimes requires innovation. For instance, the bio-technology industry still regularly finds new ways, assisted by enzymes and bacteria, to convert certain materials into usable carriers of energy (TI-KVIV 2007). An overview of existing energy conversion processes will clarify which forms of (waste) energy can be converted to a usable form, and provide basic information about the associated costs and practical aspects of the conversion process.

3.4.2 The right place

On the regional scale the low-ex principle has implications for planning. Low-caloric heat cannot be transported over long distances: heat losses would be too big. Therefore, spatial functions should be concentrated and mixed: horticulture near industry, residences near horticulture. The SREX research project (Roo et al. 2005) focuses on this synergy of space and exergy.

Each method of transporting energy has characteristic features. Electrical energy can be transported at high voltage over large distances with relatively little losses. Transport of heat over larger distances however quickly reaches a point where the energy losses exceed the energy content. The losses are partly transmission losses to the environment and partly losses incurred by displacing the energy carrier (e.g. pump losses). Energy carriers in a solid or fluid state (e.g. wood products or liquid gas) can be transported by road, rail or waterways. Every method of transport has a price.

The right place to generate electricity may be disputed. Should this be the place where, for example, biomass is available? Or is it the place where biomass or some other fuel can be easily delivered? Or should it be close to areas of living, where waste heat can be used for space heating? Or should it be at some location in-between? Every location has its pros and cons in terms of logistics, efficiency, public inconvenience, transport losses etc. For a well-deliberated decision on the matching of supply and demand of energy and the location of conversion, it is essential that the characteristics of the possible methods of transport are known.

3.4.3 The right time

Finally, timing can be an obstacle in realising a working energy system. Usable energy may be available in the right amount at the right place, but at the wrong time, necessitating energy storage for a short or long term. For instance, photovoltaic systems may require an overnight storage for electricity generated during the day, for use at night (e.g. lighting). Long-term seasonal energy storage will meet the demand for space heating in winter, with excess solar energy captured during summer. Similarly, waste heat continuously produced by industrial processes may be usable only in winter.

Storing energy is always associated with energy losses and, besides, costs, space and energy (for loading and unloading). Each form of storage has its own characteristics. Fuels such as fossil fuels, plant-based oils, bio-ethanol, but also biomass in general are the highest form of exergy. They essentially are chemical stores from which energy can be released by combustion or in another way. As a result of their energy density they require relatively little space. There are many ways to store heat, such as in the thermal mass of buildings or underground heat buffers. Storage of electricity is more difficult than of heat. The electrical grid is sometimes used, but this is only possible as long as the changeable power from wind turbines or solar systems is relatively limited. An increasing share of electrical energy produced by the sun and wind will require a different solution for storage, possibly hydrogen. The selection of an appropriate energy storage method is determined to a large extent by the form of the energy required and by the duration of storage. Locations and regions will vary in their particular requirements and potentials for storage.

4. Using local features at different scales, two examples

4.1 The regional scale: the province of Groningen

Following the investigation of a new regional plan for the Northern Netherlands (Roggema et al. 2006) based on a sustainable energy system, the northern province of Groningen commissioned an energy potential study. The findings of this study, presented in e.g. Dobbelsteen et al. (2007), would be included in the new provincial development plan, for which climate change was also one of the steering principles.

Figure 4a shows the map of all potentials for electricity generation. It gives the best location for wind parks, a tidal plant and a few 'blue energy' plants along the coast, for a biomass-based industrial cluster in the centre, and for a new type of plant: an inundation plant for occasional flooding of the deepest polders in case of emergency. Furthermore, there are small decentralised bio-digestion installations with combined heat and power (CHP) generation, spread through the country-side which contains many isolated farms and villages. Energy values of solar radiation showed little variance over the province, so use of photovoltaic panels is possible anywhere. For large-scale solar plants, the energy properties of a northern place as Groningen are unfavourable. Local self-supply, however, can be helped by solar panels, as well as small wind turbines.

Figure 4b is the overlay map of heat and cold potentials. The map depicts the potentials of geothermal heat from aquifers at 3000 meters of depth, to be deployed through empty gas fields, shown as grey grids. The drill-holes of gas locations are indicated by small blue triangles. The small dotted areas depict reasonable to good potential for heat and cold storage in shallow aquifers (30 tot 150 meters deep). Hollow circles are heat (red) and cold (blue) demand within the municipalities, whereas full circles pinpoint major sites of excess of heat or cold, which can be considered sources of supply. The excess of heat in industrial areas is evident. Nevertheless, the largest producer of heat, the Eems harbour area, now has no heat-demanding function close to it. This can be altered through spatial planning that takes these heat potentials into account.

Solar heat, again, is available anywhere and should be seized when possible. This also applies to local exchange of heat and cold with exhaust air, the soil and open water.

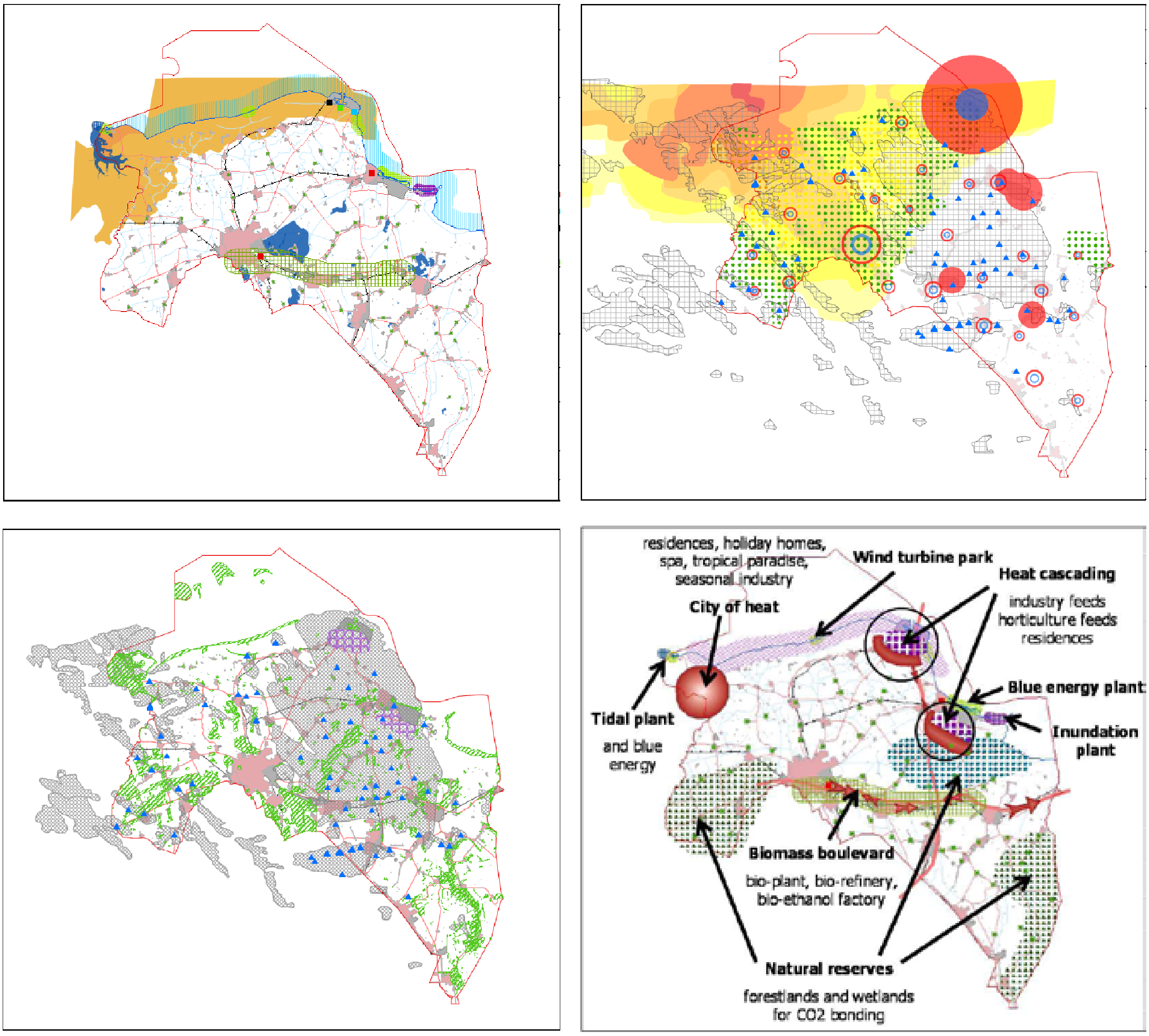

Figure 4 Overlay maps of energy potentials of Groningen for the generation of electricity (a, top left), the provision of heat and cold (b, top right) and for CO_2 use in greenhouses, compensation by plants and storage in gas fields (c, bottom left), as well as the map with proposed interventions (d, bottom right) (Dobbelsteen et al. 2007).

The principle of human influence on the climate is quite simple: prehistoric lush jungles that captured carbon dioxide (CO_2) over millions of years evolved into fossil fuels, which are again converted into CO_2 in a time period of two centuries. To compensate for that, new jungles should thrive another couple of million years, but this time man obstructs the natural regeneration of plants. A four-steps strategy may be (1) avoid emission of CO_2 by energy-saving and sustainable energy resources, (2) make CO_2 useful in industrial and horticultural processes, (3) compensate for CO_2 emissions by planting trees and other green absorbers, and finally (4) storing CO_2 underground. This last option is possible in emptying gas fields that are not watered out after abandonment. Figure 4c summarises the last three options for the province of Groningen. The gas drill-holes are again given.

Figure 4d finally represents the interventions proposed on the basis of energy potentials. These proposals involved a wind park, a tidal plant, blue energy (osmosis) plants, an inundation plant, a cluster of biomass-related industrial activities, heat cascading solutions by horticulture and housing developments against industry, and wet biotopes for CO_2 bonding.

4.2 The urban to district scale: Almere East

Almere, a new town near Amsterdam established in the 1970s has gradually grown, to Dutch standards, to middle-sized proportions but continues to grow with the increasing demand for space for living in the Amsterdam metropolitan area. The municipality of Almere intends to make a 'scale leap' to twice the size of today and therefore is planning three new districts and an upgrade of the inner-city. One of the new districts will be Almere East, to be realised in a predominantly agricultural environment.

Almere has expressed and put into their general policy that all new developments be done in a sustainable way. On April 9th of 2008 they even presented their 'Almere Principles', seven guidelines based on the philosophy of Cradle to Cradle (McDonough & Braungart 2002). Fitting into this town-wide supported ideal was amongst others the study of energy potentials for the new area of Almere East.

The methodology applied to this energy potential study (Dobbelsteen et al. 2008) follows the generic approach presented in this paper. On the basis of fundamental information energy potential maps were drawn, of which figure 5 gives two examples.

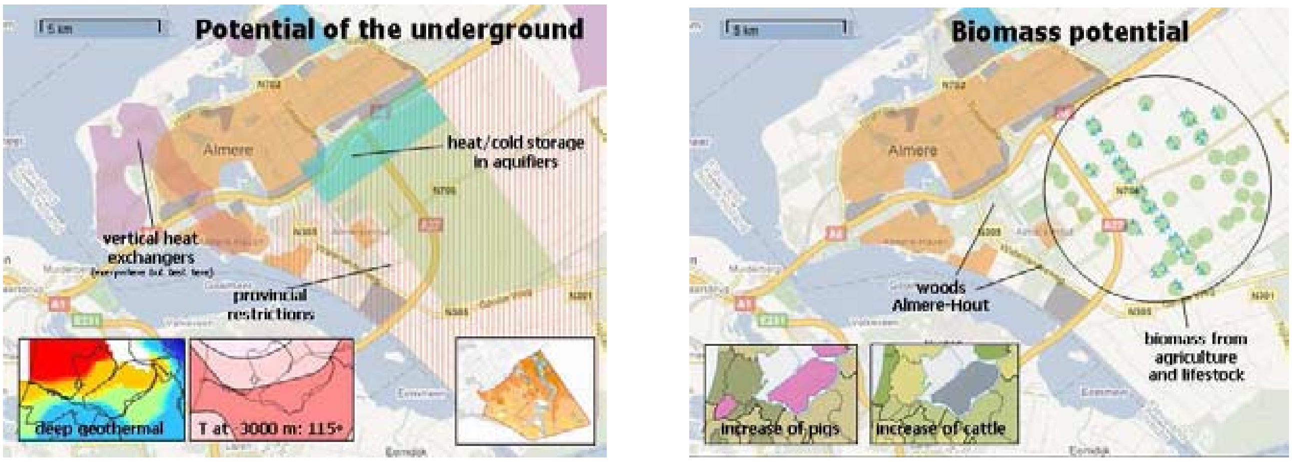

Figure 5 Examples of the energy potential maps for the new district Almere East: potentials of the underground (left) and potentials of biomass (right) (Dobbelsteen et al. 2008).

Using the findings of the energy potentials, two maps with spatial interventions were drawn (figure 6).

The measures proposed for the north side of Almere East in the picture on the left encompass intensive developments alongside the A6 motorway with industry and housing (for the exchange of heat and cold), extension of the heat and cold network from Almere-City and the use of open heat and cold storage in aquifers. The approach for this dense area can be described as heteronomous (Timmeren 2006). For the open agricultural area of Almere East, autonomous clusters are proposed around farms: low-temperature heating dwellings with greenhouses, bio-fermentation with bio CHP, small wind turbines and PV. Alongside the A27 motorway, large windmills will provide additional sustainable power and reed fields will purify water of the area.

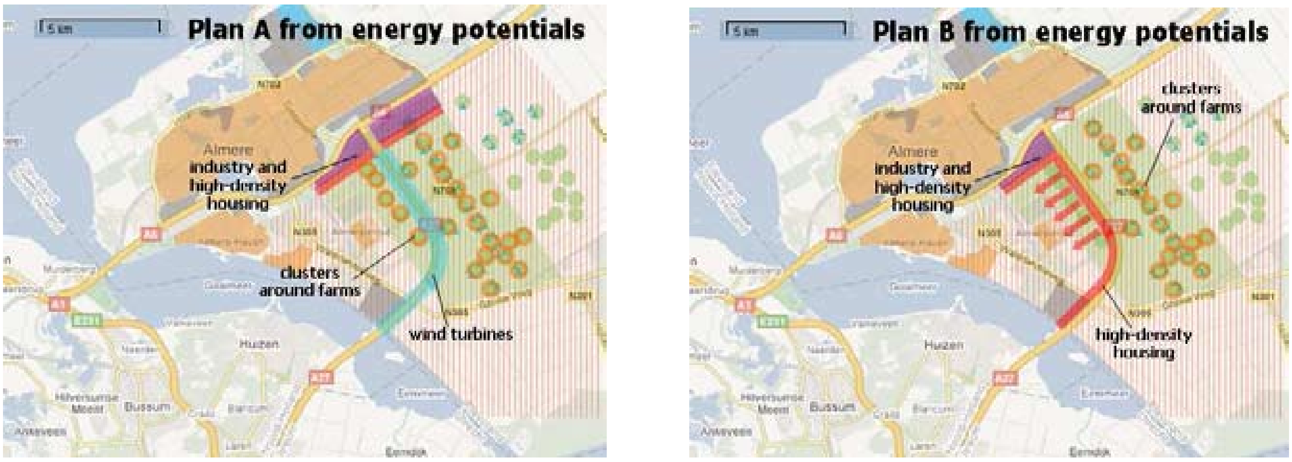

Figure 6 Two possible plans for Almere East that optimally use the energy potentials (Dobbelsteen et al. 2008).

As another option (figure 56, right), only the part west of the A27 motorway is developed, with highly intensive housing against the A27 (noise wall) with a centralised energy infrastructure, and less dense housing towards the west.

These proposals are currently taken into account for the elaboration of Almere East. An energy potential study of the whole Almere region is ongoing, and new studies are expected for two additional new areas for development.

5. Conclusions and discussion

5.1 Conclusions

In this era of energy depletion and climate change, regions throughout the world have become inter-dependent on energy whilst losing the ingenuity to deploy regional and local features in energy-effective planning systems. Smart vernacular planning enables better use of local potentials of energy provision. Energy potential mapping, on the basis of a profound study of local characteristics and possibilities of reusing waste energy flows, will support this smart vernacular planning, as two case studies demonstrated. The methodology for this is generic yet applicable to different scales, from the region to the building scale. It may be combined with potential maps related to social and economical issues. Studies indicated that significant improvements to energy performance can be achieved where efficiency increases to our current system lead to marginal improvements.

5.2 Consideration

The approach presented in this paper implicitly presumes a direct relationship of spatial planning with meticulously located energy potentials. Submitting to this approach would therefore imply direct spatial consequences to found energy properties. A society based thereon could be considered site-bound. Although drastic in its impact to current plans, with the current developments in energy provision this vernacular planning seems an appropriate shift from the old paradigm of disconnecting functions and planning regardless of place and time, made possible through site-independent fossil fuels. In the near future however society may head in a different direction when a substitute is found for fossil fuels, e.g. sustainably produced hydrogen. In such a situation planning can again be 'footloose' and disconnected from its energetic underground.

These are two entirely different scenarios that lead to fundamentally different spatial planning needs. An intermediate scenario is most probable as the footloose society on e.g. hydrogen will at least partly be tied to the local generation of sustainable energy.

5.3 A message of urgency

The Stone Age did not stop because man ran out of stones; it stopped because man found better material for tools. Likewise, the Fossil Age will not stop because of the depletion of fossil fuels; it will find an ending through better solutions for energy. Our current generation has the great honour to make this transition. We hope the methodology presented in this paper can contribute to that.

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CASE STUDIES OF APPLICATIONS OF A QUANTITATIVE MODELING SYSTEM FOR OPTIMIZATION OF COMMUNITY-SCALE SUSTAINABLE DESIGN DECISIONS

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Abstract
Green building practices are revolutionizing the building sector by changing the way that buildings are designed, built, and operated. This trend is expanding from its initial emphasis on the performance of individual structures to the characteristics of **neighborhoods and entire communities**. The design of green buildings has often been closely associated with increasingly sophisticated modeling approaches. These tools can represent and integrate the performance of mechanical, electrical, water, and waste systems. These tools work well for individual structures, but they typically cannot be used directly at neighborhood or community-scales.

This paper describes the application of an innovative information technology called the CTG Sustainable Communities Model ® (SCM), a software application using a systems-based modeling approach to analyze the costs, benefits, and sustainability implications of design alternatives for community developments. SCM has been used as the basis for the design of communities consisting of thousands of individual homes, commercial buildings, infrastructure and open space. This paper provides examples of several such developments and the types of design decisions enabled by the use of the SCM tool.

Keywords: communities, sustainable, modeling, decision tool, metrics, case studies

1. Introduction

Green building practices are revolutionizing the building sector by changing the way that buildings are designed, built, and operated. The design of green buildings has often been closely associated with sophisticated computer modeling approaches to optimize the performance of proposed building designs. Such tools include: DOE-2, eQuest, Ecotect, IES, and Green Building Studio. These tools can represent and integrate the performance of mechanical, electrical, water, and waste systems. These tools work well for individual structures, but they typically cannot be used directly at neighborhood or community-scales. There are also a number of modeling tools that function at the community scale, for traffic and transportation (e.g. URBEMIS), storm water and hydrology (SG Water), air pollution (EMFAC), and other civil engineering analyses. However, these tools only look at the large-scale performance of the individual systems modeled, without regard to the interactions with other systems or the impacts of building-scale systems. A third class of modeling tool is one that looks at the conceptual layout of a proposed community design, and evaluates certain urban planning metrics (such as walkability, adjacencies of related functions, etc.).

Each of these modeling tools has a useful application in the analysis of new buildings and communities, but there has been a missing capability which tied the multiple scales (building, community, infrastructure) together into a single set of metrics which could interact and allow alternative design scenarios to be evaluated. In other words, a system-based modeling environment was needed; something that could bring together disparate information sources and facilitate quantitative evaluation and comparison. It was this missing capability which drove the development by CTG Energetics of its information technology called the CTG Sustainable Communities Model ® (CTG SCM). In the same way that the energy modeling tools can be thought of as "whole building modeling", the CTG SCM enables "whole-community sustainability modeling" and optimization.

The CTG SCM is a calculation engine using a systems-based modeling approach to analyze the costs, benefits, and sustainability implications of design alternatives for community developments. The CTG SCM has been used as the basis for the design of communities consisting of thousands of individual homes, commercial buildings, infrastructure, and open space. The most significant contribution of this tool is its ability to quantify the evaluation and comparison of design options at different scales at the same time, and to compare multiple options on the basis of both economic and environmental impacts. This capability enables users to evaluate various sustainability features and their relative cost (both construction cost and operating costs), so as to be able to select features that provide the maximum environmental benefit for a given level of economic investment.

The CTG SCM is differentiated by its ability to provide an integrative environment that facilities quantitative, systems-based analysis of whole community performance. The CTG SCM provides a flexible platform for the analysis of project alternatives with exceptional capability to accommodate a range of project detail (e.g. increasing project specification during entitlement and design). These features distinguish the CTG SCM from compliance-oriented tools that focus on subsets of issues or rigid “default” assumptions. For example, there are tools that evaluate the degree to which a proposed community design conforms to “smart growth” concepts, but they do not quantify either the actual environmental loadings generated by the design options or the relative economic performance of those options which it evaluates. There are also rule-based tools, such as LEED for Neighborhood Developments™, which is an assessment system which provides a set of pre-requisites and credits which can be used to evaluate a proposed community design. But again, it provides no quantitative metrics other than the “LEED Rating” which is a single number which conveys no actual quantitative significance, either environmentally or economically. Thus, these types of tools are seen as more of a compliance evaluation tool than a design optimization tool.

This paper provides examples of the types of design optimization decisions enabled by the use of the CTG SCM tool for some recent projects.

2. The CTG Sustainable Communities Model

The authors developed the CTG SCM model with the following goals in mind:

- To quantify the relative environmental impacts and linkages of various development design decisions
- To analyze environmental impacts, economic costs, savings, synergies and trade-offs
- To enable optimization of community design based on a variety of sustainability metrics.

The CTG SCM models a community from the ground-up, using detailed sub-models for each element of a community, including residential, commercial, public and other buildings; parks and other open-space; physical roadways and streetscaping; transportation systems (car trips, bus trips, etc.), stormwater systems, onsite energy generation systems, landscaping pallet and irrigation; domestic water usage, etc. The types of elements which can be modeled are described in Figure 1 below.

Figure 1 Elements of the SCM modeling vocabulary.

Figure 2 below shows an example of the elements which might make up a typical neighborhood modeled as part of a community model.

Figure 2 Elements of an SCM Neighborhood

The environmental performance of each of these elements is individually variable, and can be modeled using industry-standard modeling tools and techniques for each. For example, the energy performance of each type of building in the neighborhood can be modeled using DOE-2, Energy 10 or other energy modeling software, the outputs of which become inputs to the CTG SCM at an element level. Alternatively, building performance information can be derived from statistical data, such as the California Building Energy Reference Tool or the Commercial Building Energy Consumption Survey (CBECS). Similar kinds of modeling or statistical analyses can be done for water usage, solar energy, materials usage, etc., with the calculated outputs of those building-level models becoming the input to the various CTG SCM scenarios which will be evaluated. This can be separately modeled for every different building condition or configuration in the neighborhood. For infrastructure scale features, similar kinds of external modeling can be performed for transportation systems, hydrology, stormwater, etc., with the results used as inputs to the CTG SCM.

One major advantage of using industry-standard modeling tools as inputs to the community-scale analysis done by the CTG SCM is that those tools are familiar to the various design disciplines working on a community plan. The models have typically been subjected to peer review and use over extended periods of time. The analysis is often done as a standard part of work by the appropriate subject-matter experts on a design team, both to optimize their various discrete sub-systems and to document discrete environmental loadings as required for various permitting programs. Thus, these analyses which were already being performed for a project can be utilized as inputs to the CTG SCM to enable the community-wide assessment of whole-community sustainability optimization.

Individual elements are combined to form neighborhoods as shown in Figure 2 above. Neighborhoods can then be aggregated together, along with additional infrastructure elements, to form larger planning areas, districts, and communities, as shown in Figure 3 below.

Figure 3 Elements of an SCM community

From a data flow perspective, the types of inputs and outputs of the CTG SCM are shown in the block diagram of Figure 4 below. From left to right in the diagram:

1. The inputs are detailed description of the various elements of the neighborhoods and community elements in the terms in which they are typically described. Thus, energy inputs are described in typical energy modeler's terms, transportation in typical transportation modeling terms, etc.
2. The computations by the model are all based upon peer-reviewed publicly available algorithms and data, which can be reviewed and revised as new or better data become available.
3. Finally, the outputs are presented in an aggregated form which enables the quantitative assessment of the whole community on a variety of environmental and economic metrics.

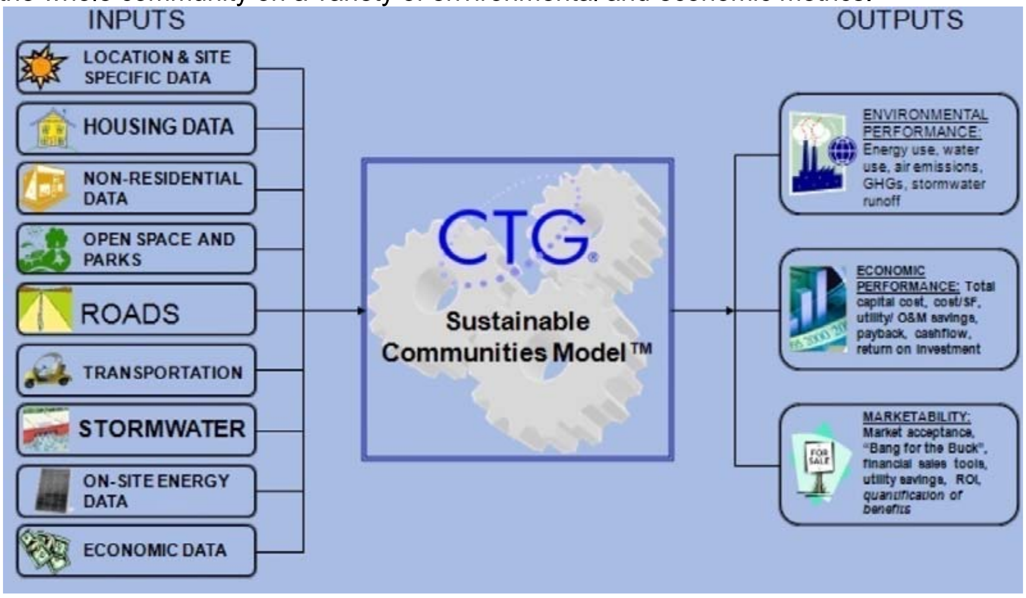

Figure 4 CTG SCM input-output block diagram.

The CTG SCM model links together all of the various "system interactions" and upstream and downstream resource flows. For example, the embodied energy in water pumping, treatment and distribution are modeled. The energy usage, air emissions, carbon footprint, stormwater pollutants, potable water usage, etc. are all modeled quantitatively at the same time. Thus, the model captures synergies and tradeoffs between various design alternatives, and helps determine the designs that provide the best benefit-cost relationship.

3. Case Studies Using the CTG Sustainable Communities Model

This paper shows examples of the types of analysis and decisions enabled by the CTG SCM for two new mixed-use development projects in Southern California, USA. The first is the Rancho Mission Viejo Ranch Plan, a large mixed use development in Orange County including15,000 dwelling units and 4 million SF of non-residential buildings (shopping plazas, restaurants, business parks, and civic facilities) and a multimodal transportation system on a total developed area of 6,000 Acres. The SCM was used as the basis for numerous sustainability design decisions as part of a "…regional, comprehensive master plan for Rancho Mission Viejo that will be developed in phases over the next 20 to 25 years". The second project is the Heritage Park project by Lennar Corp. in the City of Irvine, CA, also a large mixed-use project but on a brownfield site (the redevelopment of the old El Toro military base). This project encompasses 3,900 dwelling units and 5 million SF of non-residential buildings on 2,200 Acres of developed land. The balance of this paper shows examples of the types of analysis performed by the SCM and the decisions thus enabled for these two case study projects (the data are not ascribed to specific projects, due to confidentiality concerns of the project developers).

An example of the value of the integration of multiple systems described above for Figure 4 is that it enables the design team to ascertain where the most significant environmental impacts are for the "whole community", as a guide to where to focus attention on mitigation. Figure 5 below shows the set of base case metrics for an example community on multiple environmental impact criteria. These base case data enable the design team to identify which elements of the community are having the most impact on the various environmental impacts. For example, it is clear that transportation has the single biggest energy impact, much more than either the residential or commercial buildings. This is even more striking in the air pollution metrics, where transportation represents 90% of the total community impacts. By contrast, for stormwater impact, the commercial buildings are far and away the largest impact, due to relatively large roof areas and parking lots. Which impacts are most important to minimize will depend upon the local environmental conditions and upon the goals of the project team.

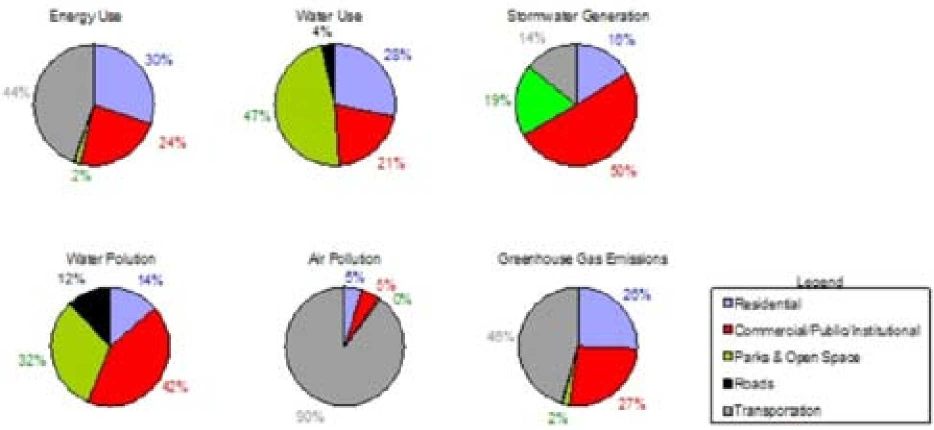

Figure 5 Integrated environmental metrics.

An example of how the inputs from the many different systems can be aggregated into a combined set of integrated end-use summary metrics is shown in Figure 6 below. This enables buildings, landscaping, transportation systems, and other infrastructure features to be combined to see their total demand upon various resources.

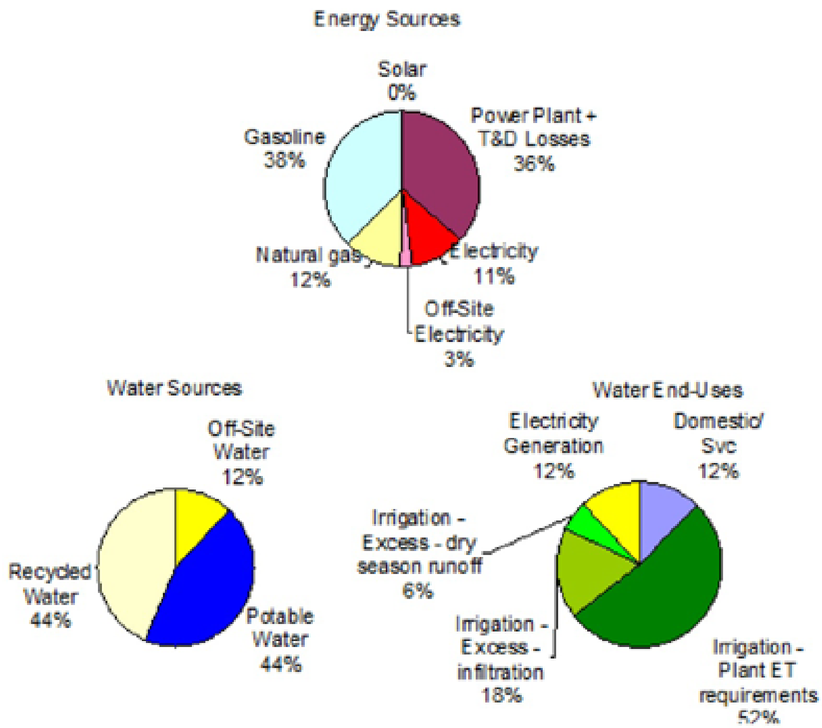

Figure 6 Aggregated end-use analysis

One useful analysis is to focus on a single set of design decisions and look at all of the environmental impacts associated with those decisions. In Figure 7 below, the residential design optimization was done looking at a wide range of sustainability measures, in this case with and without PV Solar power on the dwellings; both options are compared to the Base Case of standard code-compliant design.

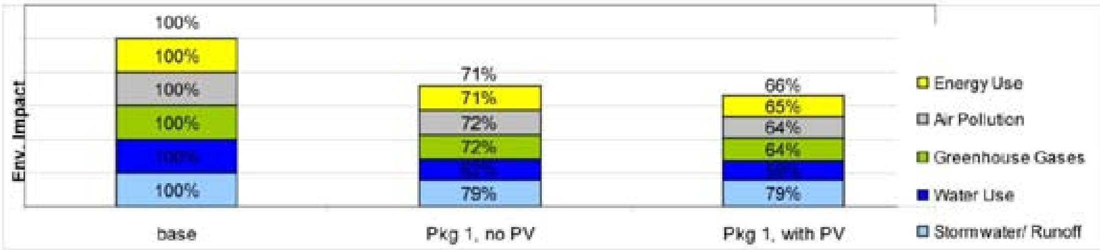

Figure 7 Residential Optimization.

In this case, the environmental impacts in each category (energy use, air pollution, etc.) were totaled and for the base case were assumed to be 100%. The impacts of each category were then stacked. The combined set of design alternatives resulted in a percent reduction from the baseline. The advantage of this representation is that it avoids subjective weighting between the impact categories and assumes each to be equal.

Another way to apply the tool is to look at a single environmental metric and evaluate the potential impact on that metric by various design choices. Figure 8 below shows the analysis of all buildings in the community on the basis of annual GHG emissions.

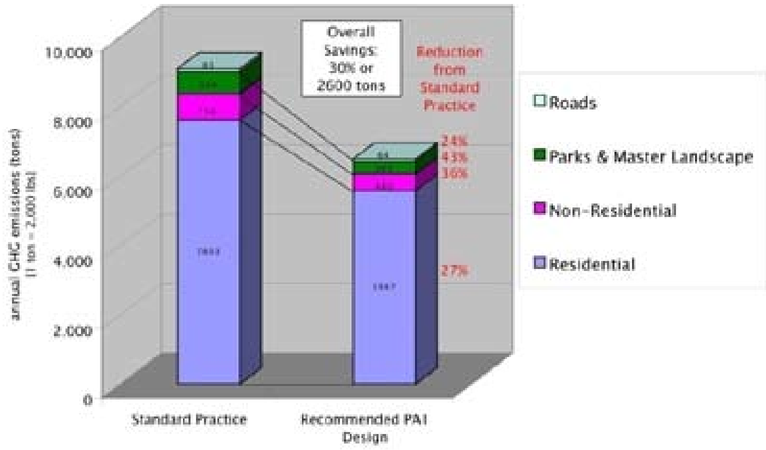

Figure 8 Annual GHG Emissions.

Still another useful approach is to compare the environmental impacts to the construction costs of various measures, and to the Return-on-Investment (ROI) of the measures (the annual rate of return on economic savings from the analyzed sustainability measures). An example of this multi-variate analysis is shown in Figure 9 below.

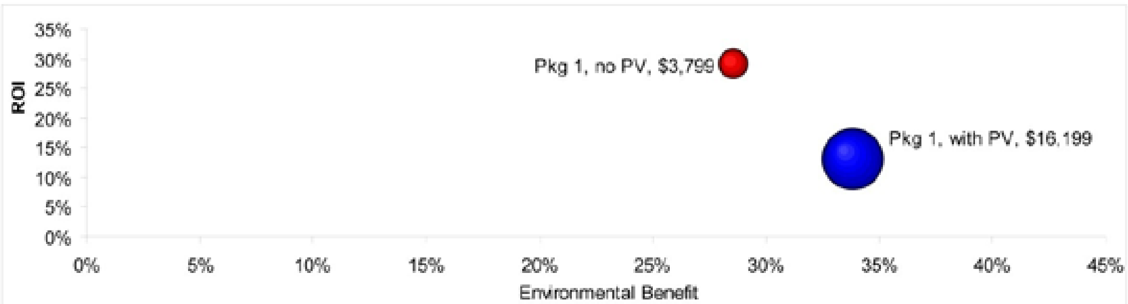

Figure 9 Environmental Impact vs Economic Returns.

One of the most interesting abilities of the model is the comparison of the total environmental impact of different sustainability measures which are otherwise not commensurable. This is accomplished by computing the total environmental impacts of the community with and without the specified measure. The impact here is measured as the percentage reduction of the sum of energy consumption, water consumption, air pollution emissions, stormwater runoff. This can be done with or without a weighting scheme to vary the effect of each separate environmental element. In Figure 10 below, an example output graph is shown for a project in which no weighting is used (i.e. all environmental impacts are considered of equal weight); a discussion of the possible impacts of weightings is beyond the scope of this paper. Thus, in Figure 10 the measures with the highest impact are shown towards the left end of the X-axis, with declining impacts as one moves further to the right of the graph. As a separate data point on the graph, the absolute cost of each sustainability measure is shown as a diamond on the graph.

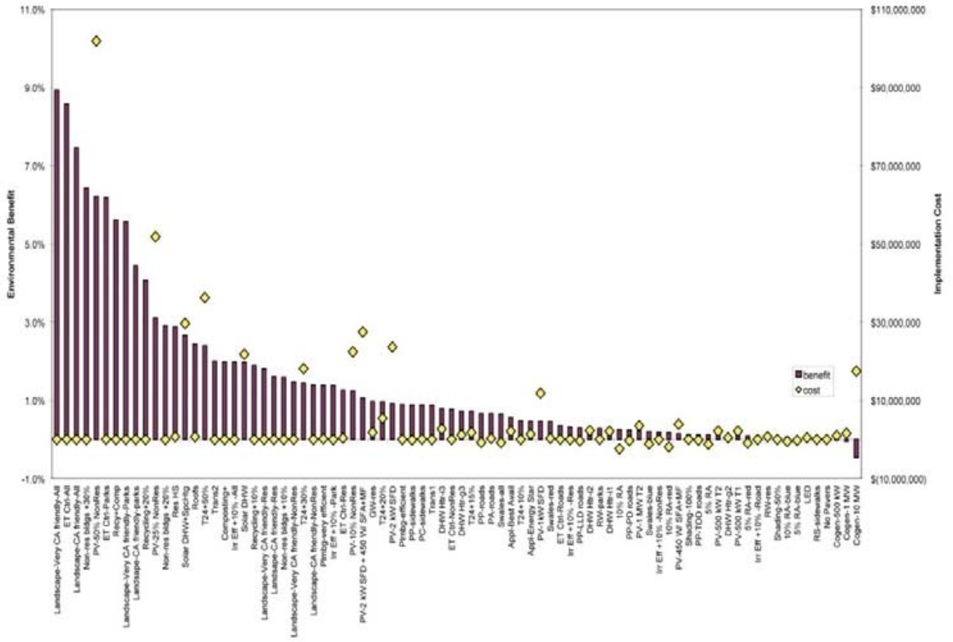

Figure 10 Environmental Impacts and Costs.

Perhaps a more useful way to look at the combination of the impact and cost of each sustainability measure is as shown in Figure 11, which is the "Cost-Savings Ratio" for each measure. This is computed as the ratio of the Environmental Impact Reduction (the left-hand axis of Figure 10) to the First Cost of each measure (the right-hand axis of Figure 10). Thus, measures with higher impact and/or lower cost will appear to the left of the X-axis on Figure 11, whereas measures with lower impact and/or higher cost will appear towards the right. Note that the first 14 measures shown at the left end of the X-axis actually have a cost *savings* for the measure, so that there is both an environmental benefit *and* an economic benefit to those measures.

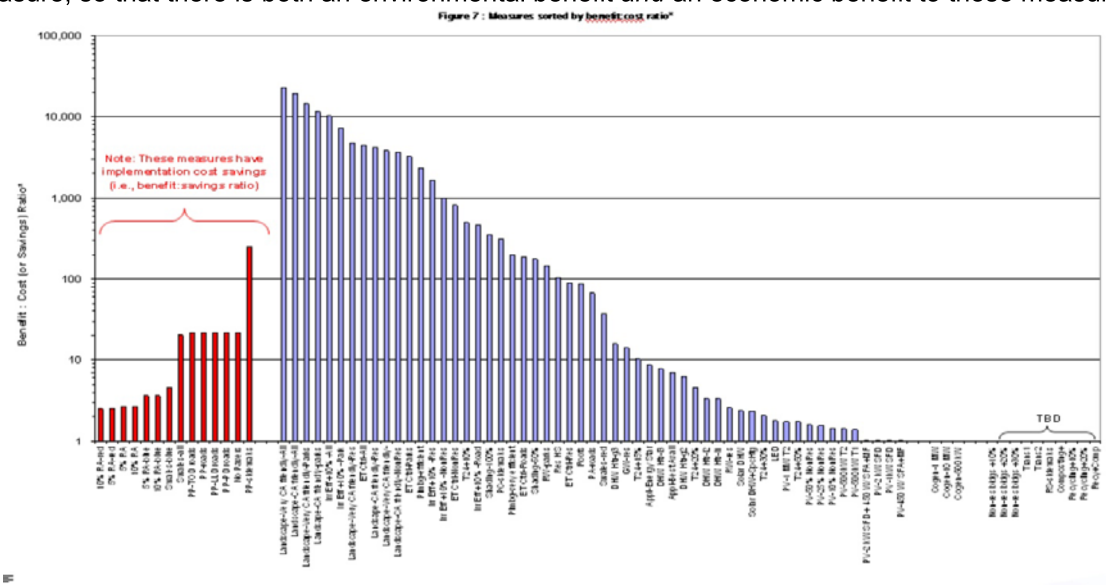

Figure 11. Measures Sorted by Benefit-Cost Ratio.

The types of decisions enabled by using the SCM include the following:

- Trade-offs of building energy conservation vs. transportation options to minimize total carbon footprint of community for a given capital cost.
- Design of "smart streets" that combine traffic calming, stormwater control, landscaped rights of way, reduced paving areas, etc. in a way that optimizes the total environmental benefits.

- Development of community greenhouse gas reduction goals to comply with environmental review requirements under the California Environmental Quality Act (CEQA).
- Justification for increased density and increased number of residential units by demonstrating that the environmental performance of the community overall and compared to key metrics would be reduced (on both a total and per capita basis).

The tool also enables evaluation of the impacts of different information on different decisions by different stakeholders:

- For Policy Makers:
  - The opportunities for environmental impact mitigation through various policy options.
  - Quantification of the environmental impacts from real project design options.
- For Developers:
  - The costs and benefits of project infrastructure design
  - The potential impacts of design guidelines for the buildings
  - Setting measurable quantified goals for sustainability of the project.
- For Builders (of the buildings):
  - The costs and impacts of specific design decisions on building performance.
  - The ability to quantify value of cost increases to prospective home-buyers.
- For Homebuyers and Tenants:
  - The potential savings and returns of any increased “green” premiums on buildings.
  - Quantified environmental impacts in terms they can understand.

Box 1. Challenges for Sustainable Projects that are Facilitated by the CTG SCM

- High construction & housing costs
  - utility savings, improved cash flow, energy efficient mortgages,
- Slowing housing market
  - sustainable developments = competitive advantage
- Bewildering array of competing & confusing “Green” programs
  - Need a project-specific analysis of what makes sense.
- Daunting number of “sustainability” decisions & tradeoffs
  - Quantify benefits, utility savings, and environmental impacts
- Limited money to implement
  - Optimize “Bang for the Buck”
- Consumer education & buy-in
  - Translate vague undefined “green” to real dollars saved, tons of air pollution reduced, gallons of stormwater reduced, etc.
- Need to identify and defend project design features and mitigation measures that save energy and reduce greenhouse gas emissions
  - Identify cost-effective features to reduce greenhouse gas emissions
  - Evaluate community-wide goals based on feasible packages of features

4. Conclusions

The CTG SCM is a systems-based, integrated modeling environment which has been developed for and applied to the real-world development planning process for major mixed use development projects pursuing cost-effective and measurable sustainability goals. The SCM provides the flexibility needed to accommodate changes in the level of detail and specification common to design processes. Early in the planning phases, the SCM helps project teams understand the “big picture” by supporting scoping and schematic analyses. As project specifications become known, the SCM can answer progressively more complex and nuanced questions. Late in the process, the SCM can inform critical design trade-offs with quantitative analysis about their cross-cutting implications. As projects transition into sales and operations, the SCM can evolve to support marketing, education, and performance monitoring. This provides the ability to support an entire sustainable community planning and design process for developers, builders, homeowners, and even public policy makers.

EVALUATION ON SUSTAINABILITY OF URBAN ENERGY SYSTEM BY ENERGY FLOW ANALYSIS

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Keywords: Energy Flow, Sustainability Index, Residential Sector, Urban Heat Island.

Summary

In this paper, the urban energy flow of Osaka City, Japan is estimated. The energy flow consists of supply, conversion, consumption and discharge of energy. Since Osaka City is the third largest city in Japan, it provides a base for further urban energy investigations. The energy flow in the residential and non-residential sector is estimated by a detailed end-use simulation model. For the residential sector, this simulation model considers the diversity of households and building types in the city. For the non-residential sector, energy consumption in the city is estimated from district energy uses classified by district characteristics (e.g. central business district, commercial district, residential district, etc.). For the industrial sector, energy flow is estimated from 1997 data by considering the reduction of factories, shut down of blast furnaces and power plants. For the transportation sector, the latest statistics are used for estimation. The estimated energy flow chart of Osaka City for 2005 is made and compared with the energy flows in 1997.

In the latter part of this paper, an index for evaluating sustainability of urban energy flow is discussed. In addition the impact on the atmospheric environment, global environment, urban heat island, non-renewable resource consumption, eco-efficiency are evaluated. In addition, exergy flow of the residential sector is estimated for evaluating the thermodynamic efficiency of energy consumption.

1. Introduction

Activities in modern cities are supported by enormous artificial flows of material, energy and water. These flows cause various kinds of impacts on urban, regional, and global environments. For example, an expansion of energy flow means an increase in consumption of non-renewable resources and an increase in emissions of CO_2, other air pollutant and waste heat, which is one of the important factors of urban heat island phenomenon. The residential and non-residential sectors especially have considerable percentages of energy flows in urban areas and their energy flows have close relationships with other sectors. Therefore, it is very important to estimate the potential of energy saving measures of building stocks on total urban environment by clarifying total energy metabolism in the city. In addition, since energy flows of residential and non-residential sectors indicate the average energy efficiency of the building stock in the city, appropriate measures for improving existing buildings' energy efficiency can be discussed by evaluating energy flows.

The authors (Shimoda et. al. 2000a and Shimoda et. al. 2002) estimated energy flows of Osaka City (Population: 2.6million [Third largest in Japan], Area: 209km^2) as of 1997 for industrial, transportation, residential and non-residential sector and evaluated the energy flow from the viewpoint of environmental impacts on urban heat island, global warming and local/regional atmosphere.

In this paper, energy flow of Osaka City as of 2005 is estimated and compared with the energy flows in 1997. The energy flow in residential and non-residential sector is estimated by detailed end-use simulation model. These models enable us to estimate energy flows of each end-use, to estimate the effects of energy saving measures for appliances and buildings, and to evaluate energy flows by thermodynamic (exergy) efficiency.

In the latter part of this paper, an index for evaluating sustainability of urban energy system is discussed. Sustainability of energy system is a synthetic concept and may consist of several aspects: environmental load on inside/outside the city; rate of non-renewable resource consumption; efficient utilization of energy for required and appropriate amount of service. In this paper, quantification methods for these indexes are investigated.

Bose et. al (1996) optimized the energy flow in Delhi, India for the objectives include minimizing energy demand, maximizing capacity utilization, minimizing energy expenditure, minimizing emissions of pollutants and minimizing energy resources. Ivancic (2004) analyzed and diagnosed energy flow in Barcelona, Spain. Energy and Environmental Balance Simulator of the city is developed and it was used for future perspectives and scenario analysis. For estimating energy flow of residential sector, a geographical information system and cooling and heating load simulator were used.

2. Estimation of Energy Flow in Osaka City.

An urban energy flow chart consists of energy inflow classified by energy source, energy conversion (electricity generation), energy use classified by sectors and end-uses and anthropogenic heat release. Since the climate condition during summer in Osaka is severe, energy flow must be evaluated from the viewpoint of heat island phenomena caused by anthropogenic heat release. Therefore, the anthropogenic heat release is classified into sensible heat, latent heat and waste heat to water system respectively since these impacts on air temperature are quite different.

2.1 Industrial Sector

Energy consumption in the industrial sector is evaluated from the survey results for large facilities and estimates for the other facilities as of 1997. The change of energy flows due to shut down of facilities in the last decade are estimated. In addition, the change of energy flows due to the change of blast furnaces to electric furnaces in steel plants is also considered. Energy flow in power plants is modified using the data of 2005.

2.2 Transportation Sector

In the transportation sector, gasoline and diesel oil consumption by automobiles, trucks, busses and electricity consumption by trains are estimated from the statistics of 2006.

2.3 Residential Sector

Energy consumption in the residential sector is estimated by the detailed energy end-use simulation model developed by the authors (Shimoda et. al, 2007). This simulation model considers the diversity of household and building types in the city. For each category of household, energy consumption is simulated by the aggregation of each appliance's energy use schedule based on occupant's behavior. Energy use for heating, cooling and hot water use is calculated from the heat load calculation. Figure 1 shows the estimated energy flow. Such a detailed estimation enables us to evaluate the energy metabolism with understanding for which purpose and by which appliance energy is utilized and with which form of anthropogenic heat is discharged to environment as shown in figure 1.

In the residential sector of Japan, most of the energy is used for heat consumption such as heating and hot water supply. Among home electric appliances, energy use for refrigerator is largest.

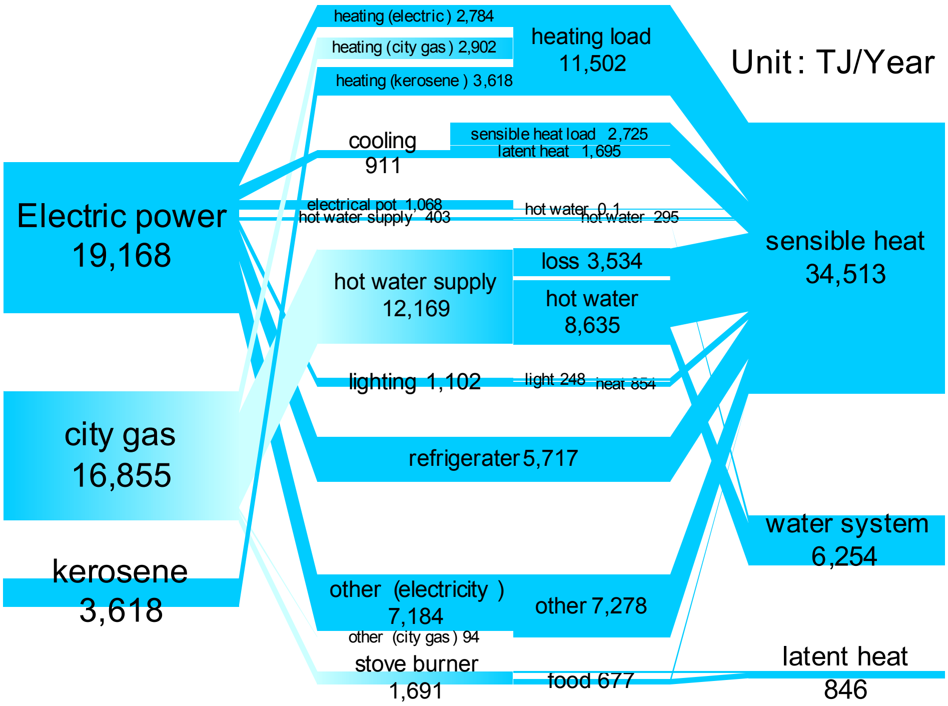

Figure 1 Energy flow in residential sector.

2.4 Non-residential Sector

For the non-residential sector, energy consumption in the city is estimated from energy use of the district classified by its district characteristics (e.g. central business district, commercial district, residential district, etc.) (Yamaguchi et. al. 2007). For each district, energy consumption is estimated by aggregation of each building's energy simulation which includes bottom-up simulation of equipment energy use and dynamic heat load calculation. Figure 2 shows the estimated energy flow for non-residential sector in Osaka City. The central business district, which is only 2.5% of total city area, consumes 27% of total energy use of non-residential sector.

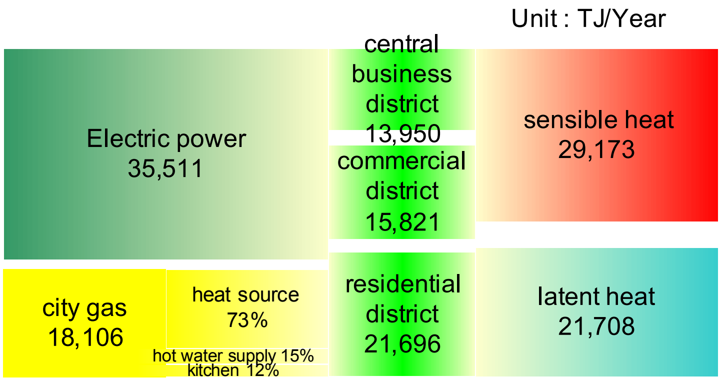

Figure 2 Energy flow in non-residential sector.

2.5 Total Energy Flow and Comparison with 1997 Energy Flow

Estimated energy flow in Osaka City is shown in figure 3. Total energy input to this area is 313,747TJ/year. As a composition of energy sources, both electricity and natural gas each occupy one-third of the total. Excluding the power generation sector, total energy consumption is 237,696 TJ. It means 1.5% of energy end-use in Japan concentrates only 0.06% of national land. The ratios of industrial, residential & non-residential and transportation sector are 28%, 39% and 23%, and the ratio of residential & non-residential sector is quite large compared to the ratio in Japan (28%).

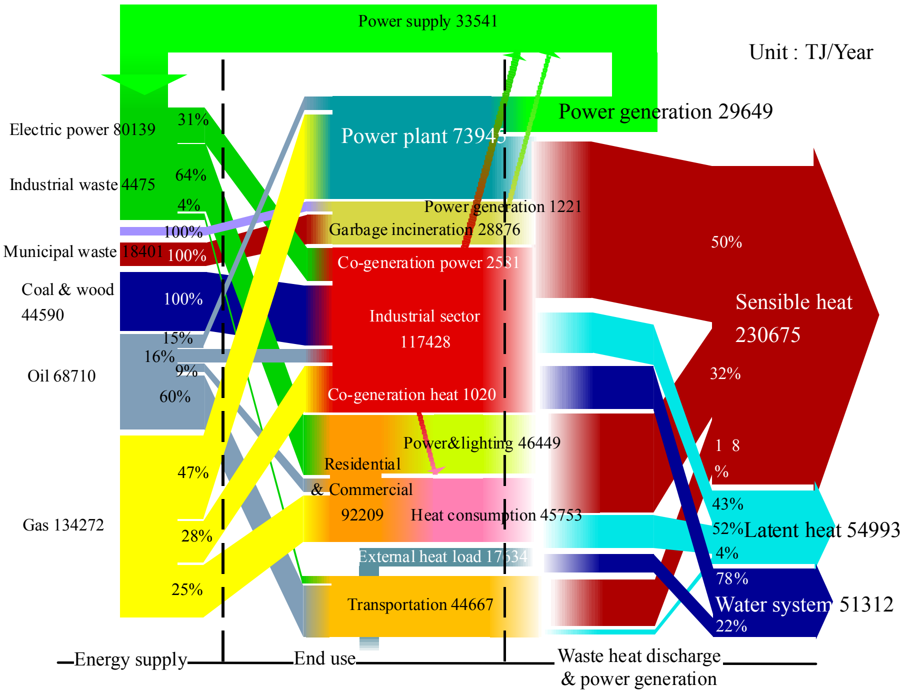

Figure 4 Energy flow in Osaka City (1997)

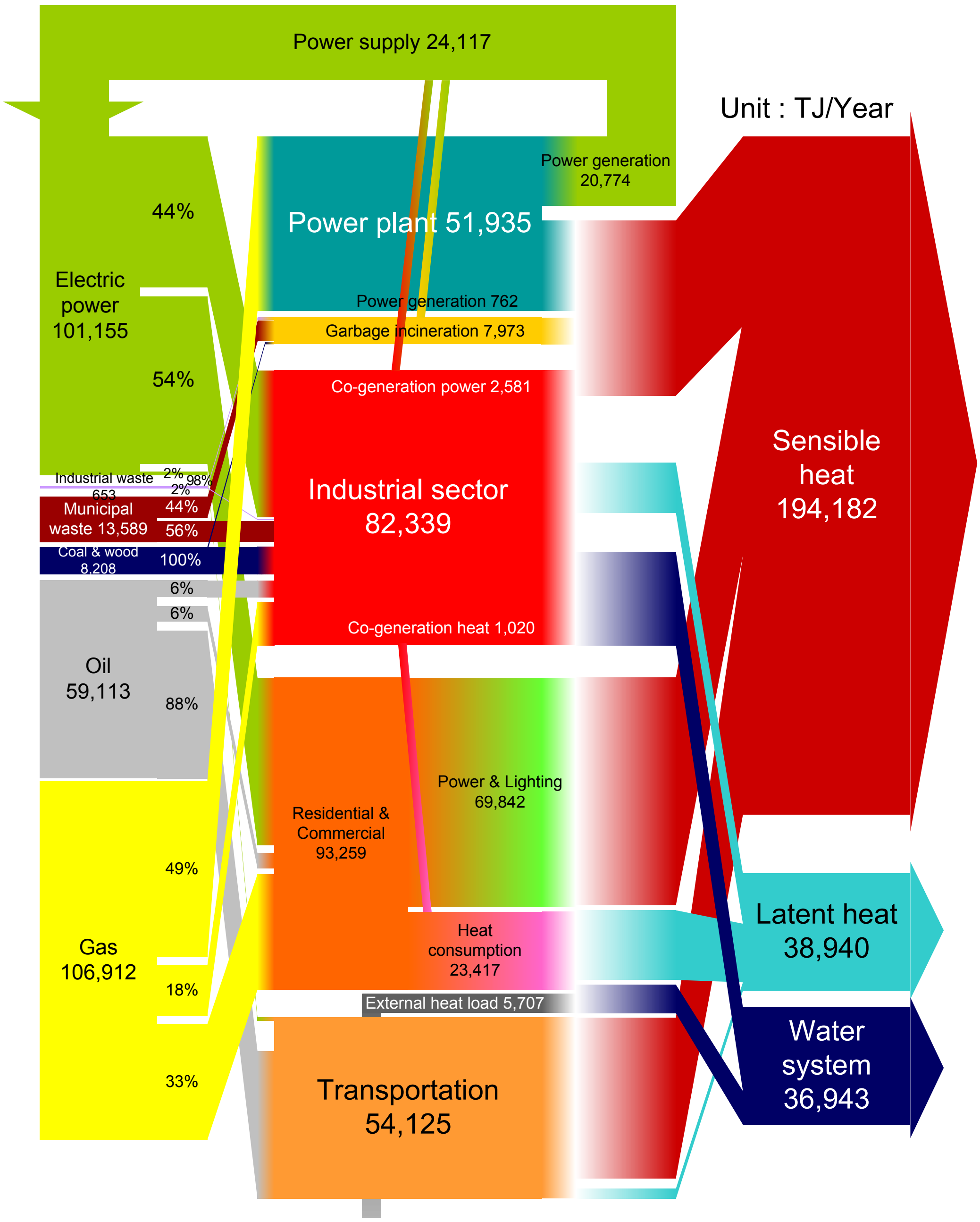

Figure 3 Energy flow in Osaka City (2005)

Figure 4 shows the energy flow in Osaka Prefecture in 1997. In total, energy consumption in Osaka City decreased from 1997 to 2005. The reduction of coal use is particularly large. Most of this reduction is due to the conversion of blast furnaces to electrical furnaces in the steel plant. On the other hand, energy use in the transportation sector has increased by 18%. No significant change occurred in the residential and non-residential sectors, while it should be noted that the method of estimating the energy flow for this sector is different between the result for 1997 and 2005.

3. Evaluation of Urban Energy Flow.

3.1 Sustainability Index of energy flows

Sustainability is a multidimensional problem. As an index of sustainability in urban energy flow, we propose three kinds of index as follows:

- Magnitude of environmental load on city/regional/global environment.
- Rate of non-renewable resource consumption.
- Efficiency in utilization of energy for required service.

Quantitative evaluation methods for these indexes are examined as follows:

3.1.1 Environmental Emission

The environmental load due to energy use in Urban Area can be classified into the following three categories: (1) air pollution; (2)greenhouse gas emission; and (3) thermal pollution (i.e. urban heat island).

(1) Air pollution: In air pollution, the magnitude of environmental impact depends on not only the amount of pollutant but also on the place where the emission occurs. Therefore, the authors developed a database which shows the link between the unit consumption of energy end-use (electricity, city gas and oil) and the amount and the place of air-pollutant emission, greenhouse gas emission and resource consumption. This database considers not only the direct emission but also indirect emission such as extraction of fossil fuel and marine transport. Table 1 shows the estimated atmospheric emission for unit electricity consumption. Figure 5 shows the total amount of air pollutant emission due to energy flows in Osaka City classified by the place of emission. Excluding the on-site emission, emission at the marine transport and extraction occupied large portion. The ratio of residential and non-residential sector in the total emission is much smaller than the ratio of energy consumption (39%). This is due to cleaner energy sources such as electricity and natural gas are mainly used in this sector.

Table 1. Estimated Environmental Emission for Electricity

	Extraction	Marine Transport	Domestic refinement	Power plant
kg-CO_2/MWh	16.6	3.9	8.4	354.0
g-NOx/MWh	20.8	42.5	15.3	41.4
g-SOx/MWh	12.9	12.0	6.8	21.8

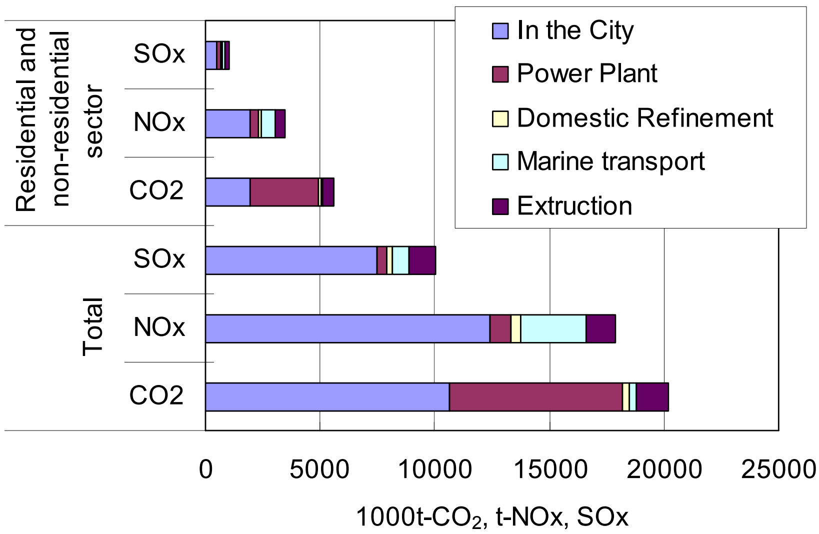

Figure 5 CO_2, NOx and SOx emission due to energy consumption in Osaka City classified by the site of emission.

(2) Greenhouse gas emission: In this paper, only CO_2 is considered as a greenhouse gas. As well as air pollutant, CO_2 emission due to the energy use in the city is estimated from the database which considers indirect emission as shown in table 1 and the result is shown also in figure 5. Large amounts of CO_2 are emitted at the power generation plant outside the Osaka City, especially in the residential and non-residential sector. 54% of the CO_2 emission occurs at the power generation plants. In the residential and non-residential sector, CO_2-emission per person is 2.12t-CO_2/person, which is smaller than the Japanese average (3.05t-CO_2/person).

(3) Thermal pollution (urban heat island): Usually, the urban heat island phenomenon is a serious problem only in the densely urbanized area. Since the impact of anthropogenic heat release on air temperature varies according to the phase (sensible heat to atmosphere, latent heat to atmosphere or hot water effluent to water system) of anthropogenic heat, the energy flow chart distinguishes the anthropogenic heat release by the phase. As shown in figure 3, Total anthropogenic heat release is 277,986TJ/year and it corresponds to 28% of total solar radiation in Osaka City. 73% of total anthropogenic heat is released as the sensible heat, which has direct impact on air temperature. As well as the phase, time variation and horizontal distribution of anthropogenic heat release affect the magnitude of urban heat island. Therefore, grid database of anthropogenic heat release is necessary for evaluating on heat island impact of urban energy flow. (Shimoda et. al., 2000b)

3.1.2 Rate of non-renewable resource consumption

As a sustainability indicator of non-renewable fossil fuels and uranium ore, normalized weighted resource consumption NWR is used. This is normalized value of resource consumption index of EDIP method (Wenzel et. al., 1997) and calculated by equation (1). This index means the rate of non-renewable resource consumption toward the depletion. Electricity consumption is transformed to non-renewable resource consumption using our database.

$$\mathrm{NWR} = \sum_j \frac{\text{Annual consumption of resource }(j)\text{ per capita}}{\text{Known reserves of resource}(j)} \tag{1}$$

Calculation results for total energy consumption in Osaka City and the residential and non-residential sector in Osaka City are shown in table 2. Resource consumption rate of uranium ore and natural gas have a large portion among all non-renewable resources. Rate of non-renewable resource consumption in the residential and non-residential sector is corresponds to 40% of the rate of all sectors. The residential and non-residential sector occupies 39% in energy end-use and 28% in CO_2 emission. This suggests that the residential and non-residential sector accelerate the non-renewable resource consumption rate by depending on low-carbon but more scarce energy sources such as nuclear power and natural gas.

Table 2. Rate of resource consumption

	Osaka City (All Sectors)		Residential & non-residential sector in Osaka City	
	Resource consumption per capita	NWR(j) ($\times10^{-12}$ /year)	Resource consumption per capita	NWR(j) ($\times10^{-12}$ /year)
Coal	227.6kg	0.25	114.1kg	0.13
Oil	760.0ℓ	3.98	101.6ℓ	0.53
Natural Gas	1296.6kg	9.57	204.0kg	1.51
Uranium Ore	49.4g	10.77	35.2g	7.67
Total		24.56		9.84

3.1.3 Efficiency in utilization of energy for required service

One way of quantitative evaluation on sustainability of energy consumption is ‘eco-efficiency’ (OECD 1998).

$$\text{eco-efficiency} = \frac{\text{value of products and services}}{\text{environmental pressures}} \tag{2}$$

If energy consumption or CO_2 emission is selected as an indicator of ‘environmental pressure’ and population or GDP is selected as ‘value of products and service’, calculation results of eco-efficiency are as shown in table 3.

Table 3 eco-efficiency indicators

Indicators	Osaka City All sectors	Osaka City Residential & non-residential sector	Japan All sectors	Japan Residential & non-residential sector
Energy/population(TJ/Person)	0.090	0.035	0.122	0.034
Energy/GDP(TJ/Mil. Yen)	0.011	0.004	0.029	0.008
CO_2/population(t-CO_2/Person)	7.675	2.118	9.158	3.054
CO_2/GDP(t-CO_2/Mil. Yen)	0.945	0.261	2.169	0.723

These results suggest that energy use and CO_2 emission per GDP in Osaka City is smaller than the Japanese average due to the composition of industries in Osaka City where tertiary industries are dominant. However, more discussion is needed to evaluate these values, for example, difference in primary energy and secondary energy, difference in daytime population and night time population, composition of GDP, and so on.

Another way of evaluation is thermodynamic efficiency of energy consumption. In this case, energy flow (enthalpy flow) is transferred to the exergy flow. Exergy E_x is calculated by equations (3) and (4).

$$E_x = Q \times \varepsilon \quad \text{(in case of fuel)} \qquad (3)$$

Where: Q : Amount of energy (enthalpy)

ε :Exergy ratio

$$E_x = \rho \cdot V \cdot C_p \times \left\{ (T - T_0) - T_0 \ln \frac{T}{T_0} \right\} \quad \text{(in case of fluid)} \qquad (4)$$

Where: ρ : Density of fluid.

V : Volume of fluid

C_p : Specific heat of fluid.

T : Temperature of fluid [K]

T_0 : Temperature of environment [K]

The exergy flow of the residential sector in Osaka City is shown in figure 6. This is distinctly different than the enthalpy flow shown in figure 1. Exergy loss from space heating and hot water supply is quite large. For example, exergy efficiency of city gas (12,169TJ/year) to hot water (397TJ/year) is only 3%, whereas enthalpy (energy) efficiency is 71%. It suggests that use of low-level heat energy such as waste heat from other sectors and use of heat pump are more appropriate for such purpose and these measures have a great potential of energy saving. Therefore, exergy flow evaluation is an important index to evaluate the efficiency of heat consumption.

4. Conclusion

Drawing urban energy flow diagram enables us to grasp the composition of energy source used in the city, the composition of energy end-use in each sector, the composition of energy use of each appliance and the composition of anthropogenic heat release classified by phase at a glance.

In addition, several kinds of sustainability index such as greenhouse gas emission, air pollutant emission classified by the place of emission, rate of non-renewable resource (fossil fuel) consumption can be calculated from the urban energy flow diagram. The results show Osaka City's energy use in the residential and non-residential sector accelerates the rate of non-renewable resource consumption by depending on low-carbon energy sources such as nuclear power and natural gas.

The flow of exergy, which shows the thermodynamic efficiency of energy use, is also investigated. It shows that exergy flow evaluation is an important index to evaluate the efficiency and to suggest the better way of heat consumption.

Further discussion is needed for the appropriate area size and time span of basic unit for urban energy flow, synthetic evaluation method for sustainability indexes.

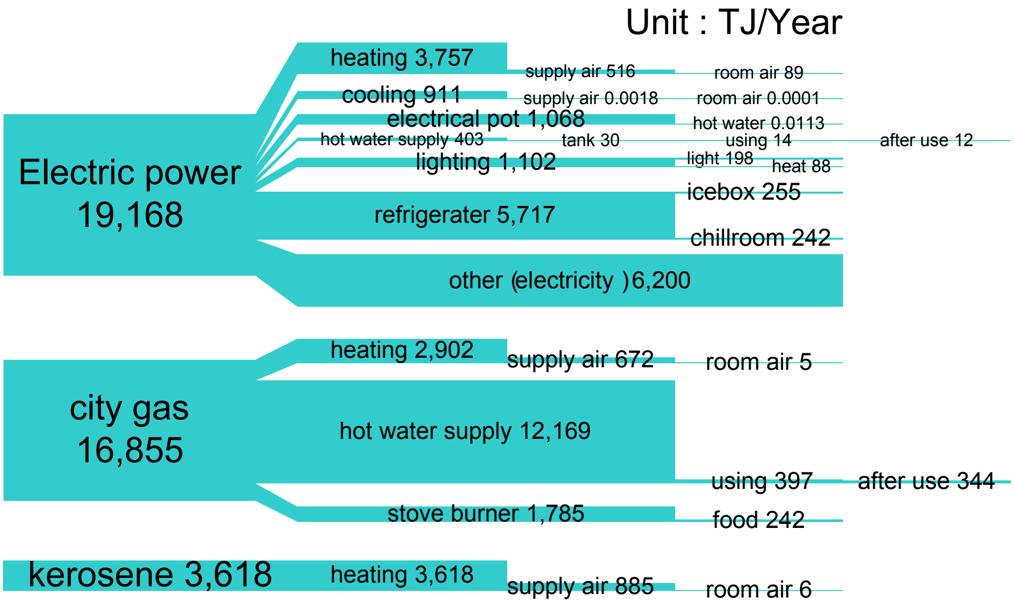

Figure 6 Exergy flow of residential sector in Osaka City.

Acknowledgement
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MICRO-CLIMATE STUDIES FOR HIGH DENSITY AND HIGH RISE SUSTAINABLE PUBLIC HOUSING DEVELOPMENTS IN HONG KONG

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Keywords: healthy living, sustainable community

Summary

Since 2004, Hong Kong Housing Authority initiated the comprehensive application of Micro-climate Studies in the planning and design of high density and high rise housing development using latest proven technologies, including computational fluid dynamics simulations and wind tunnel tests etc. These studies enable holistic consideration to optimize the development potential and enhance the built environment of the neighbourhood. They cover core topics of wind environment, natural ventilation, daylight and solar heat gain, as well as other special topics such as urban heat island effect, pollutant dispersion, etc. This Paper introduces the following key initiatives –

a) Passive design approach to enhance natural ventilation and pollutant dispersion of the domestic dwellings and public areas

b) Sun-shading and daylight studies to enhance the master layout and open space planning

c) Environmental façade design concept to mitigate solar heat gain and enhance human comfort

Up till March of 2008, over 30 public housing projects in Hong Kong have adopted the micro-climate studies, which provide greater human comfort for residents by enhancing sustainability with cleaner and greener environment for healthy communities.

1. Introduction

In the high-rise, high-density environment of Hong Kong, environmental performance of buildings has a significant impact on the public. High density living has the advantage of efficient land use, public transport and infrastructure, as well as the benefits of closer proximity to daily amenities. We have more than 7 million people living in 1,100 sq. km of which, only about 200 sq. km is developed and another 400 sq. km is devoted to country parks. There is a global trend in the shift from rural to urban populations and the corresponding increase in population densities and urban consumption patterns is reflected in every urban city.

About one-third of Hong Kong's population is residing in public housing. Among the stock of over 2,300,000 permanent residential flats, over 674,000 flats are public rental housing stock under the management of HKHA. It is always HKHA's prime objective to provide healthy living environment in sustainable housing developments. Environmental aspects of sustainable housing design comprises low energy consumption and high performance concept. In 2001, HKHA initiated the application of Micro-climate Studies, based on holistic approach, in the planning and design process of public housing developments to optimize the development potential and enhance the built environment of the neighbourhood. These Studies have recently won the Special Architectural Award 2006 organized by The Hong Kong Institute of Architects and the Annual Award 2007 organized by The Hong Kong Institute of Planners. The ensuing sections of this paper are to present some key features of the micro-climate studies in our planning and design process.

2. Wind Environment

We use the micro-climate studies as urban planning tool to optimize estate planning, disposition/orientation of blocks and building permeability to enhance wind environment for the housing development and as-built neighbourhood.

2.1 Site Wind Availability Data

Hong Kong lies in the tropical climate zone. With high rise and high density developments around the city, air ventilation condition with low wind speed, particular in urban areas, becomes common phenomenon. It is necessary to account for the characteristics of the natural wind availability of each housing development site. We make use of wind data from weather stations of local Observatory to qualitatively estimate the prevailing wind directions and magnitudes of the site for evaluation. For sites with weather stations nearby, wind rose with reduced set of prevailing directions covering most of the time in a typical reference year is vital for micro-climate studies whereas for those with specific site topography and being remote from weather stations, wind tunnel simulation test becomes more appropriate.

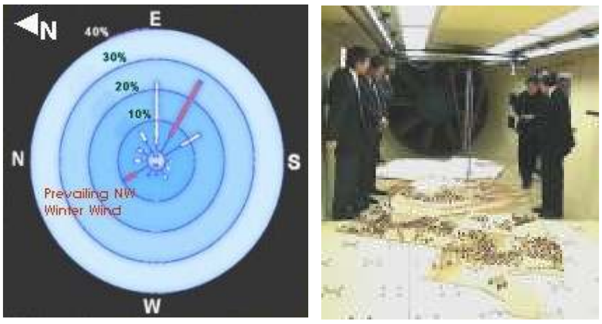

Figure 1 Wind Rose Diagram + Wind Tunnel Test

2.2 Air Ventilation Assessment (AVA)

Air ventilation assessment is an indicator to relate the wind availability of a city and the urban geometry, and to assess the built form's capability to optimize the available wind. This indicator addresses what minimum wind environment, and in what form, is needed to guide design and planning so as to achieve a better wind penetration into, and hence, air ventilation of the city, especially at the pedestrian level. It is represented by Wind Velocity Ratio –

$$VR_W = \frac{V_p}{V_\infty}$$

V_∞ is the wind velocity at the top of the wind boundary layer not affected by the ground roughness, buildings and local site features

V_p is the wind velocity at pedestrian level (2 metres from ground) after taking into account the effect of the housing development

VR_w indicates how much of the wind availability of a location could be experienced and enjoyed by pedestrians on ground taking into account of the as-built surroundings

With test points allocated at strategic site locations, wind velocity ratios at these points are identified to indicate the effects of different planning options of a housing development for comparison purpose. It is through comparison of different planning options in holistic approach that the optimal solution is derived.

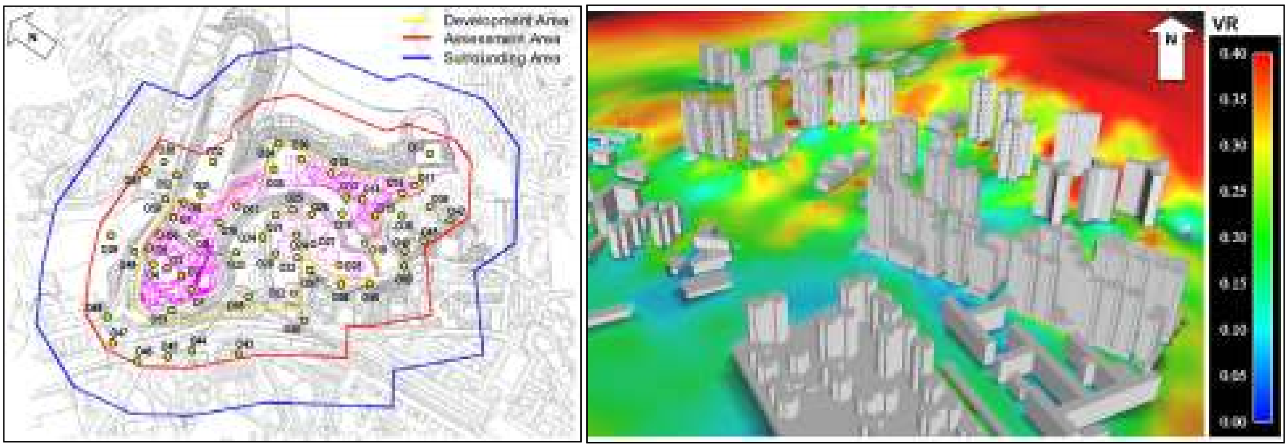

Figure 2 AVA Study for Choi Wan Road Housing Development

2.3 Wind Environmental Initiatives

In achieving the objectives to optimize estate planning, disposition/orientation of blocks and building permeability, we apply computer fluid dynamics (CFD) analysis to study the wind flow pattern and magnitude at low, mid, high zones of the high rise domestic towers (up to 40 storeys or above) for different enhancement measures in site planning and building design options, external circulation and open spaces, and impact on as-built surroundings. By comparing the micro-climate study results of various green initiatives, the most optimal planning and design option is worked out on both qualitative and quantitative basis in a scientific approach -

a) Effectiveness of “Wind Corridor” design, in quantitative terms, for enhancing site permeability for prevailing wind is identified by comparing simulation results of ‘Before’ and ‘After’ implementation of the development. The increase in air velocity with wind corridor under the prevailing “East” wind condition ranges from 18 to 250%.

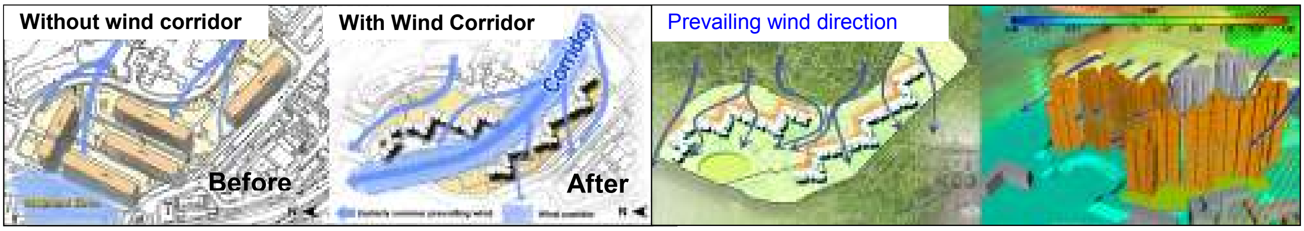

Figure 3 Environmental Performance “with and without” Wind Corridor

b) For constraint of narrow linear site configuration, design options for disposition and orientation (deviation up to 10 degrees) of domestic towers are compared to streamline the wind flow across the development and the as-built neighbourhood. In Figure 4, option 1 represents the wall effect in aligning the domestic towers along the frontage; in option 2, the domestic towers are inclined at 10 degrees with one another and truncated at the end wing to create the louver effect for enhancing wind penetration. The wind speed at open space between domestic towers increases substantially by 100 to 133% by adopting Option 2.

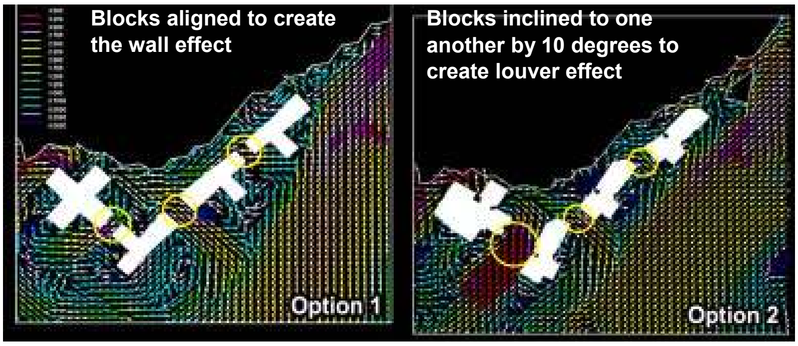

Figure 4 Environmental Performance with different orientation and configuration

c) CFD analysis is an effective tool for adjustment of variables in building separation and heights on site platforms at different levels to divert winds to lower levels. Site specific design options “with” and “without” full site coverage podium (based on same permeability condition) are compared for identification of the significant variance in building permeability for air ventilation at pedestrian level. The average wind speed and velocity ratio at street level (leeward side) increases by 13% and 14% respectively for the development without podium.

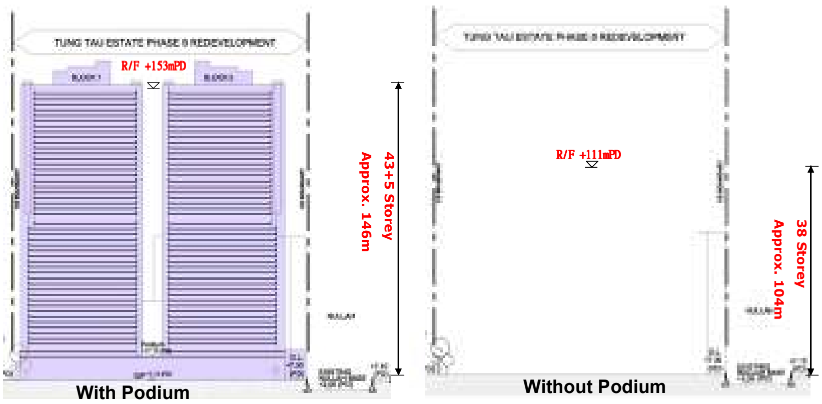

Figure 5 Environmental performance with and without podium

d) Urban greening filtrates the air flow and provides shade and cooling. To enhance the building permeability, a green deck garden is designed in one of the developments to link up the high rise domestic towers at 1/F level. It also extends the external garden into the habitable spaces.

Figure 6 First floor deck garden enhances building permeability with green filtration

3. Natural Ventilation and Pollutant Dispersion

We use the micro-climate studies as building design tool to optimize configuration of blocks, detailed architectural layout and window openings to enhance natural cross ventilation in habitable accommodations, public and circulation areas.

3.1 Natural Ventilation Initiatives

Functional and Cost-effective Design approach is developed to optimize the life cycle costing of public housing in Hong Kong, while meeting the crucial needs – comfort, safety, health and a quality living environment.

By simulating the wind flow pattern and magnitude of typical domestic units, lobby and public areas at low, mid and high zones of the high-rise domestic blocks, and ground floor entrance lobby etc., ventilation coefficients are determined to identify the ventilation performance of each design option at scheme design stage and fine tune the detailed design, in quantitative terms, to enhance natural ventilation with effective pollutant dispersion from toilet accommodations and refuse storerooms etc. -

a) Effectiveness of "Cross Ventilation Corridor" design for enhancing building permeability is reflected by quantitative results of 'With' and 'Without' the ventilation initiative. The increase in air velocity with cross ventilated corridor at selected points around the development ranges from 18 to 250%.

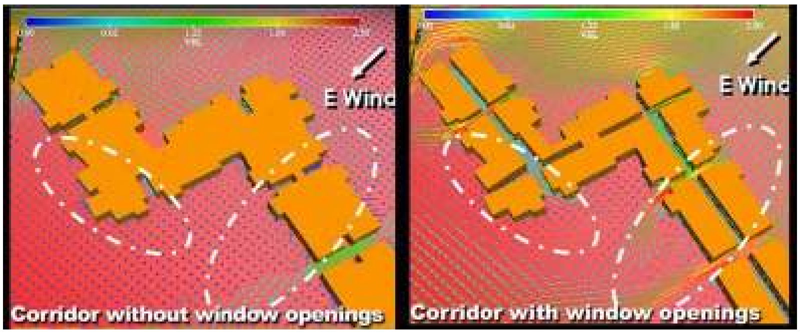

Figure 7 Environmental Performance with and without cross ventilated corridor

b) Effectiveness of "Wing Wall as Wind Deflector" for enhancing natural ventilation of domestic blocks at sites with low ventilation rate is reflected by quantitative results of 'With' and 'Without' of the ventilation initiative. In Figure 8, the wing wall increases the air velocity inside corridor under the prevailing wind condition by 2.5%.

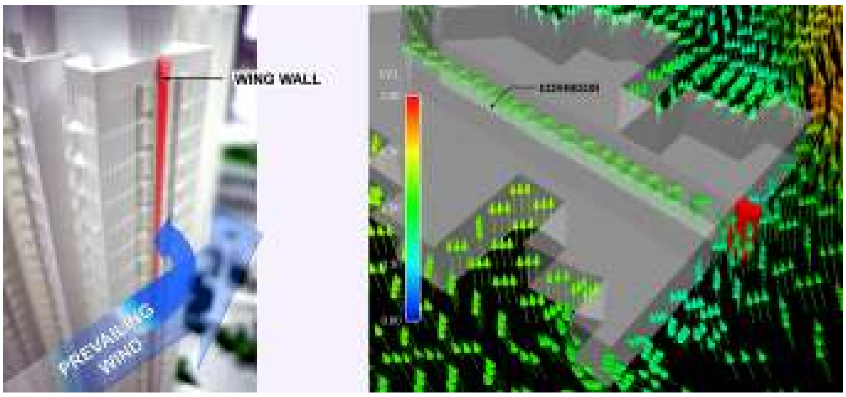

Figure 8 Environmental Performance enhanced by wing wall

c) Effectiveness of "Modular Design" for enhancing natural cross ventilation of domestic flats is reflected by quantitative results of the ventilation initiative.

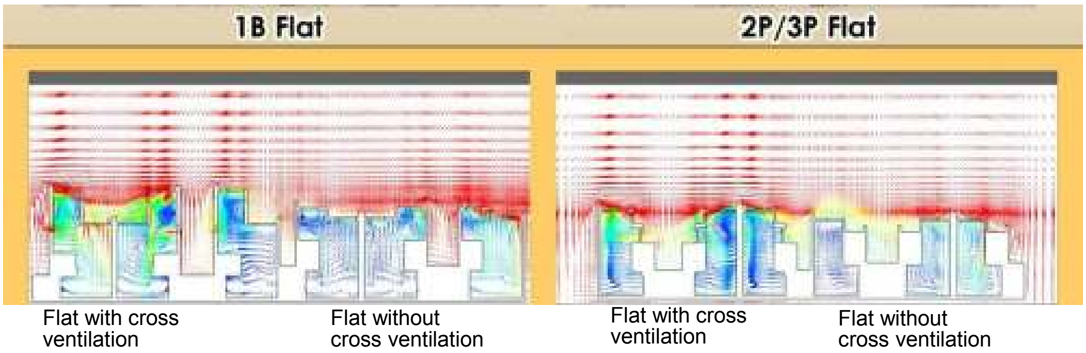

Figure 9 Comparison of ventilation performance for modular flats with and without cross ventilation

4. Daylight and Sunshading

We use the micro-climate studies as building design tool to optimize daylight penetration in domestic units and public areas of domestic blocks for energy efficiency, comfort and health, and optimize the passive and active open space layout planning within the development.

4.1 Natural Lighting Initiatives

Daylight has psychological effects and increases the comfort level of individual space. The amount of daylight on the surface of a building façade is related to the extent of its exposure to the natural environment. In high density and high rise developments, much of the daylight penetrating through window openings at lower floors come from the reflected light of the surrounding surfaces. We adopt the performance-based approach using "Vertical Daylight Factor (VDF)" (a ratio in percentage of the total amount of illuminance falling onto a vertical surface of a building to the instantaneous horizontal illuminance from an overcast sky) as a design tool for optimizing the natural lighting performance –

Figure 10 Natural lighting for modular flats and common corridor

a) Effectiveness of "Modular Design" for enhancing daylight penetration into domestic flats is reflected by performance based assessment.

b) Effectiveness of "Cross Ventilated Window Openings" for enhancing daylight penetration into the public areas of high rise domestic towers is reflected by performance based assessment. The windows at cross ventilated corridors bring about 13% saving in energy cost.

4.2 Sun shading Initiatives

High rise living renders it significant for environmental planning of the open spaces. Simulation of annual 3-D sun path diagram dedicated to Hong Kong context identifies the sunlight and shade pattern at external areas of the proposed housing development at different time of the day and different seasons of the year, taking into account of the site surroundings. It is an integrated design approach for optimizing the sunlight exposure to green areas, morning exercise and outdoor laundry space, sun-shading for leisure sitting, children play and ball courts, particularly for west facing open spaces –

a) Comprehensive performance-based open space planning for sustainable high density community: Activity areas that desire shading (e.g. children play area and foot massage trial) are planned at adequately shaded area. Areas exposed to sun heat most time of the day would be shaded by trees or shelters.

b) Detailed study of local landscaping layout by performance based assessment -

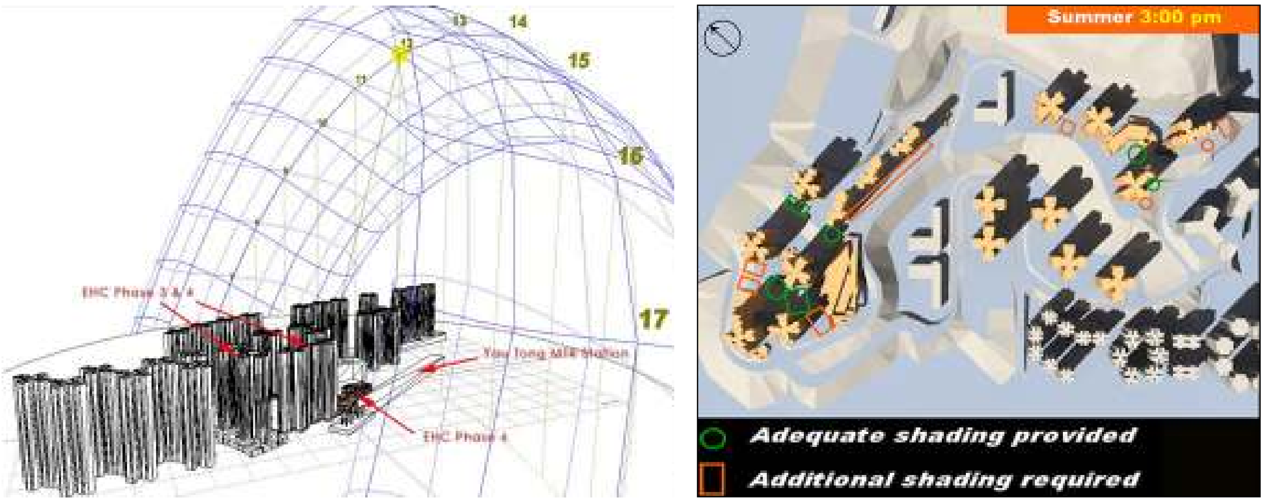

Figure 11 Using stereographic sun path diagram for open space planning

5. Solar Heat Gain

Hong Kong lies in the tropical climate zone. We use the micro-climate studies as building design tool to minimize solar heat gain in domestic units in order to have higher energy efficiency and better human comfort.

5.1 OTTV as an Indicator

The facade of a building is a complex system, comprising a range of components which coordinate to create a healthy living environment. Amount of energy saving resulting from a cost-effective and high performance facade design to maintain a thermally acceptable environment could be quantified through Overall Thermal Transfer Value (OTTV) which relates to fabric thermal mass, glazing, passive solar design, window design and shading devices. We have made use of the OTTV, as an effective indicator, for external wall colour scheme design.

5.2 Environmental Façade Design Initiatives

With the availability of latest proven simulation technology, we apply advanced computer programme which consists of modules of ventilation, thermal comfort and building energy analysis for computing the temperature profile for the internal environment of habitable rooms. Since the façade features that affect cooling load and achievable ventilation rates and daylight illuminance include (but not limited to) wall/roof construction, window/wall area ratio, glazing type, building orientation, configuration and separation, floor level, external wall finishes and colour, shading device etc., it demands an optimization study (e.g. Ant Colony Optimization (ACO) method etc.) taking optimization of the life cycle cost of the public housing blocks. We apply the study to design solar shading devices for reducing solar heat gain both on the building façade and in individual dwelling, to reduce the energy consumption on air conditioning and/or other mechanical ventilation means. In order to optimize the life cycle cost, the shading fins are integrated in the precast façade panels, taking into consideration of the transportation economy and loading for on-site installation.

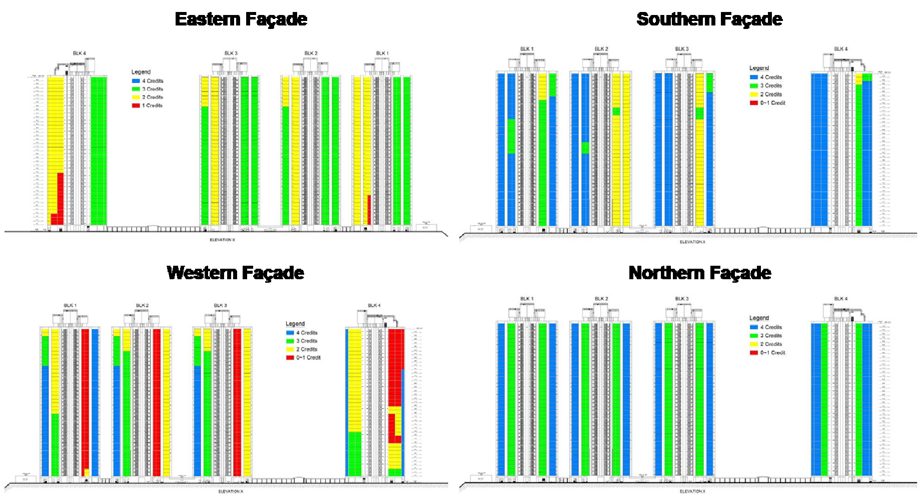

Figure 12 Climatic Colour Mapping in Environmental Façade Design

6. Miscellaneous

6.1 Holistic Environmental Planning and Design Approach

In terms of environmental planning and design, we adopt a holistic approach with balanced considerations on wind environment, natural ventilation and pollutant dispersion, daylight and solar heat gain etc. We apply a scoring system in working out the most optimal solution for the development. On-going researches are being conducted for establishment of local benchmarks. With a common goal and concerted effort by users, academia and researchers, regulators and practitioners, more healthy living environment will be created for now and the future.

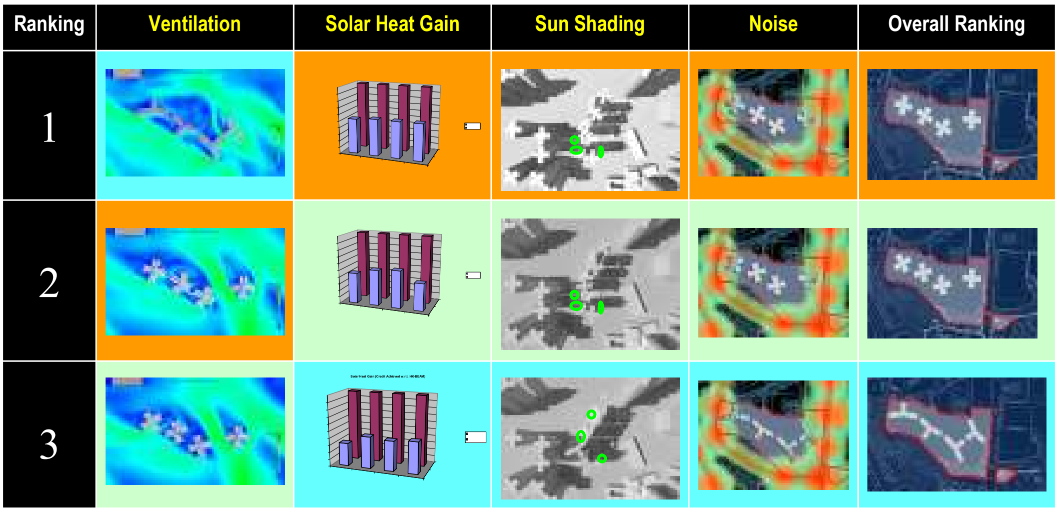

Figure 13 Comparison table on simulation results on different environmental aspects

6.2 Calibration of Simulation Tools at Planning and Design Stage

Apart from validating the simulation tools, we fine-tune the software by model calibration during the planning and design stages. Two completed high rise public housing developments with different micro-climatic conditions are selected for the model calibration. The process is composed of two parts, namely on-site measurement for actual field condition and model simulation for predicted field condition. The calibration exercise demonstrated the high accuracy of the simulation results with the software calibrated to local specific climatic conditions. The discrepancy is generally within 10%.

6.3 On-site measurements at Construction and Post Occupation Stages

Apart from fine calibrating the simulation tools, we conduct on-site measurements during the building construction and post occupation stages. The objectives of these on-site measurements are to -

a) test the effectiveness of current methodology adopted for the micro-climate study;

b) generate the data for the reference to benchmark the performance improvement of the projects as compared with the conventional design;

c) fine-tune the construction prior to building completion.

Initial results of on-site measurement for the projects on the pipeline indicated the actual wind environment, natural ventilation, daylight and thermal comfort conditions of the development under construction being comparable to the simulated ones at planning and design stage. Upon completion of the whole process, we shall generate field data for the statistical assessment of the study and establish benchmark for application in other projects.

Figure 14 On-site measurements for projects at construction and post-occupation stages

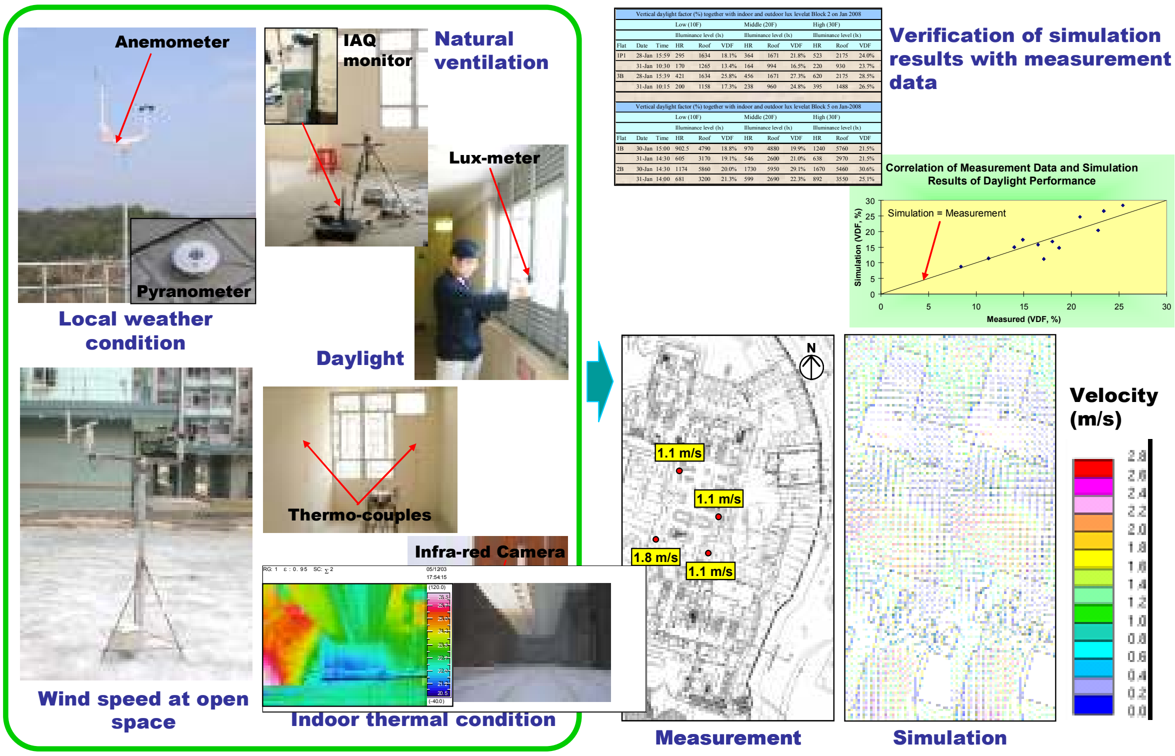

Figure 15 Process of on-site measurements

7. Conclusion

Public housing in Hong Kong has made an enormous contribution towards the well-being of the community. With the availability of the advanced simulation technology, the micro-climate studies are instrumental to improve the environmental performance for each new public housing development, which have long-term benefits to enhancing the built environment and quality of living of the society as a whole. Given a healthy living environment it helps to achieve a socially sustainable community. The application of the micro-climate studies in urban planning increases the practitioners' and public awareness of the importance of sustainable development in the society. This is a big challenge as well as an excellent opportunity to bridge the gap between policies and practice for the good of the coming generations. We need to continue to engage all stakeholders to gain their support as we articulate our strategies and lay out a road map in driving sustainability initiatives.

Acknowledgement

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EVALUATION OF NATURAL VENTILATION SYSTEM BY SIMULTANEOUS MULTIPOINT AIRFLOW MEASUREMENT

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Keywords: multipoint measurement, long-term measurement, thermal environment, heating value

Summary

This study is an evaluation of a natural ventilation system in a large laboratory. The laboratory utilizes more than one hundred of the most current techniques for energy saving in order to reduce loads on the environment. The natural ventilation system is one of the techniques used in this laboratory. The ventilation system serves as a heat exchanger for a hygienic air supply by the stack effect through window openings and towards a large atrium with roof outlets. This system is controlled automatically by the metrological date of the BEMS system. In this project, energy consumption, air flow characteristics and thermal environment of the natural ventilation system were measured using 34 anemometers and 64 thermometers. This study was conducted in Nagano, Japan. Nagano is a cooler city than Tokyo. The study was performed from September to October 2006 and from June to September 2007. The measured data shows that the natural ventilation system can effectively create a comfortable indoor environment and reduce the loads on the environment. The comfort range was acceptable as shown by the -0.5 to 0.5 PMV. This mean was that indoor was neither warm nor cool. The reduction of environmental loads was approximately 100 [MJ/㎡] during one year.

1. Introduction

A natural ventilation system is a promising strategy to achieve energy-efficient laboratories and office buildings. It is expected to not only reduce air-conditioning loads but also to improve the level of comfort indoors. Therefore, such a system is being introduced with increasing frequency.

However, a natural ventilation system has problems such as an unstable amount of ventilation, deterioration of the thermal environment, external noise, and the inflow of smells and dust. Also, there have been very few studies documenting this system. Because of these problems, some buildings have actually discontinued the system[1)]. Therefore, more information about the operation and control of this system is needed.

The purpose of this paper is to estimate the amount of energy saving, clarify the indoor thermal environment and determine the air flow characteristics of natural ventilation.

2. Outline of test building

The laboratory is a large building located in Nagano, Japan. The climate this is cool compared with Tokyo. The mean air temperature is 5^0C lower than Tokyo in 2007. Therefore it was expected that it is opened long time in summer season. This laboratory total floor space is approximately 13,000 [m^2] and the maximum height is 37.9 [m]. Therefore, the internal load is large. In order to achieve 64% reduction of CO_2 emission in comparison to the 1990 benchmark, this laboratory utilizes many techniques to reduce its loads on the environment. Figure 1 shows the outside appearance of this building and Table 1 summarizes some building characteristics.

Figure 1. Appearance of test building

Table 1. Summary of Building Characteristics

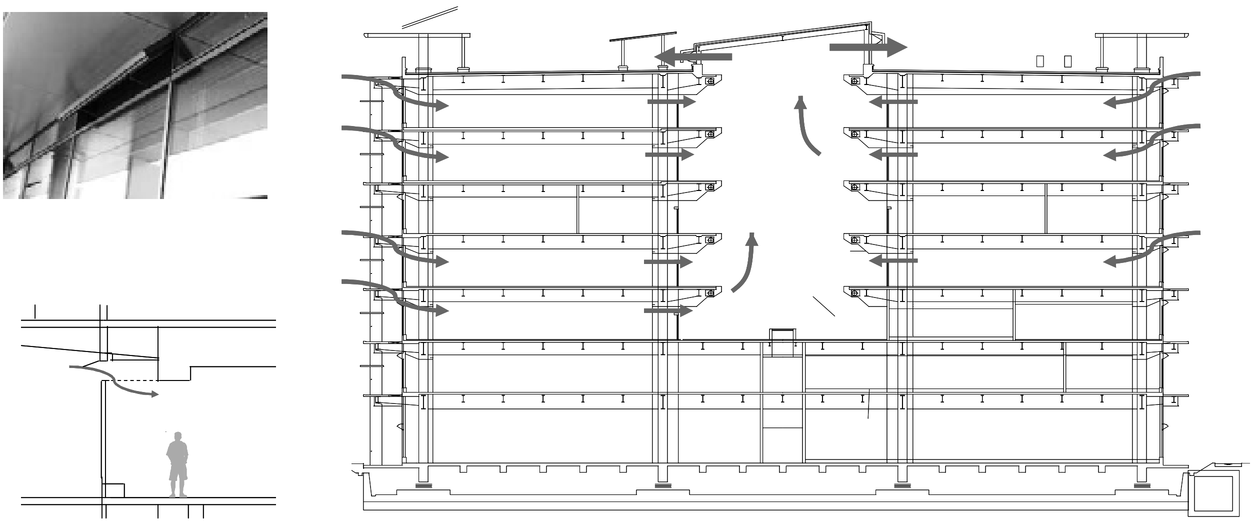
Location	Nagano in Japan
Use	Laboratory
Number of floors	Seven floors and an attic room
Total area	29,525m^2
Total floor space	13,178m^2
Maximum height	37.9m
Date completed	February 2006

3. Outline of natural ventilation system

Windows for natural ventilation are positioned in every office room from the second through the sixth floor and in an attic room. There is no controlled natural ventilation on the fourth floor and the north side of the second floor because these spaces are laboratories and a dining room. Figure 2 (a) shows a photo and outline of a window for natural ventilation. The window size is 1.6 [m^2]. Figure 2 (b) shows the natural ventilation system. Air flow into the office rooms, into the atrium, then upward and out through roof outlets. This system utilizes the stack and venturi effects. A switching operation is controlled by the Building Energy Management System (BEMS) and manual systems. The BEMS is dependent on the outside temperature, humidity and velocity from April to October (Table 2). This system is operated not only in the daytime but also during the nighttime as a night purge system.

Table 2. Building Conditions

		Day time	Night time	Attic room
	Time	8:00-22:00	0:00-8:00	Day and Night Time
Condition for opening	Indoor Temperture(Ti)	24^0C≦Ti	20^0C≦Ti	35^0C≦Ti
	Outside Air Temp.(To)	18^0C≦To≦Ti	15^0C≦To≦Ti	-
	Outside Dew-point Temp.(Tr)	5^0CDP≦Tr≦19.5°CDP	5^0CDP≦Tr≦19.5^0CDP	-
Condition for closing	Indoor Temp.(Ti)	Ti≦20^0C	-	-
	Wind Velocity(v)	15m/s≦v	15m/s≦v	18m/s≦v
	Rain	○	○	○

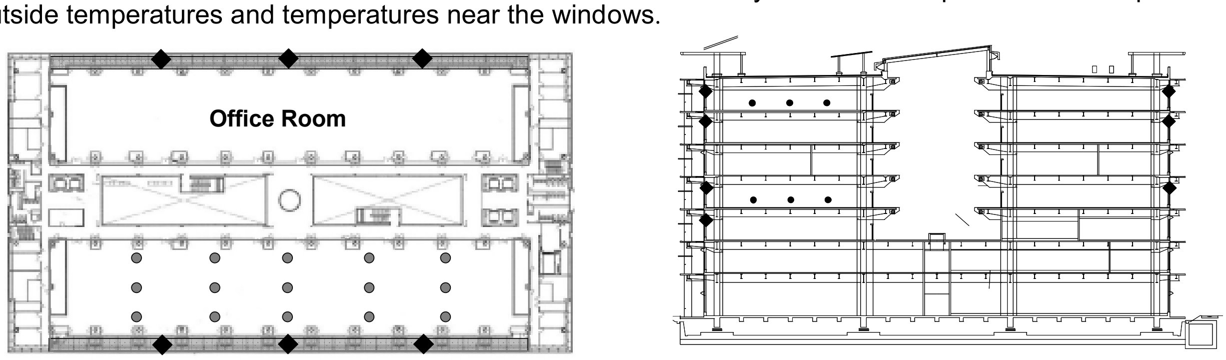


(a) (b)

Figure 2. Outline of natural ventilation system: (a) Photo and outline of window (b) Outline of entire system

4. Method

The opening and closing conditions of the windows, the indoor thermal environment and the amount of energy saving were investigated in this study. Figure 3 shows the positions of the sensors. Confirmation of the opening and closing conditions was obtained after two year of accumulating BEMS system data. The data were recorded in 10-minute intervals. Estimation of the indoor thermal environment was obtained by using 15 thermometers and 1 anemometer on the south side of the third and sixth floors from June to September 2007. The amount of energy saving was evaluated using 32 thermometers and anemometers near the window. In the direction of the air flow was determined by the relationships of indoor temperatures, outside temperatures and temperatures near the windows.



(a) (b)

Figure 3. Position of sensors: (a) Floor view, (b) Outside view

5. Results and discussion

5.1 Outside air temperature and wind velocity

Figure 4 shows the monthly averages of the outside temperature and wind velocity. The mean air temperature was 12.1 [^{0}C]. The maximum temperature of the monthly averages was 25.9 [^{0}C] in August 2006 and the minimum was 0.6 [^{0}C] in January 2007. The wind velocity was less than 4 [m/s] during the entire measurement time.

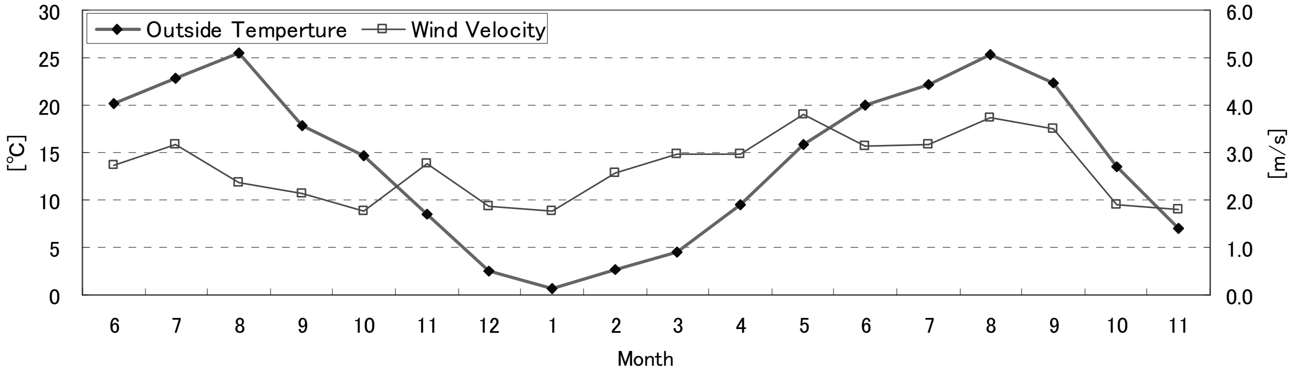


Figure 4. Monthly averages of outside temperature and wind velocity

5.2 Air flow characteristics by natural ventilation system

Figure 5 shows the air flow characteristics by natural ventilation when the velocity of the wind was 2 [m/s] and 10.1 [m/s]. As expected, the ventilation volume increased as the velocity of the wind increased. The air flow volume reached a maximum of 58,568 [m^3/h] when the wind velocity was 2 [m/s] and 245,444 [m^3/h] when the wind velocity was 10.1 [m/s]. For the 58,568 [m^3/h] volume, there were 11 air changes within one hour; for the 245,444 [m^3/h] volume, there were 45 air changes within one hour.

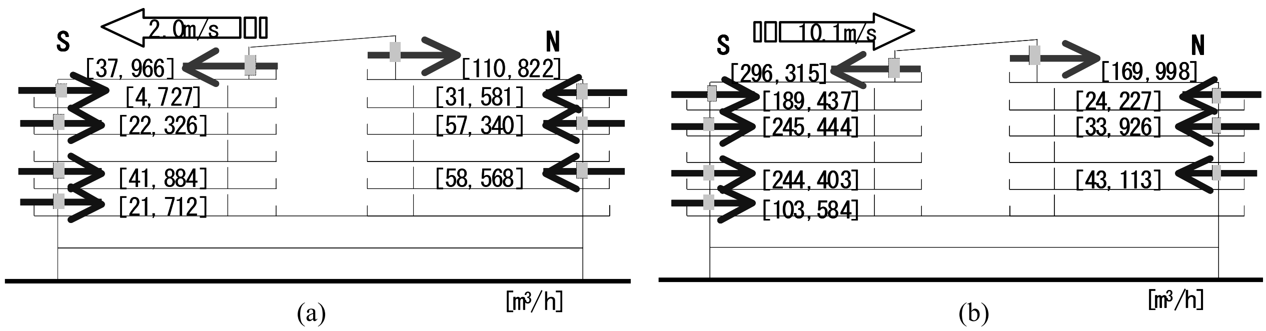


Figure 5. Air flow volume by natural ventilation: (a) Wind velocity 2 [m/s], (b) 10.1 [m/s]

5.3 Elapsed open time

Figure 6 shows the elapsed time for open windows from June 2006 to November 2007. The maximum elapsed time was 250 [h/month] in July 2007. This value of 250 hours is 34 [%] of that possible on July. The total amount of open window time was 1012 hours for one year. Even in the summer, the windows were opened, for example, 160 [h/month] in August. The reason is assumed to be that this laboratory is located in a cool climate. In the winter, the windows were a few opened though no control automatically. The reason assumed they were opened manually.

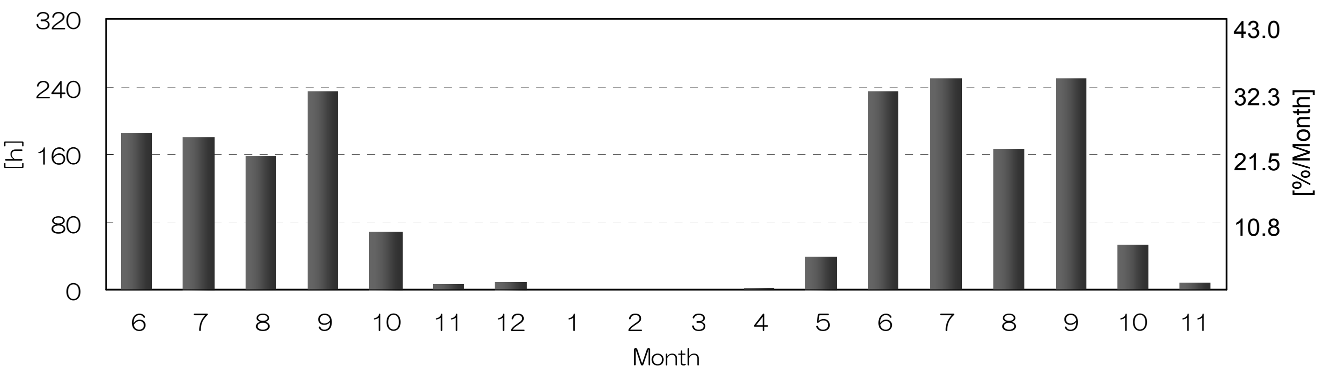


Figure 6. Elapsed time for open windows

5.4 Indoor environment

The indoor environment was compared for natural ventilation and air-conditioning. The maximum time at 26 [^{0}C] was 34 [%] for natural ventilation and the maximum time at 27 [^{0}C] was 58 [%] for air-conditioning (Figure 7(a)). In a comparison of the indoor wind velocity, the wind was less than 0.05 [m/s] for 62 [%] of the time for natural ventilation, and 91[%] for air-conditioning (Figure 7 (b)). Figure 7(c) shows the PMV evaluation for the natural ventilation. It was assumed that 0.50 was the [clo] value and 1.2 was the [met] value. The result from -0.5 to 0.5 is that indoor is neither warm nor cool. This result indicates that the indoor environment was comfortable.

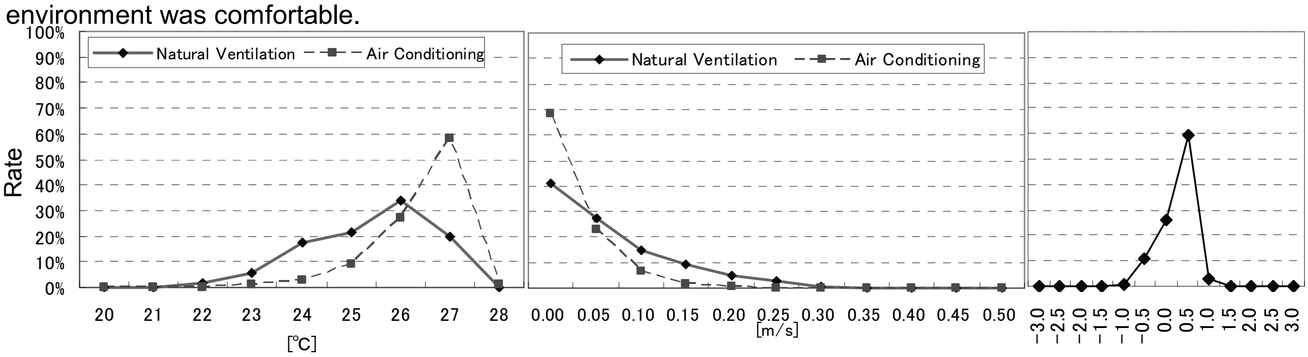
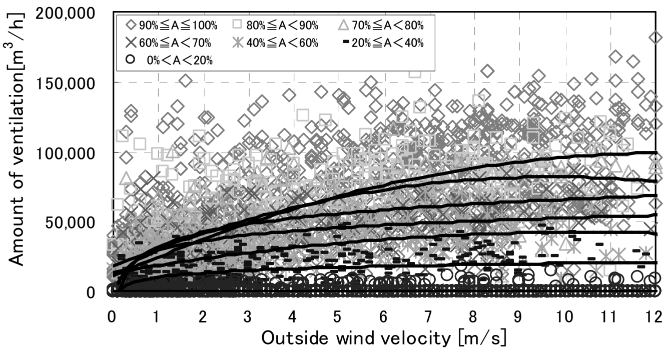
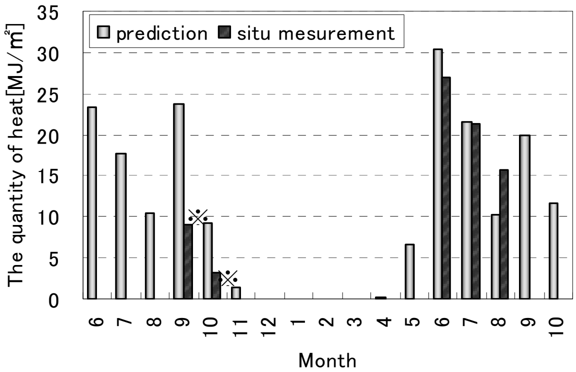


Figure 7. Indoor environment: (a) Indoor temperature rate, (b) Indoor wind velocity rate, (c) Evaluation of PMV

5.5 Amount of energy conserved

Figure 8 shows the relationship between inflow air and outside wind velocity. The line shows recentness carves by each rate of natural ventilation openings. This rate defined for all controlled ventilation windows is the ratio of opened ventilation windows to the total number of windows. Figure 9 shows the amount of energy saving by the natural ventilation system. The inflow air was assumed to be the relation of the outside wind velocity and the rate of natural ventilation openings. Therefore the amount of the inflow air during year was presumed from Figure 8. The situ measurements were smaller than the predicted measurements for September and October 2006 because the term was from shorter (17/09 to 13/10). The maximum energy saving (27 [MJ/m^2] heat saving) occurred in June 2007 for the situ measurement. The amount of energy saving was 103 [MJ/m^2] during one year.





※09/2006 situ measurement is 17/09/2006-30/09/2006
10/2006 situ measurement is 01/10/2006-13/10/2006

Figure 8. Relationship between outside wind velocity and inflow air   *Figure 9. Amount of energy saving*

6. Conclusion

This study estimated the reduction of loads on the environment and the influence on the indoor thermal environment by a natural ventilation system in a large laboratory building. This system was in operation 1012 hours during one year and the removed quantity of heat was 103 [MJ/m^2] during that one year. There was almost no difference in the operation time between the air-conditioning and natural ventilation system. For the natural ventilation system, the PMV evaluation was -0.5 to 0.5, which is that indoor is neither warm nor cool. This result indicates that the indoor environment was pleasant.

In summary, the natural ventilation system is efficient for energy conservation and can provide a pleasant indoor environment. It should also be noted that people can gain more pleasing effects from natural wind in comparison with air-conditioning. It is considered that this system has great potential for future applications.

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THE EVALUATION OF THERMAL PERFORMANCE IN THE SUSTAINABLE OFFICE BUILDING WITH ENVIRONMENTAL ADJUSTABLE SYSTEMS

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Keywords: Sustainable Office Building, Environmental Design, Double-Skin-Facade, Thermal Storage and Task Air-Conditioning

Summary

This report shows a summary of the actual building project which adopted the air conditioning load reduction method integrated with the building environmental design. Generally, the thermal load of HVAC system is one of the major energy consumption sources of a building. Reduction of such load shall play a significant role on the environmental effect, but often in return causes the decrease of work-environment performance. This paper introduces a case of low story building (with floor area of 20,000 m^2), and the project's environmentally-conscious design and the evaluation of thermal performance based on the field measurement.

1. Project Outline

The building is a headquarter office in the suburbs of Tokyo. It is a four story building. Its typical floor plan consists of two wing zone with an atrium in between. Each wing is pillar-less, and length of wing is 33.6 m x 38.4 m which is approximately 1,500 m^2. South Façade, typical floor plan and outline of the building are shown in Figures 1, 2, 3, and Table 1, respectively.

Figure 1. Facade of the building

Figure 2. Workplace in the building

Table 1. Outline of building

building data	Building type	Office
	Site area	4,782㎡
	Gross area	19,169㎡
	Stories	below:1F above ground:4F
	Highest height	25.81m
	Structure	SRC
M/E-data	Heat source system	Ice storage system with Gas fired absorption chilled and hot water unit
	Air conditioner system	Underfloor airconditioning system in interior zone
		perimeter-less system in permeter zone with double-skin
	Supply of electric power system	High voltage electric supply (main and sub)
	Water supply system	Public water supply and the utilization of rain water and the well water

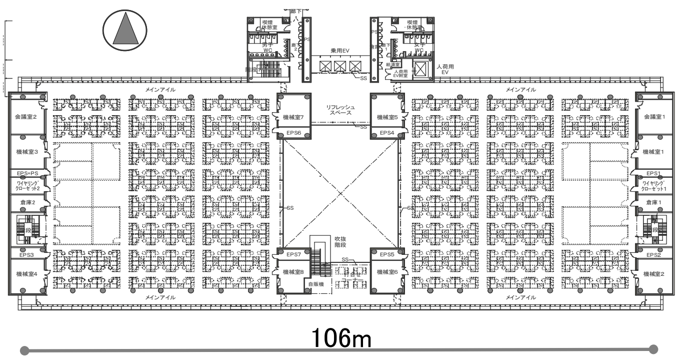


Figure 3 Typical floor plan

2. Environmental Design Concepts

This building is placed upon a quake-absorbing structure. The main air conditioning system is "under floor air conditioning". A concept of the environment design in this project is the introduction of the environmental adjustment technology which can maintain the both of energy saving and comfortable indoor environment. In addition, and these technologies are integrated with the design of building at the same time.

As for the building, peculiar design is made with full-scale glass on north and south side. The adoption of seismic isolation structures, the big span PC slab and the furniture layout by "Universal unit patterns" to achieve a high functional work space. The air conditioning system unified with these design concepts was proposed. The outline of the various techniques is shown in the Figure 4.

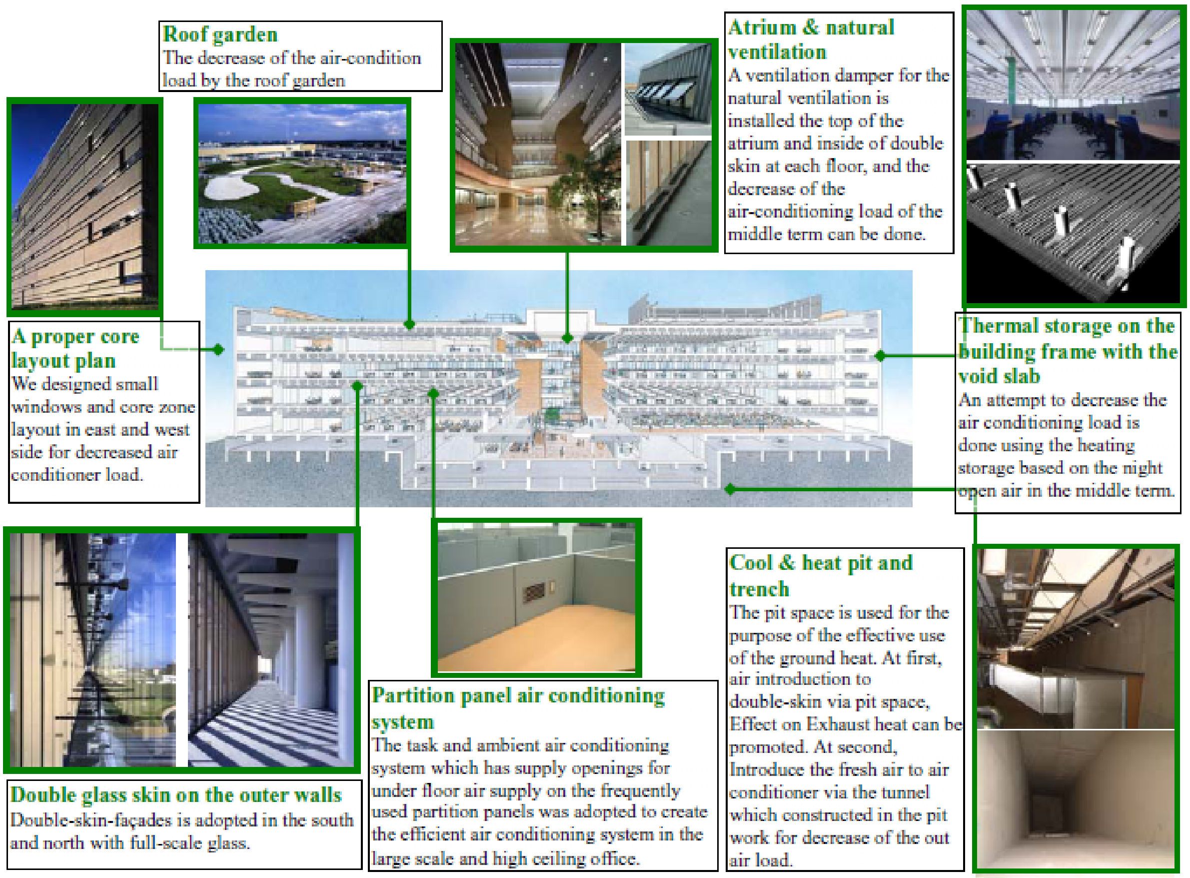


Figure 4. Main technologies of environmental design

2.1 System Outline of Double-Skin Façade (DS)

Double-skin façade (DS) covers the whole surface façade with glasses of full story height.

DS which has large scale opening will offer the comfortable work-environment from aspect of brightness and view. Under the climate of Japan, the double-skin glass is required to satisfy various functions such as the discharge of heated air between glasses in summer, the effective thermal insulation performance in winter and gaining the natural ventilation in spring and autumn.

These functions are achieved by the automatic control ventilation dampers in DS. DS has various ventilation dampers such as top ventilation dampers, bottom ventilation dampers, top ventilation dampers of atrium, and floor ventilation dampers of each floor. (Figure 5)

In the inside of DS during summer, top dampers and bottom dampers were opened, and heat in DS is exhausted by the natural ventilation. As a result, the thermal load of the building is decreased. The DS would be effective for the insulation performance if the top dampers and the bottom dampers are closed in winter. In middle season such as spring and autumn, natural ventilation can be useful by opening the bottom ventilation dampers, floor ventilation dampers, and top ventilation dampers of atrium. Patterns for controlling each ventilation dumpers are shown in Figure 6.

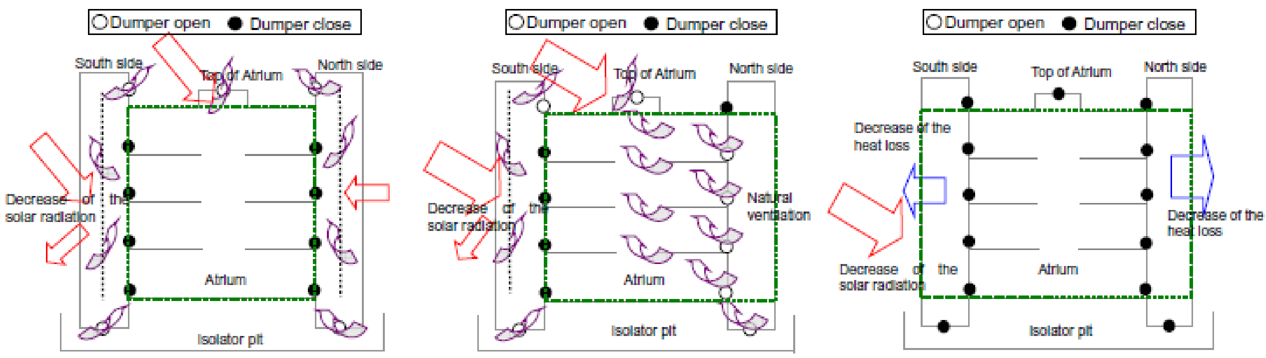


Figure 6. System outline of DS

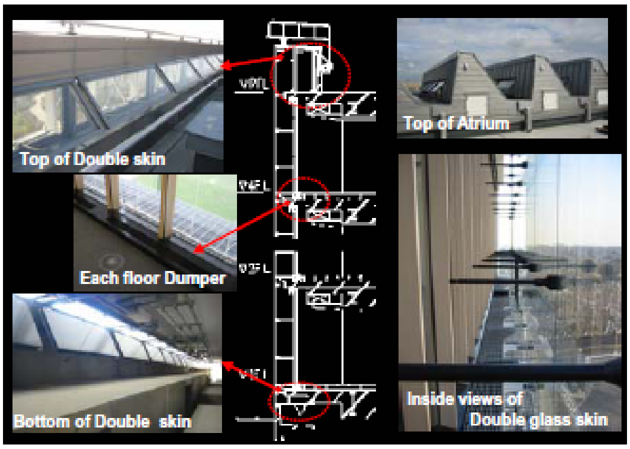


Figure 5.Ventilation dampers around DS

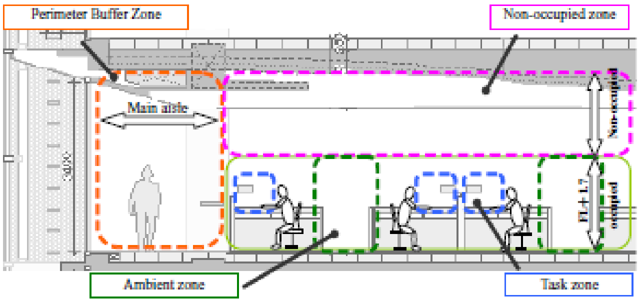


Figure 7. Outline of air-conditioning system

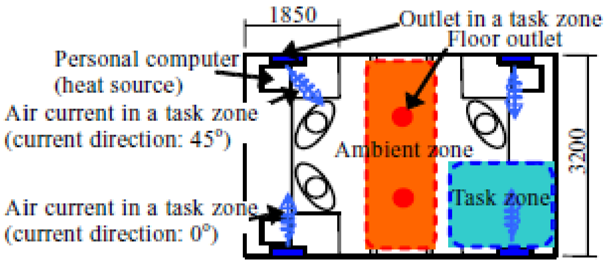


Figure 8. Booth layout

Figure 9. Partition-based outlet

2.2 System Outline of Task Air Conditioning (TAC)

The airflow is made to reach to the occupied zone (FL+1,700mm) by the under-floor air distribution system. The temperature makes stratification in higher zone than the occupied zone. The air-conditioning zone is divided into occupied zone and non-occupied zone in vertical direction. Moreover, it is divided into ambient zone and task zone that had been delimited by the partition in occupied zone. The air-conditioning system in task zone is the task/ambient air conditioning system (TAC) using the outlets installed in partitions (Figure 7)

Moreover, the main aisle is planned by the DS, so main aisle can state as perimeter buffer-zone. As a result, this building has no air-conditioning system for perimeter. In this building, the air-conditioning that adjusts to the characteristics of workspace - a high ceiling by a widespread space - is planned considering vertical zones an air-conditioning zone combined with a plan zoning. (Figure 8, 9)It is a combination system with under floor air-conditioning system of pressure type, process for design in the outlets installed in partition is as follows;

1) The air-conditioning capacity (the amount of air conditioner volume) in the task zone and ambient zone in total becomes less than planning capacity value (75CMH/person).

2) Using supply air volume control by differential pressure (pressure difference between under floor and upper floor, △P=15Pa) with under floor air-conditioning system.

3) Using supply temperature-set-point(19～20℃) of under floor air conditioning system.

2.3 System Outline of Thermal Storage on the Building Frame (TSS)

In this system, the void slab which forms the structure of the building is used as an air conditioning duct. At the usual air conditioning time(in daytime),the cooled air is supplied by under floor air conditioning system, and warmed return air passes through this void slab from the ceiling side. And the other way of the void slab is used for air supply route at night. (Figure 10)

The void slab is cooled with supply air from AHU (Air Handling Unit) at night, and this thermal storage (TSS) is filled with warmed return air from the room at the daytime. In summer, the peak load of electric power can be shifted by using both of the thermal storage and the ice storage system installed as a heat source. (Furthermore, in middle season, the cooling air conditioning load in daytime decreased with this thermal storage system using outdoor air cooling at night instead of using chilled water from heat source.)The void slab which used as air conditioning route has two kinds of forms. One is the form that circle ducts are installed in the slab which is close to perimeter zone. These circle ducts are used air conditioning supply and return route, and these are aimed for thermal storage and radiation mainly. This form is arranged on northern and southern four zones per each floor of the building (Figure 11). And the other form is the big mid-air layer in the slab installed in the interior zone. And the openings for an airflow connected with the mid-air layer are installed on the bottom side of a slab to face inside. (Figure 12)

When air conditioning at daytime, the air from AHU passes through this mid-air layer first, and then the air passes through the zone where circle ducts are installed. And finally it goes back to the AHU.

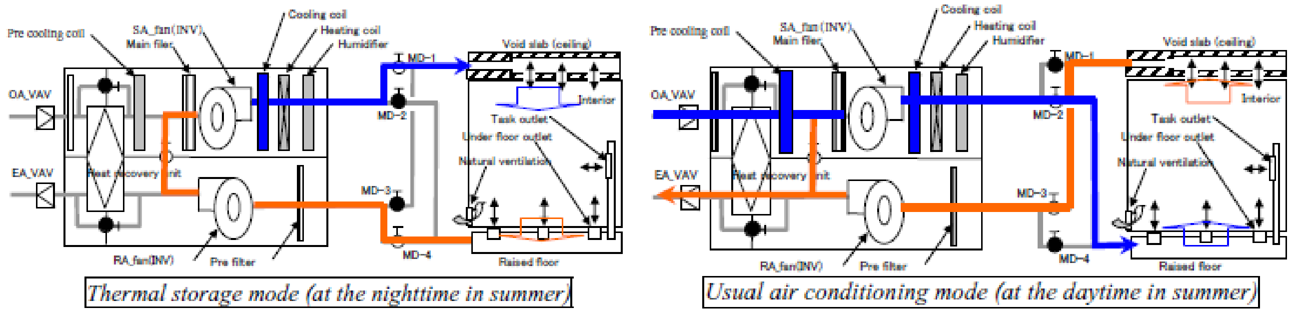


Figure10. Operation mode of air conditioning system

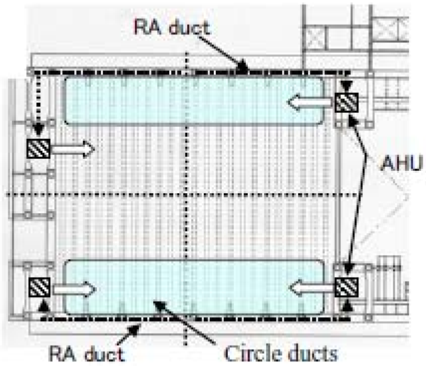


Figure.11 Layout of AHU

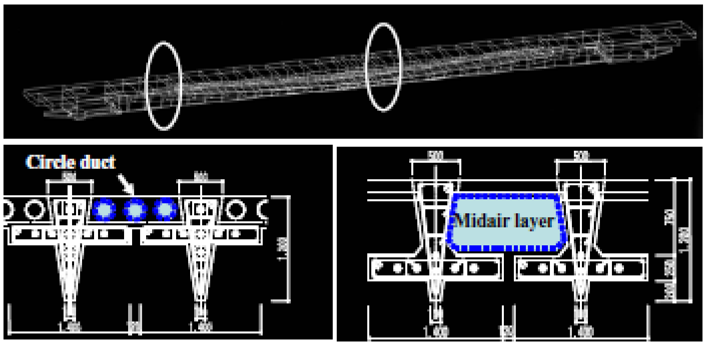


Figure 12. Outline of Void slab

3. Evaluation of Thermal Performance

3.1 Thermal Performance of DS

We carried out a performance prediction of DS by the simulation using the thermal ventilation network [2] at the design stage. In 2005, we confirmed the DS performance in operation at each season in summer, autumn, and winter. The measured items were temperature, the glass surface temperature, velocity in DS, and quantity of solar radiation etc.

In summer, the inside temperature of DS on the fourth floor was 35.4℃ on the south side, and 36.5℃ on the north side. The north side and the south were similar temperatures though the strong solar radiation beats down on only south side. The maximum temperature on the inside glass surface of the third floor were almost equal to the outside temperature in summer both south and north side. The results show that the solar heat shielding has been effectively removed the heat in DS. Profiles of temperature in each season are shown in Figure 13, 14, 15.The room temperature near the inside glass was almost equal to the room temperature set-point (27.5℃), and the thermal environment in the perimeter zone was maintained. As for the temperature in autumn DS, the difference of the fourth floor and the first floor was large(△T = 9.6deg). As for the north side, natural ventilation was performed, and the temperature in DS became almost the same temperature in the fourth floor to the first floor. The indoor glass surface temperature was 30℃ on the south side and 24℃ on the north. In addition, the air temperature in DS was 24-25℃, and appropriate thermal environment was maintained. Figure16 shows the measurement result concerning the solar heat gain ratio of DS. The solar heat gain ratio at daytime was about 0.23, and the high solar shielding performance was confirmed. Moreover, the measurement result concerning the thermal insulation efficiency in winter is shown in Figure17. The over-all heat transfer coefficient of DS was about 2.7W/m^2・K.

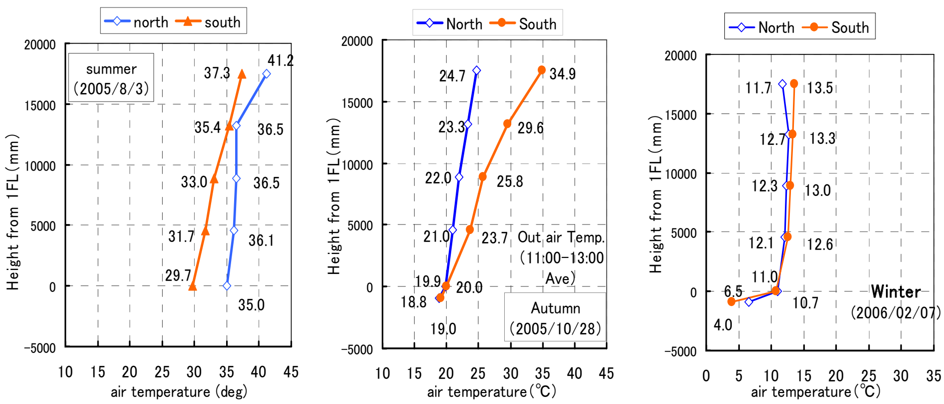


Figure 13. Profile of temperature (DS)

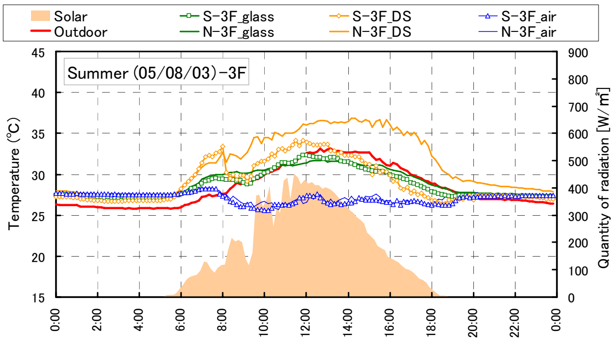


Figure 14. Result of field measurement at 3F in summer

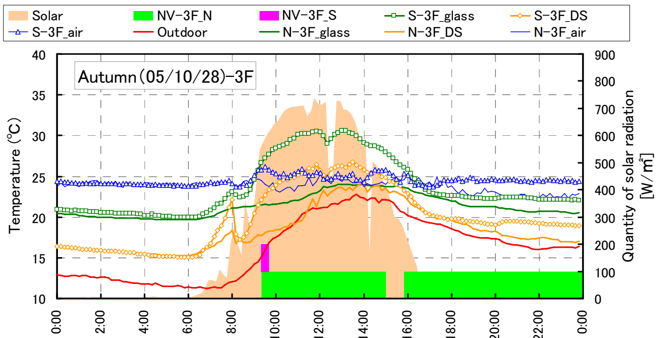


Figure 15. Result of field measurement at 3F in autumn

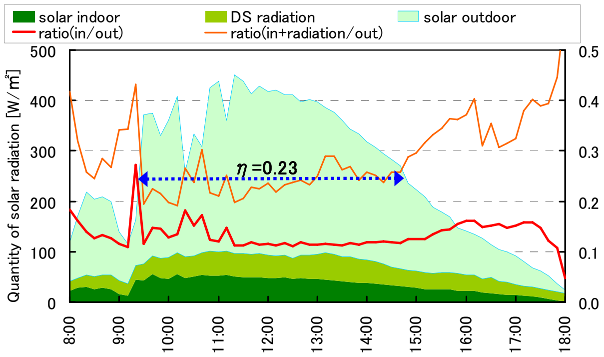


Figure 16 Solar heat gain ratio of DS

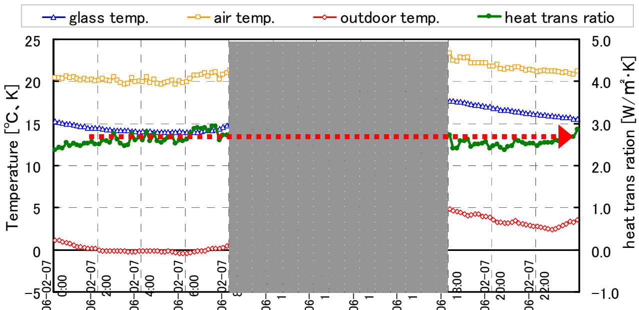


Figure 17. Over-all heat transfer coefficient of DS

3.2 Thermal Performance of TAC

One of the advantages using TAC is to provide fresh air to the occupants' breathing zone directly. Clean fresh air may increase work productivity of the occupants. The air change effectiveness was evaluated using SF6 tracer gas. Tracer gas concentration with or without supply air from partition-based outlet were monitored every second. So the effects of the both of partition-based outlet and the floor outlets were calculated, respectively. The experiment was conducted on 22nd (Saturday) and 23rd (Sunday) of October, 2005. [4]

Task air conditioning involved blowing out air from outlets on partitions. The efficiency of ventilation was monitored to understand the effects of the task air conditioning on its quality of the air in the respiration zones of people in task and ambient zones.

The monitoring conditions were set for different airflow rates at the task and floor outlets, different outlet angles, and different places of gas application.

In the conditions in which the gas was diffused through the task outlet, the air was blown at angles of 0deg, toward person, and 45deg. (Figure19)

Melikov et al. [5] conducted a laboratory experiment using a different air terminal device (ATD).

A comparison with the results of Melikov et al. is shown in Figure 20.

These were similar to the values calculated by Melikov et al. for a task air conditioning system that blew out air from the front, and the test was carried out in a laboratory.

Therefore, TAC in this project was effective in supplying fresh air to the occupant on the seat.

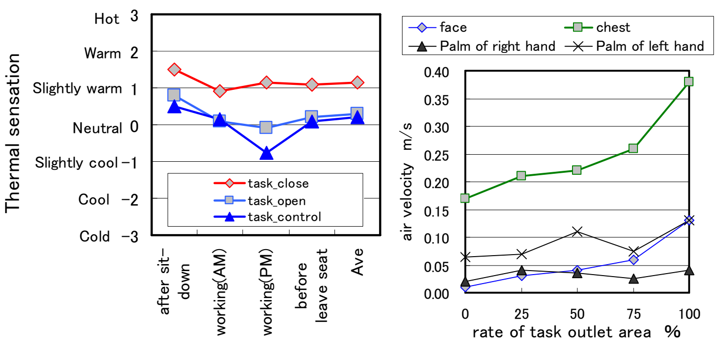


Figure 18. Thermal performance of TAC

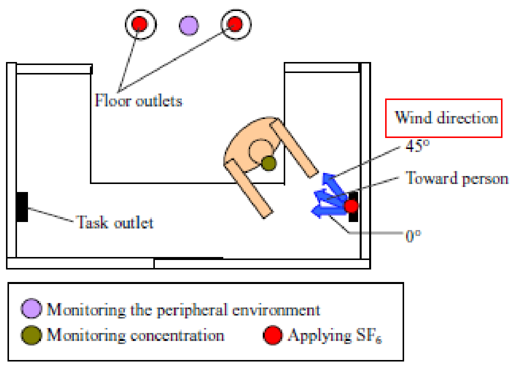
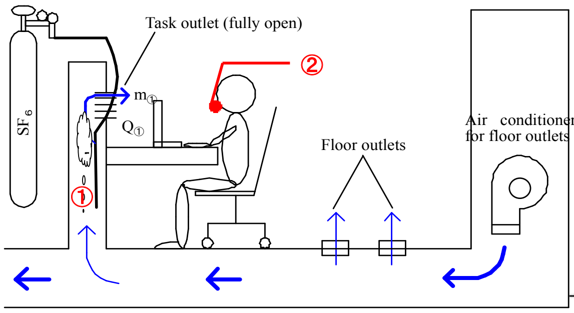


Figure 19-1 Location of gas generation and monitoring points (Plan)



(1): Task outlet (where SF_6 was generated)
(2): Respiration zone (where monitoring was conducted)

Figure 19-2 Location of gas generation and monitoring points (Section)

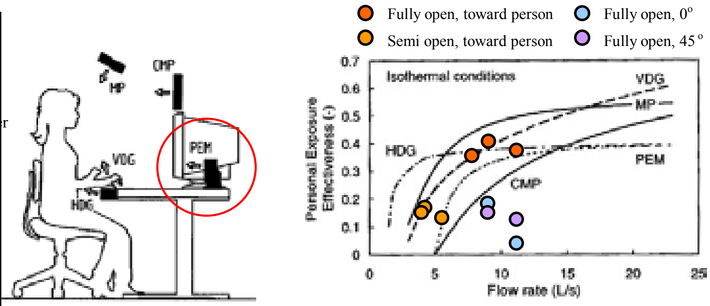


Figure 20 Comparison with the results of Melikov et al.

3.3 Thermal Performance of TSS

To grasp the performance of thermal storage system, we measured the temperature distribution, thermal load and energy consumption in an actual state of operation. The measurement elements were the air supply volume of AHU and the thermal storage driving time, and examined a characteristic of the system and the best operating method at the third floor south zone (366m^2) on 1st to 25th of August, 2006.

We prepared the total of four cases and a usual operating mode (CDN: Cooling Down) for the comparison and to a reference of three TSS modes. (Table 2)

Moreover, TSS driving mode was tried in the same air-conditioning zone with the number of patterning to reduce the deflection of the indoor thermal load in each case. It was assumed that the CDN and TSS （the comparison verifications） operation were usually done for the measurement period on the condition (verification day) which the thermal load situation was near.

In Figure21, the temperature of the mid-air is almost the same level at night time, between CDN and TSS at night time though the temperature of the mid-air slab in TSS had lowered at the air-conditioning time (daytime). So, we guessed for using up to descend, and to have been operated on that day by a proper amount of thermal storage.

Figure 22 shows the comparison of the peak loads.

The peak cut operation will be done from the result which could reduce both thermal and fan power peak load by CASE3 (air volume rate 50%, Operation time 2h).

Next, the primary energy (both cooling and fan power consumption) are shown in Figure23. CASE3 could be decreased the primary energy compared with CASE1. It is because the high effect of the reduction of fan power that accounts for about 30 percent of the total energy.

Table 2. Condition of verification for TSS

Case	CASE 1	CASE 2	CASE 3	CASE 4
mode	CDN	TSS	TSS	TSS
air supply Volume	–	50%	50%	100%
TSS operation time	–	1h	2h	2h
date	8/16-18 8/21-25	8/2	8/1 8/8-11	8/3

CDN:"Cooling down mode" for usual start up of AHU
Air supply volume: The ratio to the maximum value

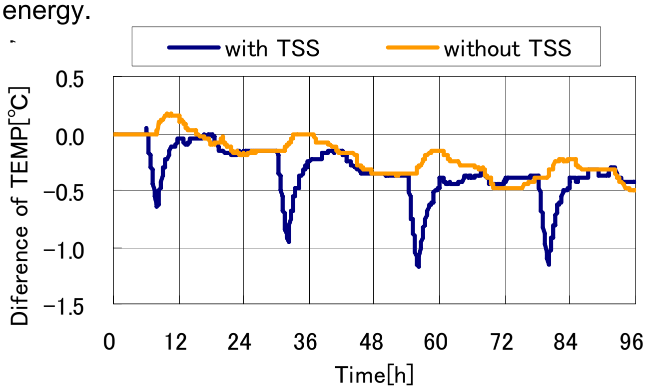


Figure 21. Comparison about the temperatures At midair of Void slab

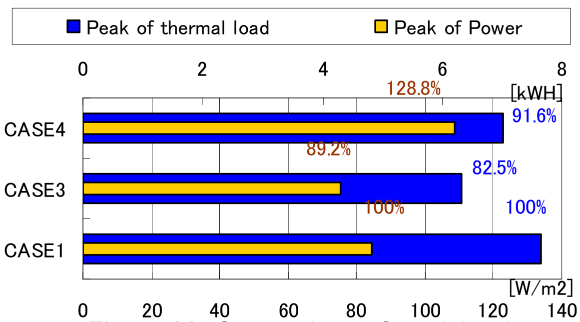


Figure 22. Comparison of peak load

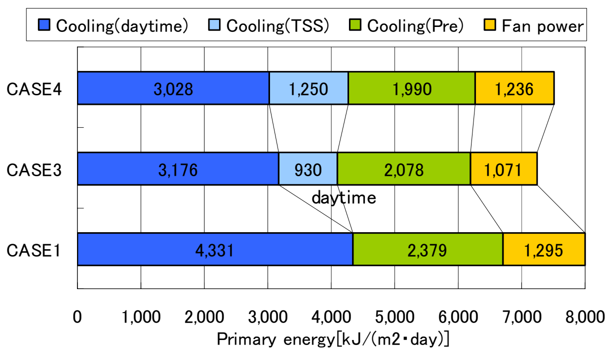


Figure 23. Comparison of total energy

3.4 Filed Measurement of Energy Performance

Figure 24 shows the annual heat source load. By effects such as reduction of thermal load by environmental technologies (DS, natural ventilation, etc), hot water load in winter, and both cold and hot water load in middle season were little. Figure 25 shows the primary energy consumed in this building from July, 2005 to June, 2006. The primary energy consumed value was 1,657 MJ/m^2 ･year.

It was estimated that 21.9% (comparison building value: 2,121MJ/m^2･year) of reduction in the primary consumed value could attain by the DS, TAC, and various technologies (ex: natural ventilation, cool and heat tubes, using sunlight, etc). And, it was 16.3% less in the primary consumed value that compared the standard office building in Japan (1,980MJ/m^2･year).Table 3 shows primary energy equivalent value by calculation.

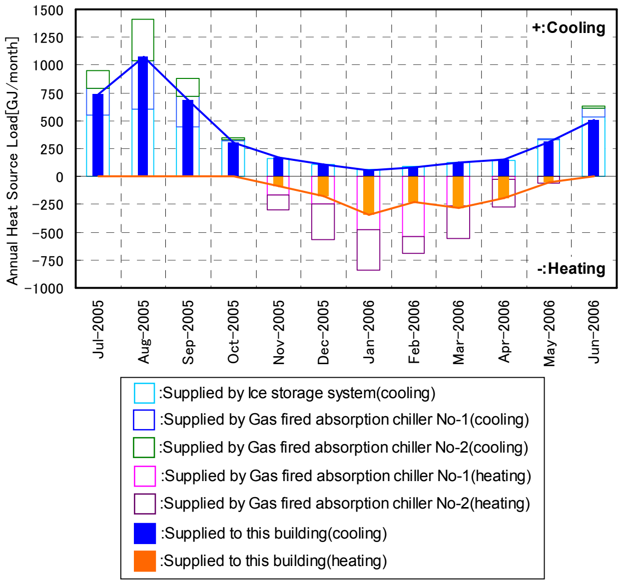


Figure 24 Heat source load

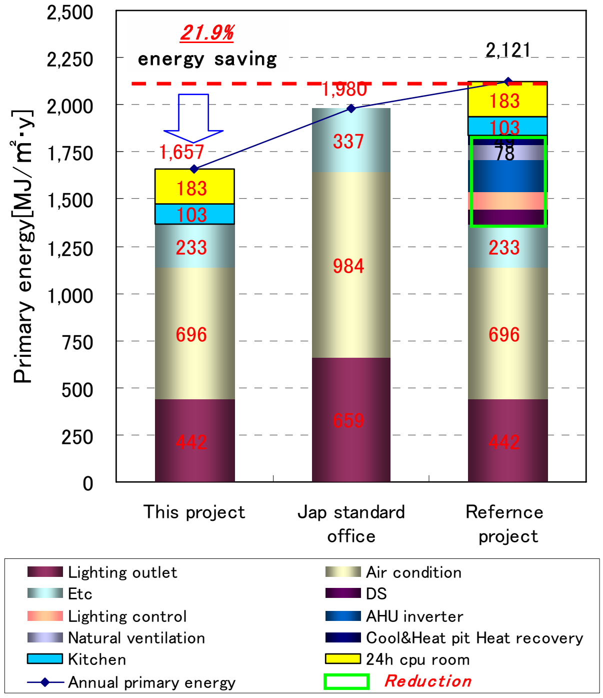


Figure 25. Primary energy consumed value

Table 3. Primary energy equivalent value

Electirc power	Natural gas
9,760 MJ/kWh	45,000 kJ/Nm3

3.5 Environmental Assessment (CASBEE)

CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) in Japan is an evaluation tool that is intended for implementation of the environmental assessments based on new concepts including BEE (Building Environmental Efficiency).

The concept of this project is “Improvement of environmental quality and performance” and “Reduction of environmental load” for global headquarters.

At the design stage, we evaluated with CASBEE, it was a classification of S-rank (Excellent BEE=3.7). [1]

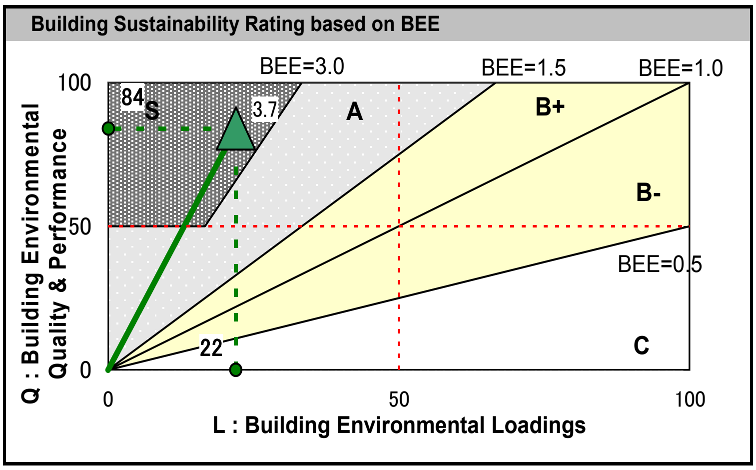
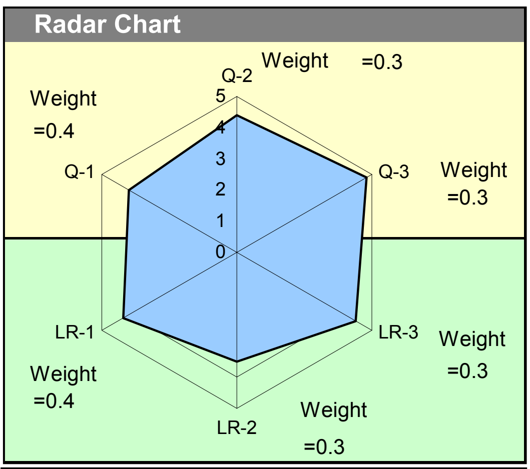


Figure 26. Result of CASBEE
(Environmental assessment in Japan)



Q-1. Indoor Environment
Q-2. Quality of Service
Q-3. Outdoor Environment on Site
LR-1. Energy
LR-2. Resources and Materials
LR-3. Off-site Environment

4. Conclusion

The concept of this project is “Improvement of environmental quality and performance” and “Reduction of environmental load” for global headquarters. So, this building has integrated various environmental technologies.

We were able to obtain the following findings about both “Indoor Thermal Environment and “Reduction of Thermal Load” through the field measurement.

1) It was confirmed to be maintained within the range where the thermal environment at the perimeter zone was proper at each season. For the thermal performance evaluation about DS, the solar heat gain ratio shows about 0.23 and the U value shows about 2.7W/ m^2.Though DS is composed of the clear glasses, the performance of solar shading show the same as the high efficient heat reflection glass and the performance of U value shows the same as the pair glass.

2) We verified the performance of the air change effectiveness in an actual office with a thermal mannequin and tracer gas method too. The performance of TAC in this building shows the same tendency with Melikov’s laboratory experiment.It was shown that TAC was shown to be effective in supplying fresh air to the occupant on the seat.

3) We confirmed the peak cut performance about the energy consumption of the air conditioning system.TSS operation has the possibility which could be decreased both peak load and the primary energy compared with usual system based on the field measurement.

4) It was estimated that 21.9% reduction in the primary consumed value (comparison object value: 2,121MJ/m^2/year. this value is predicted by not installed various energy saving technologies in this building.) and, it was 16.3% less in the primary consumed value that compared the standard office building in Japan (1,980MJ/m^2・year).

5) From the aspect of the comprehensive environmental performance evaluation, it was a classification of S-rank (Excellent BEE=3.7) using Japanese evaluation tool called “CASBEE”.

References

[1] Japan Sustainable Building Consortium (JSBC) 2003.CASBEE Manual 1 Dfe (Design for Environment) Tool. The Institute for Building Environment and Energy Conservation.

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SUSTAINABLE RESIDENTIAL LOW DENSITY URBAN DEVELOPMENT – INTEGRATING SUSTAINABLE CONSCIOUSNESS WITH COMMERCIAL VIABILITY

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Keywords: sustainable housing, energy efficiency, thermal performance, gated community

Summary

This paper will discuss the present integration of sustainable features in a self-contained residential development in the growing urban density in Malaysia - consisting of 36 units semi-detached and 4 units terrace houses – within the constraints of commercial viability of such a project. The projects features the layout planning for green-shared landscaped courtyard area, a rainwater harvesting system links all units for landscaping needs, double brick walls for energy efficiency, heat reclaim system for hot water and roof insulation for heat gain reduction. Each unit features a four-storey structure with a double frontage design, foyer space in the 1st level. Dining, kitchen and living on the 2nd level. Bedrooms and a family room on the 3rd and 4th level. The focus includes the outcome of an evaluation of the energy efficiency impact of the double cavity external wall and a heat reclaim system used in each unit in the development - where air conditioning heat is reclaimed at night for hot water use in the morning. A solar shadowing impact of two adjacent developments consisting of high-rise condominiums on the entire developments for different times of the day were also done to ascertain roof surfaces which can be used for grid connected solar panels. The paper presents an attempt by an ecological conscious developer to integrate green features – including rainwater harvesting and communal strategies such as shared green space within the commercial and resource constraints of a project.

1. Introduction

The paper presents a recent housing development in which the developer attempted to integrate a range of sustainable features, within the costs constraints of the project. It represents an initial model for upper middle class housing – a section of society, which typically consumed high energy within their lifestyle. This residential development consisting of 36 units of semi-detached and 4 units terrace houses in a gated community. Each unit's built-up area ranges from 3719 sq.ft. to 4333 sq.ft. The units are aligned in a courtyard arrangement with a central communal garden with communal facilities such as gym and multi-purpose hall located at opposite ends of the courtyard. Of particular interest is the impact of the use of double cavity brick as external wall material in the first three levels of the house – particularly in terms of reducing the heat gain into the internal space. The impact in terms of reduction in energy use and improved occupant comfort are also of interest. Ecological features implemented in the development but not tested in this study include a rain harvesting system, which collects rainwater for landscape maintenance in the development.

Due to the rapid rise of urbanization and development in urban areas in Malaysia, a rise of air-conditioning use has also been observed. This is related also to the widespread availability of technology and the rising income and lifestyle of city dwellers. The assumption of air conditioning usage reverses the prioritization of bioclimatic strategies from open-planning/lightweight construction towards more heavyweights, thermal mass, compact massing and planning. The following is a summary of a study of the impact of selected features in a residential development consisting of 36 units of semi-detached and 4 units terrace houses in a gated community.

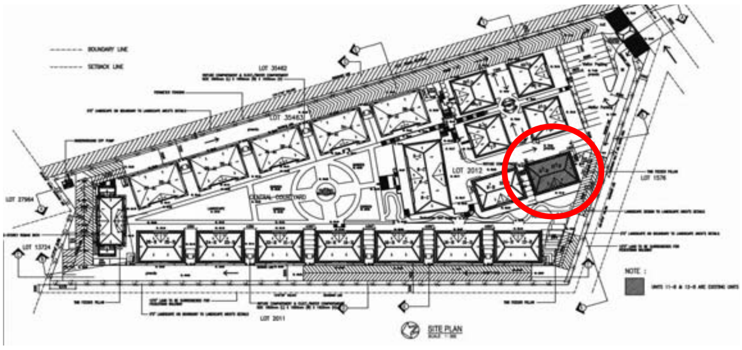

Figure 1 Site Plan - Whole development highlighting the location of unit modeled in study

1.1 Orientation of model (whole development)

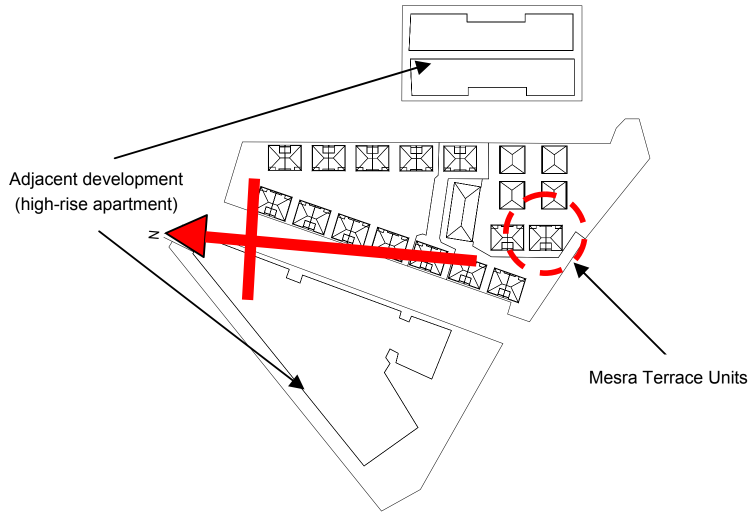

Figure 2 Orientation of model – Whole Development including all units and adjacent high-rise apartments (selected unit for study highlighted)

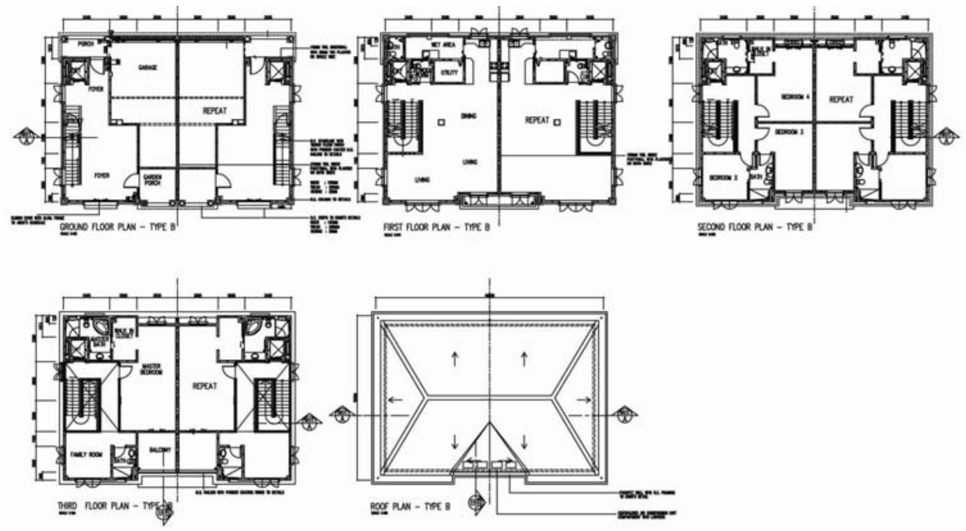

Figure 3 Typical floor plans (All floors - Selected unit – BEDFORD)

1.2 Layout and Planning

The layout of the development is aimed at a communal way of living, where units are arranged around a central courtyard that acts as communal space. In this way, green open spaces are utilised in an optimum manner, and maximised for the benefit of the community.

Figure 4 Overall layout and planning of the Mesra Terrace Development

1.3 Simulation Studies – Multi-Zonal Analysis

The MULTI-ZONAL ANALYSIS tool is used to analyze the impact of infiltration and natural ventilation in the building on the predicted temperatures within the internal spaces which are linked an assessment of the thermal comfort conditions of occupants. Under Malaysian conditions, comfort conditions for users and occupants can be enhanced through both mechanical means and enhancement of certain passive design features. Basically under the Malaysian conditions, comfort is difficult to achieve - particular in the daytime - but can be primarily enhanced through inducing cross ventilation and air movement and reducing solar gain and heat gain from all potential sources. The analysis uses a zonal-airflow model to calculate bulk air movement in and through the building, driven by wind and buoyancy induced pressures.

1.3.1 Internal Temperatures

The internal temperatures were analyzed using a multi-zonal tool. The following figures show the internal temperature patterns for one week in January for selected spaces in the house. The results also show trends for one representative day in January. The internal temperatures are compared with the external temperatures taken from the external weather data used in the program. The focus of the output is:

- The foyer, family and living, and selected bedrooms
- With and without cavity brick wall for selected areas

1.4 Assumptions (all models)

1.4.1 'All windows closed'

In almost all models and options, the windows are assumed to be closed. The aim here - and justification - is to attempt to highlight the impact of the double wall option on the internal temperatures. This serves to isolate the impact of heat gain through conduction gains through the external wall. Hence ventilation gains are not included in this calculation (except for infiltration gains - which is set at 0.5. ac/hr).

1.4.2 'With selected windows opened'

In the multi-zonal analysis, only the categories 'External glazing', 'Internal glazing' and 'Door' are important. Elements in these categories are called 'openings'. They may be assigned data allowing the tool to simulate the passage of air through them. An opening type is a type of building element which can be selected and consists of a specification of the element's air flow characteristics and the way they vary with time.

In the energy analysis, it is assumed that only the windows in one bedroom are opened for a total of two hours to 'air' the house.

In terms of internal temperatures, under naturally ventilated conditions i.e. the more windows are opened, the more the internal conditions will follow closely the external climatic conditions. Under such naturally ventilated conditions, improved comfort conditions depend on higher indoor air speeds. The flow of outdoor air through a building extends the upper limit of the comfort zone beyond the limit for still air conditions and this provide a direct physiological cooling effect. Hence when efficient cross ventilation is achieved during daytime, the temperature of indoor air and surfaces closely follow that of the ambient air temperature.

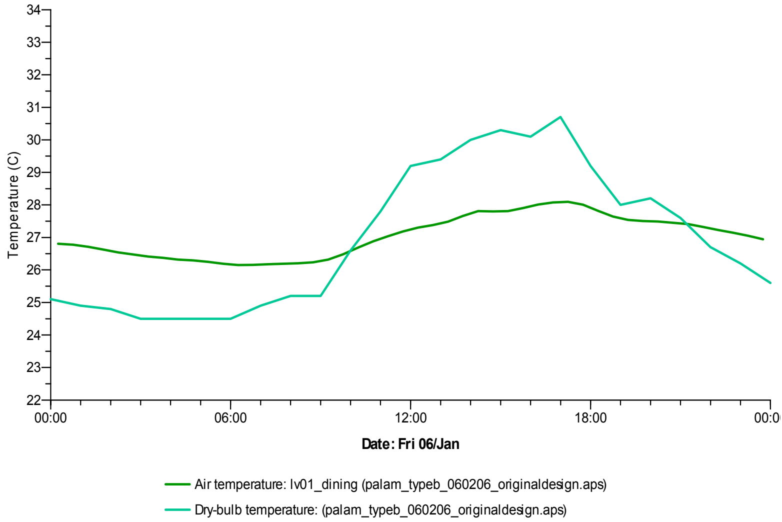

Figure 5 *Temperature distribution in dining area for one representative day in January (internal vs. external temperature) with cavity wall (windows closed, A/C OFF)*

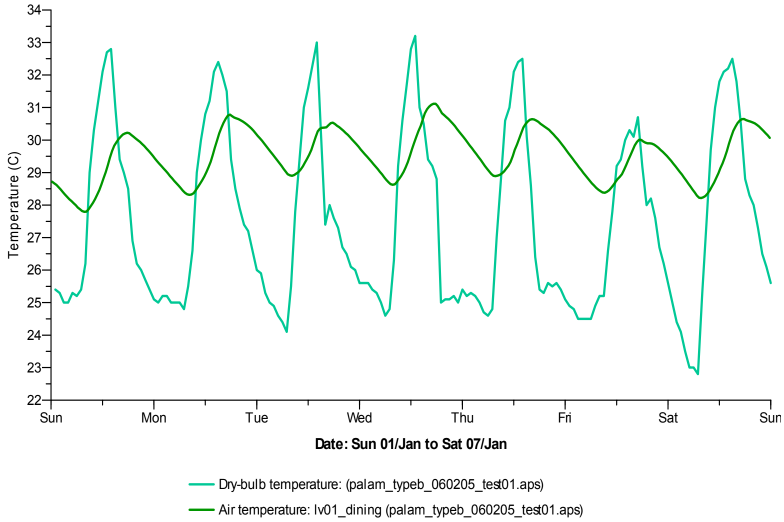

Figure 6 *Temperature distribution in dining area for one week in January (internal vs. external temperature) without cavity wall (windows closed, A/C OFF)*

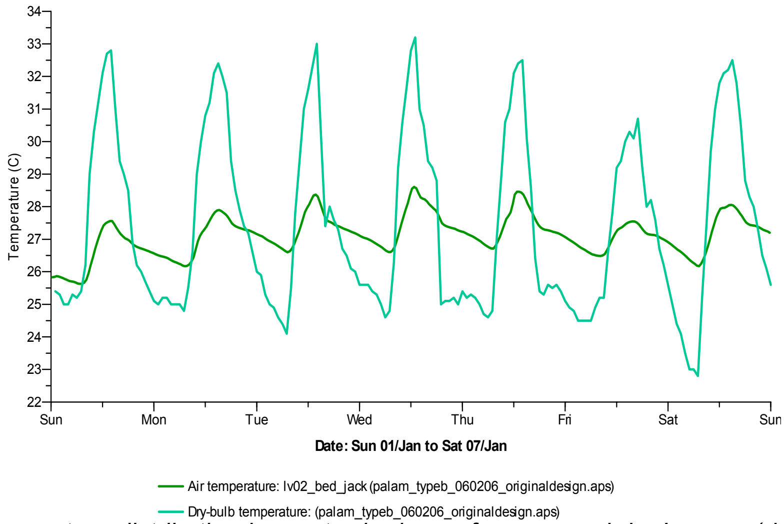

Figure 7 *Temperature distribution in master bedroom for one week in January (internal vs. external temperature) with cavity wall (windows closed, A/C OFF)*

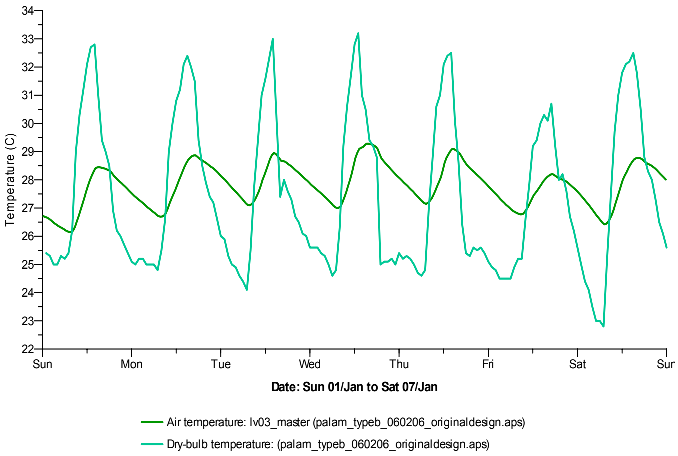

Figure 8 Temperature distribution in master bedroom for one week in January (internal vs. external temperature) without cavity wall (windows closed, A/C OFF)

2. Energy Saving Estimation of the Condenser Heat Reclaim System

An energy saving feature of the development is the heat reclaim system installed in selected rooms in all units. Typically there is an amount of energy required for the heating of the water - this is linked to all the bathrooms within the house. This heating requirement if supplied by conventional electrical heaters, the total cost of energy use per year would be considerable. Heat rejected from the air conditioning condensers represent energy that can be reclaimed at the supply water tank to save a considerable amount of the total cost of water heating.

2.1. Estimation and parameters in calculation

Assuming that the heat reclaimed from two cooling units of full capacity (2.93 kW operating according to the schedule), the coefficient of performance of the air-conditioning system (COP) is taken as 2.0 and the cooling set temperature is taken as 24°C.

Using the annual weather conditions data for Subang Jaya (1995), and according the operation schedule as shown above, the total electrical energy can be estimated for the cooling of the two of the bed rooms in the unit. This calculation takes into consideration the climatic variation throughout the year. The combined mechanical and electrical efficiency of the compressor can be considered in the range of 65%, and the heat exchanger efficiency at the water storage tank is taken as 80%. The following equations are used in this calculation;

$$COP = \frac{Q_L}{W} \quad (1)$$

$$Q_H = Q_L + W \quad (2)$$

Where COP is the coefficient of performance of the refrigerator, Q_L is the cooling load, Q_H is the heat rejected at the condenser and W is the compressor work. Table (1) shows the values of Q_L and the reclaimed heat for the whole year.

Table 1 The values of Q_L and the reclaimed heat for a whole representative year.

Date	Q_L(MWh)	Q_H(MWh)	$Q_{Reclaimed}$(MWh)
Jan 01-31	1.3	1.2	1.0
Feb 01-28	1.2	1.2	1.0
Mar 01-31	1.5	1.5	1.2
Apr 01-30	1.5	1.5	1.2
May 01-31	1.7	1.6	1.3
Jun 01-30	1.6	1.6	1.3
Jul 01-31	1.7	1.6	1.3
Aug 01-31	1.4	1.4	1.1
Sep 01-30	1.5	1.4	1.2
Oct 01-31	1.5	1.5	1.2
Nov 01-30	1.3	1.2	1.0
Dec 01-31	1.2	1.1	1.0
Summed total	**17.3**	**16.9**	**13.5**

From the results presented Table 1, it can be concluded that **a total of 13.5 MWh of heating energy can be saved which means a total reduction in the water heating cost of about RM 3800 per year**.

3. Rain Water Harvesting

The development is designed with a Rain Water Harvesting system to capture runoff from the roof. The system is designed to collect water that is captured at gutters into downpipes and store it into an underground tank placed at the center of the courtyard to for landscape maintenance purposes. As Malaysia receives an average of 1000mm of precipitation annually, the development capitalizes on this advantage to retain some amount rather than to let all the free water runoff to the public sewer.

The system focuses on reorienting the plumbing design so that water from gutters can be brought down using uPVC pipes directed it to a 2ft-deep sump. The water then goes into a filtration system to filter out debris and to make sure the stored water is clear of sediments. These waters will then be stored in a large tank underneath the central pond at the courtyard centre, and can be used by using a motorized pump to push the water back up and water the lush landscape.

The design also takes into advantage the natural slope condition of the site, placing the 4 x 20 x 1.5m rectangular tank in the dead centre on the site before re-distribution. The tank is connected by 5 main lines of water catch pipes from 2 main 150mm Ø uPVC feeding pipe lines.

With proper technology, these waters can also be used for day-to-day needs like drinking and cooking purposes. If the maximum collection is 90% efficient, the net amount of rainwater harvested annually amounts to approximately 1,200,000 litres that would benefit in saving water thus reducing water bills.

LEGEND					
	Water outlet for utility usage		65Ø HDPE recycle water supply pipe		150Ø uPVC recycle water collection pipe

Figure 9 Water-harvesting system diagram

Figure 10 from left – construction detail showing water harvest system at the community center & Rain water downpipe and the collection sump under construction

4. Roof ventilation design and insulation

To reduce internal temperature in areas below the roof, the roof was designed with heavy insulation. The roof design is a 20mm thick concrete roof tiles with light grey color finish. The use of light color was chosen to help repel heat. The roof tiles are made to rest on timber truss rather than a galvanized iron (G.I) truss. G.I. is commonly practiced in the Malaysian construction industry due to its low cost. The use of timber truss is because timber has a lower emissivity value which emits lower heat radiation. The insulation material used is a woven insulation foil, backed by fiber quilts and secured by a wire mesh to the soffit of the roof truss. As commonly practiced, these layers are then covered by a plastic sheet to make sure the fibres or dust will not fall and gets into the interior space. Not only that the layers repel heat, it also repels noise.

Figure 11 Roof construction layers

4.1 Roof ventilation system

To help trapped air escape from the roof area, the ridge is installed with ventilation holes using a ventilation product. The product is rubber based and is flexible. It is placed under the top most tiles before the ridge. As it is placed at the top, hot air raises and escapes through the deigned outlet. Figure 12 is showing the test session on the product. The system was testing for smoke escape as well as rain penetration at high horizontal winds. These studies were also crucial for fire departments approval for the building design's low party wall. The study shows a majority of smoke flow out from the roof area through these vent holes suggesting the performance of the product which makes the roof area to "breathe" which increases thermal comfort.

Figure 12 Roof construction mock up: to test the ventilation device effectiveness.

5. Discussions

Overall, the results demonstrate the thermal benefits of increasing thermal mass i.e. use of a more massive structure (such as a double cavity wall) - which amongst others, are the attenuation of the daily temperature swings and slight delay in reaching peak temperatures during the day. The difference in peak temperatures may range from 3°C to even 6°C during the day. The day night variation is also reduced from a range of 23-33°C to 26°C to 28°C. In this study, the indoor peak temperatures are found to occur at about the same time as the outdoor peak temperatures. The results thus demonstrate that the double wall has a positive impact on considerably decreasing surface temperatures and consequently, internal temperatures within the house.

The results reflect the general principle that the use of increased thermal mass in a building reduces and attenuates peak temperatures during the day. However because it stores some of the heat, it later releases some of these heat during the night –partially to the outside and partially to the inside of the building.

In colder climates with large diurnal swings, the re-radiated hear may be beneficial to offset heating requirements, however under the hot, humid climate, the increase in nighttime temperatures may lessen the impact in terms of energy savings – particularly when the A/C is used predominantly at night. Hence in such a case the use of ventilative cooling (cooling effect through air movement and ventilation) can be an effective strategy when employed at night.

The significant effect of the double wall can be particularly felt in space facing the full impact of the afternoon sun such as the master bedroom which shows a marked decrease in peak temperatures in the afternoon. (Refer *Figure 6 and 7*)

Similar results has been found in studies by Szokolay (1990) for example, which showed that in the tropical humid climate (in the case of Queensland), most comfortable conditions all year round was achieved by a 'heavy' construction (in this case slab-on-ground floor, reverse brick walls with insulation on the outside of the mass layer, a well-insulated roof and full shading of all windows) through the application of heavy construction. Cooling through passive means such as ventilation should be encouraged at night.

This has been supported by other studies such as Machado (1999) who tested a house design for the climate of Venezuela. The study found that the best performance was achieved by a heavy weight building with night ventilation. Soebarto (1999) also found that for the climate of Jakarta (Indonesia) for a heavyweight house, daytime closure of the windows kept the inside 3-4 deg K cooler than the outside. Hence in purely temperature terms, a building (with closed operation during the day) is slightly better as the heavier mass would also reduce the peak load and hence reduce energy use.

Conclusions

The project is an important attempt to incorporate a range of sustainable features which are in line with international rating systems and in line with the general definition of sustainability. In developing countries such as Malaysia, due to the drive for progress, sustainability is not a cultural-ideological movement - compared to the more developed countries. Many of the features in this project were initiated by the developer, while designers, researchers and suppliers provided the technical input in terms of design, specification, simulation and calculations. The developer is working within the constraints of not only, lack of institutional support within this context for sustainability, but also the press of fulfilling commercial and financial viability of the project. Though this project represents an urban gated community development targeted for the upper middle class homeowners, it can be argued that sustainability should be targeted to this group of people since they have the means of both ' spend' and 'save'. They are also a strata within society who are open to new forms of living, and whose level of education and lifestyle have given them exposure to sustainable ideas and ways of living. This is an important project which highlights that sustainability can be practised within the time constraints and financial limits of a commercial project.

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CONTROLLING CHP MICRO-TURBINES AS A VIRTUAL POWER PLANT

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Summary

Deploying gas micro-turbines as a source of combined heat and power (CHP) in residential complexes offers the potential for substantial reductions in overall energy use and greenhouse-gas emissions. Here we use mathematical modeling to predict the operational behavior of micro-turbine CHP in a hypothetical network of residential apartment buildings.

In our models the micro-turbines generate electricity for local needs and for participation in the national energy market, while delivering space heating and hot water to the residences in the network. The micro-turbines are operated using management strategies that optimize economic performance while satisfying the heat and power demands of the residential customers. The heat and power demand data has been synthesized using multiple information sources and is intended to represent a plausible demand pattern for residential apartment buildings in Victoria, Australia.

We demonstrate that deploying gas micro-turbines for CHP in residential apartment complexes promises substantial reductions in energy use and greenhouse-gas emissions. We also demonstrate that micro-turbine CHP can be an economically viable option for residential apartment complexes in Southern Australia, at least under certain market conditions. Our experiments uncover relationships between micro-turbine generation capacity, utilization of this capacity, energy demand and overall economic performance. The insight gained from the experiments has relevance in the specification and design of future sustainable buildings that incorporate micro-turbine CHP.

1. Introduction

Thermal generators for electric power only transform part of the chemical energy contained in their fuel into electrical power, most of the difference is transformed into heat. Data from the Combined Heat and Power Partnership, US Environmental Protection Agency [2002] indicates that a typical steam turbine used in a large coal fired plant has an electrical efficiency of between 15 and 38% while a micro turbine with combined heat and power (CHP) has a total efficiency (including heat) between 56 and 75%. Therefore, using micro turbines situated close to heat demand can reduce the emission of greenhouse gases compared to the currently dominant central generation model with large power plants far away from potential heat demand.

One example for using distributed generation in order to reduce CO_2 emissions is the TrigenAir technology project at the Hornsby Central Library where CSIRO Energy Technology installed a micro turbine driven system that not only provides electrical energy but also uses the waste heat of the turbine to provide air conditioning services [CSIRO Energy Technology, 2004].

Control strategies for single CHP plants have already received considerable attention in the literature. Kong et al. [2005] present a linear program for controlling a CHP plant with afterburner and integrated absorption chiller for cooling loads. A very similar setup is investigated by Cardona et al. [2006] for a plant at Malpensa airport in Italy. This paper also compares future investment options.

Lin and Yi [2000] investigate how a large scale CHP plant used in district heating can be used to reduce peak loads in the electricity network and present a dynamic programming approach to compute control solutions.

In this paper, we are concerned with micro turbines, used as decentralized CHP generators. Alanne and Saari [2004] present a general review of issues that can influence decisions when considering small-scale CHP (like micro turbines) as an alternative energy source for buildings, with a focus on the European market.

Another technology that can be used in small scale CHP are fuel cells. Aki et al. [2005] present strategies for controlling a set of four homes with CHP fuel cells that can exchange hydrogen, electric power and hot water. There is also a number of papers that propose algorithms for optimizing the dispatch of decentralized

CHP generators given a heat and power demand profile [Song et al., 1999, Rooijers and van Amerongen, 1994, Hernandez-Aramburo et al., 2005].

In contrast to these works, we do not assume a fixed demand that we are trying to match as cost-effective as possible. We assume that a company runs a set of micro turbine CHP generators that provide apartment complexes with heat and hot water. The electricity generated by the turbines is either sold for a fixed retail tariff to the occupants of the apartment complexes or sold in larger chunks on the national electricity market. Since the prices on the spot market can vary in orders of magnitude over one day, deciding when to sell how much electricity is critical for the profitability of the proposition.

2. The Business Model

A power company owns micro turbines connected to the hot water and space heating systems of apartment complexes. The company wants to offer the electric power to the national power market while keeping the temperature in the hot water and heating systems connected to the micro turbines in a given comfort range. The generated electric power that is not sold on the electricity market can be used to satisfy power demand in the apartment complex.

The company running the micro turbines obtains a fixed fee for the heating services it provides and wants to earn additional profit from selling the aggregated electric power of the turbines on the National Electricity Market in Australia. On this market, electricity generators submit bids one day ahead of dispatch. As described in the characterization of the Australian energy market [NEMMCO Ltd, 2005], the market operator then determines for each time slot the market price and the power will be dispatched if the market price is higher than the price requested in the bid. We further assume that the revenue from generated electric power that is used inside the apartment complex is equal to the retail price.

3. The Physical Model

The heating systems of the different apartment buildings are independent of each other. We assume that both the hot water service and the space heating service for each building use tanks containing hot water as energy storage. We assume that there is a constant loss of energy per time slot from the tanks even if no hot water is used due to imperfect insulation. Hot water use by the residents of the apartment complex draws additional energy from the tanks.

We assume a water based underfloor space heating system for the apartment complexes because it is well suited to CHP applications. These systems have a fairly large thermal inertia so that we can assume the energy demand for space heating to be almost constant over any given day. This means that the energy loss from the tank reserved for space heating is constant over time.

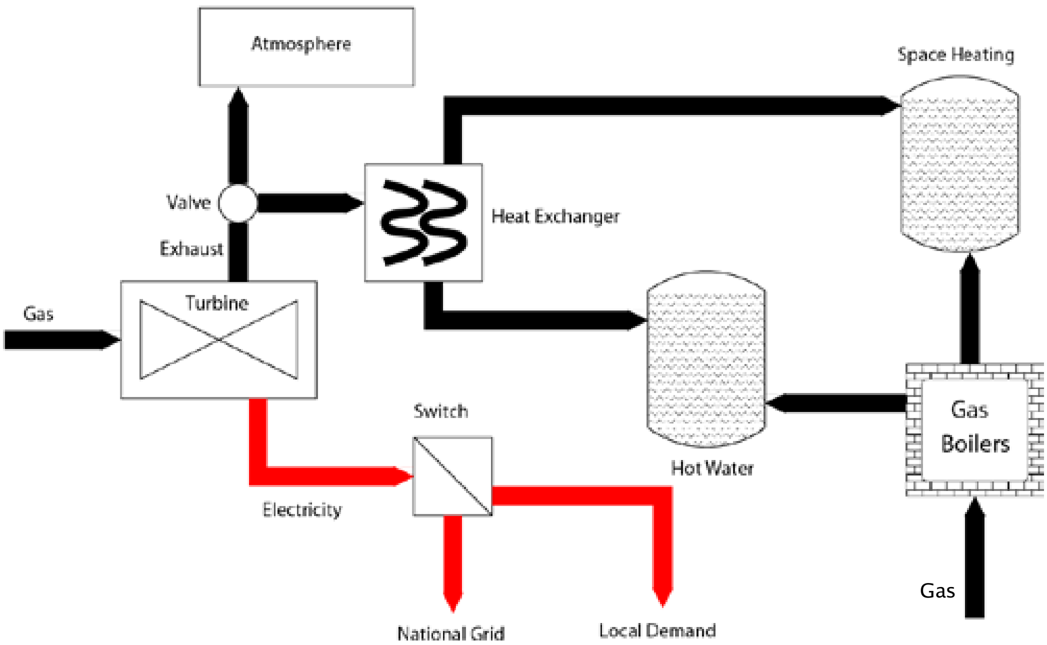

Figure 1: Energy flows in our micro-turbine model. Note that losses are not depicted but are part of our mathematical model

For each of the two tanks, there are two ways in which the temperature and thus the stored energy can be raised: Water can be heated in a heat exchanger using the hot exhaust of the micro turbine or the water can be heated using gas boilers. We assume that the connection between added energy and water temperature is linear. The linearity assumption can be justified since the water temperature in the tanks is always kept inside a narrow range. The turbines have minimum on- and off-times defined by the manufacturer.

When a turbine is running during a time slot, it produces a fixed amount of electrical power and a fixed amount of heat power. An arbitrary part of this heat power can be vented into the atmosphere. The remaining heat power passes through a heat exchanger and is split between the hot water and the space heating storage tanks associated with the micro turbine. The ratio of the split can be freely chosen. Figure 1 gives an overview of the energy flows in our model, excluding the losses.

4. The Optimization Problem

We assume that the price development in the NEM is similar each day in the sense that the power demand and thus the price is always very low during the night. We also assume that the hot water demand in the apartment complexes is very low during the night. This justifies the assumption that the heating systems connected to the micro turbines are in a similar state early each morning before the hot water demand ramps up. We therefore treat each day as a separate optimization problem

We assume further that we want to offer at most one **block** of power to the NEM each day. A block is a fixed power output provided during a time interval without interruptions. Thus, the daily NEM bid is defined by three values:

- The start time of the bid block
- The duration of the bid block (defining the “width" of the block)
- The electrical power we want to offer (defining the “height" of the block)

The electrical power is bounded from above by the sum of the capacities of all micro turbines.

4.1 The Profit Maximizing Integer Program

We assume that the operator of the micro turbines has three revenue streams:

- The NEM bid submitted each day: This revenue depends on the characteristics of the offered block (power level, start time, duration) and the price development in the NEM on the given day.
- Electricity generated by the turbines used to satisfy the apartment's electricity demand: We assume that this electricity displaces electricity that the occupants would buy from their local retailer and the turbine operator obtains the same price as the retailer from the occupants.
- A fixed fee for providing hot water and heating services to the apartments: Since it is obligatory to meet this commitment and the fee is fixed, this revenue stream has no effect on the operation policy for the turbines and we ignore it in our optimization model.

The variable costs for the turbine operator are:

- Fuel costs: This includes the cost of the gas used by the turbines as well as by the gas boilers. We assume that at each point in time, a turbine is either running at full power or is off while the gas boilers can be run at any power level below their maximal output.
- Maintenance costs: We treat these costs exactly like fuel costs since a turbine has to be maintained after a fixed number of operating hours.

We do not include any fixed costs in our model since we concentrate on the question how an operator would run existing turbines and handle the NEM-bid rather than on the question if it is profitable to install the turbines in the first place.

We describe the optimization problem as an integer linear program. The constraints are also linear and can be grouped into the following groups:

- NEM block constraints: These constraints guarantee that exactly one block of power without gaps is offered on the day in question and that this block has at least a defined minimum duration (set to half an hour in our model). Another group of constraints guarantees that the power reserved at each turbine for the NEM-bid sums up to the required power level.
- The electricity distribution constraints: These constraints ensure that in each time slot and for each turbine, the amount of electric power output allocated does not exceed the amount of power produced by the turbine. The amount of power used consists of the following components:
    - The amount of power from the turbine reserved for the NEM-bid
    - The power used to satisfy power demand in the apartment building of the current turbine
- The heating constraints: The heating constraints make sure that for each turbine in each time slot, the water temperature in the hot water and space heating system remains inside the allowed ranges. The temperature is increased by one of the following mechanisms:
    - Using heat from the heat-exchanger of the turbine
    - Using the gas boilers

  There are also two mechanisms that lower the temperatures in the heating systems:
    - Insulation losses, that we assume to be constant over time
    - Heating demand: For the hot water system, this demand is caused by the use of domestic hot water. We model this demand with our hot water demand simulator, described in

Section 5. For the space heating system, we assume currently that the demand is constant over the day. This is not realistic but given that a hot water driven space heating system would have to be combined with under floor heating, which has a considerable thermal inertia, the demand differences over the course of the day should not be as large as for the hot water system.

- Turbine run constraints: Once a turbine has been switched on, it has to stay on for a certain minimum amount of time. When it is switched off, it has to stay off for a defined minimum of time. These constraints make sure that the turbines are not switched off and on frequently, which would shorten their lifetime.

5. Scenario Input Data

The amount of input for the model is considerable. For a one day problem instance with a time resolution of 30 minutes, 100 turbines, each associated with an apartment building of 25 apartments, the inputs amounts to 270 kilobytes of data. The solution data computed by the system is in the order of 500 kilobytes.

We assume that Capstone C65 micro turbines are used with 65 kW electrical output. According to the data sheet of this device the hot water heat recovery output of this device is 120 kW. In our model we will assume that the micro turbines can be in one of two states: either off or working at full capacity. Therefore, we will assume that the recoverable heat is 120 kW when the turbine is running. The amount of fuel needed to run the micro turbine is 230 kW at full capacity (data from the Capstone data sheet) and we assume variable maintenance costs of 0.534 AUD per hour (data taken from Firestone [2004]). The gas price (relevant for the turbines as well as the boilers) is assumed as 0.672 c/MJ (Origin Energy Melbourne CBD, excludes GST).

According to NEMMCO, generators with more than 30 MW dispatchable capacity have to submit bids to the National Electricity Market (NEM), while smaller capacity generators may also do so if they can show that they have the technical infrastructure (telemetry and remote control capabilities) to do so. If we wanted to set up a virtual power plant with 30 MW using the 65 kW Capstone turbines, we would need 462 of them, corresponding to the same number of apartment buildings. This does not seem realistic for a single operator in Victoria, so we assume a total power capacity of 6.5 MW, corresponding to 100 turbines.

We assume that each apartment complex has 25 apartments each with 100 m^2 floorspace. Note that the average floor space of new flats, units, semi-detached houses and townhouses was 134 square meters in 2003 according to the Australian Bureau of Statistics. But we assume a slightly smaller value which seems more realistic for apartment complexes.

The Nationwide House Energy Rating Scheme (NatHERS) established that houses built in Australia in 1990 averaged about 1 star on the NatHERS scale [Nationwide House Energy Rating Scheme, 2007]. If we are dealing with houses or apartments with a 2 star rating situated in Melbourne, the space heating demand is 462 MJ per square meter and year.

To simulate changes in the space heating energy need during the year, we modulate the space heating power needed using the average minimum temperature for Melbourne in each month such that the space heating power needed for a whole apartment building in February is 0 and 78 kW in July, which is consistent with the average heating power for a 2 star dwelling given by NatHERS.

Since water tanks are not completely insulated there will be heat loss associated with the tanks for space heating and hot water service. Harrington and Wilkenfeld [1997] provide in Table 5 information on heat loss: A tank of 400 liters loses 2.87 kWh/day. We assume that one such tank is used in each building for space heating and 25 for hot water service (because of the variable nature of the corresponding demand).

We set the temperature band over which the hot water is allowed to vary between 60 and 70 degrees. The reason for the 60 degree lower bound is that at lower temperatures (below 55 degrees) pathogenic microbes such as Legionella can grow. The upper bound of 70 degrees is chosen as a compromise between the ability to store energy in the tanks and the need for a consistent hot water temperature.

For the space heating system, we assume a temperature range from 45 to 55 degrees. Since this water is in a closed loop, bacteria are not an issue and 50 degrees is a typical temperature for underfloor heating. We use hot water demand data consisting of the total hot water demand for each apartment building and each 30 minutes time slot. We create this data using a simple demand simulator with the following assumptions (mostly computed from data contained in Energy Australia [2006] and Office of the Renewable Energy Regulator [2008]):

- The number of persons in each household is 3.
- 62% of people have one shower a day, 29% have two per day and 9% have three.
- Each shower uses 10.31 MJ of energy
- The first showers are normally distributed around 07:30, the second showers around 19:30 and the third showers around 21:30.
- Each household has an additional hot water use event 2.34 MJ that is uniformly distributed over the whole day. This simulates a dish washer or washing machine.

Since the hot water demand is very variable and we do not want to run the turbines constantly, we assume that we have additional gas boilers in each apartment complex with a combined power of 350 kW and an efficiency of 92%.

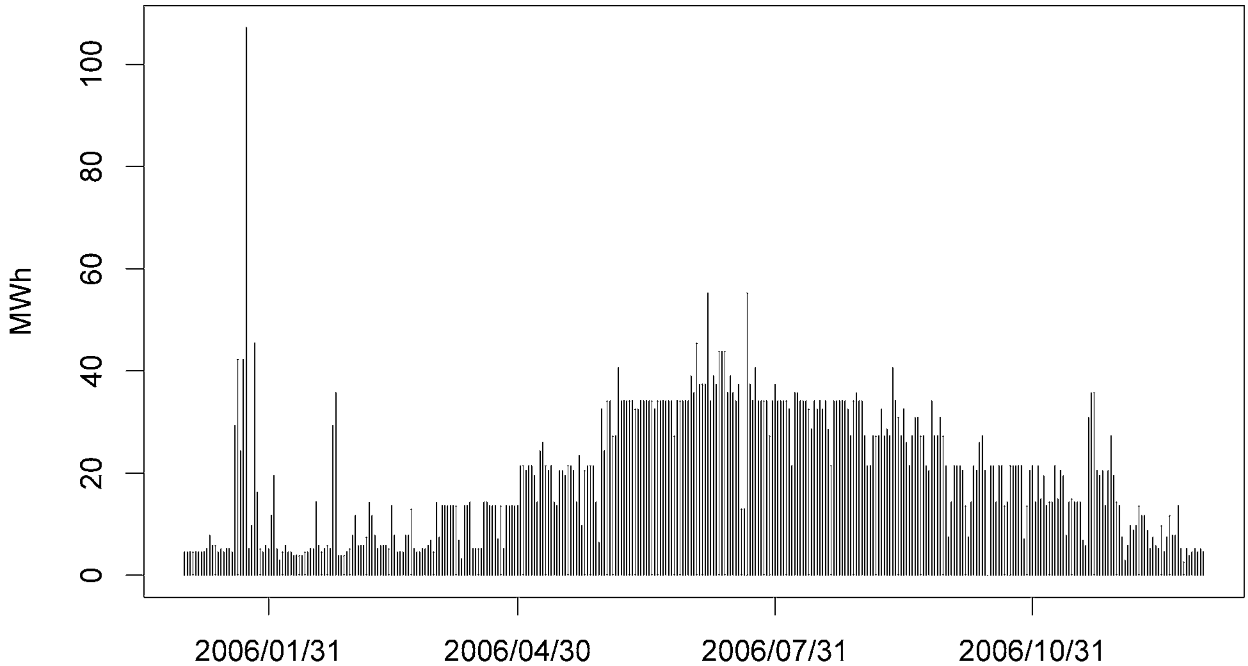

Figure 2: Amount of energy delivered to the NEM on each day in 2006

Our data for the local electricity demand in each apartment building is generated from half hourly winter and summer peak demand provided by EMET Consultants [2004]. We obtained our own winter and summer peak demand patterns by removing all space heating and hot water electricity demand from this data as well as pool pumps since our apartments are heated centrally and they do not have pools. To obtain demand pattern for all months, we generate linear combinations of these patterns depending on the average minimum temperature in the month. We obtain different demand data for each building by multiplying each type of demand (like dishwashers, freezers and TVs) with a uniformly distributed random number between 0.9 and 1.1. We assume a residential power price of 13.54 c/kWh (Origin Energy commercial residential tariff, Melbourne CBD)

6. Optimization Results

We want to use the optimization framework to predict how much power a rational operator with perfect knowledge about the power demands and prices on the next day would feed back into the grid as bids on the NEM. This will give us a benchmark for measuring the performance of optimization methods that use predictions for price and demand.

To see how much power the control strategy would provide to the NEM over a whole year, we used the half hourly resolution price data of NEMMCO for the Victorian part of the National Electricity Market in the year 2006. We compute a near optimal control solution for each day by running our integer linear programming model for each NEM-bid power level from 0.65 MW to 6.5 MW (the total turbine electricity output) in steps of 0.65 MW and choosing the solution where the objective function (maximizing the income from the bid and local power sale minus the fuel costs) is maximal.

Figure 2 shows for each day in 2006 the amount of electric power our strategy provides to the NEM. There is a pronounced spike in January at a day where wholesale price in the Victorian part of the NEM was exceptionally high for a number of hours. These extreme peaks mainly happen during summer when electricity demand is high due to air conditioning load and the interconnectors to other parts of the NEM are near capacity. The average amount of power delivered each day was 75.87 MWh while the total for 2006 was 27,693 MWh.

In general, the figure shows that more power is delivered to the NEM in winter when the CHP-system can take advantage of combining heating load with electricity production resulting in a low marginal price for electricity. The plot shows a concentration at certain values because the power levels of the NEM bid can only take 10 different values (from 0.65 MW to 6.5 MW) and each NEM bid block has a duration which is a multiple of 30 minutes in our model.

To evaluate the financial attractiveness of the CHP system, we compared it with a base case. In this base case, all electricity for local demand in the apartment buildings is bought at the standard electricity retail rate. All heating needs are met using gas boilers with an efficiency of 92%. For each day of the year 2006, we calculate the savings achieved with the CHP system compared to the base case as follows: Let l be the energy that was produced by the CHP system and used to satisfy local electricity demand in the apartment buildings (note that the CHP system does not meet all local electricity demand). Then the savings is the difference between the expenditure in the base case (gas for heating and buying l amount of energy from the retailer) and the expenditure of the CHP system (which is gas for the turbines and the boilers) plus the income generated by selling power to the NEM.

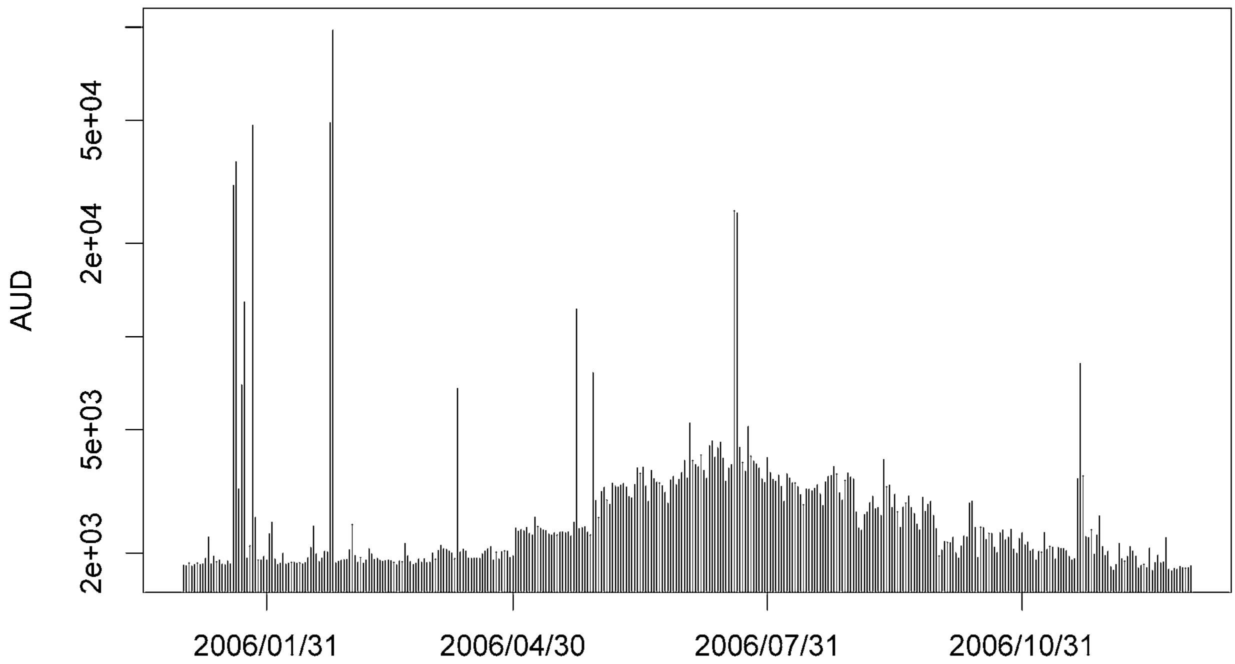

Figure 3: Savings achieved using the micro-turbine CHP scheme for each day in 2006. Note the logarithmic scale

Figure 3 shows the savings for each day in 2006 on a logarithmic scale. As expected, the savings are in general higher in winter when there is sufficient heat demand to lower the marginal price of electricity generation. However, the savings are huge on days where the wholesale price in the NEM is extraordinarily high. The average daily savings were 814.42 AUD while the total savings for the whole of 2006 were 297,262.68 AUD. Figure 4, where the profits are sorted in decreasing sequence, shows just how important the days with high wholesale price in the NEM are: the lion's share of the year's savings are obtained in just a few days with favorable market conditions. The CHP proposition would look much less attractive without access to the wholesale market. This result agrees with a recent paper by Toke and Fragaki where they stress the importance of aggregation in enabling distributed generators to profit from high prices on the wholesale market (D. Toke and A. Fragaki, 2008).

To compute the amount of CO_2 saved, we again compared with the base case where all electricity is bought and all the heating needs met using the gas boilers. According to the State Government of Victoria [2002], 1.444 kg CO_2 equivalent is produced for every kilowatt hour of electricity produced in Victoria. For each

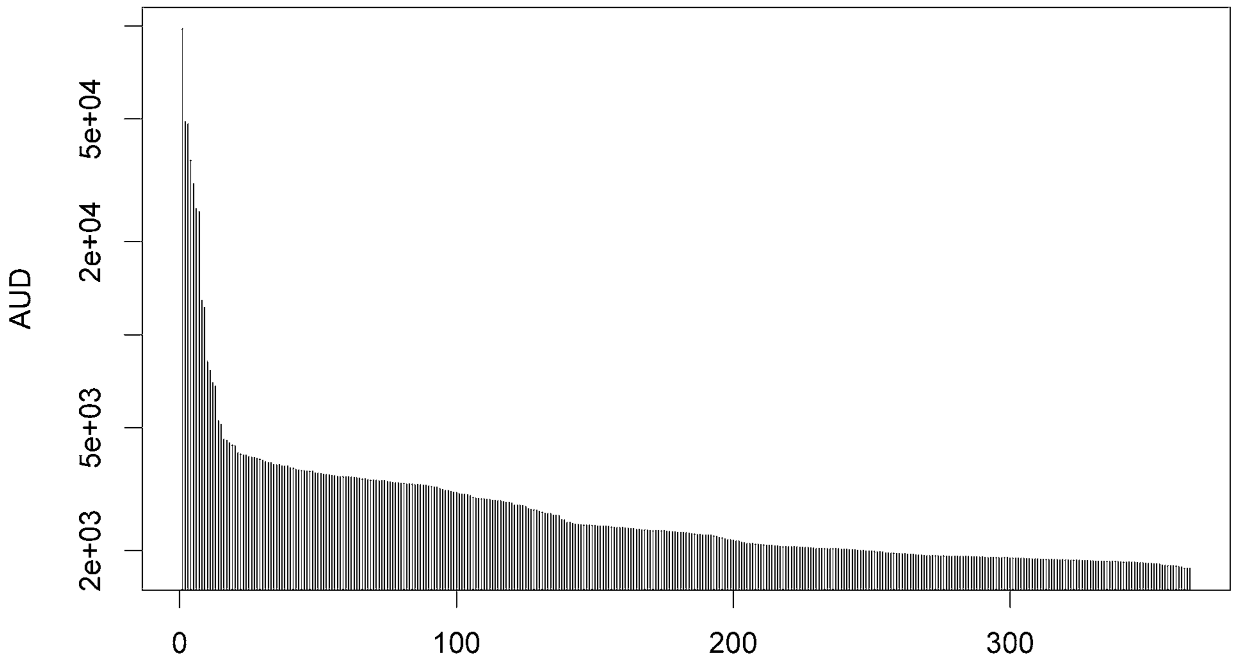

Figure 4: Daily savings achieved by the CHP scheme sorted in decreasing sequence. Note the logarithmic scale.

gigajoule of natural gas, the amount of CO_2 equivalent produced is 51.7 kg. These are the numbers we used to estimate the amount of CO_2 saved compared to the base case. As the base case CO_2 emissions, we added the emissions from the heating system to the emissions produced for generating the electricity that is produced by the turbines in the CHP solution (local use as well as export to NEM). From the resulting tonnage, we subtracted the CO_2 equivalent of the natural gas used by the turbines and boilers in the CHP solution.

The result of the comparison of CO_2 emissions is shown in Figure 5. The plot looks very similar to Figure 2, where the amount of energy exported to the NEM for each day is shown. This indicates that not only from a financial point of view, but also from an environmental point of view, access to the NEM is crucial for

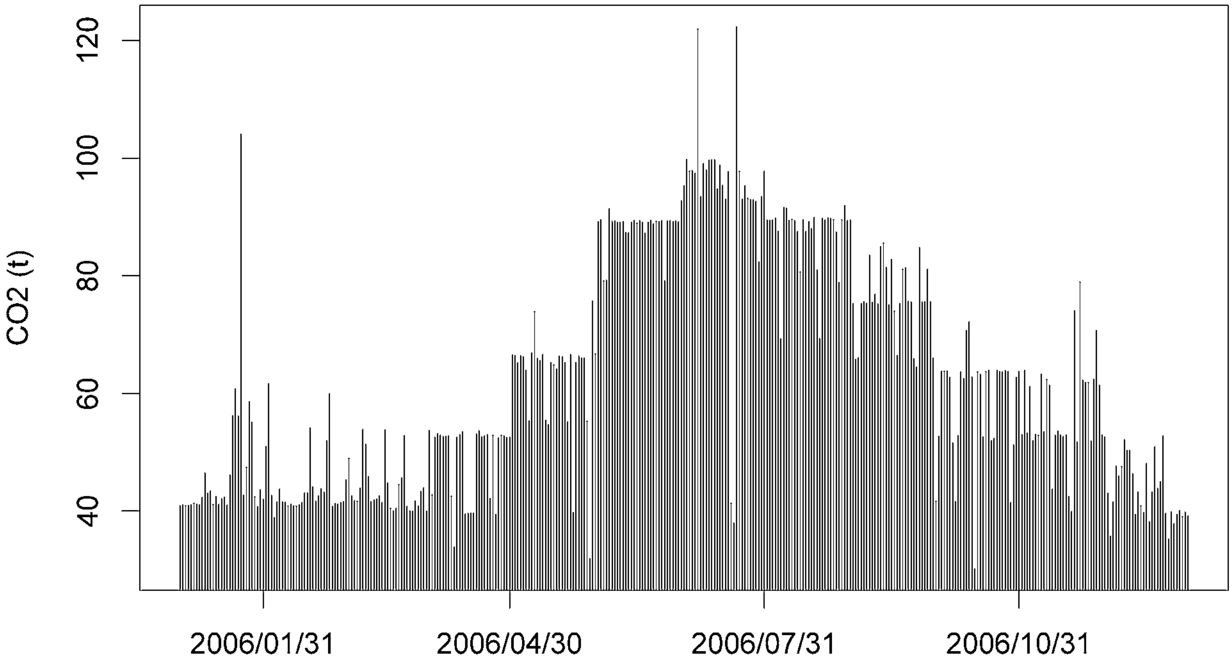

Figure 5: Savings in CO_2 emissions for each day in 2006

harvesting full benefits from the CHP scheme we suggest. The savings in emissions are around 40 t in summer and can go up to more than 120 t in summer. The mean daily savings were 63 t and the total savings for the year 2006 were 22,861 t. Assuming that an average car has CO_2 emissions of 226.1g per km (Federal Chamber of Automotive Industries, 2008) and drives 15,000 km per year, this is equal to the emissions of 6740 cars.

7 Conclusion

In this paper, we suggested scheme where an operator owns micro-turbines in apartment buildings that are not only used to provide heat and power to the residents but also act as a virtual power plant in the NEM. This allows the operator to benefit from extreme price events on the wholesale market in addition to benefiting from the combination of heat and power production. Our computational results have shown that the system can be run in such a way that savings can be achieved every day with substantial savings in winter and on days with high wholesale prices.
We have also shown that access to the wholesale market is crucial for the financial attractiveness of the scheme. The savings in CO_2 emissions are also substantial and benefit from access to the wholesale market. In the future, we want to develop strategies for controlling the micro-turbine CHP system as a virtual power plant that do not rely on perfect foresight of the local power demand and the wholesale price. Machine learning strategies may be well suited for this application as well as fuzzy logic or other rule based strategies.

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ANALYSIS OF MATERIAL AND ENERGY EFFICIENCY OF MEXICAN, PERUVIAN AND DUTCH DWELLINGS USING THE THREE-STEP-STRATEGY

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Keywords: sustainable building, energy, materials, method, international study

Summary

Buildings consume resources and produces emissions to the environment during their life cycle. They consume materials during their construction, maintenance and renovation activities, consume energy and water during their use, and produce waste at the end of their useful life. There are several sustainable building methods for environmental assessment; the results of these depend on the approach taken and therefore also on the objective or endpoint of the assessment. The most common strategies aim at reducing their impacts, but buildings will always have an environmental load. Therefore, to calculate the absolute damage of a building to the environment, as it is done in the Life Cycle Assessment may be considered inadequate for assessment when the objective is to improve the environmental performance of the building from design. The three step strategy is an option being a method that focuses on a different approach. This strategy establishes that for a sustainable use of resources, three steps are necessary: a) to reduce the need or use of resources, b) to use renewable sources to sustain the need and c) to be efficient with the remaining need. The method has advantages and disadvantages related to accuracy, data needed, output, and interpretation of results. In this research, the method is applied on case studies. Dwellings are analyzed to improve their environmental performance with the objective to point out at the limitation of the method in relation to its applicability and usability.

1. Introduction

Construction is considered one of the activities that contribute the most to the environmental burden. During its life cycle, a building consumes resources and releases emissions and waste into the environment having great responsibility for fossil fuel consumption and global warming (Edwards, 1996). The materials used in buildings also have a significant influence on the environment; concrete and steel having the greatest impact. In addition, these materials are the most intensively used on a global scale. Cement production emits greenhouse gases that contribute to global warming, while steel is one of the most energy-intensive materials (UNEP-IETC, 2002). The manufacture and final use of these materials is also water intensive.

The environmental burden and the quality of the building both depend on the interaction of the building with its surrounding environment. This interaction is defined from the design phase of the building. The type and quantity of resources used for the building, such as materials, energy and water are partly determined by design. In addition, the conditions of the indoor environment also depend on the design. Furthermore, the life cycle of the building is influenced by early decisions. The efficiency of maintenance, renovation and demolition activities will be defined by the potential of the building to allow such activities.

Design is an essential part of the construction process. If designed properly, dwellings can promote well-being of the occupants and ecological sustainability (Lawson, 1996). During this phase, environmental issues can be better incorporated. The design of the building determines the potential for good environmental performance during the entire life cycle (during maintenance, renovation and demolition activities).

An environmental assessment of the building is needed to determine the potential impact of the building on the environment. There is a great variety of environmental building assessment methods (Itard & Klunder, 2007), but these often have limitations that can cause uncertainty in the results or be ineffective in the assessment. These assessment methods, originally developed to calculate the environmental impact of buildings, are now used for design purposes (Ding, 2007). These methods can contribute to better understanding a building's impact on the environment, being most useful when the materials, construction processes and systems are chosen. Nevertheless, these methods may be unsuitable for a design analysis because they do not provide information on the choices made during the design of the building.

This study uses a method that allows analysis of the performance of the building in relation to design choices based on the Indicator Approach by Rovers (2005). This study was part of the Atlas Project (Rovers).

The impact of housing on the environment in three countries is assessed to point at the major environmental problems. Since this is a quantitative method, reference houses are needed. The reference houses were defined with the aid of demographic statistics and legislation. Reference houses were selected as representative of the average house. The reference dwellings provide examples of the most common building materials used. These examples are analysed focusing on materials and energy efficiency.

2. Methodology

2.1 The Approach

The approach followed for assessing the environmental performance is based on the Three Step Strategy. The strategy provides detailed information about building characteristics and has a direct relationship with design. The aim of the Three Step Strategy is to limit the inflow and outflow of resources and to retain for a longer time the incoming flows within the system (Hendriks, 2001). In order to decrease the environmental impact there are three steps that must be followed: reducing volume flows, using renewable sources, and being efficient with the remaining need. This is suitable for analysing the potential environmental impact of choices made during the design process because it provides detailed information about different aspects of the design of the building and point at the problems or areas for improvement. This study focuses on the resource efficiency of materials and energy.

2.2 Materials

An essential part of the design process is the selection of materials based on their sustainability (Jong-Jin & Rigdon, 2007). Materials possess characteristics that make them more or less sustainable in relation to the phases of the material's life cycle: pre-build, build, and post-build.

Hendriks (2001) and Jong-Jin and Rigdon (2007a) identified criteria for choosing construction materials according to their environmental sustainability. They group the criteria in the three phases of the life cycle of building materials: Pre-building, Building and the Post-building phase. The criteria for the Pre-building phase include the use of materials that produce a limited amount of waste and emissions during their manufacture, have low embodied energy, have a high content of recycled materials, and prevent depletion of natural stocks. The criteria for the Building phase are the use of non- or less toxic materials, with high durability, usability, reparability, safety, energy efficiency, and ability to withstand calamities. The criteria for selecting materials in relation to their performance in the Post-building phase are the use of materials with high potential for recycling and reuse, a low deterioration rate, and a long technical lifespan.

Most of the methods for determining the sustainability of materials (Hendriks, 2001) focus on the post-use or post-building phase of the life cycle of the building, Table 1 shows the methods and literature used. They are presented according to the steps of the Three-Step-Strategy.

Table 1 Summary of approaches to choose materials based on their sustainability

	Indicators		
	Material efficiency (2.2.1)	Renewability (2.2.2) and impact to environment (2.2.3)	Dismantling and reusability
Three Step Strategy	Step 1: Reduce need	Step 2: Use of renewables	Step 3: Increase efficiency
Hendriks	Avoid depletion of natural stock	Use materials with less emissions	Reuse materials Use materials with higher usability, reparability, and longer lifespan
Jong-Jin and Rigdon	Reduce waste	Reduce emissions Use materials with low embodied energy Higher recycled content Use of natural materials	Reuse materials Recycle material Use materials with longer lifetime
Design for recycling	Use fewer materials	Use of recycled materials	Design for dismantling Identification of materials

Sources: Hendriks (2001), Jong-Jin & Rigdon (2007)

Only the first two steps of the Three-Step-Strategy are considered in this paper. Therefore the objectives are to use fewer materials and to use renewable materials or materials with low embodied energy and emissions. In the present study, the following indicators are used:

2.2.1 Material efficiency: total embodied materials per useful living area. The quantity of embodied material consumption as a consequence of the design can reduce the demand on virgin resources and the production of waste, thereby reducing the environmental impact and energy and water consumption when needed for extraction and manufacturing (Jong-Jin & Rigdon, 2007a).

2.2.2 Renewability of materials: quantity of renewable materials. In a human perspective, a material is only considered renewable if it can be grown at a rate that meets or exceeds the rate of human consumption (Jong-Jin & Rigdon, 2007b). Non-renewable materials are materials that have a slow growth rate in relation to the consumption of the material for human activities.

2.2.3 High impact materials and low impact materials: embodied materials with high or low impact to the environment. Low impact materials have a low or no impact on the environment during their manufacture, requiring less processing and less embodied energy. High impact materials are those whose manufacture requires significant use of resources, high embodied energy and high production of emissions.

2.3 Energy

The design of the building plays an important role in energy consumption. The thermal properties of the building determine the energy use for heating and cooling. Another important characteristic of the building is the natural lighting of spaces; the better the natural illumination, the less energy is needed for artificial lighting.

According to the Three Step Strategy the steps needed are: reducing the use of energy, using renewable energy, and being efficient with the remaining need. This paper only focuses on step one. The energy indicators used are the following:

2.3.1Total energy consumption refers to the total consumption of energy per household. It includes energy used for artificial lighting, indoor climate, and for appliances, cooking and water heating. It is important to make a difference between primary energy and delivered energy. The efficiency of the generation of energy is given by the percentage of energy that is lost during the production and transport of energy. For this approach, only delivered energy is taken into account because the designer has little choice in the type of energy used, and therefore on the energy efficiency of the source (Rovers, 2005).

2.3.2 Energy used for heating or cooling: delivered energy used for heating or cooling per useful living area.

2.3.3 Energy use for artificial lighting: delivered energy used for artificial lighting per useful living area.

2.3.4 Energy used for appliances, cooking and heating water: delivered energy for appliances, cooking ans heating water per useful living area.

3. Reference dwellings

The goal of the international analysis is to place housing in a broader context for a better understanding of the situation. The dwellings used for the analysis are a Mexican reference house, a Peruvian reference house as defined in the Atlas Project (Wageningen University, http://www.iconwise.com/ue/), and a Dutch reference house.

The objective of the analysis is to determine the effects of different construction methods on resource consumption and sustainability. The institutional, cultural and social contexts are not deal with in the analysis. The goal of the analysis is to help to analyse housing design in relation to its context. Therefore the differences between the countries do not cloud the analysis but make it more useful. Nevertheless, the climate is an important factor affecting the performance of the dwelling therefore degree days are used to normalize the temperature in the three countries. The reference houses are introduced in next section. Table 2 summarizes the characteristics of the reference houses.

3.1 Mexican dwelling

In Mexico there is a great variety of climates due to its land extension, mountains and coasts. The climate in the selected area of study is semi-cold. Mexico City, Toluca, Tlaxcala, Puebla and Morelia are some of the cities with this climate. For the case study, the city of Toluca was chosen. The cold climate is due to its high altitude at 2,680m above sea level. During the night, temperatures can drop below 0^{o}C even in summer, and the maximum temperature rarely exceeds 27^{o}C.

Statistical data was used for the selection of the reference dwelling. The reference dwelling consists of a single-family row dwelling set over two floors. On the ground floor there is a living/dining room, separate kitchen, and toilet with sink. On the first floor there are three bedrooms and two bathrooms. The dwelling has continuous stone footing, confined masonry walls of fired clay units and reinforced concrete elements, reinforced concrete floor and roof, and a layer of gravel in roof as insulation.

Electricity produced in a thermoelectric plant is used for artificial lighting and appliances. For cooking and heating water the most common fuel used is gas. To calculate energy consumption in modern houses, a collection of data from a small sample of similar houses with different family composition was realized.

3.2 Peruvian dwelling

Most common type of construction in Peru is the self-build, carried out by the owners of the dwelling. The Peruvian case study and the data for the analysis was taken from Torres Mendez (2005), where a reference dwelling in the city of Lima was defined according to the typical construction processes, layout and construction procedures in the city. It is a three-level single-family dwelling with concrete with steel reinforcement footing, concrete with steel reinforcement beams and columns, walls of hollow clay and gypsum units. Energy consumption is based on a 5 person household.

3.3 Dutch dwelling

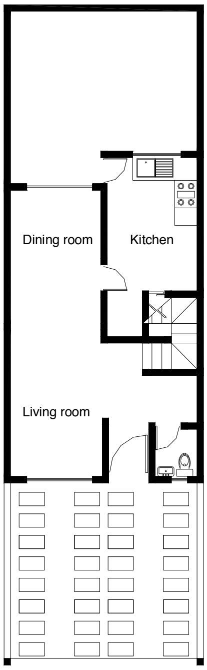
In the Netherlands, 70% of the housing stock consists of single-family dwellings. The Dutch case study was taken from the reference houses defined by the Agency for Sustainability and Innovation (Senternovem). In the Netherlands, reference dwellings have been defined and are widely used for comparative quantitative research. For this research, the “attached” house was chosen because it represents the average dwelling.

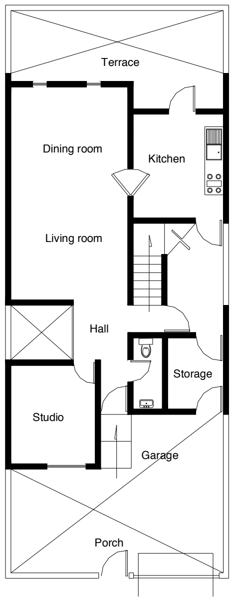
Data on energy consumption was obtained from the KWR survey (Ministry of VROM, Netherlands), and it represents the mean value for row houses with a four-person household. The dwelling consists of concrete and steel beams and poles footing, beams and columns made of concrete and steel, exterior walls made of double layer cavity gypsum walls with mineral wool or meranti insulation, interior walls made of gypsum walls filled with wool or fibre, wooden roof with concrete and ceramic tiles.

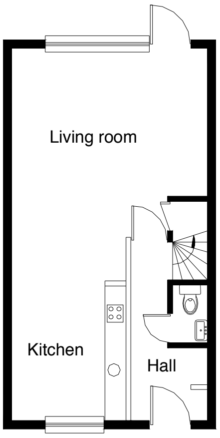
Table 2 Reference dwellings in Mexico, Peru and the Netherlands

	Mexican dwelling	Peruvian dwelling (*1)	Dutch dwelling (*2)
Useful Living Area	108m^2	214m^2	111m^2
Average outdoor temperature	10^{o}C–15^{o}C	18^{o}C	5^{o}C–18^{o}C
Layout	Row single-family dwelling over two floors	Two levels and service area on third floor	Row single-family dwelling
Electricity	Electricity generated in thermoelectric plants	Electricity generated in thermoelectric plants	Electricity generated in thermoelectric plants
Water boiler	Low efficiency boiler (turned on all day)	Electric boiler (turned on for 2 hours per day)	High efficiency boiler
Energy for heating water	LPG	Electricity	Natural gas
Energy for cooking	LPG	Natural gas	Natural gas
Number of occupants	4	5	4
Kg/m^2 material	2126.92	1405.27	1068.87
MJ/m^2 energy per year	282.96	82.66	756.15 (*3)

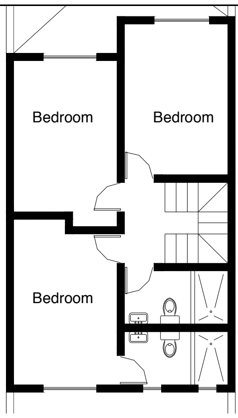
Ground floor

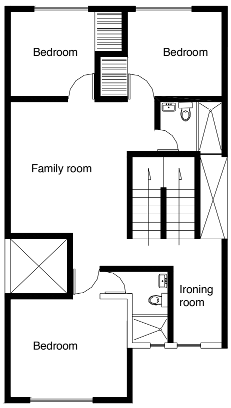


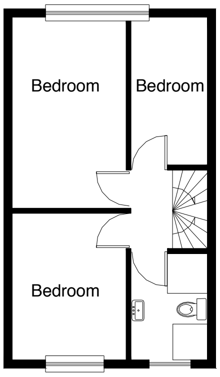


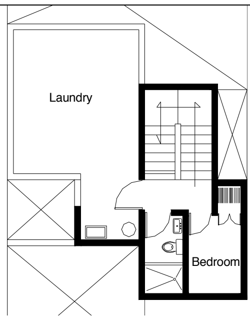
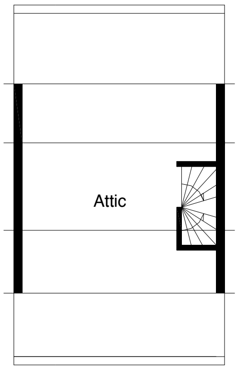
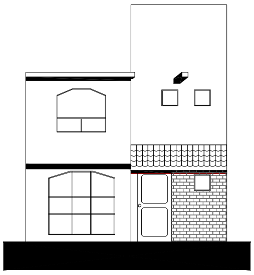
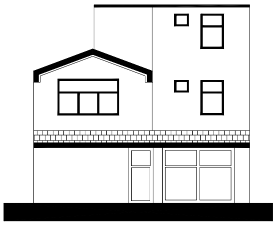
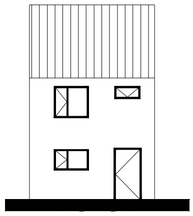


Second floor







Second floor			
Facade			

Sources:
(*1) Peruvian dwelling: Torres Mendez (2005)
(*2) Dutch dwelling: Senternovem (2005)
(*3) KWR Survey, Ministry of VROM

4. Analysis of material efficiency

4.1 Material efficiency and renewable, recovered and non-renewable materials

The Mexican reference dwelling is more material consuming than Peruvian and Dutch reference dwellings, the Dutch reference dwelling being the less material consuming. High impact materials are intensively used in all dwellings, due to concrete elements and ceramic bricks. All of the dwellings have a minimal percentage of renewable materials, which are mainly used in windows and doors. The Mexican reference house performs better than Peruvian or Dutch houses in terms of the origin of the material because of the higher percentage of low impact material from stone masonry footing used in Mexican dwellings (Figure 1).

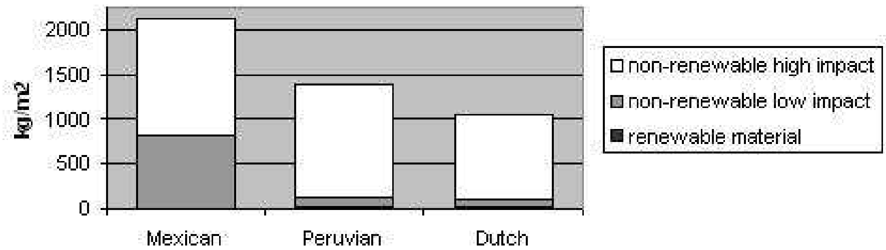


Figure 1 Percentage of renewable, non-renewable, high impact and low impact materials

4.2 Material efficiency of building elements

Figure 2 shows material use per useful living area per building element and the impact of the materials on the environment. Finishes are not shown in the graph.

Footing in Mexican housing is twice the weight of footing in Peruvian dwellings and more than triple that of Dutch houses because in Peruvian and Dutch dwellings, footing is made of concrete with iron reinforcement while footing in Mexican dwellings consists of continuous stone masonry along all walls, which increases the weight of the foundation.

Structural elements are more material consuming in the Mexican reference dwelling's walls than in the Peruvian and Dutch reference dwellings walls. Mexican vertical structural elements consist of confined masonry walls with horizontal and vertical reinforcement elements made from reinforced concrete. In addition, a higher percentage of walls in Mexican housing are structural walls. Materials used in structural walls in Mexican dwellings double the amount of materials used in walls in Dutch dwellings. The supporting elements in Peruvian housing consume half the quantity of material used in vertical structural elements of Dutch housing.

Non-structural elements in Mexican housing in comparison with Peruvian housing are lighter, given that a high percentage of walls in Mexican housing are structural. Nevertheless, non-structural walls are also made of solid brick with reinforced concrete confining elements. In Peruvian housing all the walls are non-structural; therefore consumption of materials for these elements is high. Non-structural walls in Dutch housing are very light in comparison to Peruvian non-structural walls. The weight of all vertical elements in Mexican housing is more than double that in Dutch housing and around 30% greater than in Peruvian housing. The large difference in weight between Mexican and Peruvian vertical elements and Dutch vertical elements shows that masonry structure accounts for a high percentage of material used in housing, while light walls, as in the Dutch case study, are more material efficient.

Materials in roof in the Mexican dwelling are lighter than in the Peruvian and Dutch dwellings because the roof tiles in Mexican housing do not need beams. Although Peruvian dwellings have concrete tiles like Mexican dwellings, roof tiles in Peruvian housing are hollow; therefore the use of beams increases the weight of roof tiles in Peruvian dwellings.

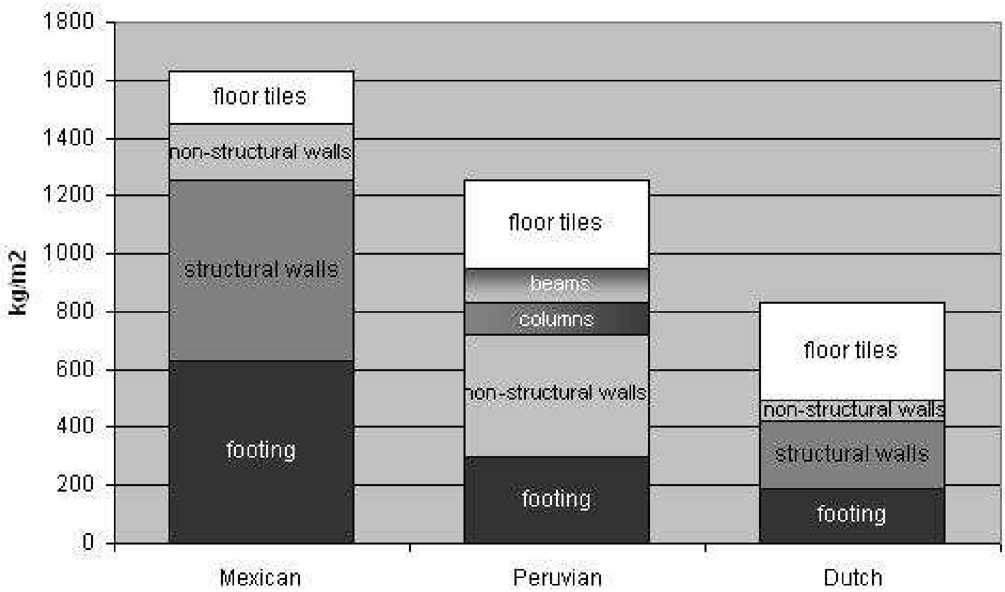


Figure 2 Material weights per useful living area per building element

4.3 Analysis of energy efficiency

Figure 3 shows the energy use for different purposes in the reference dwellings. Energy consumption in Peruvian and Mexican houses is visibly lower than for Dutch houses. Energy consumption for heating is high for Dutch housing, while in Peruvian and Mexican housing energy for heating or cooling is not used. This is because the weather in Lima is mild, and therefore, it is reasonable that energy is not used for heating or cooling. Nevertheless, Toluca is a city of cold nights, especially in winter, due to its altitude.

To test the relation between energy used for heating and the heating degree days per country, the energy consumed in Dutch houses is normalised with respect to the number of heating degree days in Mexico and Peru. Table 3 shows that in relation to the energy consumed in the Netherlands, energy in Peru is consumed according to its weather (real consumption is 0 while hypothetical consumption is 5.32 MJ), while in Mexico the energy consumed for heating is considerably lower than what is needed (real consumption is 0 while hypothetical consumption is 48.65 MJ). Nevertheless it is important to consider that the low temperature in Toluca is in the night when comfort is less needed.

Table 3 Energy consumption in the Netherlands according to degree days in different countries

	Netherlands	Peru	Mexico
Number of degree days	5328	566	3236
Hypothetical energy use in the Netherlands in relation to the degree days	80.11 MJ	5.32 MJ	48.65 MJ
Real energy use	80.11 MJ	0 MJ	0 MJ

Energy used for appliances, cooking, and for heating water in Mexican reference dwellings is higher than in Dutch and Peruvian reference houses. Energy used for cooking, heating water, and appliances in Peruvian houses equals about 80% of the total energy consumed. For Mexican houses this is about 75%. This shows a trend in Mexican houses of high consumption of energy for such activities.

Energy consumption for appliances, cooking and water heating in Mexican housing is higher than in Peruvian and Dutch housing, because of the large use of energy for heating water. The cause may be attributed to the type of boiler used in the majority of houses in the region, which is turned on all day.

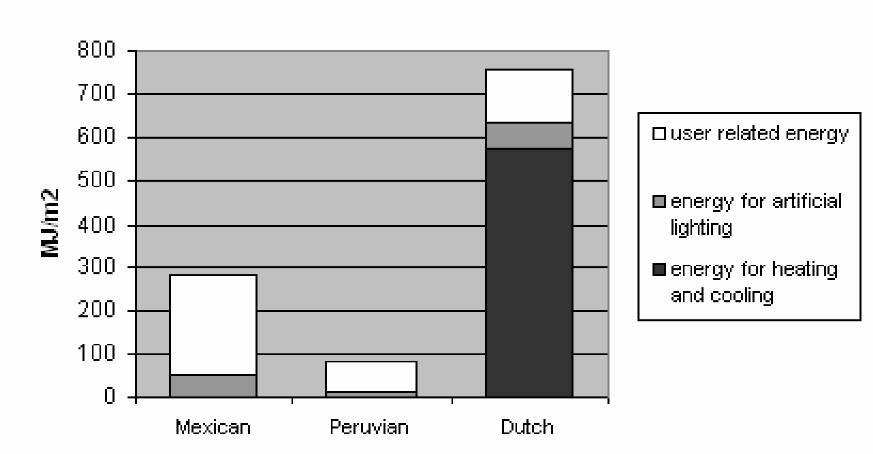


Figure 3 Energy use for different purposes

4.4. Conclusions

There is an intensive consumption of material in Mexico due to the use of continuous stone masonry footing along all the walls and due to the undifferentiated use of solid units in walls. Peruvian houses are lighter due to the use of hollow units. Dutch houses tend to have light interior walls, a factor that reduces the weight of the materials.

Non-renewable materials with high environmental impact seem to be intensively used in all dwellings due to the concrete elements and ceramic bricks. Renewable materials are almost not used with exception of the Dutch reference dwelling where wooden beams are used. The use of low impact materials makes the performance of the Mexican dwelling appear better in comparison to other countries but the amount of renewable materials is very low.

The performance of the Mexican and Peruvian reference dwellings could be improved by using more renewable materials in the structures such as in Dutch dwellings. The use of lighter walls in interiors and the use of hollow masonry units could reduce the material use in Mexican dwellings without compromising its thermal properties.

Diminishing the quantity of materials by means of using different processes in foundations would be a different solution for material consumption in Mexican housing without making structural or functional changes. Nevertheless, Mexican houses consume fewer high impact non-renewable materials than Dutch and Peruvian houses, this fact being attributable to the use of stone foundation.

Renewable energy is not used in any reference house, but in the Netherlands there is the possibility to choose sustainable sources. The energy consumption for artificial lighting is comparable in all dwellings, while energy for cooking and water heating seems higher in Mexican dwellings, followed by Dutch reference dwellings.

The high consumption of energy for heating water can be attributed to the use of low efficiency boilers in Mexico. Environmental performance in Mexican and Peruvian dwellings seems good in comparison to the Dutch reference house in relation to climate systems, because energy for air conditioning is not required. In Mexican housing there is no consumption of energy for heating in spite of the weather conditions in the region, where temperature in winter nights can drop below 0°C, and in summer nights to 5°C. This could be due to the use of massive materials in walls.

5. Discussion

Sustainable building is acquiring more importance worldwide. The current situation of sustainable construction and housing in developed and developing countries is clearly different. Developed countries have reached a high level of quality in housing but consume more energy. The main problem that these countries face is maintaining the current level of quality of life while minimising environmental interventions. On the other hand, housing in developing countries still lacks the quality reached in developed countries, but energy use is still low, which could be attributed to traditional massive materials and climate. Nevertheless, further research should be done about indoor temperatures in the region of study in Mexico. There is the indication that indoor temperatures, especially in winter nights, are cooler that in the Netherlands, which if true could lead to the conclusion that there are more factors influencing the low energy use than massive building materials alone.

The choice of indicators in the present study is based on the three step strategy and on needs identified from a designer perspective. From this perspective the use of Life Cycle Assessment is not recommended, because it is not directly related to building design. In the present study, the level of the indicators was determined by literature and estimates. However, to determine quantitatively, or to determine if a material has a low or high environmental impact, it would be better to use the Life Cycle Assessment method, or at least parts of it, because it is the only widely accepted quantitative method to determine these characteristics.

The method gives a general idea of the situation regarding material and energy use within countries. For example we saw that materials in Mexican dwellings are more intensive than in Peruvian and Dutch dwellings, that energy use for heating is higher in the Netherlands, and that energy use for heating water is higher in Mexico. Nevertheless, factors dependent on the background of the countries should be considered before trying to apply a different solution for problems in a determined country.

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FROST FORMATION AND CONDENSATION IN STONE-WOOL INSULANTS – THE COURSE OF MOISTURE RESISTANCE FACTOR

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Summary

Globally increasing prices of energy have result in raise of thermal qualities of building envelopes. Consequently, these heavy insulated constructions are facing undesirable phenomena – for instance a risk for occurrence of frost formation and condensation together with a changed thermal field in building constructions. Condensed moisture, as well as moisture trapped in thermal insulations during build-up, can also affect an increased dust contamination, algae or mould growth and structural damages.

This contribution reports on a laboratory experiment aimed at growth of frost formation and moisture condensation in stone wool opened to air for specific temperature fields – namely (+20; -20ºC), (+20; -15ºC), (+20; -10ºC), (+20; -5ºC) over fibrous specimens with varying density. Air on warm side of material samples was saturated with moisture. Frost accumulated with time in the part of specimens facing the cold air. In the part facing the warm humid air a condense formation occurred. The wider thermal field and higher density of material samples we used the more distinct border between frost and liquid condensate we observed. Also moisture resistance factor μ, as a basic moisture characteristic of an insulating material, had an upward trend for broader temperature intervals.

Next to the loss of insulating qualities, annual repetition of condensation and frost growth in stone wool can contribute to degradation of the material structure, thermal losses and, in consequence, higher energy consumption.

1. Introduction

Thermal insulation materials are very important to reduce energy load in both existing and newly built constructions. Especially demands on thermal protection of new buildings have become fundamental. Builders are using more and thicker thermal insulations for walls and roofs. A good thermal insulation should perform, among others, low thermal conductivity, durability, dimension stability, resistance to fire and as low negative impact on the environment and human health as possible. Stone wool - thermal insulation made from molten rocks, meets many of the listed features, though it has also negatives. This fibrous building material is one of the most common thermal insulation spread all over the world. Hand in hand with its great potential and expansion, there is a risk for heavy insulated structures. Thanks to insulation thicknesses a moisture capacity in a wall or roof construction is quite big. No doubt, these energy-saving trends in he building industry are right, but new findings and menace resulting from this design should not be omitted.

As we know from the building practice, thermal insulation materials are always exposed to temperature gradient through their thicknesses and to conditions for moistening and desiccation depending on ambient conditions around the layer of thermal insulation. Moisture can enter constructions via leakage in details of window sill, attics, etc. Constructions can also become wet in case of driven rain, heavy rain showers and snowfall during building processes. At the same time, the finished buildings are hardly permeable for inbuilt moisture even this tightness can worsen in time. As a result, moisture content can slightly grow depending upon actual temperature conditions, so condensation and frost formation are annually repeating in certain seasons (above all in late autumn, winter and early spring) of a year.

This contribution describes research project intent on finding possible changes of moisture properties in stone wool that could affect its future degradation. It also aims at better understanding of creation of frost formation and condensation in a limited time interval.

2. Moisture transport in porous materials

Moisture transport in porous materials is represented by vapour diffusion, surface diffusion and capillary conduction. The executed laboratory tests were based on a fundamental moisture transport theory by diffusion represented by Fick's law and its variations. Moisture flow rate *G* was obtained by laboratory measurement and then used for calculation of diffusive flux g. The point of this computational model is specification of moisture resistance factor μ as the key moisture characteristics.

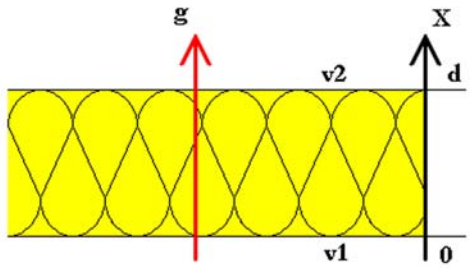

Figure 1 Diffusion of water vapour flux through a layer of stone wool where d is the width of material. Vapour permeability of material is termed δ_v (see Equation 1). Humidity by volume v is kept at v_1 at one side of the layer and at v_2 on the other side. The steady-state diffusive flux is defined as g.

According to Fick's empirical law the steady-state diffusive flux g is:

$$g = \delta_v \cdot \frac{v_1 - v_2}{d} \quad \left[\frac{kg}{m^2 s}\right] \tag{1}$$

Diffusive flux multiplied by cross-section area of the sample gives us moisture flow rate *G*:

$$G = A \cdot g \quad \left[\frac{kg}{s}\right] \tag{2}$$

The rate of diffusion, in the sample can be compared with the one obtained in stagnant air. Introducing the ratio between *D* and δ_v indicates moisture resistance factor μ:

$$\mu = \frac{D}{\delta_v} \quad [-] \tag{3}$$

3. Materials

All material specimens we used for our laboratory measurement were based on stone-wool. They all were commercial products widely used all around the world and taken from a product portfolio of a major producer. Materials with different densities and a varying sphere of use were chosen. Samples were dried and weighed prior to measurements and their dry densities ρ_d were calculated.

The heaviest material sample – SPECIMEN A is primarily used for flat-roof constructions. It is a stiff heavy board of stone wool with integrated double-layer characteristics, which is bonded by organic resin and fully hydrofobised throughout its capacity.

The second fibrous material – SPECIMEN B is a rigid stone-wool board, fully hydrofobised, especially used for flat roofs.

The lightest - SPECIMEN C is a semisoft batt, fully hydrofobised, used for insulating pitched roofs, ventilated facades and sandwich walls.

Table 1 Technical parameters of the used stone wool

Specimen	Declared thermal conductivity λ_D [$Wm^{-1}K^{-1}$]	Dry density ρ_d [kgm^{-3}]
A	0,040	145
B	0,039	112
C	0,035	44

4. Test equipment

At the Department of Civil and Architectural Engineering of the Royal Institute of Technology in Stockholm we designed and built up a special testing device to observe condensation and frost formation in fibrous insulations. The testing set-up consists of a plastic box with open roof, which was replaced by thermal insulation material – stone wool. All specimens were 100mm thick and with surface 300*300mm. Walls and the bottom of the box were insulated with 40 mm thick XPS boards on the outside and coated by an aluminous foil to prevent any weight-gain in surrounding walls caused by moisture uptake from ambient air.

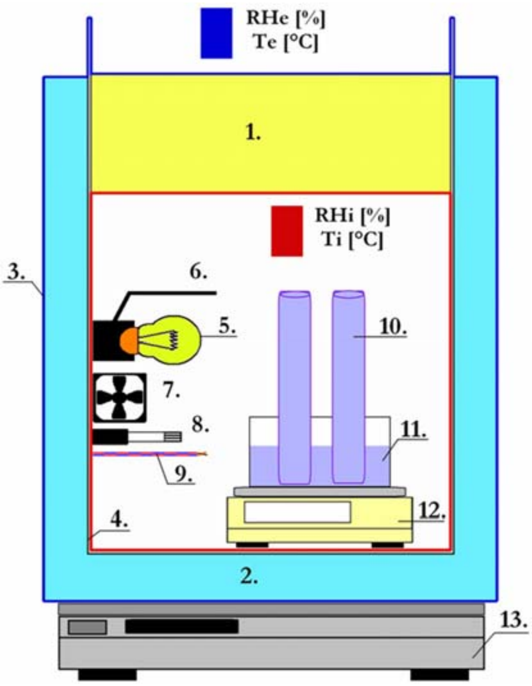

Figure 2 Composition of testing set-up including numbered list of components:

1.material sample (th. 100 mm), 2.XPS insulation of the box-walls (th. 40 mm), 3.aluminium-foil coating, 4.plastic wall of the box, 5.light bulb, 6.cover of the light bulb, 7.ventilation fan providing circulation of air in the testing box, 8.calibrated humidity sensor, 9.temperature sensor, 10.Wettex textile installed to increase evaporation of moisture in the box, 11.water reservoir circa 400 ml, 12.precision laboratory balance registering evaporation of water from the reservoir, 13.precision laboratory balance registering a change of weight of the entire system.

In the box was placed a vessel with water. Volume of water was 400ml. For faster spread of moisture in the box, the water reservoir was settled with two tubes of Wettex textile – a piece of non-woven material based on cellulose with high water retention and water sorption. Evaporating water from the inner reservoir was registered by a precision laboratory balance under the vessel. The box was also equipped with moisture and temperature sensors collecting data about inner conditions (Ti, Rhi). Stable indoor temperature in the box was provided by a light bulb connected to a voltage transformer. Bulb shielding protected specimens from heat radiation. To keep circulation of warm air in the inner space, we used a tiny ventilation fan.

Any weight change of the entire system was registered by another precision balance placed under the testing box. Thanks to both inner and outer balances, it was possible to observe the amount of moisture evaporating in the system and the amount that truly left the system. To control temperature gradient and relative humidity in material specimens, extra three moisture and temperature sensors were installed into outer sides and centre of each material sample, see Figure 3. That gave us a complex view of moisture processes in different altitudes. Moisture leakages in joint around the material sample were denied by sealing with non-absorbent polypropylene tube and silicon bonding agent.

Figure 3 Temperature and humidity sensors placed in material specimen.

The entire testing set-up was placed in a climate chamber with regulated temperature (Te). Conditions in the climate chamber were recorded by another couple of temperature and humidity sensors. Thanks to two pieces of Wettex (mentioned above) the inner volume of the plastic box (30 litres) became saturated by water flux within few minutes. After reaching the saturated state, relative humidity in the box (RHi) remained stable for the rest of the testing interval.

5. Results and discussion

Specimens were tested for four different outdoor temperatures (Te=-20°C, Te=-15°C, Te=-10°C, Te= -5°C), while the indoor temperature was always the same, Ti=+20°C. Each measurement lasted 100 hours. Material samples were cut into pieces in two altitudinal levels just after the testing period and each piece was weighed before drying. This helped us to map an extent of moisture throughout the material.

Water in the upper part of specimens was in form of frost (see Figure 4), while in the lower part it was in form of condensation. Both zones accumulated in time. The frost was equally spread over the depth of tested materials. Growth of frost formation in specimens was clearly visible in cross-sections of material samples A and B (materials with higher densities). There was no visible zone of frost formation and condensation for the specimen C (material with the lowest density) even it occurred.

The collected data were analyzed and charted into figures. Moisture characteristics like moisture flow rate *G* (kg/s), diffusive flux *g* (kg/m^2s) and, consequently, moisture resistance factor *μ* (-) were calculated.

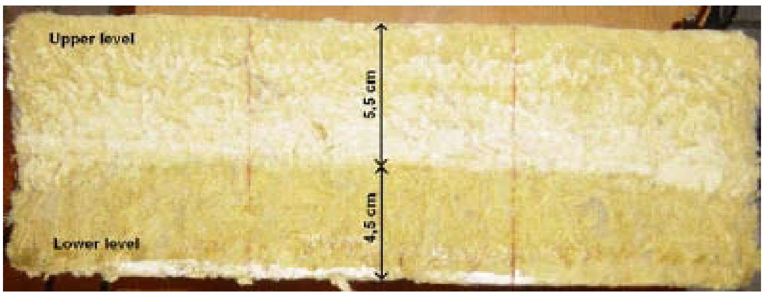

Figure 4 Specimen A - zones of frost formation (upper part) and condensation (lower part).

Measured and calculated data are summarized in Table 2 below. Moisture resistance factors *μ* for all tested materials were highest for outdoor temperature Te=– 20ºC and also the frost formation was most widespread in this case. The frost was stationary, as it is in practical cases, where it does not melt and evaporate until outdoor conditions turn.

Mi factors were compared with standards. They were found 2 times or 2,5 times higher than standard values, that are equal to 1 for both dry or wet mineral wool with density between 10-200 kg/m^3, for the highest temperature gradient through the material (Te=-20°C; Ti=+20°C). Consequently, EN 13162 says:" In the absence of measurements, the moisture resistance factor, *μ*, of mineral wool products, either unfaced or faced with a fabric with an open structure, may be assumed to be equal to 1." Remaining *μ* values for the temperature gradients (Te=-15°C; Ti=+20°C), (Te=-10°C; Ti=+20°C), (Te=-5°C; Ti=+20°C) had a downward trend (see Table 2) towards the tabulated values.

Our previous laboratory measurements for outdoor temperature Te within an interval (+20°C to +5°C) detected *μ* values in the interval <1,13-1,18> for the stone-wool specimen A. We used the same testing set-up, as well as, the same dimensions of material samples. In this case, results coincide with tabulated values introduced in EN standards mentioned above.

Table 2 Experimentally measured moisture resistance factors μ for the specified indoor and outdoor conditions within time interval 100 hours.

SPECIMEN A				
External conditions		Internal conditions		μ [-]
T_e=-20°C	Rh_e=63%	T_i=+20°C	Rh_i=72%	3,05
T_e=-15°C	Rh_e=66%	T_i=+20°C	Rh_i=75%	2,03
T_e=-10°C	Rh_e=72%	T_i=+20°C	Rh_i=78%	1,94
T_e= -5°C	Rh_e=75%	T_i=+20°C	Rh_i=79%	1,46

SPECIMEN B				
External conditions		Internal conditions		μ [-]
T_e=-20°C	Rh_e=66%	T_i=+20°C	Rh_i=72%	2,44
T_e=-15°C	Rh_e=67%	T_i=+20°C	Rh_i=75%	1,82
T_e=-10°C	Rh_e=73%	T_i=+20°C	Rh_i=77%	1,81
T_e= -5°C	Rh_e=75%	T_i=+20°C	Rh_i=80%	1,55

SPECIMEN C				
External conditions		Internal conditions		μ [-]
T_e=-20°C	Rh_e=63%	T_i=+20°C	Rh_i=72%	2,85
T_e=-15°C	Rh_e=68%	T_i=+20°C	Rh_i=75%	1,92
T_e=-10°C	Rh_e=72%	T_i=+20°C	Rh_i=76%	1,65
T_e= -5°C	Rh_e=74%	T_i=+20°C	Rh_i=78%	1,42

Taking into account results from others´ research, water vapour transport properties of stone wool are also influenced by fiber orientation and bulk densities of used specimens.

6. Conclusions

The constructed testing set-up, as well as, the chosen research approach was found effective in the studies of moisture processes in stone-wool based insulating materials. It also proved that the phenomenon of frost formation in the stone wool can exist for specific temperature gradient and moisture load - input conditions we often meet in practice.

Frost formation in the stone-wool samples opened to air was noted in all cases when the temperature field was between (+20 and –20ºC), (+20 and –15ºC), (+20 and –10ºC) and (+20 and -5°C). Air on the warm side was saturated with moisture. In the part of the specimen facing the warm humid air a condense formation occurred. Samples with higher densities (specimen A - ρ_d=145kg/m^3, specimen B - ρ_d=112kg/m^3) were visibly divided into the zone of frost formation and the zone of condensation in the cut. Also in the lightest stone-wool sample (C - ρ_d=44kg/m^3) the frost formation and condensation occurred, but no sharp borderline was observed.

Further studies are relevant in finding why moisture resistance factor (*μ*) in stone wool is comparatively high under circumstances of frost formation and if this can deteriorate in time. Last but not least, consequential degradation of the material structure together with loss of insulating qualities is paramount from the view of new trends in building industry, energy costs and sustainable development.

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EUROPEAN LIFE CYCLE STUDIES' UPDATED INFORMATION ABOUT PVC AND PVC PRODUCTS

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Summary

The importance of life-cycle thinking is underlined in the European Commission's Communication on Integrated Product Policy. The Commission sponsored a review of the Life Cycle Assessments of PVC products by a group of independent consultants led by PE International. The objective was assessing the existing information and identifying gaps. The report covers all key B&C applications.

It concludes that comparing PVC with alternative materials does not make sense in general, but has to be considered application by application, usually with the conclusion that no material scores better on all criteria. The overall impacts of products depend not only on the production of the material itself, but also on its applications. The impact assessment must take into account all the life cycle stages. It shows that PVC is a material as any other, with both strong and weak points, depending on the application and use, and hence that there is no reason to treat PVC differently from any other material.

In parallel, the 'eco-profiles' (cradle-to-gate Life Cycle Inventory) of PVC resin were updated in 2005, as part of an on-going activity for all major thermoplastics. Results show that impact of PVC is comparable to competing materials. The environmental impacts have been aggregated into an Environmental Declaration.

1. The Importance of Life-Cycle Thinking and its Instruments

The Communication of the European Commission on Integrated Product Policy of June 2003 states "Up to now, product-related environmental policies have tended to focus on large point sources of pollution, such as industrial emissions or waste management issues. Often these have been successful. Now, however, it is becoming clear that they need to be complemented by a policy that looks at the whole of a product's lifecycle, including the use phase. This should ensure that environmental impacts throughout the life-cycle are addressed in an integrated way – and so are not just shifted from one part of the life-cycle to another".

The Integrated Product Policy approach is based on five key principles, the first being Life-Cycle Thinking, which "considers a product's life-cycle and aims for a reduction of its cumulative environmental impacts - from the "cradle to the grave". In so doing it also aims to prevent individual parts of the life-cycle from being addressed in a way that just results in the environmental burden being shifted to another part. By looking at the whole of a product's life-cycle in an integrated way, IPP also promotes policy coherence. It encourages measures to reduce environmental impacts at the point in the life-cycle where they are likely to be most effective in reducing environmental impact and saving costs for business and society"

The Communication goes on by stressing that "LCAs provide the best framework for assessing the potential environmental impacts of products currently available. They are therefore an important support tool for IPP." It mentions also Environmental Product Declarations (EPD) as a "a means of presenting quantified, life-cycle based information about a product in a standardised way" and as a "potentially important instrument"

2. Life Cycle Assessment of PVC and of Principal Competing Materials

2.1 Background

On 26 July 2000, the EU Commission adopted a Green Paper on the Environmental Issues of PVC. This Green Paper followed a commitment undertaken by the Commission in the proposal for a Directive on End of Life Vehicles, i.e. to assess the impact of PVC on the environment, including related human health issues, in an integrated approach.

In the debates before and after the publication of this Green Paper, including the April 2001 debate in the European Parliament, the question of a potential substitution of PVC in some specific applications was raised. In 2002, the Commission issued a tender for a study to provide, among others, information on the life-cycle impacts of PVC from production of chlorine to disposal, a comprehensive catalogue and critical analysis of all existing life cycle assessments of both PVC and products made from the principal competing materials, and an assessment of possible gaps in the information.

In its introductory considerations, the Commission stressed that “Substitution or phase-out of a certain material is the ultimate resort if all other measures to increase its sustainable use have failed or are insufficient. In the case of PVC, due to its versatility and wide range of different applications, there is not an individual other material that could be used as an alternative, but there is a whole range of different ones, depending on the product concerned. As always in the debates about replacement of one substance or material by another, a major concern is to establish that the use of the substitutes is indeed overall beneficial. A potential substitution would therefore need to be underpinned by a comprehensive and objective assessment of the main environmental, health, social and economic impacts both of PVC and of competing materials during their whole life cycle.”

2.2 Preparation of the Report

The tender was awarded to a consortium of consultants led by PE International GmbH. The key stakeholders were involved throughout the process of assembling and assessing the information. After a final review by the Commission, Baitz et al. (2004) published the final report.

2.3 Key Conclusions

2.3.1 Regarding the methodology

LCA comparisons should be undertaken at application level rather than at material level, particularly when used to support decisions. LCAs on applications are more comprehensive and draw a complete picture of the environmental impacts over the whole life cycle. This is not to say that LCAs at material level are without merit, but they appear to be an insufficient measure for decision-support.

Depending on the kind of product, the environmental impact during use or after end-of-life can be even more important than the environmental impact of material production. Even if a material has less environmental impact during production, it is not necessarily environmentally favourable. Moreover, advanced materials with a larger environmental impact in the production phase can have a much lower impact in the use phase due to a better system quality (e.g. less weight, longer durability, lower maintenance frequency, lower thermal conductivity)

LCA approaches can easily indicate the importance of material choices within a given life cycle and quantify the effects of possible alternatives. Therefore, material choices on case-to-case bases are often carried out and are accepted. However, if LCAs are intended to be used for the overall evaluation of preferable material alternatives of a certain product group, it would be necessary to clearly define a representative life cycle for this product This must represent all possible uses and application situations in an adequate and sufficient way. If not, then no useful or comprehensive overall comparison of the alternatives is possible and a decrease in the environmental impact due to chosen preference would be unlikely. The definition of such a representative life cycle is missing today, and it is doubtful that such a representative life cycle can be defined since the individual advantages and disadvantages of different material alternatives are most often a result of specific boundary conditions and application case.

2.3.2 Some key conclusions on PVC and its life cycle

- Approximately 100 LCAs related to PVC were identified, with only 30 making comparisons at the application level. Many of the reviewed LCAs did not fulfil all requirements outlined by the ISO 14040 ff norms.
- The most important applications of PVC are in the building and construction sector (windows/shutters, sheets, flooring and pipes), the electric and electronic equipment sector (predominantly cables), the transport sector and the packaging sector. A remarkable amount of LCA information is available for building materials and products.
- The production of intermediates, particularly the processes from the extraction of crude oil and salt up to VCM production, plays a major role for the environmental impacts.
- The production of stabilisers and plasticizers plays a significant role, whereas the production of pigments offers a comparatively low optimization potential, because of the small volumes used
- Some new technologies exist, e.g. mechanical recycling based on selective dissolution, for recycling PVC in an economically feasible way. Incineration, in conjunction with municipal waste disposal, is a simple option that allows for the partial recovery of energy and substances, if state-of-the-art technology is applied.

- Regarding the positive effects of increasing recycling rates, mechanical recycling (or material recycling), which loops the material back directly into new life cycles, substitutes, to a certain extent, the processes of resource extraction, intermediate production and granulation/polymerisation during the production of virgin material. Chemical recycling (feedstock recycling) is another option of recycling PVC into another life cycle.
- In contrast to some metals, the recycling market of plastics, and therefore the demand in secondary material, is not yet established in an adequate way. Nevertheless, today and in the near future, a mix of mechanical and chemical recycling pathways and state-of-the-art disposal routes appear as the most favourable way to optimise the environmental impacts of PVC and of competing materials.

2.3.3 Main findings regarding building sector- and application-specific LCAs

- For windows, one of the most important PVC applications, the available studies conclude that there is no “winner” in terms of a preferable material since most studies conclude that none of the materials has an overall advantage for the standard LCA impact categories. The most promising potential for lowering environmental impacts of windows is expected to be through the optimisation of the design and specific construction processes, which means increasing the quality of the windows with respect to their main function of saving heating energy in the use phase. Raising the amount of secondary material used, or lowering the amount of material required for the same function, may be another ground for optimization of the constructions. Therefore the choice of material is of rather minor importance, as long as the material can provide the required system quality of the window.
- Most flooring application studies conclude that linoleum has comparable or slightly lower environmental impacts compared to PVC flooring of equivalent quality in the production phase. One study states that wooden flooring tends to have lower impacts than PVC and linoleum, but is more demanding in the use and maintenance phase. All analysed studies claim the importance of the use phase due to detergent or chemical use in cleaning and maintenance. One study concentrates on the use phase and suggests that PVC might have advantages over linoleum in this phase and that the absolute demand seems to be strongly dependent on the context of the individual application (private use, professional use, industrial use). Therefore, the use phase should be analysed in more detail to obtain a representative judgment. Some studies are already considering this in adequate detail. There is little LCA information about carpeting, a main competitor for flooring applications.
- For roofing applications, available studies conclude that the quality of the systems (thermal conductivity per thickness of roofing sheet layers) as well as the accuracy of the laying and maintenance processes has the largest influence on the reduction of environmental impacts. Additionally, the studies conclude that ‘green roofing’ (e.g. planting on the roof) further decreases environmental impacts because of the subsequent longer lifetime of the roofing systems. Three polymer solutions (one PVC system and two competing polymer systems) have the potential to perform better, with similar environmental impacts on global warming, acidification and ozone formation over the life cycle. The studies report that polymer solutions tend to have lower environmental impacts than bitumen systems, due to the heavier construction of the latter.
- The results on pipes are very heterogeneous. Some studies see clear advantages for concrete and fibre cement pipes, some report clear advantages for polymer pipes such as PVC and PE, some conclude that the material plays no role as long as no cast iron is chosen. Two studies conclude that no material preferences for pipes can be stated, moreover, that no generalizations on ‘best materials’ are adequate, as the best choice is dependant on the local situation. Important technical parameters influencing the LCA of pipes are durability/maintenance, intended duration of use, the maintenance intensity and the weight/diameter of the pipes. Cast iron waste water pipes seem to be disadvantageous in comparison to PVC or concrete pipes. This is due to the fact that cast iron has relatively high impacts in production and weight makes laying pipes rather energy-intensive. Despite the heterogeneous results, some general conclusions on the environmental impacts of pipes can be drawn. Digging, laying, installation and use have to be included in the LCA studies of pipes. Reduction of the pipes’ weight will most likely lead to less environmental impact (less material needed, easier to lay). The use of recycled material would also lead to less environmental impact and is possibly easier than in other applications as no strict aesthetic requirements exist (especially for underground pipes). Leakage has a high impact, therefore the durability and mechanical properties of the pipes are of great importance.
- PVC does not seem to have significant competitors in many cable applications, therefore few PVC cable LCA studies exist. Recycling processes have been in place for some time, due to the high economic value of the recovered copper and aluminium. Economically feasible options exist for the recycling of recovered PVC.

2.3.4 Data gaps

No data gaps were identified in the building and construction applications.

3. Eco-Profiles and Environmental Declarations for PVC as a Material

3.1 Background – Link with Life Cycle Thinking

All LCA studies on PVC products have to rely on a quantification of the impacts of PVC resin production. Although the impacts during use phase are sometimes more important, production impacts have a major role, as mentioned in section 2.3.2, and hence are a key building block for LCA studies. In addition, impacts during production are often perceived as particularly detrimental, and hence need to be assessed carefully.

A LCA or LCI (Life Cycle Inventory, defined as the compilation and quantification of inputs and outputs for a product) covers the entire life-cycle of the product, starting with raw materials in the earth and covering all chronological processing and use operations until the materials are eventually returned back to nature. It is sometimes referred to as a 'cradle-to-grave' analysis.

The same type of information, applied to an intermediate product such as PVC resin is sometimes called an eco-profile. It is essentially a 'cradle-to-gate' analysis, .This means that the assessments start with raw materials in the earth and end with polymer resins ready for despatch to the converter.

3.2 The Eco-profiles of Plastics*Europe*

APME, the Association of Plastics Manufacturers in Europe (now Plastics*Europe*) decided as early as 1990 to develop LCI data sets for all major polymers. The initial methodology was published in 1992 and the first eco-profiles were published in 1993. They have been freely available via the Internet since 1999. PlasticsEurope eco-profiles are European industry average data-sets, compiled from individual company data by independent consultants. They cover the major proportion of European polymer production.

Even though only part of the life cycle is covered, some methodology issues have to be resolved. In some cases, several rational options are possible. A typical example is the allocation of impacts between several products and by-products. Choices have to be made, which is not a problem as long as they are clearly documented and transparent. For instance, chlorine production by electrolysis of sodium chloride is a multi-output process, yielding caustic soda and hydrogen as well as chlorine. Therefore all inputs and emissions have to be assigned to the different products. As this process is totally coupled it was decided to assign all inputs and emissions to the products on a mass basis. The detailed methodology of the Plastics*Europe* eco-profiles can be downloaded from http://lca.plasticseurope.org/methodol.htm

These eco-profiles are considered by specialists as the reference for environmental impacts of plastics until and including resin production. PlasticsEurope is a partner in the European Platform on Life Cycle Assessment, a project sponsored by the European Commission; PlasticsEurope provides the Life Cycle Data for plastics and intermediates of the European Reference Life Cycle Data System (ELCD). This EU project lead by the Joint Research Centre is intended to provide the technical and scientific basis for a life cycle approach in EU policy making.

3.3 PVC Eco-profiles

3.3.1 Scope and data sources

The first eco-profiles for suspension, emulsion and mass PVC resin were published in 1993. Several updates took place, but most were merely based on revised data for upstream manufacturing steps, for instance ethylene production. The only complete revision before the one reported here took place in 1999.

The eco-profiles for suspension-PVC, emulsion-PVC, vinyl chloride monomer (VCM) and chlorine production have now again been fully updated, based on plant data for the reference year 2004, collected in 2005 throughout the manufacturing chain,. The eco-profiles were prepared by the IFEU-Institut in Heidelberg and followed strictly the methodological guidelines of Plastics*Europe*. Minor issues were ironed out by close contact with the industry, through a dedicated industry task force and a review by manufacturing experts.

The results are very robust: Data obtained for VCM, S-PVC and E-PVC cover a total annual production of 5.6 million tonnes of PVC, representing 92% of Western European production. For one process type, bulk (or mass) polymerisation, information was obtained only from one plant and hence, for reasons of confidentiality, the eco-profile for bulk PVC could not be published this time.

The data relevant to chlorine production were obtained from PVC producers also producing chlorine, or from companies belonging to the same group. This yielded an eco-profile representative for the sub-set of Western European chlorine plants supplying vinyl chloride plants. The data cover nevertheless more than 50 % of the Western European chlorine production capacity.

3.3.2 Key results of the most recent update

Some key results for PVC are given in Table 1

Table 1 Some Key Results per kg of Suspension or Emulsion PVC

Emissions	Unit	Suspension PVC	Emulsion PVC
Carbon dioxide	kg	1.8	2.3
Methane	g	< 3.9	< 5.4
Sulphur dioxide	g	< 2.6	< 3.3
Nitrogen oxides	g	< 3.7	< 4.5
Mercury, to air and water	mg	< 0.24	< 0.41
Dioxin, to air and water	µg TEQ	$< 0.3 * 10^{-3}$	$< 0.3 * 10^{-3}$
Vinyl chloride, to air and water	mg	< 74.3	< 472
Total energy consumption	MJ	56.7	65.9

Energy consumption and related emissions (carbon dioxide, methane, sulphur dioxide and nitrogen oxides) are close to those of the main polyolefin polymers PE and PP. 90 % of the mercury is emitted to atmosphere, as a result of burning coal or oil in power plants.

The level of dioxin emissions during all the steps leading to PVC resin represents a yearly emission of less than 2 g per year for the whole European Union, i.e. far less than emitted by the metal extraction and processing in Germany alone (Federal Ministry for the Environment of Germany, 2005). The level of monomer emission is within the ranges quoted as “Emission levels associated to Beat Available Technology”, (European Commission (2006).

3.4 Further Work on the Eco-profiles of Plastics*Europe*

A project was initiated early 2007, in cooperation with the European Plastics Converters association EuPC, in order to take polymer eco-profiles one step further. Data are being gathered about the energy consumption and emissions of the key plastics conversion processes. PVC pipes and fittings, profiles and flooring will be covered. Completion is expected during the first half of 2008.

3.5 Environmental (Product) Declarations - EPD

ISO TR 14025 defines “Type III” labels, called “environmental declarations”, as the means of supplying environmental data based on Life Cycle Assessments on a business-to-business basis in the supply chain. A Type III EPD is a set of quantified environmental data consisting of pre-set categories of parameters based on LCA, but may also include additional environmental information provided within a Type III environmental declaration programme.

EPD schemes have been developed in order to provide credible information on the environmental impact of products. Their main function is providing input for sustainability solutions and for stakeholder dialogue. They are often used in business-to-business communication, but are also gaining importance in business-to-consumer communication. EPDs are a good example how key environmentally relevant product information can be provided in an easy-to-understand and condensed format.

An important advantage of using EPD is the possibility to add up LCI/LCA-based information along the supply chain. This feature makes EPDs specifically valuable for the building sector where the final building is based on a large number of materials, construction products and semi-manufactured products.

3.6 EPDs of PVC resin

In 2005, Plastics*Europe* developed Product Category Rules (PCR) for “Uncompounded Polymer Resins (or Reactive Polymer Precursors)”. The PCR document was published in September 2005 (Plastics*Europe*). The general programme rules were published in March 2007. The resulting EPD documents for polymer resins will be derived from the corresponding eco-profile data.

The EPDs for suspension PVC and emulsion PVC were the first published under this new Plastics*Europe* programme (September and October 2007 respectively, both updated in January 2008). Some key quantitative information given by these documents is included in Table 2.

Table 2 Input and output parameters as indicated in the Environmental Declarations for 1 kg of PVC

Parameter	Unit	Suspension PVC	Emulsion PVC
Non-renewable energy resources	MJ	55.4	64.4
Renewable energy resources	MJ	1.3	1.5
Water used for process (cooling excluded)	kg	10	11
Global Warming Potential	kg CO_2	1.9	2.5
Acidification Potential	g SO_2	5.3	7.0
Photochemical Ozone Creation Potential	g ethene	0.42	0.45
Nutrification potential	g PO_4	0.62	0.80
Dust/particulate matter	g PM10	0.43	0.75
Total particulate matter	g	0.49	0.83
Non-hazardous waste	kg	0.14	0.23
Hazardous waste	g	8	5

The Ozone Depletion Potential could not be calculated, as the entries in the eco-profiles were below quantification limits. Indicators such as Human Toxicity Potential and Fresh Water Aquatic Ecotoxicology Potential were not determined, because the methodology for assessing toxicity impacts on humans and the environment within LCA is still subject to scientific debate. Additionally, emissions potentially contributing to toxicity impacts originate essentially from the combustion of fuels for energy production and from oil refinery, not from specific PVC processes.

In addition to such input an output parameters, the PVC EPD documents provide a brief process description, information about the use phase and end-of-life management, as well as additional environmental, health, technical and economic information.

4. General Conclusions

All manufactured materials and products have an impact on environment during their entire life cycle. In order to be significant and comparable with other competing products having the same performances, the evaluation of the global environmental impact and of the sustainability of products has to be developed in a normalised way. The ISO 14040 series of standards issued as from 1998 are the reference method for evaluating the life cycle of a product or service.

Both sets of data described in this paper follow this standard. They show that PVC has both strong and weak points, depending on the application and on its use, and that there is no reason to treat PVC differently from any other material. Comparing a material such as PVC with alternatives does not make sense when made in general, but has to be considered application by application. Such comparisons usually conclude that no material scores better on all criteria.

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MAINTAINING GREEN BUILDINGS - BEYOND THE DESIGN PROCESS

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Summary

If there is one thing that most buildings services engineers can agree upon, it is that building services rarely perform as well as desired. The causes emanate from deficiencies in design, construction, commissioning, fit out changes and maintenance.

With the advent of greener buildings, considerable attention has been paid to preventing faulty design, construction, and commissioning. Poor maintenance, however, is much more universal, and its causes and remedies are not so widely understood.

This paper will focus attention on the objectives to be pursued by maintenance to help ensure that the building services are operated efficiently and effectively. Drawing from extensive experience gained in a number of buildings, it will highlight how small changes to maintenance procedures can deliver substantial energy savings, whilst improving occupant comfort. It will also demonstrate how good maintenance should begin at the design stage.

It is no longer appropriate for design professionals to believe that their sustainability obligations cease at the end of the design process. To be truly sustainable, we need to do much more than just deliver green buildings, we need to ensure that what we deliver continues to deliver, and that can only happen with proper maintenance.

1. Introduction

The performance of the building services installations in modern commercial, retail and industrial buildings, (and in particular air conditioning) rarely lives up to the owners' expectations. This is despite the fact that, in most cases, the services are installed to provide pleasant and efficient conditions for the occupants (and consequently to make the building more attractive to tenants).

The causes for this poor performance arise from a number of activities which include :

* design faults
* construction faults
* commissioning faults
* tenancy alterations
* poor maintenance

Perhaps the most universal of these problems is poor maintenance. Even if the design is excellent in all respects, the installation and commissioning faithfully carried out, and the tenancy alterations properly controlled, good maintenance is needed to keep the installation in that condition.

With the move towards greener buildings, and the proliferation of building energy performance rating systems such as the Australian 'NABERS Energy and Water', maintenance is taking on much a more important and urgent role. The effects or poor or inappropriate maintenance can significantly impact upon the building rating, which in turn may have leasing or performance guarantee implications.

2. Why Maintain?

It is somewhat ironic that many buildings owners and property managers understand the value of having their cars serviced regularly but consider the maintenance of their building services as more of an inconvenience. Ask property managers why they get a car serviced and they are likely to answer that a) it reduces the chance of a break down, b) it keeps the car running efficiently and c) it keeps the car safe. The same reasoning should be applied to building services. Proper maintenance should aim to -

- **P**RESERVE the asset
- Maintain its **E**FFECTIVE operation (eg, provide comfortable conditions)
- Maintain its **E**FFICIENT operation
- Maintain its **R**ELIABLE operation
- Maintain its **S**AFE operation.

Obviously, the weight to be given to each of these objectives will vary from one application to another. Reliability may be paramount in the air conditioning of a major computer installation, while efficient operation may be more important in an office building.

2.1 Preserving the asset.

Preserving the asset is an easily understood concept . Ensuring that an item of equipment is kept substantially in the same condition as when it was installed will of course prolong its life. Given the replacement of an asset is considered a "capital" item of expenditure and therefore not normally recoverable from tenants whereas maintenance is a legitimate "outgoing" that is recoverable you would expect all building owners to put "preserving the asset" high on their list of priorities.

In an industrial building complex north of Sydney the owners were faced with a potential $400,000 bill for the replacement of air conditioning units that had rusted away. The units were only 5 years old. Proper maintenance directed at preventing the corrosion would have cost less than $10,000 per annum.

2.2 Maintain its effective operation

Good maintenance is essential for effective operation. The equipment may appear to be in perfect condition, it may be very safe, it could even be efficient in operation, but if it fails to provide the desired end result it is not effective and therefore of limited value. In some cases the costs associated with ineffective operation can be clearly calculated (loss of production, high component failure rates etc) but in commercial buildings the costs are hard to quantify.

2.3 Maintain its efficient operation

The loss of system efficiency is the hidden cost of poor maintenance. A building does not generally become suddenly less efficient, it is a gradual change that makes it escape the notice of many property managers. Poorly maintained buildings systems often settle at a certain level of inefficiency so after a while the energy bills seem relatively reasonable (relative of course to the previous bill) and are accepted as a normal part of the building occupation costs. Proper maintenance could bring the building back to peak efficiency or even prevent it from degrading in the first place.

A study of nine commercial office buildings in and around Sydney yielded some interesting results. The mechanical services in each of the buildings were being maintained by a number of reputable contractors who carried out their maintenance tasks with little or no supervision. Prior to a proper maintenance specification and program of works being established, "Base Year" energy costs were calculated (the base year is calculated for each month of the year - based where possible, on the energy bills for the previous 3 years). Maintenance contracts were then let, and the work supervised by a third party. In every single case there was a substantial saving in energy.

The new maintenance contracts were let on a competitive basis and in most cases the cost was lower or equal to the price of the previously 'undefined' maintenance contract. After establishing the proper specification and program of works (a one off fee that varied depending on the complexity of the task), the only additional cost faced by the property manager was the cost of supervision.

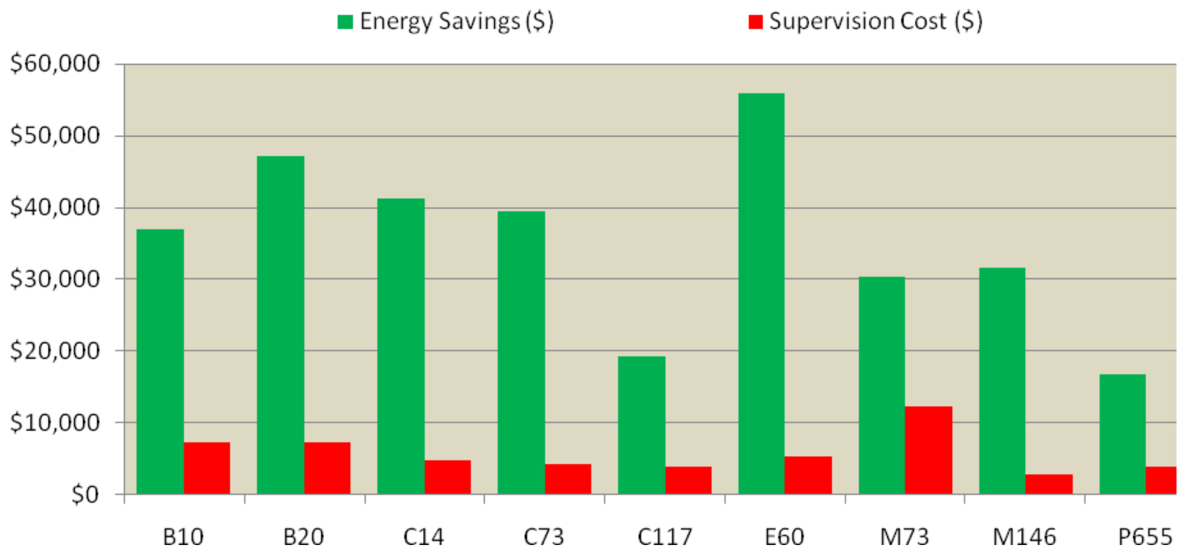

Figure 1 Supervision Costs Vs Energy Savings

The graph shows clearly that the savings in energy far outweigh the cost of supervision.

With the advent and proliferation of energy and water performance benchmarks, it is possible for tenants, investors and the like, to get a simple and comparative rating for a range of buildings. This is focusing attention on the energy and water efficiency of buildings in a way that we have not seen before.

2.4 Maintain its reliable operation

Maintenance to ensure reliability is a concept most owners and property managers can relate to. Making sure the bearings are lubricated, fans can turn, drains are clear etc are items we can all understand and it is not unusual to find maintenance programs that address this issue at the expense of all others.

2.5 Maintain its safe operation.

Maintaining safe operation should go without saying. Many would think that this is about checking guards etc and of course that is partly so. But it also includes the verification of safety device operations eg the ability of staircase pressurisation fans to sustain sufficient air flow velocity and pressure. Until quite recently it was common to find such safety checks were either not carried out, or tests were made and the results fabricated to cover up problems. In such cases the cost of poor maintenance could be measured in lives lost.

If all the above reasons were not enough to convince a property manager of the benefits of proper maintenance, there is always the law. There is an increasing amount of statutory work such as cleaning cooling towers, testing fire safety systems, etc, and often the legal responsibility for ensuring that these operations are carried out lies with the owner. Many building owners and managers are content to leave these matters to a contractor, but in our increasingly litigious society this is a dangerous road to follow, especially in the absence of proper contract documentation. Either way, tenants will be looking to the owner for damages and compensation of attributable losses, and building owners are perceived, rightly or wrongly, as having very deep pockets.

3. Ensuring Proper Building Services Maintenance

An owner or property manager who leaves a contractor to decide what equipment to include in the maintenance agreement, and how it should be treated, is taking a big risk - not least because the contractor's objectives may be quite different from his own.

Dealing specifically with the mechanical services, it is not uncommon for the building owner to place the maintenance of the plant in the hands of the installation contractor at the completion of the warranty period.

Some owners call for competitive prices to maintain the plant. Often such processes focus on cost, not value, so the contractor that quotes the lowest price will probably get the job, so there is a temptation to quote to provide the lowest standard of maintenance that they think will satisfy the client. To compound the problem, if there is a contract document, it will often be one that was written by the contractor (or his association) which would naturally tend to favour the contractor.

In the above case the owner is placing a great deal of trust in the contractor. Many owners do not have the technical knowledge to enable them to judge whether the contractor is doing what should be done, they simply hope that if they keep on paying, the end result will be satisfactory. Unfortunately, and the owner's hopes are not always realised.

The best way for the owner/property manager to get the desired results is to clearly define what is wanted in the form of a properly specified maintenance agreement. The agreement should include:

- a program of works
- concise instructions for the technician
- a requirement that the technician must report his results

The program of work should list what has to be done and when. It is not enough to say a certain job should be carried out annually or quarterly - the precise month and day the job is to be completed by should be nominated. The work should be schedule so that major services occur immediately before the equipment is expected to operate at its peak potential (eg service a chiller in September - immediately prior to the onset of the peak cooling season).

The instructions should be both item and job specific. A generic maintenance specification is an invitation for the service technicians to do what maintenance they see fit. Instructions such as 'set the damper as per the manufacturers instructions' is one of the best ways of ensuring the task is not done (technicians do not walk around sites carrying handfuls of manufacturer’s instructions, and they are unlikely to go looking for them).

Item specific instructions have their place, but maintenance specifications should also take into consideration that the building works as a system. Since almost no two buildings are the same it follows that the maintenance specifications should also differ from building to building. This is especially true when looking at controls - ensuring control strategies are properly maintained is the key to efficient operation.

With a properly prepared maintenance specification, the property owner/manager can call for competitive tenders secure in the knowledge that all parties are quoting to do the same level of work. Given that service company labour rates are fairly uniform throughout the various services disciplines, in theory the tenders should be fairly close. Obviously the owner should have a fair idea of the cost of the work before calling for tenders, and a company that has made a mistake during estimating should stand out when the prices are reviewed. Owners should avoid the temptation to award contracts solely based on the lowest price especially if it is obvious that the contractor has made an estimating mistake (any perceived saving will often be negated by the cost of extra supervision needed to ensure that the specified works are faithfully carried out).

Maintenance specifications can go too far. Some specifications list to the n^{th} degree all manner of maintenance tasks. Often the only useful function these will serve is as ammunition for the building owner to use against the contractor after some maintenance related disaster has occurred. It is essential that the specification is pragmatic (without being condescending), detailed (without being too detailed) and easy to administer and supervise.

Maintenance work by its very nature is difficult to supervise. Service technicians need to work throughout the plant, not primarily at work benches, and one often cannot tell by casual inspection whether the maintenance has been carried out or not.

Obviously it is necessary to keep the cost of supervision to a minimum, and the best way to do this is to have the servicemen report back to the owners supervisor on what they have done.

A specification should be based around service log sheets, and they can be made to function in a number of ways-

- As check lists to be sure that the contractor does not forget the obscure pump in a dark corner of the basement, or to treat rust before it is beyond repair;
- A reminder to the serviceman of special features of the installation such as an interlock to prevent a large chiller from running after hours, etc;
- A medium on which he is required to record all readings of pressures, temperatures and so on; and
- A communication tool between the serviceman in the field and his area supervisor, between the serviceman and the consultant supervisor, and between the contractor's area supervisor and the

consultant (this is also an excellent way for conveying recommendations, suggestions, prices for extras, etc).

An example of a service log sheets that satisfy these criteria appears in figure 2. The sheet is for the service technician to test and calibrate an air handling unit controller located in a commercial office building. The results give the supervisor a snapshot of the air conditioning performance, and when combined with readings taken at the same time (noted on other sheets), they become a valuable diagnostic tool.

Report for the Month of _______________, 19____		Equipment Numbers				
		AHU -8	AHU -9	AHU -11	AHU -12	AHU -14
AHU Controller						
- Using a recently calibrated thermometer measure temperature at room sensor (average out if TR4100 averaging sensors are used)	ºC					
- Note the corresponding temperature displayed at the controller	ºC					
- If the temperatures differ by more than 0.5ºC then re-calibrate controller.	OK/AR*					
- Adjust setpoint to equal display temperature.						
Check DA and RA outputs = 0 V	OK/AR*					
Check that both the hot and chilled water valves are fully closed	OK/AR*					
- Raise the set point and note temperature at which heating valve starts to open	ºC					
- Continue to raise the set point and note temperature at which heating valve is fully open	ºC					
- From the controller what is the DA voltage	V					
- From the controller what is the RA voltage	V					
- Lower setpoint until setpoint = sensor temperature. Is heating valve fully closed	OK/AR*					
- Lower the set point and note temperature at which cooling valve(s) starts to open	ºC					
- Continue to lower the set point and note temperature at which cooling valve(s) is fully open	ºC					
- From the controller what is the DA voltage	V					
- From the controller what is the RA voltage	V					
- Raise setpoint until setpoint = sensor temperature. Is cooling valve(s) fully closed	OK/AR*					
- Adjust set points as follows						
Set outside air thermostat at 20ºC (actual)	OK/AR*					
Set humidistat at 75%RH	OK/AR*					
Set controller to 22.5ºC	OK/AR*					
- Is the system operating properly	OK/AR*					

Figure 2 An example of an effective Service Sheet

The service sheet lists the check procedures, which are unique to this installation. The technician is taken through the tasks step by step with clear concise instructions. If the technician were told to 'check the controller and ensure it is operating correctly' it is very unlikely that any of the work would be done especially given that even the equipment supplier would not have some of the sequence information readily available.

Of course, with the advance in hand held computer technology, combined with bar coding or even more sophisticated identification means, it is no longer necessary to rely on paper based reporting systems, though the principals noted above remain the same

Whilst the specification can be designed to allow much of the supervision to be carried out from the supervisor's office, obviously it is necessary to visit the site often enough to ensure that the serviceman is diligent with his reports.

4. Statutory Requirements

As alluded to earlier, maintenance of building services is becoming more regulated. Fire and lift services have for some time been the subject of close government control, but it is only relatively recently that air conditioning maintenance has come under the spotlight.

An occupier, owner or his agent are liable to prosecution should they fail to comply with certain legislation. In addition, since mandatory maintenance requirements are to some extent better defined, so it is easier to determine negligence on the part of the building owner (no doubt we will see a growth in tenant initiated damages actions in the near future).

5. Better Building Maintenance

With all the apparent benefits associated with properly specified and supervised maintenance agreements it might be hard to understand why most buildings don't have them in place. To some extent the answer lies in a lack of awareness, both on behalf of the building owner/manager, and also the tenant/occupiers.

The preparation of proper specifications takes time, money, thought and experience. Owners do not normally have the engineering expertise to do this work themselves, and at the same time often lack the courage or conviction to employ a suitable consultant (ironically many owners understand the value of consultants during development and construction of a building, but not for maintenance).

An owner would assume that by appointing a property management company such matters as proper building services maintenance would be well addressed. Many property management companies make great issue of their 'in house' engineering expertise, but management fees are very competitive and sometimes the managers cannot afford to allocate the resources necessary to ensure proper maintenance. At the very least the owner should be prepared to pay a premium for better maintenance supervision. It is also desirable that an independent specialist check the maintenance procedures to ensure that the owners objectives are indeed being met.

It is usually the owner or property manager who makes the decision to implement properly specified maintenance, but it is the tenants who reap the benefits of energy savings. Because energy costs make up only a percentage of the total outgoings in a building, many tenants fail to comprehend the energy related benefits associated with proper maintenance (this in turn reduces the owner/managers incentive to try and achieve better energy efficiency). In the nine buildings used in the study above, the energy savings amounted to an average of \$3.60/m²/annum. Perhaps tenants need to take a more pro-active approach to such issues as proper maintenance.

6. Coping With Change

Putting in place proper and effective maintenance systems is not a ‘set and forget’ exercise. Buildings go through a number of changes throughout their life, including times of extensive refurbishment. It is essential therefore that the maintenance systems respond accordingly.

Good maintenance starts at the design stage. Systems and equipment must be inherently commissionable and maintainable. Involving maintenance personnel in the design review process can pay significant dividends further down the track.

With a move towards green retrofits of buildings, we are seeing an increase in the use of independent commissioning agents. Such agents are helping to ensure that buildings are handed over properly commissioned and fully operational. As part of this process there is a requirement to produce effective operation and maintenance manuals. This is the time to embed the principles expounded above.

Building professionals are also starting to embrace the concept of ‘soft landings’, whereby designers and commissioning agents continue to be actively involved in the building for a period of time after handover, primarily to ‘fine tune’ systems and ensure the building better meets the needs of the occupants. This soft landing period also presents a great opportunity to fine tune the maintenance systems, and to provide feedback to the design professionals such that they might improve the maintainability of future buildings.

7. Conclusions

There are many reasons why building services installations do not live up to expectations. These start with the initial design, and run through construction, commissioning, tenancy modifications and maintenance.

However, even if the design, construction, commissioning and tenancy work are all flawless; lack of proper maintenance will soon bring the quality of the building services down.

Maintenance contracts are usually not properly specified or supervised.

Good maintenance should achieve the owner's and the tenant's objectives (better conditions, longer plant life and more satisfied tenants), and the cost savings resulting from the energy savings alone usually amounts to more than the full cost of the maintenance itself.

Owners should be aware that property management companies with in house engineering expertise, may not necessarily be addressing the maintenance issues properly, and that at the very least their performance should be periodically checked by an independent specialist.

As tenants generally bear the costs and accrue the benefits associated with maintenance, it is in their interest to become better educated about the cost implications of proper maintenance, and to put pressure on the building owners and managers to perform better.

Owners and tenants should be aware that building services maintenance is becoming more regulated. In our increasingly litigious society it is more important than ever to stay abreast of the changes.

In short, maintenance can be much more satisfactory than is usually the case; it just needs careful thought and planning to deal with its intrinsic problems. The benefits to be gained are very substantial indeed.

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COST EFFICIENCY ANALYSIS OF DESIGN ELEMENTS FOR AN ENERGY EFFICIENT APARTMENT COMPLEX

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Keywords: apartment complex, energy, Building Energy Efficiency Rating System, cost efficiency

Summary

The demand for sustainability capable of coping with worldwide climate changes has been increasing. Energy efficient buildings are essential for maintaining such sustainability. Buildings are responsible for over 25% of the energy consumption in Korea, and 68% of the total energy consumption in the building sector comes from residential use. This situation is not considered to be much different in almost every country. Improvement of energy efficiency may lead to the rise of construction cost. If each design element can be prioritized according to its cost efficiency, energy efficient buildings can be designed more cost efficiently. Thus, this study aims to analyze the cost efficiency of each item related to the energy efficiency of an apartment complex, which is the most common type of residential building in Korea. A baseline model apartment complex was set up, based on an actual apartment complex. Among all the assessment items in the Building Efficiency Rating System of Korea, items that were appropriate for cost efficiency analysis and applicable to the baseline model apartment complex were selected as target items. Then, alternatives for each target item were set up, and then construction and energy costs of each alternative were estimated through actual price data and the assessment method of the Building Energy Efficiency Rating System. Finally, the results presented four kinds of cost efficiency index-the LCC, the NPV, the IRR and the payback period-and the order of priority of each alternative in accordance with each index.

1. Introduction

With the effectuation of the Kyoto Protocol, many countries in the world have been endeavoring to reduce their emissions of greenhouse gases in various fields of industry. In particular, it is anticipated that Korea will be confronted with much more international pressure to lower its emissions of greenhouse gases after 2013 when the second commitment period of the Kyoto Protocol goes into effect because Korea has been ranked 9th in carbon dioxide (CO_2) emissions (IEA, CO_2 Emissions from Fuel Combustion, 2004) and 10th in energy consumption (BP, Statistical Review of World Energy, 2006) in the world. Greenhouse gases are usually generated from energy consumption. Buildings are responsible for over 25% of the energy consumption in Korea, and 68% of the total energy consumption in the building sector comes from residential use (Korea Energy Economics Institute, 2005). This situation is not considered to be much different from in almost every country. Consequently, energy efficient residential buildings can play a key role in reducing greenhouse gas emissions and further solving environmental problems caused by the use of fossil fuels.

The energy efficiency of residential buildings are being enhanced by numerous systems or projects such as the Home Energy Rating System (HERS) and the Energy Star New Homes of the USA, the MNECH1997 of Canada, the Code for Sustainable Homes of the UK, the Passive House of European countries and so on. In Korea, the Building Energy Efficiency Rating System has been in force since 2001 in an attempt to improve the energy efficiency of the apartment complex, which is the most common type of residential building.

Improvement of the energy efficiency may bring about a rise of construction cost. If each design element can be prioritized according to its cost efficiency, energy efficient apartment complexes can be designed more cost efficiently. Thus, this study aims to analyze the cost efficiency of each item related to energy efficiency of the apartment complex by using the assessment method of the Building Energy Efficiency Rating System. First, a baseline model apartment complex was set up, based on an actual apartment complex recently completed and regarded as the most common type. Among all the assessment items in the system, items which are suitable for analyzing the cost efficiencies were selected as target items. The lower and upper limit values of each target item were determined. Then more alternatives whose values vary stepwise between the lower and upper limits were set up. And construction and energy costs of each alternative were estimated through actual price data and the assessment method of the Building Energy Efficiency Rating System. Finally, the LCC, the NPV, the IRR and the payback period of each alternative were obtained as indexes of cost efficiency, and then an order of priority of each index was given to all the alternatives.

2. Building Energy Efficiency Rating System and Passive House

Substantial numbers of systems or projects in the world are being implemented to improve the energy efficiency of residential buildings. HERS is a standard measurement of the home's energy efficiency and Energy Star New Homes is a national mark given to the homes that meet guidelines for energy efficiency of USA. MNECH1997 and the Code for Sustainable Homes are national code of Canada and the UK, respectively, for energy efficient homes. The Passive House of the European countries, which is a voluntary project for very rigorous energy efficient buildings, is considered as a very strong project for energy efficient buildings in the world. And the Passive House, along with a domestic system, was selected for this study because it can provide criteria for a high performance energy efficient building.

2.1 Building Energy Efficiency Rating System

The System has been enforced by the Ministry of Commerce, Industry and Energy (MOCIE) and managed by Korea Energy Management Corporation (KEMCO). There are several regulations related to this system such as the Building Energy Efficiency Rating Regulation (MOCIE, Notification No.2005-10), Guidelines on the Funding of Energy Use Rationalization Work (MOCIE, Announcement No.2006-371) and the Building Energy Efficiency Rating System Management Regulation (also referred to as the Management Regulation hereinafter). An apartment complex with more than 18 units is qualified to apply for certification. Energy efficiency is determined by comparison of the energy demand reduction rate between the evaluated apartment complex and the standard apartment complex. The evaluated apartment complex is rated as 3 grades, as presented in Table 1. For the first or second grade, some incentives, such as loan at very cheap interest and so on, are given to the builder. The standard apartment complex, which is a hypothetical complex configured in accordance with the specifications mandated by the building codes currently in force, represents a complex with the minimum level of energy efficiency. The standard apartment complex is almost identical with the evaluated apartment complex except that each assessment item of the standard apartment complex has a value mandated by the building codes. Other physical conditions such as shape, size, structure, floor height, ceiling height, energy source, heating plant type and so on are the same as the evaluated apartment complex.

Table 1 Certification Grades of the Building Energy Efficiency Rating System[1]

Grade	Energy demand reduction rate against the standard apartment complex
1	33.5% or more
2	23.5% - 33.5%
3	13.5% - 23.5%

The energy demand reduction rate of the evaluated apartment complex is calculated by using eqs. (1), (2) and (3). In eq. (1), HED_{unit_std} and HED_{unit} are calculated in the same manner as HERS, by using the variable heating degree day method and the 2-zone model[2]. Assessment items of the System are divided into two types, the basic and the extra. Basic items are required to calculate the HED_{unit_std} and HED_{unit} in eq. (1), which include items mandated by the building codes. Extra items are optional items, not mandated but recommended by the building codes. These are composed of one that is related to the heating, domestic hot water, electric power, lighting and so on.

Energy demand and energy cost of the evaluated apartment complex can be obtained by extending the way of assessment in the system. HED_{apt_std} and HEC_{apt_std} can be obtained using eqs. (4) and (5), respectively. After calculating the RED_{apt} using eqs. (1), (2) and (3), ED_{apt} and EC_{apt} can be obtained using eqs. (6) and (7), respectively.

In eqs. (6) and (7), the terms ED_{apt} and EC_{apt} are used instead of HED_{apt} and HEC_{apt} because RED_{apt} includes the energy demand reduction rates for the extra items related to not only the heating but also to the domestic hot water, electric power, lighting and so on. In eqs. (1), (2) and (3), as well, both terms of heating energy and energy are used due to the same reason.

$$RED_{unit} = \frac{HED_{unit\_std} - HED_{unit}}{HED_{unit\_std}} \times 100 + \sum RED_{unit\_extra} \quad (1)$$

$$RED_{bldg} = \frac{\sum (RED_{unit} \times A_{unit})}{A_{bldg}} + \sum RED_{bldg\_extra} \quad (2)$$

$$RED_{apt} = \frac{\sum (RED_{bldg} \times A_{bldg})}{A_{apt}} \quad (3)$$

[1] Building Energy Efficiency Rating Regulation (MOCIE, Notification No. 2005-10), Appendix 1.

[2] Yu, K.H., 2006, A study on the energy efficiency rating and certification of apartment houses, Journal of AIK, Vol.22, No.12, pp. 322

HED_{unit}	Heating energy demand of the unit in the evaluated apartment complex (GJ/year)
HED_{unit_std}	Heating energy demand of the unit in the standard apartment complex (GJ/year)
RED_{unit}	Energy demand reduction rate of the unit in the evaluated apartment complex (%)
RED_{unit_extra}	Energy demand reduction rate by the extra item for unit, applied to the evaluated apartment complex (%)
RED_{bldg}	Energy demand reduction rate of the building in the evaluated apartment complex (%)
RED_{bldg_extra}	Energy demand reduction rate by the extra item for building, applied to the evaluated apartment complex (%)
RED_{apt}	Energy demand reduction rate of the evaluated apartment complex (%)
A_{unit}	Floor area for private use of the unit in the evaluated apartment complex (m^2)
A_{bldg}	Gross floor area for private use of the building in the evaluated apartment complex (m^2)
A_{apt}	Gross floor area for private use of the evaluated apartment complex (m^2)

$$HED_{apt\_std} = \Sigma HED_{unit\_std} \quad (4)$$

$$HEC_{apt\_std} = HED_{apt\_std} \times HER \quad (5)$$

$$ED_{apt} = HED_{apt\_std} \times \frac{100 - RED_{apt}}{100} \quad (6)$$

$$EC_{apt} = HEC_{apt\_std} \times \frac{100 - RED_{apt}}{100} \quad (7)$$

HED_{apt_std}	Heating energy demand of the standard apartment complex (GJ/year)
ED_{apt}	Energy demand of the evaluated apartment complex (GJ/year)
HEC_{apt_std}	Heating energy cost of the standard apartment complex (₩/year)
EC_{apt}	Energy cost of the evaluated apartment complex (₩/year)
HER	Heating energy rate per GJ (₩/GJ)

2.2 Passive House

The Passive House refers to the concept of highly insulated and air-tight residential buildings that can keep indoor environmental conditions comfortable. In the Passive House, the heating energy demand is minimized by means of passive ways such as super insulation, heat recovery, solar gain and so on. The Passive House has a limited energy demand of around 15kWH/m^2 for heating and around 120kWH/m^2 for heating, domestic hot water and all other electrical equipments combined and it is reported to have less than one fifth of the heating energy demand mandated by the building regulations currently in force in the participating countries.

Promotion of European Passive Houses (PEP) provides technical solutions[3] to achieve the Passive House level. It is a guideline about technologies applied in Passive Houses, and these technologies are composed of super insulation, heat recovery, passive solar gain, electric efficiency and on-site renewable. In addition, it provides the corresponding value range of each solution. Among the variable solutions, the one related to performance of the thermal envelope such as high insulation of walls, roofs, floors is selected for this study and the corresponding values are as follows: walls' U-value ≤ 0.15W/m^2K and roofs' U-value ≤ 0.15W/m^2K.

3. Baseline Model, Target Items and Alternatives for Cost Efficiency Analysis

3.1 Outline of the Studied Apartment Complex

In general, an apartment complex is divided into two types, the hall type and corridor type. Currently, the hall type is preferred because it offers privacy and more floor area for private use. The hall type "A" apartment complex, which was completed recently, has the unit of national housing size[4], so it was selected for this study. "A" apartment complex has fourteen buildings with eight types of units whose floor areas for private use range from 85m^2 to 273m^2. Considering that it may be appropriate to give precedence to national housing, it is assumed that the floor area for private use of every unit is 85m^2, while the gross floor area of the apartment complex is maintained. The analysis results of actual and reorganized apartment complexes are considered to show no difference because construction and energy costs of an apartment complex are mainly influenced by the gross floor area. Figure 1 and Table 2 show site plan and outline of the studied apartment complex, respectively.

3.2 Setting the Baseline Model

The baseline model is a unit building that has only 85m^2 units, nineteen floors and two cores. On every floor,

[3] Promotion of European Passive Houses (PEP), Passive House Solutions, 2006

[4] National housing defined in the Housing Act of Korea is originated from the housing policy to relieve the housing shortage. It can be regarded as the most common and normal housing for ordinary people. Its floor area for private use should be 85m^2 or below.

there are four units. The four units of the top floor have attics and there is a piloti at the right corner of the ground floor, so the baseline model has 75 units. The studied apartment complex was assumed to have only baseline model buildings. Figures 2 and 3 show a unit floor plan and a sectional plan of the baseline model, respectively, and Table 3 presents the outline of the baseline model.

Figure 1 Studied Apartment Complex Site Plan

Figure 2 Baseline Model Unit Floor Plan

Figure 3 Baseline Model Sectional Plan

Table 2 Outline of the Studied Apartment Complex

Location	Seoul
Gross floor area	192,451.98m^2 (Residence: 140,325.56m^2, Car park: 52,126.42m^2)
The number of units	Existing: 885 units → Converted: 1,263 units
Converted gross floor area for private use	107,384.40m^2
Heating plant	District heating

Table 3 Outline of the Baseline Model

Gross floor area	8,329.61m^2
Gross floor area for private use	6,374.25m^2
Floor area of the unit	111.16m^2 (floor area for private use: 84.99m^2)
Floor height	Top and ground floor: 3.0m, Base floor: 2.9m
Insulation	Wall:65mm, Side wall:90mm, Roof:110mm, Ground floor:50mm
Glass	16mm Pair glass(5CL+6Air+5CL)
Orientation	South

Table 4 Target Items

No.	Description	No.	Description
0	Balcony window U-value (W/m^{2}K)	16	Energy efficient control systems of ventilation fans of underground car park
1	Window U-value (W/m^{2}K)		
2	Window area (m^2)	17	Automatic control systems using computer, networking or internet
3	Door and others (facing the outside) U-value (W/ m^{2}K)	18	High efficiency induction motor (application rate, %)
4	Wall (facing the outside) U-value (W/ m^{2}K)	19	Voltage drop of main power line (%)
5	Wall (facing the outside) Area (m^2)	20	Bank configuration enables to control the number of current transformers in operation
6	Roof U-value (W/ m^{2}K)		
7	Ground floor U-value (W/ m^{2}K)	21	Peak demand control system of electric power
8	Wall and door (facing the unheated space) U-value (W/ m^{2}K)	22	Automatic control systems of equipments for receiving and transforming the electricity
9	Awning coefficient factor.	23	Application of high intensity discharge lamp and automatic on/off control system of the outside lightings
10	Thermostat per each room or zone		
11	Electric circuit configuration which enables to break the main power outlet of the living room conveniently or installation of certified energy efficient appliances	24	Energy efficient control systems of service water pumps such as inverter control, etc.
		25	Automatic adjustment equipment of power factor for power condenser installed in a group
12	Windbreak space at the building's entrance		
13	Average efficiency of pumps for heating water, service water, domestic hot water, etc. (%)	26	Decentralized control system with open protocol, which enables intensive control as well as data compatibility with each control system of mechanical and electrical equipments
14	Equipments, pipe and duct insulation		
15	Energy efficient control systems of heating water pumps such as inverter control, etc.		

※ 0~9: basic items for heated space, 10~11: extra items for unit, 12~26: extra items for building

3.3 Setting the Target Items and Alternatives

Among all the assessment items in the Building Energy Efficiency Rating System, the items which are suitable for analysis of cost efficiencies and whose performance values are changeable in the baseline model were selected as target items. The selected 27 target items are presented in Table 4. The overall performance range of each target item was determined. In the case of the basic item, a lower limit value was set to the value of the baseline model. The upper limit value was set to the value to reflect the Passive House level and the Management Regulation. Then, more alternatives of which values vary stepwise between the lower and upper limits were set up. Performance values of the alternatives were determined by dividing the overall performance range into 5 steps while consideration was given to practical matters such as the specifications or dimensions of the products on the market. In the case of extra items, the Building Energy Efficiency Rating System just assesses whether they are applied or not, or provides step-by-step performance values. The performance value of each alternative was set with consideration of these criteria. Table 5 shows the performance value of every alternative in the case of a typical.

Table 5 Alternatives for Each Target Item in the Case of Typical Floor

No.	Units	Low ◄ Performance range ► High						No.	Units	Low ◄ Performance range ► High				
0	W/m²K	3.3	3.1	2.9	2.6	2.4	2.2	11	-	Not applied			Applied	
1	W/m²K	3.3	3.1	2.9	2.6	2.4	2.2	12	-	Not applied			Applied	
2	m²	23.14(25.6%)		21.22(23.5%)		19.30(21.4%)		13	-	1.04Ebelow	1.04E-1.08E	1.08E-1.12E	1.12E-1.16E	1.16E more
3	W/m²K	2.4			1.6			14	-	Not applied			Applied	
4-1	W/m²K	0.410	0.364	0.293	0.245	0.197	0.148	15	-	Not applied			Applied	
4-2	W/m²K	0.418	0.370	0.297	0.248	0.198	0.149	16	-	Not applied			Applied	
4-3	W/m²K	0.336	0.294	0.267	0.227	0.185	0.148	17	-	Not applied			Applied	
4-4	W/m²K	0.401	0.353	0.285	0.240	0.193	0.146	18	%	50below	50-60	60-70	70-80	80more
5	m²	67.11		69.03		70.95		19	%	6.0more	5.0-6.0	4.0-5.0	3.5-4.0	3.5below
6	W/m²K	0.285	0.248	0.229	0.199	0.176	0.149	20	-	Not applied			Applied	
7-1	W/m²K	0.262	0.247	0.212	0.198	0.175	0.149	21	-	Not applied			Applied	
7-2	W/m²K	0.468	0.421	0.329	0.270	0.212	0.149	22	-	Not applied			Applied	
8-1	W/m²K	0.574	0.511	0.437	0.338	0.238	0.151	23	-	Not applied			Applied	
8-2	W/m²K	2.6			1.7			24	-	Not applied			Applied	
9	-	0.520		0.507		0.485		25	-	Not applied			Applied	
10	-	Not applied			Applied			26	-	Not applied			Applied	

※ stands for the value of Baseline model apartment complex.

※ Actually, several extra items are applied to the studied apartment complex. However, this study assumes that extra items are not applied to the baseline model apartment complex because extra items themselves are the subject of cost efficiency analysis. In each case of No.13, No.18 and No.19, the value of RED_{extra_bldg} of the baseline apartment complex is zero.

※ No.2: The window area of the unit in baseline model is 23.14m², which is about 25.6% of total wall area. The window width is fixed for the day-lighting purpose, and the window heights of the living room and master bed room cannot be changed because they are entrance to the balcony. Window heights of the other 2 bed rooms are changed from 2.3m to 1.5m. Therefore, there are 3 alternatives for No.2: one is the baseline model, another is the case of only one bed room of 1.5m in height, and the other is 2 bedrooms of 1.5m in height.

※ No.3: According to the Management Regulation, only the two values can be approved as alternatives.

※ No.4: 4-1 the front wall, 4-2 the back wall, 4-3 the corner side wall, 4-4 the side wall except for corner side wall.

※ No.5, 9: There are 3 alternatives because No5 and No.9 are dependent on No.2.

※ No.7: 7-1 floors facing the outside directly, 7-2: floors facing the outside indirectly.
In the baseline model, there are 3 units in the ground floor because there is a piloti. These 3 units face the outside indirectly (there are underground car park) and one unit above the piloti faces the outside directly.

※ No.8: 8-1 wall, 8-2 entrance door. According to the Management Regulation, only the two values can be approved as alternatives for No.8-2.

※ No. 13, 18, 19: According to the Management Regulation, five values can be approved as alternatives.

4. Cost Efficiency Analysis

The spatial range for this analysis was set as the baseline model apartment complex, which means whole studied apartment complex composed of only the baseline model. Specific information on the cost efficiency analysis of each alternative of the target items is as follows.

4.1 Construction Cost and Annual Energy Cost

4.1.1 Construction Cost

Based on the construction project supplied by the government, the construction cost of a baseline model apartment complex and the construction cost difference between each alternative and the baseline model apartment complex were estimated, including both material and labor costs. Material cost reflects the price in Feb. 2008 and labor cost reflects the Standard Labor Work Estimation prescribed by the government in Jan.

2008. Estimated construction cost of the baseline model apartment complex is ₩ 15,276,753,777 (₩ 1,000 is about USD 1.00) and the construction cost difference between each alternative and the baseline model apartment complex is shown in Table 7.

4.1.2 Annual Energy Cost

HED_{apt_std} calculated by eq. (4) is 55,905.52 GJ/year. Energy rate of the Korea District Heating Corp. (KDHC) was applied to the value of HER in eq. (5). Monthly energy rate for the residential buildings of KDHC is presented in Table 6. HEC_{apt_std} calculated by eq. (5) is ₩813,843,820/year. The energy demand reduction rate of the baseline model apartment complex, calculated by eqs. (1), (2) and (3), is 23.74%. The energy cost of the baseline model apartment, calculated by eq. (7), is ₩ 620,637,297/year. The differences of both the energy demand reduction rate and energy cost between each alternative and the baseline model apartment complex are shown in Table 7.

Table 6 Monthly Energy Rate for Residential Buildings (KDHC, Mar. 2008, ₩ 1,000 is about USD 1.00)

Base Rate	Energy Rate
₩ 42.02/m^2 (exclusive residential floor area)	₩ 13,589/GJ

4.2 Cost Efficiency Index

4.2.1 Outline of the Cost Efficiency Index

There are various cost efficiency indexes such as NPV (Net Present Value), LCC (Life Cycle Cost) and IRR (Internal Rate of Return) which consider the time value of money, and the Payback Period which does not consider that. LCC is the sum of both the initial investment cost and operating costs during the lifetime. All operation costs are to be discounted to their present value prior to addition to the LCC total. LCC of both baseline model apartment complex and each alternative can be obtained by using eqs. (8) and (9). NPV is the sum of the present value of both investment and profits. NPV can be calculated by using eq. (10). The value of each alternative's NPV means the difference of LCC between the baseline model apartment complex and each alternative. Therefore, a negative NPV, which means an alternative is in the condition of discounted cash outflow, should be rejected. IRR is any discount rate that makes an investment's present value the same as the profits' present value, that is, specific discount rate that results in a NPV of zero. The greater an alternative's IRR, the better its rate of return. On the other hand, if an alternative's IRR is less than the standard rate of return (e.g., standard value can be real interest rate. see eq. (11)), that alternative should be rejected. NPV expresses cost efficiency of an alternative as a sum of money (i.e., the unit is ₩, see eq. (10)) and IRR does as a percentage (i.e., the unit is %). Therefore, the IRR can be a more effectual standard of decision-making under limited investments, because the size of the investment hardly influences the IRR. The payback period, which refers to the period of time needed to repay an investment amount, can be obtained by dividing the profits by the investment amount. It can be calculated by using eq. (12).

$$LCC = CC + PW \times EC \quad (8)$$

$$PW = \left(\frac{1+i}{1+R} \times \left(\left(\frac{1+i}{1+R}\right)^n - 1\right)\right) / \left(\frac{1+i}{1+R} - 1\right) \quad (9)$$

$$NPV = \Delta LCC = -\Delta CC + PW \times \Delta EC \quad (10)$$

$$r = \frac{1+R}{1+i} - 1 \quad (11)$$

$$PP = \frac{\Delta CC}{\Delta EC} \quad (12)$$

LCC	Life cycle cost (₩)	CC	Construction cost (₩)	PW	Present worth coefficient
EC	Energy cost (₩)	i	Price rise rate (%)	R	Interest rate (%)
n	Lifetime (year)	NPV	Net Present Value (₩)	r	Real interest rate (%)
PP	Payback period (year)				

ΔCC / ΔEC / ΔLCC Difference of Construction Cost / Energy Cost / LCC between Alternative and Baseline Model Apartment Complex

4.2.2 Calculation of the Cost Efficiency Index

LCC of the baseline model apartment complex and the difference of LCC between each alternative and the baseline model apartment complex are calculated using eqs. (8), (9) and (10). In eq. (9), i was set to 3.2%[5], which is the average consumer price index during the last ten years from 1998 to 2007. And R was set to 7.78%[4], which is the average loan interest rate of the Bank of Korea during the last ten years from 1998 to 2007. The age of an apartment complex used to determine the qualification of reconstruction is prescribed in the City and Residential Environment Maintenance Act as 20 years after the completion, which implies the minimum value of economic lifetime. However, n was set to 30 years, considering the fact that the body of research on the lifetime of a Korean apartment complex suggests 30 years or so, and knowing that the LCC

[5] Economic Statistics System of Bank of Korea, ecos.bok.or.kr

Table 7 Cost Efficiency Analysis Result

No.	Case	CC	ΔCC	RED	ΔRED	EC	ΔEC	LCC	NPV(ΔLCC)	IRR	PP	OP-1	OP-2
Baseline		15,276,753,777	-	23.74	-	620,637,297	-	25,460,421,604	-	-	-	-	-
0	1	15,432,114,144	155,360,367	24.49	0.75	614,533,469	6,103,829	25,515,627,882	-55,206,277	1.10	25.45	69	68
	2	15,690,109,680	413,355,903	25.31	1.57	607,859,949	12,777,348	25,664,121,613	-203,700,009	-0.48	32.35	72	72
	3	16,180,743,501	903,989,724	26.66	2.92	596,873,058	23,764,240	25,974,478,073	-514,056,469	-1.47	38.04	78	73
	4	16,229,299,536	952,545,759	27.68	3.94	588,571,851	32,065,447	25,886,824,546	-426,402,942	0.06	29.71	75	71
	5	16,434,711,330	1,157,957,553	28.80	5.06	579,456,800	41,180,497	25,942,672,900	-482,251,295	0.42	28.12	77	70
1	1	15,405,933,417	129,179,640	25.23	1.49	608,511,025	12,126,273	25,390,628,453	69,793,151	8.60	10.65	26	46
	2	15,620,448,915	343,695,138	26.76	3.02	596,059,214	24,578,083	25,400,829,608	59,591,996	5.85	13.98	29	53
	3	16,018,739,754	741,985,977	29.19	5.45	576,282,809	44,354,488	25,474,621,197	-14,199,593	4.28	16.73	64	58
	4	16,068,773,499	792,019,722	30.88	7.14	562,528,849	58,108,449	25,298,974,394	161,447,211	6.09	13.63	16	52
	5	16,239,568,989	962,815,212	32.63	8.89	548,286,582	72,350,716	25,236,077,008	224,344,596	6.32	13.31	9	50
2	1	15,144,786,999	-131,966,778	24.55	0.81	614,045,163	6,592,135	25,220,288,410	240,133,195	-	-	8	2
	2	15,012,820,221	-263,933,556	25.20	1.46	608,755,178	11,882,120	25,001,521,421	458,900,184	-	-	2	1
3	1	15,390,613,227	113,859,450	26.21	2.47	600,535,355	20,101,942	25,244,440,253	215,981,352	17.52	5.66	12	32
4-1	1	15,288,668,697	11,914,920	24.31	0.57	615,998,388	4,638,910	25,396,219,416	64,202,188	38.93	2.57	27	13
	2	15,322,008,271	45,254,494	25.18	1.44	608,917,946	11,719,351	25,313,380,246	147,041,358	25.87	3.86	17	22
	3	15,355,366,347	78,612,570	25.77	2.03	604,116,268	16,521,030	25,267,950,439	192,471,166	20.95	4.76	14	27
	4	15,405,394,210	128,640,433	26.36	2.62	599,314,589	21,322,708	25,239,190,418	221,231,187	16.40	6.03	10	34
	5	15,488,761,647	212,007,870	26.96	3.22	594,431,526	26,205,771	25,242,434,583	217,987,021	11.94	8.09	11	39
4-2	1	15,295,722,204	18,968,427	24.55	0.81	614,045,163	6,592,135	25,371,223,615	89,197,990	34.75	2.88	24	15
	2	15,348,970,508	72,216,731	25.79	2.05	603,953,499	16,683,798	25,258,883,824	201,537,780	23.06	4.33	13	25
	3	15,402,220,307	125,466,530	26.62	2.88	597,198,595	23,438,702	25,201,296,430	259,125,174	18.57	5.35	7	31
	4	15,482,094,258	205,340,481	27.46	3.72	590,362,307	30,274,990	25,168,997,801	291,423,803	14.49	6.78	4	38
	5	15,615,216,513	338,462,736	28.28	4.54	583,688,788	36,948,509	25,192,618,251	267,803,353	10.35	9.16	6	42
4-3	1	15,308,537,758	31,783,981	24.20	0.46	616,893,616	3,743,682	25,430,777,744	29,643,861	11.30	8.49	38	41
	2	15,340,763,185	64,009,408	24.48	0.74	614,614,853	6,022,444	25,425,612,311	34,809,294	8.62	10.63	37	45
	3	15,405,214,037	128,460,260	24.92	1.18	611,033,940	9,603,357	25,431,306,097	29,115,508	6.27	13.38	41	51
	4	15,501,890,315	225,136,538	25.36	1.62	607,453,028	13,184,270	25,469,225,309	-8,803,705	4.10	17.08	62	59
	5	15,630,792,020	354,038,243	25.76	2.02	604,197,652	16,439,645	25,544,711,499	-84,289,895	2.29	21.54	70	65
4-4	1	15,290,495,014	13,741,237	24.20	0.46	616,893,616	3,743,682	25,412,735,000	47,686,605	27.22	3.67	34	19
	2	15,325,242,933	48,489,156	24.86	1.12	611,522,247	9,115,051	25,359,347,320	101,074,284	18.69	5.32	21	30
	3	15,359,990,852	83,237,075	25.29	1.55	608,022,718	12,614,579	25,336,673,561	123,748,043	14.92	6.60	19	36
	4	15,412,112,730	135,358,953	25.74	2.00	604,360,421	16,276,876	25,328,702,985	131,718,619	11.58	8.32	18	40
	5	15,498,982,527	222,228,750	26.20	2.46	600,616,739	20,020,558	25,354,144,941	106,276,664	8.15	11.10	20	47
6	1	15,285,255,461	8,501,684	23.83	0.09	619,904,838	732,459	25,456,904,798	3,516,807	7.68	11.61	52	48
	2	15,292,307,994	15,554,217	23.87	0.13	619,579,301	1,057,997	25,458,615,779	1,805,825	5.40	14.70	53	54
	3	15,306,413,061	29,659,284	23.94	0.20	619,009,610	1,627,688	25,463,373,131	-2,951,527	3.57	18.22	60	61
	4	15,320,518,127	43,764,350	24.00	0.26	618,521,304	2,115,994	25,469,465,870	-9,044,266	2.59	20.68	63	63
	5	15,341,675,727	64,921,950	24.06	0.32	618,032,997	2,604,300	25,482,611,143	-22,189,538	1.24	24.93	66	67
7-1	1	15,277,530,434	776,657	23.75	0.01	620,555,913	81,384	25,459,862,873	558,731	9.85	9.54	54	43
	2	15,280,365,233	3,611,456	23.77	0.03	620,393,144	244,153	25,460,026,897	394,708	5.34	14.79	55	55
	3	15,281,782,633	5,028,856	23.78	0.04	620,311,760	325,538	25,460,108,909	312,695	4.96	15.45	56	56
	4	15,284,617,432	7,863,655	23.80	0.06	620,148,991	488,306	25,460,272,932	148,672	4.60	16.10	57	57
	5	15,288,869,631	12,115,854	23.81	0.07	620,067,607	569,691	25,463,189,743	-2,768,139	2.38	21.27	59	64
7-2	1	15,277,661,978	908,201	23.82	0.08	619,986,222	651,075	25,450,646,702	9,774,902	71.69	1.39	50	8
	2	15,280,976,912	4,223,135	23.99	0.25	618,602,688	2,034,610	25,431,260,043	29,161,562	48.18	2.08	40	11
	3	15,284,291,845	7,538,068	24.10	0.36	617,707,460	2,929,838	25,419,885,709	40,535,895	38.87	2.57	35	14
	4	15,289,264,246	12,510,469	24.20	0.46	616,893,616	3,743,682	25,411,504,232	48,917,373	29.91	3.34	33	16
	5	15,294,304,761	17,550,984	24.31	0.57	615,998,388	4,638,910	25,401,855,480	58,566,124	26.41	3.78	31	21
8-1	1	15,278,046,321	1,292,544	24.46	0.72	614,777,622	5,859,676	25,365,566,222	94,855,382	453.34	0.22	23	4
	2	15,305,005,104	28,251,327	25.33	1.59	607,697,181	12,940,117	25,276,346,261	184,075,343	45.80	2.18	15	12
	3	15,358,922,670	82,168,893	26.53	2.79	597,931,055	22,706,243	25,170,017,284	290,404,320	27.62	3.62	5	18
	4	15,466,757,803	190,004,026	27.85	4.11	587,188,316	33,448,981	25,101,581,219	358,840,385	17.46	5.68	3	33
	5	15,491,500,795	214,747,018	28.91	5.17	578,561,572	42,075,726	24,984,773,098	475,648,506	19.50	5.10	1	29
8-2	1	15,365,163,777	88,410,000	24.81	1.07	611,929,169	8,708,129	25,405,945,103	54,476,501	9.13	10.15	32	44
10	1	15,675,230,277	398,476,500	24.49	0.75	614,533,469	6,103,829	25,758,744,015	-298,322,410	-4.43	65.28	74	76
11	1	15,402,927,477	126,173,700	23.99	0.25	618,602,688	2,034,610	25,553,210,608	-92,789,003	-4.16	62.01	71	75
12	1	15,311,500,239	34,746,462	23.99	0.25	618,602,688	2,034,610	25,461,783,370	-1,361,765	4.10	17.08	58	60
13	1	15,277,033,777	280,000	24.04	0.30	618,195,766	2,441,531	25,420,639,968	39,781,636	871.98	0.11	36	3
	2	15,278,033,777	1,280,000	24.19	0.45	616,975,000	3,662,297	25,401,609,151	58,812,454	286.12	0.35	30	5
	3	15,279,033,777	2,280,000	24.34	0.60	615,754,235	4,883,063	25,382,578,333	77,843,272	214.17	0.47	25	6
	4	15,281,213,777	4,460,000	24.49	0.75	614,533,469	6,103,829	25,364,727,515	95,694,090	136.86	0.73	22	7
14	1	15,368,951,493	92,197,716	24.24	0.50	616,568,078	4,069,219	25,485,849,927	-25,428,323	1.92	22.66	67	66
15	1	15,283,483,777	6,730,000	24.24	0.50	616,568,078	4,069,219	25,400,382,211	60,039,393	60.46	1.65	28	9
16	1	15,285,903,777	9,150,000	23.99	0.25	618,602,688	2,034,610	25,436,186,908	24,234,697	22.18	4.50	43	26
17	1	15,301,733,777	24,980,000	23.99	0.25	618,602,688	2,034,610	25,452,016,908	8,404,697	7.11	12.28	51	49
18	1	15,279,963,777	3,210,000	23.84	0.10	619,823,454	813,844	25,450,277,726	10,143,879	25.32	3.94	49	23
	2	15,281,123,777	4,370,000	23.89	0.15	619,416,532	1,220,766	25,444,760,786	15,660,818	27.92	3.58	48	17
	3	15,283,223,777	6,470,000	23.94	0.20	619,009,610	1,627,688	25,440,183,847	20,237,757	25.13	3.97	45	24
	4	15,284,223,777	7,470,000	23.99	0.25	618,602,688	2,034,610	25,434,506,908	25,914,697	27.22	3.67	42	20
19	1	15,522,950,777	246,197,000	23.84	0.10	619,823,454	813,844	25,693,264,726	-232,843,121	-11.15	302.51	73	77
	2	15,769,148,777	492,395,000	23.89	0.15	619,416,532	1,220,766	25,932,785,786	-472,364,182	-12.25	403.35	76	78
	3	16,015,346,777	738,593,000	23.94	0.20	619,009,610	1,627,688	26,172,306,847	-711,885,243	-12.69	453.77	79	79
	4	16,258,676,777	981,923,000	23.99	0.25	618,602,688	2,034,610	26,408,959,908	-948,538,303	-12.91	482.61	80	80
20	1	15,286,753,777	10,000,000	23.99	0.25	618,602,688	2,034,610	25,437,036,908	23,384,697	20.27	4.91	44	28
21	1	15,290,329,777	13,576,000	23.99	0.25	618,602,688	2,034,610	25,440,612,908	19,808,697	14.74	6.67	47	37
22	1	15,332,214,777	55,461,000	23.99	0.25	618,602,688	2,034,610	25,482,497,908	-22,076,303	0.63	27.26	65	69
23	1	15,316,282,777	39,529,000	23.99	0.25	618,602,688	2,034,610	25,466,565,908	-6,144,303	3.07	19.43	61	62
24	1	15,280,753,777	4,000,000	23.99	0.25	618,602,688	2,034,610	25,431,036,908	29,384,697	50.87	1.97	39	10
25	1	15,289,977,777	13,224,000	23.99	0.25	618,602,688	2,034,610	25,440,260,908	20,160,697	15.16	6.50	46	35
26	1	15,361,753,777	85,000,000	23.99	0.25	618,602,688	2,034,610	25,512,036,908	-51,615,303	-2.02	41.78	68	74

CC: Construction Cost (₩), ΔCC: Construction Cost Difference between Alternative and Baseline Model Apartment Complex (₩), RED: Energy Demand Reduction Rate (%),

ΔRED: Energy Demand Reduction Rate Difference between alternative and baseline model apartment complex (%), EC: Energy Cost (₩/year),

ΔEC: Energy Cost Difference between Alternative and Baseline Model Apartment Complex (₩/year), LCC: Life Cycle Cost (₩),

NPV: Net Present Value (₩) = ΔLCC(LCC Difference between Alternative and Baseline Model Apartment Complex), IRR: Internal Rate of Return (%), PP: Payback Period (year),

OP-1: Order of Priority of LCC and NPV, OP-2: Order of Priority of IRR and PP

(shaded)	this alternative is rejected (NPV < 0 and IRR < real interest rate)

of an apartment complex for more than 30 years hardly affects the entire cost.[6] As a result of the calculation, the LCC of the baseline model apartment complex is ₩ 25,460,421,604 and each alternative's LCC is shown in Table 7. And the calculation results of NPV, IRR and the payback period of each alternative are also presented in Table 7.

4.3 Cost Efficiency Analysis Results of Each Alternative of Target Items

Table 7 shows the cost efficiency analysis result. In the case of No.2 (window area), both construction and energy costs of Alt1 and Alt2 are smaller than those of the baseline model apartment complex. This is because the construction cost is directly proportional to the window area. With respect the energy cost, the decrement of heat loss is more than that of solar heat gain through the window with the decrease of window area. The IRR and payback periods of Alt1 and Alt2 for No.2 cannot be calculated, and Alt2 of No.2 is given the first priority because of its more decrease in construction and energy costs.

Alternatives with negative NPV, No.0 (balcony window U-value), Alt3 of No.1 (window U-value), Alt4 and 5 of No.4-3 (corner side wall U-value), Alt 3, 4 and 5 of No.6 (roof U-value), Alt5 of No.7-1 (ground floor U-value facing the outside directly), No.10 (thermostat per each room or zone), No.11 (electric circuit configuration which enables to break the main power outlet of the living room conveniently or installation of certified energy efficient appliances), No.12(windbreak space at the building's entrance), No.14 (equipment, pipe and duct insulation), No.19 (voltage drop of main power line), No.22 (automatic control systems of equipments for receiving and transforming the electricity), No.23 (application of high intensity discharge lamp and automatic on/off control system of the outside lightings) and No.26 (decentralized control system with open protocol, which enables intensive control as well as data compatibility with each control system of mechanical and electrical equipment) should be rejected. In addition, with respect to the IRR, these alternatives also proved to be cost-inefficient due to their IRR value being lower than the real interest rate, 4.44%, which is calculated applying the price increase rate, 3.2% and interest rate, 7.78%.

All but the rejected alternatives are arranged according to their NPV values. In case that if there are several alternatives for one target item, only one alternative having the best NPV value among them is selected. As a result, Alt5 of No.8-1 (wall U-value facing the unheated space), Alt2 of No.2 (window area), Alt4 of No.4-2 (back wall U-value) and Alt5 of No.1 (window U-value) are proven to be superior from the point of NPV. In the same manner, Alt2 of No.2 (window area), Alt1 of No.13 (average efficiency of pumps for heating water, service water, domestic hot water, etc), Alt1 of No.8-1 (wall U-value facing the unheated space) and Alt1 of No.7-2 (floor U-value facing the outside indirectly) are proven to be excellent with respect to IRR. Alt2 of No.2 (window area) is proven to be quite good regarding both NPV and IRR. And the order of priority of NPV shows the same as that of LCC, and IRR appears also the same as payback period.

5. Conclusion

This study analyzed the cost efficiency of each item related to the energy efficiency of an apartment complex by using the assessment method of the Building Energy Efficiency Rating System of Korea. The baseline model apartment complex was set up, based on an actual apartment complex. Among all the assessment items in the system, items that are suitable for analyzing cost efficiencies were selected as target items, and alternatives for each target item were set up. Construction and energy costs of both each alternative were estimated by using actual price data and the assessment method of the system. As a result, the LCC, the NPV, the IRR and the payback period as indexes of cost efficiency and the order of priority in accordance with each index were presented. In addition, very cost efficient alternatives with respect to the NPV and the IRR were suggested. The results of this study are expected to be the guideline for developing energy and cost efficient design models of an apartment complex.

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BENCHMARKING OF THE HEALTH PERFORMANCE OF RESIDENTIAL BUILDINGS FOR A COMBINED LIFE CYCLE ASSESSMENT, LIFE CYCLE COSTING AND HEALTH IMPACT ASSESSMENT TOOL FOR PUBLIC HOUSING IN HONG KONG

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Summary

In 2005, a consortium comprising of thegreenroom, The University of Hong Kong, Davis Langdon & Seah Management Ltd., and the Business Environment Council completed a combined Life Cycle Assessment/Life Cycle Costing Study of a public rental New Harmony Block for the Hong Kong Housing Authority. The decision making tool measured the financial implications and ten environmental impacts of selecting 110 alternative building materials from the standard specification. The results showed that NHB block generated 1.54 HKE-points/CFA and cost HK$18040.46/CFA (US$2313.08/CFA) for the whole 55-year building life-cycle. If Ordinary Portland Cement block partition is changed to gypsum partition, the environmental impacts and the cost would increase by 0.26% and 0.07%, respectively. The decision-making tool assessed environmental and economic sustainability but did not assess the health advantages/disadvantages from alternative materials. To test the possibility of a health assessment, we identified three quantitative health indicators suitable for integration to the LCA and LCC tool: 1) risk-of-illness 2) burden of diseases in DALYs and 3) medical cost. This paper defines the health benchmark for existing residential building blocks in HK and it indicates the total cancer burden of residential building blocks with the three health indicators. The paper will demonstrate a three-tier decision-making process for health, environmental and cost performance with the three indicators and the health benchmark of a typical HK residential building. The final tool will assess the environmental, economic and health performance of housing developments.

1. Introduction – A Combined LCA and LCC Assessment Tool for HK Public Housing

In 2005, a combined Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) building assessment tool for Hong Kong Housing Authority (HKHA) was completed by thegreenroom, The University of Hong Kong, Davis Landon & Seah Management Ltd., and the Business Environmental Council in collaboration with Building Research Establishment (BRE), UK. The building in assessment was the New Harmony Block (Option 2) (NHB), a 40-storey concrete-framed residential building for public-rental that accommodates a total of 3,196 individuals (fig. 1).

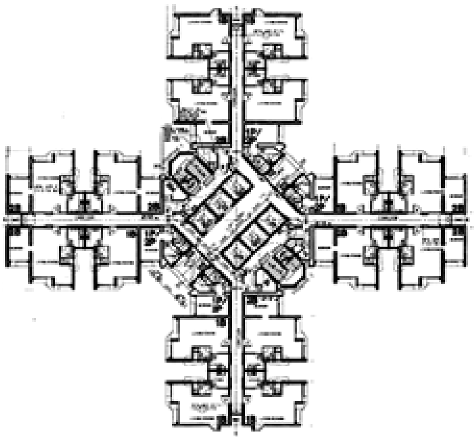

Figure 1 Typical floor plan (left) and the appearance (right) of the New Harmony Block (Option 2)

The goal of the combined tool was to measure the following ten environmental impacts and determine the financial implication of selecting 110 alternative building-materials under standard HKHA specification in the whole life cycle perspective, including (1) raw material extraction, (2) building material manufacturing, (3) transportation, (4) construction, (5) building operation, (6) repair and maintenance, and (7) disposal (Amato et al., 2006):

1. Energy (MJ)
2. Resource depletion (kg)
3. Water consumption (m^3)
4. Waste (kg)
5. Climate change (kg CO_2 eq.)
6. Acid Rain (kg SO_2 eq.)
7. Photochemical smog (kg C_2H_2 eq.)
8. Ozone depletion (kg CFC-11 eq.)
9. Toxicity to humans (kg toxic eq.)
10. Toxicity to ecosystems (kg toxic eq.)

a) Capital cost (initial cost)
b) Recurring cost (operational cost; repair and maintenance cost), and
c) Demolition cost

The tool characterised[1], normalised[2] and weighted[3] the ten environmental impacts into a notional HK Environ-pt (HK E-pts), which was equivalent to the ten environmental impacts generated by one HK citizen annually. By means of HK E-pts and the money spent, architects and other building management professionals can quantitatively judge the environmental-friendliness and cost-effectiveness of alternative building materials from the building life-cycle point of view. For example, the alternation of ordinary Portland cement block with gypsum partition can reduce life-cycle environmental impacts of NHB by 0.26% HK E-pts and increase the life cycle costs by 0.07% (Amato et al., 2006). The existing tool did not assess the social sustainability, which could include the aspect of health, skill, ability, education and social-connection (Hart, 1999).

1.1 Quantitative Health Impact Assessment and Indicators Combined with LCA and LCC

Existing LCA and LCC tool can potentially integrate with a Health Impact Assessment (HIA) module to measure improvement or decline in disease burden brought about through the use of alternative materials. To allow such an assessment, the selection of health indicators sensitive to modification of building materials would be important in the whole process. Wong et al. (2006) tested the sensitivity of various health indicators and found three that can be used to measure the disease burden from building materials (see table 1).

Table 1 Three types of quantitative health indicators appropriate for measuring burden of diseases related to building materials (Wong et al., 2006)

	Types of health indicators	Example of measurement
1	Risk of illness or dying	Probability of have specified illness or incidence rate per 1,000 or 100,000 population
2	Positive and negative burden of disease	Disability Adjusted Life Years (DALY) which measures both Years of Life Lost (YLL) and Years Lived with Disability (YLD)
3	Externality cost	Medical or treatment cost for illness

This paper provides a measurement of the potential disease burden of a typical 40-storey high-rise residential building in Hong Kong. The result can act as a comparison benchmark for the combined LCA,

[1] Howard *et al.*, (1999) described characterization as: *"The purpose of this is to translate different inventory inputs (emissions) into directly comparable impact indicators. The characterization process follows international practices in the characterization of inventory data for their potency with the different impact categories."*

[2] Howard *et al.*, (1999) described normalisation as: *"The purpose is to express impact indicator data in a way that can be compared among impact categories. The procedures normalized the characterized results by dividing by selected reference values, which can be:*

- *The total emissions or resource use for region that may be local, regional or global*
- *The total emissions or resource use for an area on a per capita basis"*

[3] The ten environmental impacts were weighted for their local, regional and global importance as set up according to a series of HKHA workshops organised in 2002.

LCC and HIA tool for public housing. This paper will use (1) the selected health indicators, (2) the health benchmark of typical HK residential building, and (3) the combined LCA and LCC decision-making tool to measure the health implications, environmental impacts and economic implications from applying different alternative partition materials on NHB housing block and discuss the benefits and the drawbacks.

2. Object of Study – A Typical Residential Premise

A typical HK residential building built in the 1990s is a 40-sorey high concrete-framed building. It accommodates 320 residential flats including 240 three-bedroom units and 80 two-bedroom units. The building can lodge as many as 1100-1200 individuals, which is one-third the population of NHB.

Figure 2 Typical floor plan (left) and appearance (right) of a residential building

Table 2 summaries the local indoor contaminant concentration level of a typical HK residential building and provides comparison to the mean Volatile Organic Compounds (VOC) concentrations of non-industrial indoors in Japan, the Level 1 and Level 2 Indoor Air Quality (IAQ) objective of HK Environmental Protection Department (HKEPD), and the carcinogen classification of those indoor air contaminants by the standards of the International Agency for Research on Cancer (IARC) (Ho 1996; Lee et al. 2002; Azuma et al., 2006; Indoor Air Quality Group Management Group 1999). Under IARC classification, Group 1 agents are carcinogenic to humans, Group 2A agents are probably carcinogenic to humans, Group 2B are possibly carcinogenic to humans, and Group 3 agents are not classifiable as to their carcinogenity to humans (IARC, 2007). Most of the indoor contaminants found in HK residential indoors have been classified as probably/possibly carcinogenic to humans, while radon, benzene and formaldehyde are definitely known for their carcinogenicity to humans (IARC, 2007). Note that carcinogenicity is defined by the concentration level and the occupants' exposure time to the carcinogen. This study assesses the potential cancer risk of these contaminants.

To benchmark the burden of cancer from radon and VOC concentrations of residential indoors, we applied the most updated epidemiological data from USEPA. Particularly, the data on radon was based on the cohort study based on the latest epidemiological follow-up of 68,000 underground miners (National Research Council, 1999). WHO (2000) considerers the epidemiological study on miners adjusted to residential context as the most reliable data for application to public health concerns.

We considered the hours of exposure data from different age groups to calculate the burden of disease Figure 3 shows the total hours of stay for HK dwellings (Chau et al., 2002) with the longest number of hours spent in bedrooms in HK residential buildings (7.9 to 9.8 hrs per day). Youth and elderly tended to stay longer in residential premises than other adults. Individuals of less than 18 years age and those above 60 years spend 57% and 68% of their time during weekdays at home, respectively. During weekends, the >60 age group could spend as long as 74% of their time indoors. Thus, the youth and elderly age occupants could have higher cancer potential from indoor contaminants than the adult group. According to our survey undertaken in a new town in HK, 12.4% of the population were smokers; 14% of the population was less than 15 ago old 30% was in the age group of 15-34; 44.3% was 35-64; and, 11.8% was higher than 64 age old living in a residential building.

Table 2 Radon and VOC concentration levels of HK residential dwellings, non-industrial indoors in Japan compared with the EPD Level 1 and Level 2 IAQ objective and International Agency for Research on Cancer classification of carcinogenicity to humans (Ho 1996; Lee et al. 2002; Azuma et al., 2006; HKEPD 1999; IARC, 2007)

			HK	Japan	HKEPD
		IARC classification of carcinogenicity to humans	Living room [4]	non-industrial indoors measured from 1995-2004) [5]	IAQ objective [6]
Contaminants	**Units**	**Group**	**conc. range (mean)**	**mean conc.**	**Level 1, Level 2**
Radon (window close)	Bq/m^3	1	114	-	150, 200
Radon (window open)	Bq/m^3	1	92	-	150, 200
Benzene	ug/m^3	1	1.5-9.9 (4.7)	4.554	16.1
Toluene	ug/m^3	3	26-77.2 (52.1)	80.443	1092.0
m, p-xylene	ug/m^3	3	1.6-7.7 (3.9)	-	1447.0
o-xylene	ug/m^3	3	1-10.8 (4.5)	-	Xylene (o-, m-, p-isomer)
Ethylbenzene	ug/m^3	2B	N.D.-4.7 (2.6)	17.977	1447.0
1,3,5-trimethylbezene	ug/m^3	Nil	N.D.-4.5 (1.8)	4.71	
Trichloroethylene	ug/m^3	2A	N.D.-2.1 (1.8)	3.045	770.0
Tetrachloroethylene	ug/m^3	2A	N.D.-4.4 (2.5)	17.977	250.0
1,4-Dichlorobenzene	ug/m^3	2B	1.2-4.3 (2.6)	114.149	200.0
Chloroform	ug/m^3	2B	1.6-3.6 (2.6)	1.147	163.0
Methylene Chloride	ug/m^3	2B	6.8-10.2 (8.8)	9.842	
Formaldehyde	ug/m^3	1	3.2-20.1 (16.0)	46.91	30, 100

N.D. –Not detectable; 4 - **(Lee et al. 2002; Ho 1996); 5- (Azuma et al. 2006; 6 - (HKEPD, 1999)**

Table 3 Time activity pattern for different age group during Weekday and Weekend (Chau et al., 2002)

	6-18 age	6-18 age	18-60 age	18-60 age	>60 age	>60 age
	Weekday	**Weekend**	**Weekday**	**Weekend**	**Weekday**	**Weekend**
Indoors at home	**hr/day**	**hr/day**	**hr/day**	**hr/day**	**hr/day**	**hr/day**
Bedroom	8.63	9.83	7.92	9.06	8.13	8.38
Living/ dining room	3.83	4.01	3.10	4.20	4.81	5.60
Kitchen	0.41	0.31	0.81	1.01	2.25	2.52
Bathroom	0.88	1.03	0.97	1.08	1.15	1.15
Total hr at home	13.75	15.18	12.80	15.35	16.34	17.65

3. Results of a Health Benchmark Study on a Typical HK Residential Premise

According to the time activity pattern, the indoor and VOC concentrations found in a typical residential premise, the surveyed population mix, and the smoking prevalence of occupants, we calculate the health performance of a typical concrete-framed residential building if all occupants live for 30 years in the dwelling. The indicators were in terms of cancer risk, cancer DALYs and cancer treatment cost. Table 4 shows the health benchmark result. Nearly 96% of the cancer risk arises from lung cancer associated with the radon concentration of the concrete-framed building and smoking habits of occupants. The 2nd and 3rd hotspots were leukaemia risk caused by benzene and nasopharynx cancer caused by formaldehyde, respectively. These contaminants were associated with 2nd-hand smoking, outdoor air pollution, cooking combustion and off-gassing of building materials (Niu et al., 2001).

Table 4 The potential cancer risk of a typical HK residential building built in the 1990s if all occupants live for 30 years in the dwelling

Health Indicators	Cancer Risk
Risk of cancer per 1,000 people	2.6-2.7
Cancer DALYS per 1,000 people	78.56-79.85
Cancer treatment cost per 1,000 people (US$)	278,514-282,968

4. Result of Health Performance of New Harmony Block (Option 2)

After setting up the benchmark, we utilised the combined LCA and LCC decision-making tool, the health indicators and the health benchmark to assess the health performances from different partition materials for a typical public housing block. The assessment of a public housing block was based on real ventilation measurements, and the results of studies on the actual population mix, window operation patterns and real exposure survey. These data will be explained in more detail in future publications.

Figures 3 – 5 show the difference of cancer risk, DALYS and treatment cost per 1000 people between a typical public housing block and the health benchmark of a typical HK residential building. The public housing block has 5-6% lower cancer risk, less cancer DALYs and lower cancer treatment costs than the benchmark for a typical residential building in HK of all occupants live for 30 years in the dwellings. This is because public housing block has better cross-ventilation than a typical residential block which lack corridor windows and whose main doors are always closed due to security demands from occupants, resulting in reduced potential air circulation.

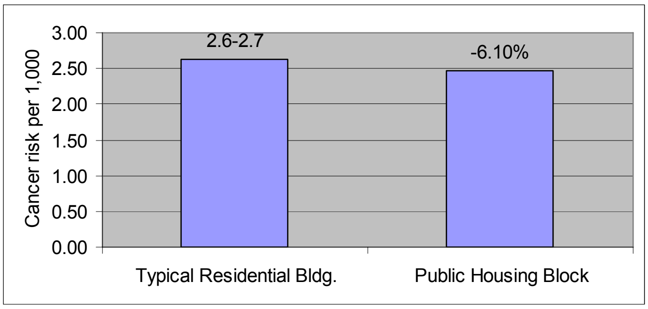

Figure 3 Cancer Risk per 1,000 people for a Public Housing Block and Health Benchmark

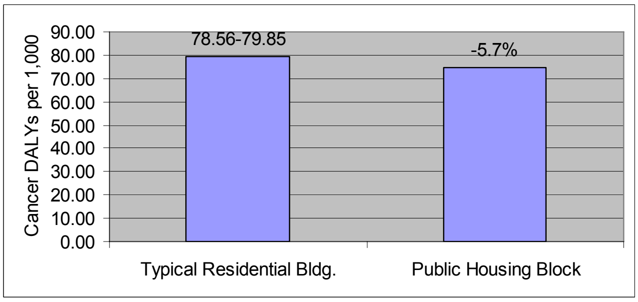

Figure 4 Cancer DALYs per 1,000 people for a Public Housing Block and Health Benchmark

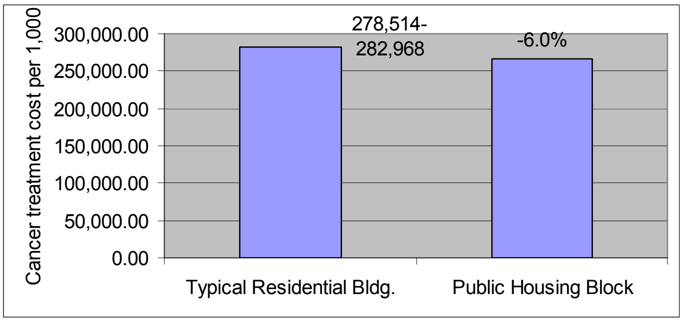

Figure 5 Cancer Treatment Cost (US$) per 1,000 people for a Public Housing Block and Health Benchmark

5. Alternative Study to Reduce Radon Cancer Risk from Partition Materials

Five alternative partition materials were tested by Mui (2005): PFA concrete block, lightweight concrete partition, gypsum partition, red brick partition and autoclave aerated concrete (AAC) block partition. These partition materials are made of soil or rock and they emit radon at different emanation rates as shown in Figure 6 (gathered from local literature by Mui 2005).

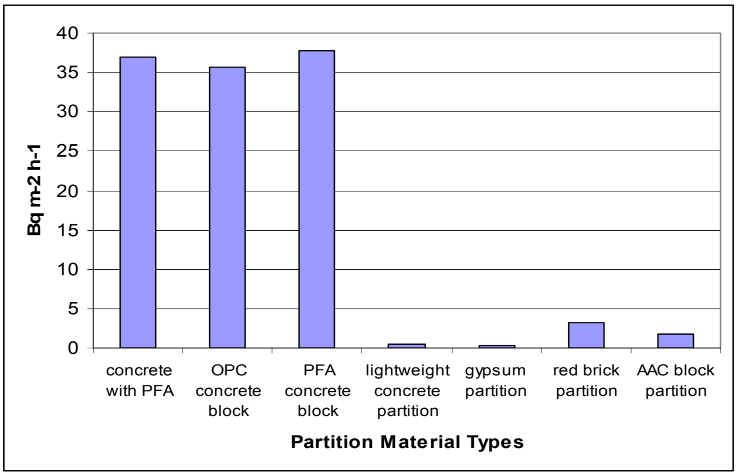

Figure 6 Radon Emanation Rate (Bq. m-2h-1) of different partition materials from local literature (Mui, 2005)

Some partition materials for example, gypsum partition, emit small amounts of carcinogenic VOCs. By applying the mass balance model and the VOC time decay pattern of building materials, the life-cycle environmental performance in terms of HK E-pts, life-cycle cost and the operational health improvement in terms of the three health indicators for a public housing block with gypsum partition are shown in Table 5. Gypsum partition increases the life-cycle environmental impacts by 0.26% and increases the life-cycle cost by 0.07%. Figures 6-8 show the cancer risk, cancer DALYs and cancer treatment cost per 1,000 people between health benchmark, the public housing block without any alternative materials and with gypsum partitions.

Table 5 Comparison of the life-cycle environmental impact and life-cycle cost between a public housing block without any alternative materials and a public housing block with gypsum partition

Case	Life Cycle Env. Impact (HK E-point per CFA)	Whole Life Cost (HK$ per CFA)
Base case with hollow concrete block	1.540	18040.5
Alternation from hollow-concrete block to gypsum partition	1.544 (+0.26%)	18053.1 (+0.07%)

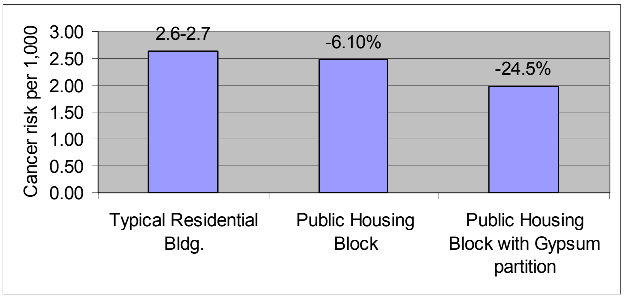

Figure 6 Cancer Risk per 1,000 people for a Public Housing Block and Health Benchmark and a Public Housing Block with Gypsum Partition

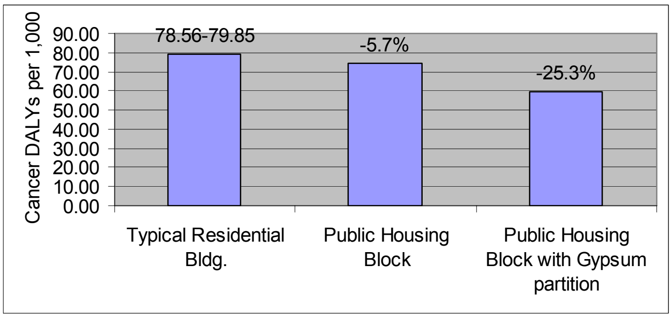

Figure 7 Cancer DALYs per 1,000 people for a Public Housing Block and Health Benchmark and a Public Housing Block with Gypsum Partition

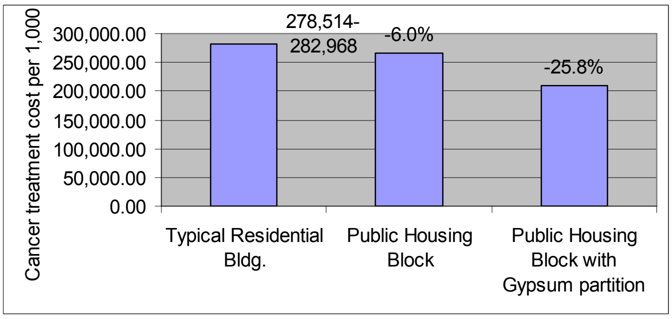

Figure 8 Cancer Treatment Cost (US$) per 1,000 people for a Public Housing Block and Health Benchmark and a Public Housing Block with Gypsum Partition

Compared to the benchmark for a typical HK residential building, a public housing block with gypsum partition can improve the health performance of the building during operation stage with 24.5% less cancer risk, 25.3% less cancer DALYs and 25.8% less cancer treatment cost. Although the gypsum partition increases the life-cycle environmental impacts and the life-cycle cost by about 0.3%, these costs are considered to be negligible in comparison to the greatly improved health performance by over 25% and reduced potential cancer treatment cost by 25.8%. In the long term, these can greatly reduce the burden on the society's health investment.

5. Conclusion

This paper demonstrates an example of the combined LCA, LCC and HIA decision making process. The combined LCA, LCC and HIA tools can potentially help decision makers to justify the environmental, economic and health performance of any building. This paper also measured the health, environmental and cost benefits from source control approach with gypsum partition.

Future publications will investigate the health, environmental and cost benefits from improvement on ventilation approaches and other alternative material applications. The future focus of our research will address the health burden of other life-cycle stages other that the 55-year building operation period included in this analysis. The final tool will assess environmental, economic and social sustainability of the whole building life-cycle and facilitate holistic decision-making for public housing.

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METHODICAL SYSTEM APPROACH FOR USER ORIENTED INFRASTRUCTURAL ENERGY FLOWS IN THE BUILT ENVIRONMENT: FLEXERGY

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Summary

During the last decades, the main focus of research in Building Services was on reduction of energy consumption of buildings. But no longer it is sufficient to look only at the building itself the occupant and the energy infrastructure need also be considered too. The strong focus on the energy reduction led to situations in which health and comfort are endangered. Integration between end-user and building is the ultimate in the intelligent building concept. "Connecting" the end-user to a building is complex. User-connectivity, the combination of usability and user interface together, is studied and developed further.A further challenge for future sustainable developments is a renewable energy infrastructure to reach an acceptable price level and a minimized environmental impact.

Design tools for renewable energy installations are available on the level of individual installations. There is a need for an Integral Design approach which describes at the conceptual level the process as a chain of activities, which starts with an abstract problem and which results in a solution. The paper will discuss the approach to reach the goal of integration of end-user and energy infrastructure.

1. Introduction

In today's modern buildings people expect a comfortable working environment. This is achieved by good integration of advanced technology for ventilation, heating and cooling in our buildings. Over the years energy efficiency of buildings has increased. At first by better ways of constructing followed by applying better insulation and better glazing. Also the introduction of more efficient building equipment has lead to further reduction of the energy use of buildings. Still there is a persistent discrepancy between increasing demands for comfort in buildings and the need to decrease the use of energy. Global warming, caused largely by CO2 emissions as a result of energy consumption, shows an increasing effect. Climate change is becoming a major problem. As results of Global Warming (Alley 2007) become more and more prominent, it is necessary to look for new possibilities to save energy and to generate sustainable energy to be used for comfort in the built environment. Preservation of energy resources, occupant comfort and environmental impact limitation are the key issues of modern and sustainable architecture. A major portion of primary energy consumption, about 40 %, is due to create thermal comfort in buildings by heating, cooling, ventilating and lighting. At each level in the design process different decisions have to be taken. One of those decisions is the application of sustainable energy systems and components. However this is rather complex to integrate in the early stages of building design as many aspects have to be taken into account. During the last decades, the main focus of research in Building Services was on reduction of energy consumption of buildings. The strong focus on energy reduction led to situations in which health and comfort are endangered.

Instead these sustainable energy systems are added during the final design stages. This results in sub optimal solutions and often leads to complete rejection of proposals to use sustainable energy systems at all. At the early design stages, usually only conceptual sketches and schematics are available, often rough and incomplete. Architects tend to develop their designs in a drawing-based, graphical way (prototypes are used to investigate the design concepts). As the design proceeds, more information and detail will be developed.

In office buildings most of the energy is needed for thermal comfort especially cooling. Present energy efficient technology is not sufficient to further reduce the energy use of buildings. New comfort control technology, such as individual control, offers new possibilities to further reduce energy consumption of office buildings. Dynamic online steering of individual comfort management and building management could save up to 20% of current energy consumption. Misunderstandings and wrong conceptions about indoor comfort and energy use are common. Most office users are not even aware of the fact that they can affect the energy use. The behaviour of building occupants needs to be taken into account as it is responsible for almost half the outcome of planned energy reduction (Claeson-Jonsson 2005). When the comfort control system is not working adequately, a lot of energy is wasted by too much heating or cooling. As a result of this overshoot indoor temperature is the most common issue in occupants' complaints about thermal comfort.

As until now the user has not been part of the building comfort system control strategy in offices, the energy consequences of the user behaviour are not accounted for. New technological development is needed to incorporate the behaviour of occupants of buildings. We did some development in this field. The first experiment was part of the European EBOB-project (Energy efficient Behaviour in Office Buildings). In EBOB so called *Forgiving* Technology was developed, with this technology each user in the building was given control of his or her personal comfort (Claeson-Jonsson 2005). The goal of the project was, by giving the user a choice in combination with feedback on the energy consumption/cost efficient operation was enhanced. In the SMART/IIGO project the agent technology was developed. SMART stands for *Smart Multi Agent Technology* (Jelsma et al. 2002) and IIGO (Kamphuis et al.2005) is a Dutch acronym for *Intelligent Internet mediated control in the built Environment*. The in SMART developed technology was tested in an extended field test in the IIGO-project. The lessons learned in these projects are used in the Flexergy project. In this project SMART control of the building is combined with agent technology for energy purchase on an open market. This technology was developed by ECN in the POWERMATCHER-project (PM). The PM-technology combines local demand and supply of electricity and efficiently incorporates distributed generation into the network (CRISP 2002).

The energy supply on a system level should be dominated by trends in demands by the occupants of the buildings (Fig.1).

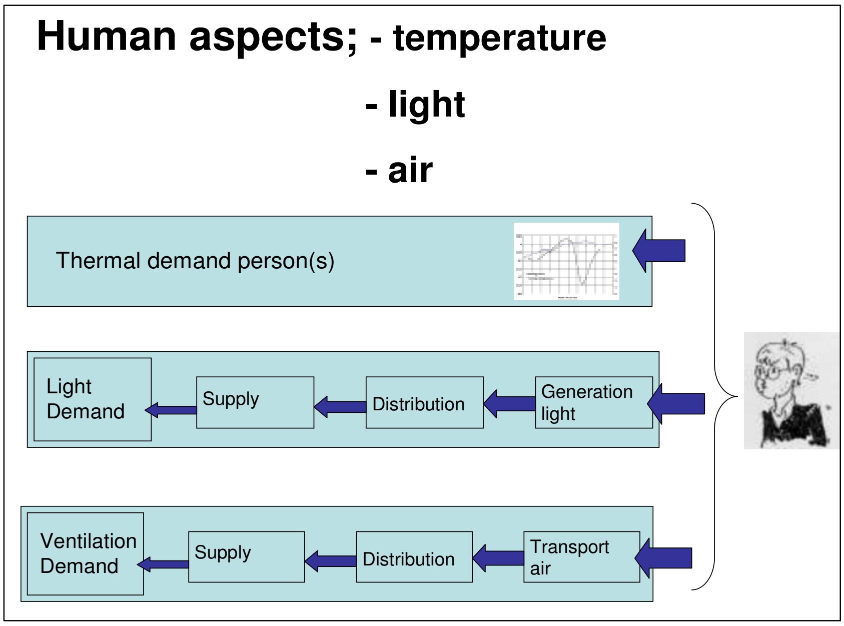

Figure 1 Human demands and needs

Until now the user has not been part of the building comfort system control strategy in offices and the energy consequences of the user behaviour were not accounted for. Integration between end-user and building is the ultimate in the intelligent building concept. "Connecting" the end-user to a building is complex. User-connectivity, the combination of usability and user interface together, is studied and developed further. Information and communication technology connects people and helps them to communicate with the building. New technological development is needed to incorporate the behaviour of occupants of buildings.

The energy supply on a system level should be dominated by trends in demands by the occupants of the buildings (Fig.2).

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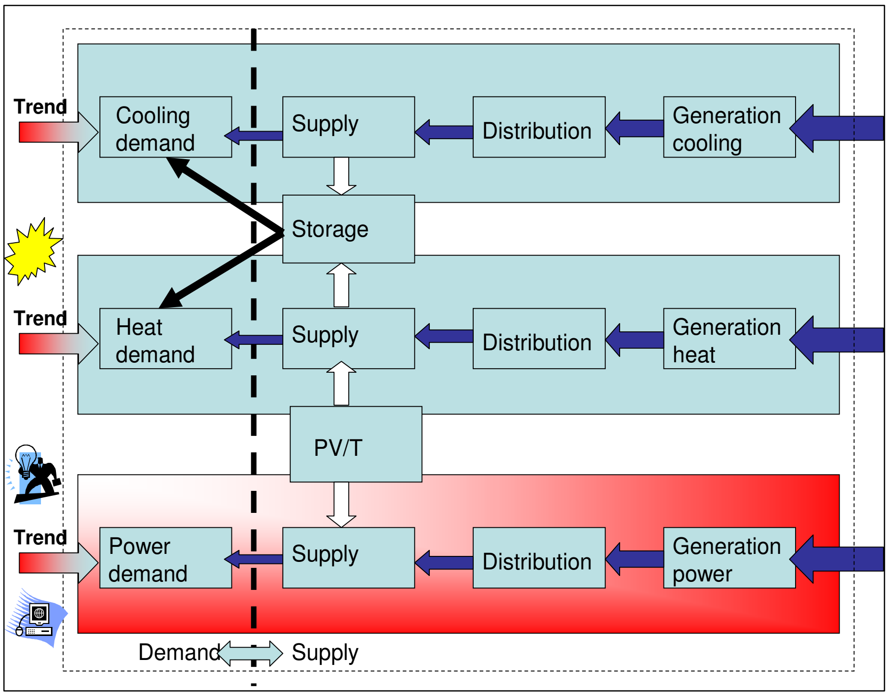

Figure 2 Demands and supply on system level

Such novel control systems should not only improve the energy performance of the building, but should also offer benefits to users (i.e. building operators as well as workers). Comfort management should be linked with improving energy efficiency. Individual comfort management makes it possible to optimize comfort, energy efficiency and costs. This combination would be beneficial for building operators as well as occupants. Therefore in commercial buildings, the inclusion of options for individual comfort management is an important feature to make such systems attractive to end users.

The making of the built environment has become more and more complex. In the conceptual design phase, in order to create conditions to assure a better built environment, the ingenuity of the whole design team existing of different disciplines should be used, not only architecture.

2. Methodology

2.1 Open building principle

Open building developed by N.J. Habraken (Habraken 1961) attempted to integrate industrial building and user participation in housing, but the concept can also used for office buildings. It approached the built environment as a constantly changing product engendered by human activity, with the central features of the environment resulting from decisions made at various levels. During the design process participants and their decisions were structured at several levels of decision-making; the infill-level, the support-level and tissue-level. On each level there has to be made a balance between the performance of supply and demand for the building during the life-cycle.The levels of city structure, urban tissue, support, space and infill were usually distinguished. Open building entailed the idea that the need for change at a lower level such as the dwelling, emerged faster than at upper levels, such as the support. The “thinking in levels” approach of Open building was introduced to improve the design and decision process by structuring them at different levels of abstraction. At each level in the design process different decisions have to be taken. One of those decisions is the application of sustainable energy systems and components. However this is rather complex to integrate in the early stages of building design as many aspects have to be taken into account. During the design process participants and their decisions are structured at several levels of decision-making; the infill-level, the support-level and tissue-level. On each level there has to be made a balance between the performances of supply and demand for the building during the life-cycle. Instead these sustainable energy systems and elements are often added during the final design stages. This results in sub optimal solutions and often leads to complete rejection of proposals to use sustainable energy systems and components at all.

Central idea of Open Building was to respond to the various needs of individual users through the phasing of the design and implementation process. In order to provide prospective occupants with the opportunity to influence their building, the elements decided by the occupants must be easy to change. Thus adaptability is not merely a means for modifying the dwelling during use; it is first and foremost a strategy for enabling the fulfilment of individual wishes without compromising. Thinking in levels is the basic Open Building principle.

To apply the principles of Open Building design to the optimization of the energy infrastructure of a building and the surrounding build environment, a methodology was developed by us. Not only the building to design but also the design process itself became a topic of study. The results of this new approach are called "Duurzaam Flexibele Proces Integration" – sustainable flexible process innovation. This makes it possible to integrate in a flexible way the energy flows connected to heating, cooling, ventilation, lighting and power demand, within a building and between buildings and the built environment. This leads to flexibility of energy exchange between different energy demands and sustainable energy supply on the different levels of abstraction in the built environment.

2.2 Design methodology

Our integral approach encompasses the built environment from initiative to design, construction and real estate management as a seamless whole. This seems to contradict with the subdivision of the construction industry in phases, in which parties operate with opposing interests, resulting in disintegration and waste. The coordination of these independent phases, scales, decision-makings and disciplines are crucial to the creation of a sustainable built environment in which the people concerned feel comfortable.

When attempting to integrate sustainable energy aspects into design decision-making, the process must identify opportunities of sustainable energy. Instead of developing new design methods, this research study attempts to utilize existing architectural design characteristics and decision making for the introduction of sustainable energy – resulting in good building designs. This implies defining a methodology that acts as a bridge between architectural elements, such as shapes and materials on the one hand, and sustainable energy use together with the aspects of indoor climate issues such as overheating and ventilation on the other.

To develop our required model of design support, an existing model from the mechanical engineering domain was extended: Methodical Design. This design model by van den Kroonenberg, it was based on the combination of the German (Kesselring, Hansen, Roth, Rodenacker , Pahl and Beitz) and the Anglo-American design schools (Asimov, Matousek, Krick) (Blessing 1994). This design model was chosen as a basis because; " it is one of the few models that explicitly distinguishes between stages and activities, and the the only model that emphasis the recurrent execution of the process on every level of complexity (Blessing 1993, p.1398)". Especially the horizontal dimension is not strongly represented in other familiar design models and thus tend to be forgotten (Roozenburg and Cross 1991, p. 216); "not so much by its authors but by its users and, above all, its critics, leading to faulty arguments and misinterpretations of the model." This design model was extended into an integral design model by us, by adding an evaluation step.

Our Integral Design process can be described at the conceptual level as a chain of activities which starts with an abstract problem and which results in a solution. The original design process is extended from three to four main phases, in which eight levels of functional hierarchical abstraction, stages can be distinguished. A feature of our extended model of design, Integral Design, is the occurrence of a four-step pattern of activities in each stage, see figure 3.

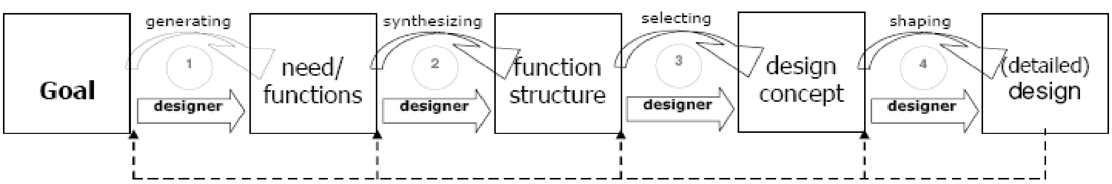

Figure 3 The four-step pattern of Integral Design

In order to survey solutions, engineers classify them according to various features. This classification provides the means for decomposing complex design tasks into problems of manageable size. Decomposition is based on building component functions. This functional decomposition is carried out hierarchically so that the structure is partitioned into sets of functional subsystems. Decomposition is carried out until simple building components remain whose design is a relatively easy task. This like the decomposition which is described in the guidelines 2221 and 2222 of the "Association of German Engineers", VDI (Beitz 1985). It possible to compare this highly abstract approach with the hierarchical abstraction of Open Building which is more commonly known in the building industry, see figure 4.

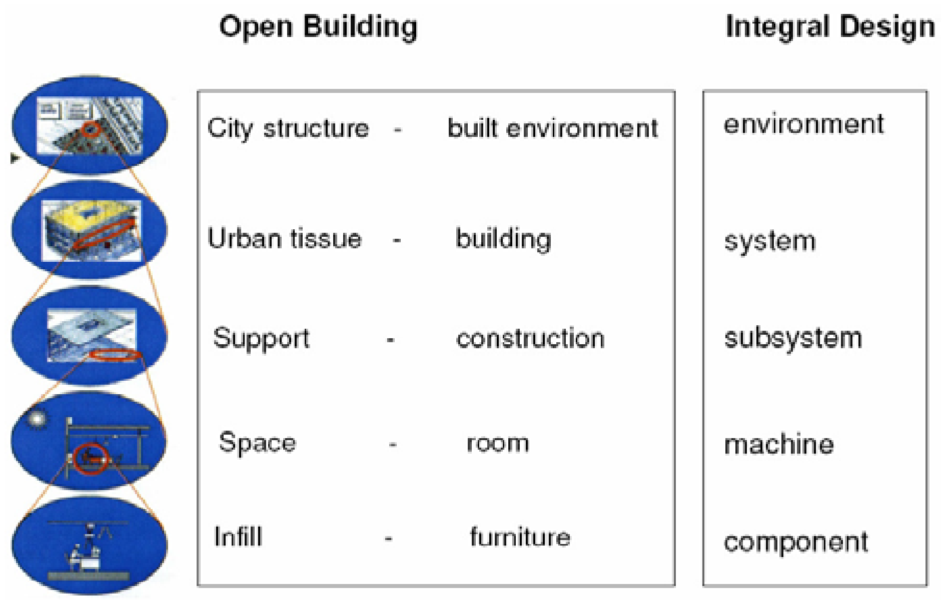

Figure 4 Comparison hierarchical abstraction Open Building and Integral Design approach

2.3 Morphological Overviews

For the synthesize activities of the Integral Design process morphological overviews can be used to generate alternatives in a very transparent and systematic way. General Morphological analysis was developed by Fritz Zwicky (Zwicky&Wilson 1967) as a method for investigating the totality of relationships contained in multi-dimensional, usually non-quantifiable problem complexes (Ritchey 2002). The Morphological overview is a key methodology that can improve the effectiveness of the concept generation phase of the design process (Weber and Condoor 1998). It is this aspect which we focus on in our research.

Based on definition of functions, morphological overviews make it possible to assess client's needs on higher abstraction levels than what a program of requirements (which is often too detailed) provides. The morphological approach has several advantages over less structured methods. We think it may help to discover new configurations, which thus far may not be so evident and could have been overlooked. The morphological chart gives a complete overview of aspect elements or sub-solutions that can be combined together to form a solution. The purpose of the vertical list is to try to establish those essential aspects and functions that must be incorporated in the product, or that the design has to fulfil. These are often expressed in rather abstract terms of product requirements or functions. Also the morphological approach is an excellent way to record information about the solutions for the relevant functions and aspects. It aids in the cognitive process of generating the system-level design solutions (Weber and Condoor 1998). The morphological approach has several advantages over less structured methods, it may help to discover new configurations, which may not be so evident and could have been overlooked. It also has definite advantages for scientific communication and for group work (Ritchey 2002). We think like Ritchey (2002) that the morphological approach has definite advantages for communication and for group work.

2.4 Technology layers

Design takes place in an environment that influences the process and as such it is contextually situated (Drost & Hendriks 2000, de Vries 1994). The context of a model of design is composed of a "world view". One of the major problems in modeling design knowledge is in finding an appropriate set of concepts to refer to the knowledge, or -in more fashionable terms- finding an ontology. Our model consists of 4 worlds (the real world , the symbolic world , the conceptual world and the specification world). These worlds are coupled to specific abstraction levels. The contents of the different abstraction levels are based on the technical vocabularies in use, technology-based layers (Alberts 1993):

1. Information Level: knowledge-oriented, representing the "conceptual world".

This level deals with the experts' knowledge of the systems. One of the essential ideas behind this is that human intelligence has the capacity to search and to redirect search. This information processing capacity is based on prior design knowledge.

2. Process Level: process oriented, representing the "symbolic world".

This level deals with physical variables, parameters and processes. The set of processes collectively determines the functionality of the variables that represent the properties of a device. Modelling at the functional level involves the derivation of an abstract description of a product purely in terms of its functionality. This abstraction reduces the complexity of engineering design to the specification of the product's desired functionality.

3. Component Level: device orientation, representing the "real world".

This level describes the hierarchical decomposition of the model in terms of functional components and is domain dependent. Generic components represent behaviors that are known to be physically realizable. They are generic in the sense that each component stands for a range of alternative realizations. This also implies that the generic components have yet to be given their actual shape.

4. Part Level; parametric orientation, representing the" specification world".

This level describes the actual shape and specific parameters of the parts in the form of which the components exist. Relevant technical or physical limitations manifest themselves in the values of a specific set of parameters belonging to the generic components. These parameters are used to get a rough impression, at the current level of abstraction, of the consequences of certain design choices for the final result.

The technology-based layers can be combined with the abstraction levels from the Integral Design methodology. The method/contents matrix, represents the recursion of the design steps of a design process from high abstraction level to lower abstraction levels and is now combined with the principles of Open Building and the technology-based layers of building services, see fig.5, which shows the relation between the technology layers of building represented in relation to the conceptual world view model.

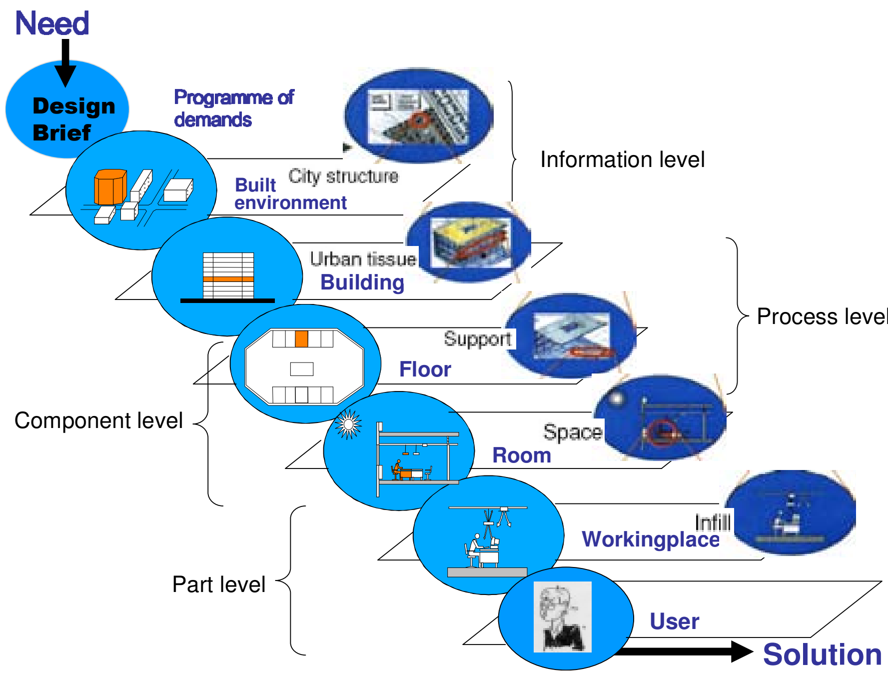

Figure 5 Hierarchical abstraction levels by functional decomposition and the different aspect levels

3. Results

The function-oriented strategy allows various design complexity levels to be separately discussed and, subsequently, generated (sub) solutions to be transparently presented. This way the interaction with the other participants of the design process is aided, and at the same time design process information exchange is structured, see fig. 6. Combining the concept of morphological overviews with hierarchical functional abstraction levels leads to a structure of different sets of morphological overviews for cooling, heating, lighting, power supply and ventilation.

In fig. 5 an example of the different abstraction level morphological overviews are presented. In these overviews the alternative solutions for generation, central distribution, central storage, local distribution, local storage and supply are presented to fulfill the need on the specific abstraction level of built environment, building, floor, room, workplace and person. The overviews are used to generate new possibilities for a flexible energy infrastructure in and between buildings to optimize the combination of decentralized power generation, use of sustainable energy source on building level and traditional centralized energy supply.

The overviews are used to generate new possibilities for a flexible energy infrastructure in and between buildings to optimize the combination of decentralized power generation, use of sustainable energy source on building level and traditional centralized energy supply. The energy flows of heat, cold and electricity have to be optimized together. For this a new design and control strategy based on Integral design and the use of agent technology is developed. The work on these subjects within the project will continue till 2010.

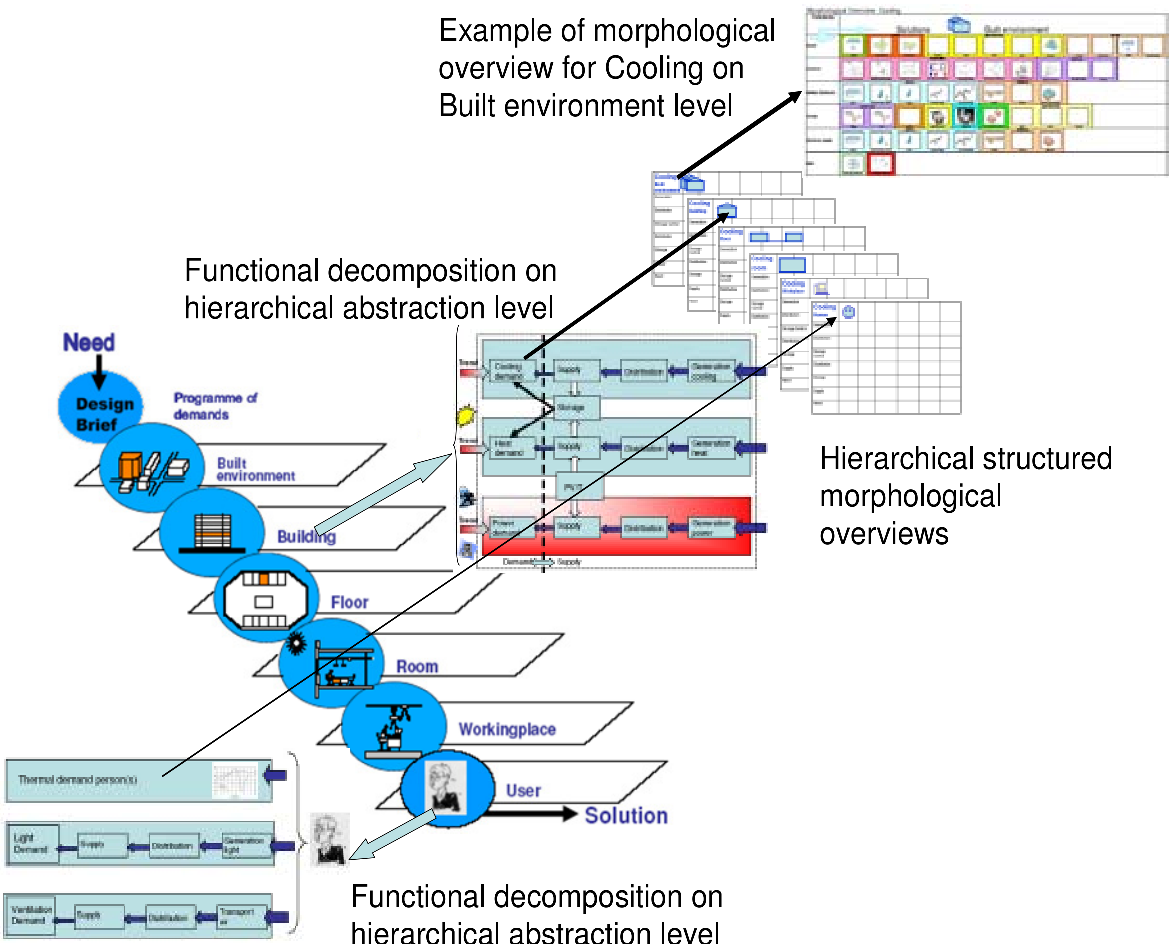

Figure 6 Set of connected morphological overviews about cooling on the different hierarchical abstraction and the infill on the built environment level

4. Conclusion

Taking the principles of Open Building as starting point, a new design methodology is defined for the energy infrastructure within and between buildings. The possibility to combine and exchange different energy flows within the building and between buildings results in an flexible energy infrastructure called Flexergy.

We think that the proposed design methodology is a possible solution to the direct design process support, it will be possible to supply information about sustainable energy applications at a much earlier stage in the design process.

In order to allow a stepwise approach in which each design decision has well defined implications, four different ontological levels are distinguished for designing energetic process: Information level, Process level, Component level and Part level. These levels provide a structured framework for morphological schemes.

Synergy between environment, its sustainable energy sources and the comfort needs of the building's occupants is the ultimate in a sustainable building strategy. The participants work on research for new energy infrastructural concepts to implement and combine the different energy flows on the level of building and built environment. Central in this approach is the abstract approach to the building design process which makes it possible to generate new solutions for a sustainable energy infrastructure to make buildings comfortable .

Acknowledgement

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EMBODIED CARBON ASSESSMENT: A NEW CARBON-RATING SCHEME FOR BUILDINGS

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Summary

Embodied carbon (CO_2) emissions need to be considered alongside other, more readily measured sources of carbon emissions related to the operation and use of buildings, to help establish a full picture of the carbon impacts of building and development. A new embodied carbon assessment scheme, developed by Davis Langdon during 2007, is intended to help construction clients and their professional advisors understand the carbon footprint of their buildings and developments and, if appropriate, to make informed decisions about how to reduce it in a cost-effective way.

This paper identifies key methodological issues associated with the development of a new scheme for assessing the embodied carbon of buildings and construction at an early stage in design development. It comments on the availability of data on the embodied energy and carbon associated with key building materials, products and components, and discusses key data shortcomings and how they may be addressed. It presents and discusses initial results from the new carbon assessment scheme developed by Davis Langdon, which suggest that embodied carbon in buildings is highly significant, potentially representing over 50% of operational carbon emissions and concludes with key questions for research and for the practitioner community in developing a common, shared understanding of embodied carbon assessments for buildings.

1. Introduction

The energy consumed in the production of a building's constituent materials and components is often referred to as 'embodied energy'. Similarly, the carbon (CO_2) emissions associated with this energy – and, additionally, arising from chemical processes involved in the production of materials and components (for example, in the production of cement) – are referred to as 'embodied carbon'. In this paper we use the term 'carbon' as shorthand for carbon dioxide (CO_2). Furthermore, the paper focuses principally on CO_2 and does not generally consider other greenhouse gases (GHGs) nor their CO_2–equivalent impacts.

The assessment of embodied energy in building materials is not new. Over 25 years ago Stein et al (1981) for example, assessed the embodied energy for a range of building materials and components in the USA using an Input/Output approach, and developed models of a range of building 'assemblies' to aid calculation. One of the current paper's authors (Connaughton, 1987) drew attention to the significance of embodied energy in UK construction vis-a-vis the energy used to operate and maintain buildings over their typical life cycles. However, more recent concerns about the impact of greenhouse gases on the global climate and, in particular, the significance of buildings in generating a considerable proportion of the anthropomorphic carbon dioxide in the atmosphere - due mainly to the consumption of fossil fuel for operational purposes (heating, lighting, cooling; and for equipment and appliances) – has brought with it a strong focus on carbon reduction in the building design strategies of government and businesses alike (see, for example, in the UK, Department for Communities and Local Government, 2006). Hand-in-hand with that is a realization of the significance of the embodied carbon in building materials and components to a building's overall carbon 'cost' (ie embodied carbon plus carbon emitted during building operation, hereinafter referred to as 'operational carbon'), especially when regulatory changes are increasingly targeting reductions in this operational carbon but not yet, to the authors' knowledge, focusing on embodied carbon.

Until relatively recently, construction clients and their advisers have had no readily available, accessible means of knowing how significant embodied carbon might be in the buildings they are commissioning/designing. Nor have they had the means of assessing the embodied carbon of a range of commonly used building materials and components, and their alternatives, so as to help reduce the overall carbon impact of buildings. Furthermore, designers have had to cope with frequently inaccurate and inconsistent data on embodied energy from a variety of sources that lack a coherent underlying assessment methodology (Pullen, 2000, for example, identifies a wide range of values for the embodied energy of timber from the literature, and suggests that differences are due to a number of factors, including methodological and estimating practices). In seeking to develop a usable and accessible embodied carbon assessment tool for buildings, the authors have had to address some of these challenges.

This paper reports on the development of the Davis Langdon embodied carbon assessment scheme and, in so doing, sets out to:

- Propose a workable, simplified scheme to assess the embodied carbon in buildings, focusing on the early stages of design and providing a complementary assessment to design cost estimating
- Present some initial results from the scheme in use, and discuss some of their implications
- Identify some key methodological challenges
- Conclude with some important questions for both the academic/research and practitioner communities in developing and adopting such a new scheme.

2. The Davis Langdon embodied carbon assessment scheme

2.1 Origins

As noted above, one of the authors of the current paper has had an interest in embodied energy in construction for some time. In the past 10 years or so Davis Langdon has undertaken ad hoc embodied energy assessments of important building projects, both in the UK (for example, a new headquarters building for Wessex Water in Bath – CABE 2007) as well as a headquarters building for the National Trust in Swindon (Koralek, 2005) and elsewhere (see for example, the report of work carried out in 2002 for the Hong Kong Housing Authority, one of the largest social housing providers in South East Asia - Amato & Humphrey, 2003). However, such opportunities have been relatively rare and, in the main, restricted to those clients and/or designers with a particularly strong interest in improving all aspects of building environmental performance.

More recently, however, the authors have witnessed a growing interest from both clients and designers in understanding the embodied carbon impact of buildings, and its relative significance over the building life cycle. This may be motivated by an increasing awareness of the importance of embodied impacts more generally (see for example, CNW Marketing Research [2006], examining the embodied and operational carbon emissions of a wide range of motor cars available in the USA. This analysis received some prominence in the UK via publication in the popular *What Car?* Magazine), or of the potential of Life Cycle Assessment in construction to provide a through-life picture of the environmental impacts of building products/components (for example, see Rankine at at, 2006). Regardless, the authors detected sufficient interest to prompt them to revisit their earlier work on embodied energy and consider developing a more formal scheme for estimating embodied carbon.

2.2 Key principles and estimation methods

2.2.1 Key principles

The authors were conscious of the complexities involved in undertaking assessments of embodied carbon based on Life Cycle Assessment methodology, compounded in the construction sphere by a lack of reliable, consistent and readily available data (this is discussed further in section 2.2.2 below). In particular, they wanted a framework that could provide estimates of embodied carbon at an early stage in design development (when the broad parameters of the proposed building project are known, together with some indications of material choices – for example, steel structural frame, aluminium-framed glazed wall cladding – but without full design and specification details). An analogy may be made here with the early design estimates typically undertaken by construction cost estimators/quantity surveyors, which can be used to guide subsequent design development (for an overview of cost estimating in construction, see Kirkham, 2007). Such a framework would not, of course, produce precise results, but the authors felt it should:

- Be transparent and open to enquiry and challenge
- Be robust, providing sufficiently reliable results to help guide design development, particularly as to the potential for *reduction/mitigation* of embodied carbon impacts through the selection of alternative design approaches/specifications
- Relate to the potentially more significant materials/products in terms of embodied carbon impact – our working hypothesis was that, in general, these tended to be materials/products with a *significantly high mass* relative to the overall mass of the building.

Of course, our criteria for robustness and significance can only really be tested following a thorough analysis, so the development of the scheme is somewhat iterative, with confirmation (or revision) of working assumptions following examination of initial results. Experience of the scheme in use, together with early results (discussed further in section 3 below) suggest that these criteria were justified.

2.2.2 Estimating methods and data sources

The core assessment methodology is based on Life Cycle Assessment (LCA). LCA was originally developed for the assessment of energy consumption associated with food production (Franklin Associates, 1991). It is a relatively recent development and an international standard for LCA has only been available since 1997 (International Standards Organisation, 1997). LCA aims to be an objective process that assesses the energy, materials and waste impacts of products or activities at each stage of the life cycle – from 'cradle to grave'. While there is a growing literature on LCA – and its appreciateness for different forms of environmental assessment – there are, in practice, a variety of interpretations of how the methodology in best applied, particularly in respect of the boundary conditions (see for example, Hunkler and Rebitzer, 2005) and data sources.

A critique of LCA is beyond the scope of the current paper; however, it may be noted here that while one of the more commonly used boundary conditions in LCA is 'cradle to grave' (which seeks to assess impacts to the end of the material/product lifetime, and can sometimes – though not always – include disposal and end-of-life impacts), another boundary condition more commonly used in construction is 'cradle to site' (which includes, in this case, carbon emissions from the extraction of raw materials to the delivery and fixing in place of the product at its point of use). **The 'cradle to site' boundary condition was adopted for the development of the Davis Langdon embodied carbon assessment scheme.**

The approach taken to embodied carbon data was, in so far as possible, to rely on secondary sources. The authors were aware of a growing body of literature on embodied energy (and carbon) and, primarily for practical reasons, did not wish to replicate research already undertaken. A number of publicly available embodied energy/carbon inventories were identified (for example, International Aluminium Institute, 2003, and European Copper Institute, 2005, Athena Institute, Various). However, an initial appraisal suggested that the Inventory of Carbon and Energy (ICE) produced by Bath University Department of Mechanical Engineering (Hammond and Jones, 2006) provided a potentially consistent and usable dataset for construction. The authors decided to adopt this as the core energy/carbon database for the Davis Langdon embodied carbon assessment scheme. The Bath ICE offered a number of important features:

- A 'cradle to site' boundary condition – although this is not universally maintained throughout the ICE database
- A degree of transparency in the sources used, enabling checking and comparison of apparently inconsistent and/or erroneous data; and a breakdown (where appropriate) of energy/carbon associated with primary materials, recycled content and feedstock energy (the latter can be important as feedstock input – oil, for example, is used as a material rather than fuel input to some manufactured products – may have lower carbon emissions than fuel inputs)
- Relevance to the UK construction sector (and growing recognition and adoption by practitioners and others in this sector).

Other sources were used to supplement this data, principally:

- The author's own estimates, using an LCA methodology with a 'cradle to site' boundary
- The Ecoinvent 2 database provided with the SimaPro LCA analysis package (for more information on Ecoinvent see links to http://www.ecoinvent.org/en/we-about-us/bodies-of-the-ecoinvent-centre/ for more information on SemaPro see links to http://www.pre.nl/simapro/)

2.3 The scheme in outline

2.3.1 Overview

Davis Langdon provides construction cost management (and quantity surveying) services on a great variety of construction projects worldwide. Because of this the firm has developed a good understanding (backed by comprehensive data) on material inputs to construction and buildings of all types. Building cost estimating models developed by the firm for early stage design cost estimating embody this understanding, and contain routines that generate key quantity data on the basis of simple building parameters (and based on historic records of similar building types). While the precise details are commercially confidential, it is sufficient for the purposes of this paper to note that similar routines are used to generate material quantities for the purposes of estimating embodied carbon.

2.3.2 Using existing cost model data and formats

For costing purposes, and in line with established convention in the UK and similar markets, such quantities are usually measured in terms of surface areas or a count derived from the extent of product used, or alternatively based on building floor area. They are typically aggregated into composite work items (for example, an upper floor quantity will be an amalgam of floor deck, concrete and applied finishes). To convert this data into data that can be used to assess embodied carbon, a degree of manipulation is therefore necessary to:

- Disaggregate the individual material inputs from composite work items (for example, cement, aggregate, steel reinforcement, and timber for formwork from a square metre of 150mm thick reinforced concrete upper floor slab)
- Express them in terms of material mass (usually kg) and, if appropriate
- Sum the embodied carbon amounts and re-combine them to express an overall carbon estimate for the composite item as CO_2 per element/floor area.

Figure 1 below outlines a simplified process of disaggregation/conversion, resulting in an embodied carbon estimate expressed per square metre of curtain wall area.

This form of analysis and presentation has a number of benefits:

- It utilizes existing data and early design cost estimating models with which clients and practitioners (including designers) are already familiar

- It is directly comparable with typically-used construction cost breakdowns – this is particularly important when seeking to reduce/mitigate carbon impact, when both clients and designers are very interested in consequential cost implications
- It is intuitive and easy to understand.

An important feature of the Davis Langdon scheme is its focus on composite construction items, as described above, rather than individual material inputs . This approach has the benefits of being compatible with design and estimating practice, and helps to highlight specific items of work where mitigation might be practical.

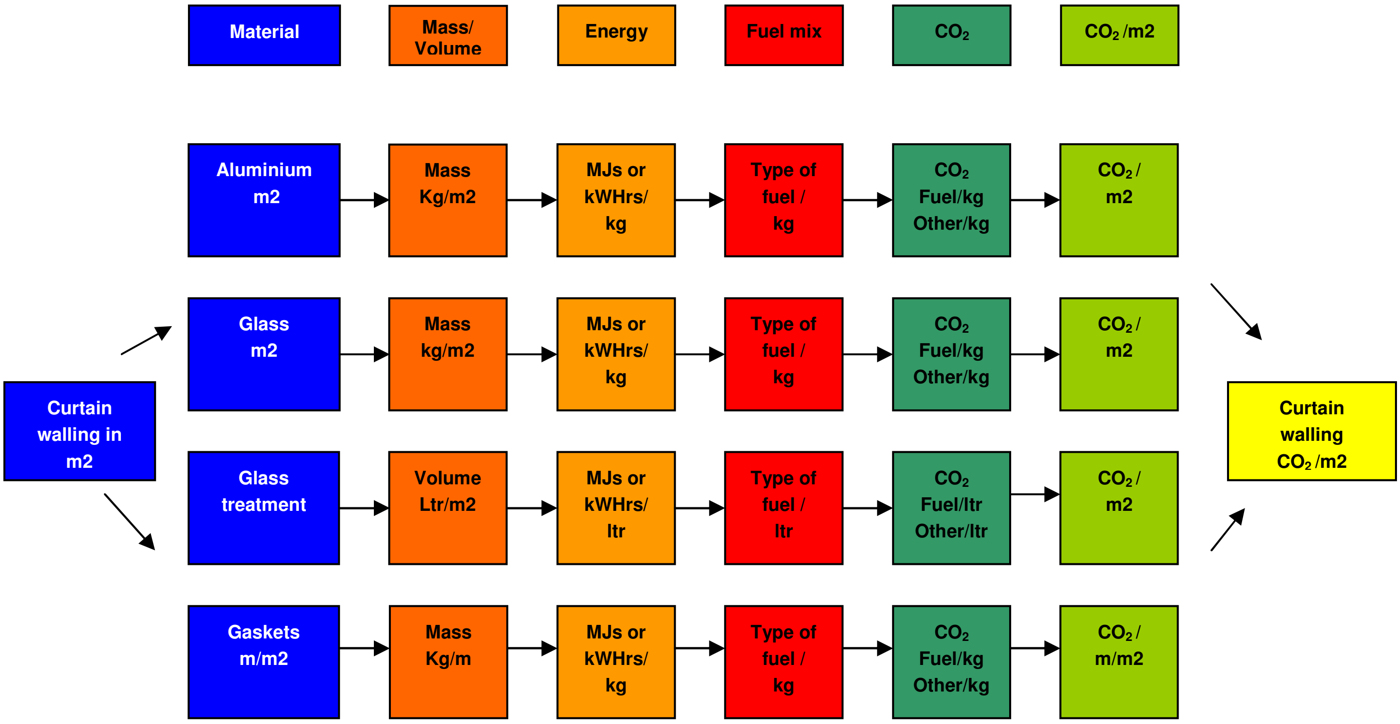

Figure 1 Disaggregating composite cost items into material masses for embodied carbon assessment

The scheme allows for changes in the fuel mix for energy inputs to individual materials – this is especially important for imported materials/products, where the electricity fuel mix can be quite different in the country of origin compared to the country of use (see further discussions under section 4 below). It also allows CO_2 emissions other than from energy inputs (shown as 'other' in Figure 1) to be included.

3. Initial results and case studies

3.1 Overall findings

The authors have undertaken assessments of the embodied carbon of two sample buildings – a distribution warehouse and a low-energy office building – using the methodology, data and the new scheme outlined in section 2 above.

Initial findings indicate that embodied carbon equates to about 23 years of operational carbon for the distribution warehouse building (ie the CO_2 emissions associated with the use of the building, fuel use for heating, lighting and cooling, equipment and appliances) and some 30 years of life for the low-energy office building. See Figure 2 below. Operational carbon was assessed on the basis of benchmark data taken from CIBSE, 2004. Recall also that the method of assessing embodied carbon does not (yet) account for all material inputs to the building, only the more significant ones in terms of mass. The authors' current best assessment is that the Davis Langdon scheme (as outlined) currently accounts for in the region of 85-90% of embodied carbon impacts.

These initial findings appear significant (and in line with recent, albeit partly anecdotal, emerging evidence from the UK – see Lane, 2007). For the distribution warehouse (with a floor area [net lettable] of some 46,000 square meters), there are relatively high lighting and heating requirements, as this particular building is operated on a 24 hour basis. For more traditional warehouse buildings with, say 12 hour operation, embodied carbon would represent a far more significant proportion of total carbon emissions over its design lifetime (assumed here to be 30 years) Whether of course the building as constructed will remain without major alteration for a full 30 years is an interesting point. Even casual observation of the distribution sector would suggest that this is highly unlikely, with a range of highly dynamic drivers (fuel prices, increasingly stringent transport emissions legislation, spatial planning requirements and changing demographic and consumer patterns) all exerting a strong influence on the nature and extent of the distribution infrastructure required.

For the office building, the authors selected a relatively low-energy naturally-ventilated office building of some 11,200 square metres net lettable area. The initial assessment of embodied carbon, at some 12,800 tonnes for the building is just over 1.1 tonnes per square metre of floor area. This is equivalent to about 30 years of operational carbon emissions, or about one third of total lifetime carbon emissions, assuming a design life of 60 years. Once more, it is highly unlikely that contemporary commercial buildings will remain for a full 60 years without major alternation and/or demolition and re-construction, and so the estimated proportion of embodied to operational in this case may be somewhat conservative. Of course, for an analysis of a fully air conditioned office building, the proportion of embodied carbon to total lifetime carbon emissions would be less than this, although the embodied carbon of the additional plant and distribution pipework/ductwork would need to be taken into account.

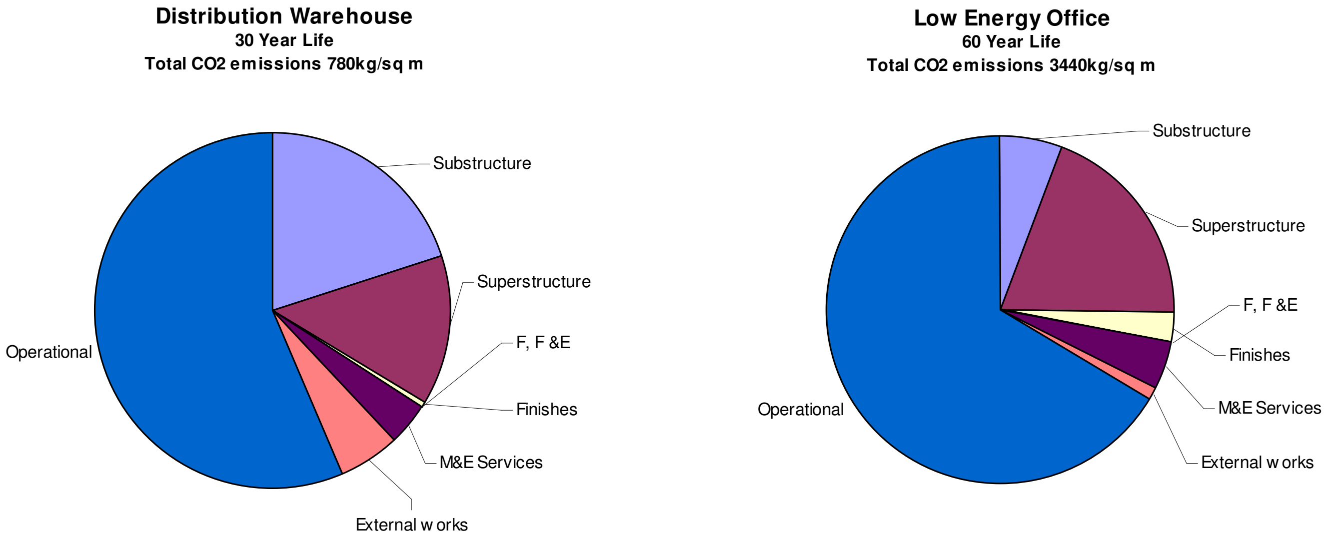

Figure 2. Proportion of embodied carbon to operational carbon for two sample building types.

3.2 Detailed analysis and potential for mitigation of carbon impact: office building

From the breakdown of embodied carbon for the office building (more detail is provided in Figure 3 below) it would appear that the more significant opportunities for carbon mitigation are likely to lie in the following elements:

- Substructure
- Structural frame and upper floors
- Windows and external doors, and
- Environmental (M&E) services

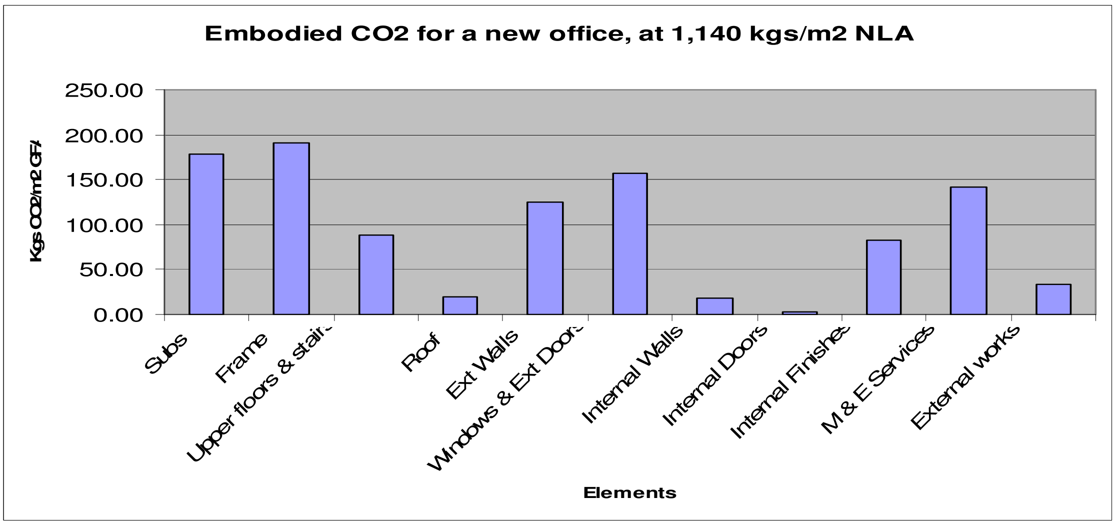

Figure 3: Elemental breakdown of embodied carbon for sample office building

Closer examination of the likely materials specifications for these elements suggests that the following material substitutions may provide significant carbon mitigation potential:

- Masonry and aluminium-clad timber framed windows instead of aluminium-framed curtain walling, and
- Ground Granulated Blast Furnace Slag (GGBS) instead of 40% Ordinary Portland Cement in the concrete mix for the substructure (ground floor slab), structural frame and upper floors and external works elements.

These relatively simple material substitutions realize savings of some 220 tonnes of CO_2, equivalent to over 20% of the building's total embodied carbon (see Figure 4). Further, this is equivalent to about 5 years of operational carbon for this building.

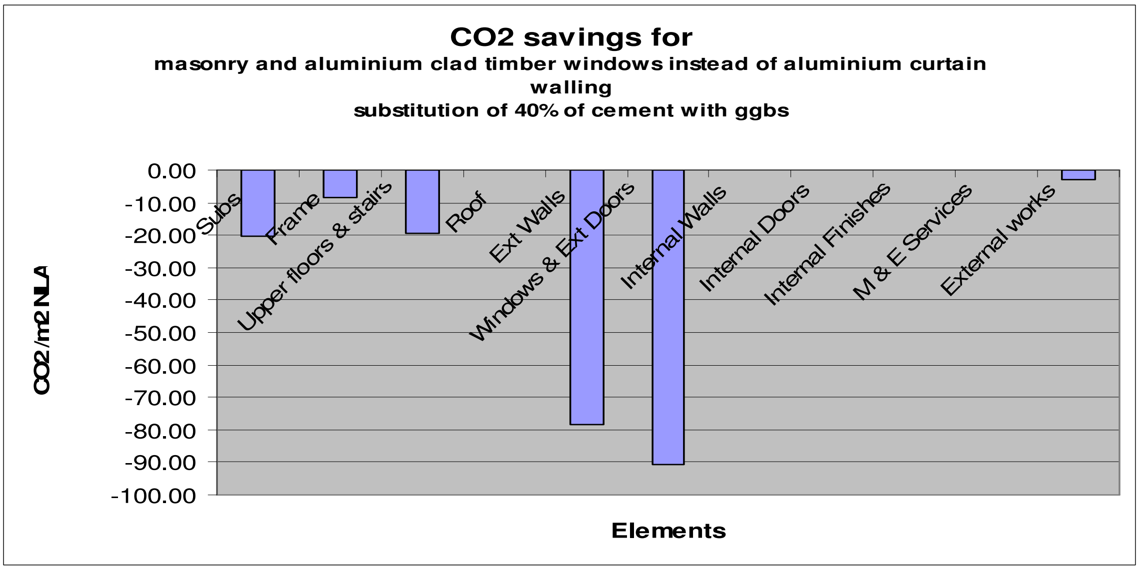

Figure 4: Embodied CO_2 savings resulting from key material substitutions: sample office building

3.3 Further mitigation potential

Further material substitutions are, of course, possible. Our initial analysis suggests that mitigation needs to focus on the energy/carbon intensive elements/work items to have any practical affect. For the distribution warehouse and office buildings examined, the following offer considerable potential (broadly in order of reducing significance):

- Cement substitutes. The most popular is GGBS, which is a by-product of steel manufacture. In the UK, most of this is utilized but that is not always the case in other countries. China, for example, has a large steel production industry but does not fully utilize GGBS. Pulverised Fuel Ash (PFA) can also be used but with a lower level of substitution is pemissible, and it affects curing times and appearance. Views vary on the appropriateness of PFA as a cement substitute; however, supply is plentiful in many countries as it is a by-product of coal-fired power generation. In the UK about 7M tonnes are produced each year.
- Re-use of recovered materials, such as steel beams or bricks.
- Recycled materials, or materials with a high recycled content, especially metals. Using recycled materials or recycled content does not always save money, but it nearly always saves energy/carbon (see, for example, Amato and Raven, 2000)
- Greater use or organic material such as timber, bamboo, hemp etc. However, like bio-fuels, problems may emerge if production of some organic material is scaled up too much, since land transferred for the growth of organic construction materials may be lost from other uses, such as food production or nature reserves.

While our analysis for the purpose of this paper focuses on material substitution, it is noted that carbon reducing potential may also be exploited via other design approaches.

3.4 The particular challenge of building/environmental services elements

In section 2.2.2 above, we provided an overview of the data inventory used for the Davis Langdon carbon assessment scheme. In general this – and other similar inventories that are publicly available – concentrate in the main on basic materials or part-processed construction items/products (such as timber particle board) only. Composite and/or highly manufactured items are more difficult to assess, and there is very limited data available for highly engineered components such as those found in building environmental services elements.

While it is possible to assess the embodied carbon of some of these components from first principles based on LCA methodology and data on basic materials inputs, for sophisticated plant and controls items the calculation process is lengthy and laborious. The authors are currently investigating a number of simplified approaches. One, for example, is based on regression analysis of key items of mechanical and electrical plant to discover the relationship between key output criteria (such as kW for a boiler) and weight This might enable reasonable predictions of plant weight to be estimated, from which broad 'first order estimates of embodied carbon could be calculated.

4. Some methodological challenges

The methodological issues associated with LCA in general and the assessment of embodied energy/carbon in construction in particular are well covered in the literature. The particular challenges faced by the authors in developing a simplified scheme for early design stage estimation of embodied carbon can be characterized principally as follows:

- The estimation of energy/carbon for manufacturing and fabrication
- The problem of international data
- Unknown and ambiguous boundary conditions.

For materials/components having little or no published data on embodied energy/carbon, we initially approached the larger manufacturers (such as those producing boilers and chillers) to see what data they could let us have. In general little useful data was forthcoming, as the supply involved chains were often very long and complex, involving overseas sourcing of key components. We are currently investigating whether smaller companies specializing in key manufacturing activities (such as casting) might provide more useful data on their energy/carbon intensity per unit/mass of output. Initial findings suggest that this may be a more useful approach to help develop initial estimates for composite and highly manufactured products.

The basic manufacturing processes for construction materials, requiring heat and other energy, tend to change little from one country to another in the developed world. However, the fuel mix for electricity used for manufacturing varies considerably between countries. The UK, for example, emits relatively high kgCO2/kWhr for mains electricity (as only about 3% of electricity generation is from renewable source and a good deal is from fossil fuel including coal). Norway, by contrast, generates over 90% from renewable sources, mainly hydro; France relies heavily on nuclear generation.

We noted in section 2.2.2 that we adopted a 'cradle to site' boundary in the development of the Davis Landon scheme. The available data tends to adopt a either a 'cradle to factory gate' or a 'cradle to site' basis, and in general we have not found the difference between them to be great. However, for some key construction materials there are significant differences in their embodied energy/carbon values depending on assumptions about boundary conditions. These materials include:

- Steel – a key consideration is the extent to which it may come a recycled source or from primary materials. For a discussion see Amato et al, 1996.
- Concrete – again, a key consideration is the extent to which concrete can be recycled (as agrgregate) and the re-carbonation of cement that can occur in the crushing/recycling process or at the end-of-life. For a discussion, see Clear & De Saulles. 2007,
- Organic materials, such as timber, especially end-of-life assumptions – a key issue is the release of CO_2 (and Methane) from decomposing organic material sent to landfill.

The authors do not have ready answers to these challenges. From the perspective of practitioners and, through the medium of this paper, they would like to appeal to the LCA community and those involved in assessing the embodied carbon of construction to develop workable protocols to address them.

4. Conclusions and recommendations for further work

Initial results from the Davis Langdon embodied carbon assessment scheme suggest that embodied carbon in buildings is highly significant – potentially representing over 50% of operational carbon emissions, and perhaps more if embodied energy in through-life repair and refurbishment is taken into account. With legislation in many countries now focusing on reducing operational carbon, it is likely that the significance of embodied carbon will increase in future. While some significant methodological problems remain and pose a challenge to those wishing to develop consistency and comparability in embodied carbon assessment, the authors believe that these can be resolved by a collaborative effort on behalf of the LCA community and those involved in embodied carbon assessments in construction.

The authors believe that the focus of policy making in the arena of carbon reduction in building and construction needs to shift more towards the life cycle carbon emissions associated with buildings, rather than only operational emissions. This requires careful consideration of embodied carbon and, in particular, the development of methods and tools for the estimation and mitigation of embodied carbon early in the building design stage. It also requires the development of a life cycle carbon index or rating scheme for buildings that, in time, would allow buildings of a similar function and performance to be benchmarked on the basis of embodied carbon as well as capital cost.

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The $LCCO_2$ REDUCTION EFFECT AND ECONOMICAL EVALUATION OF THE REINFORCED CONCRETE STRUCTURE USING HIGH-STRENGTH CONCRETE

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Summary

Recently, the construction of super tall buildings utilized by high strength-concrete in the whole world is tending to be on the rise. The application of high-strength concrete in buildings results in the excellent cut-down effect in construction materials due to section reduction and long-life in view of durability. Therefore, in order to investigate the $LCCO_2$ reduction effect and economical evaluation for the reinforced concrete(RC) structures with high-strength concrete, comparisons of $LCCO_2$ in life cycle of building structures between high-strength concrete and normal-strength concrete have been performed.

As a result, it is concluded that RC structures with high-strength concrete showed the $LCCO_2$ reduction effect by 4.12% in construction step and by 1.12% in whole progress of 60 years, compared to RC structures with normal-strength concrete and had also the economical benefits of 2,760 thousand dollars during 60 year-life cycle.

1. Introduction

With serious environmental problems like global warming, resources depletion and pollution, there have been great attention to international conventions for environment conversion, and the conventions are increasingly asking the world for compulsory observance. The existing policies of many countries, which were centered on their development, are consequently under the situation of prompt changes into environment-friendly ones. According to the report of Environmental Protection Agency (EPA), the energy consumption and the carbon dioxide emission of the buildings in the United States are 70% and 38% of the entire energy consumption and the entire carbon dioxide emission of the country. That means the field of construction can be called an anti-environment industry featuring mass consumption and disposal, so there are demands for technology development to be an environment-friendly field: Architectural production activities thus should be changed to a new paradigm centered on sustainable development for the purpose of reducing environmental load and improving residential environment functions through the life cycle of buildings ranging from design, construction work and maintenance to demolition, rejecting fragmentary and anti-environmental development policies. Under the system of WTO, international organizations such as UN, OECD and ISO have made positive research into techniques of architectural production with the subjects of prevention of global warming by CO_2 reduction, environmentally sound and sustainable development and life cycle assessment (LCA) and have set up compulsory regulations including goals and practice terms of environmental load reduction(Damtoft, J.S. 2007, Sjostrom, C. 2001).
In addition, super tall buildings have been increasingly constructed since the early 2000s because of the intensive use of land for economical efficiency and developed construction techniques, and much attention has recently been given to environmentally sound and sustainable green buildings which can conserve the global environment and coexist with the ecosystem. Those high buildings are advantageous for supplying broad greens and open space, reducing the building-to-land ratio, and yet have weak points from the point of sustainability such as lack of social contact and ground connection, and difficulty of natural ventilation indoor. Consequently, there have been demands for research into sustainability assessment of super tall buildings for environment-friendly construction and city development which considers our environment, being harmonious with surroundings, under the principle of Environmentally Sound and Sustainable Development (ESSD), which is now firmly established as an international paradigm(Urushizaki, N. 2003).
As a part of the environmental performance evaluation for super tall buildings, this study examined the energy and life cycle CO_2 ($LCCO_2$) by the application of high-strength concrete used in tall buildings. Using SUSB-LCA ver.1.0, an environmental load assessment program developed by the researchers of this study, the previous design of a tall building (30-storied) and the re-design by applying high-strength concrete were compared and reviewed, and then based on the comparison, the effects of $LCCO_2$ reduction and economical benefits were evaluated.

2. Environmental Load Assessment Program for Buildings (SUSB-LCA ver. 1.0)

2.1 Overview

SUSB-LCA ver. 1.0 (Sustainable Building Life Cycle Assessment ver. 1.0) is a program to calculate LCE (Life Cycle Energy), $LCCO_2$ (Life Cycle CO_2) and LCC (Life Cycle Cost) through a building life cycle in order to evaluate the environmental performance of a building, so that it allows comprehensive and quantitative assessment of the effect of $LCCO_2$ reduction. In addition, it is able to compare LCE, $LCCO_2$, LCC of buildings applied with environment-friendly techniques with those of existing non-applied buildings and to compare the effects of LCE, $LCCO_2$, LCC reduction after the application of eco techniques. The major functions of the program include calculation of LCE, $LCCO_2$, LCC through a building life cycle and comparison of environmental load values according to the application of eco construction techniques, and specifically, LCE, $LCCO_2$, LCC can be calculated by entering material volumes used for the construction of a building to be assessed, energy consumption during its operation and waste quantities at its demolition.

2.2 Assessment Method

SUSB-LCA ver. 1.0 assessed the environment load of a structure through its life cycle classified into construction, use/maintenance and removal/demolition: The stage of construction included construction material production, construction material transportation and construction work of a site, and inter-industry relations analyses were carried out to measure CO_2 released during the construction material production; The stage of use/maintenance was divided into use of a building and its maintenance stages, and it was analyzed by considering the assessment period and the life of the building, based on the annual energy consumption; And, the stage of removal/disposal was divided into removal of a structure and disposal of the removed wastes. Figure 1 is the overview of environmental load assessment for buildings, which was conducted by SUSB-LCA ver. 1.0(Shin, S.W. 2007).

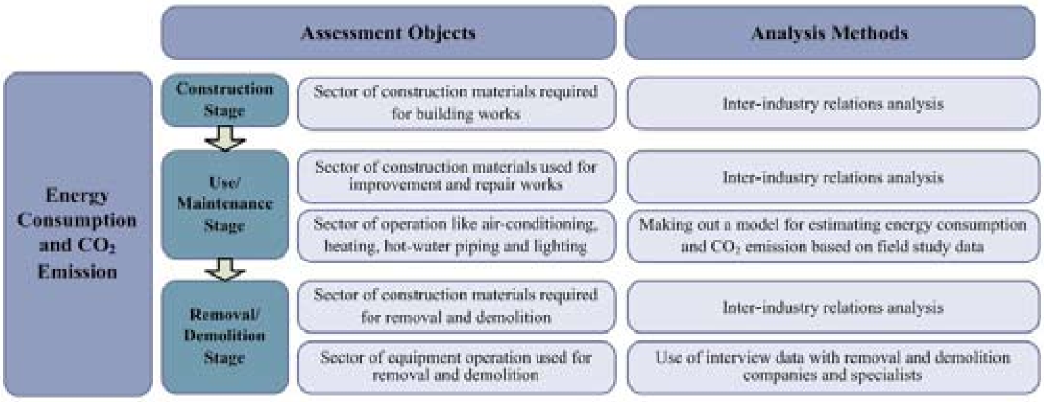

Figure 1 Environmental Load Assessment of SUSB-LCA ver.1.0

2.3 Construction Stage

The construction stage was divided into 3 sub-stages, construction material production, transportation and construction work. The production stage ranged from the time when raw materials are gathered to produce building materials to be used in the construction work stage to the time when producing building materials; The transportation stage meant the time during which produced building materials of various kinds are transported to construction sites; And, the construction work stage ranged from the starting point of construction of a first building to the completing point of construction. The construction stage was also divided into 3 kinds of works, construction work, public work and facility work, and the energy consumption and CO_2 emission were found out per work kind: The construction work included sub-works of 17 types including temporary, pile, reinforced concrete, masonry, waterproofing, tile, stone and steel works; The public work was composed of 3 types of sub-works, retaining wall and waterproof, pile, and appurtenant public works; And, the facility work included 17 sub-works including facility, piping of machine rooms and gas piping works.

The energy consumption and CO_2 emission in the stage of construction material production were calculated by applying a unit of a construction material, which was drawn by inter-industry relations analyses, to the material volume to be used for buildings. SUSB-LCA ver. 1.0 showed greater ability of data update, compared to other environment assessment programs for buildings[3], thereby allowing user's convenient update and modification of inter-industry relation analyses which were conducted in the construction material production of the construction. In addition, users were able to add or remove wanted types of construction, public and facility works and are able to select easily construction materials used in existing or newly added works to calculate their energy consumption and CO_2 emission.

2.4 Use and Maintenance Stage

In the stage of use, energy sources used for air-conditioning, lighting, cooking and so on were classified into electric, heating and gas energy when evaluating. To be specific, the heating energy was divided into district, central and individual heating in terms of heating method and into LPT, heavy oil, light oil, kerosene, and so on by heating source types, so that the emission of CO_2 was calculated by finding the use amount of the sources and inputting it to the program. SUSB-LCA ver. 1.0 presently sets up the heating type in the case of district heating as follows: LPG (65%), heavy oil (25%), incineration heat (9%) and light oil (1%). And, the ratio can be configured by users.

The energy consumption and CO_2 emission in the maintenance stage can be calculated, based on the life of a structure, by using data on repaired and replaced volumes of building materials owing to their wear-out, damage and destruction and by using breakdowns of oil and electric power used for repair and replacement works. For user's convenience, SUSB-LCA ver. 1.0 sets up the estimation basis of the energy consumption and CO_2 emission used in the maintenance stage as $6.24MJ/m^2$/year and $0.59kg\text{-}CO_2/m^2$/year, respectively. The energy consumption and CO_2 emission can be also estimated, as said above, with consumed materials, oil and electricity.

2.5 Removal and Disposal Stage

The stage of removal and disposal included removal and demolition of buildings ending their lives and transportation to handle building wastes, which means the stage ranges to the transportation of wastes generated from the removal of buildings to places for recycling or filling-up, and the recycling of building wastes was left for future consideration. The objects of analyses were materials and equipment used for the removal, and vehicles, oil and electric power required for the transportation of wastes. The stage of disposal was divided into 2 cases, loading and uploading, and the energy consumption of vehicle's returning to a waste generating place from a disposal area was assumed to be the half of the energy consumption of the loading case.

Table 1 The Classification of Environmental Load Assessment of SUSB-LCA ver. 1.0

Stage	Classification	Sub-Classification
1. Construction	1) Construction material production	① Construction work ② Public work ③ Facility work
	2) Construction material transportation	① Transportation
	3) Construction work of a site	① Construction site ② Public work ③ Gardening ④ Power consumption
2. Use/Maintenance	1) Use of a Building	① Power consumption ② Heating energy ③ City gas consumption
	2) Maintenance	① Improvement and repair stage
3. Removal/Disposal	1) Removal	① Removal
	2) Disposal	① Loading ② Returning

(1) *The data input screen of the operation stage*

(2) *The analysis result screen ($LCCO_2$)*

Figure 2 The Data Input Screen of the Operation Stage & The Screen of Analysis Results

3. Assessment

3.1 The Overview of a Building Assessed

The building assessed was an apartment with 35 stories above ground and 3 stories below, with the total area of 14,424 ㎡, of which construction was complete in May 2004. It was a reinforced concrete structure and had a district heating system. The breakdowns showing construction materials used in the construction stage of the building and the actual energy consumption for the last year were examined to estimate $LCCO_2$. Table 2 shows the overview of the building.

Table 2 The Overview of the Building Assessed

Building Overview	· Apartment with 35-story below ground and 3-story below · RC Structure · Total Area: 14,424m^2 · Building-to-Land Ratio: 59.22%
Assessment Conditions	· Assessment Period: 60 years · Service Life: Existing Building (40 years) Environment-friendly building applied with high-strength concrete (60 years) · Heating: District Heating

3.2 Application of High-Strength Concrete

3.2.1 Overview

The building, as the object of this study, was a residential and commercial complex with 35 stories above ground and 3 stories below of RC structure, and there were total 13 buildings from A to M. Among them, the building I was selected to be applied with reinforced concrete, and the height of the building was 104.8m and that of a story was 2.9m. To compare and review the volume of concrete and reinforcing bars, only vertical structural members (Column, Wall, Core Wall, Wall Column) were considered. The compressive strength of the concrete of the vertical structural members was divided into 4 types depending on the stories, as shown in Table 3.

Table 3 Re-Design of High-Strength Concrete

	Previous Design	Re-Design of High-Strength Concrete
27～TOP	24MPa	40MPa
20～26 Stories	27MPa	40MPa
10～19 Stories	30MPa	40MPa
Basement～9 Stories	35MPa	40MPa

3.2.2 Reduction of Required Materials by the Application of High-Strength Concrete

Applying high-strength concrete of 40MPa to the stories with the compressive strength of 4 types (24, 27, 30, 35MPa), structural analyses were carried out. As a result of the analyses, the reduction ratio of concrete and reinforcing bar of the vertical members was 8.8% and 30.3%. In case converting the percentage to that of the entire concrete and reinforcing bar used for constructing the building assessed (Building I), it became 5.7% and 19.7%. The volume of concrete and reinforcing bars for reinforced concrete works of the construction work was thus reduced according to the reduction rate calculated in such a way. The reason of material cut-down is thought that the section of vertical members was decreased due to the use of high-strength concrete. In particular, the reduction rate of reinforcing bar was higher than that of concrete. On the other hand, the use of cement was increased in the case of high-strength concrete application, thereby emitting much more CO_2, compared to the case of non-high strength concrete. There have been several proposals to solve such a problem: for example, partial replacement of industrial wastes like blast furnace slag. This study thus substituted blast furnace slag for 20% of the entire cement.

And the compressive strength of this chapter, 40MPa, is the lowest limit of the compressive strengths ensuring at least 60 years of a building life in durability assessment tests for neutralization.

Table 4 The Reduction of Volume of Concrete and Reinforcing Bars by Applying High-Strength Concrete (40MPa)

		Previous Design	Design of High-Strength Con'c Application	Reduction Rate (%)
Vertical Members	Concrete(㎥)	11377.30	10374.10	8.8 ↓
	Steel (ton)	545.33	379.94	30.3 ↓
Total Members Horizontal + Vertical	Concrete(㎥)	17596.06	16589.57	5.7% ↓
	Steel (ton)	1667.94	1339.44	19.7% ↓

3.3 Results of $LCCO_2$ Assessment

Based on the breakdowns of building materials used in the construction stage of the building assessed and actual energy consumption for a year, the emission of CO_2 through a life cycle of the building including construction, use and maintenance, and removal and disposal stages, on the assumption that the life of the building is 40 years, was calculated. Then, comparing assessment results of the existing building and those of the environment-friendly building applied with high-strength concrete, the effect of $LCCO_2$ reduction was found out per stage and in the entire process.

3.3.1 CO_2 Assessment Results in the Construction Stage

Figure 3 shows the results of CO_2 calculation per stage for the assessed building applied with high-strength concrete. As shown in the figure, CO_2 emission in the construction stage of the case applied with high-strength concrete (40MPa) was reduced by nearly 4.12%, compared to the case applied with existing concrete (below 35MPa). Such an effect of CO_2 reduction is due to the decreased cross-section of vertical structural members by the application of high-strength concrete. Consequently, it shows that those techniques which can reduce building materials, like using high-strength concrete, are effective to decrease $LCCO_2$ of buildings.

In addition, high-strength concrete improves durability of buildings, so reducing maintenance costs in the operation stage. To be accurate, the aspect of maintenance should be also considered in estimating CO_2 reduction thanks to high-strength concrete, but this study purposed to assess $LCCO_2$ in terms of material reduced by using high-strength concrete, not considering effects of CO_2 reduction in the operation and disposal stages. In other words, the CO_2 emission in the operation/maintenance and removal/disposal stages was same as that of the existing case applied with non-high strength concrete (35MPa).

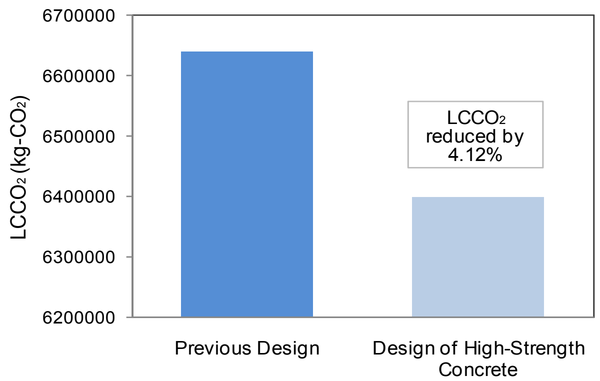

Figure 3 CO_2 Assessment Results in the Construction Stage

3.3.2 CO_2 Assessment Results through a Building Life Cycle

Figure 4 shows the results of $LCCO_2$ estimation for the assessed building applied with high-strength concrete. As shown in the figure, the $LCCO_2$ emission in the case using high-strength concrete (40MPa) was reduced by about 1.21%, compared to the case applied with existing strength concrete (below 35MPa). To be quantitative, the $LCCO_2$ emission of the 2 cases, one applied with the compressive strength below 35MPa and the other one with high-strength concrete, 40MPa, was calculated to be 22,820,631,10kg and 22,545,639.01kg. It is hoped that further assessment on environment-friendly performance of buildings will be possible through such estimation of $LCCO_2$ emission with application of new eco architecture techniques.

4. Assessment of Economical Efficiency

This study calculated the reduced volume of concrete and reinforcing bars after using high-strength concrete and evaluated effects of the reduced materials on the $LCCO_2$ emission of buildings. In this chapter, the reduced emission of carbon dioxide was converted to the present price traded in carbon exchange stations in Europe, for the purpose of assessing economical efficiency.

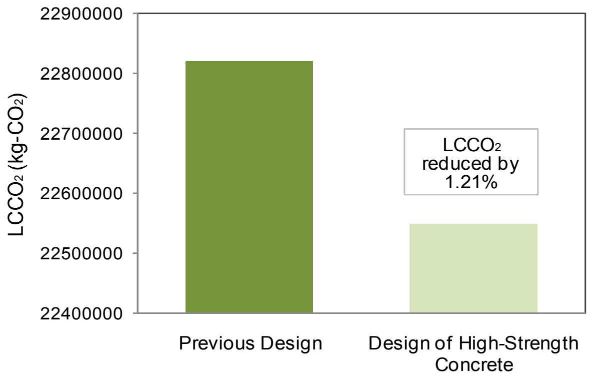

Figure 4 $LCCO_2$ Assessment Results through a Building Life Cycle

Table 5 shows the $LCCO_2$ assessment of an existing building using concrete with compressive strength below 35MPa and of a building using high-strength concrete (40MPa). As shown in the table, the $LCCO_2$ emission of the existing building and the other building was 22,820,631kg and 22,545,639kg. In case applying the reduction rate of $LCCO_2$, 1.21%, which was calculated in "3.3.2 CO_2 Assessment Results through a Building Life Cycle," the reduced volume was 274,992kg, which was found out to reach 2,760 thousand US dollars.

Table 5 Assessment of Economical Efficiency by Reduced CO_2

$LCCO_2$ Emission (kg-CO_2)	
Existing Building	22,820,631
Environment-Friendly Building	22,545,639
Reduced Volume (kg-CO_2, Reduction Rate : 1.21%)	274,992
Economical Benefits (Thousand US Dollars)	2,760

5. Conclusion

The purpose of this study was to assess effects of $LCCO_2$ reduction and economical efficiency thanks to the application of high-strength concrete, so various conditions of each stage, construction, use and maintenance, and removal and disposal, were entered to the program, SUSB-LCA ver. 1.0 and results drawn from the program were comparatively analyzed. The findings from the analysis are as follows:

1. In case using high-strength concrete (40MPa), the volume of used concrete and reinforcing bars was apparently reduced, thereby decreasing $LCCO_2$ released during the stage of construction material production. But, the higher strength concrete has, the more cement and aggregates are required. It is thus needed to design a proper mixture configuration.
2. The reduction rate of $LCCO_2$ emission of a tall building using high-strength concrete (40MPa) was 4.12% in the construction stage and 1.21% through the entire process.
3. The economic value of reduced CO_2 after using high-strength concrete in the building assessed was calculated to be 2,760 thousand dollars.
4. As this study purposed to assess $LCCO_2$ emission in terms of materials reduced by applying high-strength concrete, the effect of CO_2 reduction in the stages of operation/maintenance and removal/disposal was not taken into account. It is being, however, planned to conduct further assessment on effects of CO_2 reduction considering operation/maintenance and removal/disposal stages, for the sake of more accurate estimation of $LCCO_2$.

Acknowledgments

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EXCELLING THE UPTAKE OF LEED INDIA - INTEGRATING LESSONS LEARNT FROM THE DEVELOPMENT OF GREEN STAR

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Keywords: Sustainable building, rating tools, Green Star, LEED, India

Summary

A number of environmental rating tools exist globally which aim to push market transformation towards a sustainable future. In 1998, the World Green Building Council was formed with the mission to create a sustainable built environment through market transformation. Tools such as LEED (Leadership in Energy and Environmental Design) in the United States and BREEAM (Building Research Establishment Environmental Assessment Method) in the UK, are seen as leaders in the development of sustainability rating tool. The Green Building Council of Australia (GBCA) launched the Green Star suite of tools in 2003. Green Star has been based, in parts, upon combining the best from both the LEED and BREEAM tools and adapting them to the Australian context.

Of the new 'tiger economies' in the Asian region, India in particular is turning her attention to lowering overall environmental impact. As a new member country to the World Green Building Council, the Indian Green Building Council (IGBC) is developing its own built environment sustainability rating tools based on LEED. The IGBC's auspicing body is the Confederation of Indian Industries (CII).

This paper investigates the development and implementation of Green Star and outlines the issues and barriers which occurred during the process. Lessons learned from the development of Green Star suite of tools in Australia are expected to help create a set of the best rating tools for India and excel the uptake of the tools in that market. The study found numerous lessons of use to CII, and indeed any other country setting up their own sustainability rating tools.

1 Introduction

The IPCC Report (2007) documents the observations of climate change and states quite clearly that the warming of the climate system is unequivocal. Adaptation and mitigation options and responses to climate change include developing policy frameworks that integrate climate change considerations into design, land use policies and building codes.

It is well documented that the building and construction industry is a major contributor to greenhouse gas emissions and landfill globally (IPCC 2007, OECD 2008). Energy efficiency of the building stock is dependent by the construction and building efficiency regulations and best practice in the market place today. In a recent report released by Mckinsey Global Institute (Bressand et al 2008), global energy demand has been expected to accelerate over the next 20 years. Most of the demand would be by the developing countries, namely, China and India.

In Australia, the operation of inefficient and poorly constructed buildings is responsible for 23% of national greenhouse gas emissions (CIE 2007), a typical figure for most developed nations. The interim report of the Garnaut Climate Change review (2008) identified an important role for Australia in establishing a realistic approach to climate change, particularly with regard to mitigation of climate change. The Garnaut Report also focused on putting in place major reductions in emissions in Australia.

This paper presents the findings of a study prepared for the Victorian Building Commission by the Centre for Design at RMIT University. The purpose of the study was to provide support to the Confederation of India Industries (CII) arising out a Memorandum of Understanding signed between the Victorian government and the Confederation of Indian Industries (CII) in 2006. CII is India's building industry body currently responsible for developing a sustainable building rating tool, based on the USA's LEED system.

Established in 2003, the GBCA has been at the forefront of green building rating tool implementation and may now offer valuable learnings to others embarking on the implementation of new building ratings schemes. A literature review combined with personal interviews with past and present GBCA executives and senior stakeholders was undertaken to provide an insight into the underpinnings of rating tool development in Australia. Among them were GBCA founding board members, present members of the Green Star Technical Advisory Group, and industry representatives. Questions were tailored around the differences between Green Star tools and LEED, approaches taken by the GBCA, establishing industry support in Australia, lessons learnt and how India could fast track its own rating tool processes from these experiences.

1.1 International Green Building Rating Tools

Sustainability rating tools are frameworks to assess sustainability of the buildings or the built environment. They are typically developed to provide guidance and incentive towards more sustainable building practice and design. They ensure minimum environmental performance, benchmark environmental performance and establish best practice. They enable a means to measure and benchmark the environmental performance of the built environment, allow comparisons of environmental performance between buildings, provide independent third party certification of the sustainability claims of a building, provide a guide and a framework for building professionals and push market transformation and encourage improvements in the sustainability of the built environment.

Tools usually provide a score, or they may provide a simple pass/fail or compliance outcome. Most scores are in the form of stars as in the case of Australia (5 star for housing), or, they may be in the form of silver/gold or platinum rating (LEED in the US).

India is still in the early stages of developing its suite of building rating tools and is currently contextualising the US LEED rating system for Indian conditions. This adaptation is important as the physical, economic, technological and social environments in India are very different from that of the US.

In recognition of the need for a centralised organisation for green building, the World Green Building Council (WGBC) was founded in 1999 by the founder of the US Green Building Council (World Green Building Council 2007). Different Green Building Councils are set up under this umbrella organisation. GBCA and IGBC have both received support from the WGBC.

It is recognised that the development of new rating tools or the application of building rating tools in different regions remains a difficult task. Lui et al (2006, p. 374) outline the following:

- Expanding numbers of tools are developed with different scopes, emphases, functions, underlying assumptions as well as limitations relating to the specific conditions in their origin regions
- Duplications and overlap of tools
- Lack of transparency and an implicit assumption about the capabilities of user groups to choose appropriately can cause uncertainty and confusion
- Conditions and requirements for developing EB tools within a specific region are multifaceted and complex
- Difficulty of customizing existing tools into specific regionally appropriate formats without avoiding their inherent problems

2 Green Star

The Australian best practice rating tool is Green Star, administered by the Green Building Council of Australia (GBCA). GBCA's aim is to assist the property industry to reduce the environmental impact of buildings and improve occupant health and productivity, while showcasing innovation in sustainable building practices (GBCA 2006).

In the first few years since GBCA's inception the focus has been to set up a suite of tools for the Australian building and construction industry, and to raise the awareness of the tools. At the time of this study (September 2007), the GBCA had over 400 members and more than 400 projects registered for accreditation.

The original template for the Green Star suite of tools was created by Sinclair Knight Merz (SKM) for the Building Research Establishment in the UK. This template began as an Australian version of BREEAM, until the Green Building Council Australia commissioned its development as a working tool, with aspects of LEED to be incorporated as appropriate. The resulting suite of tools uses the core principles and structure of BREEAM with the points and star awards of LEED, contextualised to suit the Australian building industry environment.

The decision to develop a new rating tool system rather than adopt LEED or BREEAM in their original format was made for a number of reasons. At the time of Green Star's development, BREEAM and LEED were 10 and 5 years old respectively, and as such, an update was considered warranted by the Green Star development team. When reviewing the rating tools, the GBCA also formed the view that a single rating tool cannot adequately address all building types, and that a suite of tools adapted for different buildings within the Australian context would be more suitable.

2.1 The Structure of Green Star

In Green Star, the lowest denominator is points, groups of which form credits. Groups of credits form categories. Similar to BREEAM, the category score weighting system ensures that alterations to individual credits do not result in a change in the overall influence of its category. In other words, adding another credit item, or increasing the number of points a credit is worth within a category, will not affect the overall impact of that category in the overall score.

This feature enables variation of the tool across different Australian states. This is an important consideration in Australia where local climatic and environmental conditions can vary significantly across the country. This feature is not included in the LEED tool, but its importance is recognised and the USGBC are currently developing a bioregional weighting system to address this.

The design of the Green Star tool, its categories, and weightings have been developed by referring to the BREEAM and LEED models, with extensive consideration to a variety of scientific and stakeholder input. Table 1 shows the approximate weighting of each Green Star Category as it compares to LEED and BREEAM. The data demonstrates that the Green Star category weightings are more closely aligned to BREEAM than LEED.

Table 1: Comparison of Building Assessment Tool Category Ratings

Category	LEED	BREEAM	Green Star
Management	7	15	10
IEQ	22	15	17
Energy	24	12.5	20
Transport	6	12.5	9
Water	7	5	9
Materials	16	10	16
Ecology	13	15	12
Emissions	4	15	7
Total	99%	100%	100%

(Shown as a percentage of total allocated points)

Data source: Green Star Office Design V2 Technical Manual (GBCA 2006)

2.2 Technical Content Development Process

New rating tools are developed and existing tools revised over time in response to changes in market demands and specific requests from industry. Each new tool or revision is developed involving contribution from industry experts and stakeholders.

The process for developing a new tool, shown in Figure 1, commences with a 16-week period of review and development by a Technical Working Group, comprising of industry representatives. Once the GBCA complete the draft, it is released for stakeholder feedback before a Pilot revision is implemented.

The process of revising a tool is illustrated in Figure 2. Industry working groups are involved in the revisions, and Green Star applicants are invited to provide feedback throughout the process, ensuring that major stakeholders are consulted. Tool revisions also incorporate technical clarifications from the previous revisions[1].

3 The Accreditation Process

Compiling the documentation for a Green Star submission is a time consuming and thus costly task for the applicant. Once submitted, up to four GBCA Assessors review the submission. Where the documentation for applied credits is not met, applicants are given the opportunity for one re-submission, which is again reviewed by the GBCA Assessors. The process of accreditation is also time consuming and costly for the GBCA.

In hindsight, it may have been possible to reduce the level of documentation required in the development of the tool, but this holds the risk of compromising the quality of the final assessment. It has been suggested that the initial review could be done in-house with the assistant of a Green Star Assessor. This holds the advantage of having direct access to the project knowledge, so that issues encountered in interpreting the technical documents, and insufficient documentation, may be addressed prior to submission to the GBCA, reducing the GBCA's workload. An online user interface could also be considered to lessen this resource demand.

4 The Green Star Tools

It was recognised in the early stages of Green Star development that the design, construction, and ongoing operation phases of building life should be addressed within the suite of tools. Three different assessment tools: Office Design, As Built, and Existing were created to address this.

The documentation required to achieve a Green Star Office Design rating is arguably less rigorous than that required for Green Star Office As Built, and it can be easier to prove the intention of a project than it is to actually complete it as per its original intent. It is also often difficult to gather documentation from project participants after the project is finished. The GBCA recognise this and take the stance that the Green Star As Built rating is more prestigious than the Design rating. Unfortunately the difference between a Design and an As-Built accreditation is not widely recognised in the market. One of the positive outcomes of enabling a Green Star Office Design rating is that it may be achieved in time for development approval, and this has been adopted by some government departments as conditions for development of their own assets.

The Green Star Office Existing rating tool has recently been added to the suite and is designed to address building ownership and operation, in response to the recognised need to improve asset performance. The Green Star Office Existing tool remains focused on the physical features of the building, not the ongoing performance as is assessed under other rating tools such as AGBR and NABERS[2]. In this manner, Green Star remains distinct from and complimentary to these other tools.

5 Green Star Implementation

5.1 Industry Support

It was recognised that the support of industry is essential in the acceptance and subsequently the success of Green Star. To gain this support, industry was continually consulted and represented in all stages of Green Star development.

Importantly, private developers were involved in the early stages, and some of the largest property groups used the tool in pilot projects across the country. This was done in recognition that the key influences within the industry were these property developers themselves, and industry support was unlikely to happen if the tool is developed in isolation and without their involvement. Government groups have also been key supporters of the GBCA and continue to be involved in the GBCA through participation in Technical Working groups. However, there is also a recognised balance in the involvement of industry, government, and private company representatives. Whilst the contribution of each of these groups is valuable, care must be taken to ensure that individual agendas do not hijack the process or outcome.

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[1] During the assessment process, it is sometimes evident that a project meets the intent of that credit but not in the manner outlayed by the credit criteria. In this case the applicant may submit a Credit Interpretation Request (CIR), which is reviewed by the GBCA Assessor and if accepted is published as a Technical Clarification, setting precedent for other applicants.

[2] ABGR and NABERS are Australian rating tools that measure building performance.

Figure 1: New Green Star Tool Development

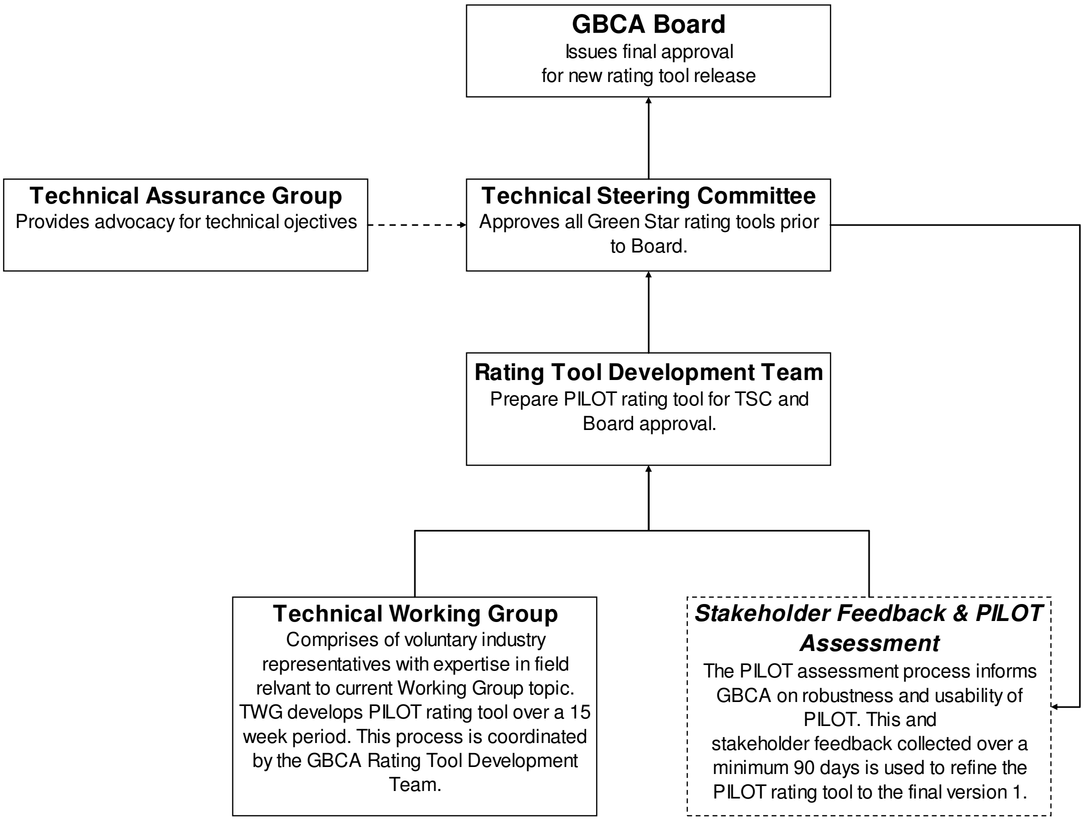
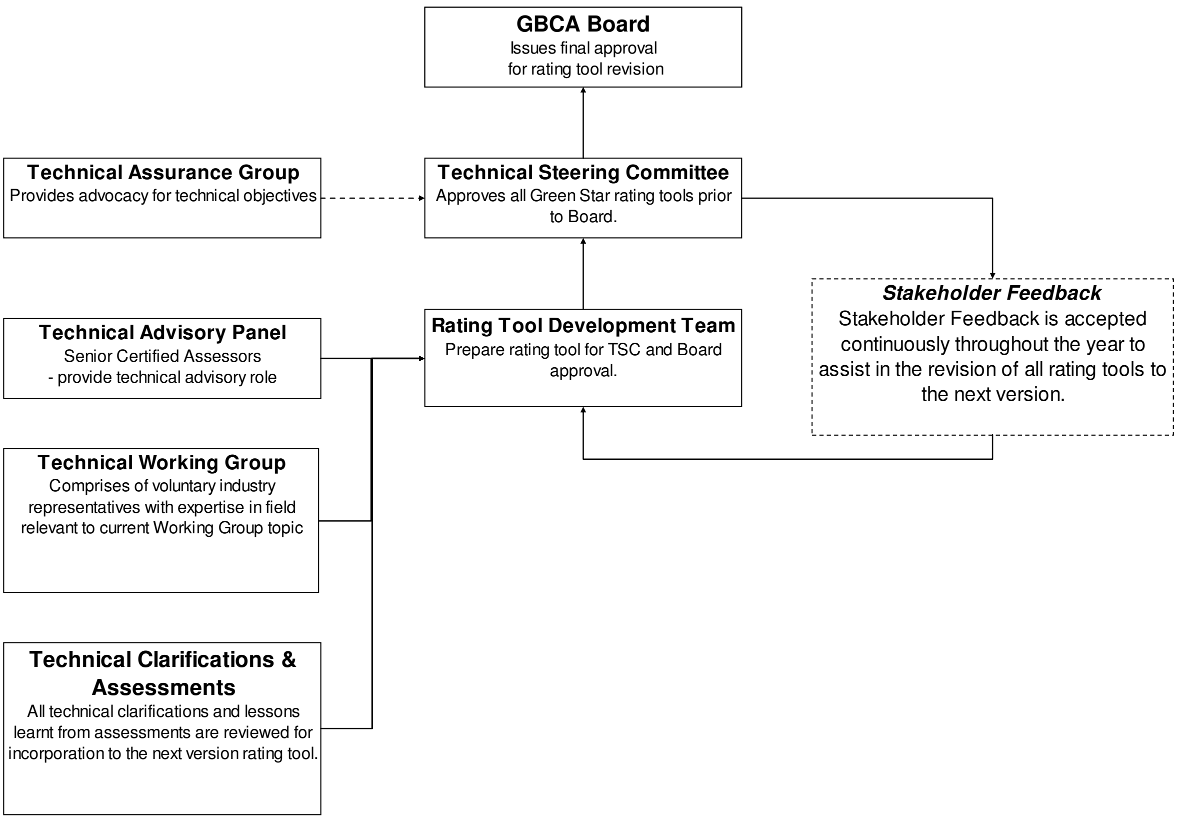


Figure 2: Green Star Tool Revision Process



5.2 Market Uptake

The market uptake of Green Star in Australia was relatively smooth, largely because there was already recognition in the marketplace that a structured set of guidelines were needed to drive changes in the industry. Industry involvement and government support also assisted the process. A quick and comprehensive campaign to increase market awareness of the tool by presentations through conferences and other means of general industry education also greatly enhanced the rate of uptake.

One of the barriers to incorporating green building objectives into building projects has been the perception that green buildings are costly. This perception has shifted somewhat in the past few years with the increased availability of local examples where a business case can or has been demonstrated.

The availability of technical expertise at the commencement of the development program has also been identified as important in rolling the tools out in the market. While, there must be a strong base of technical knowledge behind the tool development, there also needs to be sufficient technical support available to those using Green Star for the first time.

6 Current Challenges for Green Star

6.1 Tool Revisions and Streamlining of the Green Star Suite of Tools

There is concern over the number of Green Star rating tools and there is a perceived need to streamline the suite. The US LEED model avoids having a multitude of different rating tools by flexibility in how the criteria are applied, so that many types of buildings can be assessed with the same tool. However, recently the US Green Building Council has recognised that this approach can lead to confusion, and is in the process of developing a guide to show applicants how to use the tool for different building types. With the current proliferation of tools at the GBCA, care needs to be taken that the distinction between them is maintained, particularly when it comes to Design/As Built/Existing ratings of buildings of the same class.

It is also important that as the Green Star tools are revised and fine-tuned over time. The release of new tools and revisions needs to be done in a timely manner so that people are not waiting for impending releases that are continually delayed. It is acknowledged though that as sustainable technology and practice become efficient and widespread, rating tools will need to change accordingly to reflect changes in the industry.

6.2 GBCA Strategic Direction

A common theme of recent climate change studies has been the building and construction industry's contribution to greenhouse gas emissions. The Green Star approach for reducing environmental impact through all stages of construction may position property well around the objective of meeting carbon-neutrality targets in response to climate change initiatives. It is appropriate that the GBCA determines its direction and role in this process.

There are also a number of other building performance rating tools in use in Australia to address operational performance of commercial buildings, and the residential industry. It is important that the GBCA maintains and continues to clarify the distinction between Green Star and other rating schemes, and works to maintain the synergy between the different schemes. The GBCA's position as an industry leader needs to be maintained.

The Green Star rating tools are currently targeted at the top 25% of buildings, and as such are aimed at best practice. In the past few months there has been increasing focus on the performance of existing building stock in cities, and various national and international groups are preparing to take on this issue. The GBCA are now facing the challenge of finding an effective way to expand Green Star for application on a much broader scale.

6.3 Resources

The GBCA's workload increased dramatically in 2007 following the announcement of new revisions of the Green Star Office rating tools. As Green Star becomes increasingly recognised in the Australian market, resourcing demands will continue to be an issue for the GBCA.

Resources are required in the areas of technical assistance and training, and as described in Section 3, the accreditation process is also demanding on the GBCA's time. The accreditation process must strike a balance between managing the legal and reputational risk of certifying projects that do not meet the requirements, and the resources required for the thorough interrogation currently demanded in the certification process.

7 Summary of Lessons Learnt

It is anticipated that the lessons learnt by the GBCA will be of use to CII and other Green Building Councils in the development of tools. The lessons identified throughout are listed below. They are not arranged into any order of significance.

7.1 Establish the Rating Tools Governing Body within the Marketplace

1. Establish connections and support from key industry and government groups early, and involve them in the creation of the Rating Tools and development of CII internal protocol.
2. Whilst developing the industry associations, be selective – avoid groups who may seek to 'hijack' the process to suit their own agendas.
3. Work quickly in the initial awareness campaign. Implement a quick and comprehensive campaign through conferences, industry education activities, and other means of general industry education. This can greatly enhance the rate of uptake and acceptance of the tool.
4. Prepare examples of the business case green buildings, with local examples where possible.
5. Work with and promote the building industry's need for green building practice.
6. The uptake may seem to start slowly, but be prepared for it to gather momentum quickly.

7.2 Protect the Brand

7. Ensure suitable legal protection to deal with unsuccessful submissions.
8. Ensure all appropriate copywriting and trademarking is in place, and regulate false advertising to protect the brand.
9. Be mindful of the need to differentiate the ratings, so that the variation between rating types is understood in the wider community.

7.3 Technical Adaptation of the Rating Tool for India

10. Consider the differences in conditions between the US and India, and make allowances to adapt the tool for local climatic, social, government, and other regional conditions that can influence the relative impact of building activities.
11. Consider a means for future adaptation to be built into the tool as regional building impact conditions change; such as a category weighting system.
12. Find a suitable balance in the level of documentation required to prove a case. Too much will be labour intensive and will discourage uptake, but it must be comprehensive enough to maintain the quality of the assessment and the brand.

7.4 Benchmarking

13. Be certain that the benchmarks for final ratings are reflective of the current building industry in India and are positioned to drive positive change.
14. Check benchmarking for individual categories and credits.
15. Consider the recognition of third party certification. This can greatly reduce the assessment workload, but care must be taken to maintain the standards (and protect the brand) of the rating tool.

7.5 Ongoing Technical Development of the Rating Tool

16. Develop a process for updating and adding to the proposed tool early. As a minimum it needs to:
    - Capture feedback from rating tool users;
    - Be thorough in its assessment technical detail;
    - Be implemented in a timely and efficient manner;
    - Engage stakeholders throughout the process.
17. Consider adaptations of the tool for different applications, whether it be to address different phases of the building lifecycle, or different types of buildings. However, ensure that this does not lead to the release of too many tools, causing confusion in the market.

7.6 Resources and Training

18. Ensure there is efficient and effective training available. Allocate resources to this as education will greatly enhance the rate of uptake and reduce future technical advisory resource requirements.
19. Develop additional resources online and in any other suitable means to reduce technical advisory workload at the CII.
20. Engage sufficient technical expertise early to ensure that as many issues are addressed in the development phase as is possible.
21. Anticipate a rapid uptake in the future, and if possible prepare extra staff to administrate the tool as demand increases.
22. Consider alternative options for assessments. This includes initial assessments in-house, external outsourcing and online or otherwise automated user interface.

8 Conclusion

This project set out to review and document the learnings of the Green Star rating tools developed and implemented by the GBCA. These lessons have been particularly analysed for the Indian context, however, these lessons can be applied to the development of suitable tools in other countries.

Literature reviews, primarily through desk research and interviews with key persons involved in the inception of Green Building Council and the development of the Green Star suite of tools were undertaken. It is anticipated that CII will be able to 'fast track' their tool development, documentation and processes.

In terms of its strategic role, the GBCA fulfils a need in the market place by nudging innovation and being the industry leader for best practice in building design and construction in Australia. A challenge that GBCA faces is meeting industry expectations in the development and constant finetuning of its tools in the face of sustainability challenges and technological advancement.

Lessons learnt include the setting up of appropriate governing structures with transparent feedback mechanisms from industry, ensuring there are appropriate procedures for protecting the brand, adaptation of tools sensitive to the cultural, climatic, government and industry structures in India, benchmarking to set baseline standards and directions for tool development into the future, appropriate technical support and communication structures to assist in tool development. Training and education to assist and enhance the rate of uptake of tools also need to be considered in parallel.

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'TOWARDS ZERO' – METHODOLOGY AND STRATEGIES TOWARDS ZERO EMISSION OFFICE BUILDINGS IN AUSTRALIA

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Summary

The ultimate goal for an office building is 'net balance carbon neutral', not only in operation but over its whole life cycle. Internationally there are a number of projects, legal frameworks, rating systems and projects pursuing this target. In the Australian context 'Towards Zero' has derived definitions, processes, technologies, strategies and an exemplary design in this pursuit. The team defined the project within a typical urban context and identified factors required to approach zero net emissions. A methodology was developed to implement leading architectural and engineering solutions in an integrated process taking into account that modern developers, owners and tenants understand the significant implications of a healthy and sustainable working environment on staff and corporate reporting. An exemplary design was developed for a typical Melbourne CBD site to prove that pioneering sustainable design can be successfully integrated architecturally. Each team member has been implementing the gained knowledge into their organisations educating respective staff and clients thereby producing more informed projects. Finally, recent advances and remaining challenges in the industry are identified.

1. Context

The project originated early in 2006 when the first office (base) buildings in Australia achieved the highest 6-Star Green Star (equivalent to L.E.E.D. in the US) Office Design V.2 rating by the Green Building Council of Australia. Investa Property Group, Spowers Architects and Connell Wagner Engineers looked at the 'next step' in the energy category i.e. a development's carbon-equivalent net neutrality, a concept that was already being pursued by projects internationally on mostly smaller scales. The client converted this idea into a project brief to:

- derive a methodology to identify key factors and processes to approximate zero net emissions in a typical Australian context,
- produce an exemplary concept design for a 45,000 m2 GFA (Gross Floor Area) office building on a site to be chosen in the Melbourne, Australia applying the generic methodology and
- inform and enhance the practices of all parties involved for their projects across the board.

For developments of this scale it is typical in Australia for developers to invest in a speculative proposal and adapt and finalize the design when a large scale tenant is signed up. After the initial lease the building is likely to have to accommodate a very different kind of tenant with different requirements.

Concrete Government emission targets with financial incentives for the property industry for significantly reducing its emissions footprint were not in sight during the project. Energy prices compared to developed world standards were very cheap while Australia generates some of the world's highest CO_2-e emissions per capita due to a large portion of brown coal fired power generation. Incentives through the short to medium running cost savings alone were low while respective public funding for respective research and demonstration is still minimal.

Only recently significant emission reduction targets have been promised within the framework of the Bali negotiations. The importance of raised building standards and building upgrades has been identified as a cost efficient key factor (Liana Downey et al 2008, and IPCC, Working Group III, Technical Summary, 2007) in the Australian climate change mitigation efforts where buildings account for 23% of national emissions (Centre for International Economics 2007).

2. Methodology

2.1 Definition of Zero Net Emissions

CO2-e (Carbon Dioxide equivalent) emissions of a building development are often only understood as operational emissions. For a more accurate net balance neutral view however the project team proposed the following aspects to be incorporated into the overall equation.

- Embodied energy/emissions through the construction process and materials
- Operational energy/emissions over the life time of the building
- Embodied energy/emissions through renovation cycle processes and materials (base building, fit-outs)
- Embodied energy/emissions through demolition and reuse/recycling/disposal processes

Other emissions such as sewage, waste, noise etc were not the prime focus of this project as the respective aspects are covered by the holistic approach of the Green Star rating system which was used as a complementary methodology using the highest (6-Star) rating of Green Star Office Design V.2 as target.

It is apparent that in order to speak of a true zero-net emissions building/development these emission 'handicaps' have to be compensated through an operational negative emissions or regenerative performance to a degree that the net emissions balance at the end of the anticipated life span is indeed zero. This also means that if the development exceeds the anticipated life span it becomes a 'positive' contributor to the public emissions balance.

The above is of course a simplification to illustrate the definition. In reality advancements in technology are likely to alter operational balance through a renovation/retrofitting cycle.

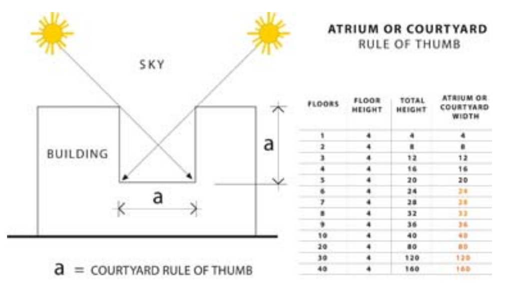
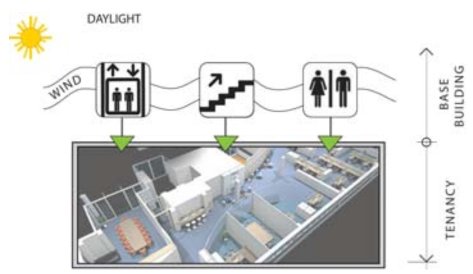
2.2 Generic Design Principles

The project team looked at key factors that affect the life cycle net emissions balance of the building. The scope focused largely on the architectural analysis with services and power generation complementing the strategies generically.

2.2.1 Base Assumptions

The following base assumptions were derived in order to optimize the scheme's passive properties:

Table 1 Generic Base Assumptions

<table>
<tr><td></td><td>A. Overall Building</td><td>B. Base Building Common Areas</td></tr>
<tr><td>Strategy</td><td>Daylight Optimisation</td><td>Daylight Optimisation + Natural/Mixed Mode Ventilation</td></tr>
<tr><td>Benefit</td><td>1. reduced artificial lighting energy use
2. reduced heat gains from artificial lighting
3. improved amenity, health and productivity</td><td>as per A plus
4. reduced energy consumption fans, chillers
5. interaction with outdoor climate</td></tr>
<tr><td>Design Guideline</td><td>
</td><td>
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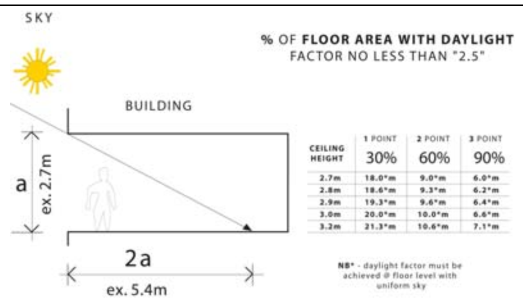
<tr><td></td><td>
</td><td>Note 1: Natural/Mixed mode ventilation for the tenancy areas of this high-rise development was not factored into the base assumptions as comprehensive and tested double façade elements were considered capital-cost-prohibitive at the time as the Melbourne market returned significantly lower yields (up to AUD 400/m2NLA) than eg Sydney (up to AUD 1,200/m2 NLA).

Note 2: The Australian Building Codes do not regulate a maximum distance from view glazing or minimum daylight level/factor for work spaces.</td></tr>
</table>

2.2.2 Development of a Matrix of Building Typologies vs. Key Base Assumptions

Based on the brief of 45,000m2 GFA Spowers developed site-independent architectural typologies. These consist of towers, slabs, spine-wing and atrium types. They are further broken down into various subtypes with different organizations of common areas vs. office space complying with BCA egress requirements. The developed types (which do not yet represent actual building shapes) were then assessed generically against the base assumptions.

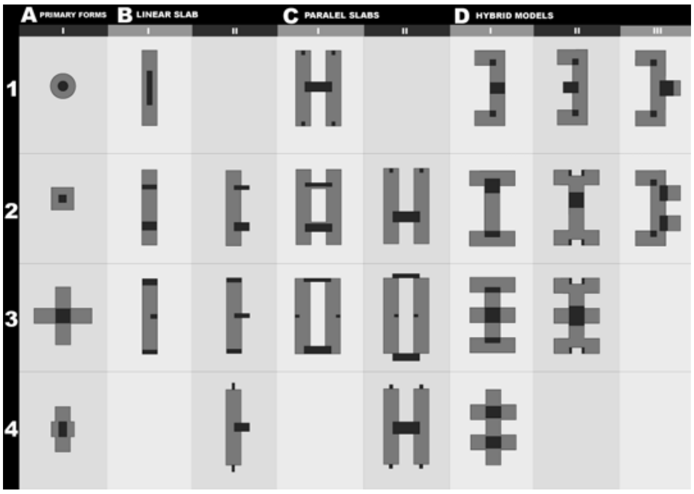
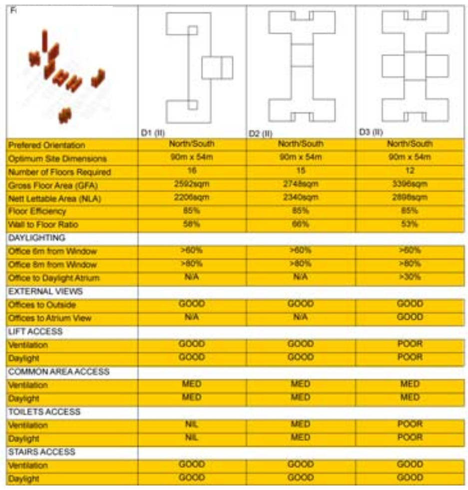


Figure 1 Extract from Generic Typology



	D1 (II)	D2 (II)	D3 (II)
Prefered Orientation	North/South	North/South	North/South
Optimum Site Dimensions	90m x 54m	90m x 54m	90m x 54m
Number of Floors Required	16	15	12
Gross Floor Area (GFA)	2592sqm	2748sqm	3396sqm
Nett Lettable Area (NLA)	2206sqm	2340sqm	2898sqm
Floor Efficiency	85%	85%	85%
Wall to Floor Ratio	58%	66%	53%
DAYLIGHTING			
Office 6m from Window	>60%	>60%	>60%
Office 8m from Window	>80%	>80%	>80%
Office to Daylight Atrium	N/A	N/A	>30%
EXTERNAL VIEWS			
Offices to Outside	GOOD	GOOD	GOOD
Offices to Atrium View	N/A	N/A	GOOD
LIFT ACCESS			
Ventilation	GOOD	GOOD	POOR
Daylight	GOOD	GOOD	POOR
COMMON AREA ACCESS			
Ventilation	MED	MED	MED
Daylight	MED	MED	MED
TOILETS ACCESS			
Ventilation	NIL	MED	POOR
Daylight	NIL	MED	POOR
STAIRS ACCESS			
Ventilation	GOOD	GOOD	GOOD
Daylight	GOOD	GOOD	GOOD

Figure 2 Extract from Analysis

2.2.3 Generic Building Section Based on Key Assumptions and Integrated Energy/Services Concept.

From the base parameters and typologies high-rise generic building sections were developed. These incorporated an 18m deep typical floor plate to allow not only for daylight/ventilation optimisation but also represented a framework for required flexible, large (> 2,000 m2) sub-dividable tenant floor plate organisation types. The typical section incorporates optimising strategies including daylight/artificial light, potential for cross-ventilation and efficient air handling and thermal mass utilisation. The floor plates can be connected vertically to facilitate communication, break-out spaces and vertical travel energy savings. Based on the generic architectural strategies engineering solutions were developed that included options for central/floor-by-floor air handling, on-site/off-site power generation, ground-air heat exchange and utilising thermal mass to balance the building.

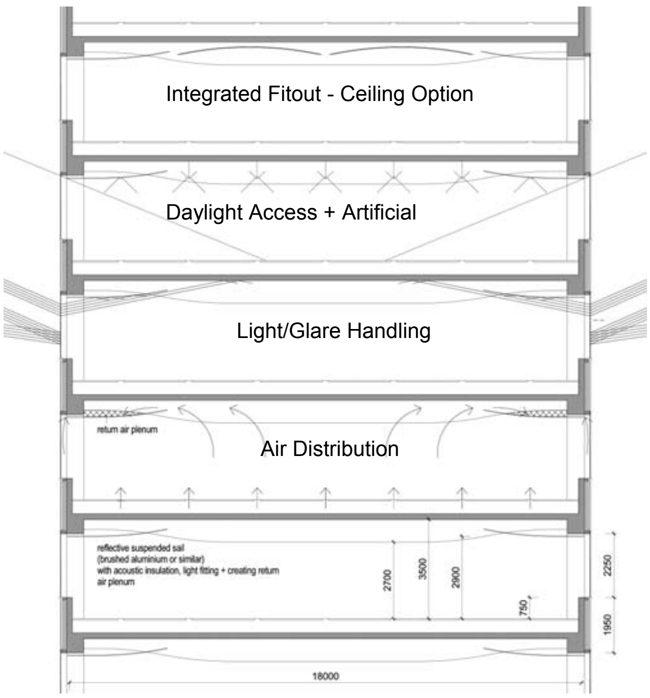


Figure 3 Generic Architectural Concept Section

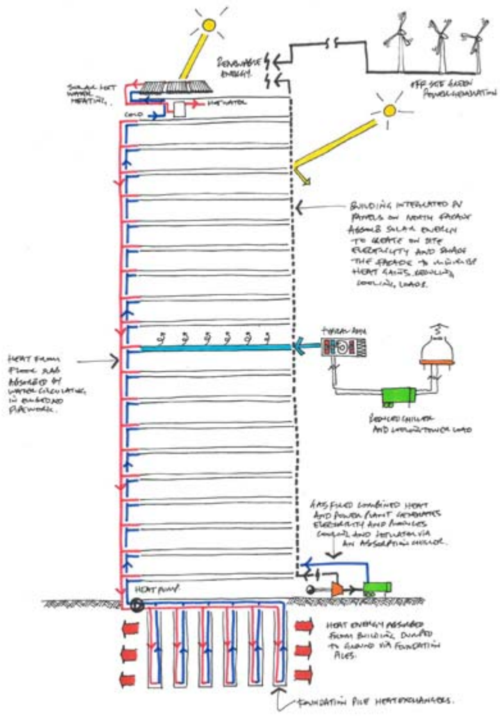


Figure 4 Generic Engineering Concept

2.2.4 Base Building Load reduction Using the Australian Building Greenhouse Rating Methodology (ABGR)

Base case for assessing the building's emissions balance was a projected ABGR rating of 4.5 Stars (116kgCO2e/m2) which represents a typical good practice large tenant brief. The following graph illustrates the incremental improvement through commercially viable and readily available (in Australia) technology. Note: The State of Victoria uses mainly CO2-intense brown coal for power generation which gets factored into the ABGR rating. Thus buildings in this state need to work harder for the same rating.

Table 2 Emissions Improvement Using ABGR Rating Methodology

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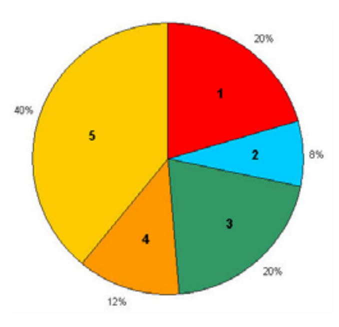
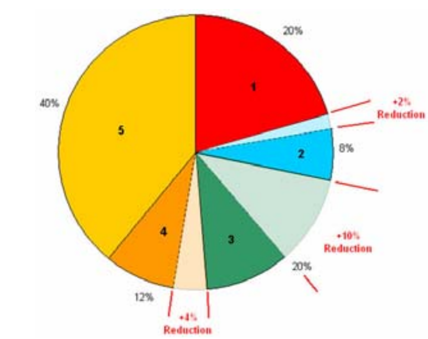
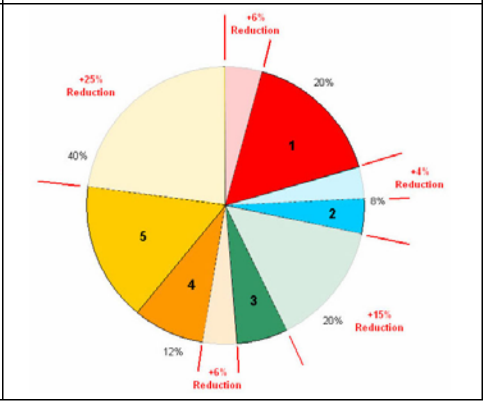
4.5 STARS: 116 kgCO2e/m2 base case	**5.0 STARS:** 101 kgCO2e/m2 **(- 16%**	**5.0 STARS + 40%:** 61 kgCO2e/m2 **(- 56%)**
Variable Air Volume system 1 Boiler Energy 2 Chiller Energy 3 Fan Energy 4 Central Plant Pump Energy 5 Base Building Lighting & Small Power	10% Underfloor air distribution (UAD) 2% Improve chilling plant 4% Reduce pump energy	15% highly optimised UAD 4% Improve chilling plant 6% Reduce pump energy 25% Improved building light and power, open car park deck, naturally lit public spaces 6% Heating plant - condensing boiler
		

Further load reduction needs to look at strategies, technologies and synergies that have not been adapted to the Australian/Victorian environmental and commercial large scale context such as

- Space saving super insulation such as vacuum insulation and triple/vacuum glazing
- Comprehensive façade systems allowing high-rise natural ventilation and resulting load reduction
- High-rise daylight re-direction systems that minimise artificial lighting cooling requirements
- Large scale ground-hydronic heat exchange systems or phase change material storage (performance data from the Australian-first CH2 project was not available yet)
- Large scale hydronic slab activation (when tenant is not known at early design stage the option of exposed/activated elements can not be guaranteed within the overall ESD strategy of the building.)

The following options were studied and to be incorporated with the tenant on board to ensure acceptability.

2.2.5 Co-Generation

A conventional natural gas co- and tri-generation plant is a typical leading technology for minimising CO2e emissions even to reach the highest Green Star Office Design V.2 rating. However, it is logical that in order to achieve a net zero CO2e emissions balance (even just on an operational base) needs to incorporate some form of renewable power generation. The crucial question here is generation on-site vs off-site (including the question of green power top up).

A number of on-site options (including Photovoltaic systems, integrated or mounted, Wind Turbines and Bio Fuel) were considered and compared to regenerative off-site options (Wind, Solar, Bio fuel) as well as investment into 3rd party companies (Wind, Solar, Bio Fuel, 'Clean Coal', Geothermal) to demonstrate the principal implications for the client.

To illustrate the issue the following sample calculation and comparison between building-integrated PV cells and off-site sun-tracking solar dishes with a single PV cell was conducted:

Table 3 Sample Calculation Building Integrated Conventional PV Modules vs. Heliostat Concentrator PV System Off-Site in Optimal Solar Location

Resulting building electric energy demand: 50 kWh/m2, year x NLA 35,000m2 = **1,750,000 kWh/year**		
Location	ON-SITE - Melbourne	OFF-SITE - Mildura (North West Victoria)
BCA Climate Zone	Zone 6	Zone 4
Mean dayly Solar Radiation	4.94 kWh/m2, day	6.1 kWh/m2, day
PV efficiency	12% (flat panel, nominal, eg BP4170)	19% efficiency (heliostat concentrator photovoltaic sun-tracking dish w. single PV cell, nominal eg Solar Systems)
Electr.generation/m2, a	218.87 kWh (fixed angle unobstructed)	423 kWh (sun-tracking)
PV area required	7,995 m2	4,137 m2
Panels/Dishes required	6,352 Panels (á 1.26m2)	32 dishes (á130m2)

While the calculation shows a nearly double efficiency for the large scale sun-tracking dishes in a sunnier climate the advantages of an on-site solution include direct usability, less grid-loss and infrastructure, potential provision of uninterrupted power supply to tenants, local peak reduction, potential elimination of building cladding materials, visibility and marketability must be considered. These issues are mostly the client's decisions and are important for the integrity of the project's philosophy.

2.2.6 Good Architecture

As the embodied energy/emissions in buildings represent a significant portion of their life cycle net-emissions balance it is important to ensure that the building is

- Attractive and flexible to maintain its appeal to tenants/users through changing requirements
- Efficient, to optimise (not maximise) the actual use of the building i.e. number of work stations, formal/informal meeting spaces and amenity rather than merely m2 NLA thus fostering a healthy and productive work environment.
- User-robust, well-aging and up-gradable to allow efficient refurbishment, disassembly and renewal as well as efficient and flexible services upgrades

For a successful design and construction process and feasible outcomes it was identified as important to integrate optimal building's passive properties with the most efficient complementary systems thereby maximising synergies to allow efficiency (elimination/down-sizing) of systems and plant space while optimising amenity.

3. Design

3.1 Brief

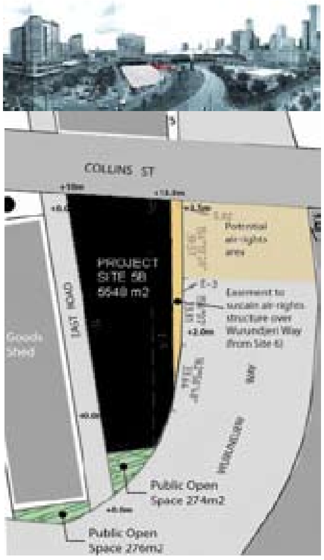
The building to be developed was to be of premium grade, incorporate 45,000 m2 GFA of largely column free, >2,000m2 NLA floor plates at >85% efficiency, with an optimum ratio of compactness vs. daylight/ventilation access. While it was to fulfil all base assumptions it was not necessarily to be ESD branded, i.e. with purposely visible features.

The speculative site was chosen in the Melbourne Docklands (Site 5B) immediately adjacent to the Western CBD. With its long sites East and West this only partially obstructed site does not have perfect solar access which was consciously accepted as it represented typical rather than ideal inner city conditions.

The generic typology overlay and analysis vs base criteria resulted in three applicable types a combination of which was chosen as actual base for the architectural design process.

3.2 Specific Concept Design

Solar and wind studies were undertaken to analyse the site's access to sun, daylight and breezes to further inform the footprint. Urban and architectural considerations of frontages and volumetric composition led to the modification of the building's typology into an actual shape.



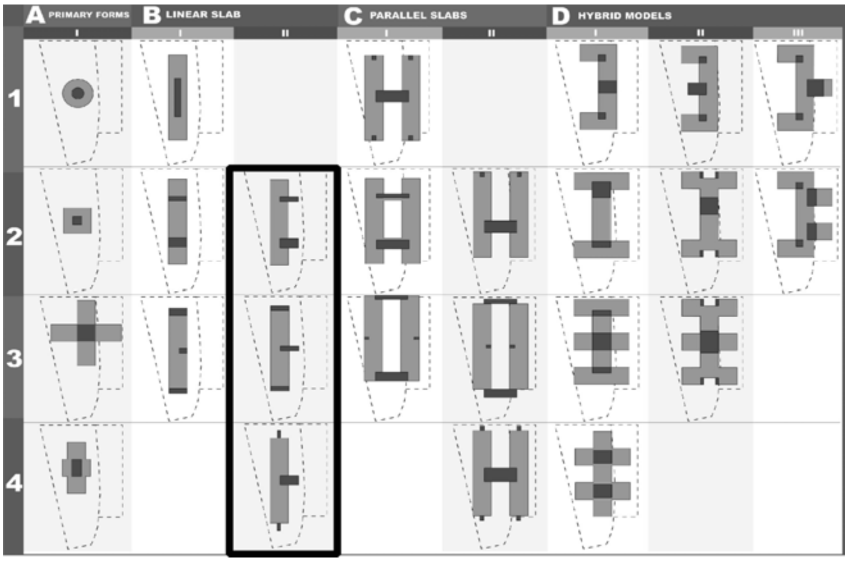


Figure 5 Site Location *Figure 6 Layout and Typology Overlay/*

Figure 7 Floor Plate Evolution

The concept design features East/West facing screens that modify the climate in terms of daylight, thermal radiation, acoustic shielding and air flow. These dominate the architectural presence and are broken up by multi-floor break-out spaces/sky gardens which indicatively show how typical floor plates can be connected and broken up to produce an interesting 3-D working landscape. These spaces can be naturally ventilated, operate at a wider temperature band and be used for informal meetings, as a casual work environment or for functions etc. The overall break-up into two major volumes facilitates marketability with potentially two addresses/foyers and easy floor plate sub-divisions.

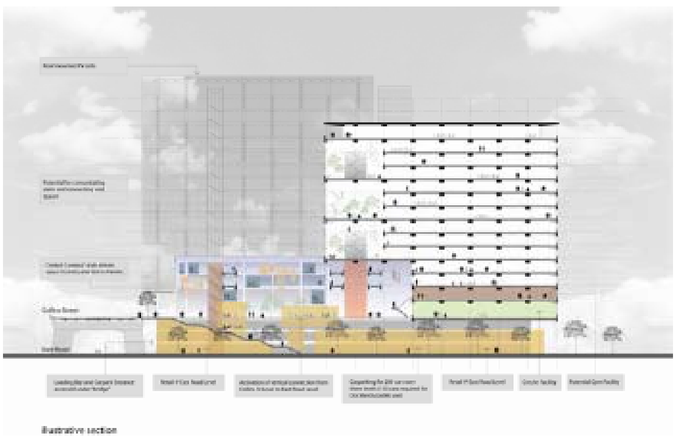


Figure 8 Artist's Impression (Collins St. View) *Figure 9 Exemplary Section*

4. CONCLUSIONS

4.1 Project General

To achieve zero net emissions over the entire life cycle of a project is an aspirational target that represents world's best practice. Strategies and technologies exist to realise this objective. A series of challenges have been identified for an Australian CBD context:

- Density, i.e. the access to sufficient renewable energy sources in a high-rise, dense urban environment
- Supply chain for innovative high-efficiency solutions including multiple suppliers
- Advanced façade engineering, component supply and respective warranties
- Yield structure in Melbourne which is low in Australian comparison.

The way forward can be facilitated through:

- factoring buildings efficiency in to the Australian carbon trading scheme
- comprehensive and future oriented valuation of high-efficiency buildings.

An informed and integrated inception and design process by an innovative design team is a pre-requisite to break through barriers of common practice in all fields of consulting, technical as well administrative and financial. Power generation and management concepts are important to consider early on. In particular, precinct-wide solutions as further investigated by members of the project team promise economies of scale and synergies that significantly improve the viability of pursuing a zero-net-emissions target. Furthermore the supply chain needs to be encouraged to connect to internationally leading technologies and innovation.

4.2 Industry Changes

Since the completion of the study mid-2006 significant developments have occurred. The Green Building Council has embraced (operational base building) CO-e net neutrality as the highest rating within the energy component of the Green Star Design V.3 rating tool. The change of government has effected the ratification of the Kyoto protocol and promised to install a carbon trading system by 2010. The current discussion (03/2008) in the industry revolves around how to account for buildings in the carbon market as it is widely recognized that an up-grading of the building stock is amongst the most effective ways of emission reduction. Tenant demand/awareness has improved and more case studies with new technologies have come on-line.

4.3 Property Development Effects

Generating power is a fairly new part of project development and facility management in Australia. Strategies should be devised early on in a project as this affects the capital cost expenditure, valuation, design, ownership and maintenance/operational aspects of the facility. Multiple options range from 3rd party contracting through specialised companies to developer-investment, ownership and operation.

In the development context of this project bringing the tenant on board of the zero strategy is crucial. Green Leases and contractual arrangements to fairly share costs and benefits between developer, owner and occupier are essential. There may be a tenant education process involved to ensure they understand and value the significance over the term of the lease regarding staff procurement and productivity, corporate sustainability reporting and the eminent effects of factoring the CO2-e emission balance into the electrical power equation.

One of the most important learning experiences from 'Towards Zero' has been the value of taking an intellectual approach to the conception and development of major commercial office buildings.

Using the backdrop of a proposed new tower at 1 Richard Johnson Square, Sydney, Investa gathered its project team to examine how this new building could minimise its carbon footprint. This was achieved via a presentation on 'Towards Zero' demonstrating the thought processes which were applied. All project consultants were asked to consider evolving new technologies in building design and materials, how they impacted on other aspects of the development and how they could each collectively contribute to producing a world class premium asset.

Key factors considered were; the proposed building's typography and position in the Sydney CBD, advances in glazing technology, on-site power generation and water recycling and mechanical services innovations.

As it was found in the initial 'Towards Zero' study, the zero emissions target may be elusive; however, it is achievable. But 'Towards Zero' is more than simply identifying green and greener innovations, it is an attempt to marry the goal of zero emissions with design excellence, ever increasing tenant demands and the need for commercially acceptable terms. No element was blindly pursued in isolation of other elements. This synergistic approach has lead to a more cohesive outcome.

Furthermore this project has been used as process and design model to educate staff. This has led to better comprehension of project briefings and design processes needed to facilitate optimal outcomes.

4.4 Engineering Effects

The methodology which was developed is considered to be readily applicable to projects which seek to achieve net zero emission outcomes for both new and existing buildings which will become increasingly important in a carbon constructed world.

The principles of minimising the energy usage in commercial buildings through the application of good passive solar design and the design of energy efficient lighting and air conditioning systems are well known. The challenge in a zero energy commercial building is to optimise the application of these principles without compromising the requirements of the building to accommodate contemporary workplace layouts which are sought by companies in Australia i.e. large floor plates with minimal columns.

'Towards Zero' has balanced the requirements to optimise daylight and views with the need to deliver these large flexible floor plates.

Once the passive and active elements of the building have been optimised to reduce the energy usage (and resultant green house emissions), the greatest current challenge is to cost effectively provide the energy required for a high rise building using renewable energy sources. There are technical challenges such as the availability of north facing facades and roof areas for photovoltaic cells and the ability to locate wind turbines on respective commercial office buildings in the city. The financial challenges become easier to overcome as the cost of energy goes up and the cost of renewable technologies continues to decrease.

There remains the strategic question of whether it is more appropriate to deploy the renewable technology on the building being constructed or refurbished or whether the financial resources are better spent generating the power in a remote environment with more suitable climatic conditions for the respective renewable power. This needs to be examined on a project by project basis and the potential marketing benefits associated with mounting the renewable technologies on the building to be balanced against the potential decrease in output associated with localising the renewable generation technologies in a sub optimal location.

Also, embodied energy/emissions of new construction vs. retrofitting has become a significant factor in the assessment of projects.

4.5 Architectural Effects

The typologies derived in 'Towards Zero' have become part of the 'tool box' for early project stages. Base assumptions and principles have been adopted into the client briefing and concept design processes. Since the project Spowers have achieved ISO 14001:2004 certification to ensure quality, continuous improvement and the transfer of acquired knowledge into projects across the board. Power generation has become a typical option to consider on respective projects. As for Investa, 'Towards Zero' has been used as educational case study for staff and raised the bar as showcase for clients.

Precinct approaches have been designed on following projects showing respective higher efficiencies and the potential for cost-effective inclusion of renewable energy sources.

Last not least the project has highlighted the possibilities for investments into leading building typologies.

4.6 Further Research

It is important to investigate the possibilities 'towards zero' on new projects. The complimentary step however should be applying and adapting the methodology to existing buildings and deriving processes and strategies to upgrade the typical building stock across Australia respectively to prepare the respective stream for meeting the projected emission targets.

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THE EFFECT OF ROOF COLOUR ON THE OUTDOOR TO INDOOR TEMPERATURE DIFFERENCE IN PASSIVELY COOLED NON-AIR-CONDITIONED BUILDINGS

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Keywords: cool roof, passive cooling, building simulation

Summary

A recent study has highlighted the importance of roof colour on the heat gain of a building. For non-air-conditioned buildings a key parameter for the effect of roof colour is the temperature difference between the outside and inside, $\Delta T = T_{outside} - T_{inside}$. The previous study assumed that the temperature difference approaches zero in well-designed passive buildings, but now we detail how ΔT depends on the quality of passive cooling design. The present study considers day-time occupied school buildings evaluated in ten different Australian locations. We employ USDOE EnergyPlus software for these simulations with the DesignBuilder user interface. Our main finding is that ΔT approaches zero for very good passive cooling designs, and is very negative (by more than 5 K) for dark coloured buildings that are not otherwise well designed for passive cooling. We suggest that ΔT may be positive during early morning occupation, if night purging and thermal mass is effectively managed.

1. Introduction

Energy efficient building design is gaining global recognition as a key pathway to combat climate change [1, 2]. The benefits of radiation control coatings (e.g. a white roof surface reflecting short wave solar radiation) are currently not fully recognized in building energy codes as an alternative or adjunct to thermal insulation R-value requirements, especially for warm climates [3]. Radiation control coatings are perhaps better described as "insulators" or "thermal diodes", as they tend to be more effective in restricting heat flow in one direction (e.g. an aluminum foil at the roof underside is effective in restricting downward heat transfer). Clearly a better understanding of the effect of radiation control coatings will inform sustainable development in the tropics of the world, where the most rapid industrialization is currently underway [1].

In tropical buildings without air-conditioning careful building design, often involving building simulation, is required to ensure thermal comfort for occupants. For a passively cooled building a measure the effectiveness of this design is the temperature difference, $\Delta T = T_{outside} - T_{inside}$. This temperature difference, for example, depends on the solar reflectivity and thermal emissivity of the roof surface, the thermal mass and ventilation of the building, but also the internal loads of lights and people [4]. The significance of building simulation is confirmed by new building codes [5] which allow alternative solutions within a given annual energy intensity limit.

For permanently air-conditioned buildings in hot climates the temperature difference $\Delta T = T_{outside} - T_{inside}$ usually is positive, i.e. there is a continuous heat gain that needs to be removed the air-conditioning system. For passively cooled buildings, on the other hand, daytime solar heating and internal heat sources tend to make the outside to inside air temperature difference ΔT negative, i.e. passive buildings usually have a temperature above ambient to reject heat.

One could evaluate occupant comfort by conducting full year (8860 hour) simulations and then summarize the proportion of occupied hours that indoor temperature is deemed to be acceptable. But in the present study we provide hourly simulations for the difference in temperature between outside and inside, ΔT, on one single hot day with a recognized hot weather design temperature. We then suggest ΔT be subtracted from the constantly varying outdoor temperature to provide an order-of-magnitude estimate of the indoor thermal comfort conditions.

2. Building Models

The present study models a day-time occupied school building as shown in Fig. 1, in 10 Australian locations for both a “dark” red tile and highly reflective “white” roof and wall [the walls are shown dark for both buildings, but the properties have been simulated as stated].

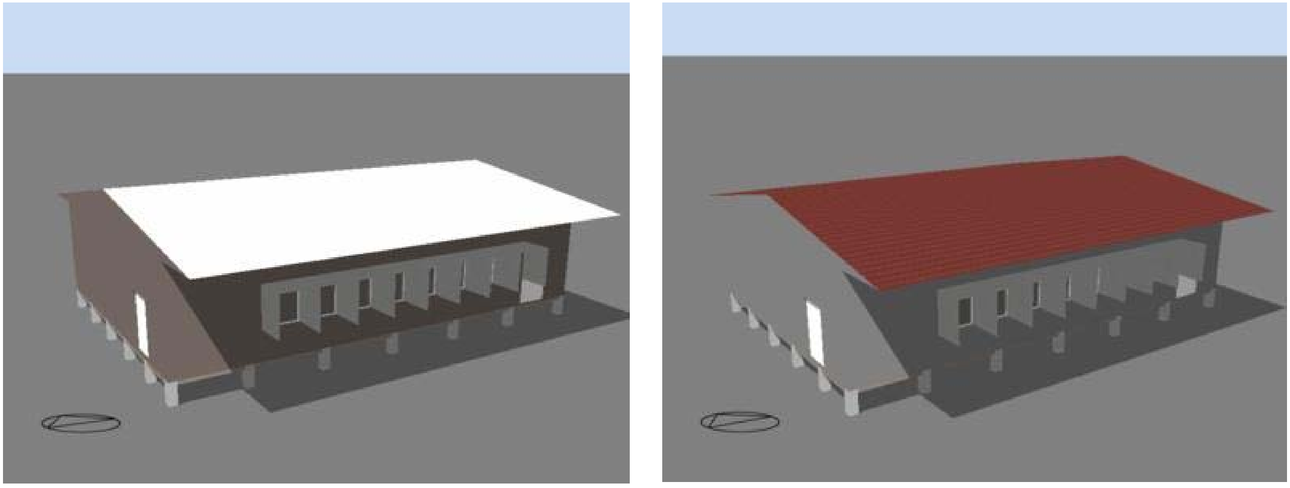

Figure 1 *Simulation case study: Lightweight one room school building with white and dark clay tile roof.*

Table 1 outlines the design conditions taken from ASHRAE [6]. Our simulation assumed clear sky solar radiation on 15th January (the height of summer), with the ambient temperature following a sinusoid with the minimum at 3 AM and the maximum at 3 PM. These values are normally applied in air-conditioning cooling load estimates and conventionally used to specify equipment capacity.

Table 1: 99.6% maximum dry bulb design temperatures and coincident minima used in the simulations

	max T [°C]	min T [°C]	Latitude°	Longitude°	Elev [m]
Townsville airport	33.2°	26.7°	-19.25	146.75	6
Brisbane airport	31.1°	23.7°	-27.38	153.10	5
Sydney city	30.7°	24.8°	-33.87	151.20	66
Canberra airport	32.7°	19.7°	-35.30	149.18	577
Melbourne city	34.7°	25.1°	-37.82	144.97	113
Hobart city	28.0°	19.9°	-42.88	147.32	57
Darwin airport	33.9°	27.1°	-12.40	130.87	30
Alice springs airport	34.7°	25.1°	-23.80	133.90	541
Adelaide city	34.7°	25.1°	-34.92	138.62	101
Perth city	34.7°	25.1°	-31.95	115.87	20

In the present study we evaluate a building with a gable roof consisting of two 87 m^2 roof areas - one sloped 10° north the other 10° south. The east and west gable ends are 6 m^2 each, and the wall areas are 49 m^2 north, 32 m^2 east, 49 m^2 south, and 32 m^2 west. There is 126 m^2 of indoor plasterboard ceiling area and also a 45 m^2 outdoor plasterboard area under the roof overhang. It should be said that the plasterboard ceiling reduces/delays heat gain from the roof to the occupied zone. The roof is assumed to be clay tile 25 mm thick with no bulk insulation provided other than the effect of specified surface reflectivities and emissivities. Walls of the building and vertical gable ends of the roof space are assumed to be metal clad with plasterboard walls inside, and foil linings are included only for the "white" case. Clear single glazed windows are externally shaded with 1 m overhang and projections. Windows total 13 m^2 north facing and 13 m^2 south facing. The floor of the indoor area is elevated above ground where outdoor air flows freely. The floor has been specified as linoleum on plywood over a 150 mm air space with timber sheeting, and given extra reflective foil lining only in the "white" case. The internal load due to fluorescent lights is at 8 W/m^2, controlled to exploit natural daylight from windows. Three air changes per hour indoor natural ventilation were assumed during occupancy 8 AM - 6 PM, and 0.5 air changes after hours. Roof ventilation was set at 1.0 air change per hour to represent well-ventilated construction at roof level. The building population of 24 people is 0.19 per m^2, with metabolic load of 108 Watts/person = 20.5 W/m^2.

For both the nominal "dark" and "white" case we have set roof and wall thermal emissivities to 0.9. The solar reflectivity, on the other hand, has been set to 0.3 for the "dark" case and 0.7 for the "white" to represent degradation after some dust and dirt has settled on the roof surface. In the "white" case we also set the emissivity of the tile underside to 0.05 to represent a single side of reflective foil lining.

Using the DesignBuilder software two alternative materials specifications were created, and subsequently 20 simulations were run in the EnergyPlus engine supplied with DesignBuilder [as per reference 7].

3. Results

Townsville conditions are used to illustrate the results of the simulations (Figs. 2 and 3). Figure 2 shows the roof cavity and room air temperatures together with the outdoor temperature and Fig. 3 the room loads. It is apparent that the temperatures vary significantly with roof colour. In particular Fig. 2 shows the room below a dark roof is substantially hotter than the room below white roof.

Further simulations may investigate the impact of higher mass constructions, to establish if room comfort conditions could be improved further. Nonetheless, it is clear from the lightweight construction high internal load example that radiation control barriers appreciably reduce indoor space temperatures. The results from Townsville can be compared in Table 2 among the ten Australian locations simulated.

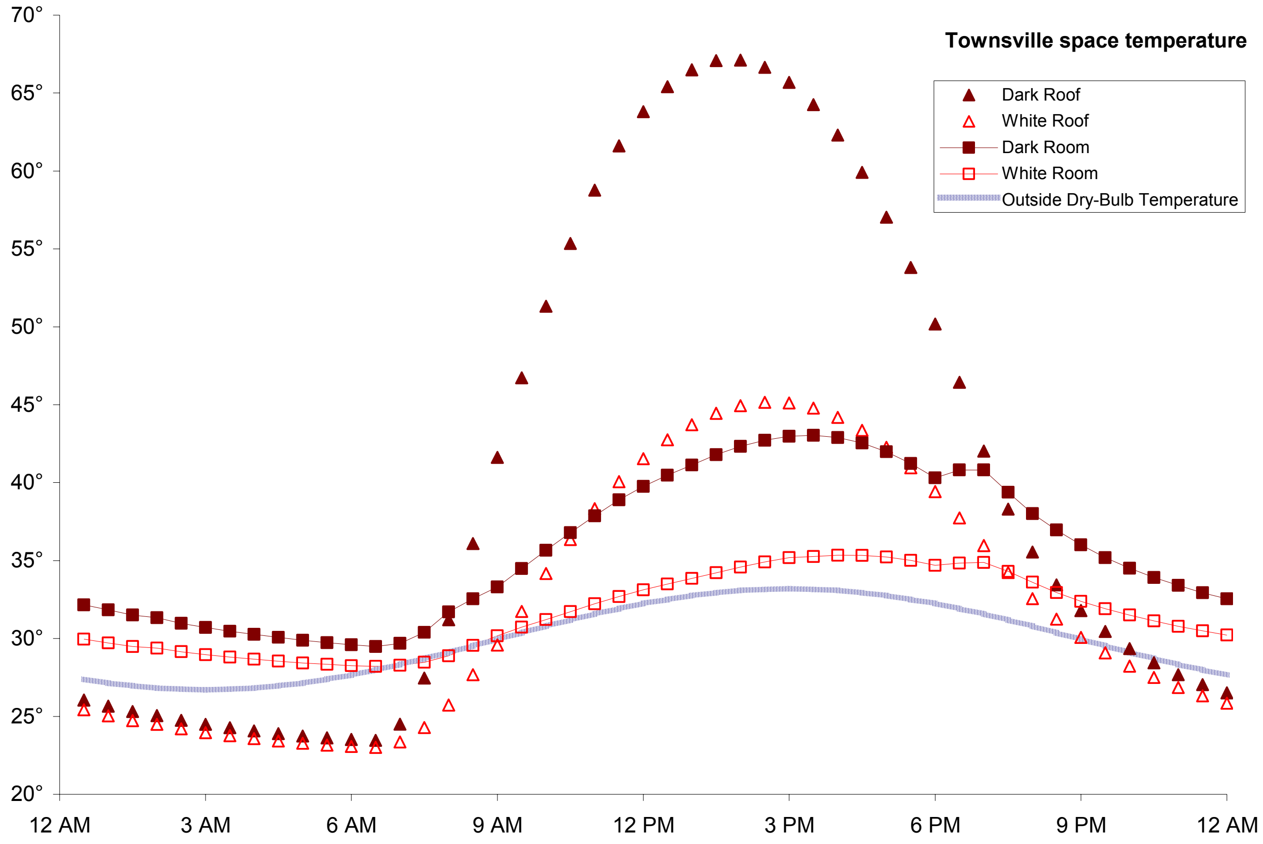

Figure 2: Temperatures in roof space and room below plasterboard for the dark and white school building during 99.6% design hot weather conditions in Townsville.

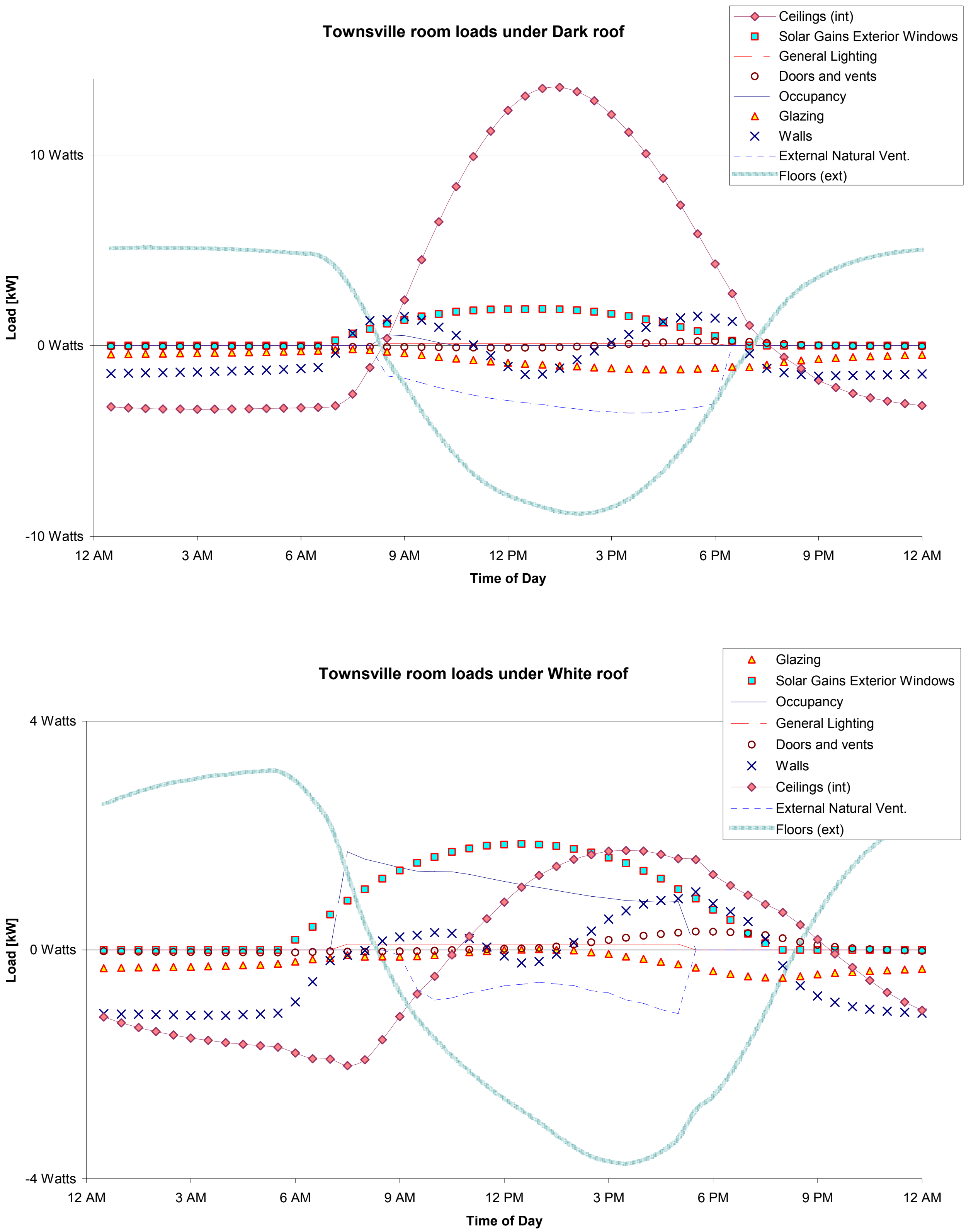

Figure 3: Heat transfers internally and through the fabric of the room of the Townsville school building. (a) The "dark" case; (b) "white" case. The difference between all of these loads translates into space temperature changes (see Fig. 2), mitigated by thermal mass.

The average outdoor to indoor air temperature difference values, ΔT, of the naturally ventilated light weight buildings with day-time occupation 9 AM through 5 PM are tabulated in Table 2 outdoor temperature. The building receives a net-cooling-benefit of about 6 K by changing the un-insulated roof and walls from "dark" to "white" and by adding foil into the wall cavities and under the roof and floor. For the above temperature reductions to be achieved it is important that the high solar reflective roof also maintains a high thermal emissivity to the sky and low thermally emissivity to the ceiling below.

Table 2. Average outside to inside temperature difference $\Delta T = T_{outside} - T_{inside}$ for the roof space and room in simulated lightweight school buildings for ten Australian cities (9 AM to 5 PM).

City	Net Cooling Benefit changing from Dark to White	Dark roof ρ=0.3 (Outdoor air – Ceiling space)	Dark building ρ=0.3, Outdoor –Room ΔT [K]	White roof ρ=0.7 (Outdoor air – Ceiling space)	White building ρ=0.7 Outdoor –Room ΔT [K]
Townsville	6.4	-27.9	-7.7	-8.5	-1.3
Brisbane	6.6	-28.8	-8.1	-9.0	-1.5
Sydney	6.6	-29.6	-9.4	-10.0	-2.8
Canberra	6.6	-26.7	-6.8	-6.7	-0.2
Melbourne	6.5	-25.9	-6.5	-6.2	+0.0
Hobart	5.9	-27.3	-7.6	-8.0	-1.7
Darwin	6.0	-25.6	-6.9	-7.1	-0.9
Alice Springs	6.6	-24.2	-5.5	-4.5	+1.1
Adelaide	6.5	-26.1	-6.6	-6.4	-0.1
Perth	6.6	-26.3	-6.8	-6.5	-0.2
Average [K]	**6.4**	**-26.8**	**-7.2**	**-7.3**	**-0.8**

Besides indicating a building's passive cooling capability relative to the ambient temperature, our simulation results enable reading of Fig. 4, taken from a previous study on the effect of roof colour [4]. The present study considers passively cooled buildings where there may be negative $\Delta T = T_{outside} - T_{inside}$. Generally we find from Table 2 that the average ΔT from 9 AM to 5 PM is of order of -6 to -9 K in the case of dark un-insulated building, but near zero for the white building with reflective foil cavities.

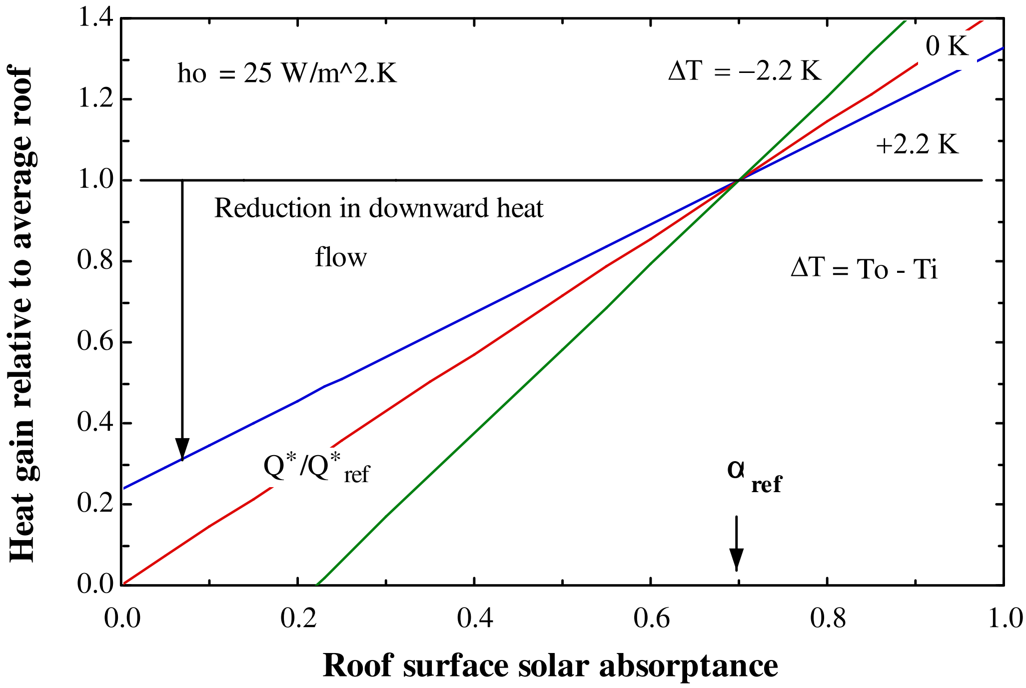

Figure 4 Effect of solar absorptance on the roof heat gain relative to an average roof with α = 0.7 solar absorptance (Note solar reflectance ρ = 1 - solar absorptance α for opaque surfaces).

Figure. 4 from the prvious study shows [4] how a reflective roof colour reduces the heat gain of buildings in the tropics. That study estimated ΔT = +2.2 K as a population-weighted annual average for air-conditioned building in northern Australia, and speculated that $\Delta T \approx 0$ K would a conservative approximation of passive cooled case buildings.

Discussion and Conclusions

This study has focused on a comparison between school buildings with dark and white roofs without bulk insulation. The results suggest that significant improvements to the building energy efficiency or comfort level can be achieved with the selection of an appropriate roof colour (white for hot climates) and the inclusion of reflective air spaces. For the building with white roof the temperature difference between the ambient and the room air temperature approached zero, which suggests ΔT = 0 K may be an appropriate base-case for "well-designed" passively cooled buildings. Poorly insulated buildings with dark roofs, on the other hand, may have a substantially negative ΔT (i.e. the inside room temperature is substantially higher than ambient), which suggests that the benefit of lighter roof colour was understated in the previous study for passive buildings [4].

The present study has succeeded to quantify the effectiveness of passive cooling with a “cool roof” and walls that include reflective foil but use no bulk insulation. Very good solar shading was applied to both the “dark” and “white” buildings. In both cases the electric lighting was reduced when sufficient natural day lighting was available. In future research it would be interesting to re-run the “dark” vs. “white’ simulation with double glazed low e-glass, more sophisticated ventilation schemes and some use of bulk insulation. But most important would be to quantify how ceiling bulk insulation restricts the passive cooling of the buildings in hot climates.

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CITY AS A CATCHMENT: A STRATEGY FOR ADAPTATION

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Keywords: integrated water cycle management, WSUD, water sensitive city, city as a catchment

Summary

The municipality of the City of Melbourne is committed to conserving water and protecting the beneficial uses of its waterways through stormwater quality improvement projects. Viewing the '*city as a catchment*' enables water management decisions to be understood in terms of the overall contribution to achieving water conservation and water quality targets across a municipality.

City as a catchment is one of the fundamental principles of a water sensitive city and seeks to minimise importing potable water, and exporting wastewater, from and to areas outside of the boundaries of the city. Instead it optimises the use of water resources within a city, recognising the natural catchment relationship, but working within the artificial city catchment (including its roads, roofs, and impermeable surfaces).

Understanding the quantity and location of water flowing through the municipality, and the pollutants being carried with these flows helps local government to initiate and assess sustainable water management projects. Sites across the city can be categorised as a 'source' (eg: sites that can harvest stormwater such as a road, or harvest rainwater such as a building with large roof) or a 'sink' (eg: large water-using business or park). Quantifying a water balance and stormwater pollutant budget enables links to be made between these sources and sinks. Demand management practices and harvesting alternative water supplies is crucial to achieving more sustainable water management practices.

Applying the *city as a catchment* philosophy to the City of Melbourne's management of water is an adaptation strategy done in response to climate change. It provides a basis for moving towards an informed city as an ecosystem approach that encompasses greenhouse mitigation and habitat protection and stretches beyond single municipal boundaries.

1. Introduction

An emerging challenge for urban communities is to incorporate design strategies that provide resilience to future uncertainty associated with drought and climate change, while catering for increased demands placed on the supply system due to population growth.

The concept of *city as a catchment* strives to close the loop on the urban water cycle within a catchment, and in this project within the municipality boundary of the City of Melbourne. *City as a catchment* espouses that government and urban water managers will minimise the use of potable water and optimise the use of alternative water resources across a catchment in a 'fit-for-purpose' capacity that is shaped by a carbon sensitive approach. Stormwater discharged to receiving waters should be treated to improve its quality and minimise its impact on the ecologic health of these systems.

Committing to the principle of *city as a catchment* provides a basis for the development of an implementation plan to strategically integrate sustainable water management practices into the urban landscape. Implementation plans will strengthen organisational commitment to sustainable water management by implementing WSUD across all their assets (including parks and gardens, building and roads). Local governments influence needs to extend beyond adoption within the public domain, through the regulation and provision of incentives to facilitate the uptake of WSUD in the private domain (including commercial and residential sites). It requires institutional capacity as a prerequisite to accomplishing integrated water management at all scales of urban design and development.

This paper explores the water balance and pollutant budgets for the City of Melbourne, water management targets and implementation to achieve the targets. For more information refer to *City as a Catchment* report (EDAW, 2008) and *Total Watermark – City as a Catchment Strategy* (City of Melbourne 2008).

For the remainder of this paper the term 'City of Melbourne' refers to the 3650 ha municipality area under the jurisdiction of the City of Melbourne council and located at the bottom of the Port Phillip Bay catchment including waterways Victoria Harbour, Yarra River, Maribyrnong River and Moonee Ponds Creek.

2. Climate Adaptation

The City of Melbourne has recently released a draft *Climate Change Risk Assessment and Adaptation Strategy* that sets out the likely local climate changes including rainfall decreasing between 2-4% by 2030, higher evaporation, reduced stream flows of between 3-11%, more frequent and intense storm events, and higher sea levels and associated groundwater levels.

The draft *Climate Change Adaptation Strategy* recommends that stormwater harvesting is one of two key high value adaptation measures that Council can undertake to assist in both flash flooding events and insufficient water supply. Stormwater harvesting is a central platform of the city as a catchment philosophy.

It is identified that progress from the water industry in applying rainfall data in modelling program to reflect climate change is needed as a priority to ensure we are best providing for future rain events.

3. Water cycle management targets

The City of Melbourne has committed to a range of integrated water cycle management targets directed at water conservation, stormwater quality and wastewater minimisation. The baseline year selected to calculate water volumes and pollutant loads is 2000. The percentage reduction targets are measured against this baseline year data.

For stormwater quality improvement the City of Melbourne has drawn on State best practice targets that were introduced in 1999 for the mean annual load reduction in litter, sediment and nutrients. To reach an 80% reduction in mean annual load of total suspended solids (TSS) and a 45% reduction in mean annual load of total phosphorus (TP) and total nitrogen (TN) Council has committed to a 20% reduction in mean annual load of TSS and a 15% reduction in mean annual load of TP and a 30% reduction in mean annual load of TN generated across council managed assets by 2020. At a municipal wide level the TSS:TP:TN targets are 20:25:40 by 2020.

The City of Melbourne's water saving target sets a 40% reduction per resident in mains water use by 2020, a 40% reduction in total water demand that is attributable to council activities, and 50% reduction in water use per employee for commercial/industrial by 2020 (Total Watermark, 2004). This will total an absolute saving of 22% allowing for 120% population growth to occur by 2020.[1]

4. Water balance and stormwater pollutant budget

The water balance calculated for the City of Melbourne has been separated into council, residential and commercial demands (sinks) and different sources of urban runoff to provide insight to the potential for harvesting stormwater to meet a proportion of the total demand across the municipality.

Water Sinks

Figure 1 shows that commercial practices place the greatest demand of 72% on mains water supply (18,243 ML/yr) followed by residential at 22% (5,541 ML/yr) and council at 6% (1,585 ML/yr) of demand. Even though Council's demand represents a relatively small proportion of the total, Council has an important role to play in providing leadership in the community.

88% of mains water is discharged to sewer as wastewater (22,510 ML/yr) from the municipality. Demand management practices and programs design to stimulate their uptake across the commercial sector are critical to conserving mains water and reducing wastewater flows. A total of 11% (2,959 ML/yr) of mains water is used for outdoor purposes (including residential garden watering and irrigation of public open spaces). Irrigation of public open spaces represents 65% of the demand placed on mains water supply by council managed assets which equates to 4% of municipal-wide demand. Ample stormwater is available to meet the municipality's mains water demands such as irrigation requirements by tapping into catchment drainage that flows adjacent to parks and gardens.

[1] *The above targets are all proposed at the time of writing and available for consultation. The targets will be considered by the Council of the City of Melbourne prior to the SB08 conference and may be confirmed or modified accordingly.*

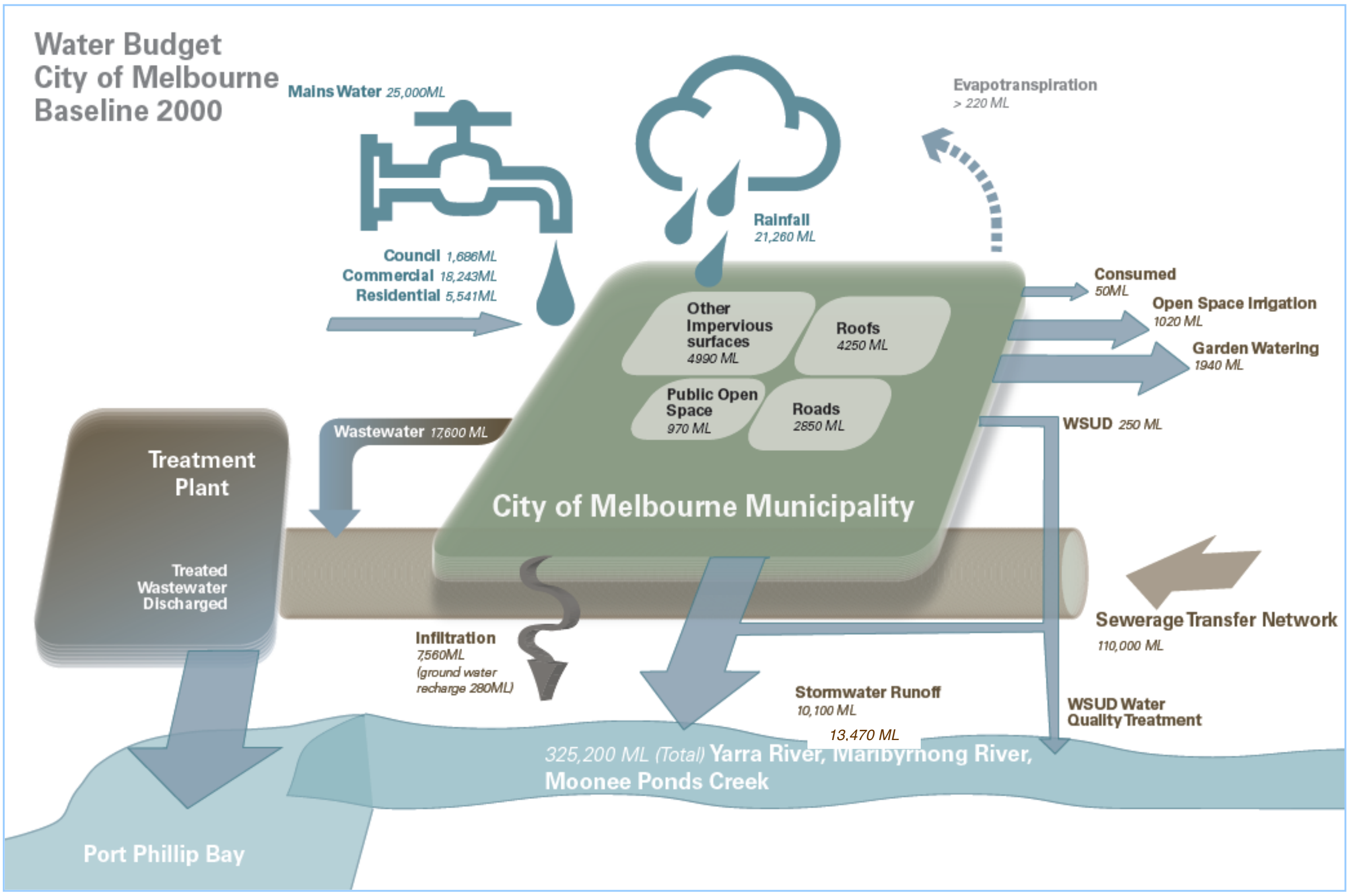

Figure 1. Water balance for the City of Melbourne

Water Sources

The mean annual rainfall volume across the municipality is 21,260 ML, of which 63% (13,470 ML) is discharged as surface runoff, 1% (220 ML) is returned to the atmosphere via evapo-transpiration processes and 35% (7,560 ML) infiltrates into the underlying soils. 1% (280 ML) of the infiltrated runoff contributes to groundwater recharge across the municipality.

Across the City of Melbourne existing stormwater harvesting projects (undertaken on both privately owned land and in the public domain) collectively remove about 2% (250 ML) of runoff (and associated pollutants) discharging to waterways. This water is predominantly used to supplement mains supply for irrigation of parks, gardens and sporting facilities, toilet flushing, and wash down of enclosures at the zoo.

A total of 4,230 ML/yr of roof runoff is generated across residential and commercial sites providing an abundance of water that could be harvested and used for garden irrigation, toilet flushing, hot water and laundry purposes. Private impervious areas and roads are other sources of runoff that could be harvested to provide a valuable supply.

Whilst the water budget shows that harvesting rainwater and stormwater could meet 70% of local potable water needs on paper, it is limited by available sites for storage. Using large sites in the CoM as a case study, it was demonstrated that the harvesting potential averages about 43% of the needs of the site with storage sizing based on an 80% reliability. Typically 90% of rainfall volume is attributed to frequent events smaller than the 1 in three month annual recurrence interval (ARI). Smaller rainfall volumes are easy to harvest because the equipment (such as tanks or storage pond, lakes) to hold this volume of runoff can be relatively small.

These opportunities; rainwater tanks, stormwater harvesting and wastewater recycling; to source water are readily available within the municipality. The COM adopts an alternative water source hierarchy for for use across the municipality, as set out in Table 1. The hierarchy seeks consideration of demand management strategies in the first instance followed by local sources, before offsetting any shortfall from sources outside of the municipal boundary or wastewater harvesting (which typically has high energy demand implications).

The water hierarchy reflects that alternative water sources have unique reliability, energy cost, environmental risk and economic profiles.

Table 1 Water Management Hierarchy for the City of Melbourne

Water source	Advantages	Challenges	Recommendations
Water Management from within the local catchment			
Demand Management	▪ Cost efficient ▪ No treatment ▪ Reduces wastewater ▪ Provides resilience to climate change	▪ Relies on behaviour change from all household or workplace members	▪ Demand management measures to be underway and demonstrated prior to alternative water sourcing
Roof runoff	▪ Multiple water cycle benefits (mains water conservation and reducing stormwater volumes and pollutant loads discharged to environment) ▪ Minimal treatment required as roof runoff is considerably cleaner than other alternative sources of supply ▪ Provides resilience to climate change	▪ Volume of supply to meet competing demands ▪ Reliability of supply ▪ Potentially higher pollutant concentrations conveyed to receiving waters from other landuse practices across catchment because runoff is not diluted with cleaner roof runoff (treatment of stormwater quality from sources, such as roads, is important to counteract this potential issue)	▪ Decentralised system requiring minimal infrastructure and maintenance. ▪ Greatest water conservation and ecosystem protection benefits achieved when used for indoor demands such as toilet flushing ▪ Also viable for other purposes such as garden irrigation when other sources are not a practicable supply option
Stormwater runoff	▪ Multiple water cycle benefits (drinking water conservation and minimising stormwater discharge to the environment thereby reduce pollutant loads to receiving waters) ▪ Provides resilience to climate change	▪ Reliability of supply ▪ Land uptake for treatment and storage requirements in confined spaces ▪ Dependent on committed on-site management.	▪ Decentralised system – preference is to supplement open space irrigation. ▪ Water not harvested should be treated to improve water quality and manage flows prior to discharge to receiving waters ▪ Provides landscaping values
Wastewater	▪ Multiple water cycle benefits (water conservation and minimising wastewater discharges to receiving waters) ▪ Provides resilience to climate change ▪ Constant supply	▪ High energy expenditure for treatment to meet end use water quality requirements ▪ Limit direct pathway for ingestion to minimise risk ▪ Storage requirements if supply-demand do not match ▪ Possible increase in salt and nutrient levels in supply, irrigation rates need to be well managed to ensure excess runoff does not enter waterways and impact ecological health ▪ Least greenhouse efficient approach	▪ Broader sustainability impacts should be considered (such as, energy and sodicity) especially if treatment facility is not currently available
Water Management from beyond the local catchment			
Sewer Mining extracted from Melb Water Sewerage Transfer Network	▪ Multiple water cycle benefits (water conservation and minimising wastewater discharges to receiving waters) ▪ Minimal storage requirements ▪ Provides resilience to climate change ▪ Constant supply	▪ High energy expenditure for treatment to meet end use water quality requirements ▪ Limit direct pathway for ingestion to minimise risk ▪ Possible increase in salt and nutrient levels in supply, irrigation rates need to be well managed to ensure excess runoff does not enter waterways and impact ecological health ▪ Least greenhouse efficient approach	▪ Broader sustainability impacts should be considered (such as, energy and sodicity) especially if treatment facility is not currently available
Stormwater from Yarra River, Maribyrnong River and Moonee Ponds Creek	▪ CoM is at 'bottom of the catchment' and is able to draw water without negative environment or habitat implications ▪ Minimal storage requirements ▪ Constant supply	▪ Surface waters are saline in CoM and if extracted, would need to be desalinated before use (high energy use) ▪ License requirements to ensure appropriateness of extraction ▪ Least greenhouse efficient approach	▪ Energy and treatment considerations of desalinating need to be carefully accounted for if this is to be pursued.
Mains water	▪ Inexpensive supply (because externalities remain unaccounted for and supply was heavily subsidised by government in its establishment phase) ▪ Existing infrastructure is accessible and regulations/approval process are well understood ▪ Most greenhouse efficient approach	▪ Reliant on single source of supply that is vulnerable to drought ▪ Population growth and urban consolidation across Melbourne is placing greater pressure on mains supply ▪ Climate change will result in less runoff due to higher temperatures and lower soil moisture levels ▪ No ecological protection 1. issues associated with environmental flows downstream of water supply reservoirs, and 2. no means to reduce stormwater or wastewater discharges to the environment	▪ Mains water is an important part of the water supply mix, but where possible, other alternative sources should be sought first. ▪ Demand management already undertaken in water management hierarchy to reduce water use ▪ Harvest alternative sources of water to conserve mains water and complement potable water use.
Groundwater	▪ Minimal storage requirement ▪ Can be sources close to end-use	▪ Groundwater shallow and saline in CoM and Yarra Delta region (SKM (2006)) ▪ CoM located on unconsolidated quaternary alluvium deposits and hence very low storage potential for ASR. ▪ Groundwater, if extracted, would need to be desalinated (high energy use) ▪ License requirements to ensure appropriate extraction ▪ Climate change will impact on groundwater flow and quality due to sea level rise	▪ Not considered a viable solution for the CoM due to the shallow and saline nature of the groundwater.

Water Pollution

For stormwater runoff volumes generated from different land use types across the municipality pollutant loads are quantified. Table 2 shows that land use types responsible for the greatest pollutant loads are roof areas for nitrogen loads, and roads and other impervious surfaces for total suspended solids.

Table 2 Stormwater pollutant budget for the City of Melbourne

	City of Melbourne managed assets			Private ownership			Total
	Roads	Public open space	Nature strips	Roof	Other impervious surfaces	Pervious areas	
Flow (ML/yr)	2,850	970	115	4,250	4,990	325	13,466
Total Suspended Solids (kg/yr)	875,000	12,500	1,470	108,000	860,000	4,230	1,861,200
Total Phosphorus (kg/yr)	1,660	99	12	591	1,450	34	3,845
Total Nitrogen (kg/yr)	6,740	920	107	10,000	11,500	310	29,577

The greatest water pollution reductions made to date in the City of Melbourne have resulted from rainwater harvesting which diverts stormwater and its pollutants (primarily nitrogen) from the waterways. Rainwater harvesting projects by Council have included Queen Victoria Markets, childcare centres, and sporting pavilions. The private community has generally embraced rainwater tanks with their increasing prevalence in households, industrial premises and large entertainment venues.

In addition to rainwater tanks, stormwater management projects are now being realised on the ground. With the generous support of Melbourne Water, ten projects to date are treating stormwater quality prior to discharging to receiving waters; these projects may involve more than one treatment measure such as the street pit trees located in the Docklands and in Little Bourke Street and also includes large and small scale wetlands, and biofiltration systems.

The stormwater pollution budget for the City of Melbourne shows that private impervious surfaces, roof areas and roads generate the greatest volume of runoff across the municipality. Land uses responsible for the greatest loads of pollutants in the City of Melbourne are:

- *Roads and other impervious surfaces for total suspended solids.*[2]
  The generation of total suspended solids is very high in the City of Melbourne for both Council land and non-Council land. TSS is primarily generated from roads, and is therefore very high in the City because of its highly urbanised nature and road coverage.
- *Roof areas for nitrogen loads*
  Like TSS, nitrogen in stormwater is generated from roads, footpaths and driveways, however one of the other primary generators is roofs (as roof water picks up atmospheric pollutants which largely includes nitrogen). Nitrogen is particularly relevant for non-Council land because of the large amount of roof space.

[2] based on updated stormwater flow concentration parameters used by Coomes (2007) using Fletcher (2005) recommendations

5 Achievements to date

Quantifying and understanding targets for the City of Melbourne enables implementation plans to be developed that define the fundamental building blocks and interim targets that can be realistically achieved over time. Simultaneously considering management targets for different aspects of the urban water cycle highlights where complimentary benefits are found. Table 3 summarises the flow management benefits achieved through the implementation of WSUD practices to date (demand management practices refers to permanent fittings and fixtures).

Since 2000 there has been a 34% reduction in the volume of mains water used across the municipality. This is largely due to the uptake and installation of demand management practices across council owned assets and residential areas. Reductions across council managed assets are 28% (refer to Table 3) which is attributable to demand management practices including improved irrigation practices in parks and gardens.

Table 3 Flow management benefits achieved across the City of Melbourne

	Water stream	Land ownership	Baseline 1999 Volume generated (ML/yr)	Current 2006/2007 Volume reduction (ML/yr)	Current 2006/2007 % reduction	2020 reduction target
Demand	Mains water supply	Municipality (total)	25,470	8,500	34%	22%
		Council	1,685	489*	28%	40%
		Private residential	5,541	1,142*	20% 39% per resident	40% per resident
		Commercial/industrial	18,243	6813	37% 48% per employee	50% per employee
Source	Stormwater	Municipality (total)	13,466	238	1%	9%
	Wastewater	Municipality (total)	22,510	6,424	29%	30%

*current water use accounts for a 6% reduction attributed to restrictions rather than to the installation of permanent demand management fixture and fittings

The highest proportion of mains water consumed is across the commercial/industrial sectors. Programs designed to address their high water consumption have been initiated since 2000; the benefits of which are assessed as part of future WSUD benefits. Indoor demand management practices have inherently contributed to a 29% reduction in wastewater generation across the municipality (shown in Table 3).

Four percent of the total pollutant loads for nutrients and TSS has been achieved to date through the implementation of WSUD projects. Table 4 quantifies predicted stormwater pollutant loads removal across the municipality through WSUD projects by 2020. This information was used to quantify viable 2020 water quality targets and establish a strategy for implementation with works identified to achieve the targets.

Pollutant load removal across the private residential sector is entirely attributed to the uptake of rainwater tanks. These reductions are considered minimum volumes given that tank uptake is based on rebate data from the water retailers and these data sets do not capture all tanks installed private properties.

Table 4 Stormwater pollutant load removal and predicted percentage removal by 2020

Pollutant	Land ownership	Pollutant generation baseline year 1999/2000	% removed by 2020
TSS	Total	1,861,200	20%
	Council	888,970	15%
	Private residential	291,669	46%
	Commercial/industrial	680,561	16%
TP	Total	3,846	23%
	Council	1,771	17%
	Private residential	623	59%
	Commercial/industrial	1,453	15%
TN	Total	29,577	37%
	Council	7,767	28%
	Private residential	6,543	109%
	Commercial/industrial	15,267	10%

6 Towards innovation

The City of Melbourne has a strong foundation on which sustainable water management objectives can be built. To date, strategies have included finding ways to save mains water through efficiency, design and behaviour changes; minimising wastewater disposal to sewer through demand management, and recycling where practicable; treating stormwater to meet water quality objectives for harvesting and reuse and/or discharge to waterways; protecting groundwater from contaminants and disruption; and managing catchment hydrology, particularly for aquatic habitats.

The City of Melbourne has designed and established a tool to help staff to get a more operational understanding of how WSUD projects improve water quality. This has taken the form of a 'ready reckoner' that staff are able to use in the earliest days of conceiving projects. As seen by the examples below, water quality improvements are expressed in points which reflect the proportion of pollutant removal it can achieve, and enables useful comparisons in the function and costs of different WSUD treatments.

Using the language of 'points' has created a simpler feel for staff in understanding water pollutant loads as it is commonly the lack of confidence of staff that is the biggest implementation barrier rather then the lack of skill and capacity of staff. A language of points has helped staff to compare WSUD treatments and costs and give a sense of scale to the challenge of meeting municipal stormwater targets.

Treatment	WSUD treatment area	Catchment Area Treated	Points (reflecting proportion of pollutant removal)	Approx Cost
1 small wsud street tree pit	1 sq. metre	260 sq. metres	1	$2,500-$7000 per tree in residential area (not CBD)
1 large wsud street tree pit	3 sq. metre	780 sq. metres	3	
1 raingarden	10 sq. metres	2500 sq. metres	10	$1,200-$2,200 per m2
1 swale	40 metres	1 ha	50	$50 - $300 per m2
100kL rainwater tank	1.3ML/year of roofwater	2500 sq. metres	1	$75-$400 per kL
porous paving	30 sq. metre	1000 sq. metres	4	$150 - $500 per m2
1 small wetland	1000 sq. metres	5 ha	100	$150-$200 per m2
stormwater reuse 7ML/year	400 KL storage	5 ha	80	

NB: Costs are based on the small number of projects done to date, and will be revised when additional data becomes available. It is likely that the costs will decrease as works become standard procedure.

It is acknowledged that some new works will be constructed in the City of Melbourne that will generate more stormwater and potentially lower stormwater quality. Therefore 'negative points' will be assigned by staff to works that increase impermeable area. For example, changing open space to an impervious surface will be -6 points, and changing open space to porous paving will be -1 point.

City as a catchment provides the platform for integrated water management which can then be applied to all works undertaken across the municipality using a range of tools and resources designed by the City of Melbourne including WSUD Guidelines, Draft Climate Neutral Sustainable Water Schemes Framework, and Draft Risk Management Framework for Sustainable Water Schemes. The integration of these key pieces of work will ensure all civic and external projects plan for more sustainable water needs and carry these through to implementation.

The City of Melbourne prioritises action for the *city as a catchment* strategy by:

Firstly, saving water and preventing stormwater pollution *at source by using non-structural techniques* including demand management strategies which engage, communicate and educate to bring about behavioural change. Other strategies include regulation, town planning controls and fiscal incentives.

Secondly, saving water and preventing stormwater pollution *at source by structural techniques* to treat and/or harvest alternative water supplies.

Thirdly, saving water and preventing stormwater pollution *in system by structural techniques*. Such infrastructure is installed within drainage/stormwater systems to manage stormwater quality and quantity before it is discharged to receiving waters.

These measures are preferable to treating and/or harvesting stormwater at the *end of pipe* where the quality of water and velocity of flow make sustainable water projects less efficient and effective.

Decision Making Guidelines

Decision-making guidelines have been set out to guide sustainable water management on a site-by-site basis. Some of the guidelines are listed below with the full list in *Total Watermark – City as a Catchment* (CoM 2008).

1. All City Sites as Catchments

All city sites (buildings, roads, open space) are to be considered holistically to contribute to sustainable water management across the municipality. Over time this will build resilience to the ongoing pressures of urban consolidation and climate change on water resources and aquatic environments.

2. Community Engagement

Community engagement is integral component of all projects and needs to include:

a) information sharing and feedback from relevant stakeholders and community about water options and potential issues;

b) community consultation to direct the scale of the project.

4. Hierarchy of Sustainable Water Solutions

A hierarchy of guiding rules have been set out to promote the adoption of sustainable water management practices across council managed assets, residential and commercial/industrial land uses.

The hierarchy establishes a general approach based on least cost, least energy intensive options in the first instance through to more complex solutions in which the water cycle benefits need to be considered in context of the projects affect on broader sustainability sectors. Water hierarchy decision guidelines are:

(1) **Protection of receiving waters** including waterways, harbours, bays or groundwater. Recreational, tourism and economic uses of waterways must not negatively affect their social or ecological values. To protect receiving waters:

a) all planning or building proposals need to demonstrate no net negative effect on receiving waters in terms of quality and/or quantity;

b) all road renewal projects and street tree replacement to promote passive irrigation where possible, and meet best practice stormwater quality standards by applying water sensitive urban design (such as, rain gardens);

c) all new building and other infrastructure in the municipality must treat catchment runoff to meet best practice stormwater quality standards by applying water sensitive urban design (this generally requires to the 3 month ARI peak flows to be treated);

d) infiltration into the water table is encouraged when treatment ensures water quality meets best practice stormwater quality standards through integration with WSUD (such as, rain gardens).

(2) **Demand management** conserves water and minimises the generation of wastewater:

a) all new building, other infrastructure and private open space works need to minimise water consumption through the installation of demand management fixtures, fittings, appliances and educational signage;

b) all refurbishments, upgrades and extensions need to minimise water consumption through the installation of demand management fixtures, fittings, appliances and educational signage; and

c) all council managed assets (including buildings, parks, gardens and sporting facilities) need to consider opportunities to retrofit demand management landscaping, fixtures, fittings and appliances.

(3) **Stormwater quality improvement** to protect receiving waters to be considered in all urban design:

a) treatment is to reduce total suspended solids, total nitrogen, total phosphorus and litter to best practice standards; and

b) WSUD treatments to be integrated in various stages of the water cycle, where appropriate, and recognising where existing water quality treatment is already occurring upstream.

c) WSUD treatments are to be modelled to demonstrate achievement of best practice water quality. Models for private land are requested to be provided to Council so that Council can acknowledge the contribution of private land to improving waterway quality.

Reference

EDAW, 2008, City as a Catchment: A Strategy for Adaptation, report prepared for City of Melbourne, EDAW, Ecological Engineering Practice Area.
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OPPORTUNITIES FOR SEMI-DECENTRALISED WATER REUSE AND POWER PRODUCTION

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Summary

Semi-decentralised water and energy systems can function autonomously but are still connected to infrastructure such as mains water, sewer and the electricity grid. The system proposed here is both for the provision of fit for purpose energy in the form of heat and electricity, and treatment of waste water for the provision of recycled water for non-potable purposes. The purpose of this paper is to explore the potential for both these systems to reduce waste such as transmission losses and their ability to produce sufficient amounts of fit for purpose outputs, while looking at the potential of the two systems to be integrated synergistically.

The basis of this paper is a literature review presenting the argument of the consideration of semi-decentralised systems in high density developed areas. This showed that there are serious issues with the current approach to the provision of energy and water in our current centralised systems. There are transmission losses which for water are 12-30% and for energy are 1-9%, the systems are built to disassociate the user with the water and energy they are receiving while being so large there is limited ability to adapt and react to changes in requirements. Lastly because they focus on only one output – electricity and drinking water, centralised systems miss the opportunities provided by using other outputs at a level that is fit-for their purpose, with the potential of saving of 50% in energy production and 80% in water provision. It is within this last point that the main gains can be made.

1. Introduction

By semi-decentralised this paper means systems that function autonomously but are still connected to infrastructure such as mains water, sewer and the electricity grid. The system proposed here is both for the provision of fit for purpose energy in the form of heat and electricity, and the treatment of wastewater for the provision of recycled water for non-potable purposes, nutrient and gas recovery.

Decentralised water systems have been written about by numerous authors (see for example, Mitchell and White 2003, Crites and Tchobanoglous 1998, Weber, Cornel and Wagner 2007); while decentralised energy systems have been used for decades in areas where the expense of brining in grid electricity is too high. The purpose of this paper is to explore the potential for both these systems to provide efficient, when compared to centralised systems, amounts of fit for purpose outputs, while looking at the potential of the two systems to be integrated in a single synergistic system.

Firstly both the water and energy issues are framed followed by a discussion on the problems generated by centralised systems. Secondly, the opportunities for semi-decentralised systems are outlined with a view to the effective use of limited resources. Finally, options as discussed for brining both of these systems together.

Water

Decentralised wastewater systems are defined as "*systems that collect, treat and reuse or dispose of wastewater at or near its point of generation*" (Crites and Tchobanoglous 1998). They include single-home onsite systems and cluster systems that may serve many hundred of homes. Centralised systems are those that serve entire communities or multiple communities (Hamilton 2004: xxi).

Weber and associates make the argument for Semi-centralised Supply And Treatment Systems (SESATS) for mega cities in developing countries based on two aspects: shortage of potable water in those areas and the rapid and unpredictable growth of cities which results in the inability to plan and implement effective centralised water infrastructure (2007:349). Figure 1 shows the SESATS arrangements. Note the use of semi-centralised as opposed to semi-decentralised, for all general purposes the definition of this system: *"are combined treatment facilities for water, wastewater and (organic) waste which provide service water for household use and intra-urban irrigation for an entire district within a city"* (2007:350) aligns to the one presented by this paper. Their argument for the use of semi-decentralised systems is to protect the environment from pollution and to manage resources sustainably. Abu-Sharkha and colleagues also argue for semi-decentralisation as it provides the best of both worlds, local production with the security of grid connection (2006:86).

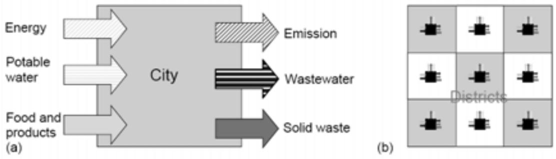

Figure 1 Comparison of centralised (a) and semi-centralised (b) systems (Weber et al. 2007:350).

For the purposes of this paper, the idea of clustering is important, that is finding an optimum amount of inputs and outputs based on technology used, type of development and types of inputs and outputs. It is different to a lot scale, or individual house level, and municipal scale, such as a catchment. Mitchell et al. (2001:616) spell out that this differentiation is needed for the discussion and understanding of a decentralised system: *"[a] cluster represents a group of uniform unit blocks that form a local neighborhood or suburb and the associated roads and public open space. The cluster can be used within the model to represent the spatial scale at which community supply and disposal operations may be managed."*

Energy

Within the city semi-decentralised systems are typically solar panels on a roof connected to the grid. There are many examples though of other systems such as wind turbines and Combined Heat and Power (CHP) systems. The definitions above for water and clusters can similarly be used to describe energy semi-decentralised systems.

2. Problems with current centralised systems and opportunities for semi-decentralised systems to address them

For both energy and water there are problems with the current centralised systems. These fall into four areas: transmission losses, waste through use of a level of energy or water above what is required for its purpose (called fit-for-purpose use), disassociation of the user with the system and the focus on the transmission system rather than the production system (Luising 2006, Langergraber and Mullegger 2006, Timmeren 2006, Timmeren et al. 2007a/b/c, Naji et al. 2006, UNEP 2004). These problems at their core mean that both water and energy resources are being used inefficiently.

Transmission losses

For water transmission losses occur in the forms of leaks and unaccounted for water. For energy it is the energy lost through the transport of the energy from the point of generation to the point of use. The Department of the Environment and Water Resources estimate lost or unaccounted for water to be 20-40% (Pers Comm Paul Starr DEWR, 2007) of the total amount used in buildings. For Melbourne this represented 49 billion litres last year (WaterSmart 2006). Leaks are thought to be a significant part of this at 12% of total water supplied (WSAA 2003:12), unaccounted water in addition is also water lost through meter slippage, theft, community service obligations etc. For energy the amount of electricity loss in transfer is around 1-9% of total energy production depending on the quality of the network (Jörß et al. 2003). Importantly, for the purpose of this paper, the further electricity is transported the higher the loss.

Fit-for-purpose use of resources

Fit-for-purpose use of resources, is the use of resources at a level of refinement appropriate for its task. As an example of the waste that is caused by using resources that have been produced to a level above what they are needed, a recent paper by Othman and Jayasuriya (2006) showed that Metropolitan Melbourne uses approximately 500 GL of drinking water for non-potable uses (Melbourne Water, 2005). The average household uses 19 - 25 per cent of its potable water supply for toilet flushing, and 35 per cent for garden watering (Water Resources Strategy Committee for the Melbourne Area 2001, ATSE 2004).

This is an inefficient use of high quality water and has led to the development of the water quality cascade (Chanan et al. 2003:2). The cascade includes fit-for-purpose water use but also water sources including potable water from the main centralised system, rain water, stormwater, grey water (showers, washing machines etc.), black water (toilets) and waste water from cooling towers. Through its use it is estimated that there could be a drop in the potable water consumed of 80% or more and reduce effluent discharge by more than 90 per cent (White and Turner 2003:6).

> *"The principle of the water quality cascade involves matching the end use of water with the quality of the water source, and utilising all water sources to meet water service needs"* (White and Turner 2003:3)

For example drinking water is not required for toilet flushing or watering the garden. When tested against the perception of risk from users, what as found was that "*customers do not necessarily want more water, rather* *they want the services that water provides, such as aesthetically pleasing landscapes, sanitation and clean clothes"* (Howe and White 1999).

For energy production, aside form the transmission losses there are significant losses in the production of energy, for coal for example, up to 70% of the energy is lost by the time it reaches the end user. Much of these losses are due to heat and the chemical conversion processes. Efficiently using the waste heat is one way of reducing the losses, but often where the power is produced there is not the demand for heat. Using a decentralised cogeneration system for example, where gas is turned into heat and electricity, can result in a doubling of the thermal efficiency and a significant reduction if carbon dioxide emissions. If natural gas is used then the production of electricity in this type of plant, emits less than half the greenhouse gasses per unit of energy produced than the most efficient thermal power station (Roarty 1999: paragraph 2).

Tanaka and Nasu (ndg:61-62) from the Japanese Ministry of Land Infrastructure and Transport, in their paper on a shift in Japan to 'A Recycling Society', describe the potential of using all of the synergistic opportunities afforded by recycling of water including use of the biosolids and production of energy. Again, relating to this need to use resources optimally by looking at the fit-for-purpose production of energy and water.

> "*Introducing source separation concepts in municipal wastewater management does allow adequate treatment of the different flows according to their characteristics. This is the key to technical solutions for the efficient reuse of water, energy and fertilizer*" (Otterpohl et al. 2002: paragraph 1)

Disassociation of the user with their water and energy system leading to overuse and misuse

> *"The lack of transparency and understanding about the value of water and energy and the systems that provide these resources has led to the overuse and mismanagement of both resources".* (Lofman et al. 2002: 73)

Due to the historic development of centralised systems which provide energy and water at the home and remove all waste away without any direct intervention by the occupant, there is a disassociation between the resource and the user. This means that if a resource needs to be limited extensive education and regulatory initiatives need to be put in place. These are expensive and need ongoing reinforcement, while they also assume that the restrictions are temporary. This does not encourage ownership of the problem. Several researchers have shown that by using more decentralized systems the user becomes more aware and responsible in their use of the resource leading to better management and reduces consumption (Naji et al. 2006, Lofman et al. 2002, Timmeren 2006).

Timmeren (2006:316) argues that if a system is within a decentralised system it increases the flexibility of the system while allowing for local response and adoption "*local decisions [and responsibility] with out abandoning the principle of scale size*", that is it links people to their responsibility allowing for better management. Further, you can identify costs and attribute these more precisely, you can anticipate market changes, transport costs are reduced, faults are identified more quickly and allows for smaller incremental investments with fewer risks. Finally, it allows the use of the outputs in a manner that is fit for purpose minimising the waste of resources.

Focus on the transmission system rather than the treatment system – response to error and ability to adapt

> *"The 'economy of scale' of central sewage pants is very often pointed out in wastewater management. However, this essentially correct fact cannot be seen isolated. In most urban areas wastewater collection and transport cause 70 to 80% of the total costs." (*Otterpohl et al. 2002:35)

For both the energy and water resource provision research has shown that most of the investment is in the transmission of the water and the energy. This is particularly true for water systems where one researcher concluded that the majority of the cost of a centralised water system is in non-productive transport, though is some areas much is done by gravity, there is still a great deal of infrastructure cost (Otterpohl et al. 2002). Rather than focusing on optimising the water treatment or energy production system much of the investment is on the maintenance of the pipes, transfer stations and other transmission systems.

Secondly this leads to two further consequences, the inability for rapid adaptation and often a delay in the response to errors. If a leak is found in your home you quickly turn off the water and get it fixed, if a leak is present in the centralised network, it may never be found, as shown by the 12% of wasted water discussed above, or if it is visible it often takes significant effort to be located and fixed. A semi-decentralised system with an on hand management system or person can identify problems, adapt to changes in influences on the system and can fix problems because of the reduced size and complexity of the system. It allows the "*real time connection to inputs and coordination and better harmony between input and outputs – supply and demand"* (Timmeren et al. 2007b:2).

Why inefficiency is a problem

The above problems are based on the assumption that there is a limited amount of energy and water resources. Further, this limited amount is being put under pressure from increasing populations combined with increases in demand and reduced supply. Melbourne's water supply will now be discusses as an example: water resources are scarce, climate change will have unpredictable impacts on it, but most agree that for Melbourne rainfall will decrease by 4 to 14% by 2020 (CSIRO 2005). Modelling and planning of the water resources are predicated on a rainfall of around 638.8mm per annum yet in the last ten years the average has been 557.7mm, a 13% drop (BOM 2007), leading to a rapid using up of water stored in catchment areas; in Victoria water storages have dropped from 80% in 2001 of capacity to around 30% in 2006 (Beeton et al. in DEH 2006:60). In the next 10 years, this change in rainfall together with an expected increase in consumption through population growth – over one million people by 2030 – (DOI 2002) will lead to a water crisis.

This paper argues that by addressing the problems listed above semi-decentralised systems should be considered in growing cities and in new developments. The next section identifies the types of semi-decentralised systems and their potential benefits for water and energy provision.

3. Opportunities with semi-decentralised systems to address problems

From the above it can be summarised that a semi-decentralised water or energy system can lead to a reduction in demand, reductions in investment costs for infrastructure, reduction in the cost of waste water treatment, takes up less overall space, improved chance of management and fine tuning, improve flexibility and the ability to react to changing conditions – say through incremental growth – and a more sustainable outcome through the more effective use of limited resources (benefits summarized from the work of: Hunt et al. 2004, Timmeren 2006:315, Hamilton 2004:6-7, Fane et al. 2004, Weber et al. 2007, U.S. Environmental Protection Agency 1997).

> *"The combined treatment offers new technical possibilities, such as mass and energy flows within the facilities, e.g. cotreatment of organic waste and wastewater and the direct use of biogas. These techniques lead to an increase in system efficiency and a decrease in the amount of residues to be disposed. Another characteristic is the proximity between consumer and treatment facilities, which allows short sewer and pipe systems, resulting in an economic reuse of water."* (Weber et al. 2007, p350)

The disadvantages to semi-decentralisation is that is needs more careful and thorough management, the economies of scale are often not there, though some of the authors cited above argue that it is more cost effective, Hamilton (2004: xxiii) concludes that it is depended to the situation and the context of the plant. Similarly Crites et al. (1998) suggest that decentralised waste water systems are not always the best solution, their research showing that it depends on the context but particularly if there is the opportunity for use of the various products in a fit-for-purpose manner, or where resources are under strain (for both water and energy it seems that climate change will be something that will increase this strain for many countries (IPCC 2007)). Depending on the system it may require a greater amount of cooperation by the residents, for example, by not using certain detergents, and the issues associated with change of ownership. Finally the responsibility of management of the system and ability to ensure it is running smoothly is highlighted as a potential problem.

As discussed above each semi-decentralised system needs to be designed and implemented based on the resources and needs of the sites, a outer suburban bungalow development will be different from a high density development in the inner city. Friedler and colleagues suggest that for water multi-storey residential buildings, in densely populated urban areas is where the potential is greatest (Friedler et al. 2005:222).

Livingston and associates (2004: 581), quoting Australian research, show that Australia scarcity of water is a major driver in the exploration of alternate and recycled water sources in major cities (Dillon & Ellis, 2004, Radcliffe, 2004, Naji and Lustig, 2006). They conclude: *"[t]he traditional approach to augmenting supply to meet growing demand is no longer regarded as a desirable option (Australian Senate, 2002), with growing awareness of the environmental impacts of such an approach*". Australia is not the only country though, as mentioned above Japan is looking at increased efficiency through becoming a recycling society. While in fast growing areas such as China the problem of insufficient supply, disposal and treatment in the next couple of years will be a crucial issue (Weber et al. 2007).

4. Types of potential water and energy systems

This section briefly outlines some of the technologies that could be used in a semi-decentralised system for the provision of either water or energy. The aim is to lead to a synergistic system where a combination of these technologies provides a holistic solution to the environmentally responsible provision of energy and water.

Water systems

Crites defines the elements of a decentralised wastewater management system as: wastewater pretreatment, wastewater collection, wastewater treatment, effluent reuse or disposal and biosolid and septage management (Crites et al. 1998:7). This paper is mainly concerned with discussing the water treatment aspect, though the other elements also have crucial roles to play in effective provision of fit-for-purpose water. For high density situations with little excess space the literature recommends anaerobic treatment systems (Timmeren et al. 2007c and Otterpohl et al. 2002). Depending on the regulatory context there will be a need to further treat the outputs from this system using either aerobic post treatment or advanced membrane technologies such as ultrafiltration/microfiltration followed by reverse osmosis.

Energy systems

Semi-decentralised energy systems are numerous, as mentioned previously these can be grid connected solar panels, wind turbines, and so forth. For the purpose of this paper generation using cogeneration systems are of greatest interest. Cogeneration uses gas as its source of fossil fuel, this can be natural gas but can also be methane or other biogas alternatives. As discussed previously using this type of system can halve the greenhouse impact per unit of electricity produced (Roarty 1999, Abu-Sharkha et al. 2006), furthermore, being close to the point of use heat generated can be used while minimising transmission losses. Depending on the context the heat could be used for heating of hot water, space heating or with an absorption chiller could be used for cooling.

The term cogeneration can refer to many types of systems depending on the input fuel, scale, use of heat and electricity. The main types for small scale use in a semi-decentralised system are: reciprocating engines; Stirling engines; gas turbines; and fuel cells. For the purpose of this paper the main criteria is the effective use of gas as the source of the energy. Madlener and Schmid (2003) studied nearly 5,000 CHP systems and found that 17-18% of them ran on landfill or biogas as the fuel. Considering the potential methane output from the water recycling system the potential starts to become obvious.

Being semi-decentralised the challenge will be in its interaction with the grid, as Lasseter (2002) points out it is possible for local generation with limited central control so that there is an even transition to stand-alone mode in case of power loss in the grid, the challenge is in how to re-synchronise once the grid is operational once again.

Energy water nexus

The central point of this paper is the need to use our limited resources more efficiently and this is possible by decentralising water provision and treatment and energy provision. There is a strong link between energy and water use, researchers such as Thirlwell et al. (2007) and others write about the energy water nexus – that is the direct link of energy and water – that is you need water to create energy and you need energy to collect, transport, treat and supply water. Improvements in efficiency in one leads to increase efficiency in the other similarly scarcity in one will lead to greater use of the other and ultimately scarcity and increased costs. For example, to produce one kilowatt-hour of electricity requires 140 litres of water for fossil fuels and 205 litres for nuclear power plants (Thirlwell et al. 2007:4).

This illustrates that we need to stop looking at our energy, water and waste systems as separate systems that are not affected by each other, this misses efficiency opportunities and does not represent the real world (Timmeren 2006: 315). Everything is interconnected and if you look at it from this perspective there are many opportunities that can be taken up. Looking at the issue from this perspective allows for the potential to develop more imaginative schemes *"for meeting the local requirements in a flexible manner with the small scale generators and consumers closely integrated."* (Abu-Sharkha et al. 2006:85)

5. Integrated system

Thus bringing together water treatment and provision with energy production in a semi-decentralised approach would seem to play to these synergies. Taking water, treating it, collecting the gas, nutrients and treated water and providing both fit-for-purpose water and energy. Increasing the capacity of the system by also adding green waste should also be considered. The research now needs to focus on the feasibility of these systems not only to provide adequate water and energy and the facilities that are needed to allow effective use of all of the outputs, particularly the heat and the nutrients. Further it is crucial to look at how the brining together of different technologies can be managed and the delineation of responsibilities and ownership.

> *"Decentralized systems turn out to be able to gain efficiency advantages as compared to fully centralized systems, particularly through the design of an integrated system of energy generation and supply, and through the connection of this system to a waste water treatment system coupled to nutrients recycling."* (Timmeren et al. 2007a:10)

Case study

The system advocated in this paper has been designed for a small residential (250 homes) and commercial/education area called the “EVA Lanxmeer” in Culemborg in the Netherlands. This system has not yet been built but it is expected that when it is operational that it will treat all of the effluent of the development and provide a total energy production 118 kWh/day, 37 is needed for the plant and the rest is available for use in the development. This combined with the reduced requirement for energy and water transport and losses is expected to save 194 kg/home/yr of CO_2 (Sidler et al. 2004). This is increased if the if the sludge is further used in the living machine this increases to 210 (Timmeren and Tawil, 2006). Given these figures it would seem that further work needs to be done on the energy outputs, as the system would need to be augmented with additional gas to offer ongoing supply, again this is why a semi-decentralised system is an optimum solution.

The EVA system is called the Sustainability Implant (Timmeren and Sidler, 2007), it is a technical and architectural solution developed specifically for the unique requirements of the site, it is shown in the chart below (Figure 2) and is made up of (Timmeren et al. 2007a:5):

> *“1. Gathering black water on the one hand and green household waste (and to some extent garden waste) on the other, and leading them into the system;*
>
> *2. The fermentation process, with biogas, effluent and sludge as its output;*
>
> *3. Purifying and improving the gas into natural fossil gas equivalent;*
>
> *4. Purifying the effluent until it has surface water quality;*
>
> *5. Composting sludge into usable garden compost.*
>
> *…*
>
> *6. Collection of separated waste flows (Retourette) and e-delivery goods of the district;*
>
> *7. Using the biogas in a combined heat power plant (CHP), CO_2 in glasshouses and purified water in the spa and vitality facilities.”*

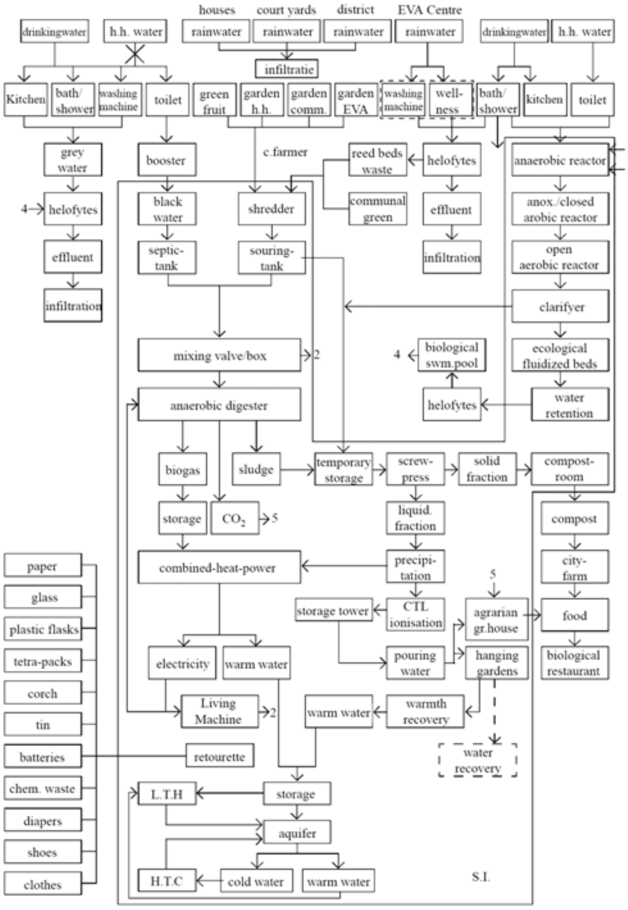

Figure 2 – Outline of EVA system (Timmeren and Sidler, 2007:31)

6. Conclusion

There are serious issues with the current approach to the provision of energy and water in our current centralised systems. There are transmission losses which for water are 12-30% and for energy are 1-9%, the systems are built to disassociate the user with the water and energy they are receiving while being so large there is limited ability to adapt and react to changes in requirements. Lastly because they focus on only one output – electricity and drinking water, they miss the opportunities provided by using other outputs at a level that is fit-for their purpose, with the potential of saving of 50% in energy production and 80% in water provision. It is within this last point that the main gains can be made in the efficient provision of energy and water while dealing with waste water and green waste.

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CARBON SENSITIVE WATER SCHEMES: IMPLEMENTATION FOR URBAN WATER SCHEMES

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Summary

Reusing or harvesting water is a great way to reduce our reliance on potable water, but it can have environmental consequences. For alternative water sources, additional infrastructure and treatment are required resulting in extra greenhouse gas emissions. This raises the questions - are we emitting additional greenhouse gas emissions which contribute to global warming and climate change? Can we be water self-sufficient and climate neutral?

The City of Melbourne has developed a methodology to help deliver carbon sensitive water reuse (rainwater, stormwater, greywater and blackwater) projects. This methodology is consistent with the Australian Greenhouse Office approach, utilises life cycle thinking to ensure interactions with other social, environmental and technical issues, and has consistency in decision-making within the institutional arrangements over a range of scales.

To demonstrate the methodology it is applied to two projects; the first at the household level for the application of a rainwater tank connected to toilet flushing, and the second an analysis of City of Melbourne's new office building CH2 which contains a water mining plant.

1. Introduction

Urban water management is increasingly under pressure. The prolonged drought, climate change and increased population density strain our already stressed centralised water system. Traditionally, Australian cities have generally been able to rely on surface water runoff from large external catchments for all urban water demands. Such centralised approaches have been successful in water service provision to the community, producing a high quality potable water source, which is used for a wide range of end uses varying from drinking to garden irrigation. There is now a need to consider alternative water sources along with behavioural change and demand management measures to provide a sustainable water future.

Alternative water sources can be decentralised or centralised. The centralised system involves augmenting existing dam storages with desalinated water or non-potable water. Decentralised solutions include precinct water mining schemes, stormwater harvesting or rainwater harvesting.

The inclusion of alternative water sources requires additional infrastructure and energy. Energy is required during construction and operation dependent on treatment type and construction materials. As Victoria’s energy is predominately sourced from non-renewable carbon sources, energy usage contributes to the production of greenhouse gas emissions. As the City of Melbourne is striving for climate neutrality, understanding the interaction between alternative water sources and greenhouse gas emissions is a challenge.

Water and climate neutrality present an ultimate goal for the City of Melbourne. The challenge lies in the translation of these principles into meaningful solutions for government and business practices. Tools to understand complex water systems are developing to assist water management strategies (Jeffrey et al., 1999; Beck, 2005). Currently a knowledge gap exists in availability of such tools and their relationship to climate change.

This paper presents one of the decision-making tools for building a viable and livable city. The focus here is on the nexus between alternative water sources and energy usage. The tool enables consistency for sustainable water schemes to be implemented without resulting in a net increase in greenhouse emissions.

2. Urban Water Management

Urban metabolism traditionally views cities as resource consumers. Sustainability initiatives have been focused on reducing consumption, minimising impacts and “doing more with less”. Traditional centralised systems have serviced cities by the extraction of external resources – both for energy and water. Moving towards a resource generation model, where cities are creating resources internally enhances the city’s self sufficiency. The challenge arises in ensuring our decentralised solutions actually reduce the city’s carbon and water footprint. Urban metabolism and nature provides a model for sustainable solutions.

2.1 Built and Natural Environments

The built environment has benefited from engineering advances, providing essential services through the construction of centralised water, sanitation and drainage systems. These large reticulation networks, predominately underground, have provided a cost-effective, reliable and efficient solution for water services. The centralised management system ensures high quality assurance and protects public health. Yet, the hidden and invisible nature of the centralised system has removed the connection between the built and natural form.

Over the past century, cities have evolved around these centralised systems. Buildings were readily connected to the ever expanding systems providing water, sanitation and drainage services, and landscapes developed as desired, with water no longer a limiting factor. As such, landscapes unable to be supported in the previous natural climatic conditions have been introduced within modern cities. Likewise, water bodies have also been widely incorporated throughout urban environments. In light of recent threats to water services and supply, such practices are clearly unsustainable and a shift in thinking is required.

Reducing demand by eliminating wastage of potable water is the first step in sustainable water management, beyond this then alternative water systems are required to enhance the landscape and create a connection between natural and built forms.

2.2 Ecosystem approach to water management

Learning from other complex systems, particularly ecosystems, provides new approaches for future water management. Insights for alternative water sources revolve around flexibility, adaptability and a resilience to change.

Nature provides a model for complex systems that have proven resilient to change. Ecosystems are often complex, with a multitude of individual components working synergistically. By examining natural ecosystems, insights can be attained and many of the attributes translated to the built environment. For an ecosystem to operate effectively and efficiently, the individual components must be able to communicate efficiently, manage material, energy and waste flows (Mitchell and Campbell, 2004). Inherent to the robust 'operation' of most ecosystems, is the ability to be resilient to change. Translating these attributes into the built environment provides direction in the creation of sustainable water systems.

In order to create a sustainable water system that is resilient, it is desirable that the attributes and characteristics of the system are analogous to those in the natural ecosystem (Mitchell and Campbell, 2004). These include:

- movement from water supply to water service provision
- diversity of water sources, and
- flexibility in infrastructure.

Diversity of water sources provides a key element in creating a viable and livable city that is connected between natural and built forms. The City of Melbourne is employing these principles within Melbourne through policy development, framework to assist implementers and on the ground projects.

3. Framework for climate and water neutrality

The City of Melbourne is committed to sustainable water management as articulated through *Total Watermark* (2005) and the City of Melbourne's *Water Sensitive Urban Design (WSUD) Guidelines* (2005). The City of Melbourne is also leading in the adoption of a climate neutral organisation through *Zero Net Emission by 2020* to mitigate the impact of non-renewable energy sources. The interaction of energy use and subsequent greenhouse gas emissions with alternative water supplies is articulated through *Carbon Sensitive Water Saving Schemes* (2008).

3.1 Policy management framework

Greenhouse gas emissions are one element to consider for alternative water sources. The following is a simple process for considering greenhouse gas emissions arising from potential water saving projects:

- firstly, when planning, consider all opportunities for water conservation (because saving water will also reduce greenhouse gas emissions);
- secondly, consider opportunities for alternative sources of water, namely rainwater harvesting, stormwater and wastewater recycling. If an alternative source is to be used, then;
- thirdly, undertake assessment of greenhouse gases emitting from proposed alternative source.

The City of Melbourne has developed the following process to help deliver carbon sensitive water reuse (rainwater, stormwater, greywater and blackwater) projects.

A policy framework was developed and consists of:

1. Greenhouse gas audit - establishes a baseline and compare with existing centralized services. For the City of Melbourne this was conducted by examining Scope 1 and 2 emissions for water and wastewater services.

2. Reduce water use – through behavioral change and demand management measures
3. Sustainable water scheme – develop an integrated water sensitive strategy
4. Consider the onsite generation of renewable energy to serve the water reuse scheme.
5. Consider the purchase of renewable energy (or 'Green Power').
6. Consider the use of emissions trading/carbon offsets.

The framework provides an approach for evaluating greenhouse gas emissions for alternative water saving schemes. Geographical location of the water reuse scheme will dictate opportunities available for alternative water sources and alternative renewable energy considerations. Further information is available from the City of Melbourne's Discussion Paper, *Carbon Sensitive Water Savings* (2008) and Blunt and Holt (2007).

3.2 Carbon sensitive water saving schemes

In the development of carbon sensitive water saving schemes, the definition of direct emissions (scope 1), indirect from purchase energy sources (scope 2) and other emissions (scope 3) enable a clear understanding of emissions sources. Table 1 outlines typical examples of emission sources and their classification. To ensure consistency with National standards, the approach is consistent with Australian Greenhouse Office with emissions calculated use emission factors from the *Australian Greenhouse Office (AGO) (2005)*. The delineation of scope 1, 2 and 3 emissions enables a clear understanding of the boundary conditions. Scope 1 emissions are a direct result of activities, scope 2 are purchased with the efficiency of operation is important. Finally scope 3 are supply chain dependent. Clear boundary definition is important for responsibility of emissions.

Table 1. Definition of emissions and scope with selected examples

Emissions Sources	Examples
Scope 1 Emissions	**Direct emissions**
Fossil fuels	Natural gas, Petroleum, diesel, biodiesel – e.g. Water tankers
Fugitive emissions	Methane from wetlands, sewage treatment plants
Scope 2 Emissions	**Indirect emissions from purchased energy sources**
Purchased energy	Purchased electricity
	Purchased steam/heat
Scope 3 Emissions	**Other emissions**
	Embodied energy in water
	Embodied emissions in purchased materials

3.3 Alternative water sources

Treatment will be required to upgrade water quality for the appropriate end use. Typically water used within the City of Melbourne will be treated to a high standard reflecting the water reuse applications. A range of water sources is available for integrated water resource management as shown in Table 2. Greenhouse gas emissions will be dependent on the water source, water end-use and the treatment technology selected. The greenhouse gases in water treatment emissions are generated by:

- energy consumption, and
- biological degradation of organic matter that produces greenhouse gas emissions.

Table 2. Alternative water sources and indicative treatment required

Water	Treatment
Rainwater	Minimal treatment required. The hotwater system (e.g. gas boosted system) can be integrated to provide thermal disinfection; alternatively UV disinfection may be installed.
Stormwater	Best practice treatment required. Typically this is through the use of natural treatment systems such as bioretention systems or constructed wetlands.

	Mechanical systems, for example filtration systems, can also be used for stormwater treatment, particularly for large scale systems where limited space is available for treatment.
Greywater	Diversion devices can be fitted to subsurface irrigation systems with no treatment required. Greywater reuse treatment systems can be situated on a household scale for reuse. Moderate treatment is required to ensure pathogens are removed from greywater for non-potable water reuse.
Blackwater	High level of treatment is required to remove pathogens and biological components to ensure water is safe for reuse. Mechanical treatment systems are typically used in cities due to the limited space available.

4. The application of carbon sensitive water saving schemes

4.1 Case study - CH_2 Water Mining Scheme

The City of Melbourne's latest building, Council House 2 (CH_2), incorporates the best practice design for a green commercial building. It achieves a six star rating by the Green Building Council's rating system. The calculation is based on 600 employees for a net lettable area of 9,373 m^2.

Step 1. Baseline establishment

The CH_2 building is compared to a conventional commercial building for water consumption and derived greenhouse gas emissions. The net lettable area is the best indicator of water consumption within commercial buildings. CH_2's net lettable area is 9,373m^2. As a baseline assessment, a conventional building typically consumes 1.4 kL m^{-2} y^{-1} of water based on the net lettable area. This equates to 13 ML y^{-1} for the CH_2 building. This water consumption correlates to a total greenhouse gas emission of 11.8 t CO_2-e/y as shown in Table 3. The existing centralized water infrastructure system will not be reduced and hence only the operational energy is considered in this analysis, with the embodied energy of the centralized system excluded.

Table 3. Equivalent tonnes of CO_2 emitted from a conventional office building

Water	Equivalent $C0_2$ generated (tCO2-e/ML)	ML/y	Conventional building (tCO2-e/y)
Potable Water	0.173	13	2.25
Wastewater	0.875	11	9.59
		Sub-total	11.8

Step 2. Demand Management measures

The City of Melbourne has implemented best practice water management in the design of the CH_2 building. Water efficient fittings (AAA taps, fittings, dual flush toilets), pressure reduction valves and appliances are installed to reduce water demand.

The total demand is calculated as 10.6 ML/y. This is comprised of a 2.0 ML/y potable water demand for drinking, hand basins and showers. An additional water demand of 8.6 ML/y is estimated for the provision of non-potable water to toilets, irrigation, cooling towers and tankers (for irrigation) and street sweepers. Best practice water management in office buildings is 0.5 kL m^{-2} y^{-1} to 0.75 kL m^{-2} y^{-1} which corresponds to 4.7 – 7.0 ML y^{-1} and correlates well with City of Melbourne's water balance of 6.4 ML/y (excluding the demand for tankers and street sweepers – outside the building). The water balance figures are used to determine the greenhouse gas emissions for the CH_2 building.

The greenhouse gas emission from the potable water supply is 0.35 t CO_2-e/y as shown in Table 4. Note as wastewater is imported into the building for additional demands there is a reduction in wastewater (on a volumetric basis). All sludge and organic matter is returned to the sewer system for centralised processing. This is highlighted by the negative value for wastewater imported.

Table 4. Greenhouse gas emissions from CH2 building

Water	Equivalent $C0_2$ generated (tCO_2-e/ML)	ML/y	Water efficient building (tCO_2-e/y)
Potable Water	0.173	2.0	0.345
Wastewater imported	0.875	3.5	-3.06
		Sub-total	1.75

The non-potable water supply is technology and systems dependent with the greenhouse gas emissions calculated in Step 3.

Step 3. Alternative water reuse scheme

Step 3a. Technology selection

A blackwater reuse system is installed in the basement of the CH_2 building. Wastewater from the building and additional water from the sewer is treated to a high water quality. Solids are removed by an initial screening process, with finer pollutants removed by the subsequent ultra-filtration and reverse osmosis. Pathogens are effectively removed by the physical separation process. This physical separation process can adjust to meet demand.

Stormwater is harvested from the roof and collected for reuse within the building. This provides an additional water source to contribute to the non-potable water supply.

The reused water (consisting of treated blackwater and harvested stormwater) is fed to a 20 kL header tank before distribution throughout the building. The water is used for toilet flushing, irrigation, cooling towers, external irrigation (i.e. supplied to tankers) and street sweepers.

The energy requirements are accounted for by the treatment train components and include:

- Pumping from sump and sewer
- Ultra-filtration unit
- Reverse osmosis unit
- Hot water system for cleaning and disinfection, and
- The design estimates for energy consumption are 2.5 – 3.0 kW/kL treated water.

The plant operates for 8 hours a day over a typical work week (5 days). The greenhouse gas produced is 248 – 297 t CO_2-e per year as shown in Table 5.

Table 5. Equivalent Greenhouse gas emission from the operation of the water mining system

Energy consumption	Energy consumption (kWh per kL of treated water)	Equivalent CO_2 produced (t CO_2-e per y)
Minimum (kWh/kL)	2.5	248
Maximum (kWh/kL)	3.0	297

Step 3b – Distribution system

The distribution system consists of a header tank situated on the roof, dual supply reticulation and a pumping system. Reused water is pumped from the basement to a header tank. The water is pressurised by a second pump before delivery to the building.

The ongoing energy requirements are from the pumping system.

- Distribution pump (situated in basement) – 5.5 kW
- Pressurised pump (situated at roof) – 4.0 kW

The pumps are assumed to operate for 8 hours per day for a typical working work (5 days). After commissioning, real data can be utilised to refine this conservative estimate.

Table 6. Greenhouse gas emissions from pumping network

Energy consumption	Energy consumption (kWh)	Equivalent CO_2 produced (t CO_2-e per y)
Distribution pump	5.5	17
Pressurised pump	4.0	12

The embodied energy requirements are due to the additional materials for the headers tanks, dual supply reticulation and associated equipment. These components are summarised in Table 7. These components are assumed to be suitable for the life of the building (50 years) to enable inclusion with ongoing greenhouse gas emissions demands. The greenhouse gas emissions from the embodied energy contribute to 0.7% of the total emissions and are immaterial for the water mining plant, with the bulk of emissions being contributed from the operational energy requirements.

Table 7. Embodied energy for rainwater tanks and harvesting system

Item	Quantity	Mass (kg)	Embodied energy (MJ/kg)	Embodied energy (MJ)	Green-house gas emissions (t CO_2-e)	Green-house gas emissions (t CO_2-e/y)
Header tank	20 kL	1000	38	38000	15.2	0.30
Holding tank	30 kL	1500	38	57000	22.9	0.46
Rainwater holding tank	10 kL	500	38	19000	7.6	0.15
Dual supply reticulation network	Throughout building an additional 1300m of copper plumbing and fittings	1650	100	165000	66.2	1.32
					Sub-total	2.24

There is a net increase of greenhouse gas emissions from the water mining treatment system. A summary of the greenhouse gas emission is provided in Table 8. The majority of the emissions are derived from the treatment and distribution energy requirements. A net increase of 314 t-CO_2e/y will have to be generated or offset to ensure there is no net increase in emissions from water recycling.

Table 8. Summary of greenhouse gas emissions

Baseline assessment - Conventional building	
	t-CO_2e/y
Water	2.25
Wastewater	9.59
Sub-total	11.8
CH2 water efficient building	
Water (mains supply)	0.345
Wastewater imported	-3.06
Treatment	297
Distribution	30.8
Sub-total	325
Net increase	**314**

Step 4 – Onsite renewable energy

In all, CH_2 will use approximately 549,257 kWh of electricity per year for all its operational needs. If this were sourced only by conventional energy this would generate 764 tonnes of greenhouse gases.

However, CH_2 building has onsite renewable energy systems including:

- Electricity from co-generation - A gas-fired co-generation plant on the roof will be used to generate electricity and heat, reducing reliance on the public electricity grid.

  The co-generation plant will have much lower CO_2 emissions than coal-fired electrical generation and will provide 164, 777 kWh per year of electricity, meeting about 30 per cent of CH_2's electricity needs. This will save 229 tonnes of greenhouse gases.

- Solar photovoltaic cells - CH_2 will use about 26 square metres of photovoltaic cells on the roof to generate about 12, 775 kWh per year of electricity from the sun's energy. This energy will power the movement of the louvres used to shade the west façade. This will provide 2% of the buildings energy needs and save 17 tonnes of greenhouse gas emissions.

  This results in on-site generation of 32% of CH_2's electricity needs.

In addition the following technologies provide efficiencies that will result in greenhouse gas savings:

- Heat from co-generation - Heat from the co-generation plant (about 100Kw) will be used to help CH_2's air conditioning plant. This heat can be used directly for heating or, via an absorption chiller, for cooling. It is estimated the co-generation plant will satisfy 80% of the building's fresh air heating/cooling requirements just by using waste heat;
- Heat recovery - Heat is recovered from the air that gets exhausted out of the offices. CH_2's fresh air system uses no re-circulated air so fresh air from outside needs to be constantly heated or cooled to be supplied at 18°C. Through a simple heat exchange process, the temperature of the air exhausted from the space is used to help heat or cool the fresh supply air;
- Solar hot water heat recovery - About 60 per cent of the hot water supply will be provided by 48 square metres of solar hot water panels on the roof. On days with little solar heat gain, a gas boiler will heat water instead; and

- Wind turbines - Six wind turbines will extract air from the offices spaces through ducts on the north façade. The turbines, especially designed for CH_2, are 3.5m high and replace electric fans that would normally carry out the same function.

Step 5 – Purchase accredited green energy

In Step 4, it could be seen that 32% of CH_2's energy needs will be supplied by renewable sources. This leaves 68% of power for CH_2 still needing to be sourced by mains electricity. Management of CH_2 has decided to fully fund the mains electricity requirement with accredited Green Power$_{TM}$.

For the purposes of the requirements for this carbon sensitive water recycling policy, it is considered that 68% of the power needed for the recycling plant should be funded by Green Power$_{TM}$.

Step 6 – Carbon trading

The owners of CH2 have agreed to supply Green Power$_{TM}$ for all their 'mains' energy needs. Because of this, there is no remaining 'mains' energy that needs to be offset by exploring carbon off-set programs.

4.2 Case Study: Single allotment – rainwater harvesting

A single household allotment is investigated for the harvesting of rainwater and reuse within the block. This scenario is based on a small inner city redevelopment. The terrace house is bordered by properties on either side. Limited garden is available within the block with the harvested water used for toilet flushing.

The roof area of 45 m^2 is collected in a 1.5 kL tank. The tank is situated within the roof and the water gravity feeding to the toilets. This removes the requirements for any pumps. In situations where tanks cannot be installed in the roof, a pump will be required for distribution and increase greenhouse gas emissions.

The harvested rainwater will be used for toilet flushing (demand of 50L/d).

Step 1. Demand management

Reducing water demand by the installation of dual flush toilet (6/3L) also reduced greenhouse gas emissions. A water efficient toilet consumes 50 L/d (18.3 kL/y) for toilet flushing. Reducing water consumption reduces the transportation of both water and wastewater through the centralised networks. It also reduces the volume of water to be treated at centralised facilities.

Step 2. Alternative water scheme

The 1.5 kL tank provides stormwater for 87% of the demand, that is, 15.9 kL/y with the remainder supplied by potable water (2.4 kL/y). This reduces the overall greenhouse gas emissions to 16.4 kg CO_2-e/y. Wastewater is still disposed via centralised treatment facilities being transported to Werribee for treatment and release back into the environment. The energy requirements and consequent greenhouse gas emissions are calculated for the transportation and treatment.

The embodied energy is calculated for materials for the rainwater tank and additional plumbing. Additional plumbing is required for collection of rainwater and supply to the toilets. No treatment is required for this scheme beyond the settling achieved in the rainwater tank. As there are no mechanical systems or electrical motors attached to this system, no ongoing energy is required. The total embodied energy is 6890 MJ. The analysis estimates a life span of 50 years and thus the average greenhouse gas emissions are 55 kgCO_2-e/y.

As an example a summary of the greenhouse gas emissions from both the conventional and water efficient household is provided in Table 9. There will be a net increase of 18 kg CO_2-e/y in the greenhouse gas emissions, predominately from the additional materials required to construct the rainwater tank and additional plumbing required. This can be offset by the purchase of green energy (refer to Step 3).

Table 9. Summary of greenhouse gas emissions from rainwater tank for toilet flushing

Baseline assessment - Conventional	
	kg-CO_2e/y
Water	5.54
Wastewater	28.1
Sub-total	33.6
Water efficient terrace	
Water (mains supply)	0.41
Wastewater	16.0
Rainwater tank	24.8
Distribution	10.2
Sub-total	51
	kg-CO2e/y
Net increase	**18**

Step 3 – purchase green energy

It is recommended to purchase green energy to off set the net increase in green house energy. This water reuse scheme will have a net increased of 18 kg CO_2e/y and this can be offset by the purchase of green power.

5. Conclusions

For both case studies, there is a net increase in greenhouse gas emissions. The operational phase of the localised treatment is the most significant source of emissions. Even the household scale system with no operational energy requirements produces additional emissions.

Sustainable water management is critical to ensure the livability of the urban environment. Learning from nature directs our community to resilient water systems. For sustainable water systems, this translates to a move to water services, diversity of water sources and flexibility in infrastructure. As the complexity of water systems increases, understanding the interactions with climate change is critical to ensure consistency with planning decisions. The key outcomes of this stuffy include:

- Livable cities require a diversity of water sources with varying emission consequences. Augmentation of centralized water systems will result in additional emissions
- Carbon and water neutrality are complex. Consistency in decision making across spatial variations is required to ensure optimal environmental outcomes.
- Carbon footprinting provide a methodology to quantify emissions from alternative water sources
- Boundary definition of the system to be studied is critical - scope 1, 2 and 3 emission are recommended to be considered greenhouse gas emissions, and
- Community values and learning from complex systems may help to drive the integration of natural and built forms.

Carbon neutrality is a competing driver to deliver alternative water sources. This methodology enables consequences of water management decisions and their impact on emissions. By understanding, defining and managing the explicit interactions with the emissions, planning decisions can be consistent for water projects.

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WATER BALANCE OF A GREEN BUILDING

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ABSTRACT

Monitoring results are presented as an annual water balance from the pioneering Landcare Research green building containing commercial laboratory and office space. The building makes use of harvested roof runoff to flush toilets and urinals and irrigate glasshouse experiments reducing the demand for city supplied water and stormwater runoff. Stormwater treatment devices also manage the runoff from the carpark helping curb stream degradation. Composting toilets and low-flow tap fittings further reduce the water demand. Despite research activities requiring the use of large volumes of water, the demand for city-supplied water is less than has been measured in many other green buildings. In line with the principles of sustainability, the composting toilets produce a useable product from wastes and internalise the wastewater treatment process.

KEYWORDS:

Green Building; Rain Tank; Compost Toilet; Stormwater Treatment, Tamaki Building.

INTRODUCTION

Landcare Research is a New Zealand Crown Research Institute primarily concerned with the terrestrial environment and sustainable development. When Landcare Research chose to relocate its Auckland office to a site on the University of Auckland's Tamaki Campus, staff wanted to demonstrate how it might be possible to build a new building that was more environmentally friendly than usual. This was made complex by the requirement for research laboratories, glasshouses and housing for the six million or so specimens in the national collections of insects and fungi.

The pioneering Landcare Research Tamaki Building won the Energy Efficiency and Conservation Authority's Energy-Wise Commercial Building award in May 2005 and it also received an "environmental hero" Green Ribbon Award from the Minister for the Environment. The building was designed to be energy efficient and make use of renewable materials and finishes that had a 100-year life.

The building's design also considered four urban waters: mains-, storm-, waste- and natural-. To minimise its impact on natural waters, it was designed to minimise demand for mains water and discharges of stormwater and sewage. This paper presents the measured operational performance of the building's water systems as an annual water balance (Figure 1) to show what has been achieved and to enable comparison of its performance with national and international practice. Context is provided by estimating the water balance of a similar building constructed using more conventional systems (Figure 2). The size of flow in the conventional water balance was estimated using the measured flow in the Landcare Research building. The annual period considered is the year ending 25 July 2007. The paper is structured around the building's *inputs* of water, *demands* for water and *outputs* of water.

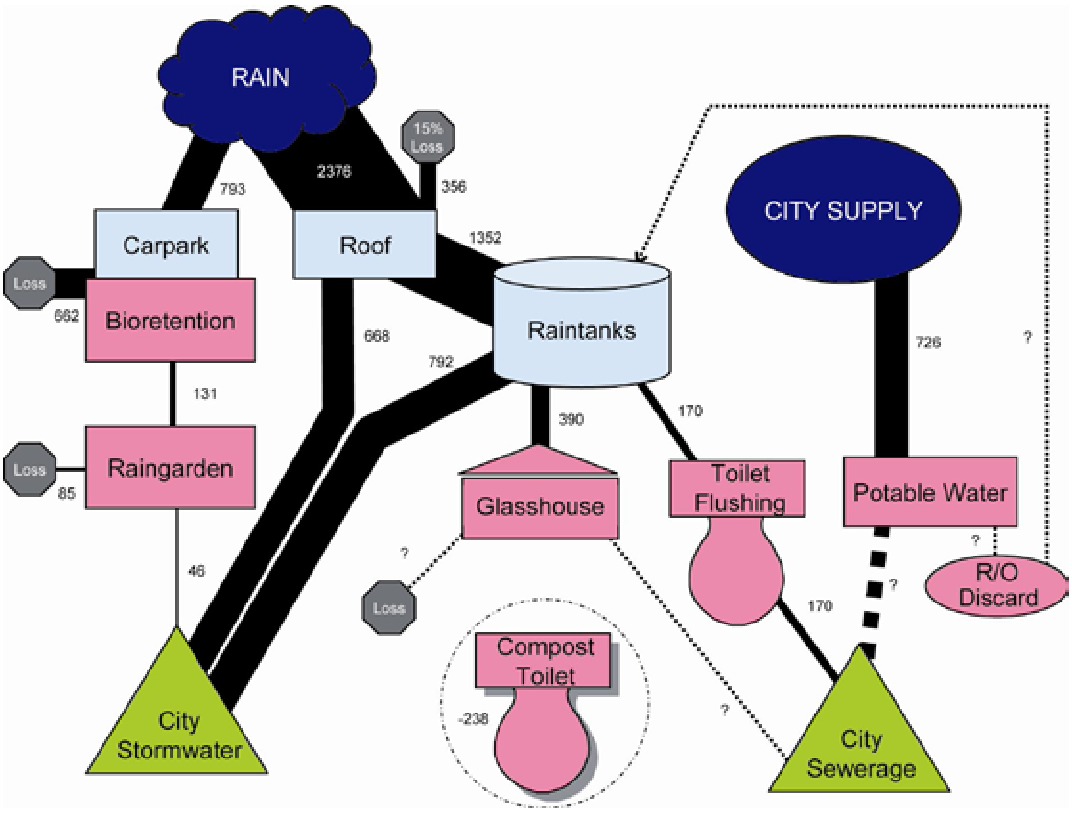

Figure 1 Water balance of the Landcare Research Tamaki Building. The thickness of the lines is proportional to the magnitude of flows, which are labelled and have the units m^3/ year ending 25 July 2007.

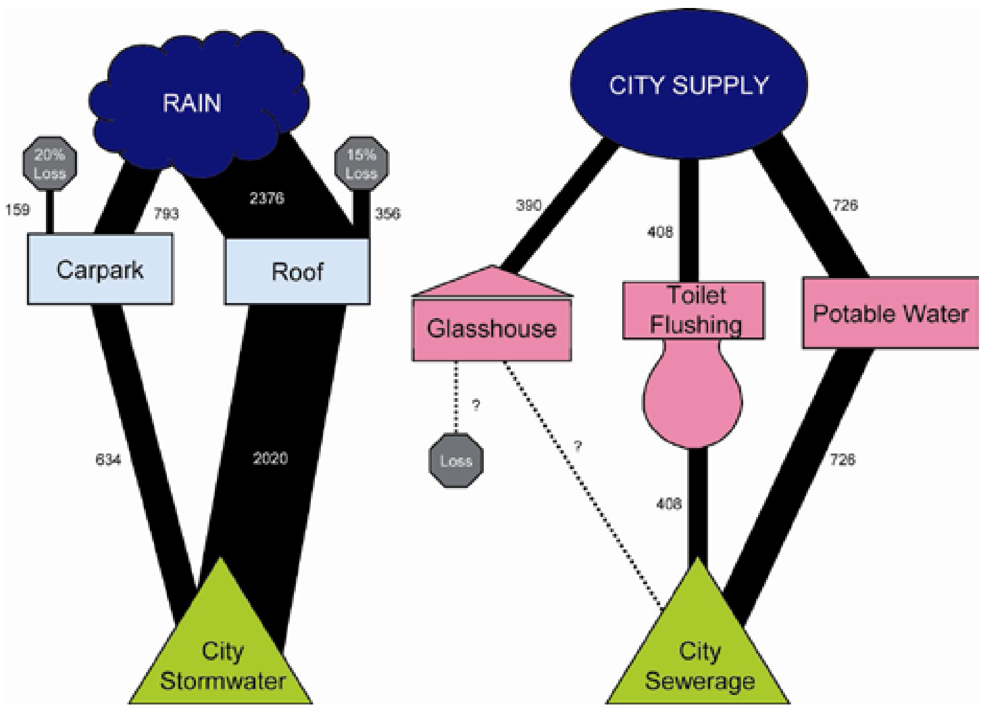

Figure 2 Water balance of a building similar to the Landcare Research building but using a more conventional system. The thickness of the lines is proportional to the magnitude of flows, which are labelled and have the units m^3/ year ending 25 July 2007.

INPUTS OF WATER

The inputs of water to the building include rainfall, harvested rainfall, and potable water supplied by the city's water main. The input size and method of measurement are presented before discussing their implications.

Rainfall

Rainfall is measured onsite using two (primary and backup), 0.2-mm tipping-bucket gauges. Data records are complete from 19 January 2005 to date. These data are further supported by climatic data collected at a weather station just 500 m from the building since December 1992. Auckland City experiences most rainfall in April to September (90-130 mm/month) and moderate moisture deficits (30-90 mm/month) from November through March. The total annual rainfall for the year ending 25 July 2007 was 1042 mm, similar to the long-term average rainfall of 1200 mm/ year (ARC 1999).

Water supply

The building is connected to the mains water supply. In addition, runoff from 1512 m^2 of roof area drains through a syphonic drainage system to three 25 000-L rainwater storage tanks connected in series. The first two tanks are connected at their base and are in hydraulic equilibrium. Water is pumped from these tanks to header tanks for use in the building. The third tank collects overflow. A mains backup is available for prolonged dry spells and for fire fighting. The volume of water running off the roof and into the tanks was 1352 m^3 in the period considered, assuming a 15% loss due to evaporation and storage on the roof. None of this water would be available for use if a conventional system had been used (Figure 2).

DEMAND FOR WATER

The core business operations of Landcare Research require laboratories and glasshouses that use a large volume of water. Rainwater harvesting, low-flow fittings and composting toilets reduce the water demand of the building (Figure 1 and 2).

Mains water

The building's potable water is supplied by the city mains supply. The local interpretation of the building code requires that hand basins, showers and kitchen appliances also be supplied by mains water. Low-flow fixtures and low-volume domestic appliances were used throughout. The building also draws on the city water supply to make water treated by reverse osmosis (RO), required for laboratory work such as washing glassware and making chemical solutions. The RO treatment process is a large consumer of water because only an estimated 30% (maximum) of the water used in the process is purified. The system has been configured so that the reject water can be sent to the rainwater tanks. The volume of reject water has not been measured.

The consumption of city mains water has been measured hourly by the building management system since May 2006. A total of 726 m^3 was used during the year ending 25 June 2007. No mains water was used to top up rainwater tanks. The number of full-time-equivalent (FTE) employees was 94 making the total mains water used 7.7 m^3/ FTE/ year. Normalising for floor area (4828 m^2), results in a mains water use of 0.150 m^3/ m^2/ year.

The well known green building rating systems LEED (US Green Building Council, 2007) and NABERS (Department of Environment and Climate Change [New South Wales], 2007) provide sections on water. This has led to a number of green buildings reporting measured water use (NABERS) or being the target of post-occupancy evaluation based on promises made in the design stage (Turner, 2006). These data are used to provide context to the measurements made by Landcare Research.

Turner (2006) collated actual measured water use in US buildings that have attained a LEED building rating (Table 1). For comparison, measurements have been converted from imperial to SI. Turner's method assumed 365 days per year based on the reported employee counts for the King Street Center building.

Table 1 Actual water use measured in green buildings (after Turner, 2006)

	LEED rating	m^3/ FTE/ year	m^3/ m^2
Landcare Research building, NZ	N/A	7.7	0.150
Viridian Place, Portland, USA (commercial office)	Certified	7.8	0.179
Anonymous office building, NW region, USA	Certified	24.5	0.187
Balfour Guthrie office building, Portland, USA	Silver	8.4	0.244
Hillsdale Public Library, Portland, USA	Gold	7.8	0.321
Seattle Central Public Library, Seattle, USA	Silver	6.0	0.329
King Street Center, Seattle, USA	Gold	7.4	0.338

The Landcare Research building has comparable performance to these LEED-certified buildings. The water use measured in m^3/ FTE/ year was similar in most buildings, with the obvious exception of the anonymous office building. The Landcare Research building performed best using the metric m^3/ m^2.

A total of 59 buildings have achieved a NABERS score for water use but only one building scored a 5-star rating (0-0.35 m^3/ m^2/ year). That was the Szencorp building at 40 Albert Road, South Melbourne, Australia, which has been dubbed "Australia's greenest building" (Szencorp, 2006) and has also achieved 5-star Australian Building Greenhouse Rating (Department of Environment and Climate Change [New South Wales], 2007) and 6-star Green Star (Green Building Council of Australia, 2007). The Szencorp building's annual measured water use (0.131 m^3/ m^2/ year) was very similar to that measured in the Landcare Research Building (0.150 m^3/ m^2/ year). Interestingly, the measured water use in the second highest NABERS-scoring building was much higher at 0.391 m^3/ m^2/ year, which rated it a 4-star (0.35-0.7 m^3/ m^2/ year) building.

The data show that the Landcare Research building is one of the best-performing green buildings in terms of mains water use, and that is despite the large water demand for laboratories and glasshouses. The key to achieving this performance was the use of composting toilets and rainwater harvesting, which are discussed in the following sections. Interestingly the volume of harvested rainfall was greater than the building's total water demand, meaning that there is the potential to perform better.

Harvested rainwater

Harvested rainwater is used to flush dual-flush toilets and urinals. It is also used to irrigate the glasshouse experiments. The building management system records hourly demand for stored rainwater for toilets and glasshouses independently. A total of 170 m^3 harvested water was used to flush toilets during the year ending 25 July 2007. The glasshouses were a large user of water, requiring 390 m^3.

There are five dual-flush toilets on the ground floor and manual-flush urinals in the male facilities on all three floors. There are four manual-flush urinals in total. Composting toilets were not practical on the ground floor because the building is situated on basalt rock, making excavation for the bins very expensive.

Composting toilets were installed on the first and second floors of the building, where seven individual toilet pedestals are connected to two Clivus Multrum (2001) composting bins. The bins are gravity-fed from the male and female toilets and use no water for flushing. Assuming a similar water use per toilet as the building's dual-flush toilets, the compost toilets reduced water demand by 238 m^3 in the period considered.

Cost savings by reusing rainwater

Landcare Research was charged NZ$4.76 per cubic metre of water that it drew from the city water main. Landcare Research paid NZ$3,456 for mains water supplied for the year in question. The reuse of rain water saved NZ$2,666. Clearly, cost savings would have been larger if the building had been fitted with more-conventional toilets and appliances. The maximum potential savings can be described as the total value of all harvested water in the year ending 25 July 2007 (1352 m^3). At city supply prices, this gives a total potential cost saving of NZ$6,436 per year.

OUTPUTS OF WATER

Traditional methods to manage urban stormwater and wastewater have been shown to cause environmental degradation, which has driven the development of more sustainable management techniques (Wong, 2007). Some of these techniques are used in the building and are described here.

Stormwater

Two-thirds of the roof area (1526 m^2) drains to rainwater tanks, which help to reduce the stormwater volume and peak discharge to the city infrastructure. The remaining third (754 m^2), mainly that on the research glasshouses, drains directly to the stormwater network. Of the water collected in the tanks, 560 m^3 was used in the building while 792 m^3 went into storage. Some of that storage was used to irrigate the site's gardens via a gravity-fed drip irrigator. The water is presumably evaporated, transpired by plants, or recharges groundwater. To provide detention volume during the rainy months, when there is a surplus of runoff water and the gardens do not require much irrigation, the tank was slowly drained to the city stormwater network. The total volume of water used for irrigation or drained was very similar to the amount drawn from the city supply; 726 m^3, meaning that the Landcare Research Building has the potential to be self sufficient in water.

A series of stormwater treatment devices manage the stormwater from the building's carpark. The building's 761-m^2 carpark was designed with a permeable surface as the first step in stormwater treatment. Constructed of compacted gravels, the surface had a "slow" (McQueen, 1983) infiltration rate. Mean saturated hydraulic conductivity, measured over 48 h using the twin-ring method, and following 48 h of pre-wetting, was 1.5 mm/h, with one-third of the test sites having nil infiltration and no site having more than 5-mm/h infiltration. The durability of the carpark surface and turbidity of runoff were below expectations. This type of surface is not recommended and on 13 July 2007 the surface was tarmac-sealed.

In an effort to control pollution at source, the 38-space carpark was designed to accommodate about half the number of cars as staff. Encouraging staff not to drive to work was supported by locating the building c. 800 m from a railway station and bus depot, providing cyclist facilities (covered storage and showers), and setting up an internal website to assist with carpooling.

The carpark drains to a bioretention strip, which in turn drains to a raingarden. The water that passes through the raingarden enters the local network of stormwater pipes, which delivers it offsite to a constructed stormwater pond and then to a local stream. The onsite stormwater devices are described.

The bioretention strip is 1.5 m wide and runs the length (30 m) of the main building. It meets sizing guidelines (USEPA, 1999), being about 8% of the catchment area. The strip is gently graded (1-3%) and runoff is designed to pond to an extended detention depth of c. 50 mm. The bioretention was planted with native groundcovers that do not require mowing and that will smother weeds to minimise maintenance. The planting was designed to filter sediment from stormwater by imitating the favourable physical characteristics of a grass sward. The plants included *Acaena microphylla*, *Fuchsia procumbens*, *Selliera radicans* and *Apodasmia similis*. A tussock edging reduces rain-splash onto the building and the dense *Scleranthus biformis* and *Selliera radicans* protect the soil surface from erosive drips falling from the building's overhang. In our opinion, the planting improves the site's visual landscaping. Untreated *Cupressus macrocarpa* sleepers fastened 30 mm above the ground by chemset bolts replace the typical curb-and-channel drainage system. These inhibit soil compaction by vehicles and encourage sheet flow delivery of water to reduce the likelihood of erosion and scour of the soils. Measurements show that during the study period, the bioretention discharged a total of 131 m^3 of water to the raingarden.

The raingarden has 18 m^2 of surface area and flanks the main entrance to the building. The northerly aspect maximises solar exposure and evapotranspiration. The key design features to improve stormwater treatment and retention include a deep (900 mm) multi-layered soil and delivery of water evenly across the upper surface. The raingarden was also planted with native plant species, which were chosen for their fine, dense and extensive root systems to maximise biofilms where biological activity is high. The *Muehlenbeckia astonii* and *Hebe speciosa* can tolerate annual clipping, which may be useful for harvesting bio-accumulated contaminants. Organic mulches were used to disperse the energy of stormwater, assist removal of contaminants, and suppress weeds until the native plants provide a dense cover. Just 46 m^3 of water was discharged from the raingarden to off-site treatment via the city stormwater network.

The annual water balance for the conventional building assumes a similar sized carpark that is tar-sealed and connected directly to the city stormwater network. A loss of 20% is assumed due to evaporation and storage on the carpark surface. In this case, the total annual volume discharging to the stormwater network was 634 m^3/ year, which is 1320% more than was measured when the treatment train was used. The estimate could be conservative given that the carpark is undersized for the building.

Figure 3 shows a well-characterised event that occurred on 24 January 2006, when 41.8 mm of rain fell in the 18 h between 3:09 a.m. and 5:45 p.m. Initial low-intensity drizzle was followed by heavy showers in which rainfall intensity peaked at 2.3 mm/10 min, and 10.1 mm/h. The event was large but not unusual. The 2-year return interval for the area is 70 mm in 24 h. Three weeks of predominantly dry conditions preceded the event, punctuated with only one small (<5 mm) rainfall event. With summer evapotranspiration rates of about 3 mm/d, it is expected that the stormwater devices had maximum water storage capacity available when rainfall began.

Once depressions in the carpark surface were filled and rainfall intensity was greater than the infiltration rate, it is likely that much of the rainfall onto the carpark became runoff. This runoff was stored in the mulch and soil of the bioretention strip for 4.5 h, during which time 7 mm of rain fell, before the bioretention started to discharge to the raingarden. A further 3 h passed, during which 2216 L of stormwater entered the raingarden, before the raingarden started to discharge. The total volume of water that fell on the catchment in the event was 31 800 L. The total discharge from the bioretention was 7889L and from the raingarden 3031 L, meaning that <10% of the water that fell on the catchment discharged to stormwater pipes. The peak flow was also attenuated. The peak flow measured exiting the bioretention device was 1.09 L/s and only 0.74 L/s from the raingarden.

The modelled conventional system had a markedly different hydrograph (black line on Figure 3). The peak flow was nearly three times greater at 2.8 L/s, there was little lag time between rainfall and runoff, and the total volume discharged was much larger (23 400 L). There is a well-documented decline in habitat and water quality of urban streams (e.g. Paul and Meyer, 2001) due to increased runoff from directly connected impervious surfaces, such as roofs and roads, hydraulically efficient drainage systems, compaction of soils, and modifications to the vegetation. This can result in increased flood flows (Leopold, 1968), stream erosion (Hammer, 1972), and decreased baseflow through decreased groundwater recharge (Schueler, 1994). The effects of the building's stormwater treatment devices are masked at the stream habitat scale by the numerous other urban stormwater inputs to the stream, but presumably if we all treated our stormwater we would limit the degradation of stream habitat.

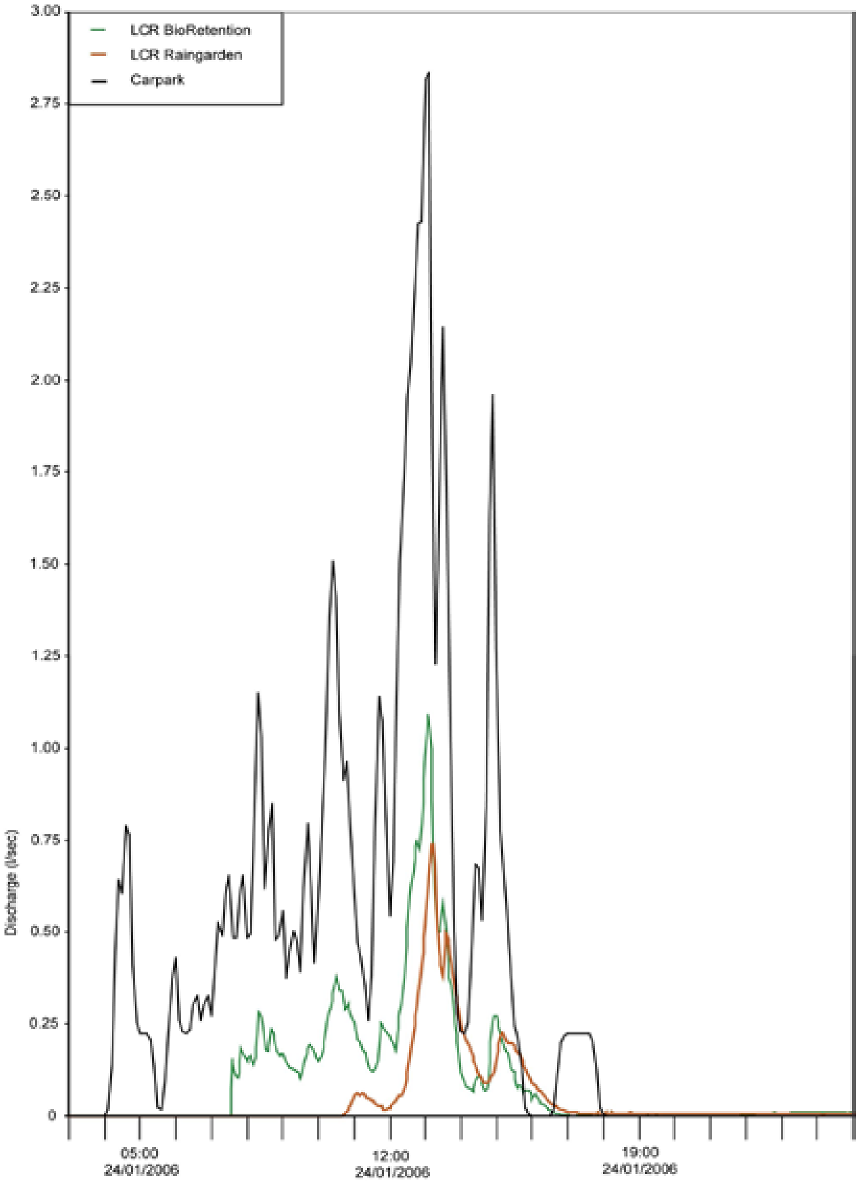

Figure 3 Hydrograph of discharge from the bioretention and raingarden at the Landcare Research Tamaki Building (brown and green lines respectively) and modelled discharge from a tarmac-sealed carpark (black line).

Wastewater

The dual-flush toilets and the urinals are connected to the city sewer system. The volume of water flowing from the flush toilets to the sewer was assumed to be similar to the volume used to flush the toilets (170 m^3). Grey water from the laboratories, hand basins, glasshouses and kitchen drains to the sewer via a local sediment trap and a 1000-L detention tank. The tank can be used to isolate the drain if necessary, for example if there is a spill in a laboratory sink. Landcare Research is charged to dispose of every unit of water supplied by the city, so the discharge of potable water was assumed to be the same as supply (726 m^3).

The key to minimising discharges to the city's sewer and wastewater system was the use of composting toilets. The composting bins are connected to the city sewer to allow liquid that has not evaporated to drain, but most of the inputs are managed within. In line with the principles of sustainability the composting toilets promote the use of a product typically considered waste. The composting toilets also better embody the traditional view of the indigenous Maori, who regard land-based disposal of human excrement and urea more appropriate than disposal to waterways (Durie, 1994).

The compost product has been shown to compare favourably to NZ Standards (NZS 4454) and commercially available composts where contribution to plant nutrition is claimed (Trowsdale et al., 2006), but the compost has yet to be used on site because of concerns about its safety. This is due in part to a lack of policy regarding appropriate handling and use of the material. While composting toilet systems have been used at the domestic scale (e.g. Vale and Vale, 2000), they are very rare in commercial-use buildings and to our knowledge these are the first compost toilets to be installed in a commercial-use building in New Zealand. Staff satisfaction of the composting toilets has increased during their 3-year operation and, in June 2007, 78% of staff said that they were completely or beyond-satisfied with using the composting toilets. This was the third highest ranked response in the building satisfaction survey.

CONCLUSION

The Landcare Research building has provided a successful demonstration of what can be achieved to address the urban water balance. Despite research activities requiring the use of large volumes of mains water, the building shows savings in the demands it makes on water resources and the wastes it emits to the environment. This was largely achieved by using composting toilets, rainwater harvesting, and stormwater treatment devices. Monitoring is ongoing to better understand and fine-tune the systems and provide data against which to benchmark building performance.

ACKNOWLEDGEMENTS

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Downsview Park: A Sustainable Community in the Making

By: Tony Genco

Abstract

This paper will describe the history of the evolution of the Downsview Park project including the mandate and vision, the various steps that have been taken to move the implementation of the opportunity forward and the current tage now where the public is being reengaged in the form of advice on the development of the Sustainable Community Development Guidelines and the Urban Development Plan for the site. An analysis will be offered as to what sustainability has meant to the development of the opportunity to date and why sustainable development will become the only way that development can take place in order to truly create a society that we can all live in and truly prosper in. Downsview Park seeks to demonstrate how sustainability is achievable and through the development of indicators and other forms of accountabilities, the ability to integrate living, working, playing and learning all is in one place will be the hallmark of the new way of living in a modern world. It will describe how and why a federal crown corporation has been tasked with this responsibility to achieve this important and relevant outcome for the benefit of Canadian society.

When the Government of Canada announced the closure of Canadian Forces Base (CFB) Toronto in 1994 it stipulated, “the existing DND-owned lands associated with the Downsview site will be held in perpetuity and in trust primarily as a unique urban recreational greenspace for the enjoyment of future generations”.

Downsview Park is the name given to the whole sustainable community composed of 231.5 hectares [572 acres] that includes public open space, recreational, cultural, residential, commercial, institutional, sports and entertainment uses, all of which will be developed according to the principles of environmental, economic, and social sustainability. Downsview Park is also referred to as the Downsview Park Sustainable Community. More than 146 hectares (362 acres) of the total land area are earmarked for park and recreational activities.

Downsview Park will be a leading edge sustainable community. It will set 21st century standard for excellence in landscape architectural design, recreation, urban planning and sustainable development. The goal is to define the leading edge of green development, implement green technologies and promote green business and to offer in the City of Toronto, for the people of Canada, a wonderful place to showcase environmental social and economic sustainability on a self-financing basis.

Parc Downsview Park Inc. (PDP) is committed to sustainability in all its dimensions and environmental, economic and social sustainability are in evidence in the current and planned operations and activities of Downsview Park.

The lands where Downsview Park is located have a very rich history and have experienced a number of previous land uses. These uses, which have included agricultural production and a military base, have helped shape Toronto and Canada and have made Downsview part of some of the most important moments in Canadian affairs. The historical uses have also defined the physical environment of the park.

After the Second World War, the Government of Canada recognized the Downsview Lands strategic importance with its proximity to Toronto's industry and infrastructure. Downsview was considered by the government to be well suited as an air station and logistical support base because of the existing airfield and hangar facilities.

The idea of transforming the Downsview Lands into a national urban park was first advanced in 1994 as the closure of the military base was being contemplated. The lands were seen as a large underutilized tract of land, contained valuable old assets as well as some heritage buildings which could be renaturalized and developed as a national and international showcase for environmental, social and economic sustainability.

Parc Downsview Park Inc.'s (PDP) aspiration is to create a sustainable community, with a national purpose and identity, of great magnitude and prestige for all Canadians and to grow Downsview Park into a model for the world.

PDP is a federal Crown Corporation, established to design, develop and maintain Downsview Park. PDP's mandate stipulates that PDP is to be a self-financing and that all revenues received shall be applied to park infrastructure, operation and maintenance requirements in perpetuity. Accordingly, approximately 71 hectares (212 acres) will be dedicated to opportunities that complement the park while providing revenue to finance the construction, development and management of the Downsview Park Sustainable Community.

While PDP seeks to generate both capital and cash flow from the Downsview lands, it will be done in a way which adds value to the public open space. Further, PDP will ensure that the vision and values of Downsview Park are evident throughout the property in a seamless and integrated fashion.

PDP is now actively moving ahead with its ambitious plans to build the Downsview Park Sustainable Community. Administration of most of the land for Downsview Park was transferred to PDP in 2006. PDP now actively manages the land for the purposes of achieving its mandate. Those actions include constructing and maintaining the urban green space; maintaining, protecting and leasing real property assets; providing a varied program of activities for the public; providing facilities for public and private access; and cultivating relationships with current and future partners in the creation of Downsview Park.

In the early stages of Downsview Park's development, the Downsview Park International Design Competition was held to realize the vision of creating a unique urban recreational greenspace, with the goal of making Downsview Park internationally recognized as one of Canada's great urban parks and a model for 21st century park building and beyond. The objective of the design competition was to promote innovative design proposals that would respond to the social and natural histories of the site, while developing its potential as a new landscape, one capable of sustaining new ecologies and an evolving array of public uses and events.

The design competition resulted in an exceptional design team and concept for Downsview Park known as Tree City. The winning design did not propose itself as a traditional national park. Rather, the site provided an opportunity to think about what it would mean to create an entirely new definition of the urban landscape, one that had the potential to redefine humankind's relationship with nature. It is a fascinating and cutting edge design, which will give Downsview Park worldwide recognition. Downsview Park may have as much influence on parks for the 21st century as New York's Central Park did for the 20th century.

Sustainability is the one word which best captures the essence of the vision of Downsview Park. Sustainability is implicit in the mandate given to PDP by the Government of Canada and is at the core of PDP's interpretation of the mandate. That vision is to create a community that is a showcase of sustainability for the world.

The vision, as developed by the Board of Directors states: "Downsview Park is a unique urban recreational greenspace, a safe and peaceful place, developed according to the principles of environmental, economic and social sustainability, for Canadians to enjoy in all seasons. The park reflects Canada's mosaic brilliance and celebrates its past present and future accomplishments." PDP is committed to sustainability in all its dimensions and environmental, economic and social sustainability are in evidence in the current and planned operations and activities of Downsview Park.

Downsview Park will be a leading edge sustainable community. It will set 21st century standard for excellence in landscape architectural design, recreation, urban planning and sustainable development. The goal is to define the leading edge of green development, implement green technologies and promote green business and to offer in the City of Toronto, and for the people of Canada, a wonderful place to showcase environmental social and economic sustainability.

Sustainable Community Development Guidelines will define the influence of the park plan on the other areas of the Downsview Park Sustainable Community and provide an explicit framework for the development of the entire site. These vital guidelines will ensure that the entire site (the greenspace, the cultural and recreational lands, the residential lands, and the business/commercial elements) become one seamless and integrated community and a showcase of urban sustainability for the world to see and experience.

The Sustainable Community Development Guidelines also a land use plan and development policies; streets, blocks and community plan; an open space plan;

sustainable urban criteria; sustainable building standards; an energy utilization plan; a sewer and water reduction plan; a sustainable housing plan; a public participation and marketing plan; a financial needs assessment for PDP; and, new ideas for further investigation.

This past year, PDP refined the urban development plan for the entirety of Downsview Park. The Downsview Park Development Plan integrates the open space plan with the development plan to demonstrate the vision for the site. The Downsview Park Development Plan identifies various neighbourhoods across Downsview Park, each of which is anticipated to include a variety of land uses. The Downsview Park Development Plan is the subject of a 25-year financial model that demonstrates its economic viability.

PDP has preserved flexibility in the specifics of the Downsview Park Development Plan in order to maximize its ability to negotiate with partners to achieve the best possible result for Downsview Park in each situation, while striving to maximize the land retained by PDP. PDP's processes will be open and transparent as it encourages innovation and excellence from itself and those with whom it does business. Downsview Park will be built with everyone who shares its vision and values.

Public consultation has been a key planning principle in the development of Downsview Park because of significant local community and stakeholder interest and expectations for Downsview Park. As such, public consultation has played and will continue to play an important role in the successful development of Downsview Park, including development decisions. In the past, PDP has been acknowledged for consultation excellence and wants to maintain a high standard in the future.

PDP has hosted a variety of public consultation events and participated in public consultation events hosted by other organizations. In addition, the dissemination and exchange of general information have been facilitated through newsletters, articles, a Web site and a public consultation phone line. For example, public input into the park vision significantly influenced the competition brief for the Downsview Park International Design Competition in 1999 and more recently in the principles and concepts for PDP's Urban Development Plan and Sustainable Community Development Guidelines.

As it builds the Downsview Park Sustainable Community PDP is also forging partnerships, strategic alliances and strong, positive relationships with the local and surrounding communities, other governments and various organizations. Some of these relationships have been formulated through tenancies while others are executed through commitments to work together in future or through joint committees on broader initiatives.

Downsview Park today is a vibrant place where hundreds of thousands of Canadians are educated and entertained through a wide variety of community programs and seasonal events. These programs and events promote and broaden the awareness of the significant historical, environmental and cultural features that make Downsview Park unique. They have also established Downsview Park as a place for people of all ages to play, learn and enjoy in every season.

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TITLE: SEISMIC RETROFIT METHOD OF TALL-NARROW BUILDINGS WHICH CAN BE APPLIED FROM OUTSIDE OF BUILDINGS

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Summary

There are many tall-narrow buildings in the center of large cities in Japan. These buildings are of single span along the street and standing side by side with a narrow space between adjacent buildings. Many of these buildings were designed and constructed according to the old seismic codes and are insufficient in the seismic capability.

There are a number of technologies available for seismic retrofit, such as adding walls or steel braces, confining columns and beams with steel plates or carbon sheets. Yet these retrofit works have not been widely practiced mainly due to the following reasons: 1) the retrofit work requires a lot of expenditure, 2) the utility of the building is reduced if walls or steel braces are added, and 3) the use of the building is interrupted during the retrofit work.

In order to overcome the above shortcomings of the conventional retrofit methods, we have proposed a seismic retrofit method appropriate for tall-narrow reinforced concrete buildings, which can be applied from outside of the buildings. The proposed method is composed of, 1) drilling bore-holes on the columns from outside, 2) poring grout in the bore-hole, and 3) inserting reinforcing bars with anchor heads on both ends. The supplemental reinforcing bars, together with the existing hoops, are expected to work as the shear reinforcement of the columns and improve the seismic capability of the buildings.

This paper firstly introduces the concept and the application procedure of the proposed method. Secondly a static loading test to study the effect of the supplemental reinforcing bars is presented. Thirdly the construction workability of the proposed method in a space as narrow as 50cm is ascertained through the field tests. Fourthly a design example is presented. And finally the reduction in CO_2 and the construction wastes by the proposed method as compared to the conventional retrofit methods is demonstrated, which shows a favorable effect of the proposed method on the environment.

1. Introduction

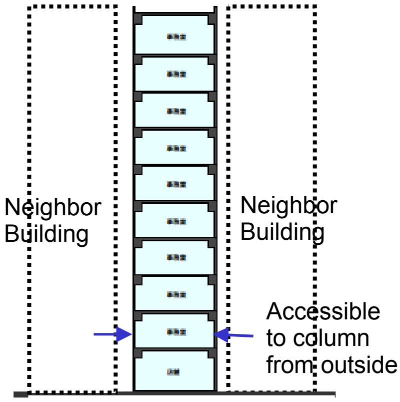
In order to make an existing building to be sustainable, the seismic safety is one of the first priorities for the buildings located in active seismic areas. In Japan as one of the most active seismic areas, many buildings designed and constructed according to the old seismic code are insufficient in the seismic capability. There are a number of technologies available for the seismic retrofit, such as adding walls or steel braces, confining columns and beams with steel plates or carbon sheets. Yet these retrofit works have not been widely accepted mainly due to the following reasons: 1) the retrofit work requires a lot of expenditure, 2) the utility of the building is reduced if walls or steel braces are added, and 3) the use of the buildings is interrupted during the retrofit work.

We have developed a new seismic retrofit method for tall-narrow buildings that are located in the center of large cities in Japan. The plan view and side view of a typical tall-narrow building are shown in Figure 1. It has a single span of 5~8 m along the street (short direction), and has several spans in the transverse direction (long direction). The same type buildings are standing along the street side by side with a narrow spacing with adjacent buildings. Both sides of the long direction are usually reinforced concrete shear walls, indicating sufficient seismic capability for this direction. The short direction, however, is basically a moment-resisting frame and has insufficient seismic capability if designed according to the old building code, and therefore requires seismic retrofit.

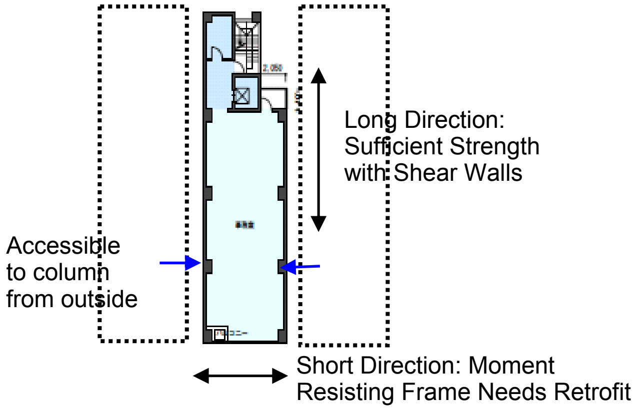
Tall-narrow buildings have special structural features such as: 1) the seismic retrofit is only needed for the short direction, and 2) as this direction is of single span, all columns, at least one face, are accessible from outside, in other words, they can be retrofitted only from outside of the building.

Taking advantage of these features, we propose a seismic retrofit method appropriate for tall-narrow reinforced concrete buildings, which can be applied from outside of the building. The proposed method is composed of, 1) drilling a hole on columns from outside, 2) poring grout in the hole, and 3) inserting reinforcing bars with anchor heads on both ends. The supplemental reinforcing bars, together with the existing hoops, are expected to work as shear reinforcement of the columns and improve the seismic capability of the buildings.

The proposed method may not be a perfect solution as a seismic retrofit, but we want to emphasize that this method is much easier than the conventional methods that building owners can accept it as a retrofit method.



Side View: Buildings are standing side by side with narrow space



Plan View: Building is Single Span along Street and Long in Perpendicular Direction

Figure 1 Typical Tall-narrow building

2. Seismic Retrofit Method

The problem associated with the columns of tall-narrow buildings which were designed according to the old building code is that the shear reinforcement is insufficient so that the columns may suffer shear failure during severe earthquakes, as shown in Figure 2. To prevent the shear failure of the columns, a retrofit method by adding shear reinforcement is proposed. The shear reinforcement as shown in figure 3 is a deformed bar with anchors welded on both ends. As the long direction has sufficient strength and stiffness due to the shear walls, only one short direction needs such retrofit. It makes the retrofit work much easier and applicable from outside.

The construction process as shown in figure 4 is composed of the following procedures:

1) Drill bore-holes on the columns from outside,

2) Pore grout mortar in the bore holes, and

3) Insert the reinforcing bars.

The bore-hole is slightly larger than the tip-anchor, and a larger hole is made in the surface part to accommodate the head-anchor. The added reinforcing bars, together with the existing hoops, are expected to work as shear reinforcement of the columns.

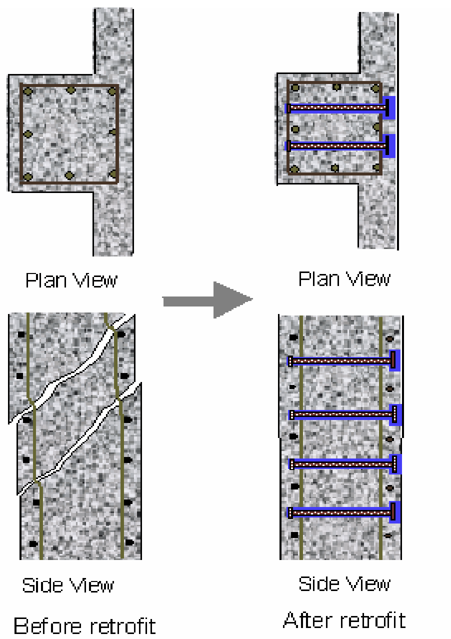


Figure 2 Concept of Retrofit: To Prevent Shear Failure of Column by Adding Shear Reinforcement

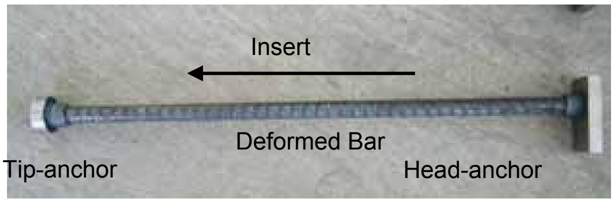


Figure 3 Deformed Bar with Anchors for Shear Reinforcement

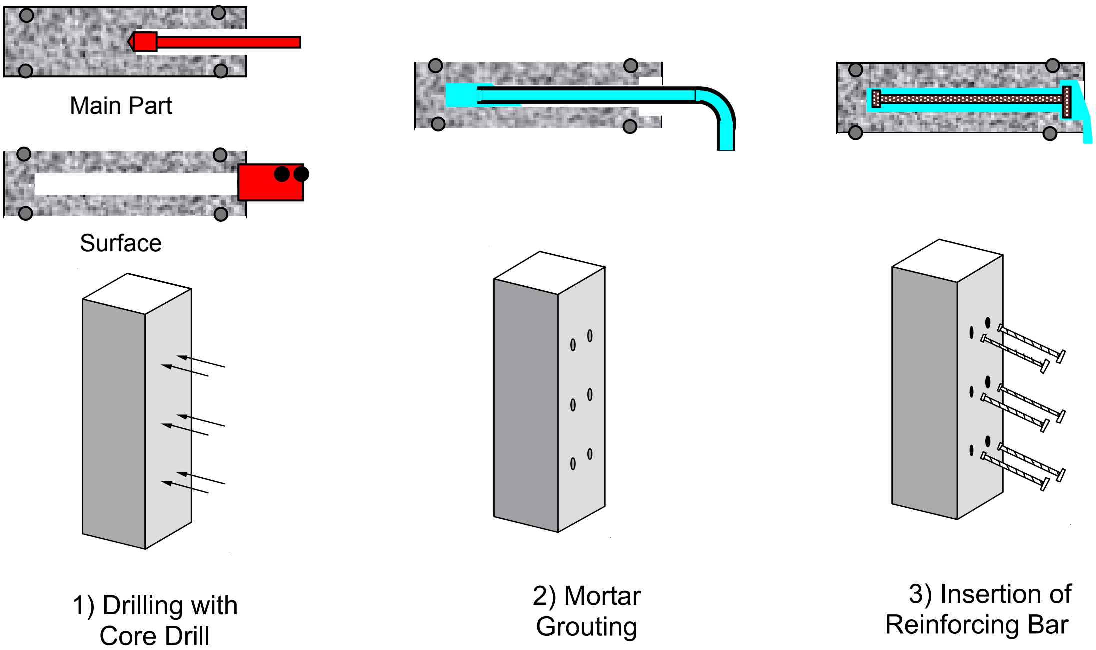


Figure 4 Construction Procedure

3. Static Loading Test

In the proposed method, the function of the supplemental reinforcing bars may not be the same as that of the usual hoop-type bars, especially their effect on concrete confinement may not be expected. The effect of the supplemental reinforcing bars was examined by static loading tests.

Real-scale column specimens with and without the supplemental reinforcing bars were subjected to constant vertical load and horizontal load reversals. Figure 5 shows the test set-up and one of the specimens. Table 1 tabulates several structural properties of the specimens. Test columns are composed of two test series of Round-bar Series and Deformed-bar Series, in which existing longitudinal and shear reinforcements are round bars and deformed bars respectively. The existing shear reinforcements are spaced with an interval of 30 cm and lateral reinforcement ratio is very small (about 0.1%), as compared to the current design practice. With the retrofit by inserting the reinforcing bars, the lateral reinforcement ratio increases to about 0.40%, where cross sectional area of the supplemental reinforcement is counted in the same manner for an ordinary hoop.

Figure 6 shows the force-displacement curves and damages at 2% drift. All specimens failed in shear, but the shear cracks are smaller and more distributed in the retrofitted columns. The test results are similar for the two series. The inserted reinforcing bars were observed to improve the energy dissipation capacity represented by loop area, as well as enhance the maximum load.

As prototype tall-narrow buildings are old, the objective of retrofit is not necessarily to strengthen these buildings to meet the current design practice but to prevent them from suffering serious damages and the occupants from losing their lives in the event of severe earthquakes. It can be said that the proposed retrofit method is likely to attain this objectives for both cases of Round-bar Series and Deformed-bar Series.

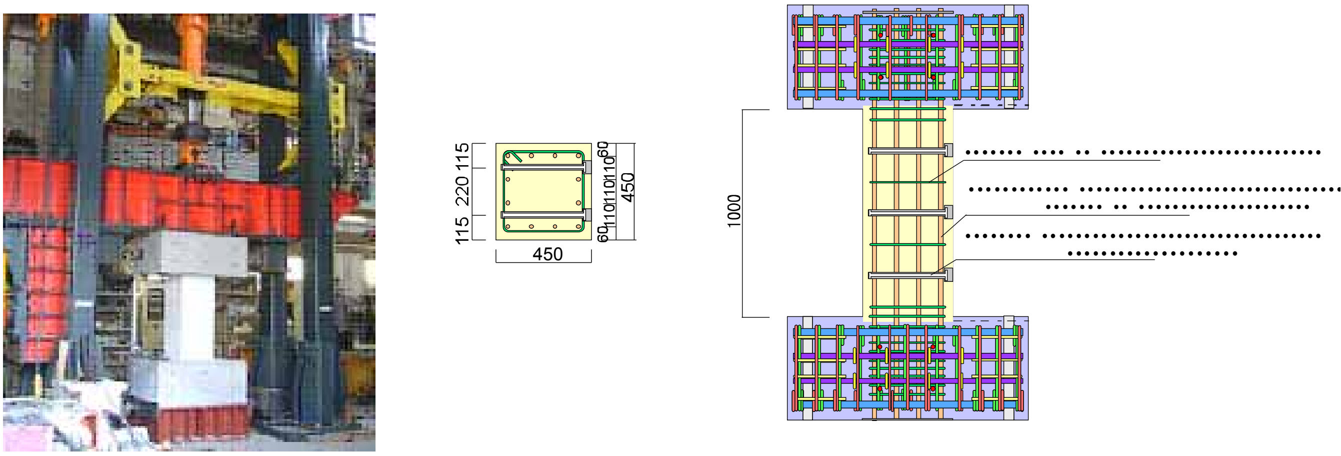


Figure 5 Test Setup and Model Column

Table 1 Specification of Model Columns

Series	Name	Cross Section (mm)	Axial Load Ratio	Lateral Reinforcement Pw(%)	Longitudinal Reinforcement Pg(%)	Supplemental Reinforcement Pw'(%)
Round Bar	RS	450X450	0.18	0.09 [2-φ9@300]	2.25 [12-φ22]	-
	RS-16					0.29 2-D16@300
Deformed Bar	DS		0.20	0.11 [2-D10@300	2.65 [12-D22]	-
	DS-16					0.29 2-D16@300

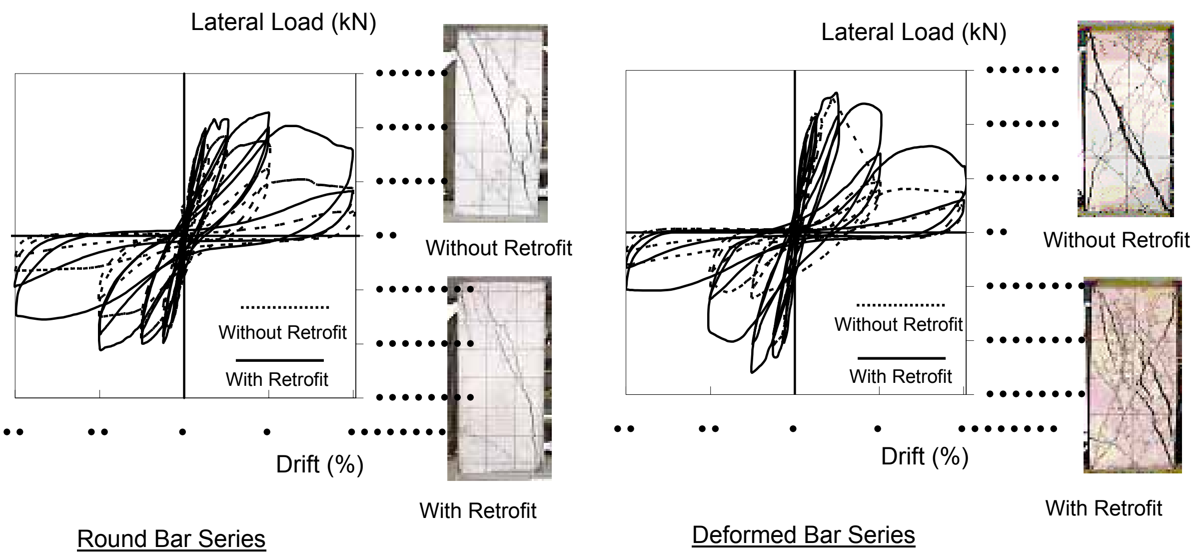


Figure 6 Test Results: force-displacement curve and damages at 2% drift

4. Application Test of Proposed Method in Narrow Space

As the proposed seismic retrofit is especially targeted to the tall-narrow buildings standing side by side, a special construction method, which can be applied in the narrow space between buildings, has to be developed. The minimum space considered for the construction was determined to be 50 cm. To minimize the construction noise to the neighborhood, a high-frequency diamond core drill was selected as a base machine. The core drill was modified to be handed in a space as narrow as 50 cm. The developed machine is shown in Figure 7. The motor is attached to the angle vertical to the drill axis to reduce the total length, and the bits are divided into pieces, which can be connected one by one as the drilling is going deeper.

The motor is attached to the angle vertical to the drill axis.

The bits are divided into pieces to be connected as the drilling goes deeper.

Figure 7 Core Drill Developed for Construction in Narrow Space

An application test was conducted using the column of an existing building. To reproduce a narrow space between buildings, a temporally wall was installed to leave the work space of 50 cm. The test column was of two stories with the height of 560cm, and its cross section was 65 cmx65 cm. Scaffoldings were installed, and the location of existing bars was censored and identified. The column and the view of the application test are shown in Figure 8. Three men are working as a team.

The application procedures after the above-mentioned preparation were composed of, guide-rail attachment and relocation, bore-hole drilling, grout pouring, and reinforcing bar insertion. Total 48 supplemental reinforcing bars with 13mm diameter were inserted at a vertical spacing of 25cm. The hole is 57cm in depth, and 30 mm in diameter for the main part and 80 mm for the surface part as shown in Figure 9. Three bit pieces were connected one by one as the drilling was going deeper. The average time needed to drill one hole is 6.0 minutes, and the total time needed for the application of 48 inserted bars, including all application processes after the preparation, is 25 hours. The working efficiency is about two insertions of the supplemental reinforcing bars per hour.

Figure 8 Model Column and Application Procedure

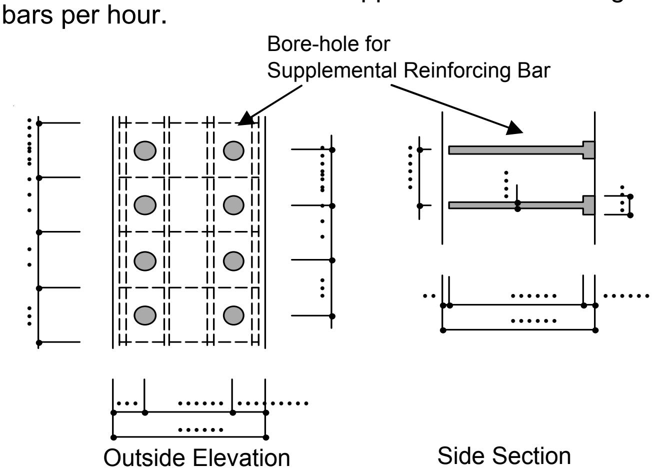


Figure 9 Bore-hole Arrangement on Test Column

5. Design Example

By taking an example building, seismic performance was compared for the pre-retrofit and the post-retrofit structures, where Japanese Standard for Seismic Evaluation and Guidelines for Retrofit was used. In this evaluation practice the seismic capacity was evaluated by index, 'Is'.

$Is = E_0 \times S_D \times T$

Where, E_0: basic structural seismic capacity index

= C (Strength Index) x F(Ductility Index)

S_D: modification factor due to structural irregularity

T : reduction factor for time-dependent deterioration

The model building is a 6 story reinforced concrete building as shown in Figure 10. It is a single-span moment-resisting frame for the short direction, while it has shear walls on both sides for the long direction. Figure 11 shows the cross section of the columns which have existing shear reinforcement of 9mm-daiameter round bar at the spacing of 30 cm. Shear reinforcement ratio is 0.071%, which is very small as compared to the current design practice. The seismic capacity was evaluated by the above method. The resulting 'Is' values are plotted in Figure 12. The 'Is' values of 1st to 4th stories are less than 0.6. Note that the Is value less 0.6 means unsafe for earthquakes.

The seismic strengthening with the proposed method was planed. For the 1st- and 2nd- story columns two reinforcing bars with 16mm in diameter are added at the spacing of 15 cm. For the 3rd- and 4th- story columns two reinforcing bars of 13mm in diameter are added at the spacing of 15 cm. The resulting shear reinforcement ratio becomes as much as 0.353% for the 1st- and 2nd- story columns, and 0.225% for the 3rd- and 4th- story columns. Totally 1600 reinforcing bars are needed.

The effect of the inserted reinforcing bars is assumed to be 0.8 of the ordinary hoop. The resulting 'Is' values after the retrofit are plotted in Figure 12. The 'Is' value exceeds 0.6 for every story, showing the sufficient seismic capability by the retrofit.

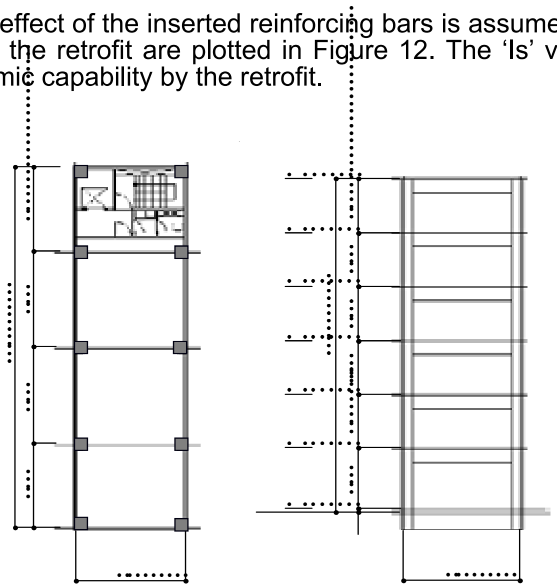


Figure 10 Model Building: 6 story RC

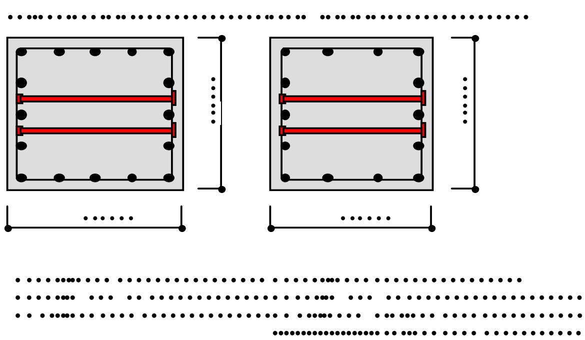


Figure 11 Column Section after Retrofit

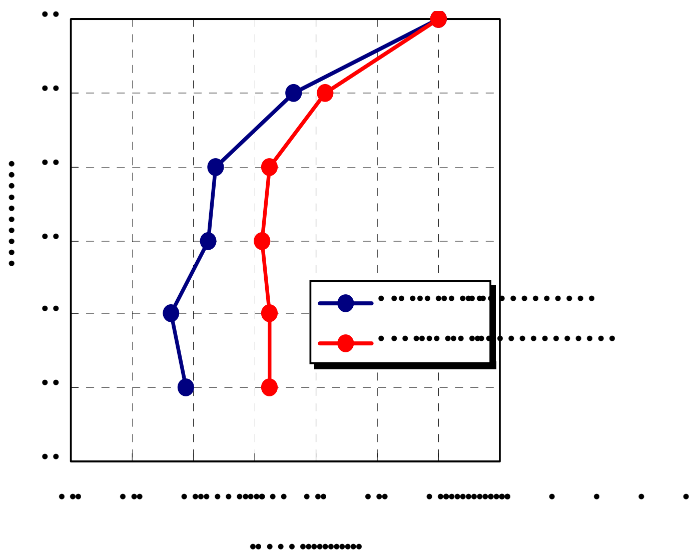


Figure 12 Seismic Capacity Index 'Is' Before and After Retrofit: Post-retrofit Is value exceeds the threshold value of 0.6 to satisfactory seismic capacity.

6. Environmental Effect

Among conventional methods for the retrofit of columns to prevent shear failure, a carbon sheet wrapping method is one of the most typical one. To apply the carbon sheet wrapping method, the interior finishing materials have to be removed to expose the column concrete. After the wrapping method is applied the interior has to be finished again. The proposed method of the supplemental reinforcing bars that is constructed from outside, the interior materials need not be replaced. Together with the reduced material usage in the proposed method compared to the carbon sheet wrapping method, the total CO_2 and wastes associated with the retrofit work can be significantly reduced.

Table 2 shows the comparison of the materials needed for the seismic retrofit, Table 3 compares the amount of CO_2 and other greenhouse gases, and Table 4 compares the amount of wastes. The reduction in CO_2 is 43% as shown in Figure 13 and the reduction in the wastes is 87% as shown in Figure 14, proving the proposed method to be environmentally friendly

Table 2 Material Used for Retrofit Work

	carbon sheet wrapping method	reinforcing bar method
carbon sheet	737.3• •	—
primer	71.8kg	—
epoxy	645.2kg	—
rebar	—	1.141t
steel plate	—	0.3t
mortar	—	2.9t

Table 3 Emission of CO_2• SO_2• NO_2 Associated with Material Manufacturing and Transportation

	carbon sheet wrapping method	reinforcing bar method
CO_2•• —CO_2••	*3,533*	*2,011*
SO•••••••• 2••	*5,382*	*2,533*
[illegible]	*7,471*	*6,414*

Table 4 Construction Wastes• t• •

	carbon sheet wrapping method	reinforcing bar method
mortar	19.4	0.3
Plaster board	0.162	—
concrete	0.2	2.4
Total	19.762	2.7

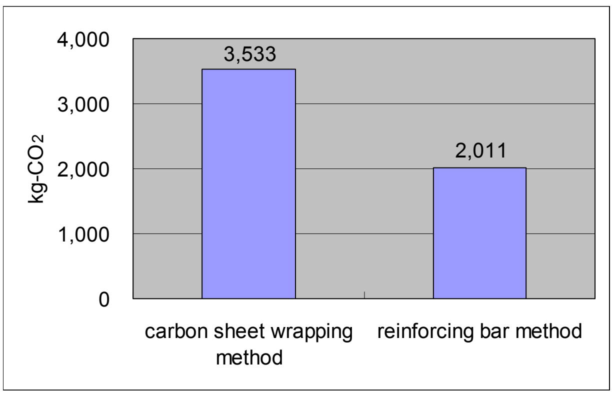


Figure 13 Emisson of CO_2

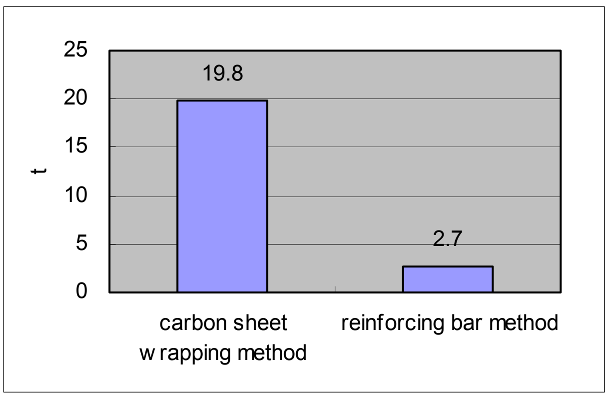


Figure 14 Waste from Construction

6. Conclusions

A new seismic retrofit method for the shear reinforcement of a column is proposed. The largest feature of the proposed method is that it can be applied from outside of the building, so that it can solve shortcomings of the conventional seismic retrofit methods: The retrofit work can be applied while the building is in use, and it does not reduce nor limit the utility of the building.

The strengthening effect of the proposed method has been proved through the static loading tests. It can be said that the proposed retrofit method attains the objective of improving shear capacity of columns of round-rebar and deformed-rebar.

A case study of applying the proposed method to a model building shows that by applying the proposed method the seismic capacity of the building can be improved to exceed the threshold value for the seismic safety in the seismic evaluation practice.

Applicability of the proposed method in a space between buildings, as narrow as 50cm, has been proved. Based on the obtained construction efficiency data, cost estimation has become possible.

As the proposed method does not require removal and re-application of finishing materials, the CO_2 consumption and the amount of wastes can be reduced dramatically as compared to the conventional seismic retrofit methods.

The proposed method may not be a perfect solution as a seismic retrofit, but we want to emphasize that this method is much easier than conventional methods so that it is more widely accepted by the building owners. By proposing such retrofit method, we hope that the seismic retrofit becomes more available and leads to the safer built environment and the longer life of buildings.

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Acknowledgements

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THE REDEVELOPMENT OF KWAI CHUNG ESTATE, HONG KONG.

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Summary

Kwai Chung Estate in the Western New Territories of Hong Kong, was built in the 1960s at a time when the population was increasing rapidly and when there was a severe shortage of safe and secure housing. The original estate was home to 22,000 people in 42 seven storey “walk-up” Mark II and III blocks, with shared toilet and washroom facilities. They were built at a time of great urgency to cope with the needs of shelter for the masses when Hong Kong was emerging as a post-war industrial city. When they were built, they were a great improvement for those who were re-housed but by the late 1980s the estate was in poor condition, with an aging population and the basic living shared toilet and washroom facilities no longer met accepted standards. The estate was identified for redevelopment under the Housing Authority’s Comprehensive Redevelopment Programme.

1. Introduction

After the upheavals of the Second World War and the civil war in China, the Hong Kong Government was faced with a huge influx of migrants to the territory. The population of Hong Kong rose from 600,000 at the end of the war to over 2,000,000 in the early 1950’s and the growing number of people had no choice but to live in crude squatter settlements on hillsides, on boats in Typhoon shelters or in overcrowded tenements. Consequently they were very vulnerable to fire and other natural disasters.

These conditions were the catalyst for the Public Housing programme in the 1950’s, which began as an emergency programme struggling to cope with a growing demand and to address the chronic shortage of safe and secure housing for people on low incomes. The standards of accommodation in the first estates were very rudimentary by comparison with the modern comprehensive estates that are built today, but for homeless people, the shelter and security provided was a huge improvement on their previous conditions. Kwai Chung Estate, in Tsuen Wan New Town in the Western New Territories, was one of the earliest ‘Resettlement’ Estates built in the early 1960’s.

Though the population and the consequent demand for housing continued to increase, stability and prosperity in Hong Kong improved dramatically. Gradually, public expectations went beyond the desire for simple shelter. The type of accommodation provided in the early estates was becoming unacceptable and by the late 1980s Kwai Chung Estate was in poor condition, with an aging population.

2. The Old Kwai Chung Estate

Kwai Chung Estate provided homes for 22,000 people in 42 Mark II and Mark III blocks of reinforced concrete construction. These buildings were some of the earliest forms of public housing in Hong Kong and were eight storey walk-up blocks with single room flats and shared toilet and washroom facilities. Each flat was designed as a single room with no partitions and no water supply. Flat sizes were 14 to 21 sq. meters to accommodate 4-6 persons (2.3m^2 per person).

The old estate had no proper public transport facilities and the estate was split into small irregular sites by the road network which made access difficult. Car parking was insufficient and not segregated from pedestrians. Estate shops were scattered under the residential blocks and local open spaces were isolated and uncoordinated with minimum soft landscape work and recreational facilities.

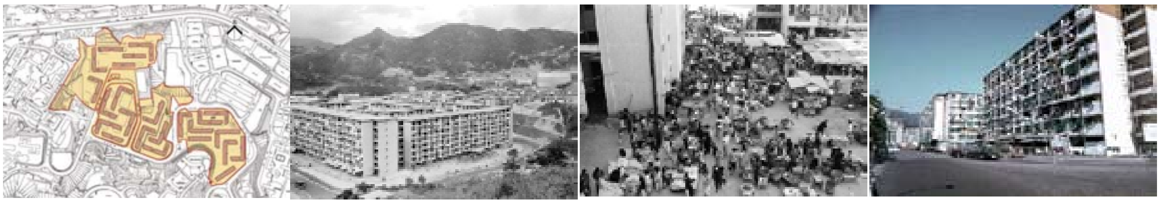

Figure 1: (From left to right) Kwai Chung Estate before redevelopment in 1960s. Master Layout Plan (top left), overview of the Estate, market bazaar, Mark III building

Public housing had been provided through several separate government agencies and in 1973 the new Hong Kong Housing Authority (HA) was formed to manage the programme more effectively. Clearer policies were developed and the experiences of the preceding 20 years led to a programme of more comprehensive and self-contained estates, each with its own public transport interchange, purpose built schools, shopping and market facilities and a wide range of social welfare services provided by both the Housing Authority and NGOs to cater for the diverse needs of a more complex community.

However, when compared to the standards of housing in the new estates built by the new Housing Authority, Kwai Chung Estate fell far short of expectations. In 1988, the HA introduced its Comprehensive Redevelopment Programme (CRP) and Kwai Chung Estate was then included in this programme.

3. The Need for Redevelopment

Since the public housing programme had began in the 1950s, housing standards had risen significantly. By the late 1980s, space standards had increased from 2.3m^2 per person to 5.5m^2. There had been a growing demand for housing and for changing eligibility criteria which exacerbated demand still further. Increased demand meant making better use of the land available and as a consequence development densities were rising and by the 1980s, developments of 2,500 persons per ha were the norm.

Larger flats and more flats in each new site meant that buildings were increasing in height from the seven storey walk up designs of the 1950s to buildings of over twenty storeys in the 1960s and 1970s and to 35 storeys in the early 1980s. By the time that the CRP had been announced, the Housing Authority was planning even higher blocks of 39 storeys with even larger flats. The improved standards of facilities, and more comprehensive estates naturally led to far greater site planning constraints.

The condition of the buildings in Kwai Chung Estate had deteriorated badly, maintenance demands were growing, and the blocks had no lifts which were causing greater problems for the aging population. Non self-contained flats with shared toilet and washroom facilities had been phased out in new estates from the late 1960s and conversion of this type of building into self-contained units was not practical when considered alongside the demands of rising standards, increasing production and greater development densities.

The old estate also had no planned public transport facilities, and the existing streets split the estate into small irregular sites and made access between them difficult. Car parking spaces were insufficient and not well planned nor segregated from pedestrians. Local open spaces were also isolated and uncoordinated with minimum soft landscape work and recreational facilities. Shops and other support services were scattered under the blocks and were a world apart from the new comprehensive shopping centres that were being built in new estates.

4. The Objectives

Planning for redevelopment commenced in early 1990. The objectives were to improve the standard of accommodation for the population, rejuvenate the community, optimise redevelopment potential, improve the road network, pedestrian access and public transport facilities, and provide modern and comprehensive shopping, social, recreational and community facilities for residents. Regeneration of ageing districts serving the people living in the area and retaining and rejuvenating community identity, is the main goal of redevelopment.

5. The Planning and Design Concept

The redevelopment was planned in phases. The CRP concept was to enable the Housing Authority to redevelop its older estates more speedily and more efficiently. It allowed a larger scale of redevelopment compared to the slower and relatively inefficient "pump primer "approach that had been tried in the late 1970s and early 1980s, when individual blocks were built in older estates. One of the main principles of the CRP was to recognise that communities had been established in older estates and hence redeveloping around those communities was seen to be an essential component of the success of the programme.

The redevelopment of Kwai Chung was therefore based on the need to re-house as many of the existing residents as possible in the same estate and if that was not possible, then in the same district. The CRP therefore relied on the construction of large reception estates to enable the first groups of residents to be moved out and allow the redevelopment to proceed.

What are now widely regarded as the parameters essential to achieve sustainable development goals, were the key parameters at the time of the planning of the redevelopment of Kwai Chung Estate and the following approach on social, environmental and economical considerations was used: -

5.1 Social considerations

5.1.1 Minimising Social Disruption to Residents

Under the CRP, an overriding principle has been to maintain many of the characteristics and essential components of the of the existing community by in-situ rehousing, reprovisioning and retention of facilities. Essential facilities, such as temporary car-parking and a market, were to be built in advance, adjacent to phase 1 and maintained throughout the redevelopment period.

Efforts were also made to retain and integrate an existing religious shrine, schools, youth centre and the premises of the local *Kai Fong Association* [Neighbourhood Community Accociation] in the master layout plan of the new Estate.

Figure 3: (From left to right) Existing school and factory building, the Kai Fong Association [Neighbourhood Community Association], Youth Centre, religious shrine, retained in the neighbourhood of Kwai Chung Estate.

Kwai Chung estate was over 25 years old and consequently with established communities and important social networks in place. The elderly residents in particular, wished to stay in the estate because of these long standing networks and because of their association with the various complementary social welfare services which provided care where required and regular opportunities for them to conveniently meet friends.

5.1.2 Establishing a Civic Hub

The design was based on a “civic hub’ concept which was strategically located to provide essential facilities and create a focal point in the estate. This ‘civic hub’, together with the podium garden, acts as a natural meeting point, with a wide range of easily accessible estate facilities where residents meet and socialise.

The central ‘civic hub’ comprises of a 3-storey central air-conditioned shopping centre with a total floor area of 5,800 sq. metres, an air-conditioned market with stall area of 800 sq. metres, 744 car-parking spaces, 112 light goods vehicle parking spaces and 75 motorcycle parking spaces. A covered public transport interchange is now centrally located along with the educational and social welfare accommodation; kindergartens, a day nursery, clinics and Residential Care Home for the Elderly, as the essential supporting facilities for the residents

5.2 Environmental Considerations - A Green and Healthy Living Environment

In the planning of the original Kwai Chung Estate, which was part of a programme for fast track emergency housing, there was no clear theme for the planning of play and recreation, with no provisions for sheltered seating nor formal planning of passive and active recreation. Though there had been estate improvements over the years, the estate lacked green spaces and external areas were fragmented and predominantly concrete paved with play and recreation facilities which fell far short of the standards of new estatesin the 1980’s.

A large housing estate such as Kwai Chung, has a significant impact on the district as a whole and hence play and recreation spaces for the district were planned in consultation with the Leisure and Cultural Services Department (LCSD) of the Hong Kong Government and with the local District Council. Two sites have been specifically designed in consultation with the LCSD as local open spaces for the use of the residents of the district and will be under their management upon completion. Landscaping, play and recreation within the estate follows the HA’s comprehensive guidelines and they have been built at-grade (in phase 5) and at podium level (in phase 3 and 4) and are all linked to other estate facilities and domestic buildings.

The overall area of open space has been increased in the redevelopment from about 4.8 ha to 6.5 ha. An area has been excised in consultation with the Government and a playground has been re-provisioned, as a District Open Space. About 30% of the estate area has been landscaped with over 100 old trees retained and about 150,000 new trees and plants provided in the new Estate. Environmental and landscape features include a bamboo garden, planting on the podium and a well landscaped noise barrier.

Figure 4: The footbridges connecting Phase 4 and Phase 5; and the Bamboo Garden in Kwai Chung Estate Phase 5 with Phases 3 and 4 beyond

The open spaces in the estate have been strategically located and integrated with the main pedestrian circulation networks. Active and passive recreation areas, including badminton courts, basketball courts, volleyball courts, table tennis tables, children's play areas, and a Tai Chi court, have been provided as part of the overall landscaping design of the estate. These open spaces, together with the main podium plaza, provide greatly improved opportunities for the residents day to day recreational needs and for formal planned community activities.

5.3 Economic Considerations

5.3.1 Optimising Site Potential

The HA has routinely formulated its design briefs in close consultation with Government but over time the supply of land has become more difficult. In the late 1990's there was a critical shortage and demand for flats for rent and flats for sale had been increasing dramatically. The Government set annual production targets for both the public and private sectors, with 50,000 flats per annum required of the public sector.

Steps were taken to maximise the development potential of new HA developments and there was a gradual alignment with private sector practices. Phases 3 and 4 of the redevelopment were designed with a podium to accommodate the new transport interchange, a new modern shopping centre and car-parking for estate residents and for shoppers. Residential blocks were built above the podium with recreation space and landscaping on the podium decks. This approach allowed an increase in number and size of flats, improved the extent and standard of the estate facilities and at the same time provided greater opportunities for landscaping.

The redevelopment has optimised the site potential with a plot ratio of 5.5 providing 430,000 sq. metres domestic gross floor area. The number of new flats in the redevelopment has increased from 8,850 to 14,543 and the population from 22,000 to 40,000, yet still allowed for an impressive upgrading of the whole estate and hence a much improved living environment. The flats are also generally larger and to a much higher quality than those in the old estate. The mix of flat types and flats sizes has been more finely tuned to fit the profile of the estate residents, with flat sizes ranging from 17 sq. metres to 47 sq. metres, suitable for 1 person, and families up to a household size of 6 persons to cater for changing demographic needs.

5.3.2 Improving Pedestrian Accessibility, Road Network and Transport Provision

The old housing sites were fragmented, with level differences and consequent accessibility difficulties. The sites were small and split by the local road network and so did not allow sufficient development opportunities. The space required for some of the improved and more comprehensive estate facilities required larger sites and this, along with the need for clear and simple communication links through the estate, provided the opportunity to simplify and realign the road layouts, thereby improving the traffic flow, and at the same time allowing the optimisation of the overall development potential.

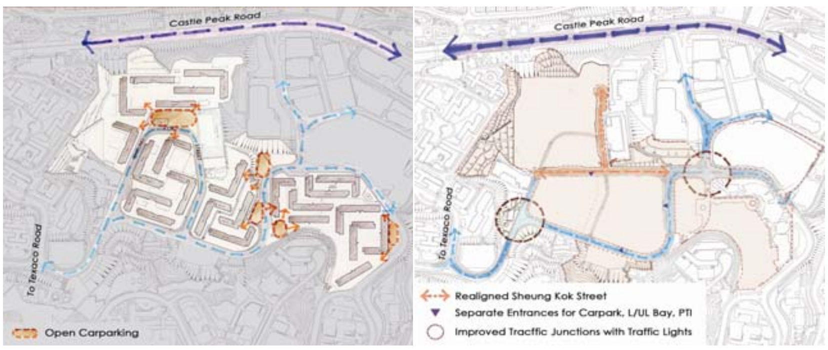

Figure 5: The road network before development (at left) and after redevelopment (at right)

The redevelopment has created a predominately vehicular free environment, with a well planned pedestrian network with footbridges and lifts which provide above grade connections throughout the estate between domestic blocks, schools and the "civic hub". A link has also been provided to the Tai Wo Hau MTR station so that there is now a quick, efficient and convenient link to Kowloon and Hong Kong Island and the KCRC and West Rail connections to the New Territories.

6. Social Aspects

6.1. Local Rehousing

Under the CRP, the redevelopment was to allow for in-situ rehousing, reprovisioning of open space and retention of existing facilities and features as far as possible, so was to be implemented in stages. As a first step, residents on the site of Phase 1 were to be moved to a new reception estate in Kwai Shing Estate so that the construction of new blocks on the site could begin. The new blocks in phase 1 would eventually re-house people from other parts of the estate and trigger the overall redevelopment in a planned and sequential manner. Phase 1 of the redevelopment was completed in early 1998.

Figure 6: Phase 1 completed in 1998 (left). Small Household Block completed in 1999 providing housing for elderly residents (right)

6.2 Retention of Existing Heritage and Community Buildings

The existing religious shrines, youth centre, schools and *Kai Fong Association* [Neighbourhood Community Association] were essential local heritage and community facilities which had to be retained, so the new estate was designed to accommodate them. Temporary arrangements for vehicular and pedestrian access to these locations was provided to maintain proper functioning of activities during the redevelopment.

6.3 Updating of Development Parameters, Social and Policy Changes

During the last 10 years of the redevelopment programme, there were substantial changes in the development parameters in response to adjustments in public housing policy, such as intensification of development potential, introduction of quality initiatives, cessation of flats for sale through the Home Ownership Scheme (HOS), and enhanced design features to emphasise the identity of the Estate.

In February 1998 the government began to look at the opportunities for increasing land supply for housing by redeveloping old HA factory sites. There were four 7-storey factory buildings completed in the mid 1960's next to Kwai Chung Estate. These factory buildings were under-utilised and in 1999 were selected for redevelopment to become part of the new Kwai Chung Estate. Relocation of affected factory tenants was to be resolved before redevelopment, so special ex-gratia allowances were made to assist them to re-establish their businesses in other accommodation.

6.4 Housing for the Elderly

From the start of the housing programme, family sizes have reduced and estate populations have naturally aged. The HA had been extending its support services for the elderly since the early 1970's, but because of the high housing demand, accommodation for elderly was only provided on a shared basis. By the late 1980's the demand was acute and the HA built more self-contained small flats for 1 to 2 persons in its main residential blocks of the time, the Harmony blocks. New blocks of small flats were designed to be linked to the main residential blocks and make use of their lift and utility services. These Annex blocks, as they became known, became the most common way of providing small flats.

In the mid 1990s the HA embarked on a programme of special developments for the elderly with self–contained small flats for single persons and couples, with recognised accessibility standards and appropriate support services provided by the Non-government organisations. These buildings were known as "Small Household Developments" and a programme of 25 such projects was launched in 1995 with flats of 17m^2 to 22m^2 for single persons and couples, built up to 20 storeys in height. One such block with 240 self-contained flats was built in Kwai Chung by arranging a site swap for a small but under-utilised playground next to Kwai Chung Estate. Later housing for the elderly in the final phases of the redevelopment was provided in 17m^2 flats in the 40 storey residential blocks as part of the standard flat mix along with family flats, and in Annex Blocks in phases 3 and 5 of the estate.

This redevelopment project has therefore had to respond to new policies and priorities that have arisen in the community during the design and construction programme, spanning almost two decades.

7. Environmental Aspects

7.1 Layout Design

The design of the estate and the disposition of the buildings, has made use of environmental studies to model the local wind environment and traffic noise in the area to help to plan the estate facilities more effectively. The domestic blocks are located away from the noise sources as far as possible; some blocks located adjacent to the public roads are on the podium, which serves as a noise barrier to reduce the impact of traffic noise. Noise barrier walls at appropriate locations along estate boundaries have also been provided.

7.2 New Construction Technology

When Kwai Chung Estate was included in the Comprehensive Redevelopment Programme, the HA embarked on a major programme to improve construction quality and efficiency. Though standards had improved between the 1960's to the 1980's there had been very little change in the way that buildings were built, despite the considerable increase in height of buildings, from 7 to 35 storeys.

Construction was very labour intensive in-situ concrete construction with a reliance, to a large extent, upon semi-skilled or unskilled labour. Quality was a major concern. Housing production targets were increasing and hence the increased stock of housing, led to growing management and maintenance responsibilities. The construction industry was a major employer and site safety and working conditions were a cause of concern. The HA was a major government developer and began to look at new practices to improve working conditions and site safety, quality, efficiency, and waste management.

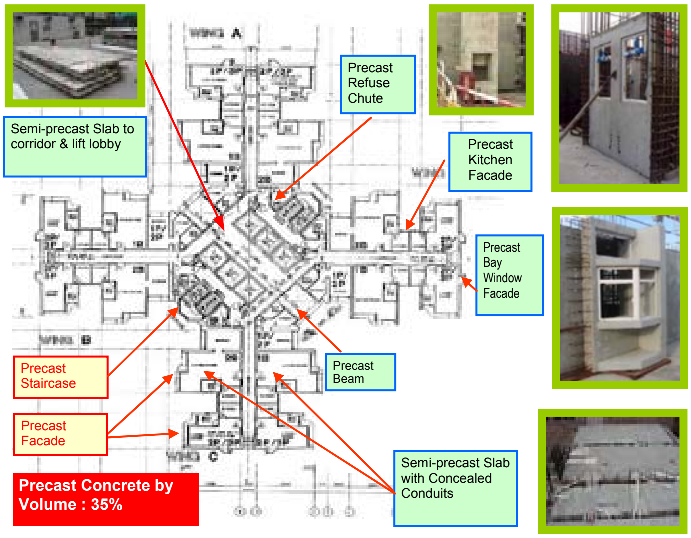

Figure 7: Precast Elements for the New Harmony Blocks constructed in Kwai Chung Estate

Prefabricated construction techniques had been tried over the years and by the late 1980's the HA embarked on a new approach in the design and construction of its buildings using modular design concepts and mandatory prefabrication. This started with pre-cast concrete components and was later extended into the fitting out of flats, with dry construction lightweight concrete partitions, door assemblies and kitchen fitments. The intention was to reduce wet trades, reduce the reliance on unskilled or semi-skilled site labour and introduce factory production as far as possible. Precast elements amounted to approximately 30% of concrete works by volume and included facades, staircases, refuse chutes, and later, features to emphasise the identity of each estate.

The last project, at the Kwai Chung Flatted Factory site, has used prefabrication more extensively, including structural elements, and components amount to over 60% of construction volume. These techniques have had a major effect on the Hong Kong construction industry and led to the development pre-cast concrete components industry in Hong Kong and latterly in southern China, which benefits the industry as a whole.

An Automated Refuse Collection System (ARCS) was also implemented for collection and handling of domestic refuse in a totally concealed environment where the refuse is automatically extracted by vacuum to centralised containers, thereby minimising nuisance caused by spills and smell. The system is one of the largest ARCS in Hong Kong and can handle a capacity of about 34 tonnes of refuse per day with 2 to 3 nos. of 10-tonne capacity containers for daily storage.

8. Economic Aspects - Continuous Provision of Basic Facilities

In order to maintain basic facilities such as shops, car parking and transport ffor the residents and the public in the vicinity, a temporary market and carparking was provided on the future district open site adjacent to phase 1. New roads were constructed in stages and remained in-use throughout the redevlopment period.

9. Continuous Community Engagement

A continuous dialogue with local residents is an important part of the redevelopment process. After public consultation at planning stage, efforts were made to seek local comments during and after completion. Resident's Surveys were carried out after occupation to obtain feedback and the findings showed that over 80% of the residents were satisfied with the estate as a whole, in particular, with the planning and design of blocks and estate facilities.

Continuous improvement is also on going after in-take. A working group formed by Members of the Kwai Tsing District Council, a representative from the Incorporate Owners of the nearby HOS court, and representatives from Housing Department conducted regular meetings over about 2 years to work out common objectives for improvements. A lift tower and footbridge were eventually planned, and are now under constrcution, to serve Kwai Chung Estate, Tai Wo Hau Estate, and the schools.

In order to promote public participation in "greening", a Community Participation Scheme was launched in mid 2007 in the new estate. The Scheme is to provide young plants to the participants approximately 6 months before completion of the Estate. The plants are to be grown at home or school and to be transplanted in the estate. The idea is to engage the community in the longer term to enhance commitment to the well-being and up keep of the estate and will be part of a series of activities to be arranged to generate more interaction and dialogue with the local community.

Figure 8: Community Participation Scheme – Action Seedling held in Kwai Chung Estate

10. Implementation and Project Cost

The first stage comprised of three 39 Storey Harmony Blocks with 2,400 flats which were completed in 1998. These blocks are adjacent to the District open space which had been built on the site used as a temporary car park and market until the car parking facilities in phases 3 and 4 were completed in 2005.

The second stage was the construction of the Small Household Development for the elderly and two New Cruciform Blocks (NCB) originally intended for sale. The NCB were fully fitted apartments, larger than flats for rent, with 10 flats per floor, rather than 20 flats per floor for typical rental housing. Prior to completion, the HA cancelled its flats for sale scheme and the buildings were eventually transferred the Government for use as disciplined services staff quarters.

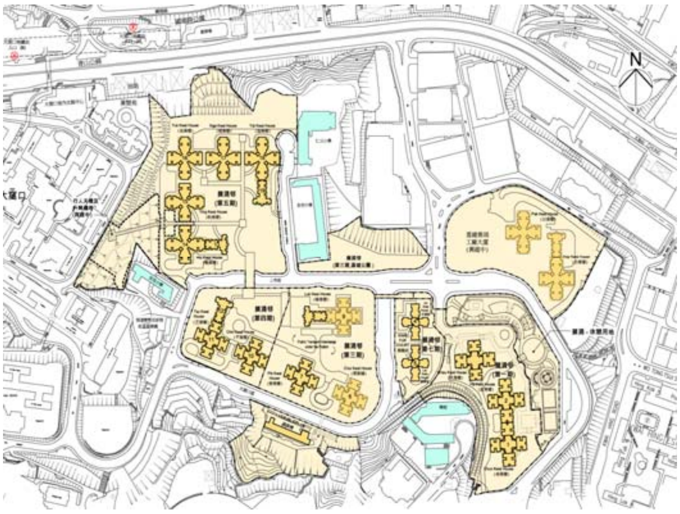

Figure 9: Master Layout Plan of the completed Kwai Chung Estate, with the civic hub at the centre.

The third stage shows the re-alignment of road network, intensification of production that was necessary towards the late 1990's when phases 3 and 4 were developed with a podium design to accommodate the "Civic Hub". The shopping centre, public transport interchange and car-parking were built beneath the podium and residential blocks built above, with social welfare facilities, and landscaped passive and active recreation facilities to cater for all ages. Social welfare support services were located at the above grade pedestrian access levels in phase 4. Residential buildings were five 40 storey modified New Harmony One blocks, and two 30 storey Annex Blocks, with small flats for single persons and couples. This stage also shows the new direction for the HA, where efforts has been made to give the buildings a clear identity of their own. Though standard building types are an efficient and cost effective way of building mass housing, there were concerns that public housing estates were becoming monotonous and not contributing positively to the urban landscape. Consequently, design teams modified the detailing of the buildings and developed unique colour treatment for each site within an overall colour theme.

The fourth and final stage was for the construction of five 40 storey New Harmony One blocks and two 30 storey Annex Blocks with small flats for single persons and couples, catering predominantly for the elderly or small families. This stage also shows the drive towards greater identity, with more modelling on the facades than those in phase 3 and 4 and a slightly different, though sympathetic, colour scheme.

Functional and cost-effective materials , such as acrylic paints for external walls and internal corridor walls, homongeneous floor tiles to common domestic floor areas , were used to ensure rational use of public resources. The final project cost for the redevelopment is estimated at HK$3,958M and is within the project budget of HK$4,974M. Average unit cost for the domestic flat is about HK$5,000/$m^2$ construction floor area.

11. The Completed Estate

Residents are now living in modern self-contained flats with a much improved estate environment, a high standard of landscaping, and ample sitting out areas for the elderly and play facilities for children. The redevelopment has allowed for more effective land use and enhanced traffic flow in the area. Key facilities were maintained during the redevelopment and out of the original 22,000 tenants, 7,000 were eventually re-housed in the new estate.

Figure 10: New Harmony type blocks above the podium in Kwai Chung Estate Phases 3 and 4

Pedestrian access has been improved by footbridges, escalators, lifts and a comprehensive covered walkway system. There is a connection to the nearby Tai Wo Hau MTR station, for convenient and quick access to Hong Kong and Kowloon. A public transport interchange is now at the core of the estate, with a wide range of shopping, social and community facilities, which have created a new focal point at the civic hub There are greatly enhanced recreation facilities and new district open spaces to serve the wider area.

The redevelopment has regenerated the area with the preservation of mature trees, religious shrines, and schools and revitalised landscaping and recreation and play facilities to serve the estate and the district. The environment of the completed estate and improvements for the district as a whole together with the community engagement programme, have fostered a renewed community identity, encouraged greater social interaction and provides for the needs of a vibrant and diverse community, with a greener, safer, healthier and more comfortable living environment.

After 12 years of work and close attention to local interests, Kwai Chung Estate has been one of the largest CRP projects with homes for 40,000 people.

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Architects: CW Ko Chief Architect 1, Hong Kong Housing Department: Phases 1 and 2
ARCA Ltd: Phase 3
MLA Architects (HK) Ltd: Phase 4
P & T Architects and Engineers Ltd: Phases 5 and 7

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A SECOND CHANCE FOR OLD BUILDINGS

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Summary

In the Netherlands, both the office market and housing market show a mismatch between supply and demand, quantitatively and qualitatively. In 2007 almost 14% of all offices are vacant, i.e. 5.9 million square meters. At the same time we see a shortage of about 1 million dwellings. A building must be able to be changed over its life cycle to adapt to the inevitable evolving needs of it's end users. The first real challenge is how to make adaptable buildings without creating unnecessary redundancy. The second challenge is the re-use of old vacant buildings because the available area for erecting new ones is very scarce in the Netherlands. In this matter, old buildings deserve a second chance in their life cycle. We need to be able to measure the transformation potential of office buildings both at location and at building level. To this end, we have developed what we call a 'transformation potential meter' (Geraedts, Van der Voordt, 2003, 2004). The meter has been tested since 2004 in practice by a number of market players, and by students of architecture. This has allowed the transformation potential meter to be evaluated and refined in 2006. Two new steps - the financial feasibility scan and the risk assessment checklist – have also been added. In this paper, we describe the principle of the new transformation potential meter.

1. Prospects of vacant office buildings

According to experts from the world of professional practice, the transformation prospects of the current offering of office buildings depend primarily on the following three factors:

1 *Duration of vacancy:* The longer an office building is unoccupied, the readier the current owner will be to convert it so that it can be used for another purpose.

2 *Reason for vacancy: market, location or building:* When an office building is unoccupied because of market factors, transformation would not seem to be an attractive option from the owner's viewpoint if the market is strengthening. If the location is unsuitable for office purposes and/or the building does not meet (or no longer meets) the requirements for office use, transformation may be a good idea. If the vacancy is due to building-related factors, the transformation potential is highly dependent on the extent to which the building can be converted by design interventions into an attractive residential property meeting the requirements and wishes of local target groups. Financial feasibility and permission to modify the zoning plan are critical factors for success in this context.

3 *Municipal policy:* When the office building in question lies in an area that has been prioritised for residential use by the municipal authorities, transformation into residential housing would seem to be an obvious solution since this is in line with municipal policy. If on the other hand the building is in an area earmarked for (re)development for office use, renovation and reuse for office purposes would seem to be more appropriate.

2. Demand for housing

Transformation of unoccupied offices into housing only makes sense if the dwelling units produced meet a need. The supply must be in line with the demand, as regards both the location – which should be a residential environment – and the features of the building (an office building will in general be converted into a block of flats comprising individual dwelling units). Since nearly a quarter of people looking for housing are under 25 (including many students), transformation into low-cost accommodation may be a good choice. Where high-rise office buildings are concerned, transformation into accommodation for families with young children is less appropriate. Conversion into flats for senior citizens might be a good choice here. Tests of the ability of a transformed building to meet the desires and preferences of potential target groups may be based on the results of various studies of the factors determining the choice of dwelling (see e.g. De Jong, 1997; Priemus, Wassenberg and Van Rosmalen, 1995). Where possible and appropriate, such studies differentiate between the various target groups concerned. The type and size of the housing, an attractive, safe dwelling environment and affordability are important criteria for all target groups. The main differences concern such matters as price and quality level, preference for a family house or a flat, and the desire to live in a lively environment with plenty of facilities or in a more peaceful environment.

Table 1 Relevant aspects on demand side residential accommodation

Location (environment)	Building (residential)
1. Tone	**1. Dwelling type**
a Nature of built environment	**2. Access**
b Social image	**3. Dwelling size**
c Liveliness	a Number of rooms
d Amount of green space	b Living room
2. Amenities	c Kitchen
a Shops	d Bedrooms
b Restaurants, bars etc.	e Sanitary facilities
c Schools	f Storage space
d Bank/Post Office	**4. Arrangement of dwelling**
e Medical facilities	**5. Level of facilities**
f Recreative facilities	**6. Outside space (garden etc.)**
3. Accessibility public transport	**7. View from dwelling + privacy**
a Distance to bus stop	**8. Environmental aspects**
b Frequency and times	a Heating
c Distance to tram or underground	b Ventilation
d Frequency and times	c Noise
e Distance to railway station	d Exposure to sun and daylight
f Frequency and times	e Energy consumption
4. Accessibility by car	f Materials used
a Distance to motorway	**9. General conditions**
b Congestion level	a Accessibility
c Parking facilities	b Safety
	c Flexibility
	d Adequate management
	10. Costs
	a Purchase price/rent
	b Other costs

If one wishes to use a Quick Scan to determine whether an unoccupied (office) building is suitable for transformation to residential accommodation for one or more specific target groups, a demand profile must first be created for each target group. This is also necessary when looking for a suitable building for a specific target group. The five target-group profiles shown in Table 2 have been defined on the basis of the dwelling preferences of the persons concerned.

3. Transformation Potential Meter

The information collected about the transformation prospects, the housing requirements of potential occupants and the target-group profiles has been used as a basis for a number of checklists that can be used to appraise the potential of the stock of unoccupied office buildings for transformation into residential housing. This appraisal takes place in a number of steps, from more superficial to more detailed and specific. Step 0 is the inventory of the unoccupied office space. Step 1 is a Quick Scan of the transformation potential of this stock, with reference to a limited number of veto criteria which fall under the headings Market, Location, Building and Organisation. Failure of a building to meet these criteria means that it does not have sufficient transformation potential and thus leads to a NO GO decision. Step 2 is a more detailed feasibility scan, which shows with reference to appropriate criteria which features of the location and the building lend themselves to transformation and which do not. This then leads in step 3 to the assignment of an overall score expressing the transformation potential of the building(s) in question on a scale varying from non-transformable to highly suitable for transformation. Depending on the results, this leads either to a NO GO decision or to further refinement of the feasibility study in two subsequent phases: step 4 (financial feasibility scan) and step 5 (risk assessment checklist). Depending on the nature of the project involved, step 5 may come before step 4. The transformation potential meter is particularly intended for use in the initial phase of the plan development process, from the first quick scan to the taking of a well-based decision as to whether or not to proceed with the project.

Table 2 Five target-group profiles with preferences for inner-city transformations

Target group 1: Starters	Target group 2: Starters
Young, low-income singles Shared accommodation **Location (dwelling environment)** 1. Urban environment 2. Plenty of amenities **Building (features of dwelling)** 3. Unit in group of 3-7 occupants 4. Bedsit, average 22 m2 5. Shared sanitary facilities 1 shower/toilet per 4 units 6. Shared kitchen with table for meals 7. Shared outside space (garden, etc, 1.5 m2/unit) 8. Shared cycle storage 9. Shared washroom 10. Total 50 m2; useful floor area 35 m2 **Costs** 11. Max. rent 160 - 220 Euro	Young, low-income singles Semi-independent accommodation **Location (dwelling environment)** 1. Urban environment 2. Plenty of amenities **Building (features of dwelling)** 3. Semi-independent unit with shared facilities 4. Bedsit, average 22 m2 5. Sanitary facilities for 2 persons 6. Kitchen for 2 persons 7. Shared outside space (garden, etc, 1.5 m2/unit) 8. Shared cycle storage 9. Shared washroom 10. Total 50 m2; useful floor area 35 m2 **Costs** 11. Max. rent 220 - 320 Euro
Target group 3: Young, two-income	**Target group 4: Senior citizens 55+**
Young couples with two incomes **Location (dwelling environment)** 1. Urban environment 2. Plenty of amenities 3. Suburban (more space, green) 4. Easily accessible by car 5. Good parking facilities **Building (features of dwelling)** 6. Big luxury flat 7. Own outside space (garden, etc.) **Costs** 8. Max. rent 550 - 750 Euro 9. ditto 750 - 1000 Euro for top flat 10. Purchase 100,000 - 200,000 Euro	Low to modal income **Location (dwelling environment)** 1. Safe dwelling environment (social safety) 2. Shops, daily amenities and public transport within walking distance (<500 m) 3. Urban environment 4. Suburban (more space, green) **Building (features of dwelling)** 5. Preferably not on ground floor 6. With lift in building 7. Preferably not with internal staircase 8. At least 3 rooms 9. Living room 25 - 30 m2; bedroom > 11.5 m2 10. Direct link living room, bedroom, bathroom 11. Extra attention to acoustic insulation 12. Adaptable for disabled occupants **Costs** 13. Max. rent 400 Euro 14. Purchase 75,000 - 110,000 Euro
Target group 5: Senior citizens 55+	
Above-modal income **Location (dwelling environment)** 1. Safe dwelling environment (social safety) 2. Shops, daily amenities and public transport within walking distance (<500 m) 3. Easily accessible by car 4. Good parking facilities 5. Some like urban, some like suburban **Costs** 17. Rent 550 - 1100 Euro 18. ditto > 1100 Euro for top flat 19. Purchase 110,000 - 500,000 Euro	**Building (features of dwelling)** 6. Preferably not on ground floor 7. With lift in building 8. Preferably not with internal staircase 9. Access via entrance hall, not via gallery 10. 4 - 5 rooms 11. Living room 30 - 40 m2; big kitchen 12. Direct link living room, bedroom, bathroom 13. Amply sized bathroom 14. Balcony or roof garden 10 - 15 m2 15. Extra attention to acoustic insulation 16. Adaptable for disabled occupants

Step 0: Inventory of market supply at district level

Before starting to use the transformation potential meter proper, an inventory should first be taken of the market supply of office buildings in a given municipality that have been unoccupied in the long term or may be expected to become unoccupied in the near future. Information for this purpose may be obtained from literature surveys, data from estate agents or the investigator's own observations. If adequate information is already available about a given unoccupied building, this step can be skipped.

Step 1: Quick Scan; first impression, assessment with veto criteria

The instrument offers the user the possibility of performing a quick initial appraisal of the transformation potential, which is not very labour-intensive and does not require much data. This quick scan makes use of eight veto criteria that fall under the headings Market, Location, Building and Organisation.

Table 3 The various steps of the Transformation Potential Meter

Step	Action	Level	Outcome
Step 0	Inventory market supply of unoccupied offices	Stock	Location of unoccupied offices
Step 1	Quick Scan: initial appraisal of unoccupied offices using veto criteria	Location Building	Selection or rejection of offices for further study; GO / NO GO decision
Step 2	Feasibility scan: further appraisal using gradual criteria	Location Building	Judgement about transformation potential of office building
Step 3	Determination of transformation class	Location Building	Indicates transformation potential on 5-point scale from very good to NO GO
Further analysis (optional, and may be performed in reverse order if so desired):			
Step 4	Financial feasibility scan using design	Building	Indicates financial/economic feasibility Sketch and cost-benefit analysis
Step 5	Risk assessment checklist	Location Building	Highlights areas of concern in transformation plan; GO / NO GO decision

A veto criterion is a criterion which if satisfied (if the answer to the relevant question is 'Yes') leads to immediate rejection of the idea of transforming the office premises in question into residential accommodation. Further detailed study is then no longer necessary. This is thus an effective means of picking out promising candidates for transformation quickly from the overall potential market.

Table 4 Step 1 – the Quick Scan with veto criteria

ASPECT	VETO CRITERION	DATA SOURCE	App rais.
MARKET			
1 Demand for housing	1 There is no demand for housing from local target groups	Estate agent or municipality	
LOCATION			
2 Urban location	2 Zoning plan does not permit modification	Zoning plan/municip. policy	
	3 Serious public health risk (pollution, noise, odour)	Estate agent or on site inspection	
BUILDING			
3 Dimensions of skeleton	4 Free ceiling height < 2.60 m	Estate agent or on site	
ORGANISATION			
4 Backer for transformation plan	5 There is no enthusiastic, influential backer	Local investigation	
5 Internal veto criteria of property developer	6 Does not meet criteria for region, location or accessibility	Property developer	
Not able to meet specific criteria	7 Does not meet criteria on size and character of building	Property developer	
6 Owner/investor	8 Not willing to sell office building	Owner	

The veto criteria apply to all target groups. Veto criteria 2 and 3 at location level concern the situation of the building within the urban fabric. If for example the office building is located on an industrial site where serious public-health hazards have been discovered, or if the municipal authorities do not allow any modification of the zoning plan at this location, there is little point in taking the investigation of the transformation potential any further.

Step 2: Feasibility scan based on gradual criteria

If the results of the Quick Scan indicate that there is no immediate objection to transformation (no single question is answered 'Yes'), the feasibility of transformation can be studied in greater detail with reference to a number of 'gradual' criteria, i.e. criteria that do not lead to a GO / NO GO decision but that express the transformation potential of the building in question in terms of a numerical score. Taken together, these criteria allow a more rounded picture to be built up of the feasibility of the transformation project under consideration.

Table 5 Step 2a – Feasibility scan on location level using gradual criteria

LOCATION			
ASPECT	**GRADUAL CRITERION**	**DATA SOURCE**	**App rais.**
FUNCTIONAL			
1 Urban location	1 Building in industrial estate or office park far from town centre	Town map	
	2 Building gets little or no sun	On-site inspection	
	3 View limited by other buildings on > 75% of floor area	On-site inspection	
2 Distance and quality of amenities	4 Shops for daily necessities > 1 km.	On-the-spot investigation	
NB: *The quality of amenities can be described*	5 Neighbourhood meeting-place (square, park) > 500 m.	Ditto	
in terms of number, variety and level	6 Hotel/restaurant/snackbar > 500 m.	Ditto	
of services provided.	7 Bank/Post Office > 2 km.	Ditto	
	8 Basic medical facilities (practice, health centre) > 5 km.	Ditto	
	9 Sports facilities (fitness, swimming pool, sports park) > 2 km.	Ditto	
	10 Education (from kindergarten to university) > 2 km.	Ditto	
3 Public transport	11 Distance to railway station > 2 km.	Town map	
	12 Distance to bus/undergr. > 1 km.	Map/transport services	
4 Accessibility by car and parking	13 Many obstacles; traffic congestion	On-the-spot investigation	
Obstacles	14 Distance to parking sites > 250 m.	Inspection/new design	
Congestion: 1-way traffic, no parking, tailbacks *Accessibility by car/parking*	15 <1 parking space/100 m2 dwelling surface	Inspection/new design	
CULTURAL			
5 Tone of neighbourhood *NB:*	16 Situated on or near edge of town (e.g. near motorway)	Map or estate agent	
Assessment depends on target group, e.g.:	17 No other buildings in immediate vicinity	Map or estate agent	
young people not in	18 Dull environment	On-the-spot	
monofunctional neighbourho	19 No green space in neighbourhood	On-the-spot	
55+ not on edge of town	20 Area has poor reputation/image; vandalism	On-the-spot and local press	
	21 Dangerous, noise or odour pollution (factories, trains, cars)	On-the-spot	
LEGAL			
6 Urban location	22 Noise load on façade > 50 dB (limit for offices 60dB)	Municipal authorities	
7 Ownership of ground	23 Leasehold	Estate agent	

The feasibility scan at location level (Table 5) comprises 7 main criteria, subdivided into functional, cultural and legal aspects, and 23 sub-criteria. The feasibility scan at building level (Table 6) comprises 13 main criteria, subdivided into functional, technical, cultural and legal aspects, and 13 sub-criteria. An answer 'Yes' to any question indicates somewhat lower suitability for transformation – though not severe enough for out-and-out rejection. At the end of the scan, the Yes's are added up to obtain the overall transformation potential score – the lower the better. This is described under step 3 below. It may be noted that the criteria vary somewhat, depending on the target group under consideration. For example, students will prefer to live in the city centre where there is more night life, while young families with children will tend to opt for a peaceful suburban environment.

Table 6 Step 2b – Feasibility scan on building level using gradual criteria

BUILDING			
ASPECT	**GRADUAL CRITERION**	**DATA SOURCE**	**App rais.**
FUNCTIONAL			
1 Year of construction or renovation	1 Office building recently built (< 3 years)	Year of construction	
	2 Recently renovated as offices (< 3 years)	Year of renovation	
2 Vacancy	3 Some office space still in use	Representative body	
	4 Building unoccupied < 3 years	Ditto	
3 New dwelling units	5 ≤ 20 -person units (50 m2 each) can be made	≤ 1000 m2 useful area	
	6 Layouts suitable for local target groups can't be implemented	Design sketch	
4 Extendability	7 Not horizontally extendable (neighbouring buildings)	On-the-spot investigation	
	8 No extra storeys (pitched roof; insufficient load-bearing capacity)	On-the-spot investigation	
	9 Basement cannot be built under building	On-the-spot or Estate agent	
TECHNICAL			
5 Maintenance	10 Building poorly maintained/looks in poor condition	External visual inspection	
6 Dimensions of skeleton *Module of façade determines placing of walls*	11 Depth of ffice building < 10 m	Estate agent/inspection	
	12 Module of support structure < 3.60	On-site or estate agent	
	13 Distance between floors > 6.00 m	On-site or estate agent	
7 Support structure	14 In poor/hazardous condition	On-site inspection	
8 Façade *External spaces dependent on target group* *Protected monuments: limits on adaptation*	15 Can't be made to blend with surroundings or module > 5.40 m	On-site or estate agent	
	16 Façade/openings not adaptable	On-site inspection	
	17 Windows cannot be reused or opened	On-site inspection or new design	
9 Installations/services	18 Impossible to install (sufficient) service ducts	On-site inspection or new design	
CULTURAL			
10 Character *cf. Location, 'Tone of neighbourhood'*	19 No character in relation to surrounding buildings	On-site inspection	
	20 Impossible to create dwellings with an identity of their own	On-site inspection or new design	
11 Access (entrance hall, lifts, stairs)	21 Unsafe entrance, no clear overview of situation	On-site inspection or new design	
LEGAL			
12 Environment *Exposure to sunlight, air and noisepollution, hazardous materials*	22 Presence of large amounts of hazardous materials	On-site or municipality	
	23 Acoustic insulation of floors < 4 dB	On-site or new design	
	24 Very poor thermal insulation of outer walls and/or roof	On-site or municipality	
	25 < 10% of floor area of new units gets incident daylight	On-site inspection	
13 Bouwbesluiteisen; bereik-baarheid; vluchtwegen	26 No lifts in building (> 4 storeys), no lifts can be installed	On-site or estate agent	
	27 No (emergency) stairways	On-site or new design	
	28 Distance of new unit from stairs and/or lift ≥ 50 m	On-site or new design	

Step 3: Determination of the transformation class

The results of the feasibility scan can be used to calculate a transformation-potential score for the building in question, on the basis of which the building can be assigned to one of five transformation classes ranging from 'ideal for transformation' to 'not suitable for transformation'. The total scores for the location and the building are determined by multiplying the number of Yes's in the respective tables by a weighting factor, which has provisionally been chosen as 5 for the location and 3 for the building to reflect the greater relative importance of the location in these considerations. The maximum possible score for the location is thus 23 x 5 = 115, and that for the building 28 x 3 = 84, to give a grand total of 115 + 84 = 199 (see Fig. 1).

Total Location (= nr. of Yes's):	**8**	x		Total Building (= nr. of Yes's):	**11**	x
Default weighting:	5	=		Default weighting:	3	=
Score Location:	**40**	**A**		Score Building	**33**	**B**
Maximum Location (23x5):	115			Maximum Building (28x3):	84	

Figure 1 The total transformation-potential scores at Location and Building level are determined by multiplying the number of Yes's in the Appraisal column by the default weighting factor

The minimum score is zero, which would indicate that no single feature of the location or the building is considered unsuitable for transformation. On the basis of the transformation-potential score, the building can be assigned to one of five Transformation classes. Buildings in Transformation Class 1 (score lower than 40), are highly suitable for transformation to residential accommodation, while those in Class 5 (score higher than 161) are totally unsuitable for transformation. All five Transformation classes are given in Table 7.

Table 7 Transformation classes for office buildings; in the example shown, a total score of 40 + 33 = 77 corresponds to Transformation class 2 (transformable)

Transformation score	Transformation class		
Location + Building = 0 - 40	1 = Excellent transformability	**Total Score A + B:**	**77**
Location + Building = 41 - 80	2 = Transformable	Min. score Loc. + Build. =	0
Location + Building = 81 - 120	3 = Limited transformability	Max. score = 115 + 84 =	199
Location + Building = 121 - 160	4 = Very poor transformability		
Location + Building = 161 - 199	5 = Not transformable	**TRANSFORMATION CLASS:**	**2**

Determination of the transformation class of a building completes the first three steps of the transformation potential measurement. If the results indicate that the building lends itself to transformation (i.e. that it falls into transformation class 1 or 2), the analysis can continue in two additional steps, aimed at studying the financial feasibility of the transformation project and carrying out a risk assessment for use in further planning.

Step 4: Financial feasibility scan

If the transformation project is not financially feasible, there is no point in taking the plans any further. The financial feasibility depends among other things on the acquisition costs, the current condition of the building, the amount of renovation or modification work required, the number of dwelling units that could be created in the building and the project yield in the form of rental income and/or sales prices. In order to determine the financial feasibility, answers must be obtained to a number of questions concerning both the project costs and the expected revenue. On the revenue side, we need to know how many dwelling units can be created and for what target groups they are intended. These questions can only be answered if a sketch has been made of the intended layout of the building after transformation. The financial feasibility can be raised by increasing the size of the building, e.g. by adding extra storeys on top, or by the inclusion of commercial functions alongside the residential ones. On the expenses side, it is necessary to know the acquisition costs for the premises, including the cost of the ground. Building and installation costs are also an important factor. What is the current condition of the building? Which parts can be reused, and which will have to be demolished? What is the ratio of façade surface area to gross floor area (GFA)? To what level should the building be finished? To what extent can the existing stairways, lifts and other means of access and façade proportions be maintained? Caused by limitations of the length of this paper the financial feasibility scan will not be presented in detail.

Step 5: Risk assessment checklist

When the Quick Scan indicates that the office building in question has transformation potential at both the location and the building level and the results of the initial financial feasibility analysis are also encouraging, work may proceed on the subsequent development phases. It is of great importance to be aware of the possible bottlenecks and risks that can occur during this process. Two checklists, based on experience gained in a large number of projects, that can prove useful in this context have been developed.

4. Conclusions

Practical trials of the Transformation potential meter in practice have revealed its utility for mapping the potential of given office buildings for transformation into residential accommodation in a number of steps from global to more detailed. It was found, however, that a number of veto criteria included in the original version of the meter were too stringent. Some buildings that failed to pass these criteria on paper were found in practice to lend themselves well to transformation to residential accommodation. For example, a project size of less than 20 dwelling units (2000 m2), a building that was still partially occupied, a duration of vacancy of less than three years or an age of less than three years for the building in question were not necessarily reasons for rejecting the idea of transformation. It was moreover found to be highly desirable to combine the first three stages of the Transformation potential meter (Quick Scan, feasibility scan and determination of transformation class) with a financial feasibility scan and a risk assessment (the readiness of the municipal authorities to approve any changes in the zoning plan required for success of the project is one of the points that needs to be thoroughly explored in advance in this context). Additional literature review is required to cover the international state of the art of the topic discussed in this paper.

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ENERGY EFFICIENCY OF BRAZILIAN BUILDINGS: STATE-OF-THE ART, POLICY INSTRUMENTS AND MAIN RECENT ACHIEVEMENTS

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Summary

Energy supply capacity has increased roughly half of the consumption growth experienced in Brazil between 1990 and 2000. Such growth is noticeable in all sectors and shows a clear trend to further increase in the upcoming years. Buildings are major players in this scenario, as residential and commercial building stocks are responsible for 48% of electricity consumption in Brazil.

Brazil is among the few countries with severe deficiencies in energy efficiency (EE) standardization for buildings, and local buildings waste significant opportunities for energy costs savings for not appropriately considering bioclimatic principles or energy efficient technologies. Earlier studies made evident the huge conservation potential (30% in existing buildings and 50% in new ones) resultant of this poor combination of design/construction decision-making.

The national energy conservation programme (PROCEL) was created in 1985. Between 1986 and 2004, it saved (avoided energy generation) around 20.000 GWh. A labeling system for energy efficient appliances was established through a Federal Act in late 1993. Ten years later, PROCEL launched a building-specific action (Procel-Edifica), with an action plan that encompasses six major activities, including bioclimatic requirements, regulation/legislation procedures and energy efficiency indicators for several building typologies. A draft for a regulation is currently open for public comment and is expected to enter into force in 2007, being initially voluntary in character and compulsory after five years. Additionally, some cities have also begun to discuss laws regarding mandatory solar energy use, triggering a strong debate among designers, specialists, contractors and the municipality.

This paper aims at tracing a historical overview of the evolution of energy efficiency actions and policy instruments developed for the building sector in Brazil, emphasizing those most recently implemented or discussed, such as the proposed national energy efficiency regulation, as well as the main challenges to overcome.

Background on energy conservation actions in Brazil

In general terms, electric energy consumption in Brazil grew until year 2000 (Figure 1). In 2001, due to the combination of failures in long term planning and lack of investment in the supply side, and the increasing consumption led to a severe energy crisis and rationing, that finally triggered the approval of an energy efficiency (EE) law after more than 10 years of considerations in the Congress.

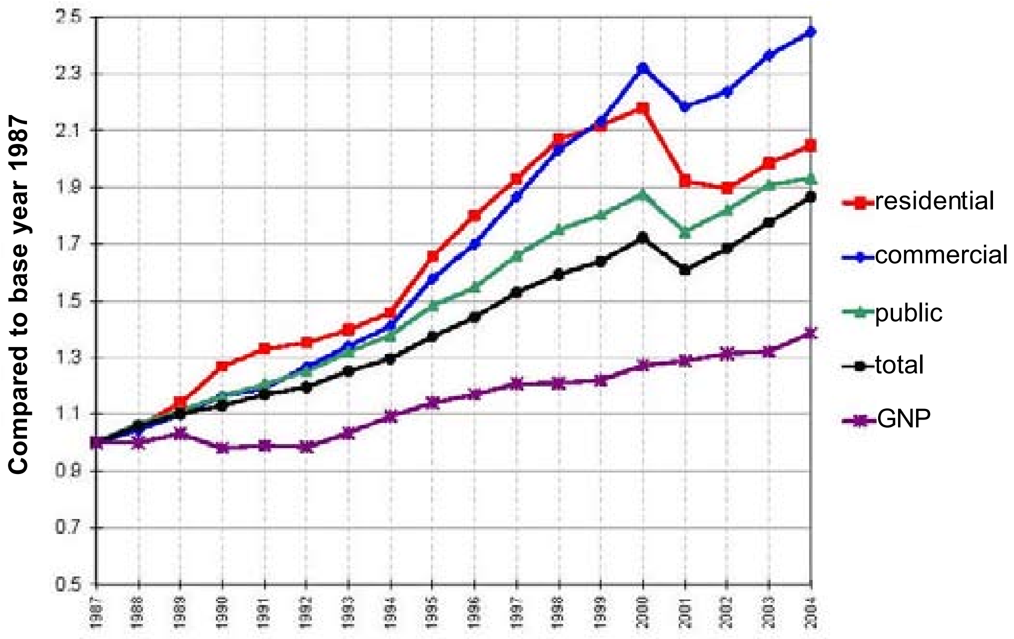

Figure 1 Electric energy consumption and GNP (base year 1987). Source: Balanço Energético Nacional | National Energy Balance 2005)

In Brazil, residential (22%), commercial (14%) and public (8%) buildings are responsible for 44% of total electricity consumption (MME et al, 2007). Among the set of energy efficiency initiatives that in some extent today influence the Brazilian building sector, some of them gathered in Figure 1, at least the following three deserve to be highlighted:

- PROCEL (Brazilian Program for Electricity Conservation) and created by Inter-ministries act MME/MIC nº 1.877, Dec 30th 1985, and maintained and converted into a federal government program by Decree of the Ministry of Mining and Energy (MME), of July 18th, 1991.
- ANEELs Resolution 242/98 (July 24th, 1998) and Law 9.991 (July 24th, 2000) that obligated the collection of private resources to be applied in energy efficiency programs in all sectors (demand side) and regulated distribution of such resources, including R&D projects.
- The Energy Efficiency Law (Law 10.295, 2001), defined the Brazilian Policy of Energy Conservation and Rational Use. The EE law instituted the Management Committee of energy efficiency levels and indicators (CGIEE), determined definition of specific indicators and regulations to be approved after public consultation - for appliances and, years later, for buildings; and the correspondent penalties for non-compliance. This energy efficiency regulation for public, commercial and service buildings refers to PBE (Brazilian Labeling Program) labeled equipment and was developed under the auspice of a PROCEL sub-program (PROCEL Edifica) and approved as in 2007 as a voluntary instrument, to become mandatory after five years.

Table 1 - Energy and CO_2 savings estimated/verified for a chosen set of energy efficiency instruments currently enforced in Brazil.

Instrument	Energy Savings	CO_2 savings[1]	Period
PROCEL (MME/MIC nº 1.877, Dec 30th 1985)	21.753 GWh/year[2]	6,5 to 12,2 million tCO_2/year (estimate DDE/SEPD/MME)	1986-2005
Law 9.991 (July 24th, 2000)	1.954 GWh[3] (DDE/SEPD/MME[4])	not available	2000- 2006
Energy Efficiency Law (Law 10.295, 2001)	Real figures not available. Duffie (1996) estimated savings potential around 12% between 2000 and 2020.	0,38 million tCO_2/year (estimate DDE/SEPD/MME, 2006)	2001-
Performance Contracting (before PROESCO)	18% (public sector) to 19,5% (industrial sector) (Source: ABESCO[5], 2002)	not available	2002
Proinfa[6]	not available	2,9 million tCO_2/year (estimate DDE/SEPD/MME, 2006)	2002-

1.1. The oil crisis and PROCEL creation

In Brazil, the oil crisis in 1973-74 and 1979-81 created the perception of energetic scarcity and elevated prices, justifying investments in increased national oil production, energy conservation and higher efficiency in the use of oil derivates and in the diversification of alternative energy sources.

The strategy adopted in the reformulation of energy offer policy considered the intensification of oil prospecting; increase in the country's production; launching of an ambitious nuclear program aiming at technology transfer in this area and the construction of several nuclear plants for generation of electricity, that however did not produce significant results in terms of energy supply at the time; creation of Proálcool (National program for ethanol production and use) for production of anhydrous alcohol to be mixed to gasoline, exploring the idle capacity of sugar industries; and, in the electricity sector, continuity to the hydraulic basis expansion for electric energy generation, that resulted in an energy surplus in the 80's.

In practice, except for the reduction in gasoline consumption resultant from Proálcool, the other mentioned efforts did not provide effective results by 1980. In 1981, the federal government launched CONSERVE, a program that had as objective to stimulate conservation and substitution of combustible oil used in industry. This program constituted the first significant effort towards energy conservation in Brazil. Several energy efficiency protocols were produced, with effects on industrial sectors like cement, steel making and paper/cellulose. Verified results however clearly pointed to a predominant focus on energy substitution, instead of the desired energy conservation: 79% of the operations approved by the BNDES (Brazilian Bank for Development) for the CONSERVE program between 1981 and 1985 aimed at energy source substitution, with intensification of the use of electricity, while the initiatives for energy conservation represented only 21%.

This was possible because of the economic recession in 1981, which reduced electricity demand and made some inactivity possible in the installed capacity of the electric energy generation park. To use this exceeding capacity, EGTD (energy guaranteed for a certain period of time) was created to guarantee energy supply at prices 30% lower for the industrial sector until 1986, facilitating amortization of investments on equipment installation or conversion. Obtained gains were considerable, however with the crescent use of electricity for industrial thermal purposes, promoted partly by CONSERVE, partly by the Eletrotermia program. What was actually verified was the responsibility transfer on energy conservation to the electric sector.

The growth in electric energy demand for industrial thermal purposes put pressure the sector's supply capacity, which was in deep financial crisis. The adopted strategy was the implementation of an electric energy conservation policy, which in turn resulted in the creation of PROCEL (Brazilian Program for

1 Source: Porto, Laura. EficiÍ ncia energÈtica no Brasil. BrasÌlia, 29 de novembro de 2006. DDE/SPDE/MME.

2 (Hydro)Plant equivalent = 5.124 MW, considering a typical capacity factor of 56% and including average transmission and distribution losses of 15% for the energy conservation parcel.

3 Results from resource application in energy efficiency programs. Source: ANEEL, apud Porto, Laura. EficiÍ ncia energÈtica no Brasil. BrasÌlia, 29 de novembro de 2006. DDE/SPDE/MME.

4 Department of Energy Development / Secretary of Enery Planning and Development / Ministry of Mining and Energy.

5 ABESCO (Brazilian association of Energy Conservation Service Companies - ESCOs).

6 Programa de Incentivo ‡s Fontes Alternativas de Energia ElÈtrica (Proinfa), created by Law 10.438, of April 26th 2002.

Electricity Conservation) in 1985 that constituted the first systemic initiative for the promotion of efficient use of electric energy in Brazil.

PROCEL was created in December 1985 by the Ministries of Mining and Energy and of Industry and Commerce (Inter-ministries act MME/MIC nº 1.877, Dec 30th 1985) and managed by an executive secretariat supervised by Eletrobrás, to integrate actions for electricity conservation across the country. In July 18th 1991, PROCEL became a Federal Government Program through a Decree of the Ministry of Mining and Energy (MME) of July 18th 1991, having its scope and responsibilities broadened.

PROCEL has gone through several phases, including stagnation between 1990-1991, due to investment discontinuity and administrative reforms in the federal Government. Other actions were carried out such as establishment of a 10-year plan and guidelines, and creation of support groups composed by national and international institutions, but only 6 action lines were actually implemented: 1. labeling of more efficient electric appliances; 2. energy diagnosis, auto-evaluation and energy optimization in industrial and commercial installations; 3. technologic R&D for insertion of more efficient equipment; 4. public lighting (basically by lamp substitution); 5. information programs, education and promotion increasing access to information to all society levels; 6. legislation and regulation for energy conservation (Jannuzzi et al, 2004)

Finally, between 1999 and 2002, PROCEL functioned as technical support instance for ANEEL (National agency of electric energy) for the analysis approbation, and implementation of wastage avoidance programs with application of 1% of utilities' net annual operational revenue.

Investments made used resources from RGR (Global reversion reserve), a federal fund composed by resources from energy (concession) companies and provided by ELETROBRAS for projects elaborated by utilities based on policies established by PROCEL, like demand controllers, tariffs, and public illumination, always in a complementary investment mode (counterpart in proportion to investments made). Results are impressive (savings around 18 times the investment made between 1986 and 2005), however reliability of some of them (e.g. publicity campaigns; diagnoses and studies; educational programs) is low, given the limitations or even absence of evaluation methods.

Brazil has mature and comprehensive programs, there is favorable legislation, but still in need of new, complementary instruments. There is a huge, unexplored potential for energy efficiency. Barriers perceived at the time of efficiency programs implementation (e.g. low, subsidized tariffs; lack of information; incipient technology; inadequate legal structure; depleted resources; lack of qualified professionals; resistance from utilities companies…) are now mostly overcome and no longer impeditive. On the contrary, market transformation gained momentum and market is now clearly driven by motivators such as cost reduction (for consumers, producers and distributors); increase in economic efficiency (reduction of energy intensity); improvement in commercial balance (reduction of diesel oil and LPG importation); and reduction of environmental impacts (Porto, 2006).

Is has become clear that legislation and legal procedures to support energy efficiency programs have significantly advanced, with remarkable results for the society, like the 60% increase in annual investment values for end-use energy projects. Results (investments and obtained savings) demonstrate that such programs are advantageous in comparison to system expansion. It is therefore necessary to define more rigid and standardized procedures to results accountancy, aiming at giving more credibility to the process as a whole (Jannuzzi et al, 2004).

2. More recent regulatory marks

2.1. The Brazilian Labeling Program (PBE): PROCEL, CONPET[7] and the energy efficiency law (Law 10.295, 2001)

The Brazilian Labeling Program (PBE) results from a cooperation protocol among the Ministry of Industry and Commerce and the Brazilian Association of Electric and Electronic Industry (ABINEE), with intervention of the Ministry of Mining and Energy. PBE promotes equipment efficiency through labels that inform consumers on the energy consumption. Implementation of this program is based on Technical Groups established for each type of equipment. Models are distributed into classes according to their energy efficiency, determined by specific laboratory tests. Despite its success in enhancing performance of energy consuming appliances, PBE's comparative labels (associated to CONPET label, in the case of gas water heaters) incentive efficiency increase of the best models in the market, but still do not prevent that low efficiency products be manufactured or commercialized. The Energy Efficiency Law (Law 10.295) therefore bridges this gap, as it excludes from the market equipments not complying with the minimum performance levels required.

Impressive results have been collected by the energy efficiency programs, like PROCEL (energy savings of 22.095 GWh/year; summing up to R$ 15,6 billion of avoided investment) and CONPET (320 million liters of diesel oil savings/year; 860.000 t CO_2 avoided per year; 19.000 t of particulates avoided per year).

The Congress passed the Energy Efficiency Law (Law 10.295) after more than 10 years of considerations, only in 2001, when a severe energy crisis hit the country. Despite its success in enhancing performance of energy consuming appliances, PBE's comparative labels (associated to CONPET label, in the case of gas water heaters) incentive efficiency increase of the best models in the market, but still do not prevent that low efficiency products be manufactured or commercialized. The Energy Efficiency Law (Law 10.295) is supposed to bridge this gap, as it excludes from the market equipments not complying with the minimum performance levels required, even though showing a more limited potential to avoid emissions (0,38

[7] CONPET (1981): Brazilian program for rational use of oil and natural gas derivate products.

million tCO_2 avoided/year), if compared to the potential of labeling programs (PROCEL+CONPET: 6,5 to 12,2 million tCO_2 avoided/year), as shown in Table 1.

2.2. The 1% obligation law (Law 9.991, 2000)

It is very unlikely that initiatives in energy efficiency (EE) and energy research and development (R&D) in Brazil would have taken place without the regulators' enforcement of compulsory programs in 1998 and later with the implementation of Law 9.991/00 by the National Congress (Jannuzzi, 2005).

In 1995, with the inclusion of the electric sector in the de-statization programs, the Federal Government looked for mechanisms to ensure that the private sector would invest in energy efficiency (Haddad, 2002). The energy distribution sub-sector then received the attribution of using part of the operational revenue in energy efficiency programs, through concession contracts and specific legislation (ANEEL's "1% resolution" (1998) and Law 9991 (2000), that determined the application of 1% of annual operational revenue in efficiency actions, for each utility company and according to an annual calendar established by ANEEL (Jannuzzi et al, 2004).

In 1998, ANEEL, the energy sector regulator, issued the ("1% obligation") resolution[8] mandating utilities to invest a minimum of 1% of their net annual revenues in EE (end-use / supply-side efficiency) and R&D programs. From 1998 to year 2000, utilities were responsible for the formulation and implementation of EE and R&D programs. This procedure privileged the selection of projects of most interest for the utilities, with very short paybacks and potentially limited social impacts (Jannuzzi, 2005). In 2000, a national law (Law 9.991/00) was approved and *(1)* changed the allocation of the resources from the "1% obligation" and created a national fund - CTEnerg, in charge of investing in public interest energy efficiency and energy R&D; and *(2)* determined that utilities could only implement end-use energy efficiency programs, eliminating the possibility of application of such resources in projects in the supply side from the investment cycle of 2000/2001 on.

In 2001, under the severe energy rationing experienced in Brazil, ANEEL directed almost all resources to public illumination energy efficiency programs and fluorescent compact lamps donation to low income consumers. It became clear that conservation costs per kW reduced/made available were far below the traditional reference generation costs, estimated in US$ 1.000/kW (Jannuzzi et al, 2004). During the year 2004, the "1% obligation" suffered its first political attack and resources were diverted away from EE and R&D.

3. New agents – the industry of energy efficiency

Activation of the energy efficiency market presumes participation of several agents, initially stimulated by governmental actions and, in a second moment, spontaneously. In this sense Brazilian ESCOs have followed (though not integrally yet) the American market model (sharing gains to make their own costs feasible and assuming clients risks) of offering specialized engineering services in projects for reduction, optimization and energy efficiency in energy processes and uses. In this kind of partnership, it is used a methodology based on Performance Contracts, that guarantees savings to the client that make the needed investments feasible. Performance contracting results (2002) are shown in Table 2.

Table 2 - Performance contracting results (Source: ABESCO, 2002).

Sector	Nr. projects	Investment million R$	Average savings %	Payback period (yrs)
Industrial	57	14,4	19,5	3,0
Commercial	35	5,4	18,5	2,4
Public	25	3,7	18,0	1,2
Total	117	23,5	18,8	2,2

In 2006, a specific credit line (Programa de Apoio a Projetos de Eficiência Energética (Proesco) was created by BNDES (Banco Nacional de Desenvolvimento Econômico e Social) to facilitate financing of projects and performance contracts developed by ESCOs, helping to overcome the major barrier faced by the Brazilian energy efficiency market, which is responsible for R$ 200 million every year.

PROESCO offers alternatives for the market as a whole, creating new business opportunities for utilities, efficient equipment manufacturers, energy consuming companies, and mainly for Energy Services Companies. Financing is available for end-use and ESCOs activities support projects, and focuses on projects capable to prove their contribution to energy savings (equipment using more efficient technologies). This ensures positive results at acceptable payback periods.

8 ANEEL Resolution 242/98 (July 24th, 1998), which aprimorated the concession contracts clauses (1% obligation) and stipulated that 25% of the resources callected through the utilitiesí 1% obligation would be applied in efficiency actions on the demand side, being at least 10% of them directed to the residential sector; 10% to the industrial sector and 10% to public buildings. Regarding the remaining 75% (supply side), 30% (connected grid system, i.e regions South, Southeast and Centerwest) and 10% (regions North and Northeast) should be applied to projects adressing improvement of systems load factor.

Items eligible for financing (up to 72 months) are: studies and projects; construction and installations; equipment and machinery; specialized technical services; information, monitoring, control and supervision systems.

According to the type of client, PROESCO offers two operating modalities:

- For ESCOs Supporting Projects: risk shared between BNDES (share limited to 80%) and the accredited financial institutions or indirect operation, when the financial agent fully assumes the amount financed and the credit risks
- For Projects from Final Users of Energy: direct operation (carried out directly with BNDES) or indirect operation (carried out through accredited financial institution). Projects under shared risk modality will be presented to BNDES bearing an analysis from the accredited financial institution, after performance of the technical viability certification by a qualified institution.

A traditional financing procedure, in which the ESCO acted as service provider and the client was in charge of fundraising, was used between PROESCO's creation last year and mid 2007. In June 5th 2007, BNDES started a partnership with a federal bank (Banco do Brasil) that makes possible that the credit be granted directly to ESCOs, increasing agility and capillarity of the program's operations.

4. Brazilian Energy efficiency regulation

The regulation is voluntary for the first five years and applies for totally, partially or non-conditioned buildings, aiming at enabling energy-labelling of office, commercial and public buildings with net area over 500 m^2 or supply tension over 2,3 Kv.

Five efficiency levels (form A to E, being "A" the most efficient) are specified for envelope, lighting systems and air conditioning. Research to fundament the regulation requirements concluded that lighting responds for 12-57% of energy consumption, and together with HVAC systems (25-75%) and equipment (6-38%) are the major players to close the energy consumption equation for office buildings in Brazil. Weights for lighting, HVAC and envelope were initially established as, respectively, 30%, 40% and 30%. Non-conditioned areas have to be simulated to demonstrate that comfort conditions are maintained for at least 95% of the occupied period. As a requirement for certification eligibility, the building must count on a sub-metering system by energy end use. Minimum requirements for certification at the highest level are also defined and other initiatives that might contribute to increase the building's global energy efficiency are recognized by a bonus point.

Energy efficiency regulations usually provide at least one of three compliance paths: prescriptive, tradeoff and performance demonstration, being the two latter ones usually a comparison between design and reference cases (Lamberts; Carlo, 2006). While the prescriptive approach limits physical properties of the building envelope materials and assemblies, the performance demonstration option requires use of building simulation tools. The Brazilian proposed regulation includes both compliance paths. For the performance compliance path, minimum functions for building simulation software are presented (MME et al, 2006).

Gathering the energy use data, and constructive, materials and components characteristics that could be considered representative of major building typologies (reference prototypes) is a daunting task, particularly considering that Brazil does not count on reference databases like RECS (for residential buildings) or CBECS (for commercial buildings) available in the United States, or similar sources in other countries. Only based on these reference performance levels, tied to the national building context, it will be possible to establish minimum efficiency requirements. The reference prototypes as the starting point that set alignment for the energy conservation measures (ECMs) to be applied for theoretically more efficient alternatives. The progressive application of ECMs tends to increase a certain building's efficiency level and their effectiveness is evaluated through simulation of thermal-energy performance. Several pieces of software are available and through cross-referencing simulation results with prototypes and possible alternatives, an energy consumption scale will be gradually delineated and allow for initial classification of buildings and to relate scale intervals to ECMs applied in each alternative. As energy efficiency is not given by energy consumption alone (Lamberts; Carlo, 2006), the proposed EE regulation combines consumption to life-cycle energy costs analyses.

5. Concluding remarks

Voluntary labeling schemes have been applied in Brazil for more than 20 years when the National Labeling Program was created in 1984. This voluntary program made possible the reduction in electricity consumption of the models available to the Brazilian consumers. Besides this mechanism, since 1994 the PROCEL Label (Selo PROCEL) is issued annually to the more energy efficient appliances and equipment within their categories. It aims to stimulate the national manufacturing of more energy-efficient equipment and to enable consumers to compare the energy use of the models they are considering. In 2006 the introduction of a mandatory minimum energy efficiency standard for residential refrigerators started to be discussed, which should be implemented early in 2007.

It is however unlikely that energy efficiency (EE) and energy R&D initiatives in Brazil would have taken place without the regulators' enforcement of compulsory programs in 1998 and later with the implementation of Law 9.991/00 by the National Congress. Power sector reforms in Brazil provided the opportunity to enhance support and in fact increase significantly the level of funding in these areas. The regulatory requirement introduced since 1998 has increased by several times the amount of investments in energy efficiency through PROCEL (Brazilian Program for Electricity conservation). Whilst PROCEL, the national electricity conservation program initiated in 1985, invested an annual average of US$ 14 million during 1994-2003, utilities' compulsory investments averaged US$ 57 million per year during 1998-2004 (Jannuzzi, 2005).

However, legislative acts alone are not a sufficient condition to ensure that resources are being used efficaciously to maximize the public interest in energy-related services. In spite of the increased investments, no independent ex-post evaluation of the programs implemented has been carried out as yet to determine impacts in terms of avoided capacity and energy savings.

Significant experience has been acquired by the regulator and utilities in terms of managing EE and R&D portfolios, there are, however, three main areas that require attention to improve the performance of the Brazilian "1% obligation": 1) the administration, governance and coordination of the resources and efforts (amongst utilities and CTEnerg); 2) the need to improve collaboration and pooling of more resources into the compulsory EE and R&D activities; and 3) program monitoring and ex-post independent evaluation (Jannuzzi, 2005).

During the initial years of the "1% regulation" (1998-2005) ex-ante evaluation of EE programs was done by PROCEL. ANEEL then transferred this evaluation to some State regulators, to bring this activity back to its own staff later on. In 2005 ANEEL contracted external consultants to evaluate the proposed utilities' annual EE programs. The ex-ante evaluation of utilities' R&D programs was initially done by ANEEL staff. In a second phase ANEEL contracted the National Research Council (CNPq) to review the R&D proposals. More recently (2003), ANEEL contracted Universities and Research Centers for this task (Jannuzzi, 2005).

Despite Brazil's mature and comprehensive programs and favorable legislation, there is still a huge, unexplored potential for energy efficiency and a clear need for new, complementary instruments. Barriers perceived at the time of efficiency programs implementation (e.g. low, subsidized tariffs; lack of information; incipient technology; inadequate legal structure; depleted resources; lack of qualified professionals; resistance from utilities companies…) are now mostly overcome and no longer impeditive. On the contrary, market transformation gained momentum and market is now clearly driven by motivators such as cost reduction (for consumers, producers and distributors); increase in economic efficiency (reduction of energy intensity); improvement in commercial balance (reduction of diesel oil and LPG importation); and reduction of environmental impacts (Porto, 2006).

Energy efficiency poses a series of challenges in the broader Brazilian context:

- Define and align governmental action instruments (PBE, Procel, Conpet)
- Orient application of available resources (PEE, Sectoral funds)
- Orient refinement of the legal and regulation system;
- Facilitate constitution of a sustainable market for energy efficiency;
- Promote permanent mobilization of the society

Finally, transformation of the energy efficiency market demands:

- encouragement to energy efficient equipment, buildings, systems and production processes;
- support for energy sources replacement;
- orientation of governmental purchasing power;
- support for technical losses reduction;
- incorporation of energy efficiency in energy sector planning.

Regarding the building sector, specifically, the EE regulation, constitutes the major achievement. Even though it was included in the EE law issued in 2001, it took six years to have the regulation's first draft, launched in the end of 2006 and already altered twice before the consultation started. The proposed regulation is dedicated to commercial and public buildings, which sum up to 22% of total electricity consumption in buildings. Ex-ante projections of savings are not available yet, but are expected to be around 15 to 20%. The next step is to develop a version for the residential sub-sector, responsible for other 22% of electric energy consumed in Brazilian buildings and that, together with commercial building, has shown the steepest growth curves after the rationing in 2001.

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INFORMATION EMBEDDED BUILDING' FOR SUSTAINABLE LIVING

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Keywords: building management, life cycle traceability, energy use monitoring, ubiquitous technology

Summary

For promotion of sustainable living by rational building management, stakeholders of building need to be assured to acquire holistic data &information necessary for environmentally conscious decision-making in building management. However, in reality, stakeholders are not always able to access to the information, because some building related data are not collected, some are fragmented and some are deleted. This paper proposes the idea of 'information embedded building': it is a building that assures stakeholders to ubiquitously access to data &information whenever and wherever they need. This paper illustrates the technology developments that realize the idea of 'information embedded building'. Those include;

- Life cycle based traceability system for building components using RFID technology
- Network based energy monitoring system accessible by various stakeholders
- Personalized portal site system as a gate to access to holistic and customized data &information package of his/her building

The paper presents background and motivation of technology developments above. The application of the developed systems proves that they have potential advantage to assure ubiquitous accessibility to holistic range of building related data & information that are indispensable for rational building management to enhance environmental sustainability of built environment.

1. Introduction

Generally, the quantity of existing building in one country is enormously larger than the capacity of new construction of building in that country. For instance, Japan has totally 8 billion m2 building stock while it produces some 0.2 billion m2 new buildings. Therefore, for environmental sustainability of built environment, enhancement of environmental performance of existing buildings by improvement of building management is significant as well as that by increase of newly constructed sustainable buildings.

Various professional and non-professional stakeholders, such as owners, residents & occupants, investors, suppliers, managers, architects, engineers etc.,perform significant role in the process of building management. If they are well informed, stakeholders could make more rational decision-makings from the aspect of environmental sustainability of building.Contrarily, if they should not be well informed, the decision-making could be irrational. For instance, old-fashioned equipments are being replaced to improve energy use efficiency in building. However, in many cases, energy use is not reduced as is expected because inefficient operation of building equipments. If data relating to operational efficiency of equipments are available, managers of building would improve operation method and try to identify real energy use demand before they replace equipments. Thus, the availability of necessary data &information for building management is one of the key factors for environmental sustainability of existing buildings.

Regrettably, in reality, stakeholders are not always assured to acquire data & information promptly when and where they need, because some building related data are not recorded nor collected, some are fragmentally stocked by different agents, and some are missed and deleted. Consequently, difficulty in availability and accessibility of data and informationis is one of the barriers for enhancement of environmental performance by rational building management.

Here the idea of 'information embedded building' is emerged as a measure to breakthrough the barriers. By the introduction of information embedded building, stakeholders are able to access data & information whenever and wherever they need them. This paper aims to propose the idea of information embedded building and illustrate the examples of technological systems developed by author based on the idea.

2. The idea of information embedded building

Figure 1 illustrates the idea of 'information embedded building'; it is a building that assures stakeholders to ubiquitously acquire building related data &information whenever and wherever they need. Acquirable data & information includes;

- Technical detail and specification of building and its components
- Maintenance record of building and its components
- Monitored performance data of building such as data on energy use, indoor air quality etc.(real time based if necessary)

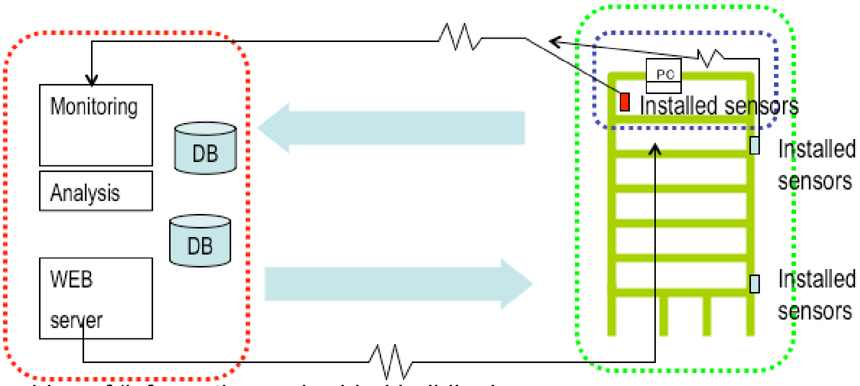

Figure 1 The idea of 'information embedded building'

The wording of information embedded building is a metaphor; It does not mean information is literally and physically embedded in building. Rather, it is a building in terms of which stakeholders of building are accessible to database at any time and at any place through embedded devices such as RFID etc. The device is a kind of access gate to the database stocked in the physically distant located servers. But for stakeholders who read, look, generate, edit and send data & information have a feeling that data & information is extracted from the embedded device. Information embedded building also means the building in terms of which stakeholders can collect performance data through ubiquitously installed digital sensors.

In order to realize the idea of information embedded building', the author developed the systems that ensure stakeholders accessibility to 'embedded' data & information. Those include;

- Life cycle based traceability system for building components
- Network based energy monitoring system of building
- Personalized home information portal site

3. Life cycle based traceability system for building components

3.1Background and motivation

Building can be recognized as a set of materials and components. Therefore, environmental sustainability of building is affected by those of installed materials and components. However, it is quite usual that residents, owners of building and professions who commits in the process of building management have difficulty to access to the information to identify the following issues.

- Technical specification and EPD of building materials and components and equipments
- Recommended maintenance method
- Previous maintenance record (home log book data)
- Fabricators, suppliers, operators, servicers who is responsible for fabrication, installation and maintenance of part of, or whole building

The difficulty of the identification of the issues above causes inappropriate treatment and use of components and equipments, delayed and inefficient repair & maintenance works, and poor traceability. Especially it should be noted that repair and maintenance works would be still less-productive by extension of lead-time if issues above is not identifiable.

3.2Developed system

Figure 2 illustrates the system developed by the author and collaborators. Here RFID device is embedded in the installed components and equipments. Professional and non-professional stakeholders can access to the database from the site at any time through the network between embedded RFID and servers. The database includes the information to identify the issues listed in 3.1. Contents of database can be input by various stakeholders who commit in the process of life cycle operation of building components and equipments from fabrication to the end-of-life of them. Stakeholders in downstream can utilize information input by those in upstream of life cycle stages. For example, residents can easily access to the updated user manual, directory of maintenance service providers and previous maintenance record. Maintenance service providers can access to the information on technical specification, maintenance manual, invisible construction details including interactions and interfaces with other components and previous maintenance records. In addition, contents of database input by downstream stakeholders are usable by upstream stakeholders. For instance, suppliers of equipments and components can identify where their products are actually installed and can contact users if they should recognize technical failures in fabrication or installation.

Thus, the ubiquitous accessibility to the database assures prompt data input by various stakeholders and immediate utilization of database whenever and wherever the stakeholder need. In a sense, the system can construct give-and-take basis data & information sharing by stakeholders, while it assures intensive protection of confidential information for specific stakeholder by advanced access control technology.

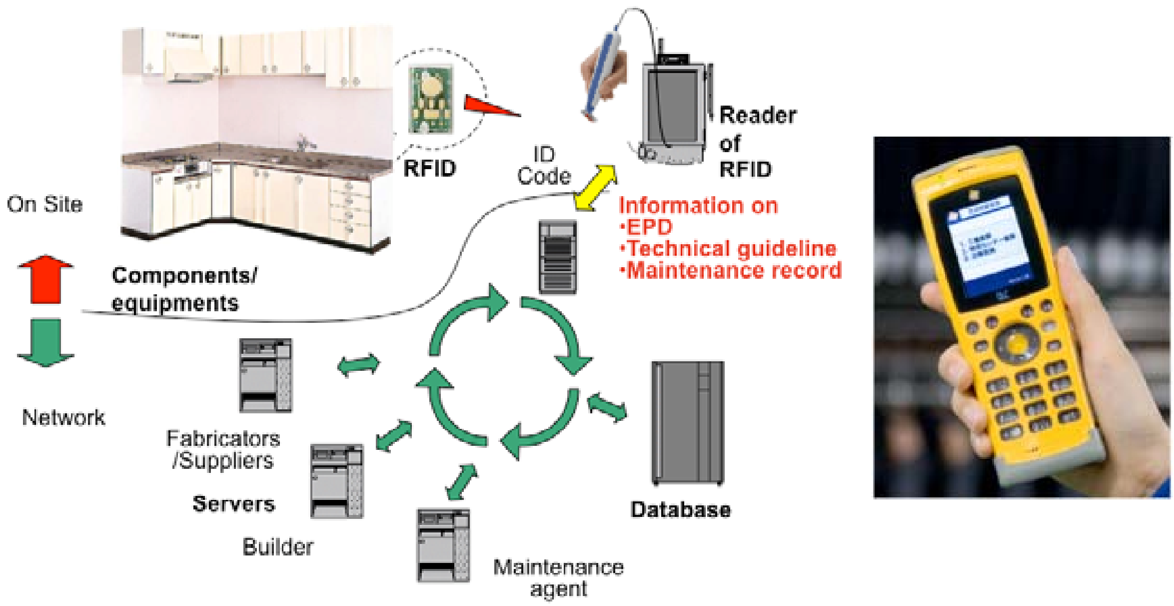

Figure 2 Life cycled based traceability system for building components and equipments using RFID

3.3 Potential benefit by life cycle based traceability system for building components

The life cycle based traceability system using RFID is now experimentally applied by nonprofit organization in Japan (Centre for Better Living). The trial experiments generate empirical lessons for application of the life cycled based traceability system for building components and equipments using RFID. It has proved that traceability system can easily form 'invisible' link between suppliers and users of components. It means that suppliers could have a chance to support users directly and to enhance the environmental sustainability of building.

The application of the traceability system has demonstrated the potential advantages to facilitate sustainability oriented building operation and maintenance by assurance of prompt information acquisition for various stakeholders of building.

4. Network based energy monitoring system

4.1 Background and motivation

A building can also be considered as a system in operation and provides a number of services to its users as well as conditions appropriate for living, working, etc. The environmental sustainability of the building relates to the services and conditions provided to occupants. A building provides the services by inducing energy, water, and various resources for its operation as well as generating atmospheric emissions, wastewater, wastes, etc.

As many previous literatures point out, there exist serious gap between the designed potential of energy performance of building and the reality of energy use. One of the reasons of the gap is weak feedback in building management process due to difficulty in data availability/accessibility in terms of energy use and indoor air quality. Thus, there exit the need to develop technical tool by which stakeholders of building know the real time energy use of whole building, or part of the building where he/she lives and works.

Building Energy Management System (BEMS) assures data availability/accessibility in terms of energy use in building. However, BEMS is mainly applied relatively larger office buildings which only occupy less than 10% of total floor areas of building stocks. Comparatively, smaller and middle sized buildings less than some 5 thousand m2 total floor area do not have resident professional energy manager, a very few stakeholders of those buildings can access to the data on real time basis energy use and indoor climate conditions that is the basis for living and work style with lower energy use intensity. In another word, it is probable that owners and residents who are active and positive for sustainable living actually behave irrationally against their purpose simply because of difficulty in data availability/accessibility in terms of energy use and indoor climate conditions. The gaps between sustainability oriented intention of occupants and the real consequences of energy use are expected to be minimized by introduction of technical tool that provide data on energy use and indoor climate conditions.

By incremental concern to global warming, policy makers advocates restricting comfort of indoor quality, For instance, Japanese government appeals to general public to keep mechanically conditioned indoor temperature higher than 28 deg C from the aspect of total peak demand control in summer time. But 28 deg C with high humidity is not comfortable to occupants; in a sense, the government's appeal is a request of compromise in well-being of occupants of building. The appeal could be emergency measures but could not be sustainable measures from the aspect of peoples' acceptance. There exist number of wasteful energy use in operation of building. Avoidance and minimization of those wastes should be the first measures before down grade of indoor environment quality. However, to avoid and minimize those wastes, energy use data availability/accessibility is essential. Thus, there is a need of cheaper technical tool that enables to provide energy use data and indoor climate data to stakeholders.

This is the background and the motivation why the author and collaborators has developed network based energy monitoring system which mainly target the smaller and medium sized buildings where BEMS is not applicable or where technical support by resident energy manager is not available.

4.2 Developed system

Figure 3 illustrates the web based energy monitoring system developed by the author and collaborators. The network system links devices such as current transformers (CT) that digitally quantify energy use in designated part of building (rooms, blocks, floors etc.), as well as sensing devices to measure characteristic of indoor climate (temperature, moisture content, CO_2 gas content etc.) All data is automatically collected through open web based network sources in terms of protocols and database architecture. Operating software is frame-worked with modulared and compatible with almost all conventional devices. Consequently, installation of the system as is illustrated in Figure 3 is relatively cheaper because any devices that is already installed in building is usable and thus additional investment is relatively lower than previous energy monitoring systems of building which applies large scale well performed but closed system composed of specific devices.

Any stakeholders can join in the circle of users of the network based monitoring system. Users can get the collected data and analysis report depending on his/her concern. In addition, owners and building managers can easily define benchmarks through the comparison with other similar buildings.

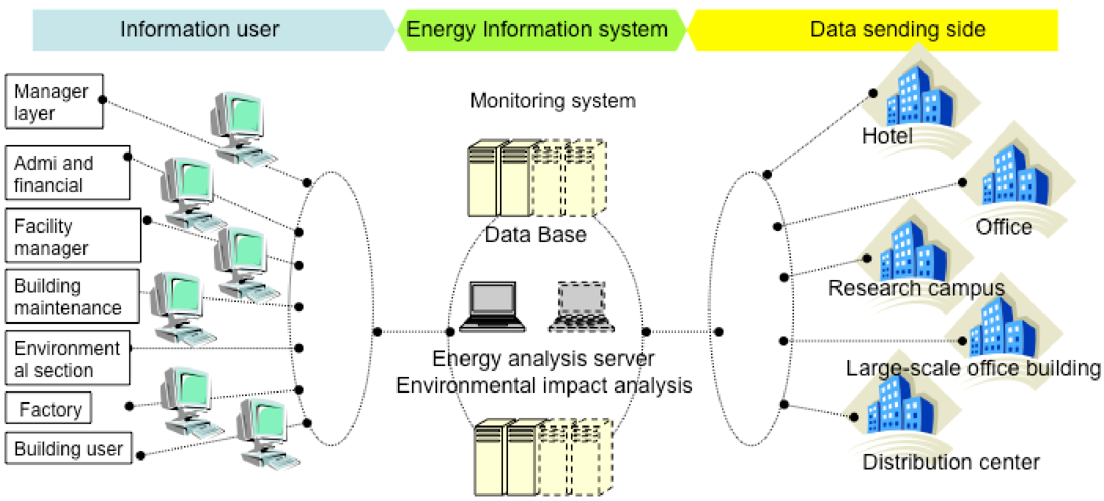

Figure 3 Outline of network based energy monitoring system

4.3 Potential benefit by energy monitoring system

The energy monitoring system is now installed and used in over 20 buildings. In many cases around 10 % reduction of energy use has been realized for five years since the installation of the monitoring system. The energy use reduction and associated reduction of CO2 emission from the building has been achieved only by improvement of operation. It includes;

- Promotion of voluntary activities by residents and occupants who became knowledgeable by provision of energy monitoring data (in other words, notice on how much energy they used respectively)
- Rationalization of ventilation by concurrently monitoring of indoor environmental sensing data (Figure 4)
- Improvement of COP performance of equipments by balancing real demand and capacity of air conditioning machines

Figure 4 illustrates the example of concurrent analysis of impact by mechanical ventilation control using energy monitoring system. Install monitoring system identified that too much mechanical ventilation is operated. Thus, building managers tried to change in operational mode of mechanical ventilation by watching real time base data of indoor CO2 concentration and energy use. It is a sort of concurrent and continual do-check-action process; If CO2 concentration is too high, ventilation is increased. Contrarily CO2 concentration is acceptably low, mechanical ventilation is decreased.

If developed energy monitoring system is used over two years, energy demand model can be constructed. Once energy demand model is established, proactive operation that optimizes COP performance over time. Actually industrial collaborator with the author invented optimization of building's operation over time; In such cases, more intensive energy use reduction should achieved by proactive operation of energy uses.

The experimental application of the energy monitoring system proved the potential benefit of building operating energy reduction by identification of inefficiency of energy use in building and by promotion of commitment by stakeholders.

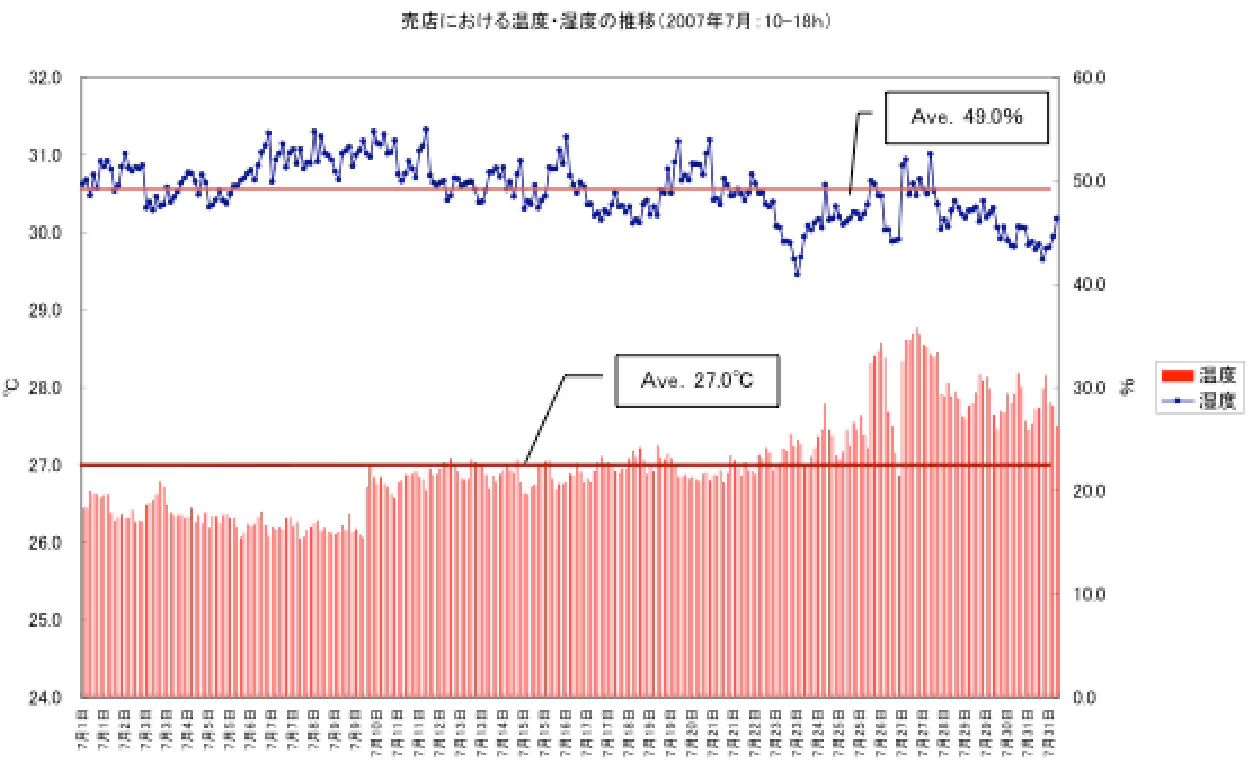

Figure 4 Example of on concurrent analysis of impact by mechanical ventilation control using energy monitoring system

In addition, developed energy monitoring system is usable to evaluate real effectiveness of new building technologies. For instance, performance of passive solar house is delicate and can be too sensitive to unpredictable factors. To realize potential benefit of well-designed passive solar house, it is desirable to introduce concurrent and continual do-check-action process like the process illustrated in Figure 4.

5. Personalized home information portal site

5.1 Background and motivation

A building can be considered as a place to live and work. Provision and realization of better environmental performance of building in broader sense upgrades serviceability, comfort, health and quality of life generated by building is a critical factor for better environmental sustainability of building over life cycle of building. Occupants and stakeholders of building are expected to take proactive and voluntary action.

In order to promote rational decision-making toward sustainable built environment, stakeholders of building who commit in the process of building management should have whole picture of state of art of the building. As it is described in previous chapters, a building can be understood as a set of materials and component. It also can be understood as a system in operation.

For realization of better place to live and work, it is desired to integrate the information on the performance related to a set of materials and components as well as system in operation. Life cycle based traceability system for building components and energy use monitoring system can provide information on performance of building whenever and wherever stakeholders wish. However, those systems only provide a kind of snapshot views taken from specific interest of the stakeholders. Thus, it is expected some methodology is created to residents and owners of building by which they can build up whole picture from multiple interests by assembling and integrating data & information generated through specific interests.

Those data & information are not stocked and maintained by single party. Rather, those are stocked and maintained by various parties who have different motivation for utilization of data & information. However, the various parties need to note that those data &information relating to one house should be primarily belong to the owner or occupants of the house. They should understand that they keep the data & information of one house on behalf of the owner or occupants of the house. In reality, a few in conventional sectors in building industry think like that. So far majority in building industry still believe tacitly that they possess the data & information. Therefore, in order to build up whole picture of building, some social system need to be introduce to facilitate the collection of data & information from different parties with different interests.

Above expectation to the methodology development as well as needs to introduce the social system in terms of data & information collection and utilizastion is the background and motivation to develop Personalized home information portal site.

5.2Developed system

Figure 5 illustrates the idea of personalized home information portal site. Here, on behalf of owner or residents of a house, information manager request various parties who keep data and information relating to the house to provide those data & information to owners or residents. Weapon of information manager to the various parties to take consent of provision of data & information is volumetric number of owners and residents behind him/her who employee information manager as a representative of their interest.

Through the Personalized home information portal site, owners and residents can collect, see, keep and edit data & information which are kept by different parties such as architect, engineers, contractors and builders, building/facility managers, maintenance firms, energy suppliers etc. Accessible data & information through the portal site includes;

- Technical detail and specification of building and its components
- Legal status of house
- Land survey documents
- List of professions, contractors and suppliers
- Traceability related data available by Life cycle based traceability system
- Construction documents including audio visual records as well as logistic logs of building components
- Building permit documents
- Inspection report and certificate by third parties
- Maintenance record of building and its components
- Performance data of building (real time based if necessary) collected through energy monitoring system etc.

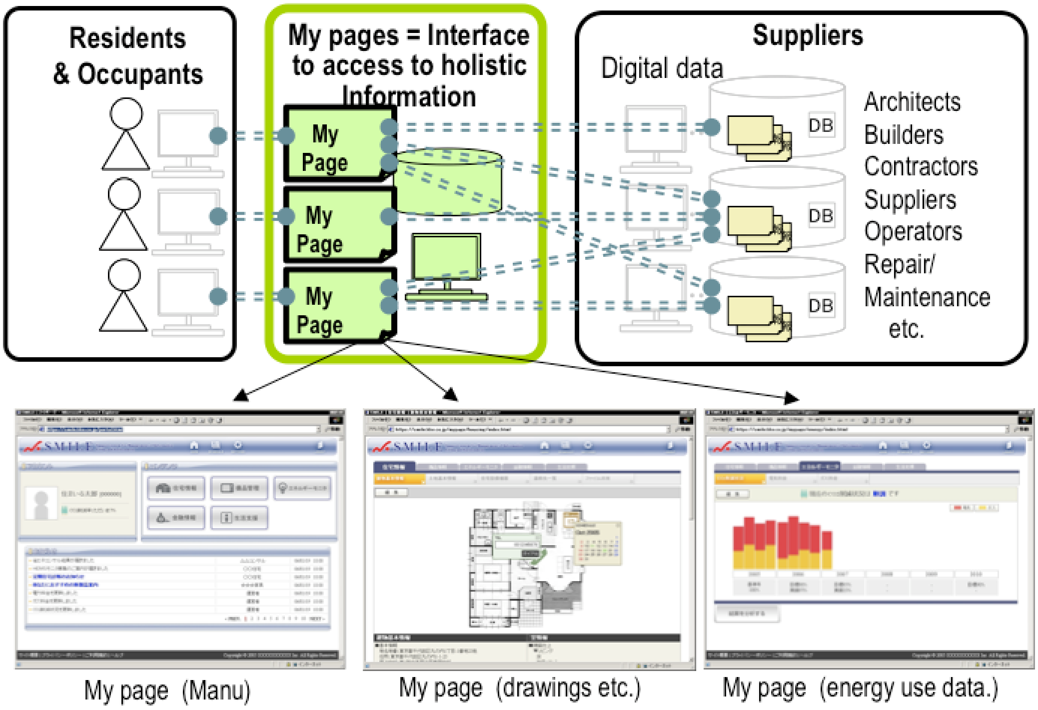

Figure 5 *Prototype of personalized home information portal site (http://www.kke.co.jp/smile/)*

5.3 Potential benefit by personalized home information portal site

The developed personalized portal site is now experimentally used by over 200 monitoring users and developers of the site is now getting the feedback from monitoring users. Through the process of experimental use, potential advantages of the portal site system have been identified. Those are;

- Enhancement of economic value of houses by assurance of traceability of houses. Consequently it generates motivation for intensive and continual investment on existing building stock
- Opportunity creation of supporting service for sustainable living; For instance, energy use data linked with schematic drawings and inventories of installed equipments generate the opportunity for effective energy use consultancy service.
- Improvement of productivity in repair and maintenance.

Concurrently, problematic issues of current version of portal site have been identified. Those are;

- Need to improve user interface for data input and data import.
- Need to prepare instructive manuals to assist non-building –professional users.

The personalized portal site system has a potential to improve the quality of life of residents with lower environmental impacts as well as to provide motivation for continual and proactive maintenance activities.

6 Concluding comments

The paper proposes the idea of information embedded building. By utilization and integration of available ubiquitous computing technology, the idea is technologically feasible. Whenever and wherever stakeholders of information embedded building can access to traceability related information, real time energy use data and building related data & information that are indispensable for well-informed decision-making in building management. For that reason, the idea of information embedded building could be generic paradigm for sustainable building.

A building can be seen as a set of building materials and components. It also can be seen as a system in operation with induced input and emitted output. Fundamentally it is place for living and work. The idea of information embedded building is applicable to these three aspects of building.

There is a gap between designed state of art of building and reality of building because a building could be affected by unpredictable factors. It is also because a building is a very complicated and integrated system so that there exist limitation of anticipation by simulation etc. In addition, it is because requirements to building is ever changing.

Consequently, to assure well being of occupants with lower environmental impact ,which is a source of sustainable building, continual management is essential to bridge the gap between dream in design and reality. Information embedded building is a set of silent and invisible technical devices , but it certainly contribute to bridge the gap by providing data & information to stakeholders whenever and wherever they wish, and to support more reasonable and well-informed actions by stakeholders.

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DEVELOPMENT OF ENVIRONMENTAL INFORMATION SYSTEM TO REDUCE ENERGY CONSUMPTION IN BUILDINGS USING BAC-NET

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Keywords: building, mitigation, environmental information system, commercial sector, BAC-net

Summary

Various technologies have been proposed for reducing carbon dioxide (CO_2) emissions and otherwise saving energy when buildings are in use. Architectural methods that take account of global environmental conservation are fundamental ways of mitigating the heat load of buildings. At the National Institute for Environmental Studies (NIES) Climate Change Research Hall (CCRH: ferroconcrete, 3 floors, 4900 m² total floor space), we collect a large amount of data on energy consumption, heating ventilating air conditioning (HVAC) operation, the indoor environment, weather etc., and use it to develop systems that automatically control HVAC and lighting, thereby achieving both environmental comfort and energy conservation. This data is also used to verify the effectiveness of the systems. We have now developed an environmental information system to help the occupants of buildings reduce the energy consumption. Our aims are as follows. We inform the occupants about such aspects of the indoor environment as temperature, humidity, energy consumption and comfort. Weather data allows them to decide whether to use natural ventilation or not. They can understand the campaigns of "Coolbiz" or "Warmbiz" and which air conditioning setting would be better as regards reducing energy consumption and operators can send the information to users to assist their efforts in this respect. The system collects data from HVAC on the BAC-net (TCP/IP) by using a web server (Windows IIS, DB: SQL) in real time. Using this information system, we can present forecast data to provide an optimal control indicator. By developing this information system, we are attempting to reduce CO_2 emissions and determine a sustainable lifestyle in the face of climate changing.

1. INTRODUCTION

In the 4th IPCC report Summary for Policymakers (SPM) [1] published in 2007, cost-effectiveness is shown to be the highest in the building sector, and aroused the interests in countermeasure technology in the building sector against global warming. Dr. Ikaga [2] reported that in 1990 about 30 % of the total greenhouse gas emitted in Japan could be attributed to the building sector. The emissions are related to design, operation, and reform in buildings, among which operation contributes more than half.

Moreover, industrialized countries are increasingly required to make an effort to reduce CO_2 emissions with a view to establishing a post Kyoto framework; there are some countries that have adopted a target of reducing CO_2 emissions by 70% or more as a national policy. It is a critical task to demonstrate how these government targets could possibly be put into practice through technical and political measures.

Among the series of measures regarding the building sector, the Building and Energy Management System (BEMS) is a key technology but has a specific problem that is not found with other control technologies. The problem with BEMS is that there is a very complex relationship between operators who are engaged in heat source management and residents / owners who are responsible for indoor management. However, advances in information technology have enabled high-speed calculation, and an information service system via the Internet is expected to be constructed at low cost and introduced rapidly, thus offering the potential for great progress.

In this study, we report an environmental information system for buildings that was constructed to resolve the above problems and its application to existing buildings. [3] [4]

1.1 Strategy of Predictive Control

In this study, there are two approaches to optimization with a view to realizing energy-saving operation, these relate to the indoor environment including comfort and equipment performance using control technology; therefore, calculation integrating both control technologies was needed. Measurements in buildings between 2004 and 2006 revealed that the control of the existing air conditioning systems operated based on the measured temperature but would not accept the room temperature within the optimum temperature range, and that the system tried to comply with a room temperature setting, therefore, the cooling and heating operation is mixed, leading to energy loss. [5]

In addition, energy-saving operation should have been adjusted for each region, taking into consideration the climate peculiar to Japan, namely hot and humid in summer and cold and dry in winter, but there has been no notion of optimization for each season. Moreover, adjustments are rarely made for problems caused by differences in information about building performance between the design and operation stages. Beyond these conditions, we established a procedure for optimizing operation taking building performance comprehensively into consideration, based on indoor environment and air conditioner settings with an energy-saving effect obtained according to an experimental result [6] (Figure 1). We developed tags for information management in BAC-net, representing a concept used for optimization calculation, and employed the following definitions for the calculation.

ENV0: External conditions (outside air temperature, relative humidity, sunshine hours, solar radiation on a south-facing surface)

ENV1: Heat source system (volume/amount of chilled and hot water, electricity, gas, and vapor)

ENV2: Indoor air conditioning system (volume/amount of chilled and hot water, motive power, and VAV wind supply)

INTE: Internal (lighting, heat build-up by equipment such as wall outlets, human bodies)

PERI: Building envelope performance (window performance, with/without the eaves)

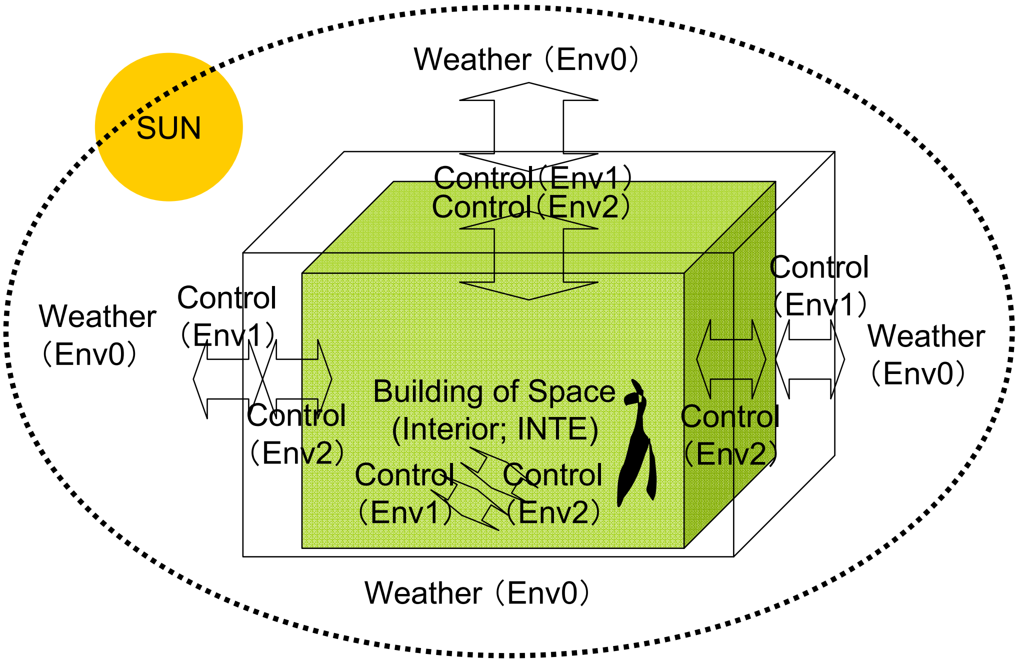

Figure 1: Control Model

Based on the weather forecast data, the difference between the indoor and outdoor heat balance is calculated over time. Then, guidance on daily air conditioning operation is established. The demand for indoor air conditioning is calculated to determine whether the system should be ON or OFF depending on the necessity of air conditioning operation.

As long as the external and internal environments are balanced, operation should be minimized. Natural energy such as natural drafts can be used. Also, in winter, the internal build-up of heat can be expected to contribute to substantial energy reduction.

1.2 Use of Prediction in HVAC Control

In this study, our optimization procedure is characterized by a virtual definition of the internal build-up of heat caused by outside conditions or indoor use (lighting, power consumption at wall outlets, and the number of persons present) as control parameters. For data collection, we have been using BEMS (Building Energy Management System, Yamatake, Savic-net EV, with a communication response of about 7 seconds) with combined use with BAC-net communication to obtain measured data at 10 min after every hour and since 30-minute integrated values [7) 8)]

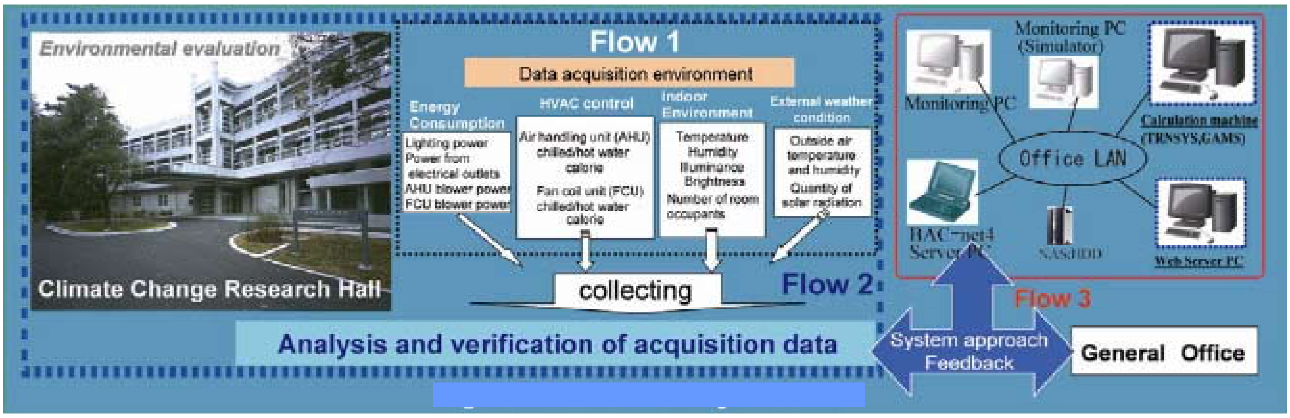

Figure 2: Communication flow of control system

1.2.1 Modeling AHU

The volume/amount of chilled and hot water, vapor, and VAV window supply are used as control parameters for air conditioning control. The indoor sensible heat load Hs and air conditioning system can be expressed as the following equation (1):

Indoor air conditioning system load (ENV2) = V x Ca x (tr - tv) …(1)

where, V is air flow; Ca is air specific heat = 1005J/(Kg/K); tr is room temperature and tv is diffused air temperature.

In this study, control was provided by the mathematical programming model Predictive Horizon Control (Ricker IMC) [9)], which operates as an energy-saving temperature and humidity control system during our development of the new control system.

1.2.2 Modeling Indoor Environment

Thermal load is calculated based on the convective heat transfer coefficient settings of six indoor surfaces including window, wall, and floor surfaces. The internal build-up of heat is calculated based on the lighting power, and power consumption at wall outlets.

Interior load (load0) = $Q_{AllS} + Q_{AllL} - Q_{AirS} - Q_{AirL} - Q_{Skin} - Q_{Vent}$ …(2)

where, Q_{AllS} is the indoor sensible heat load (kJ/h), Q_{AllL} is the indoor latent heat load (kJ/h), Q_{Skin} is the skin load (kJ/h), Q_{AirS} is the indoor ventilation sensible heat load (kJ/h), Q_{Vent} is the dragt (kJ/h), and Q_{AirL} is the indoor ventilation latent heat load (kJ/h).

In highly automated buildings that are equipped with newly developed cladding with high performance heat insulation, the heat load tends to be largely accounted for internal build-up of heat ; therefore, cooling operation is conducted in winter in the conventional control system (Figure 3).

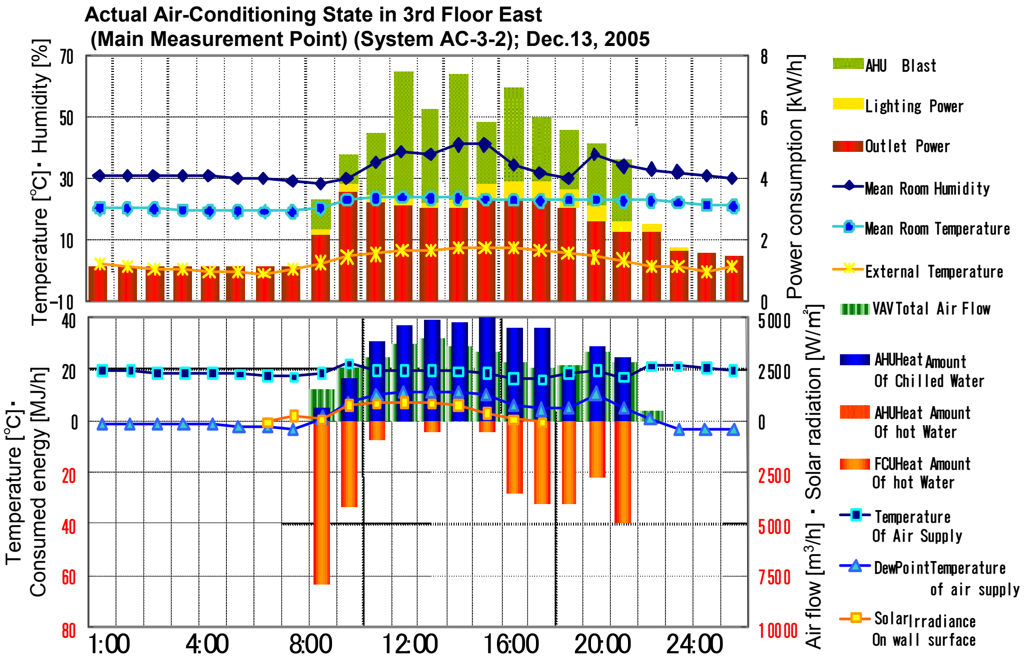

Figure 3: Conventional control on representative winter days

1.2.3 Modeling Plant

The amounts of chilled and hot water and vapor used in the heat source system are calculated according to whether the heat source system is ON/OFF and the COP setting, based on the energy consumption expected for the indoor air conditioning system.

1.2.4 Modeling Outdoor Environment

The ASHRAE comfort range[10)] is used to evaluate both the indoor environment and outside air temperature by calculating the dry-bulb temperature and absolute humidity using outside air temperature and relative humidity.

1.3 Methods of Building Energy Monitoring

The heat balance for sensible and latent heat can be expressed as Equation (3) by calculating sensible and latent heat.

The calculation is conducted continuously based on real-time information about the outside conditions.

$$env0 \rightarrow \{load1 \Leftrightarrow \{env2/ \{load0(INTE + PERI)\}^{l}\}^{m}\}^{n} \Leftrightarrow env1/load2 \leftarrow env0 \ldots (3)$$

->: Input of information

<=>: Equilibrium condition is ideal.

The guidance of heat source system operation is determined based on the processing requirement of the indoor air conditioning system.

Figure 4 shows the concepts of our control models. Different information is required for residents or energy managers, therefore, the model has indoor control parts, air conditioning parts and heat source control parts.

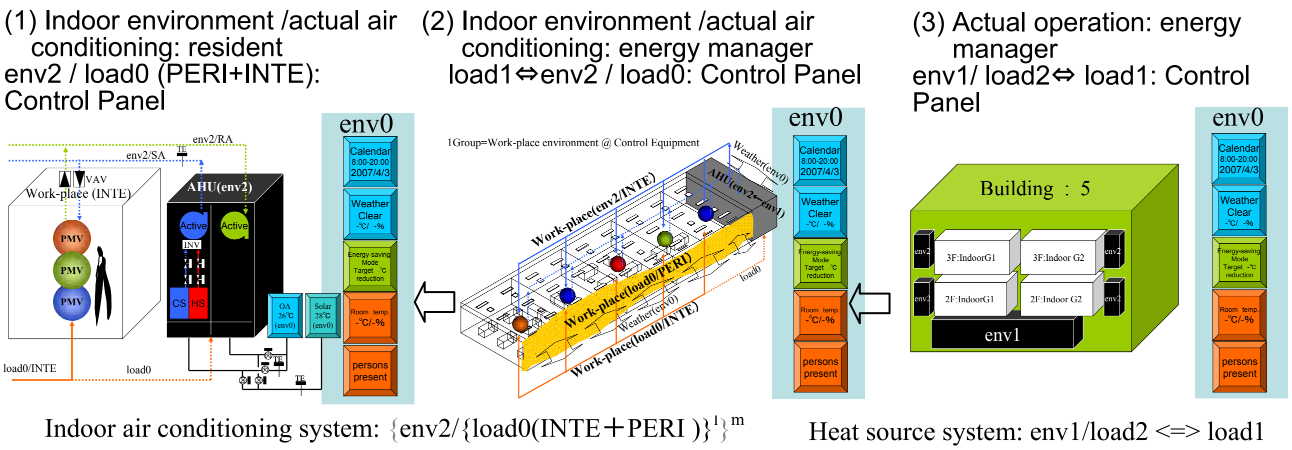

Figure 4: Concepts of control models

2. RESULT

2.1 Optimization of air-conditioning mode

Figure 5 shows indoor air-conditioning modes, including cooling, ventilation, and heating.

Room temperature corresponds to dry-bulb temperature, and room relative humidity is calculated using absolute humidity. Therefore, in both the calculation and the air conditioning system, identical data are obtained through real-time measurements and are calculated to evaluate the validity of air conditioning system operation by continuously monitoring the indoor/outdoor heat balance.

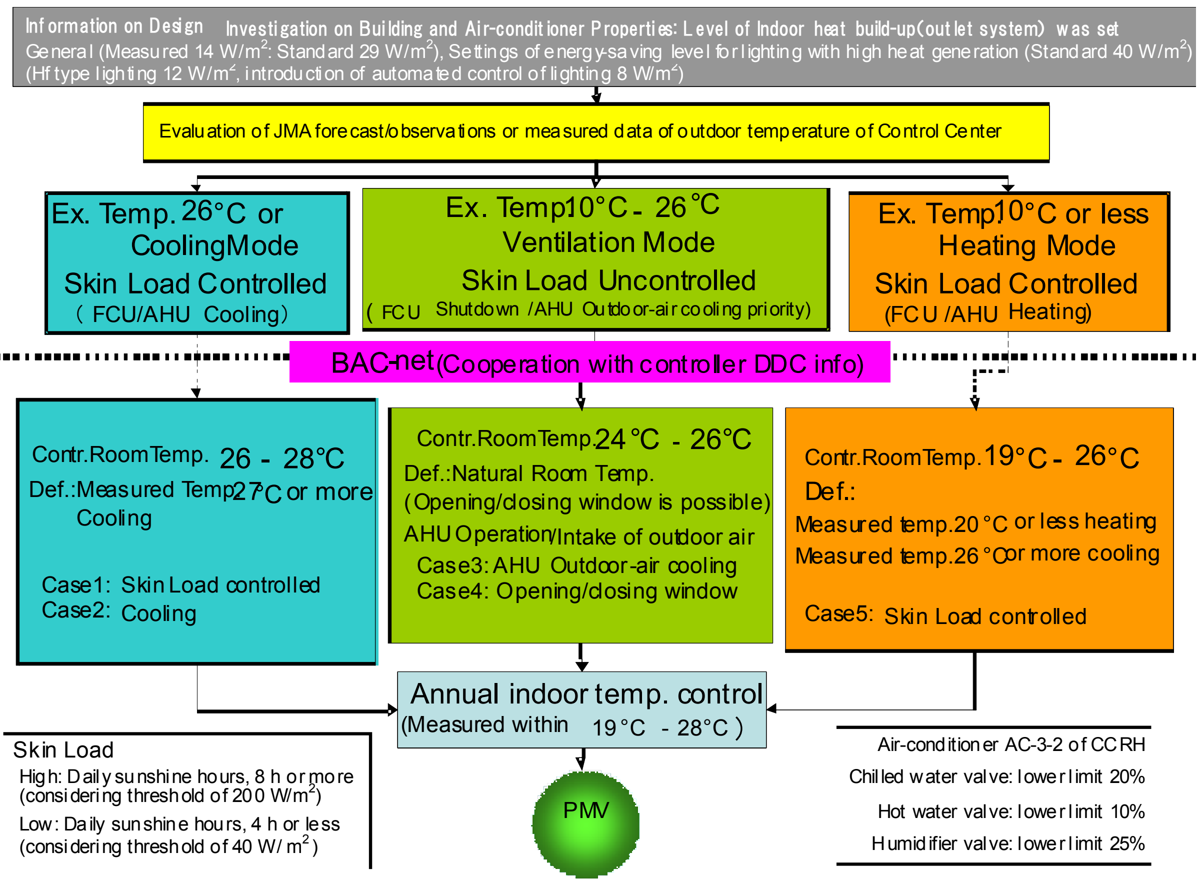

Figure 5: Determination of indoor air conditioning operation modes

In this study, we compared the energy consumption between the room temperature setting (25°C) and the experimental room temperature (27°C) and confirmed that our newly developed control system which provides cooling operation at 27°C or greater realized fairly good energy-saving operation. [6]

Conventional control in winter resulted in energy loss owing to the simultaneous consumption of FCU hot water and AHU chilled water at settings of both 23 and 24°C. When operating the new control with a conventional heating setting of 23°C or less, some AHU chilled water was consumed. Finally, a new control which provides heating for the room temperature of 20°C or less (no AHU chilled water consumption is allowed; room temperature setting at 20-26°C) realized energy-saving operation in which only indoor air was circulated (the air supply to the residential room was changed to the minimum value of 30%) and only FCU hot water was used (Table 1).

Table 1: Results of indoor air conditioning operation modes

	Cooling Mode				Ventilation Mode				Heating Mode	
	Case1		Case2		Case3		Case4		Case5	
	Skin load control		Cooling operation		Cooling by external air		With/without opening/closing windows		Skin load control	
	①	②	①	②	①	②	①	②	①	②
	Conventional control	New control	Conventional control	New control	Conventional control	New control	Conventional control	New control	Conventional control	New control
19°C									▲●	△
20°C									▲●	◎
21°C									▲●	○
22°C									▲●	○
23°C									▲●	●
24°C					▲	※	▲	△	○	●
25°C	▲	▲	▲	▲	○	※	○	◎	▲●	●
26°C	▲	○	▲	○	△	※	▲	△	▲●	●
27°C	○	◎※	○	◎※						
28°C	△	△	△	△						

Energy-saving	Excellent ◎	Ideal operation for energy-saving is possible
	Good ○	Rather energy-consuming operation, but moderate comfort is maintained.
	△	Energy-saving operation, but comfort tends to be impaired depending on individuals who find it rather cold/hot.
Non-energy-saving	▲	Non-energy-saving operation where excessive energy is consumed for cooling
	●	Non-energy-saving operation where excessive energy is consumed for heating

2.2 Environmental Information System

In the commercial sector, energy-saving measures are adopted at the initiative of government, energy managers, or resident. Different information will be required for each of them. BEMS was originally a technology designed for energy managers, while a system for residents has been established in this study.

We developed a real-time monitor (Figure 6) that monitors external conditions, the indoor environment, and air conditioning settings to evaluate the optimization of the cooling, ventilation, and heating modes (Figure 5) by incorporating the results of the developed simulation control and experimental results. The monitor also provides the resident with information on energy saving of air conditioning and displays the power consumption of lighting and wall outlets. This information system might promote residents' energy-saving behavior.

In business buildings with a total floor area of 4000 m^2 or less, the system operates making use of natural drafts that occur when windows are opened and closed, thus reducing the air conditioning load. In addition, through sharing information between the residents and energy managers, smooth communication is realized when they reexamine an energy management plan and improvement of daily operation, leading to further energy-saving measures through information exchange.

As shown in Figure 6, a monitor screen shows real-time measured data on the PCs of individual residents through a TCP/IP network. 1-14 below show information service items. The system was developed based on Microsoft Windows OS XP (WEB server IIS pre-installed) using Visual Web Developer 2005 Express Edition, Microsoft! SQL Server 2005, Microsoft Visual Basic 2005 Express Edition distributed free by Microsoft.

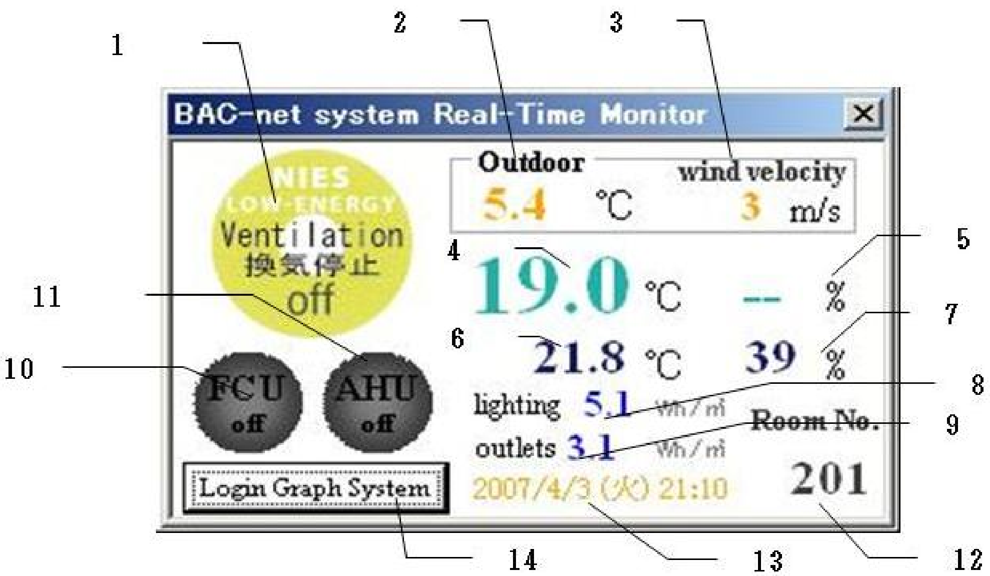

Figure 6 Example indication of indoor real-time monitor

1. Air-conditioning mode: Recommended air-conditioning mode
2. Outdoor temperature: Outside air temperature
3. Outdoor wind velocity : External wind speed
4. Indoor temperature setting: Indoor temperature settings
5. Indoor humidity setting: Indoor humidity settings (only for room where setting is available)
6. Indoor temperature: Indoor measured temperature
7. Indoor humidity: Indoor measured humidity
8. Energy consumption of lighting: Power consumption of lighting
9. Energy consumption of electrical outlets: Power consumption of wall outlets
10. Window side air-conditioning (Fan coil unit: FCU) ON/OFF: Window side air-conditioning system ON/OFF

11. Air-handling unit (AHU) ON/OFF: Inside air-conditioning system ON/OFF
12. Room number: Room number
13. Measurement date: Measurement date
14. Graph of data (1 day, 1 week, 1 month): making graphs of measured data (1 day, 1 week, 1 month)

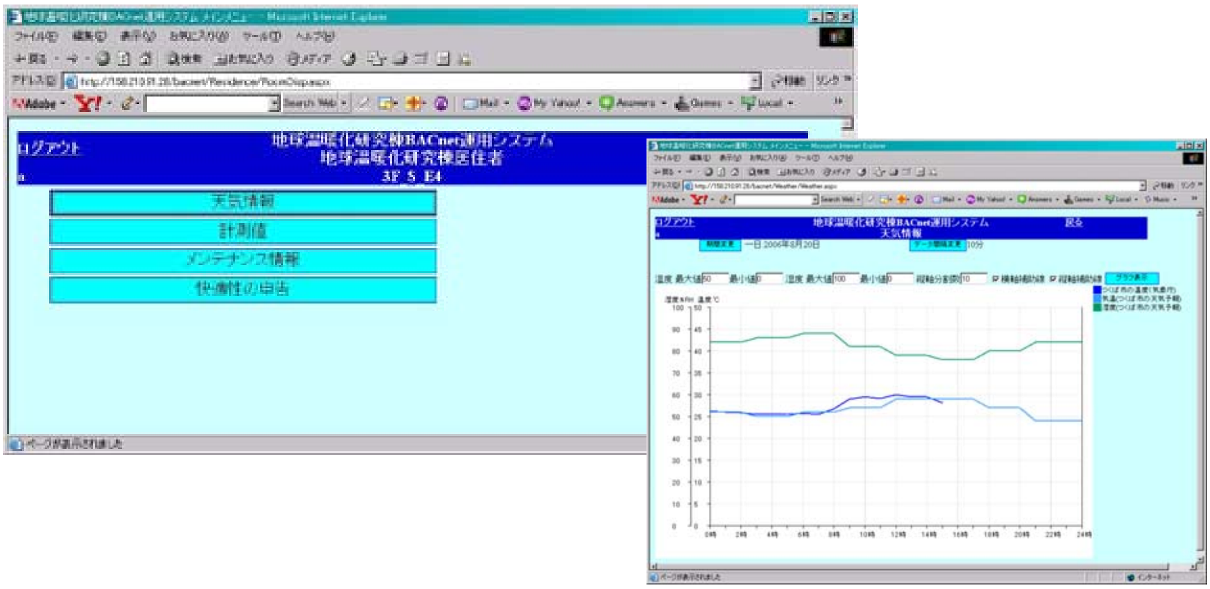

Figure 7 Left: Example of Login Graph System (selection screen: Weather information, Measured values, Maintenance information, and Comfort report, from the top)
Right: Example of Login Graph System (Graph)

3. CONCLUSION

We showed that information providing guidance on the operation of an air-conditioning system could be prepared. This was achieved by calculating the indoor/outdoor thermal load using information on the current state of measures in the commercial sector with a view to introducing BEMS technology to improve operation in existing buildings. A building-local environment assessment monitoring system based on the results of a series of energy-saving measures.

In addition to information obtained from BEMS, we developed a control equation for continuously monitoring the indoor/outdoor heat balance. The information management system and control equation used in BEMS could be integrated by manipulation to provide real-time information. Improving the operation of the air-conditioning control requires to identify the optimum temperature range and air-conditioning ranges based on the actual room usages, and helps defining the guideline for improving the air-conditioning settings.

Appropriate energy-saving information should be provided for residents and energy managers, for example, by making use of such data as Automated Meteorological Data Acquisition System (AMeDAS) measurements delivered by the Japan Meteorological Agency in real time. Therefore, we prepared a prototype of an energy management information system (real-time monitor) for residents.

Substantial energy reduction requires the deliberate and efficient improvement of the operation of the heat source equipment and the introduction of more efficient equipment after the operation of the indoor air-conditioning system has been improved. This will probably lead to the practical implementation of measures designed to combat global warming in Japan, which is our primary goal.

Acknowledgment

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TITLE: SIMULATIONS OF ENERGY INFLUENCE USING DIFFERENT CONTROL MECHANISMS FOR ELECTROCHROMIC WINDOWS

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Keywords: anti-reflective coatings, smart windows, energy simulations, optical simulations

Summary

The use of electrochromic windows could lower the energy usage for buildings as earlier simulations have shown, but initially the windows would probably mainly be used as daylight sources and units for visual contact. The need for a control system for electrochromic windows is obvious. In this study a comparison of heating and cooling need of a building, using different control mechanisms, was investigated. From an energy perspective it is preferable to have the windows in their dark state whenever there is a cooling need, but this is probably not preferable from a daylight and visual contact point of view. In this study, four control mechanisms were investigated using computer simulations. The first control mechanism is only considering the heating and cooling need of the building – energy optimization mode. The second control mechanism is limiting the perpendicular component of the incident irradiation to avoid glare and to strong daylight – daylight optimization mode. The other two control mechanisms switches between the energy and daylight optimization mode in different ways based on user presence. The results show that the need for an occupancy based control system is clearly beneficial.

1. Introduction

Future energy saving requirements together with increased comfort desires are expected to lead to a demand for windows which can vary their transmittance to reduce the heating need during cold periods and reduce the cooling need during warmer periods (Selkowitz, et al, Platzer, et al).

As earlier studies have shown the use of electrochromic windows could lower the energy usage for buildings. If there is a need for cooling the smart window is usually set to a dark state to avoid the solar heat gain. When there is a need for heating the smart windows are set to a clear state to gain the solar radiation. In real situations this is probably not the best way to control the windows. The windows are there to let in light and to enable a view to the outside. Whenever someone is in the room the daylight aspect must be considered, both to let in a fair amount of daylight and also to avoid annoying glare.

The control mechanism is a key issue for electrochromic windows in general and should consider both daylighting and heating and cooling need. In this study four different control mechanisms are investigated using computer simulations. The "energy optimization mode" described above is then compared with other control mechanisms based on daylight and user presence. These simulations are compared with simulations for a regular solar control window as comparison.

2. Method

The simulated window in this case is an electrochromic device deposited on and enclosed in a plastic foil (Azens, et al, Granqvist) and for the simulations put in a double pain window combined with a low-e pane. This type of window can easily be created from most already installed windows, i.e. this type of window can be made available also for the retro-fit window market. The EC foil was laminated onto the inside of the outer pane. The two surfaces facing the gap between the panes had single layer antireflective coatings, assuming an refractive index of the coating of n = 1.31. The transmittance and reflectance spectra for the windows were calculated using the Fresnel formalism as described in Pfrommer et al. For the electrochromic layers, refractive indices have been taken from the Windows and Daylighting Group at Lawrence Berkeley National Laboratory. The Fresnel formalism was also used to determine the transmittance and reflectance of the complete window that were "constructed", according to figure 1.

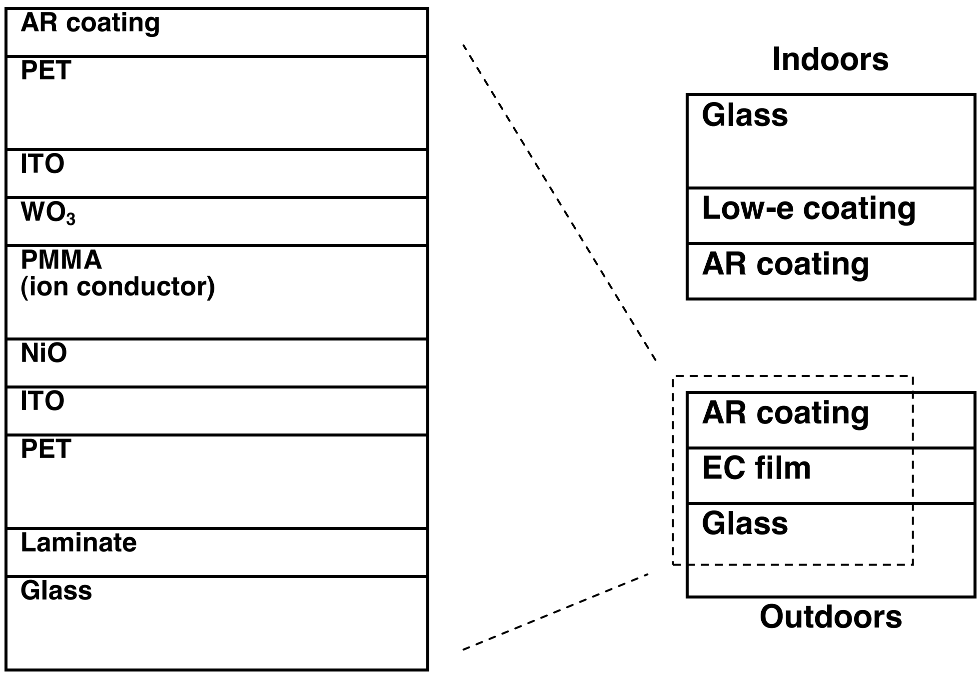

Figure 1 Schematic drawing of the simulated window configuration. To the left, the layers of the electrochromic foil. To the right, the double pane window with one low-e pane and a regular pane. (Not to scale.)

The simulation tool Winsel was used to estimate the energy balance of this smart window when placed in a building. Winsel is a tool for estimating how different windows affect the energy balance of a building. It can thus give an approximate value on how much energy that is needed to heat or cool a building depending on which windows are used. For this the program uses climate data such as outdoor temperature, direct and diffuse solar radiation and a few building parameters, such as balance temperature and a time constant for the building, i.e. how well the building can store heat (Karlsson, et al). The program calculates the energy losses due to the U-value together with the solar gain depending on the g-value.

For the energy calculations in this study an office building, with 5℃ as the balance temperature for heating and 14℃ as the balance temperature for cooling has been selected, assuming a well insulated building. The locations have been chosen to Stockholm, Sweden, and Miami, USA, and weather data were taken from Meteonorm.

Four different control strategies were investigated and compared. "Energy Optimization" means that the windows are then kept in the state which is optimized from a heating and cooling perspective. In the simulations the windows are then kept in a dark state whenever there is a cooling need. "Daylight optimization" means that the windows are in a state which should correspond to a level which is good from a daylight perspective. In the simulation this corresponds to when the perpendicular component of the incident direct sun light is 300W/m^2 or more, and then the transmittance of the smart window is regulated down to correspond to this level. This configuration of the control mechanism avoids the annoying glare caused by solar radiation when the sun is low in the sky. When the sun is higher or when there is only diffuse radiation the window is set to its clear state.

“Office hours” corresponds to having the window in “Daylight optimization” mode between 7:00am - 6:00pm and otherwise in “Energy Optimization” mode. “Presence detector” mode corresponds to having the window in “Daylight optimization” mode during half of the time between 7:00 am and 6:00 pm and otherwise in “Energy optimization” mode. This simulates the fact that many offices are unoccupied also during office hours. The different control strategies are summarized in table 1.

Table 1 Control strategies used in the simulations.

Control strategy	Explanation
Energy optimization	The windows are kept in the state which is best from an energy perspective.
Daylight optimization	The perpendicular component of the incident direct sun light is regulated to 300 W/m^2 whenever possible.
Office hours	“Daylight optimization” mode between 7:00am and 6:00pm and otherwise in “Energy Optimization” mode.
Presence detector	“Daylight optimization” mode during half of the time between 7:00 am and 6:00 pm and otherwise in “Energy optimization” mode.

3. Results

For the double pane smart window with antireflective coating on two surfaces the visible transmittance was calculated with Fresnel formalism to 66.7 %. The transmittance spectra for the solar spectrum can be seen in figure 2. Optical and energy parameters for the simulated windows can be found in table 2.

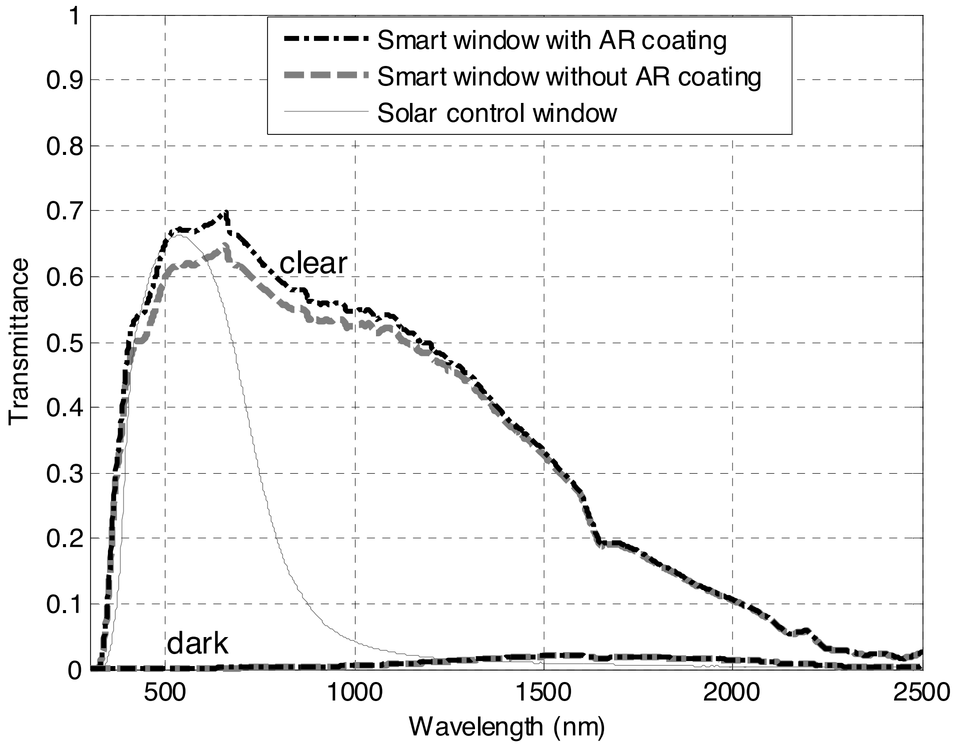

Figure 2 Transmittance of the simulated double pane window with one low-e and one electrochromic pane in dark and clear state.

Table 2 Window parameters for the simulated double pane window.

Parameter	Clear state	Dark state	Solar control
T_{sol}	53.7 %	0.51%	31.5 %
R_{sol}	12.7 %	7.40%	43.8 %
A_{sol}	33.6 %	92.1%	24.6 %
T_{vis}	66.7 %	0.21%	64.6 %
R_{vis}	11.2 %	6.17%	8.93 %
A_{vis}	22.1 %	93.6%	26.5 %
U-value	1.42 W/m^2K	1.42 W/m^2K	1.27 W/m^2K
g-value (SHGC)	0.66	0.065	0.34

When simulating the influence of a smart window with a low-e pane as the inner pane and an electrochromic foil laminated on the outer pane, the electrochromic foil decreases the g value without changing the U-value of the window noticeably.

The cooling balance per square meter window area for a building located in Stockholm, Sweden, can be seen in figure 3. It can be decreased by 10-40 kWh annually depending on the bearing direction, by limiting the daylight optimization to office hours, 7am-6pm. The most dramatic decrease would installation of presence detectors have. If assuming that the office is occupied 50 % of the time, the decrease would be between 50 and 100 kWh per square meter window area, compared to the daylighting optimization case.

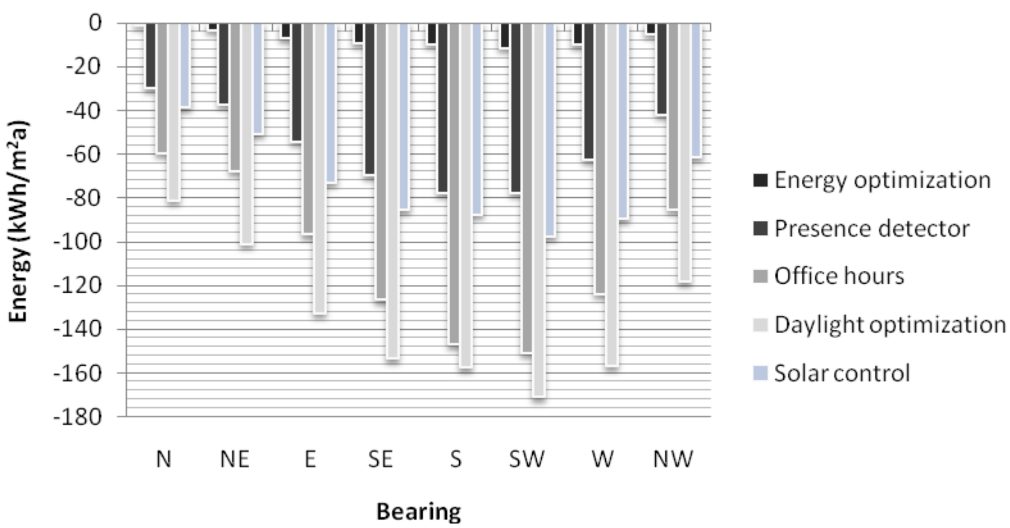

Figure 3 Cooling balance of a window in Stockholm for different bearing directions.

For the same simulation but with the building located in Miami, USA, the results are similar but because of the larger cooling need the figures change correspondingly. By limiting the daylight optimization to office hours, 7am-6pm the cooling balance for Miami can be decreased by 15-45 kWh depending on the bearing direction. Also here the most dramatic decrease the installation of presence detectors would have. The decrease would be between 150 and 300 kWh per square meter window area, compared to the daylighting optimization case.

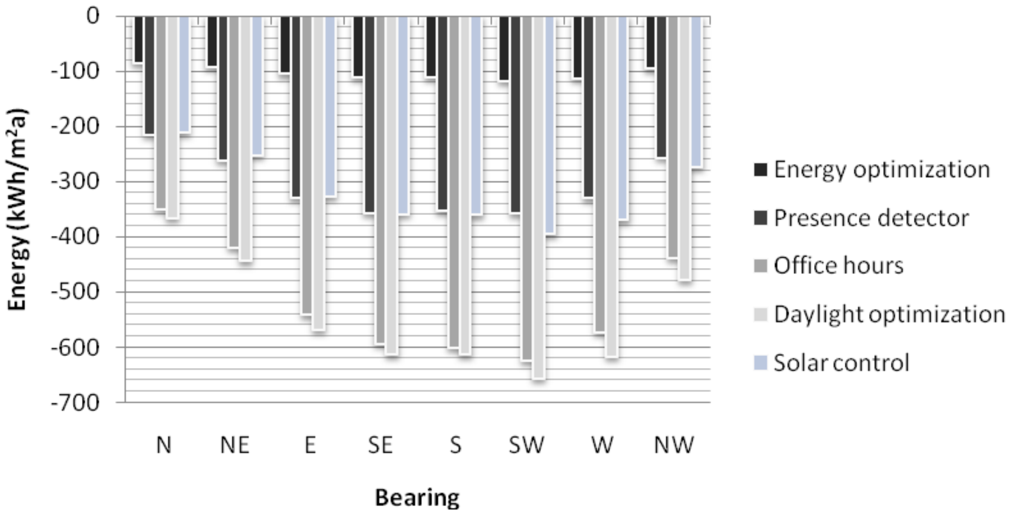

Figure 4 Cooling balance of a window in Miami for different bearing directions.

The use of electrochromic windows can lower the heating need of the building compared to solar control windows due to the larger solar heat gain with the electrochromic windows in the clear state. For heating the gain of using the "energy optimization" in favor of the "daylight optimization" is limited. If there is a heating need, there is also most often a need for daylight. The results for Stockholm can be seen in figure 5. For Miami there would be no heating need for the simulated building.

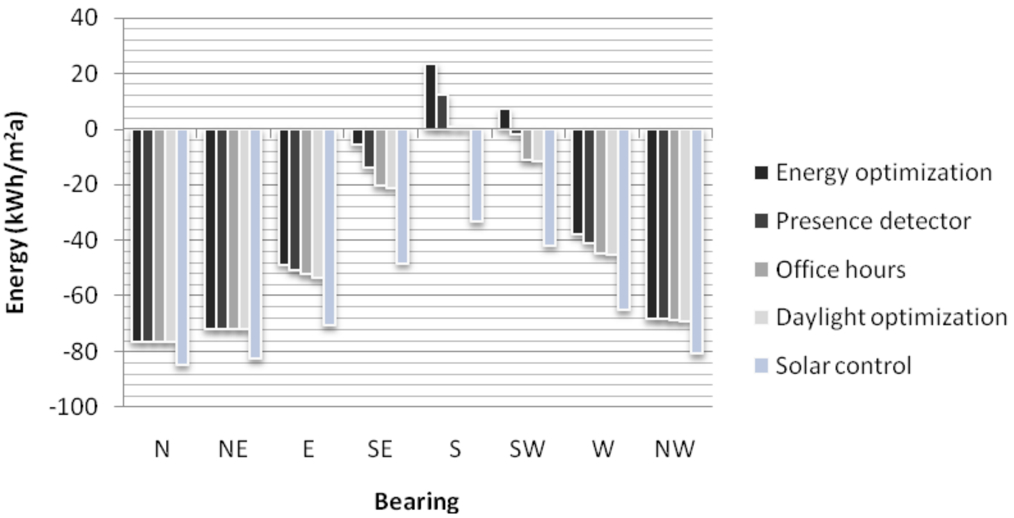

Figure 5 Heating balance of a window in Stockholm for different bearing directions.

4. Discussions and conclusions

The energy simulations in this study were made for buildings in Stockholm and Miami and for buildings located elsewhere the results can be quite different but with the same trend. The simulations in this study were based on windows in office buildings. For real estate buildings the need for cooling is usually lower and the decreased energy need using the electrochromic layers would not be as drastic.

The occupancy pattern would in a real estate case be totally different than what has been assumed here. Also the internal loads for the building would look drastically different with a longer heating season, so it is not possible to generalize these results to a real estate case.

Smart windows are usually considered to have a large potential for the future to give a decreased energy usage in buildings, due to a reduced need for cooling by air conditioning. Earlier studies often investigate the windows only from an energy perspective. The results in this study indicate that by having thoroughly worked out control strategy and system, the windows can in an energy perspective become almost as good as when sub optimizing them only from an energy perspective.

With a control strategy based on user presence the window can be set in a clear state whenever someone is in the room, letting in daylight and thereby decreasing the need for other lighting. The amount of reduced energy need due to this has not been included here but is an interesting aspect for future studies.

To get the products from the labs out in reality, user acceptance is a key issue. For high user acceptance it is important not to focus too much on the energy perspective. Windows are there to let in light and to create visual contact with the surroundings. The control system is the link between good energy and visual performance. The results show that the need for an occupancy based control system is clearly beneficial.

5. Acknowledgements

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AN EASTERN PHILOSOPHICAL APPROACH TO URBAN DEVELOPMENT

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Summary

This paper describes the results of my Masters studies at The Bartlett, University College London, a year-long exercise in experimental urban design. It begins from a philosophical basis which is rooted in an understanding of the natural systems and phenomena which surround us, and an awareness of our place within them. The investigation then seeks parallels in contemporary scientific thought, to ground the philosophy in real-world knowledge. The principles are then applied to urban planning and development through a rigorous design proposal for a large urban area in the Thames Gateway region, a vast, flood-prone urban growth area between London's Docklands and the English Channel, earmarked for extensive urban growth.

This study investigates the very basis of our approach to urban planning and development. It is based on the notion that a truly sustainable approach to urban growth requires a fundamental shift in the way we approach urban planning, and the way we perceive our place in the world. The nature of this shift is drawn from the emerging, ancient philosophies of the East, which are gaining increasing understanding in the Western world.

The resulting design proposition for a large, new urban area is based on this theoretical, philosophical and scientific framework for integrating urban development with natural systems, towards a balanced, adaptive, holistic, sustainable urban form.

Presentation of this paper shall be accompanied by an extensive sequence of images illustrating the design context, process and outputs, a small selection of which is displayed below.

1. Modern urban space and the *unhomely*

Modern urban environments often convey harsh, aggressive, unwelcoming qualities, through hard-edged and ageing built form, 'dead' spaces, and vast scale and intensity, making them feel confronting, unnatural and uncomfortable. They are perhaps most prevalent in post-industrial areas and in more urban environments, which are products of early-mid 20th century planning, with little consideration of 'human' qualities or 'liveability'. The spatial environment in London's Thames Gateway reflects its industrial heritage, with little consideration of the human impacts of these spaces, which are now unattractive, decayed and inhumane.

These environments are immediately perceived as ugly, messy, damaged or decayed, but there is a deeper human reaction which creates the discomfort or unease we feel in these spaces. These perceptions have been theorised and psychologised through the notion of the *unhomely*, or *uncanny.*

This philosophy is closely linked to, or even rooted in, notions of modernity and the city, through the writings of Vidler, Freud, Constant and others (Vidler, 1992). The industrial-era transformation of the city, from intimate and communal, to strange and unfamiliar, caused feelings of unease, isolation, and estrangement of citizens. The modern urban qualities of vast scale, heterogeneity and imposition over nature were perceived as an alien presence, strange and unfamiliar, isolating individuals from nature and from the past (Vidler, 1992).

2. Alienation from nature

Our environment is a self-balancing ecological system, in which organic and inorganic species are interacting with each other in highly complex ways. The human species is an integral part of this system, but the modern condition has led us to think we have escaped from it. Dominant forms of Western thinking suggest that nature is an inert, readily exploitable mass, and that humans are masters of the system of which they are an integral part. This is seen as originating from our adoption of environmentally unsound ideas (Dickens, 1991).

The modern city is held in sharp contrast to the natural environment - visually, aesthetically, organisationally and qualitatively. Modern ideals are characterised by a fear of emotion and spirituality, and a craving for control through the rigid doctrines of science and technology, resulting in severely reduced consciousness, and cities which are aggressive, impoverished and depressingly banal. Our times call for a greater consciousness and awareness, and a more meaningful approach to caring for our cities (Fingerhuth 2004).

Our inherent tendency towards connection with nature is evident in our yearning for a return to natural space, to seek 'reintegration' with nature, by 'escaping' the city. The current study seeks a new approach to urbanism, which reflects and responds to the emerging consciousness of our place in nature, our dependence on the fragile natural systems around us, and the need to re-think our attitude and relationships with these systems, through our most significant physical intervention in nature – our cities.

3. Finding an alternative environmental/spatial philosophy

"The world will not evolve past its current state of crisis by using the same thinking that created the situation" Albert Einstein (cited in McDonough and Braungart, 2002)

"If we want the city to remain the driving force behind human development, we must reinvent it now; otherwise there is the risk that it will become the final stage of human civilisation in the twenty-first century" (Burdett and Sudjic, 2007)

The significant recent shift in our communal consciousness towards sustainable practices is paralleled by an increasing awareness of the urgent need to drastically re-think and change our approach to urban planning, design and development.

The rapid growth of cities, particularly in developing countries, through massive urbanisation of rural populations, is the subject of much discussion and concern. Currently this growth largely reflects outdated western planning models predicated on separation rather than inclusion, which have been dumped on the fragile urban conditions of the exploding cities of the global South (Burdett and Sudjic, 2007).

The task, therefore, is to develop a new philosophy and methodology for city building, which promotes integration of urban and natural environments and systems, sustainable relationships between cities and hinterlands, and physical/spatial urban environments which are humanistic, responsive, adaptive and comfortable, as opposed to the *unhomely* environments of the modern era.

Traditional and/or indigenous cultures are seen as a potential source of knowledge and understanding, towards a more integral, balanced and sustainable approach to human action in natural systems. The cultures, cosmologies and ways of life of most indigenous societies incorporate a respect for the natural world, which results in a harmonious, non-exploitative relationship with ecological systems (Dickens, 1991).

The Eastern traditions of *Taoism* and *Zen Buddhism* provide a philosophical and methodological route towards a holistic, integral approach to living with nature, through guiding principles which are themselves derived from observations of nature, and an understanding of our place within it. These principles, which are explained below, when applied to the design of urban development, may allow built form and urban space to reflect and respond to our integral relationship with nature.

The *Tao* describes the course, flow or drift of nature. Followers of this paradigm seek to spontaneously co-operate with the dynamic process of the universe, to 'go with the grain'. This provides the potential for escape from the modern, rationalist imposition of rules and laws on nature.

Current thinking on sustainability principles also focuses on how our living patterns might integrate with natural systems in a balanced, harmonious relationship. Although designers operate within a closed system of materials and energy, our established processes contaminate the Earth's biological mass to create materials and products which quickly become waste. Nature, however, exhibits a highly effective system of metabolism and nutrient flow, in which the concept of waste does not exist. We must seek to emulate this 'cradle-to-cradle' system, rather than the 'cradle-to-grave' one we currently inhabit, if we are to develop a truly sustainable, balanced relationship with the natural systems and materials upon which we depend (McDonough and Braungart, 2002). Philosophically, the Eastern traditions adopt a view of life which reflects this eternal, cyclical principle.

4. Ancient Eastern Philosophy and Contemporary Science: Principles and Parallels

The striking resonance between ancient Eastern philosophies and contemporary scientific theories and discoveries in the Western world serve to align the mystical with the physical, and the traditional with our contemporary view of the universe and our place within it.

This Section looks in more detail at these principles and parallels, while the following Section considers the implications for urban planning and development.

4.1 Time/Space

A key aspect of Eastern mysticism, which has been confirmed by modern physics, concerns the ways in which we describe and measure nature, in that our notions of geometry are not part of reality, but parts of our maps of reality. They are constructs of the mind, not part of nature itself, and are relative, limited and illusory.

Classical physics was based on the notion of space as an absolute, three-dimensional construct, structured according to Euclidean geometry which was seen as inherently part of nature. The notion of time was also seen as fixed, and the temporal order of two events was assumed to be independent of any observer.

Einstein's Relativity Theory has forced the abandonment of classical concepts of absolute space and time, replaced by the notion that space and time coordinates are merely elements of a language used to describe an observer's environment. This opened up a range of possibilities for redefining space and time, by realising that geometry is not inherent in nature, but is imposed on it by the mind (Capra, 1991).

4.2 Unity and Interconnection

"Without leaving my house, I know the whole universe." (Lao-tzu, c. 226-259, cited in Watts, 1975)

"Ten-thousand formations, one suchness" (Watts, 2000)

The most important and essential characteristic of the Eastern philosophical worldview is the awareness of the unity and mutual interrelation of all things and events in the universe, as manifestations of a basic 'oneness'. All things are seen as interdependent and inseparable parts of the cosmic whole (Capra, 1991).

This understanding of unity and interconnection has also become a central aspect of modern physics. The classical physicists saw the universe as a collection of separate entities, isolated in space and time by definite boundaries, and capable of being precisely measured and counted, to derive scientific laws and principles. They began to believe that all of nature was governed by these Newtonian principles, and assumed they would also apply to subatomic physics. They developed laws governing separate things, only to discover that separate things don't exist (Wilber, 1979).

The revolution of quantum physics around 1925 shattered this world of classical physics, revealing that the constituents of matter and the basic phenomena involving them are all interconnected, interrelated and interdependent, and cannot be understood as independent entities, but only as integrated parts of the whole, forcing the reinterpretation of time, space, matter and structure (Capra, 1991). The fundamental building blocks of matter, seen as the last objective reality, were found to defy all forms of objective location in space and time.

The ultimate metaphysical secret is that there are no boundaries in the universe. Boundaries are illusions, products not of reality, but of the way we map and edit reality, reflecting an infinite system of relationships, of interconnections between all things and events. Buddhists describe the universe as "all in one and one in all", and modern physics as "each particle consists of all the other particles, each of which is, in the same way and at the same time, all other particles together" (Wilber, 1979).

4.3 Polarity

The principle of polarity lies at the very roots of Chinese thinking and feeling, and is symbolised in the concept of *yin and yang*, polar opposites whose dynamic interplay is manifest in the constant flow and change observed in nature. The *yin-yang* principle is not a dualism, but an explicit duality expressing an implicit unity. Any pair of opposites constitutes a polar relationship where the two poles are dynamically linked, forming different but vital aspects of the same system. The removal of one would mean the disappearance of the system (Watts, 1975).

We see opposites as being at war with each other (life with death, good with evil, positive with negative), and so we attempt to cultivate the positive and remove the negative. Our social and aesthetic values are always put in terms of opposites – success/failure, beautiful/ugly, intelligent/stupid, but nature does not know these differences, and does not concern itself with fighting one condition over its opposite, but rather calmly accepts life and death, large and small, pleasure and pain (Wilber, 1979).

4.4 Emptiness/Form, Observer/Object

"Form is emptiness; emptiness is form" (Buddhist Mahayana philosophy, cited in Watts, 2000)

In science, the classical, mechanistic worldview was based on the notion of solid, separate, indestructible particles moving in the void. Modern physics has not only radically revised this view of particles as discrete entities, but also profoundly transformed the concept of the void. In the 'quantum field theories', the distinction between particles and the space surrounding them loses its sharpness, and the void is recognised as a dynamic quantity of great importance.

This unity and interrelation between a material object and its environment is made manifest at the macroscopic scale in relativity theory, and even more strongly at the subatomic level. Here, the contrast between solid particles and the space surrounding them is overcome, and the quantum field is seen as the fundamental physical entity; a continuous medium which is present everywhere in space (Capra, 1991).

This view is closely paralleled in the Buddhists' or Taoists' conception of a single, unified essence or energy, from which springs all phenomena. In Eastern philosophy, the relationship of form and emptiness cannot be conceived as a state of two mutually exclusive opposites, but only as two aspects of the same reality, which co-exist and are in continual co-operation (Capra, 1991).

The relationship between an observer and the object of observation, traditionally considered as separate entities with no direct interconnection, is also called into question both by Eastern philosophy and Western physics. Perhaps the most important aspect of quantum physics is that it destroys the concept of the observer as separate from the world he observes, replaced by the scientist becoming involved in the world he observes (Capra, 1991).

This idea is well known to the mystical traditions, where knowledge can never be gained by observation alone. Subject and object are not only inseparable, but become indistinguishable. In these traditions, the external world and one's inner world are two sides of the same fabric, in which the threads of all forces and events are woven into an inseparable net of endless, mutual relations (Capra, 1991).

4.5 Change and Transformation, Adaptation

Central to the understanding of all things and events as manifestations of an ultimate unifying reality is that the universe, or all things, is intrinsically dynamic. The Eastern mystics see the universe as an inseparable web of dynamic interrelations, which moves, grows and changes continually (Capra, 1991).

Modern physics has also come to recognise the universe as a dynamic web of relations, within quantum theory and in relativity theory, in which matter cannot be separated from its activity, and the properties of subatomic particles can only be understood in terms of movement, interaction and transformation. Quantum theory implies a fundamental 'restlessness' of matter, which is always in motion. Seemingly passive, 'dead' objects around us are actually alive with activity, and this is also the way the Eastern mystics see the material world (Capra, 1991).

5. Applying the Principles: A new approach to urbanism

This Section describes the application of the above Principles to a design proposal for urban development in the Thames Gateway. The accompanying design proposal seeks to reflect the principles of its philosophical foundations, through urban form and spatial character. This theoretical source is based on a holistic, balanced, harmonious relationship with the natural environment, which is the core objective of sustainable development, and so is seen as a powerful, effective and resonant basis for a new approach to the way we build cities.

Therefore the proposal provides limited detail on technological devices or systems, which would of course be incorporated, but instead focuses on the formal, spatial and experiential qualities of the urban environment, and its integration with and adaptation to the natural context, as well as the opportunities for sustainability presented by this new formal approach.

The principles provide a vehicle towards a new approach to urban design and development, which reflects and encompasses our contemporary view of the world and our place within it, as well as a balanced, integral relationship with the natural systems on which our cities depend. The design explores how one perceives the city, and one's place within it, and seeks to reflect an elevated level of consciousness of our place within the

Earth's dynamic, ecological system (rather than separation from it), and a balanced, integrated, homely urban environment for people.

5.1 Time/Space

The new high-speed railway between London and continental Europe runs through the Thames Gateway, and is causing significant change in the region. Faster connections between places can effectively alter their apparent separation, bringing them closer together, and distorting our perception of geographic distance. We commonly associate places and distance by travel time, rather than physical distance, and new infrastructure can radically reduce the travel time, and therefore the perceived spatial separation. As understood by Eastern philosophy and modern physics, our understanding of time and space becomes relative, based on the travel modes available.

These connections, however, typically link major nodes, while other locations are excluded from the network, and may effectively be pulled further apart in terms of travel time. This polarity of conditions raises the potential of 'fast space' and 'slow space', where the nodes of the high speed networks are characterised by speed, intensity, activity and density, while the 'slow spaces' are more spacious, dispersed and engaged with the natural environment. Transitions between these opposing conditions are made explicit, visible and legible in the urban form.

5.1.1 Time / Space: Opportunities for Sustainability

The development of 'fast space' and 'slow space' within urban areas provides numerous opportunities for implementing sustainable design. 'Fast' spaces are appropriate locations as activity centres and transit nodes, with population intensity and high-density development to support high-quality transport and services provision, with 24-hour activity and mixed uses, focussed on work, education and entertainment. By contrast, the urban form in 'Slow' spaces is closely engaged with the landscape, forming locations suited to recreation, leisure, meandering, and landscape-oriented activities, such as urban agriculture and water treatment.

In spatial terms, the urban area escapes the rigidity and permanence of modern planning, adopting a dynamic, fluid form and resultant spatial qualities, presenting opportunities for a flexible, adaptable development which is responsive to changes in external and internal conditions (climate, occupancy patterns).

5.2 Unity and Interconnection

Urban development and planning procedures are based on defined boundaries and edges. Space is precisely measured, demarcated, fixed, and allocated to specific activities. This strict rational approach is focused on separation, constriction, and imposition of a rational order upon an apparently unordered, irrational natural landscape. As discussed above, the city effectively severs links between its inhabitants and the natural world.

This design proposal reflects a more integrated, interconnected pattern of urban development, reflecting a greater consciousness of the natural systems and relationships on which our cities depend. Rather than strict, fixed boundaries and separations between land parcels and individual infrastructure connections, the plan provides for incremental, informal growth from key infrastructure locations, with each development providing onward service connections for future 'layers' of development. These layers are defined and integrated by 'interface zones' which provide for natural light and ventilation, movement and circulation between buildings. The incorporation of cybernetic, adaptive features in the interfaces between buildings facilitates this blurring of boundaries and flexible modulation of space, as discussed below in 5.5.

The project seeks an urbanism where boundaries and barriers between buildings and spaces are blurred, broken down, and constantly changing in a dynamic balance. The boundary between urban and rural is made indistinct through engagement of built form with the land, and the penetration of landscape into urban areas.

5.2.1 Unity and Interconnection: Opportunities for Sustainability

Rather than fixed, rational boundaries, this proposal incorporates 'interface zones' or 'zones of change', within which the dynamic, cybernetic functions of built form modulate the internal and external spaces between buildings, supporting microclimates, indoor amenity, weather protection, energy efficiency and water management.

The potential of *smart material* technologies may allow the built form 'skin' to evolve from a fixed, thin, planar element, to a flexible *zone in which change occurs*, which is fully integrated and responsive to the external environment and internal use patterns. Through exploring the limits of this technology, the built form may become a dynamic, ever-changing construct of internal and external spaces.

The proposed incremental urban growth will facilitate reduced disturbance of the landscape and smaller infrastructure costs, as each development provides onward connections to subsequent 'layers' of development.

5.3 Polarity

The project seeks to encompass a range of polar opposites in urban form, programme and spatial character, expressing the transitions between them, at a range of scales, to enhance awareness of the enduring presence of opposing conditions, including: Fast/Slow, Intense/Quiet, Dynamic/Stable, Large/Small, Open/Closed, High/Low density, Deep/Shallow space and Landscape-engaged/separate. These contrasting conditions are distributed and balanced on the site according to site conditions, infrastructure and programme, with each condition offset and balanced by its juxtaposed other. This approach supports an elevated consciousness among occupants of the dynamic, sustainable balance our cities must maintain with the natural environment.

5.3.1 Polarity: Opportunities for Sustainability

The development of a diverse range of spatial qualities within close proximity, located according to natural site features and existing infrastructure elements, allows occupants to perceive these variations and transitions, while providing optimal choice for citizens. An important aspect of social and environmental sustainability is the provision of a diverse range of accommodation options, within an overall structure which supports the viable provision of services and protects surrounding areas for agriculture, recreation and conservation.

This proposal reflects an overall development density to facilitate sustainable transport, community services and walkable urban structure, while providing a diverse choice of urban qualities, for permanent residential occupation or temporary activities.

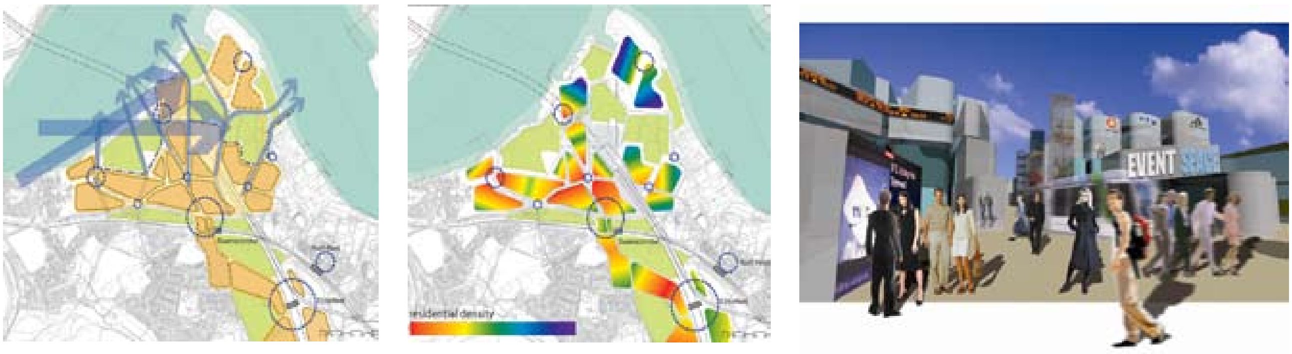

Figure 1 Site plans indicating hydrology and prevailing winds and residential density distribution, and perspective view of nodal space

5.4 Emptiness/Form, Observer/Object

In cities, we traditionally view built form as solid, closed, *figure*, against a backdrop of void, space, or *ground*. In this proposal, the spatial merging of built form with open/circulation space, serves to blur the boundaries between solid and void in the city, in that form (buildings, for occupation) is also emptiness (space between buildings, for circulation and recreation).

From the viewpoint of the pedestrian moving through the public realm of the city, the sensation of being *in* the dynamic flow of built form, rather than outside, between buildings, in left over space, reflects the merging of subject and object, observer and observed. Through merging built form with circulation and outdoor space into a dynamic continuum, the pedestrian is placed in the dynamic interplay of built form and landscape.

5.4.1 Emptiness/Form, Observer/Object: Opportunities for Sustainability

The integration of built form and open/circulation space facilitates highly compact, efficient urban development, which in turn supports sustainable services and sense of community and vibrancy through walkability (facilities within walking distance of dwellings). This is achieved through the interconnection and merging of buildings, and the use of roof spaces as public open space and 'street' space. This approach to built form also provides opportunities for enhanced thermal insulation and weather protection, water management and small-scale agricultural activities in urban areas. The integration of built form with the landscape creates opportunities for access to open space, urban agriculture, energy exchange, and increased awareness of the dependent relationship between urban and rural areas.

The principle of reduced distinction or separation between private and public realms, building and 'street', roof-space and open space requires each development to contribute directly to the public realm, depending on its location, creating a communal, cooperative approach to planning and development.

Figure 2 Images of design models, demonstrating formal and spatial manifestation of design principles

5.5 Change and Transformation, Adaptation

Notions of change and adaptation are reflected in the design proposal on a number of levels, both experiential and physically dynamic. The proposed city dynamically engages with the ever-changing natural environment, reflecting an integral, responsive relationship. The experience of transitions between opposing urban conditions reflect change and transformation, perceived as one moves through the urban area. The urban character, encompassing built mass and height, footprint size and proportion, development density and proportions of open space, is constantly changing between one location and another, as perceived by the observer.

The potential applications of smart material technology in architecture and urbanism are vast, and this project merely posits some ideas, including how these potentials might apply to the interfaces between buildings and adjoining internal and external spaces. The 'interface zones' between individual units or buildings incorporate cybernetic, adaptive capabilities, to allow the dynamic, negotiative modulation of space in response to changing conditions, such as climate or living patterns. These zones effectively blur the boundary between adjacent units, replacing a fixed line with a constantly changing adaptive space. The incorporation of adaptive capabilities also allows the establishment of various microclimate zones throughout the urban area, as well as the expansion or contraction of space demarcated as public or private, open or enclosed.

5.5.1 Change and Transformation, Adaptation: Opportunities for Sustainability

Perhaps the most critical factor of sustainable building performance is the capacity for adaptation in response to changing external conditions. As we adjust our clothing to suit the conditions, our buildings can become our 'third skin', and should also be changeable as conditions change. These conditions may include external factors such as the seasons, weather and ambient light levels, as well as internal factors such as activity type, intensity and occupation levels.

Active, dynamic systems are well established in sustainable architecture, but a more far-reaching investigation of the potential of adaptable buildings explores the very nature of the building envelope or external skin, and posits the potential for a flexible, dynamic, 'organic' urban form which changes its shape and enclosure in response to internal needs and to changing natural conditions.

5.5.2 Smart Materials

An emerging scientific field with direct application to adaptability and responsiveness in built form is that of Smart Materials. These are materials which change their form or state temporarily, in response to signals or impulses, then return to their original state or form.

In the built environment, our accepted belief that the spatial envelope acts like a boundary serves to limit our current thinking about materials. Our current design methodologies privilege the surface, and we essentially think of materials as planar. While conventional materials are applied to meet a specific need, smart materials have changeable properties, and can respond to transient needs. This allows the privileging of the static planar surface to be challenged, whereby the 'boundary' is no longer delimited by the material surface, but may be reconfigured as the *zone in which change occurs*, thereby blurring the defined boundaries of built form (Addington and Schodek, 2005).

Figure 3 Details of interconnected, incremental development, and adaptation for climatic responsiveness

6.0 Conclusion

This research and design proposal encompasses my search for an intuitive, balanced and natural approach to urbanism, based on a framework of principles which derive from ancient observations and teachings about nature and our place within it.

The work presented reflects an intensive, experimental design and exploratory research process. The outputs are not complete, final or fixed, but could be developed, tested and enhanced as we move forward towards sustainable urban development. The principles, approach and understanding, however, may be applied immediately, in place of our ingrained modern, rational, forceful approach to urban planning.

The need for change in our cities and how we design them is clear, but this work calls for a more fundamental shift, in our understanding of cities and our position within the Earth's dynamic, diverse, unified ecology.

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PUBLIC SQUARES AS A MEANS OF INTEGRATING ECONOMY, ENVIRONMENT AND SOCIETY IN BRITISH CITY CENTRES

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Summary

Sustainable Development is invariably epitomised by economy, environment and society represented as three equal sized rings in symmetrical interconnection. This assumes a separation, even autonomy, and detracts from the fundamental connections. Much debate is now centred on how to integrate these sectors, rather than seeking trade-offs between them. Up to the 20th Century, public squares, offered clear examples of this integration as they are representative of the values of the society that created them. There are numerous examples from different time periods in a variety of cultures. In the second half of the 20th Century, British cities experienced increasing competition for space, which partly led to domination by market economies. As city centres became commodities, more devices were employed to attract consumers. One of the most significant was the indoor shopping centre. As malls were constructed over city streets, increasingly public space became privatised. The public sector is now experiencing substantial decline and the balanced model of economy, environment and society has been grossly distorted. Social capital may be a means of regaining equilibrium. This paper will demonstrate the significance of squares in sustaining vibrant communities; and consider mechanisms for their re-introduction as a means of contributing to the integration of economy, environment and society.

1. Economy, Environment and Society

Sustainable Development is generally represented by the following diagram:

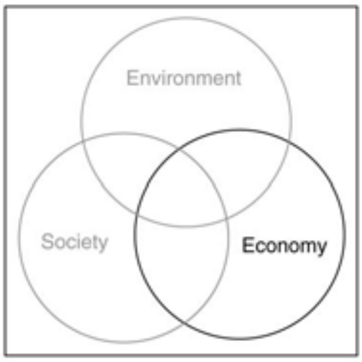

Figure 1 Common three-ring view of sustainable development

The model has a conceptual simplicity. By encouraging the classification of impacts into three convenient categories, it makes analysis more straightforward. Often sustainable development is presented as aiming to bring the three together in a balanced way, reconciling conflicts. If they are seen as separate, as the model implies, different perspectives can give priority to one of them. This view risks approaching and tackling issues of sustainable development in a compartmentalised manner. The separation detracts from the fundamental connections between economy, environment and society. It leads to assumptions that trade-offs can be made between the three sectors, such as the notion that poor environmental quality does not matter if the economy is strong (Neumayer, 1999). In most debates either the environment or the economy is given priority, and one of the effects of the three sector separation is to encourage a technical solutions. With environmental issues, this approach suggests that provided pollution control, lower resource use, greenhouse gas trading etc. are resolved, then environmental sustainability is on track. Technical solutions in the economy, such as changing interest rates, benefits or taxation are seen as ways to move the economy towards sustainable development. They are attractive to some as they can be introduced quickly; but neither these measures nor the technical environmental solutions involve a fundamental examination of the relationship between economy, environment and society. A sectoral approach can divert attention from asking questions that are important to analysing the essence of sustainable development, such as those about the nature of society. The wider social matters often disappear from the sustainable development agenda. It is partly a quantitative versus qualitative debate. Economy and environment have sufficient quantitative factors as shown by the technical solutions, that neglecting the qualitative issues may not appear to be particularly harmful. Whereas society is predominantly about qualitative issues. It is the same dilemma that has plagued numerous research agendas – quantitative factors are just easier to identify and measure. It is hardly surprising that Prime Minister Thatcher infamously stated that 'There is no such thing as society'. Political reality always gives primacy to the economy, and treats environment and society as resources to be exploited. By contrast, it could be argued that in material reality, the economy is dependent on society and the environment (Daly, 1992; Rees, 1995; Wackernagel and Rees, 1996). Society embraces a multitude of actions and interactions that encompass human life. Without society, humans would not survive as their very existence, in both evolutionary terms and in the present, is based on social interaction. In addition, human activity takes place within the environment, which provides the source of much culture and leisure. Art and spiritual beliefs, and most of science and technology, draw from the environment. Although some human needs are met through the production of commodities, many are met by other activities that take place partly or wholly outside what is described as the economy (Langley and Mellor, 2002). A more accurate representation of the relationship between economy, environment and society could be a pattern in which economy is nested within society, which in turn is nested within the environment.

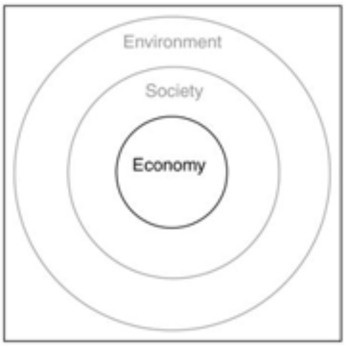

Figure 2 Nested view of sustainable development

Placing economy in the centre does not mean that it should be seen as the hub around which the other sectors and activities revolve. Rather it is a subset of the others and is dependent upon them. Human society depends on the environment, while the economy depends on society and the environment. A key issue for sustainable development is the integration of different actions and sectors, taking a holistic view and overcoming barriers between disciplines. The nested model, rather than the three-ring model, encourages a conceptual outlook sympathetic to integration. Both models are simple representations that imply one economy, one environment and one society; assuming that each sector is a unified entity. This is, of course, a further abstraction. There are a multitude of economies, environments and societies at different spatial scales. The simplified approach risks ignoring the richness and multi-layeredness of reality.

2. Dominance of Economy

As the Labour Government (1997 to date) has followed the Conservative Government (1979-1997) in abandoning Keynesian and social democratic policies in favour of neo-liberalism in social and economic policies, there has been an identifiable shift in priorities from meeting social needs to responding to the needs of capital. Thus, there is a clear discontinuity between environmental and social policies on the one hand, and economic policies on the other. The private sector is tightening its grip on city development, directing the character and priorities for development, and basing its decisions on maximising profitability. Ironically, the public sector gatekeepers, who are supposed to be protecting cities by applying environmental policy, are reduced to supporting the private sector. They are striving to attract investors, support property development and increasingly encourage the private provision of services.

Modern landmarks in British cities often reflect the values of the private sector and market forces. Traditionally, the symbols of society, such as town hall and library, stood out from the surrounding built fabric. However, the public sector is now experiencing substantial decline and the balanced model of economy, environment and society has been grossly distorted by the domination of market economics. Thus, there is now competition between commercial buildings, as to which can dominate the city. They are invariably large and anonymous, connecting neither with the community nor with the traditional built fabric, as they lack identity with place. Bookchin (1995) has argued that where there is a loss of city-ness in favour global commercialism, there is a parallel loss of citizenship. Active citizenship is discouraged and replaced by the role of consumer. Power is concentrated in the hands of large companies, and government largely acts in their favour. Smith's (2002) case that the speed and scope of development is mainly driven by property developers with no interests within a specific city, so that the urban scale and appearance is actually defined by the needs of capital, remains valid.

Throughout the 20th century, people lost much of their community perspective and became individual and nuclear family orientated. The growth of technology, such as home entertainment and cars as the primary means of transport, generated much fragmentation and retreat into the private domain. This was reflected at city scale by the decline of the public realm and privatisation of public space. As city centres have become commodities, more devices have been employed to attract consumers. One of the most significant is the indoor shopping centre - advertised to provide all the necessary retail outlets in one location and offering protection from the elements. Malls are frequently constructed over city streets to preserve the illusion of the public domain, whereas in fact the whole development is privately controlled. Arguably even more insidious, has been the colonisation of squares and pavements. While public space should allow citizens to sit and socialise, increasingly this can only be done as a consumer as all the seats are owned by cafes, bars and restaurants.

Figure 3 Cafes colonise public squares

In the second half of the 20th Century, British cities experienced increasing competition for space, which partly led to domination by market economies. Public space was reduced to the most direct means of accessing commercial and retail premises; while national and global capital generated buildings that did not respond to the special characteristics of each city. The pattern of urban form in cities changed dramatically. Appleyard (1981) notes that the greatest transformation in cities of the 20th century was from the city containing largely walkable spaces, to the onslaught of spaces designated for the sole use of the automobile. Both Appleyard (1981) and Tibbalds (1992) highlight that cities have become scarred by major road networks, invariably leaving wounds or gashes through the urban fabric. The insertion of new roads occupy large areas of land, fragment and blight neighbourhoods, destroying local social interchange and often leaving an excess of uncared-for, left-over space, vacant sites, temporary car parks and buildings facing the wrong way. Tibbalds (1992) states that such spaces are ugly and unpleasant and have lost the human scale, which is vital to successful urban areas. The Urban Task Force (1999) highlights that British cities have tolerated a lazy over-use of off-the-peg designs and layouts, allowing highway and traffic requirements to dominate urban layouts, as well as allowing developments that undermine the coherence and viability of cities, without giving careful thought to the effects on the logical hierarchy and balance of the whole urban structure. Traditionally cities were composed of blocks of buildings that defined squares and streets. The so-called comprehensive redevelopment schemes of the late 20th century tended to destroy this familiar and successful urban form. Paradoxically, the configuration of developments and space for motor vehicles that replaced it, actually reduced ground level building density - while ever larger areas of external space became neglected, left-over and unusable by society.

3. Compact Cities

It has been asserted for many years that the growth of the internet, telecommunications and global economics, has meant that people can live and work anywhere; and therefore the city does not have the significance that it occupied in the past. Some would even say that place no longer matters. This notion is counter-intuitive, but more importantly the evidence does not support it. It is true that there has been an outward migration from many cities, as people have been seeking their rural idyll away from noise and the fear of crime. Yet, at the same time, there has been unprecedented residential development in the centres of numerous cities. Moreover, although some people live miles from the city, they do not lose their connection with it. The city is still the heart of culture and society for them, as they return in the evenings and weekends for entertainment and social interaction. Gillen (2005) is one of a new breed of consultant researchers, who have concluded that the city has significance as a necessary physical hub for people whose work patterns are becoming increasingly orientated around technology-based networks. It is clear from this work that human beings need interaction that cannot be satisfied with email and video links. Meeting people, even casually for discussion, is essential to maintain a good psychological balance. It may be for these reasons that there has been a recent increase in the number of policy documents proposing improvements in the design of cities (eg. CABE, 2004; CABE, 2006; CABE, 2007; English Partnerships, 2007) However, these documents do not tackle the deep-rooted trends that undermine socio-economic quality and the environmental sustainability of urban life.

Thomas and Cousins (1996) state that the initial impression of walkable city is its concentration of activities. Lozano (1990) states that the urban form of traditional cities is rooted in pervasive factors that shape physical organizations and spaces. It has a tightly clustered pattern, with marketplace and trade streets. Often two centres of power (political and religious), and countless social and cultural institutions, such as town hall, theatre, museum and university. Cities that fall into this category tend to have a compact core and an organic system of streets and squares.

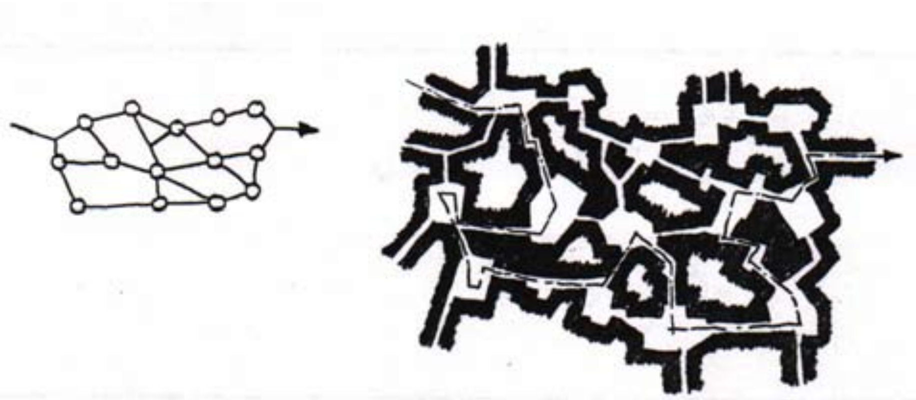

Figure 4 Organic System of Streets and Squares

Generally, as Alberti (1475) recognized, the organic layout tends to be most applicable to cities of variable terrain. The curving pattern of the organic street system is appreciated for the aesthetic advantages the curved vistas provide, by reducing the chance of monotony, and increasing the opportunity of surprise as suddenly a particular square appears. Norberg-Schulz (1971) holds much the same viewpoint, stating that in traditional cities, oblique angles and curved lines created closed perspective that enliven the experience of being there.

According to Lozano (1990), traditional cities are responses to the various factors that govern and influence form. He states that traditional cities have been consistently shaped by their location and morphology. They originate from places where human beings meet and trade, live and find recreation. There is substantial support among urban scholars for the traditional compact city. Jacobs (1961), Elkin et al. (1991), McLaren (1992), Hillman (1996), Thomas and Cousins (1996), Frey (1999), Girardet (2004) and Marshall (2005) all believe that the compact city has environmental advantages, and social benefits. A number of scholars have been calling for a return to the compact city, which is seen as ideal place to live and work. Such places have high population densities that can encourage social mix and interaction. This is emphasised by the Urban Task Force (1999), which states that the traditional compact city with its well designed and integrated framework plays a fundamental role in linking people and places together. The compact urban form highlights the value placed upon proximity and ease of contact between people. It gives priority to the provision of public space for people to meet and interact, to learn from one another and to join in the diversity of urban life. At its best, the compact city therefore operates as a series of interconnected networks of places and spaces devoted to making the most of human interaction. According to the Urban Task Force (1999) most compact and well-ordered cities are designed around a well-connected pattern of streets and public squares. Where the framework is fragmented and unstructured, as in so many modern urban developments, it contributes to social segregation and alienation. Gosling and Maitland (1984) note that the vision of the traditional compact city is more inspirational than factual in its message, less a model than a mirror of the community that created it. These kinds of cities can be seen as expressing themselves through thousands of small decisions taken over a long period of time. Tibbalds (1992) states that this is because they have certain essential qualities, like recognizable patterns and complexity within order. The question needs to be posed, then, as to why new development should not have the same richness, individuality, intricacy and user-friendly qualities of existing patterns? Valuable urban patterns recall their citizens' history, collective memory, values, beliefs and pride.

4. Public Squares

Urban space has always been the place for the community rather than the individual and is therefore public rather than private in nature. Historically, activities that took place in urban spaces have been representative of that settlement. They were the places where the framework of society was debated and formulated, and where economic activity took place. Of all types of urban space, squares are the most representative of the values of the society that created them - the agora, forum, cloister, mosque courtyard, are all examples. Squares have deeper significance than merely functional attributes. They engender a range of human responses which start with the comfort of a protected space right up to a spiritual experience. Moreover, the continued success of a city can in part, be derived from the quality of its public spaces. If the physical, psychological and spiritual well-being of a community and visitors is partially in response to these places, then sociological factors such as crime as well as economic aspects like trade and the number of visitors, must also be affected.

The argument is that the sustainability of city centres has suffered as the number of squares has declined. The neglect of squares as a part of late twentieth century city structure was based on functional justification and associated economic viability. The trend has been the transposition of outdoor activities to indoor arenas, but has this really been in response to community demands? The case for transposition is usually made in terms of increased comfort and convenience for the public, especially in relation to protection from the climate. There are however, economic and social arguments which suggest that such transposition could equally well find its source in the privatisation of public space and increased social control by the private sector. These kinds of developments are invariably large-scale single function enterprises which are consumer led. Some are out of town, which militates against the focus of the city centre. Moreover, through a subtle selection of goods and/or services on offer coupled to a particular pricing policy, in practice such developments can segregate the community through a form of social exclusion. All of this is highly undesirable and runs contrary to almost every principle of sustainable development. At the same time collective and sustainable outdoor activity is as much under threat from the reduction of suitable spaces, as the converse notion. Activities like outdoor markets, concerts, political meetings, charitable collections, theatre, religious gatherings, sporting events such as road races and cycling, spectacles like firework celebrations or laser shows, and many more functions - all have valid roles in the 21st Century. They are only hampered by the lack of suitable spaces and the unwillingness of Authority to encourage them. Secondly, does the creation of public space necessarily have to follow the rules of function and economic viability especially when the latter may be short term? The social argument is that if it acts as possibly a place for chance meetings, a focal point in the city, a recognisable landmark which offers orientation, the junction between various established routes, an entry position - especially when arriving in the centre by underground railway - a square is justified merely on those criteria, for which value cannot be measured in monetary terms. Unwin (1909) suggests that to help the positive image of a city, its principal buildings should be offered dignity by setting out a clear open space in front of them (see Figure 5). Sitte (1889) recalls the familiar feeling of the cosy old squares. He notes that only in our memory do they loom gigantic, because in our imagination the magnitude of the psychological effect takes the place of actual size.

Figure 5 Cathedral Square

Yet, the interaction between these spaces and buildings, suggests an even more significant role. As each of these buildings also displays a distinct attribute of the society it represents, then each square marks the arrival at that symbol of society. Individually, every pairing of symbolic building and square can have quite a dramatic effect on the psyche of the citizens (see Figure 5). Thus, if the most prominent squares in a city contain the symbols of society, then citizens and visitors may feel re-invigorated as they move from one symbol to the next. Thus the urban spaces are defined and there is scope for external community activities; and the symbols of society are visible and accessible, with each acting as a landmark and orientation signpost. Squares celebrate the entrance to the symbolic buildings and the whole composition offers linkages and variety within a framework.

5. Social Capital

In Britain, local authorities are under the most sustained attack in their history. This has yet to be researched and documented but there is ample evidence that the Government is removing them from so many public services that have been fundamental to their existence, and reducing their budgets accordingly. It has already been stated in this paper that local authorities increasingly occupy a support role for the private sector. Although, there is a disturbing trend in the privatization of public space, councils are still the largest owners of land in city centres. Therefore, they have the potential to re-introduce squares as a means of integrating economy, environment and society for their communities, but their influence is diminishing. Crucial to the development of this form of sustainability is the commitment and will of the community. This may need to be found in other ways than the traditional voting for councilors. Social capital may be a means of regaining equilibrium, and developing city centre spatial structures in which all members of society can fully interact. It is a way of reclaiming public life to enable societies to prosper and for development to be sustainable. Based on collective action by different groups in the community, social capital can differ in operation. It can work with elected representatives by giving a voice to the community through a network of existing organizations. Alternatively, the community can actually undertake the work themselves. (The World Bank, 1999). For example, the proposed redevelopment of the Bullring shopping centre in Birmingham, produced an alternative scheme by the community. Although the final design still demonstrated a consumer city in terms of malls, shops, cafes and restaurants, nevertheless civic society is represented by the incorporation of several public squares. It is surely not coincidence that while many cities are reporting low public esteem due to the dominance of private sector economics and declining local authorities, Birmingham has seen a significant increase in civic involvement (Field, 2003).

Figure 6 A two tier public square in the Bullring Birmingham

6. Conclusion

This paper has reviewed the theoretical relationship between economy, environment and society in sustainable development. The conclusion is that the common presentation as three rings, compartmentalises the three aspects and detracts from their connections. More damaging is the assumption that there can be trade-offs; and that poor conditions can be accepted in one sector if compensated in another sector. This can lead to a significant imbalance. In addition, quantitative issues can be given prominence over qualitative matters, because they are easier to identify, assign targets, measure and so on. Of the three sectors, society seems to suffer most in this situation. It is suggested that a nested model may be preferable, as it encourages integration.

In practice, especially since the latter part of the 20th Century, the economy has dominated city development. There has been an identifiable shift from meeting social needs to responding to the needs of capital, and the private sector has tightened its grip. The landmarks in British cities are now often a competition between commercial buildings. Power is concentrated in the hands of large companies and active citizenship replaced by the role of consumer. Nevertheless, people still have strong connections with cities. Even those who use the electronic revolution as a means of living and working in a rural idyll, still regard the city as the heart of culture and society. At the same time, unprecedented residential development is taking place in city centres.

There is substantial support among urban scholars for the traditional compact city. Many of them point to the environmental advantages and social benefits. The walkable city also appears to be synonymous with a high concentration of activities. This kind of city is epitomised by a tightly clustered pattern of streets and squares. These city centres have a high proportion of public space in which economy, environment and society can be brought together. Of all urban space, squares are the most representative of the values of the society that created them. Moreover, if symbolic buildings are located in the most prominent squares, citizens and visitors may feel re-invigorated as they move from one symbol to the next.

The re-introduction of these values and the re-construction of squares in particular is a public sector activity. However, local authorities are currently being subjugated by the private sector and national government. It would be excellent if they could restore public city structures but there is little sign that it is likely to happen. An alternative is social capital, as a means of reclaiming public life. It requires collective action by different groups in the community. Although difficult to organise, there are modest signs of its success in the city of Birmingham and others.

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BUILDING REFURBISHMENT: ONE STEP TOWARDS SUSTAINABLE BUILT ENVIRONMENT

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Summary

A sustainable built environment results from the best trade-off between each three dimension of the sustainable development (environment, society and economy). In Western Europe it is usually considered than more than 60% of the buildings to be used in 2050 are already built today and it is expected that the rehabilitation becomes a leading sector in the building industry. To ensure the sustainable rehabilitation of the built environment it is necessary to consider tens of parameters related to the overall impact of the project on the local and global environment as well as preservation of heritage, social trends, economic development, or health and safety of the users. The integration of a huge number of evaluation criteria, some quantitative, other purely qualitative, makes the assessment of such strategy very hard to carry out without a real methodological work. The aim of this paper is to present a multi-criteria decision based methodology that allows the integrated assessment of all different sustainability parameters. The proposed methodology is applied to a case study, which aim is to select the most sustainable solution between different refurbishment scenarios for a building façade.

1. Introduction

The building sector plays a major role in the perspective of a sustainable built environment. Buildings accounts for the greatest amount of the total residues production and energy consumption. Besides that, buildings are the population's center of life: an adult in a developed country spends almost 90% of its life inside buildings. Globally, buildings construction is responsible for about 40% of raw materials (stone, gravel, sand, etc), 25% of wood, 40% of energy and 16% of water annually spent all over the world (Roodman, 1995). In Portugal, in spite of existing important differences between the reality and the statistical figures, according to national energy directorate (DGGE) and national statistics institute (INE), during operation phase, buildings (houses and offices) accounts for about 25% of the national primary energy consumption, 6.7% of the total water end-use and are responsible for the annual production of 420 millions of cubic meters of residual water. According to INE, construction industry is also responsible for the annual production of about 7.5 millions tons of solid residues. These figures show that buildings are related with strong environmental, social and economical impacts that have great potentialities to be to some extent overcome.

Most of the buildings related impacts are linked to the "cradle-to-gate" stage of their materials and products and to the operation phase of the buildings. Rehabilitation allows to increases the life span of a building and therefore the embodied impacts related to the materials and products used in its construction are amortized in a larger time span. Nevertheless, rehabilitation allows updating the comfort of the building users and, on the other hand, the thermal refurbishing is on the basis of higher energy efficiency and therefore it contributes to the reduction of the environmental impacts during the operation phase.

For the reasons stated above, rehabilitation in opposition to demolition and new construction is an important step towards sustainability. Correcting the actual policy of "use and throwaway" it is possible to overcome some economic problems; to increase the occupants and users comfort; to reduce the environmental impacts through the energy consumption, raw materials and residues reduction; and to preserve the city's cultural legacy.

Many efforts have been done regarding environmental protection and urban quality, and in recent times, a greater attention has been given to pollution control, energy efficiency, proper waste disposal, landscape preservation, heritage preservation, social integration, etc.. Therefore, more and more, building operation have to consider rehabilitation, partial or complete of a building or a group of buildings, and they have to fit into numerous criteria, sometimes contradictory, concerning quality of materials used, economic pressure, improvement of quality of life and environment.

Although, there still is an important question that must be solved: the definition of the sustainable building rehabilitation concept and actions through tangible goals. Sustainability assessment is a holistic approach that doesn't consider all aspects related to the environmental, economic and social performances of a solution, but only those parameters that better compromises the objectives of the assessment, the type of solution, the available data, among others (Bragança, 2007). The application of the "Sustainable Development" concept is based on the definition of objectives and criteria to be used in the sustainability assessment and comparison of different building solutions. This way it is possible to choose the most sustainable solution, according the considered aspects.

This paper presents the first steps of a sustainability assessment methodology that is being developed to support the sustainable rehabilitation of buildings, which is based in the three dimensions of the "Sustainable Development". At the end of the paper, the methodology is applied to a case study, whose aims are the selection of the most sustainable refurnishing solution for a building façade, according to the assessment objectives.

2. Sustainability Assessment Methodology

The methodology presented in this document is a derivation and adaptation of the Methodology for the Relative Assessment of Building Solutions (MARS-SC) that was developed in order to evaluate new construction solutions (Mateus, 2004). This methodology follows these steps: definition of parameters, quantifications of parameters, normalization of parameters, aggregation of parameters, representation and assessment of the solution.

In the next paragraphs a short description of the methodology MARS-SC adapted to refurnishing operations is made.

2.1 Definition of Parameters

The sustainability assessment is holistically made, because it is impossible to consider all parameters that express the performance of a solution at the level of the three dimensions of the sustainable development. Thus, in this phase the number and type of parameters to be assessed inside each dimension are defined. The definition depends on one hand in the objectives of the assessment, type of solution to be refurnished, local conditions, functional requirements that are necessary to be fulfilled, available data, and in the other hand in the assessment boundaries: the sustainability assessment of a project to refurbish a single construction element is not based in the same parameters used for a whole building or district. Table 1 presents some parameters that could be considered in a sustainability assessment of a refurbishment technology for a façade.

Table 1 Parameters that could be used in the sustainability assessment of refurbishing solutions for building façades

Environmental	Social	Economic
Global warming potential	Airborne sound insulation	Construction cost
Destruction of the stratospheric ozone layer	Thermal insulation	Operational cost
Potential acid deposition onto the soil and in water	Structural safety	Maintenance cost
Local tropospheric ozone formation (smog)	Fire safety	Dismantling cost
Addition of mineral nutrients to the soil or water.	Water permeability	Residual value
Abiotic depletion	Maintenance aptitude	
Non-renewable primary energy consumption	Preservation of the city's heritage	
	Aesthetics	

2.2 Quantification of Parameters

After selecting the parameters it is necessary to proceed with their quantification. Quantification is essential to compare different solutions, aggregate parameters and to accurate assess the solution. The quantification method should be anticipated. There are several quantification methods: previous studies results, simulation tools, expert's opinions, databases processing, etc. (Cherqui, 2004). In some cases the parameters to evaluate are quantitative. When assessing qualitative parameters like for instance, aesthetics and preservation of the city's cultural heritage, the qualitative performance level is transformed in a quantitative scale, using the equivalences presented in Table 2.This transformation is based in the comparison of the performance with the best and conventional/minimal normalized performance.

Table 2 Equivalences between the qualitative and quantitative performances

Qualitative performance	Score
Best solution	1,00
Good solution	0,75
Slightly better than the conventional solution	0,25
Conventional solution/minimum standard	0,00

It is not easy to evaluate the environmental parameters mentioned above. Although there are some life-cycle inventory (LCI) databases about the environmental pressure related to several construction materials that could be used to support life-cycle analysis (LCA). It is also possible to use LCA tools to evaluate the parameters mentioned above.

To assess the social parameters related to the indoor environment comfort, it is possible to use one of the several normalized methodologies available. Another way is to use and process some available databases that collect common functional performance data related to some conventional refurbishing solutions. Whenever possible, experimental results should be used, because those are the ones that best draw up the real performance of the solution.

Life-cycle cost assessment (LCCA) is more straightforward than the environmental performance assessment, since there are different standardized methodologies and published construction costs databases. LCCA is a method that allows the quantification of the global cost of a product for a certain period of service life. In this method all costs are included: construction cost (capital cost), operation cost, maintenance cost and the residual value of the building or of some part of it. LCCA is an important approach whenever it is necessary to compare two solutions that have the same functional requirements but that differ at the level of their initial and operational costs.

2.3 Normalization of Parameters

The objective of the normalization of parameters is to avoid the scale effects in the aggregation of parameters and to solve the problem that some indicators are of the type “higher is better” and others “lower is better”. Normalization is done using the Diaz-Balteiro *et al.* (2004) equation (Equation 1).

$$\overline{P_i} = \frac{P_i - P_{*i}}{P_i^{*} - P_{*i}} \forall_i \qquad (1)$$

In this equation, P_i is the value of i^{th} parameter. P^*_i and P^*_i are the best and worst value of the i^{th} sustainable parameter.

The normalization in addition to turning dimensionless the value of the parameters considered in the assessment, converts the values into a scale bounded between 0 (worst value) and 1 (best value). This equation is valid for both situations: “higher is better” and “lower is better”.

2.4 Aggregation

Sustainability assessment across different fields and involves hundreds of parameters. Each sustainable dimension is characterized by several parameters or indicators. A long list of parameters with their associated values will not be useful to assess a project. The best solution to overcome this situation is to combine parameters with each other to obtain “global indicators”, allowing assessing the sustainability of each solution at the level of each sustainability dimension.

The complete aggregation method that is used in this methodology is presented in Equation 2.

$$I_j = \sum_{i=1}^{n} w_i . \overline{P_i} \qquad (2)$$

The global indicator I_j is the result of the weighting average of all the normalized indicators $\overline{P_i}$.

w_i is the weight of the i^{th} parameter. The sum of all weights must be equal to 1.

Equations 3 to 5 present how to aggregate the parameters inside each indicator in order to assess the performance of a solution within each sustainable dimension.

$$I_{Env} = \sum_{i=1}^{n} w_{Env\,i} . \overline{P_{Env\ i}} \text{ , environmental dimension} \qquad (3)$$

$$I_{Soc} = \sum_{i=1}^{n} w_{Soc\,i} \,.\, \overline{P_{Soc\ i}}$$, social dimension (4)

$$I_{Eco} = \overline{P_{Eco\ i}}$$, economic dimension (5)

In the economic dimension, the global indicator as the same value of the normalized economic parameter because the normalized parameter results from the sum of every cost found in the life-cycle costing analysis.

Weights are strongly linked to the objectives of the project: higher weights must be adopted for parameters of major importance in the project. Although the weight of each parameter in the assessment of each dimension is not consensual, as it is possible to verify when analysing the several different available methodologies to support and assess the sustainable design. This is the major inconvenient of this method, when compared to performance based methodologies, since it is possible the compensation between parameters.

In what concerns to the weights of the environmental parameters, actually there are not Portuguese impact scores for each environmental parameter, according to their relative importance in the overall environmental performance. Additionally, this issue was not dealt so far by the European Environmental Agency. However there are some international accepted studies that allow an almost clear definition of it. One of the most accepted studies is the one performed by the United States Environmental Agency's Science Advisory Board (SAB) that developed two lists of the relative importance of various environmental impacts to help EPA to best allocate its recourses (EPA, 2000). MARS-SC allocates the environmental parameters in the EPA's impact categories and therefore it considers the same relative importance. Table 4, presents the relative importance of the environmental parameter considered in MARS-SC.

In spite of being easy to quantify the functional parameters, the way as each parameter influences the functional performance and therefore the sustainability is not consensual. This assessment involves subjective rating and depends, above all, on the type of solution and on the valuator's social-cultural and economic status. This way, in a first approach the methodology considers the same relative importance for all functional and societal parameters. MARS-SC is being developed in order to accommodate a more consensual distribution of weights.

2.5 Global Assessment

It is understood that the majority of stakeholders would like to see a single score representing the overall building performance. Therefore, after assessing the performance of a solution within all dimensions (environmental, societal and economics), the next step is to combine the performance at the level of each dimension with each other in order to obtain the sustainable score. Sustainable score (SS) is a single index that resumes the global performance of a solution. As nearest to 1 is the sustainable score, more sustainable is the solution. The aggregation method used to calculate the sustainable score is presented in Equation 6.

$$SS = I_{Env}.w_{Env} + I_{Soc}.w_{Soc} + I_{Eco}.w_{Eco} \qquad (6)$$

Sustainable score, *SS*, is the result of the weighting average of each global indicator I_j. w_i represents the weight of the i^{th} parameter.

The weight of each dimension in the global sustainability is still not consensual. It depends, among other, in the objectives of the project and local priorities. In MARS-SC it is proposed to use the weights presented in Table 3.

Table 3 Weight of each sustainable dimension in the sustainable score assessment

Dimension	Weight (w_i)
Environmental (I_{Env})	0,3
Societal (I_{Soc})	0,5
Economic (I_{Eco})	0,3

The sustainable score is useful to communicate and compare results but it should not be used alone to characterize the sustainability of a solution, since the possible compensation between dimensions could cause some distortions in the results. Moreover the solution has to be the best compromise between all the different aspects: every aspect has to be considered.

3. Case Study

The scope of the case study is the assessment of a refurbishment project related to a multi-storey building with three floors, located in the city centre of Guimarães, Portugal. This building was built at the end of the 60's and most of its envelope, mainly the façade, is at a considerable degradation state, as it is possible to verify in Figure 1. This building doesn't have any kind of heritage value and in the façade it is possible to identify some cracks that endanger the water permeability of this construction element. The aim of this project is not only to improve the building aesthetics, but also to improve other functional characteristics, mainly the thermal comfort, in order to turn it compatible to the updated comfort standards and user demands. Another requirement to fulfil is that the refurnishing solution should be the best compromise between the three dimensions of sustainable development.

After examining the façade it was possible to conclude that the cracks are stable and that the original solution used in the façade is a hollow brick cavity wall without any insulation material, as presented in Figure 2.

The refurbishment solution to adopt should disturb as less as possible the indoor living conditions of the occupants. This way, the design team selected three refurbishing scenarios for this project, as presented in Table 4. Table 4 also presents the predicted energy consumption for heating and cooling according to the actual Portuguese Thermal Regulation (Decree-Law 80/2006). The time boundary considered for the project is 25 years.

Table 4 Refurbishing scenarios in assessment

Refurbishing Scenarios	Description	Expected maintenance in the time boundary	Energy consumption during operation (MJ/m^2.year)
Scenario 1	To paint the façade and replace the windows	3x painting	640,8
Scenario 2	To place a ventilated façade and to replace the windows	No maintenance	439,2
Scenario 3	To place an external thermal composite systems (ETICS) replace the windows	3x painting	439,2

Figures 3 and 4 represent the cross section of the refurnishing solution adopted in scenarios 2 and 3, respectively.

Figure 1 Elevation of the façade.

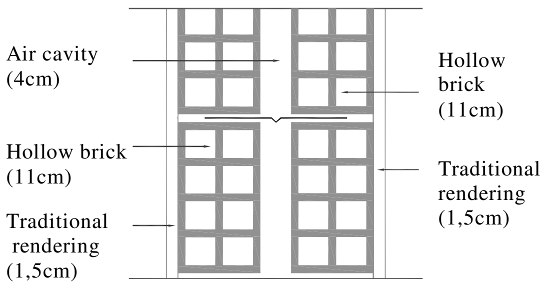

Figure 2 Cross-section of the existing solution.

3.1 Accessed Parameters and Related Weight

At the level of the environmental performance, the project team decided that the solution to adopt should have the lowest possible embodied environmental impact. The design team selected seven mid point impact categories to assess the environmental performance: abiotic depletion (AP), global warming potential (GWP), destruction of the stratospheric ozone layer (OD), local tropospheric ozone formation-smog (PO), potential acid deposition onto the soil and in water (AP), addition of mineral nutrients to the soil or water (EP) and the non-renewable primary energy consumption (PEC). The environmental performance is analysed in the following life cycle stages: construction, maintenance and operation. During the construction and maintenance stages, the study considers the construction material's embodied environmental impacts, from cradle to factory's gate, according to the material inputs. For the operation phase it considers the impacts related to the energy consumption for heating and cooling, according to the Portuguese energy mix and associated environmental impacts.

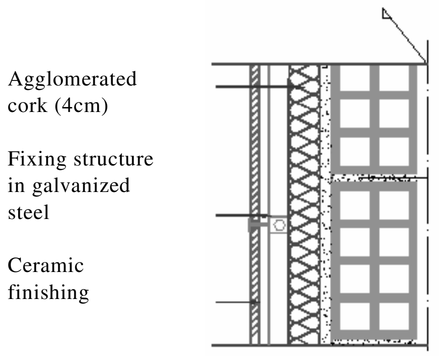

Figure 3 Refurnished façade's cross section after (solution 2).

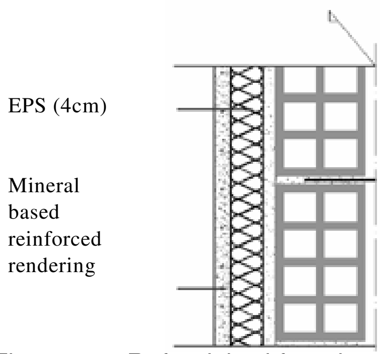

Figure 4 Refurnished façade's cross section after (solution 3).

In what regards to societal performance, the aim was to find the best compromise between two parameters related to the comfort of the building: airborne sound insulation (Dn,w), and U-value (U), related to the acoustic comfort and thermal comfort, respectively.

For the economic performance the aim was to choose the solution with lower life-cycle costs. The considered indicator is the life-cycle costs (LCC) and it considers the costs related to the construction and maintenance of the refurbishing technology as well the predicted energy costs for heating and cooling, according to actual energy costs. Table 4 resumes the considered parameters and related weights.

Table 4 Assessed parameters and related weight

Dimensions	Parameter	Weight of parameters (%)	Weight of dimension (%)
Environment	Abiotic depletion (AD)	13	
	Global warming potential (GWP_{100})	33	
	Destruction of the stratospheric ozone layer (OD)	11	
	Local tropospheric ozone formation-smog (PO)	13	30
	Potential acid deposition onto the soil and in water (AP)	11	
	Addition of mineral nutrients to the soil or water (EP)	11	
	Non-renewable primary energy consumption (PEC)	8	
Social	Airborne sound insulation (Dn,w)	50	50
	Thermal insulation (U-value)	50	
Economic	Life-cycle cost (LCC)	100	20

3.2 Quantification of Parameters

In Portugal it is not yet available the environmental inventory data related to the major part of the building materials, therefore the quantification of the environmental performance was carried out using the SimaPro software. The CML 2 baseline 2000 method was used to assess the first six mid point environmental categories and the "Cumulative Energy Demand" method was used to assess the embodied non-renewable primary energy. Table 5 lists the results of the environmental performance assessment for each refurbishing scenario.

Table 6 presents the results found in the functional performance assessment of the three scenarios and Table 7 presents the Net Present Values of the life-cycle costs. The construction and maintenance costs are based in a cost estimation drawn up by three construction companies which head-office is situated in the North of Portugal and they include all direct and indirect costs and profits related to construction works. The operation costs are base in the actual energy costs fixed by the Portuguese electricity provider - EDP – 0,1131 €/kWh.

3.3 Global Assessment of the Different Refurbishing Scenarios

Table 8 summarizes the results found in the sustainability assessment of both refurnishing scenarios, using the methodology MARS-SC. Analysing the results it is possible to see that refurnishing scenario 1 is the worst and scenario 2 is the best one, since it has the higher sustainable score. Although refurbishing scenario 2 has higher embodied environmental impacts and higher construction costs, those impacts are compensated with the lower environmental impacts and higher comfort during the operation phase. Scenario 3 is almost equivalent to scenario 2 and also a possible refurbishing solution. In fact, scenario 3 compared to scenario 2 has lower life-cycle costs and environmental impacts, but it has the disadvantage of having a lower social/functional performance. Therefore, in the analysed example and according to the considered dimensions, parameters and related weights, the most sustainable refurfishing solution is the ventilated façade (scenario 2).

Table 5 Life-cycle environmental impacts

Refurbishing Scenarios	AD[1] ($kgx10^3$)	GWP_{100}[2] ($Kgx10^3$)	OD[3] (kg)	PO[4] (kg)	AP[5] (kg)	EP[6] (kg)	PEC[7] (GJ)
Scenario 1							
Construction	6,70E-04	70,97E-03	1,03E-05	0,02	0,45	0,10	1,33
Operation	16,73	2214,60	1,31E-01	754,25	20185,25	966,50	11534,40
Maintenance	2,00E-03	2,12E-01	3,09E-05	0,06	1,35	0,30	3,99
Total	16,73	2214,89	1,31E-01	754,33	20187,05	966,90	11539,70
Scenario 2							
Construction	16,73E-03	1,24	1,55E-04	0,80	9,68	0,95	37,68
Operation	11,46	1517,88	0,09	516,96	13834,84	662,43	7905,60
Maintenance	-	-	-	-	-	-	-
Total	11,48	1519,12	0,09	517,76	13844,52	663,38	7942,88
Scenario 3							
Construction	4,87E-03	8,94E-01	3,24E-05	0,51	2,04	0,22	11,65
Operation	11,46	1517,88	0,09	516,96	13834,84	662,43	7905,60
Maintenance	2,01E-03	2,12E-01	3,09E-05	0,06	1,35	0,30	3,99
Total	11,47	1518,99	0,09	517,53	13838,23	662,95	7921,24

(1) Abiotic depletion in Sb equivalents.
(2) Global warming potential in CO_2 equivalents.
(3) Ozone depletion in CFC-11 equivalents.
(4) Smog creation in C_2H_4 equivalents.
(5) Acidification in SO_2 equivalents.
(6) Eutrophication in PO_4 equivalents.
(7) Primary energy consumption in GJ equivalents.

Table 6 Results obtained in the quantification of the functional parameters

Refurnishing Scenario	$D_{n,w}$ (dB)	U ($W/m^2.ºC$)
Scenario 1	29	1,40
Scenario 2	30	0,60
Scenario 3	29	0,60

Table 7 Life-cycle costs of each refurbishing scenario

Cost	Scenario 1	Scenario 2	Scenario 3
Construction	9300€	15075€	10350€
Operation	362372€	248367€	248367€
Maintenance	4500€	0€	4500€
Total life-cycle cost (LCC)	376173€	263442€	263217€

Table 8 Results from MARS-SC

Refurbishing Scenarios	Performance			
	Environmental I_{Env}	Societal I_{Soc}	Economical I_{Eco}	Sustainable Score (SS)
Scenario 1	0,00	0,00	0,00	0,00
Scenario 2	1,00	1,00	1,00	1,00
Scenario 3	1,00	0,50	1,00	0,75

The results also show that it is very important to consider in this kind of assessment all life-cycle stages of a building instead of considering only the initial stage (construction). The initial costs and the embodied environmental impacts are normally insignificant when compared to the same parameters in the operation phase. Therefore a solution with higher capital costs and embodied environmental impacts could be justified if it has higher performance during the operation phase that results on savings.

4. Conclusions

Sustainable building design, construction, operation and refurbishment are based in the assessment of the environmental pressure, societal performance (related to the construction standards, regulations and psycho-social characteristics of building's users, among others) and life-cycle costs. Sustainable construction seeks a better compatibility between natural and artificial environments, nevertheless without forgetting the functional quality of a building and the cost-effectiveness of a project.

The rehabilitation of the building stock is a very important aspect in order to increase the sustainability of the construction market: refurbishment increases the durability of the construction elements, which allows the amortization of the initial environmental impacts in an extended life span and, on the other hand, it allows to update the buildings' functional performance, with all societal and cultural advantages, along with the exploitation of the existing structures, with all related economical advantages.

Despite of several studies about sustainable construction indicators, up till now there is not an accepted methodology that could assist the project team in the sustainable refurbishment projects. In this paper it was presented a methodology to assess the sustainability of the building refurbishment projects. There are still some important limitations to overcome, like for instance the development of a more consensual list of parameters and weights. Although at this step, the methodology could give an important input to project teams in order to turn the refurbishment operations much more compatible to the sustainable development aims and allow that the future generations could have at least the some conditions as the actual ones.

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Building deconstruction in Portugal: a case study

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ABSTRACT: This paper presents the transfer and adaptation of the former Lisbon EXPO 98 Macao Pavilion from its original location to a town park in Loures as a case study in building deconstruction. An essential aspect for promoting Building Deconstruction is the demonstration of its multiple advantages, mainly to those directly involved in the designing and building processes, proving the compatibility of deconstruction friendly principles with architectural expression, functional efficiency and economical profitability. A description of the disassembly and reassembly operations of the former Macao Pavilion is made, identifying the main difficulties found. An analysis of the overall profitability of the operation is also made, estimating the amount of material diverted from landfill and the amount of embodied energy saved through material reuse. An economical profitability study compares the costs of disassembling and reassembling the pavilion with those of a new building.

1 INTRODUCTION

Portugal is currently facing serious challenges to its production and consumption habits. The country is very dependent on imports for its energy needs, with 87,2 % of the national yearly consumption deriving from external sources (DGEG – Geology and Energy General Directorate, in Portuguese, 2005), and energy efficiency is 25% above European Union's average with 240 kgoe/1000 Euros in 2004 (EUROSTAT, 2004).

The building construction industry, one of the largest employers in the country, is also considered a major responsible for several negative environmental impacts: energy consumption, associated emissions and waste production. Although the exact amount of construction and demolition waste (CDW) produced each year is not known, estimates point to a value of 4,4 Million tons (Farinha, 2007), the vast majority of which is land filled or illegally dumped. This value of CDW production may be attributed to lack of awareness, lack of other processing options and prevalence of construction habits that do not allow material separation or reuse. In this context, it is urgent to adapt design and construction paradigms to achieve greater resource use efficiency, reducing the amount of embodied and operational energy and also increasing the diversion of CDW from landfills.

Building Deconstruction emphasizes promotion of "reuse" of building materials and components (and even whole buildings) as a way to "close the loop" of materials, and avoid the loss of matter and energy through construction and demolition waste. Whole building reuse is an example of Deconstruction, by disassembling a building and transferring part or the whole of its components to a new site for reassembly. Such operations are quite rare in Portugal and the opportunity to follow and fully document the transfer of the former Lisbon EXPO 98 Macao Pavilion was considered a good subject for a case study in Deconstruction, as it would allow evaluating its environmental and economical profitability.

2 BACKGROUND

The Lisbon Expo 98 Macao Pavilion was designed by RISCO architectural design office in 1997 and was built in the northern central part of the EXPO 98 exhibition grounds, alongside the main pedestrian avenue, on a rectangular eastern facing sloping plot surrounded on three sides by streets while the north side opened to a another building plot (Figure 1).

Figure 1: The former EXPO 98 Macao Pavilion (Southeast view) in its original location in May 2005.

The Pavilion was a two-story building, with an doubly symmetric 55 x 30 meters rectangular shaped plan, comprising two "blocks" with two floors each. The eastern block housed exhibition spaces and was open at the street level, while the western block also housed exhibition spaces and administration / reception areas in the enclosed lower floor. Both upper levels were linked by two partially enclosed elevated walkways, which defined a patio between both blocks. The whole building had a structure of bolted metallic elements ranging in cross-section from HEA 600 to IPE 200, with enclosing walls made of 22 mm thick wood-cement viroc panels supported by metallic frames bolted to the main structure, except for the lower western block which had a brick encased metallic structure and brick partitioning walls. The floor of the upper level was made of 3 cm thick Medium Density Fiberboards and solid pinewood boards, while the roof was integrally made of corrugated metal panels, with metal rain gutters and eaves. Interior finishes (ceiling and walls) were gypsum board drywalls, including 60 mm rock wool insulation. The upper volumes had no windows, the only glass being present on the doors and panels that enclosed the street side of the elevated walkways. Windows and doors on the lower volume were double-glazed and aluminum framed. After the exhibition's end in October 1998, the pavilion was vacated and closed. In late 2004 it was bought by the Loures municipality to be reassembled in the new town park of Loures and used as a teahouse / art gallery.

3 DISASSEMBLY

Disassembly started in May 2005, taking place in three main stages over a period of approximately 14 weeks up to mid-August 2005. During the first stage, interior finishing materials were stripped, sorted by type and piled on the elevated walkways since the patio was unavailable as a sorting and stocking point. Building systems were also disassembled at this time. Doors, hardware, fixtures, cabling and piping were removed for reuse or recycling. Metals (soft steel, copper wiring) were sold to scrap metal dealers; wooden materials were removed to be used as fuel; other materials (rock wool, gypsum) were land filled.

The second stage of the disassembly took about four weeks and consisted on the dismantling of the building's external envelope, made possible since the removal of the interior finishes had exposed all of the internal connecting points for the external façade support frames as well as the roof panel's fixings. At this point, unfamiliarity with disassembly operations led to time losses as some elements were "over disassembled" rather than kept as whole components, while there was no properly established identification system for the parts.

The third stage of the process consisted on the disassembly of the steel structure. All of the elements of the steel structure were bolted, which allowed and facilitated disassembly, and were of a manageable size, which allowed manipulation and transport with commonly available means. The external access ramp, composed of two 24 meter long trusses, had to be cut in two for transport, while the main pillars bolting plates were found to be encased in concrete, and had to be cut making. A final step of the disassembly process consisted on the demolition of all reinforced concrete (foundations, ground slab and retaining wall) and brickwork walls.

In conclusion, the configuration and constructive solutions, such as assembly sequence, geometry of product edges and connection methods (Durmisevic, 2003) allowed for a systematic separation of building materials. A more thorough audit prior to disassembly would have identified materials, components and sub-assemblies worthy of disassembly and transport, an action that might have increased the profitability of the operation, as the value of harvested materials is usually inversely proportional to the number of disassembly steps necessary to acquire them (Durmisevic, 2006). A more effective labeling system for identifying components and their connections would also have benefited the whole operation, as it was later estimated that a more effective labeling of parts would have reduced reassembly time as much as 25%.

4 REASSEMBLY

The contract for reassembling the metal structure and build a new exterior enclosure was won by the Somague company, with reassembly started in the spring of 2006 and still ongoing in May 2007 (Figure 2). The reassembly was slowed down by a variety of factors namely because the materials transported had been piled up exactly on the building's future location alongside a general lack of information on the building design (original plans were not found on the architect's archives) and deficient or inexistent labeling of parts .

During rebuilding it was discovered that a few medium sized elements from the main structure were missing, and it was necessary to produce similar ones. New structural elements also had to be produced to replace those that had been encased in brickwork, while the original (and shortened) main pillars received new bolting plates.Other changes to the original project included the introduction of an intermediate steel deck.

Other than the structural steel elements, little was reused from the originally transported parts, either because materials had already been reused ("viroc" wood-cement panels were applied in the back facade of the St. Paul church scale reproduction), because they were unnecessary (façade substructures were not needed, as infill walls were now to be made of ceramic brickwork) or because they were unusable (asphalt contaminated roof panels).

Figure 2: General view of the pavilion being rebuilt in Loures as of April 2007.

5 ENVIRONMENTAL PROFITABILITY

Although it is fairly obvious that an operation of disassemble / reassemble should be environmentally preferable to a straightforward demolition, it is essential to determine exactly the benefits of such operations in order to promote design for disassembly and material reuse. There is no voluntary building environmental rating scheme in use in Portugal (such as BREEAM, LEED or Green Building Tool), and therefore there is no immediate methodological framework to evaluate the benefits associated with reuse of building components or materials.

Guy (2003) has proposed a Green Demolition Certification Draft, consisting of a credit system, rating actions at Building, Planning and Environmental Health and Safety levels of the demolition process. The system proposes the attribution of a green certificate on attaining 25 of the 52 possible credits, while setting minimum pre-requisites such as a mandatory 20% material diversion from landfill independently of building size. The literal application of this certification draft was deemed inadequate in this particular case, nevertheless the environmental profitability of this operation was evaluated on two of the most "valuable" rating aspects of the rating scheme: diversion of materials from landfill and embodied energy saved.

5.1 *Materials diverted from landfill*

The original complete bill of materials of the pavilion having been lost, a new bill of materials was calculated from EXPO archive project drawings and partial RISCO files. This allowed an estimation of the quantities of materials present in terms of weight, with composite elements (window units, facade panels) being broken into their main materials. Smaller components (bolts, door handles, etc.) were ignored for these calculations. Materials associated with building systems such as HVAC, rainwater drainage, water supply and residual waters were not considered given their low relative weight or impossibility to decompose into basic materials (as in the case of air treatment units).

In calculating the mass and weight of the materials, several references were used (Farinha, 1997), as well as catalogues and technical information reference material. Weights of structural elements (steel and concrete) were taken from the original structural bill of materials. The pavilion weighted a total of 1.820 tons, with 75% of that value being reinforced concrete present in foundations, ground slab and retaining walls (Figure 3).

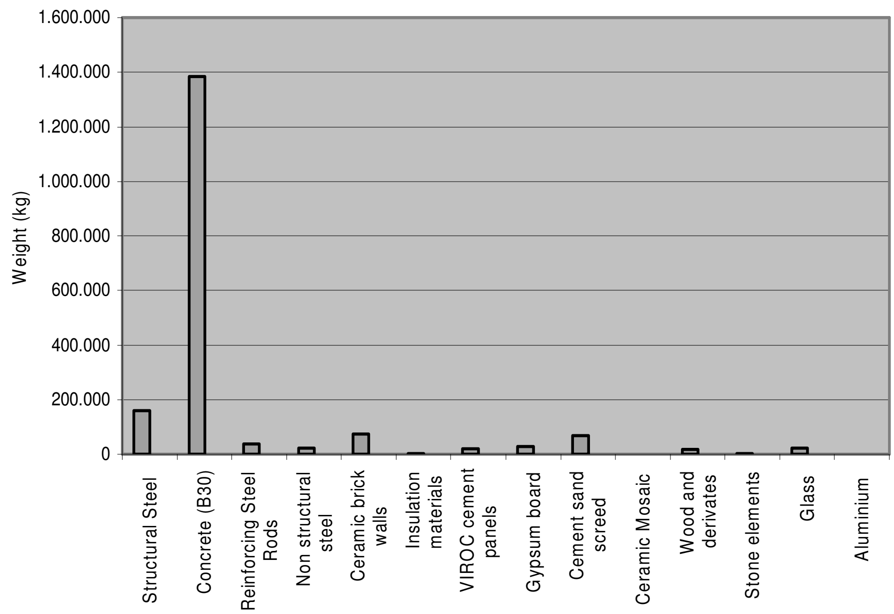

Figure 3: Volume of material per type.

Allocating the different materials per waste processing option (Figure 4), it becomes apparent that only 10% of the materials were reused (the steel structure and viroc panels), while a total of 14% were diverted from landfill (through a mix of reuse, recycling and energy recovery). While these percentages would not meet the minimum requirements of the Green Demolition Certification draft mentioned, it should be noted that almost all of the main constituting materials were adequately separated and thus the lack of a higher diversion rate from landfill could be attributed to lack of processing options and not to project or process characteristics.

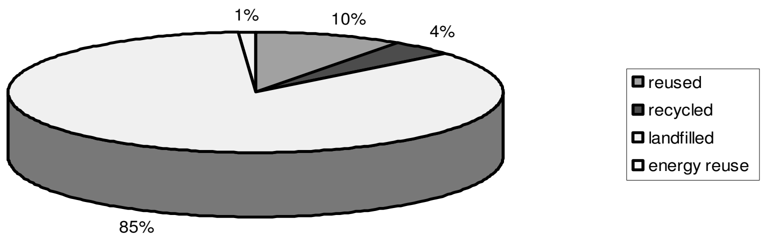

Figure 4: Volume of material per waste processing option.

5.2 *Embodied energy savings*

Another complementary assessment of environmental profitability of the transfer / rebuild operation is to quantify the amount of embodied energy saved. Treloar (1998) defines embodied energy as "the quantity of energy required by all the activities associated with a production process, including the relative proportions consumed in all activities upstream to the acquisition of natural resources and the share of energy used in making equipment and other supporting functions, i.e. direct plus indirect energy".

In the context of this study, embodied energy was understood as "process embodied energy" and not "gross embodied energy", thus excluding energy used to transport the materials and workers to the building site, upstream energy input in making the materials (such as factory / office lighting, energy used in making and maintaining the machines that make the materials, etc.) or embodied energy of urban infrastructure (roads, drains, water and energy supply). Process embodied energy values for construction materials can vary greatly since there are many different combinations of possible input / output paths to attain a certain embodied energy value per unit of material. Studies (CSIRO, 2003) have identified the following variables affecting embodied energy calculations: efficiency of manufacturing process; fuels in manufacture of materials; distances of transport and amount of recycled product used.

Embodied energy values are considered useful as an additional decision factor when comparing different building materials for a specific design problem, ideally complemented by environmental impact reference materials, since a low embodied energy material may be less favorable than another with higher energy content for a variety of reasons (lower technical service life, reciclability, etc.). Nevertheless, given the demonstrational character of this study, it was considered useful to demonstrate potential energy savings in this building transfer operation by calculating the amount of embodied energy preserved in reused building materials.

The previously calculated material volumes were converted into MegaJoules using several reference tables for embodied energy values per unit of mass. Since there are no specific embodied energy tables for construction materials in Portugal, the closest comparable source was used, namely the tables of the Spanish Instituto para la Diversificación y Ahorro de la Energía (IDAE), as cited by Gonzalez (2006). These reference values were considered to be very reliable as Spain and Portugal have similar geographic conditions, construction habits and construction material usage. In the only instance where a value for a material used in the Macao

Pavilion was not available in these tables, data from the New Zealand Institute of Architects "Comparison of building elements - Life cycle analysis" database (1995) was used. In calculating the embodied energy of steel elements a value of 14,25 MJ/kg was used, as a mean average between the values of 35 MJ/kg for virgin material and 10 MJ/kg for recycled source material considering that 83% of current steel is recycled or of recycled content (Steel Construction Institute, 2002). The original pavilion materials thus corresponded to a total of approximately 5.630.000 MJ of embodied energy, distributed according to Table 1.

Table 1: Embodied energy present in the original building, including waste processing options (RU - reused; RE - Recycled; LF - Land filled; ER - Energy recovery)

	Weight (kg)	MJ/kg	Energy (MJ)	Option
Structural elements				
Steel structural elements	159.900	14,25	2.278.575	RU
Reinforcing steel rods	38.360	10,00	383.600	RE
Concrete (B30)	1.383.120	1,20	1.659.744	LF
Exterior walls				
Perforated ceramic brick wall, 30 x 20 x 20 cm, with cement / sand mortar render	5.384	2,50	13.460	LF
Perforated ceramic brick cavity wall, 30 x 20 x 15 + 30 x 20 x 11, with cement / sand mortar render	35.148	2,50	87.871	LF
Cavity wall insulation rigid PU board (30 mm)	71	72,20	5.147	LF
VIROC wood-cement facade panels (22 mm)	18.701	9,50	177.657	RU
50 x 50 x 4 RSH facade panels metal frames	7.075	14,25	100.813	RE
Interior walls				
Perforated ceramic brick wall, 30 x 20 x 11 cm, with cement / sand mortar render	33.587	2,50	83.966	LF
Interior single 12,5 mm plasterboard wall (inc. substructure)	7.612	6,10	46.431	LF
Rock-wool insulation (60 mm thick)	1.305	14,60	19.051	LF
Floor finishings				
Cement sand screed, smooth finish (100 mm)	67.859	1,20	81.430	LF
Ceramic mosaic 10 x 10 cm	170	2,50	425	LF
Pinewood floor baseboard (20 x 70 mm section)	122	2,00	244	ER
Solid pinewood floor (30 mm)	3.936	2,00	7.873	ER
Moist resistant MDF boards (30 mm)	14.388	11,90	171.214	LF
Ceiling finishings				
Interior suspended plasterboard	9.709	6,10	59.223	LF
Exterior moist resistant suspended plasterboard	10.237	6,10	62.444	LF
Rock-wool insulation (60 mm thick)	2.459	14,60	35.905	LF
Stonework				
Door sills (average thickness 4 cm)	1.801	6,00	10.805	LF
Doors and windows				
Glass	4.720	15,90	75.041	RE
Aluminum frames	280	191,00	53.461	RE
Steel frames and doors	4.261	14,25	60.715	RE
Various steelwork				
Exterior hand-railings	1.235	14,25	17.592	RE
Roof panels, corrugated sheet metal "Alaço" type	7.809	14,25	111.271	LF
HVAC protection perforated panels, inc. substructure	1.230	14,25	17.524	RE
1 mm zinced water-drains and eaves profiles	251	14,25	3.583	RE
TOTAL	1.821.482		5.630.036	

According to the various disposal options for the different materials present in the Pavilion, it can be observed that 43% of the total EE value, corresponding to 2.450.000 MJ, was preserved due to the steel structure being reused. Considering the loss of 10-15% of the original steel components of the building, nevertheless approximately 2.200.000 MJ of embodied energy may have been saved. The production of this energy from fossil fuel would correspond to approximately 52,5 tons of oil equivalent (1 toe = 42 GigaJoules), whose combustion would release (on average) approximately 45.000 kg CO_2 to the atmosphere. The amount of energy saved corresponds to 680.000 KW/h, which would cost 75.000 Euros (at current national rates).

A comparison made using values from Portugal's General Directorate for Energy "Energy Consumption Management Regulation" (1995), which stipulate maximum tons of oil equivalent to be spent in the production of certain construction materials, yielded steel embodied energy values almost 20% higher than those obtained through the Spanish IDAE values.

As mentioned earlier the embodied energy values considered do not account for energy from transport, and so the added energy from the trips necessary to transport the pavilion steel components was not considered. However, it is important to refer that if this transport energy were accounted for, the option to reuse would be even more favorable than new building since there is no source of steel elements closer to Loures than the Expo site (the sites are just 18 km apart). CO_2 emissions and embodied energy due to transport corresponded respectively to 550 kg CO_2 and 56 MJ, from the 200 l of diesel estimated to have been used in the 20 two-way journeys to transport the structure (consumption and distance obtained in www.mappy2.com).

In conclusion, although only a low percentage of the total material volume of the existing building was reused, it did correspond to over 40% of the total estimated embodied energy present, which constituted a considerable environmental and financial saving.

6 ECONOMICAL PROFITABILITY

Parallel to the environmental benefits estimation, an equally important assessment (some would argue, the most important one) is that of the economical profitability of this operation. The Loures municipality paid a total of € 260.000 (excluding taxes) for disassembly, reassembly and construction of a new enclosure. The pavilion itself was donated, an obvious choice for the owner as the property becomes available for redevelopment at zero cost.

An economical profitability study must compare the values paid for actually (re)used elements to the value of supplying and assembling new comparable products. As seen before, material reuse was limited practically to steel structure elements, of which the original pavilion possessed 160.000 kg. Considering a 10% replacement rate for lost parts and 24.000 kg to replace the elements that were originally encased in brickwork (estimated from the original bill of materials) a total of 200.000 kg present in the new pavilion is obtained.

Considering that the value of the new foundations, enclosure walls and roof (which should be discounted) is equal to the price paid for the road transport of the elements (which should be added), an average value of 1,30 Euro paid per kg of steel is obtained.

If a fully similar building were to be built anew, the budget of supplying and assembling 160.000 kg of steel structure (the original amount needed) would be € 528.000 using 2006 average tender prices of € 3, 30 per kg of steel. If the original 198.000 kg of steel (160,000 kg from the structure plus 38.000 kg of reinforced concrete bars) had been sold for recycling, it is reasonable that a price of 0.5 Euro/kg would have been paid, resulting in a net total of 429.000 Euro to be paid for a new pavilion.

Considering both the least and most advantageous relationships between the aforementioned values, the disassemble / reassemble option is always more profitable (for the owner), with prices 65 to 100% lower than the price of an all new structure. It is interesting to consider that if a reinforced concrete structure had been used in a new similar building, the estimated cost (from average prices per sqm of construction) would have been approximately 295,000 Euro, a value still higher than the 260.000 Euro paid by the municipality.

7 CONCLUSION

Although the disassembly and reassembly of the former Lisbon Expo 98 Macao Pavilion was affected and slowed down due to the novelty of the process, the balance was nevertheless positive on both economical and environmental aspects. A low 14% diversion rate from landfill was achieved, but the materials reused amounted to almost 40% of the total embodied energy present. Economically the operation was profitable on all levels, and a more efficient planning on disassembly would have raised the profitability of the operation even further.

Studies (Boyle, 2005) have shown that transport and degree of waste processing infrastructures are the main conditioning factors to salvaged material reuse overall profitability. In the Macao Pavilion case, the very short distance between disassembly and reassembly sites reduced the negative impacts of transport, but the lack of appropriate disposal options greatly hindered the degree of diversion from landfill. This was made more evident since the original design was very favorable to deconstruction, permitting an effective reversal of the building sequence and allowing a high degree of material separation.

This operation was greatly facilitated by the fact that it was promoted by a public body which eased bureaucratic procedures, as no project and building permits were required, while the "whole rebuilding" option allowed bypassing structural calculations and verifications. A mention must also be made to the overall architectural strategy as it allowed functional adaptation with little effort, benefiting from the typology of the building (an isolated building).

This study shows that in more urbanized areas of Portugal, where building habits are more developed, more sophisticated building techniques are available and transport networks are more dense, it may prove profitable on all dimensions to design all steel structure buildings that allow disassembly and transfer, thus obtaining a higher construction material usage efficiency, and ultimately a more sustainable construction.

In order to achieve this ultimate objective, further efforts are necessary in many areas, including raising awareness of stakeholders, laying down appropriate legal framework, creating adequate processing infrastructures and raising the consciousness of designers and builders.

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APPLICATION OF GROUND-AIR HEAT EXCHANGER TO REDUCE COOLING ENERGY DEMAND OF LOW-RISE OFFICE BUILDING IN SOUTHEAST OF UK

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Keywords: Ground-air heat exchanger, TRNSYS simulation, soil temperature, LZC technology, Earthtube

SUMMARY

The use of ground-air heat exchangers (GAHX) in a ventilation system is gaining recognition as a low or zero carbon ventilation strategy. However, there is very limited research and published data on the thermal performance of GAHX under UK climate. This research project currently undertaken at the University of Brighton aims to fill this gap in knowledge. The research evaluates the thermal performance of the GAHX - so called Earth tube - under different configurations, climatic and operating conditions in the UK. Thermal simulations have been carried out, using validated thermal models developed by others and the ground temperature and climatic variables established from this research, to predict the daily air supply conditions from GAHX and to evaluate the annual energy gain/saving potential. A low rise office building located in Brighton, Southeast of UK, is used as a case study to demonstrate the potential and effectiveness of the GAHX. The issues related to the application of GAHX and the further research are discussed.

1.0 INTRODUCTION

The Ground-Air Heat Exchanger (GAHX) is a subterranean cooling system that consists of a network of pipes buried below the ground surface, through which ventilation air supply is circulated. Difference in temperature between the pipe surface and the air drives the pre-cooling/pre-heating of the ventilation air. The magnitude of the heat exchange between air and pipe surface is dependent on factors such as, soil temperature, air temperature and pipe dimensions, air flow rate, pipe burial depth, soil and pipe thermal properties (density, heat capacity and thermal conductivity) (Pfafferott, 2003). There is significant evidence of summer temperature rise in the UK, with the average temperatures expected to rise by 4-6ºC over the next 50-80 years, creating risk of building overheating (CIBSE, 2005). There is also evidence of the rise in the use of mechanical cooling in buildings with about 20% of total floor area in UK offices now air-conditioned (CarbonTrust, 2007). The concept of cooling using GAHX is well established, but the behaviour of such systems depends on climatic and soil conditions (Piechowski, 1999). The dynamic thermal performance of GAHX is therefore not universal and needs to be studied within the context of climatic, soil and building load conditions. Potential of the system for improving comfort conditions in buildings and sensible energy reduction/gain by ventilation air has been established for the climate of Southeast UK.

2.0 METHODOLOGY IN THE RESEARCH

The thermal simulation study has been carried out using the Transient System Simulation Programme (TRNSYS) which is a modular simulation environment for the study of dynamic energy systems. (TRNSYS16.0, 2005). The open modular structure within TRNSYS allows for the use of inter-connection of existing components and user written components to develop thermal simulation projects. The simulation study of the GAHX has been based on a numerical model developed by Hollmuller and Lachal (2001). TRNSED applications have been developed and used to run parametric studies for different configurations of GAHX. TRNSED application in TRNSYS is used for the development of standalone windows based applications that can be used to carry out parametric study of energy systems. Building description files have been generated for a typical low rise office building in Southeast UK using the TRNSYS building interface TRNBLD. The building description file has been coupled with the GAHX model to study the impact of GAHX on building indoor operative temperatures. Climatic and soil variables have been established for Southeast UK by collecting and analysing soil temperature records held by the UK Meteorological Agency (UKMO) and validating soil temperature prediction model. Figure 1 shows a description of the thermal simulation process and the input and output parameters.

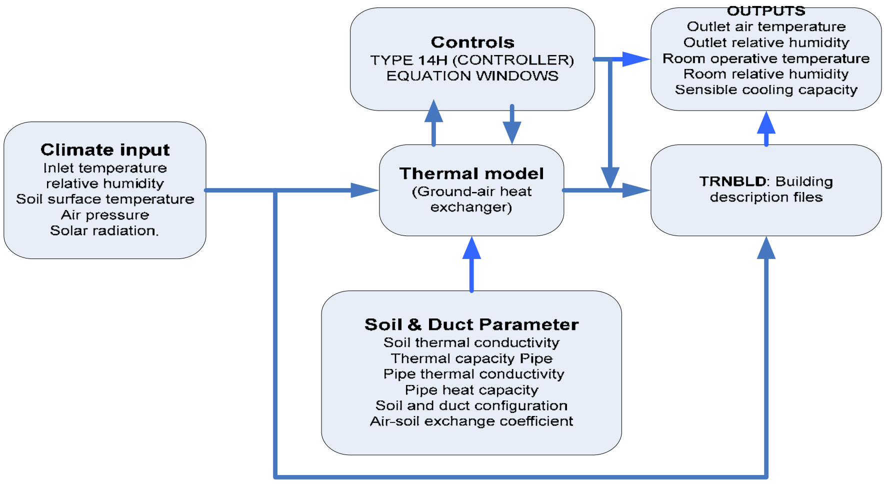

Figure 1 Thermal simulations and input parameters

3.0 THERMAL MODELLING

There are a number of attempts by researchers to develop thermal models for predicting the outlet air condition from GAHX. These models have been developed with different levels of accuracy, complexity and assumptions. A rigorous review of existing thermal models and their underlying assumptions have been carried out to establish current state of the art and to find a base model for this research. The models are grouped into:

1. Steady state models (Sodha et al., 1985, Bojic et al., 1997): solves the problem as a one-dimensional heat transfer problem, solving only the convective heat transfer between the tube and air. These models assume constant soil temperature around the GAHX. This is not an appropriate solution for a transient system in which heat loss/gain from air to the ground gradually raises/lowers the soil temperature around pipe.

2. Single pipe transient models (Mihalakakou et al., 1994a, Kumar et al., 2003, Al-Ajmi et al., 2006): solves convective heat transfer from tube to air and the heat diffusion from external tube surface to the surrounding soil. In this category there are those models that solve both heat transfers in soil and heat exchange between air/soil, the models therefore assume negligible mass transfer as a result of temperature gradient in the soil. More detailed models however, solve heat and mass transfer as well as sensible and latent heat exchange between soil and air. These models are limited to modelling single pipe configurations.

3. Multiple pipe transient models (DePaepe, 2002, Gauthier et al., 1997): these are numerical and analytical models that solve both sensible and latent heat exchange between tube and air and three-dimensional heat and mass transfer in soil and also allow for the dimensioning of multiple pipe problems. Mihalakakou et al. (1994b) used principle of superposition of the solution of a single pipe to account for thermal interference of neighbouring pipes. These models even though they account for the thermal solution to the multiple pipe configuration of GAHX, the solutions assume homogenous soil conditions and uniform surface condition, which limits their application to simple geometries.

4. Detailed numerical solutions developed by Hollmuller and Lachal (2001) has been found to be the most comprehensive solution for the thermal analysis of GAHX. The model solves both sensible and latent heat exchange between air and soil and the fully three-dimensional heat transfer in soil. It also allows for dimensioning multiple layers of pipes with non-homogenous soil profile, multiple soil surfaces and variation in air flow rate and directions. The model has been validated against analytical solution and long term monitored data from real scale installation by Holmuller and Lachal (2005). This model has been adopted for the purpose of this study.

4.0 SOIL TEMPERATURE IN THE UK

Soil temperature is the main parameter that determines the potential of GAHX. In order to study the behaviour of this system there is a need for understanding temperature changes with time and soil conditions. Soil temperature records for 10 locations in Southeast England have been collected and analysed to understand the potential of ground cooling or heating systems and the variation of soil temperature with locations within the region. Soil temperature records have been kept for most metrological stations across the country by UK Metrological Office (UKMO). The data held by the UKMO range from 10cm-100cm depth. Data indicated there is a variation of less than 1ºK between the nine locations studied within the Southeast region of United Kingdom.

4.1 SOIL TEMPERATURE PREDICTION

Soil temperature records held by UKMO is available for 10cm-100cm depths, however, there is less variation in soil temperature with increasing depth below ground surface. Because of the lack of records below 1m depth, soil temperature prediction models have been utilised to simulate soil temperature below 1m depth. Soil temperature prediction models have been developed as Fourier series based on the solution of one-dimensional heat transfer in semi-infinite solid medium with surface temperature as a harmonic function of time (Carslaw and Jaeger, 1959). The validated mathematical model developed by Labs (1989) shown in equation 1, has been used to predict the soil temperature profile for Brighton. The model uses information on soil thermal properties and surface temperature derived from soil properties and air temperature records.

$$T_{z,t} = T_m - A_s \times \exp\left[-z\left(\frac{\Pi}{8760\alpha}\right)^{1/2}\right] Cos\left\{\frac{2\Pi}{8760}\left[t - t_o - \frac{z}{2}\left(\frac{8760}{\Pi\alpha}\right)^{1/2}\right]\right\} \qquad (1)$$

T_{zt} = Soil temperature at time t and depth z (ºC).

A_s = Mean annual ground surface temperature (ºC).

α = Thermal diffusivity of soils (m^2/hr)

Z = Depth below ground surface (m)

t = Time elapsed from the beginning of the year (hours)

t_o = Phase constant (day of year coinciding with minimum surface temperature (hours).

T_m= Mean annual soil surface temperature.

Π = PI (3.1416)

Table 1 Parameters used to predict soil temperature for Brighton

Parameters	**Values**
Mean annual surface temperature (T_{mean})	12 ºC
Surface temperature amplitude (T_{amp})	11 ºC
Depth	1m
Time Shift (T_{shift})	15 days
Soil type	Chalk
Specific heat capacity	900 J/(kg.K)
Density	2290 kg/m³
Thermal conductivity	0.83 W/mK

The parameters in table 1 have been derived from 10 years air temperature records for Brighton. Ten years monthly average air temperature has been used to determine the mean annual soil surface temperature (T_m), and annual surface temperature amplitude (A_s) which is the difference between maximum and minimum surface temperature. Soil type and thermal properties have been determined from the records of British Geological Survey borehole records (Survey, 2006).

The simulation results have been validated with ten years records of soil temperature, as shown in figure 2, which shows variation of less than 1°K between simulation and measured records of soil temperature. Figure 3, shows soil temperature for 1-10m depths, the amplitude of soil temperature is damped significantly with depth. At about 10m depth the variation is almost completely damped showing almost constant temperature throughout the year. The cost of excavation may however limit depth of the GAHX, especially is areas with hard/rocky soils.

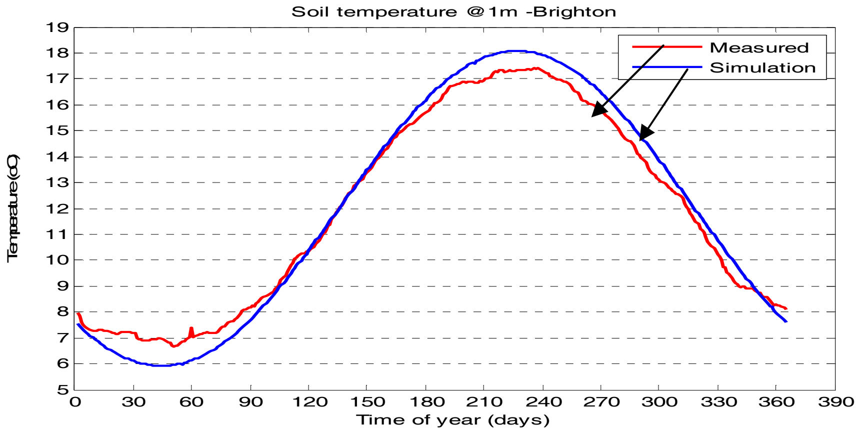

Figure 2 Comparison of simulated and measured soil temperature (1m - Brighton)

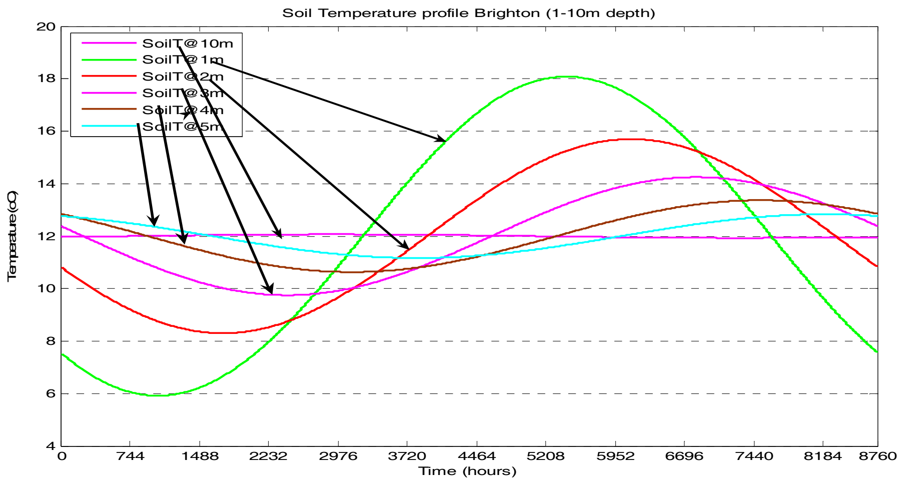

Figure 3 Soil temperature profile for Brighton, Southeast England (1-10 m depth)

5.0 SIMULATION STUDIES OF GAHX

The thermal performance of GAHX is affected by the pipe configurations and air velocity, burial depth and inlet air condition. Thermal simulations have been run using the TRNSED application developed in this research for various combinations of input parameters and pipe configurations. The outlet air temperature and sensible energy gain have been determined and presented for some pipe configurations and air velocities. Ambient air conditions for Gatwick airport have been generated and used as input to the simulations. Hourly simulation for a year has been carried out and the results presented in the following section.

6.0 Discussion of results

6.1 OUTLET AIR TEMPERATURE

The air passed through GAHX has been found lost/gained heat from the soil. The soil temperature is lower than ambient air temperature in summer and higher than ambient temperature in winter. Figure 4 shows the plot of ambient and pipe outlet air temperatures. Ambient air temperature has been damped from 29ºC to just over 20ºC during peak summer conditions. Similar benefit have been achieved in the winter, ambient air temperature of about -4ºC has been raised to around 3ºC. The outlet air temperature follows the soil temperature around pipe burial depth, there is less variation of soil temperature with increase depth below the surface. Figure 5 shows the cumulative temperature frequency distribution for GAHX buried at a depth of 1-4 m. This compares the outlet air temperature for GAHX at different depths and shows that at 4m depth the maximum outlet air temperature is 20ºC compared to 22.5ºC at 1m depth.

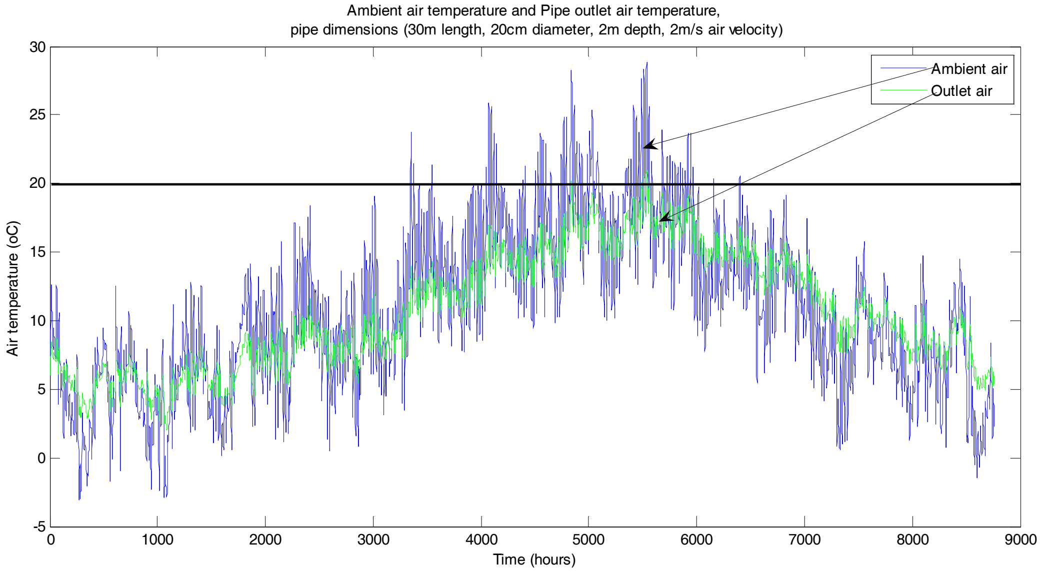

Figure 4 Ambient air and pipe outlet air temperature

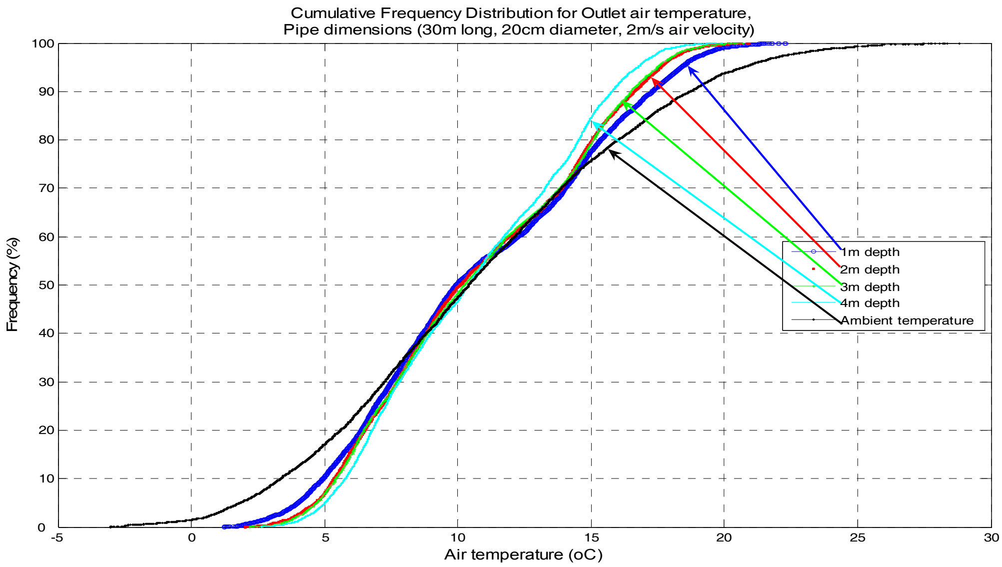

Figure 5 Cumulative frequency distribution of pipe outlet temperature (1-4 m depth)

6.2 SENSIBLE COOLING CAPACITY

Existing work on the sensitivity of pipe configuration on the performance of GAHX system focused more on the outlet air condition; in this work total sensible energy gain by the air has been used as a yardstick for comparison. The energy gain as a result of pre-cooling or pre-heating of ventilation air is a good indicator of the thermal performance of GAHX, this have been studied for different configurations of pipe, air velocity and depth, Figure 6 shows monthly sensible cooling capacity of GAHX of 20cm diameter, 30m long and 2m depth. The results reveal the need for effective control to avoid air cooling during heating season and heating during cooling season. The control will be best achieved by using outside temperature through a by-pass when the outlet air is within acceptable conditions or when the ambient temperature is lower than air temperature in summer. There is clear increase in energy gain with increase in air velocity as a result higher volumetric flow rate; this however comes with a penalty of higher fan dissipation energy.

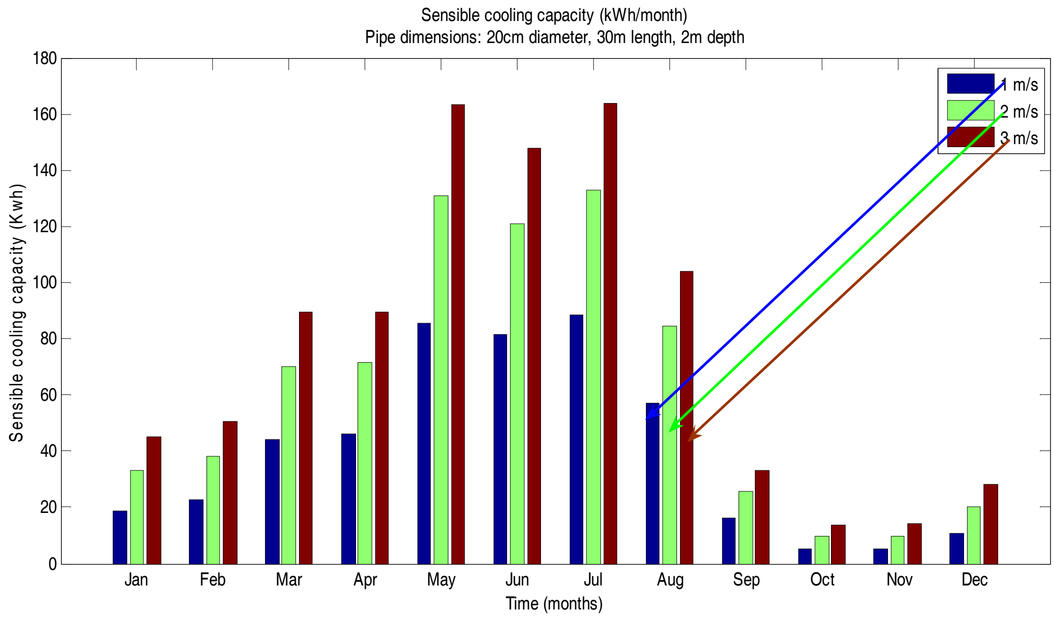

Figure 6 Sensible cooling capacities (kWh/month)

6.3 PIPE CONFIGURATION

Tube length is of significant influence on the outlet air condition and heat exchange with GAHX. Longer pipes provide more heat exchange area in contact with the soil mass. Figure 7 shows the cooling energy for pipe lengths 30-80m. The results shows that at smaller pipe diameter, however there is no significant gain in cooling capacity between 30m-80m pipe length, however as the pipe diameter increases, pipe length becomes a much more sensitive parameter. The pressure drop in the duct also increases with pipe length, therefore some of the cooling capacity may be offset by higher fan dissipation energy. Figure 7 also shows the effect of pipe diameter on the cooling capacity, which increases with increase in diameter. The diameter of pipe is an important parameter when sizing GAHX for both cooling capacity and the pressure drop, with larger diameters having lower pressure drop and hence lower fan dissipation energy. The choice of tube diameter is related to the expected air flow rate, which is dependent on the chosen mode of operation, comfort cooling, room cooling or auxiliary cooling (Zimmermann, 1998). In order to achieve complete amplitude dampening or phase shifting of ambient temperature the GAHX should exploit the more stable temperature of the soil at 2-5 m, in terms of overall cooling capacity. Figure 8 shows that there is no significant difference in cooling capacity by the EAHX from 2-4m deep, this is true because, the change in temperature beyond 1m depth not significant, as shown in figure 3.

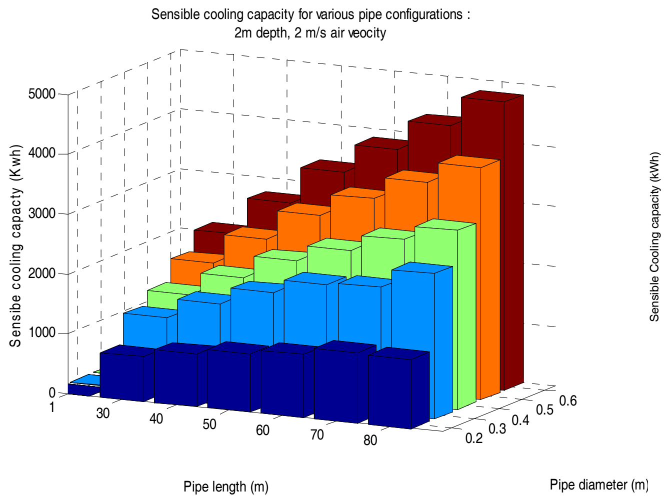

Figure 7 Sensible cooling capacity (kWh/annum)

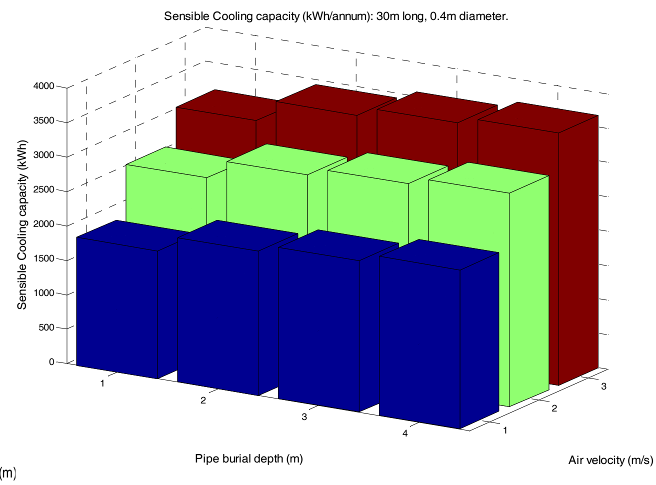

Figure 8 Sensible cooling capacity (kWh/annum) for pipe depth 1-4m

7.0 INDOOR TEMPERATURE AND COOLING LOAD

Building simulations have been carried out to compare the indoor temperatures for a ventilation system utilising ambient air and a similar ventilation system utilising outlet air from GAHX. This comparison is made assuming the building does not have any auxiliary cooling. The office building located in London near Gatwick Airport and occupied from 8am to 6 pm during weekdays has the dimensions of 5m (L) x10m (W) x 3m (H). The simulation period is from May to September. Cooling load for similar buildings has been calculated to maintain indoor temperature range of 19-24°C. Figure 9 shows comparison of indoor operative temperature of these ventilation strategies. It shows clearly that using GAHX have significant benefit in lowering summer indoor temperature. The indoor temperature has been maintained at below 25°C by the GAHX, on the other hand the building indoor temperature is around 27-30°C without the ground cooling.

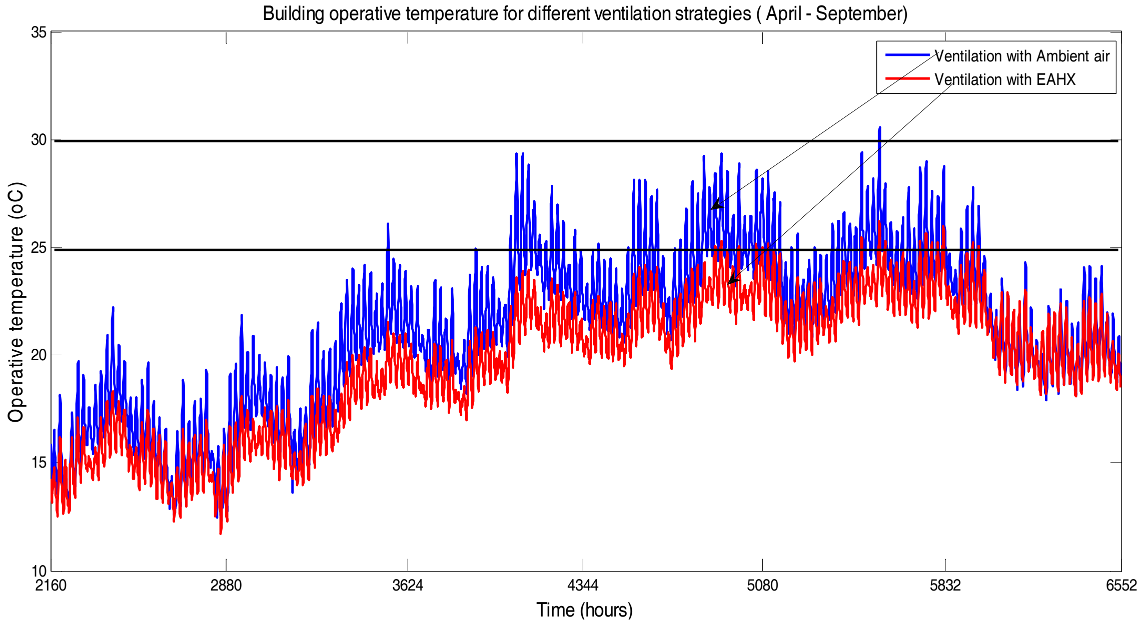

Figure 9 Building indoor operative temperatures with and without GAHX

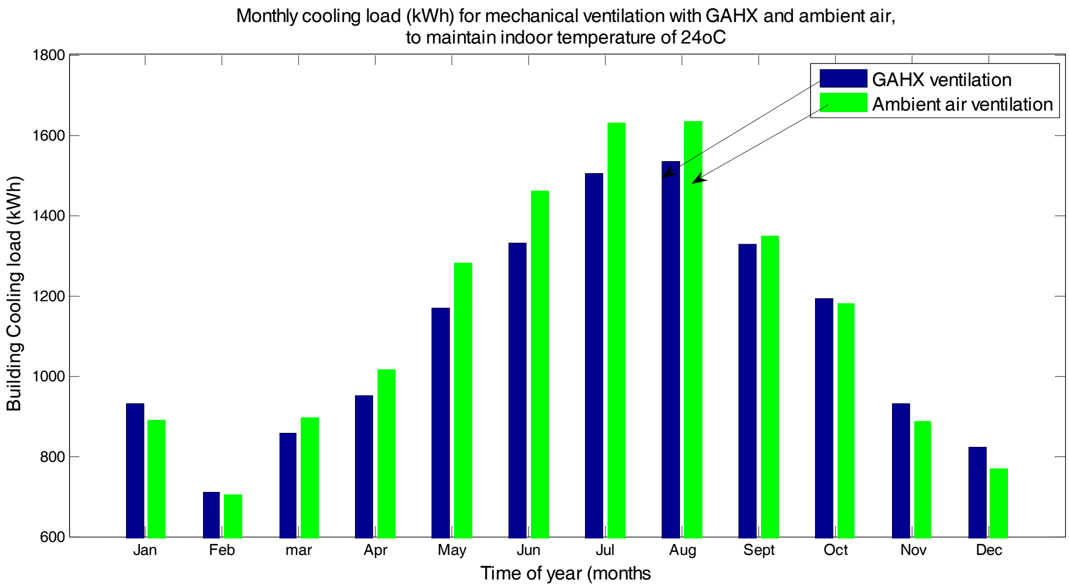

Figure 10 Monthly building cooling loads with and without GAHX

The other strategy is to use GAHX with an auxiliary cooling, where ventilation air supply to the air-handling unit is through the GAHX. Two set of simulations have been run to compare the cooling load of the building for a ventilation system utilising ambient and one with air supplied through the GAHX. Figure 10 shows the comparison of cooling load for the 2 strategies. Overall it reflects a significant reduction in cooling load when the GAHX is used.

8.0 CONCLUSION AND FUTURE WORK

This research investigates the potential of ground-air heat exchanger under the climate of the Southeast of UK. It has identified and demonstrated the impact of the key parameters on the thermal behaviour of the earth tube system. Soil temperature profile and thermal models for predicting the outlet air conditions of the earth-air heat exchanger have been determined and applied in the thermal simulation software TRNSYS. Simulation of the sensible energy gains for various configurations of the GAHX system and the cooling demand of an office building showed significant benefits in improving indoor thermal conditions and reduction of cooling load if air-conditioning is used. The on-going research will study the performance of the system in other locations around the UK and assess the cooling capacities of various system configurations and boundary conditions.

ACKNOWLEDGEMENT

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A NEW PARADIGM FOR SUSTAINABLE RESIDENTIAL BUILDINGS

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Keywords: sustainable building, modular housing, pre-fabrication

Summary

The development of mass-produced environmentally-benign housing is one of the critical factors in the transition to global sustainability. Such housing will need to be constructed from renewable and/or recycled materials, be conditioned using minimal or no conventional energy, and affordable. The need for such housing is urgent. In developing countries, their requirement is to house both growing squatter settlements, as well as those who have benefited from recent economic booms. In industrialised countries, there is a need for an alternative to the current resource- and energy-intensive housing.

Traditionally, mass housing construction can be characterised as skilled-labour intensive, and by on-site construction using non-recyclable materials with minimal prefabrication. This process is costly, can result in variable quality and is time-consuming. These houses are often constructed from a variety of materials including concrete, aluminium, steel and brick, which are energy-intensive to produce, resulting in a structure with high embodied energy content. A new design and building construct introduces Relocatable, Adaptive, Recyclable, and Environmental (R.A.R.E.) architectural concepts as a solution (Luther, Altomonte, Coulson, 2006) .

This paper explores a new paradigm in housing, where dwellings will be pre-fabricated, modular, energy efficient, transportable and use renewable and/or recyclable resources. The paper reviews previous attempts to produce housing, which meets some of the criteria for this new paradigm. Their advantages and disadvantages are discussed. An approach towards a new type of modular prefabricated unit is proposed. A preliminary energy analysis, comparing a present relocatable classroom construction with one upgraded, is provided as an example towards low energy building operation. Finally, conclusions are drawn about the requirements of future housing if we are to progress towards sustainability.

1. Introduction

Globally there is a critical need for an environmentally sustainable mass-produced housing typology, which is both thermally comfortable and affordable. In some developing countries, squatter settlements range from 40-50%. In other developing countries, recent economic growth has fuelled a housing boom. Continued reliance on traditional housing solutions is environmentally unsustainable. Tiwari and Parikh (2000) analysed the impact on resources and carbon emissions of housing in India, if housing was provided to the estimated 15% of their population that currently has inadequate shelter. The present construction trend was found to be unsustainable from both a resource and environmental perspective if conventional materials (concrete, steel, aggregate and bricks) were used.

In Australia, current housing construction practice is unsustainable in terms of materials, energy for production as well as operation. The ecological footprint of the average Australian is approximately four times the level that is globally supportable (Simpson et al., 2000). Housing has become less affordable for the next generation of homebuyers (Age, 2006) and household sizes have been steadily declining for decades (Haberkorn et al., 2004). Scenarios of constrained choice, inappropriate housing options and continued heavy environmental impact are envisaged (AHURI, 2006). This study identified a set of values for policy development. These included: diversity i.e. housing forms that are flexible and accommodate the different needs and uses of society; affordability i.e. provision of dwellings that are appropriate for all incomes; and sustainability i.e. provision of housing that has a minimal impact on the environment. There is thus a convergence of the housing needs in developing and industrialised countries.

Previous mass housing construction in industrialised countries like Australia can be characterised by on-site construction, use of traditional materials and limited design variation. While some pre-fabrication (e.g. trusses) has been adopted by the traditional mass housing market, construction mainly takes place on site by various skilled tradespeople (bricklayers, carpenters, plumbers etc). This process is costly, requires skilled labour, results in variable quality and is time consuming. The houses are constructed almost exclusively from the traditional building materials, namely concrete, aluminium, steel, brick and timber, which are energy-intensive to produce. Australia's completed houses have high embodied energy content (Newton, 2001).

2. Towards a New Paradigm

A new paradigm in housing design, materials, construction, and its services is urgently required for environmental sustainability. A direction towards this architecture is outlined through eight Sustainable Building Categories (S.B.C.'s) presented in a Renewable, Adaptive, Recyclable and Environmental (R.A.R.E.) architecture (Altomonte and Luther, 2006). The purpose is for a project to strive towards success in all eight Sustainable Building Categories, in as much as possible.

- Biodiversity, Sustainable Site & Climate Analysis;
- Flexible & Adaptive Structural Systems;
- Renewable & Environmental Building Materials;
- Modular Building Systems;
- Innovative Building Envelope Systems;
- Renewable & Non-conventional Energy Systems;
- Innovative Heating, Ventilation & Air Conditioning;
- Water Collection & Storage Systems.

Other SBC's are continuously being incorporated into the above list as they become acknowledged, for instance, daylight autonomy and optimised building control. When producing an effective design, the above SBC's set a framework for 'items' to be seriously considered.

2.1 Modular and Prefabricated Design

Sustainable construction is in search of building system that can offer R.A.R.E. building principles. It is believed here that the revisitation of an older paradigm – modular building – holds the answer to future construction. Such processes have tremendous potential over conventional systems regarding material use and waste minimisation. Today, robotic and pre-programmed building processes can offer 'one-offs' and unique diversity in pre-fabricated construction (Bock, 2007). One of the greatest intentions is to introduce modular renewable and sustainable building services into R.A.R.E. building principles.

Modular design is not new. The 1920's to the early 60's were full of inventors and innovations for modular construction and its on-site delivery. The 'Turning Point of Building' (Wachsmann, 1961) was an indication that such constructs would be the predecessor over conventional building processes, as we know them today. Relocatable school buildings represent one of the most popular forms of 'modular' construction today. Yet, the processes by which such buildings are manufactured, is a far cry from applying present technological advancements. There are significant opportunities to advance the entire modular design, its structure, building materials and most importantly services technology.

Figure 1 offers a diagrammatic analogy for the range of construction types and suggested flexibility offered by pre-fabricated building. This diagram is an attempt to organise the vast undefined chaos of modular building systems into some sort of categories. It is however, not intended to cast a specific modular system into a particular category, but rather to acknowledge various methods of construction. Most pre-fabricated buildings will in fact be a combination of several design construction systems.

2.2 Pre-fabrication, Materials and Recyclability

The mixed nature of building materials makes recycling of demolished buildings difficult and usually financially unprofitable. Hence large amounts of building waste are buried as landfill. It is estimated that 30-40% of all Australia's solid waste disposed of at landfill sites comes from the construction and demolition of buildings (Newton, 2001). Mass-market housing developers have accommodated the differences in consumer choice by offering multiple design options e.g. 2, 3 or 4 bedrooms or superficial design variations e.g. facade. While offering some degree of flexibility, this approach is limited. Ultimate flexibility, and therefore choice, can be accommodated only if buildings are constructed in a modular component or kit-of-parts basis.

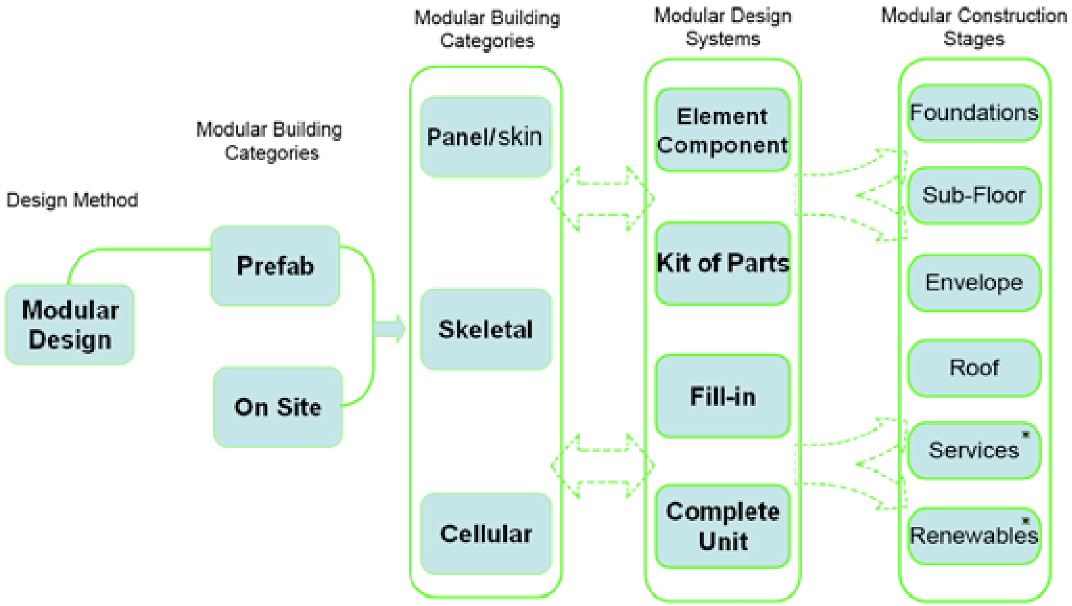

Figure 1: A Categorisation of Modular Pre-fabrication Systems and Construction Methods (Luther et.al., 2007)

Prefabrication of building envelopes has taken off in North America through the use of Super Insulated Panels (SIP's). The developments of such have advanced into the provision of the structural system within the panel itself. SIP buildings apply about 60% less timber than conventional frame construction. Their insulation properties are outstanding and the construction technique has substantially reduced unwanted infiltration in buildings.

One of the criticisms of SIP panels rests with its insulation material, applying polycyanurinate and polyurethane materials that involve oil-based products, potential CFC emissions, and out-gassing. Several of these problems have been resolved and the post baking of the material has almost eliminated out-gassing. Yet, the recyclability of the material is debated. In lieu of this, one manufacture (in the U.S.A.) has produced a SIP with compressed straw and wheat fibres claiming an 80% recyclable produce with high insulation properties. Other home manufacturers, such as SALA homes (QLD) have been applying rice and straw based products (Durra board®) as the insulated wall material.

Another construction material with growing interest is paper. Cardboard structures have been applied to many packaging applications. One of the major drawbacks is their vulnerability to moisture and water damage. Recently, an Australian manufacturer has investigated cardboard door materials that consist of a corrugated 4mm layer to either side of a 25+mm thick paper honeycomb core structure. Both corrugated sides are filed with polyurethane in their flutes, yielding an incredible structural strength, moisture proofing and a higher insulation value. The company manufacturer, Ureflute claims environmental recyclability of the product. Such products as this, hold the key to future building, yet, require extended research input.

There is room for improvement in the search of benign products that provide our palette of construction materials. According to McDonugh and Braungart (2002) our waste should equal food, and the building materials which are 'edible' will not be toxic. We need to also consider our application of materials and avoid mixing of manmade ones with those that are natural, in order to improve the capability of recyclability.

2.3 Relocatable and Adaptive

New design concepts, materials and construction techniques are essential for a new paradigm in housing. This paper explores progressive construction techniques, modularising and pre-fabricating building services and the application of benign (recyclable) materials. It follows a recently developed outline, a roadmap, towards developing a R.A.R.E. (renewable, adaptive, recyclable and environmental) responsive architecture. Several examples of previous research in this area are discussed with the idea of a particular concept – a renewable relocatable – introduced in greater detail. Design and material options, as well as the integration of services (water and energy) into the design. The results of some simulations are then presented. Some conclusions about further research directions for this building typology are finally suggested.

It is realised here that most of our buildings, unlike indigenous architecture, are static and permanent. Alternative structures consider structural systems that are flexible and removable like screw pile foundation systems. Too often our foundation methods resort to high embodied energy slab on grade concrete floors.

There are several raised insulated timber floor construction methods being explored by the University of Tasmaina School of Architecture through their test cell buildings.

In regards to relocatable and adaptive construction, it is believed that modular prefabricated design can deliver such. One of the most critical concerns is the connection points of vertical and horizontal building surfaces where potentially the most leakage can occur. The concept of building in elements that can be assembled and replaced is an important one and has been addressed by many of the pioneers of building, like John Prouve (Figure 2). Here the wall panels can be ‘switched’ or replaced with a selection of alternative making the building ‘adptive’ to various climatic conditions.

Figure 2 The Tropical House by John Prouve

2.4 Services

One of the most neglected areas of present design is the haphazard approach to which building services are integrated into the construction process. The services are one of the most labour intensive and costly items on a building project. It is therefore essential that these systems become integral components of design. In other words, they are a part of a designed system. Our present on-site installation of services, and specialised fabrication of connections is outdated and costly.

An example of such service integration is offered through an organization in Germany called Digitales Bauen, where all the services of a building are planned and divided into their ‘least common denominator’ (see Figure 3). This provides for actual pre-fabrication of entire service modules to be produced off-site and installed with minimal effort and interference of trades on-site. The approach guarantees performance and reduces operational failures and assures ‘interference free’ services.

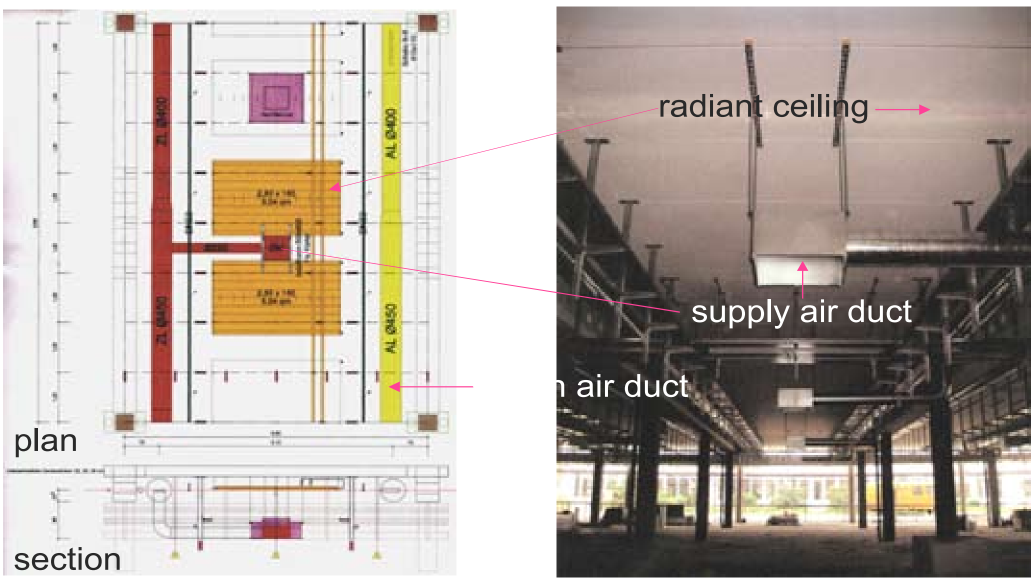

Figure 3 Total Integrated Building Services Planning (Digitales Bauen)

An example of integrating services is provided by a student project of a pre-fabricated modular house design by H. Pallot (Deakin University). This project, although not completely resolved, considered the services as complete 'snap-in' components. In this case the aim was for renewable services to be integrated into the housing design. Figure 4 shows the roof system as an energy (photovoltaic) generator, a hot water heater and a water collector. These systems are considered with an interior wall (service) component and storage into the floor foundation system.

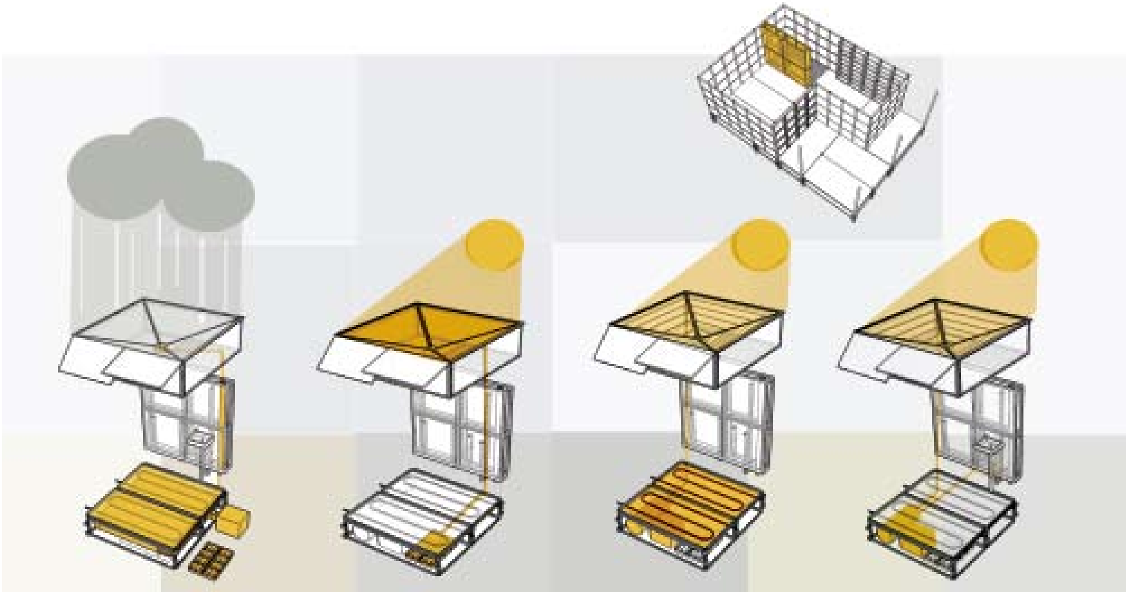

Figure 4 Service Modules Integrated into a Building System (student project: H. Pallot, 2007)

3.0 Energy Consumption and Operational Concepts

The move towards renewable energy systems for our building systems is inevitable. We need to move forward on the concepts of Reduce, Reuse and Renewables. A study on energy and comfort measurements in relocatable school buildings (Fuller and Luther, 2003) prompted further research studies into energy conservation. An energy simulation conducted for a two-classroom relocatable school building, indicated that up to a 50% improvement in the consumption of fossil fuels is reasonably achievable (Figure 5). Once this energy reduction has been realised, two aspects need to be considered: solar thermal processes and renewable energy generating systems.

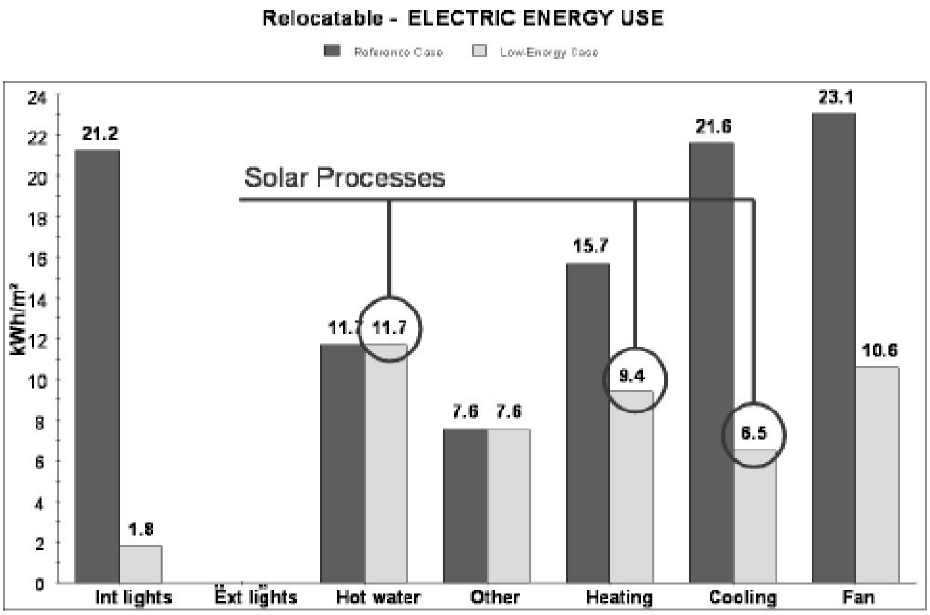

Figure 5 Annual energy consumption comparison for a reference and an energy efficient relocatable school building (ENERGY-10 simulation).

Figure 5 highlights (circled) the items that could be accommodated to a large extent through solar thermal processes. These would require minimal electric energy input. Finally, the application of photoelectric panels that cover the remaining required needs of electricity is considered. Furthermore, it is interesting to note that if only 98% of the peak hourly demand electricity load was acceptable, the original peak demand load would be reduced by 50% (Figure 6).

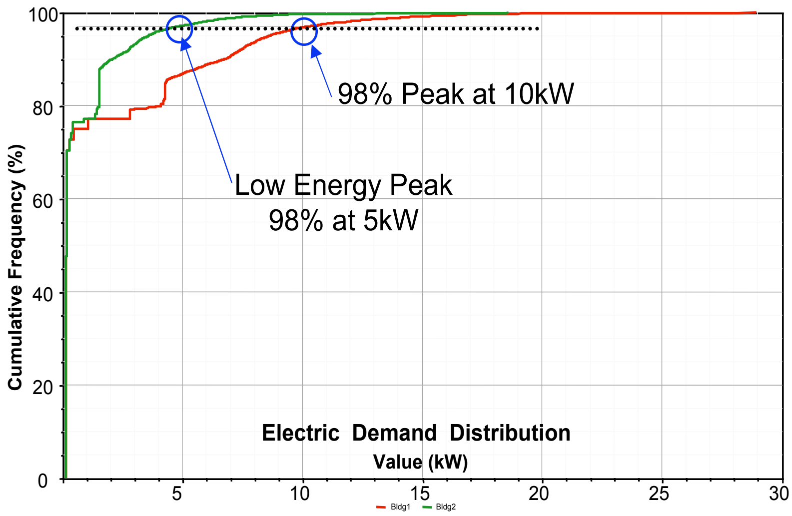

Figure 6 Peak energy demand frequency of the reference vs. the low energy building (ENERGY-10)

Another important and often overlooked aspect of energy consumption is due to leaky and unpredictable construction techniques. This issue has being researched in Australia by Air Barrier Technologies and the Mobile Architecture and Building Laboratory (MABEL). Buildings in Australia are often 2-4 times leakier than European countries (Luther, 2007). The simulation results provided by the ENERGY-10 program (Balcomb, 1998) indicate infiltration as one of the top three energy saving strategies (see Figure 7).

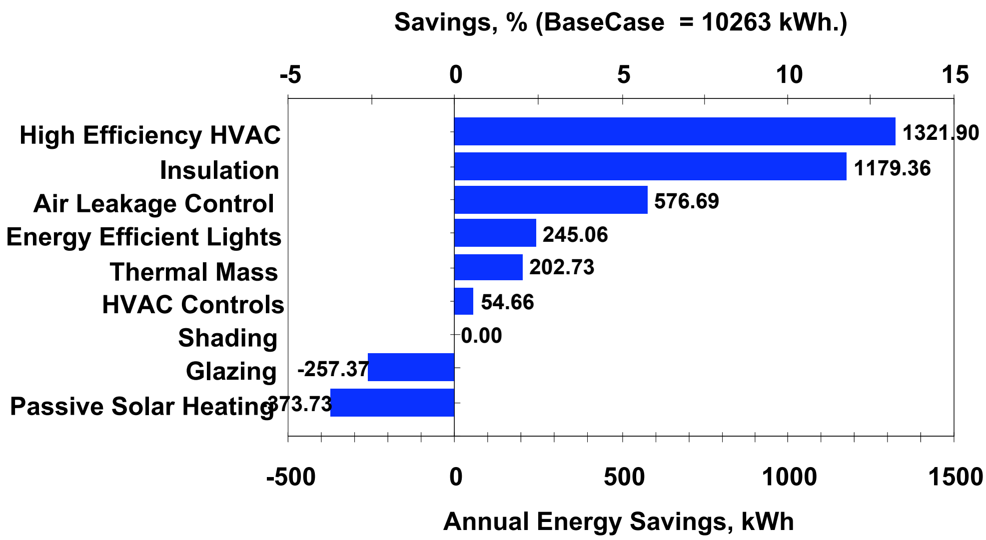

Figure 7 An energy saving strategy ranking as provided by simulation (ENERGY-10)

4. Conclusions

The development of mass-produced environmentally-benign housing is one of the critical factors in the transition to global sustainability. This new housing will have to be made from renewable and/or recycled materials, be naturally conditioned and affordable. The need for such housing is urgent. In developing countries, their requirement is to house both growing squatter settlements, as well as those who have benefited from recent economic booms. In industrialised countries, there is a need for an alternative to the current resource and energy-intensive housing.

A new approach towards sustainable housing, suggesting methods of prefabricated modular construction, recyclable materials, reducing energy consumption and introducing renewable energy has been outlined. The criterion for designing sustainable, renewable and adaptive buildings has also been introduced. The entire construction industry merits a re-visit in its methods and processes if we are to assure affordable and sustainable buildings for our future. Several of these methods have been presented in this paper.

Acknowledgements

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AUTONOMOUS CONTROLLERS FOR INTELLIGENT HVAC MANAGEMENT

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Summary

Taking advanced concepts from the artificial intelligence domain, CSIRO is developing intelligent HVAC management techniques for minimising energy consumption and operating costs whilst considering the impact on human comfort. Along with optimised space energy performance, these techniques enable automated participation in demand response initiatives, alleviating the rapidly growing pressures of peak electrical demand. Encompassing machine learning techniques, the CSIRO's Intelligent HVAC Controller technology comprises of autonomous controllers that automatically form models of the surrounding built environment, using these models to determine optimal set-point values and operating schedules. This technology is designed to be low-cost and easily retrofitted to existing infrastructure. This article details our latest work on intelligent HVAC management, with results presented from recent technology trials on two commercial office buildings (combined conditioned space totaling 13,466m^2), with a mix of under-floor and conventional overhead HVAC systems.

1. Introduction

In Australia, Heating Ventilation and Air-Conditioning (HVAC) typically accounts for over 60% of energy use in commercial buildings (Australian Greenhouse Office, 1999), is a substantial contributor to greenhouse gas emissions and is driving peak demand in the electricity network. Motivated by this, Commonwealth Scientific and Industrial Research Organisation (CSIRO) is developing Intelligent HVAC Controller technology, encompassing advanced HVAC management techniques for increased end-use efficiency and peak demand reduction, with wider application in the intelligent control of distributed energy resources (Platt *et al.* 2006).

Specific to the air-conditioning and HVAC systems domain, CSIRO is developing advanced control methodologies to provide optimised HVAC operation depending on a building operator's preferences for (in no particular order):

1. Reducing operating costs, exposure to peak electricity prices and alleviating peak demand;
2. Reducing environmental impact, particularly CO_2 emissions and;
3. Achieving acceptable thermal comfort for building occupants.

Clearly these have competing goals, and the balance between them is determined according to the combination of the desired preferences.

CSIRO's Intelligent HVAC Controller technology utilises machine learning techniques to automatically form models of the surrounding built environment, using these models to evaluate different control strategies for determining optimal HVAC operating schedules. This philosophy has been used to develop a more intelligent HVAC supervisory control system that is readily retrofitted to existing building management systems (BMS) through industry standard control interfaces such as OPC and BACnet[1]. As this technology is targeted towards both new and existing building stock with relatively minimal capital expenditure, significant inroads can be made towards reducing operating costs with relatively short payback periods. Further, improvements in building energy efficiency and performance ratings are facilitated through reduced energy consumption and associated CO_2 emission reductions.

The remainder of this article is structured as follows: Section 2 introduces advanced HVAC management techniques as utilised by CSIRO's Intelligent HVAC Controller technology. Section 3 presents "black box" modelling approaches for predicting thermal response, with a framework for determining optimal HVAC

[1] OPC (OLE for Process Control) and BACnet (Building Automation & Control Networking) as maintained by the OPC Foundation and ASHRAE respectively, are standards specifications designed to facilitate interoperability in process control and building automation.

operating schedules then introduced. Finally, results of a recent technology trial are presented in Section 4, with a conclusion drawn in Section 5.

2. Intelligent HVAC Control

Conventional HVAC control strategies involve changing set-points for chilled-water temperature, supply-air temperature, and space temperature. This is not always easy to achieve, as many installed control systems do not permit direct access to room thermostats or may not allow an operator to globally change them. Consequently, the operator may look at changing other indirect set-points, though this can have undesired second order effects. For example, for a typical variable-air-volume (VAV) system, raising supply-air temperature set-point causes the air handling unit (AHU) fan to supply a larger quantity of warmer air, resulting in increased fan power. For this strategy to achieve a net energy saving, chiller power must drop by more than the increase in fan power. What should be a straightforward HVAC set-point adjustment is found to depend on building load, building thermal mass, and part load performance of the fan and chiller.

Simulation studies to date have identified such issues and have shown the potential benefit of appropriate controls actions (Reddy and Norford 2002, Gu and Haves 2001, Xing 2004). These studies considered changes in space temperature, supply-air and chilled-water temperatures, and fan speed set-points. However, they did not consider optimal combinations of set-point adjustments and noted that the simulations were not capable of reliably modelling the impact of the control strategies on the thermal comfort of building occupants.

Motivated by these shortfalls, CSIRO's approach involves utilising a multi-objective optimisation framework for identifying optimal combinations of set-point adjustments and operating schedules. This makes it possible for building operators to set preferences for fully automated HVAC operation based on a combination of cost, CO_2, and comfort metrics.

2.1. Advanced HVAC Control Strategies

In addition to conventional HVAC control strategies, CSIRO's Intelligent HVAC Controller considers a number of more advanced control strategies when determining optimal operating schedules. These include the following:

2.1.1. Thermal Energy Storage using Pre-Cooling

The concept of pre-cooling involves cooling the space the lower bound of what is considered to be comfortable prior to a forecast peak demand period (either when electricity prices are low or when ambient conditions are most favourable), storing energy in the thermal mass of the building fabric (Braun, 2000). When a demand response (DR) is initiated, HVAC system load can be reduced during the peak demand period, with the energy stored in the building's thermal mass used to slow the rise in temperature towards ambient conditions. A wider range of acceptable internal temperatures can be used during both the pre-cooling and DR phases so as to maximise the amount of energy stored during pre-cooling, in addition to prolonging the DR duration.

2.1.2. Intelligent Load Limiting

Intelligent load limiting strategies involve the reduction of HVAC system electrical load in a manner that achieves load reduction targets whilst minimising human discomfort. An advanced optimisation algorithm can be used for the optimal control of a combination of HVAC system set-points, e.g. chilled/hot water temperature, supply-air temperature, space temperature, cooling/heating valve position, fan speed and duct pressure, based on building operator preferences for operating cost, end-use efficiency and comfort requirements.

2.1.3. Optimised HVAC System Startup and Shutdown Times

HVAC systems are typically turned on in the morning well before the building is occupied, and then off in the afternoon well after the building is vacated. This can often result in unnecessary HVAC operation and energy consumption. An optimised startup/shutdown strategy involves the utilisation of a sophisticated control algorithm that utilises machine learning based models for calculating the latest possible start time and earliest possible shutdown time, thus saving unnecessary operation and energy.

2.2. Enabling Technologies

To support the aforementioned control strategies, CSIRO has developed a number of enabling technologies to assist the Intelligent HVAC Controller in data acquisition, control of HVAC plant, and assessment of human comfort. These technologies, as detailed below, have been designed to be low in cost and to enable ease of deployment, particularly for retrofit style installations on existing buildings.

2.2.1. Informative Alerting & Comfort Feedback Software

One of the factors that affect our satisfaction with our surroundings is the ability of an individual to control his or her environment. Equipping an occupant with a mechanism to provide some level of control over their individual space whilst providing fair and timely distribution of system capacity can be used to promote thermal acceptability, comfort and increased energy savings. To facilitate this, virtual human comfort sensors consisting of a human comfort level feedback mechanism (e.g. electronic comfort survey or comfort push buttons) integrated with sophisticated comfort models are being trialed for their effectiveness in increasing comfort and reducing energy consumption.

The use of an advanced alerting system via an occupant's personal computer increases occupant awareness of a change in HVAC operating mode, thus maximising the potential for promoting thermal acceptability and encouraging energy saving behaviours. CSIRO has developed HVAC Alert software that resides on an occupant's personal computer, informing them of a change in HVAC mode of operation (e.g. Air Conditioning, Natural Ventilation, Peak Demand) via a small colour coded icon and informative "pop-up" message alert. This software also has the capability to provide historical performance data, as well as comfort feedback functionality via an electronic survey for collecting an occupant's perceived comfort level. Fig. 1 shows a screen shot of the HVAC Alert software indicating the current HVAC mode of operation via a small icon and pop-up alert, with the user submitting comfort feedback information via an electronic survey.

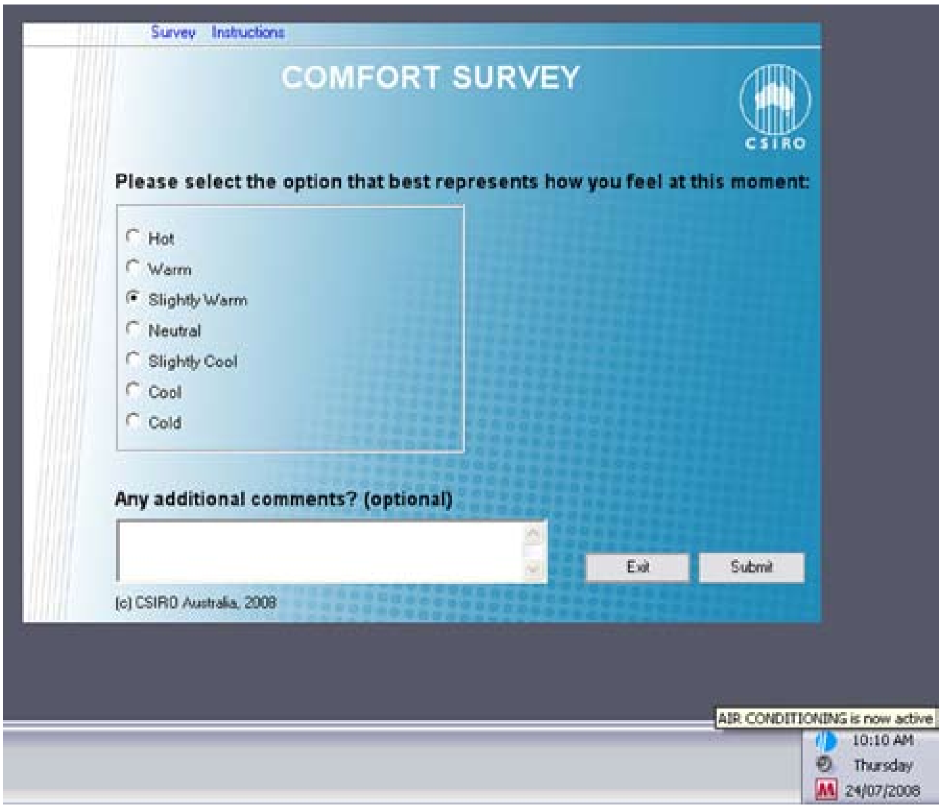

Fig. 1. HVAC Alert software with electronic comfort survey.

2.2.2. Wireless Sensor Networks

It is common in commercial buildings to condition the temperature of multiple spaces or rooms with a single HVAC system and controller. Whilst typical HVAC systems use wired sensors for transmitting information such as room temperature and humidity back to the central controller, such installations can be expensive. As such, typical HVAC installations often have a limited number of sensors located in a subset of the rooms being controlled. This method of deployment erroneously assumes every room is the same temperature as the room containing the temperature sensor. The resulting energy inefficient control decisions often cause unnecessary heating or cooling and occupant discomfort. WSN technology alleviates the deployment costs associated with conventional wired sensors and controller hardware; facilitating high spatial resolution sensor data (temperature, humidity, occupancy) for retrofit applications, with advanced capabilities including ad hoc installation, robust self-healing communications, control and actuation of HVAC plant, and up to 5 years battery operating life.

3. HVAC System Modelling and Control Optimisation

To enable intelligent scheduling of HVAC systems, a model is required that can evaluate the system response to the range of possible control actions. To allow such a supervisory control system to be easily installed and commissioned in both new and existing buildings, the "black box" models presented here are able to learn the response of the system by observing the control signals, external conditions and the resultant outputs. Once a model has been fitted to the system under control, it is able to be used as part of an optimisation loop which evaluates a range of possible control actions to identify a control strategy that minimises a number of parameters that affect operation.

As illustrated in the Fig. 2, the model is able to observe outside air temperature and zone power consumption, and learn their relationship to zone humidity and temperature. The optimisation process then identifies a range of desirable power profiles, obtains detailed ambient air temperature forecasts, and uses them simulates the zone temperature and humidity throughout the day.

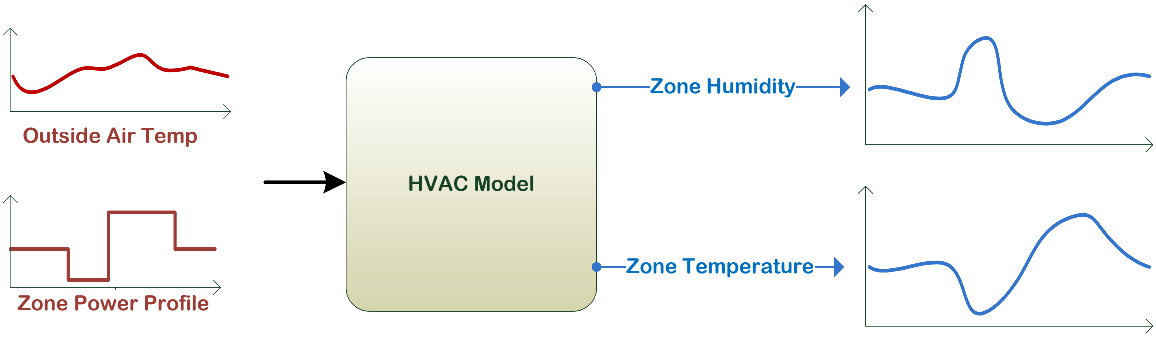

Fig. 2. Functionality of the zone power model.

This system is designed to be useful for the large range of existing HVAC installations, and the wide variety of different operational priorities they require. Some building managers may value the comfort of their occupants above the cost of operating their plant, while others may wish to reduce CO_2 emissions and claim carbon credits in a carbon trading scheme. Energy retailers absorbing the financial risk of fluctuating market spot prices may give incentives to large HVAC operators for demand response capabilities, and installations on time-of-use electricity pricing schemes may wish to pre-cool to avoid high running costs during peak price periods. This optimisation process is designed with all these priorities in mind and will allow operators to specify their preferences based on three criteria – their desire to minimise occupant discomfort, running cost and carbon emissions. This is done by specifying a cost function of the form:

$$\text{Cost}(t) = \alpha.\text{PPD}(t) + \beta.\text{energy}(t).\text{price}(t) + \gamma.\text{energy}.\text{CO}_2\text{Factor} \quad (1)$$

where α, β and γ are user-assigned values which specify how to weigh the three parameters during the optimisation, PPD is the Predicted Percentage Dissatisfied (%) comfort metric (ISO, 2005), energy is the power (kW) consumed by the HVAC system, price is the current energy price ($/kWh), and $CO_2Factor$ is the full fuel cycle emissions factor (kg CO_2/kWh) as reported in (Department of Energy & Climate Change, 2008).

The basic optimisation process is as follows:

1. The optimiser identifies a desirable power profile for the zone throughout the day.
2. *Power profile*, *weather forecasts* → **Zone Model** → *zone temperature profile*, *humidity profile.*
3. *Zone temperature profile*, *humidity profile*, *comfort parameters* → **Comfort Model** → *comfort profile.*
4. *Comfort profile, power profile, energy price forecast profile* → **Cost Unit** → *cost*.
5. Repeat with a range of potential power profiles and select lowest cost profile to follow.

The cost unit is a module that knows how to aggregate the three profiles over the course of the day and give a single number that represents their combined sum. This sum is the number that the optimisation is designed to minimise. The best power profile identified by the optimisation run is provided to a simple feedback control loop which manipulates the zone's set-point to match the power consumption. In this way, we are able to guarantee a given power consumption level at any given time, thus meeting the performance limits imposed during the optimisation run.

The advantage of this approach is the ability to evaluate the utility of control actions performed now, based on the impact they have on the system later in the day. Evaluation of many different strategies, such as optimised startup and shutdown times, load shifting and pre-cooling can all be assessed, and optimisations based on user comfort can prevent uncomfortable conditions on a zone-by-zone basis, potentially achieving significant efficiency gains. Another benefit is that the flexibility of the approach and the self-learning models eliminate the need for detailed measurements of the building and plant (such as zone volume, wall thickness, insulation losses, etc.) to be taken prior to installation, and that it can cater to a large range of preferences on how to optimise the HVAC system operation.

3.1. Thermal Modelling and Energy Prediction

To capture the zone's response to set-point changes and external conditions, several modelling approaches have been taken. Our main approach utilises "black box" models, where the models are derived solely from observation of the input/output characteristics of the system without explicit knowledge of the actual process being modelled. Such models are particularly useful for complex and nonlinear multivariable systems, and the approach avoids the need for any manual configuration of system parameters.

3.1.1. Supervised Learning Model

A widely used black box modelling technique from computer science domains known as a Support Vector Machine (SVM), as first developed by Vapnik (Vapnik, 1995), was employed to learn the relationship between the power consumed by a zone's HVAC plant, and the changes in temperature and humidity inside that zone.

SVMs are a general supervised learning modelling method which performs well on complex problems with high dimensionality, and noisy data. They have been applied in a wide range of real-world applications from stock-market prediction to satellite imagery analysis, and are well suited to learning the complex thermal model presented here. Advantages of this approach are that the model doesn't need to know specifics of the type of data it is dealing with, specific measurements such as floor areas, or the explicit effects of certain parameters on the model output, as it will learn these from patterns in the data provided. This greatly simplifies installation and retrofitting to existing systems, and will allow the model to be applied to a wide range of buildings.

3.1.2. Other Modelling Techniques

Although our research is based heavily on the SVM approach, we are utilising other system identification methods for result validation and to identify any improvements that could be made to our modelling approach. There are two additional modelling techniques we use:

1. Physical principles based modelling – where we have used detailed physical models of chiller characteristics, heat exchanges, fans, pumps, temperature flows and building envelope models. In this case, the systems characteristics are parameterised in a number of variables which we have used a Genetic Algorithm to learn. This is a "grey box" model, being based on a reasonably detailed physical model of the underlying process.
2. Polynomial approach – utilising a "black box" linear time invariant model to approximate the underlying system. The benefit of this model is that it is linear in the fitted parameters, substantially simplifying the model fitting process. Some additional detail of the polynomial approach follows.

The polynomial model utilises HVAC power, ambient temperature and an identified thermal baseload profile for the building to estimate the average zone temperature for the building. This model is of the form:

$$T_{Av} = \frac{k_1 s^2 + k_2 s + k_3}{(\tau_1 s + 1)(\tau_2 s + 1)} T_{Ambient} + \frac{k_4 s + k_5}{(\tau_1 s + 1)(\tau_2 s + 1)} P_{HVAC} + \begin{Bmatrix} Initial \\ Conditions \end{Bmatrix} + \begin{Bmatrix} Thermal \\ Baseload \end{Bmatrix} \quad (2)$$

where:

T_{Av}	is the average zone temperature throughout the building
$T_{Ambient}$	is the ambient (outside) temperature
P_{HVAC}	is the total power consumed by the HVAC system
k_1, k_2, k_3, k_4, k_5	adjustable parameters obtained by best fit to measured data
τ_1, τ_2	are the dominant thermal time constants for the building and HVAC system
S	is the complex Laplace variable
Initial Conditions	accounts for uncertainty in the internal thermal states of the building fabric and HVAC system at the start of the measurement period. These initial conditions result in a transient that is a combination of the natural modes of the system and hence is of the form: $k_6 e^{-t/\tau_1} + k_7 e^{-t/\tau_2}$. These modes are explicitly identified so as to not bias the system identification.

Thermal baseload — is an identified baseload profile that accounts for different thermal loads throughout the day. This will be dependant on factors such as solar gain and the activities of the building occupants. The thermal baseload is parameterised as a piecewise linear function.

This baseload function is assumed to be the same for every day in the data set, so is found by determining the function that when subtracted from each day of the recorded building data yields the best fit to the measured data.

Utilising data from a trial building with a conventional VAV system, five minute interval data for 16 of the hottest days was fitted to the polynomial model using regression analysis to determine the various parameters. The coefficient of determination of the fit over this data set is r^2=0.956, suggesting that the model provides a good fit. Additional second order terms were evaluated (i.e. power squared) but they did not significantly alter the quality of the fit so are not included in the model. The fit is shown in Fig. 3.

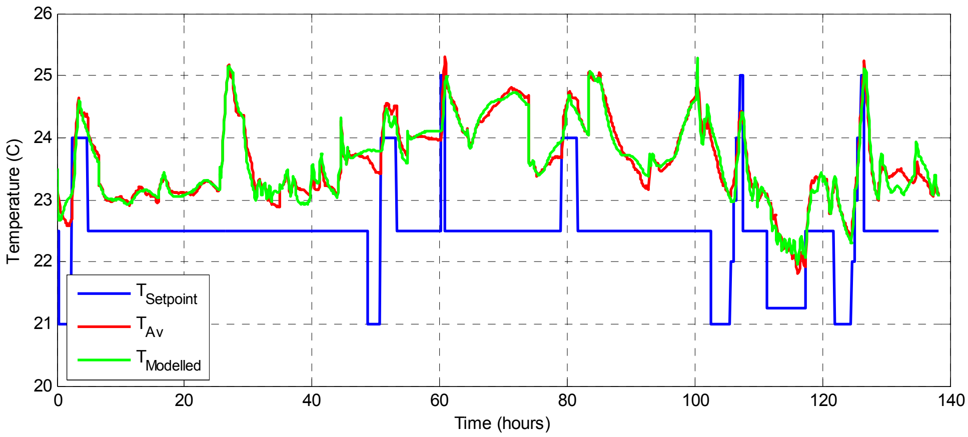

Fig. 3. Comparison of modelled and measured average zone conditions.

3.2. Optimisation Framework

Implementation of the optimisation system is derived from the Model Predictive Control (MPC) technique which is well suited to optimal control of complex processes with nonlinearities, state constraints and actuator saturations. At each sample time (every 5 minutes), the following actions are performed:

1. Current system state is measured and the system model is updated based on the new data;
2. A forecast is obtained for exogenous inputs to the system – specifically energy price data & weather forecasts for the next 24 hour period;
3. Utilising the cost function described in equation (1)– that is, a multi-objective function describing our desire to minimise PPD, CO_2 emissions & dollar cost– the optimal HVAC power profile for the next 24 hours is determined. This required running the model multiple times with different power scenarios. Depending on the model and constraint complexity, different optimisation techniques have been used, the fastest being the case of a simplified polynomial (LTI) model, for which the optimisation reduces to the well known quadratic programming (QP) problem.
4. The Building Management System runs the HVAC power at the level of the first 5 minute interval in the optimised HVAC power profile.
5. The system state is again measured and then we return to step 1.

By only every applying the first control interval of the optimised HVAC power profile, the system is able to quickly re-optimise and correct for any disturbances from the predicted strategy.

3.3. Trial Deployment Sites

To evaluate our models and techniques, two commercial buildings have been used. The first building is located at the CSIRO Energy Centre in Newcastle, Australia, and consists of around 2,911m^2 of conditioned office space serviced by an under-floor air distribution (UFAD) system. The second building located in Melbourne, Australia, consists of a VAV system servicing 10,555m2 of commercial office space.

In the following section, we show some typical optimisation results for full day ahead forecast under different optimisation criteria.

4. Results and Performance Analysis

In this section, we utilise the polynomial model described in section 3.1.2 and applied one HVAC zone of the CSIRO Energy Centre building, to demonstrate the results obtainable from our multi-objective optimisation approach. The polynomial model was trained using data from early January 2008, and the results are shown for the day of 31st Jan 2008.

Fig. 4 shows both zone temperatures and HVAC power consumption for 3 scenarios. These are (i) the actual measured zone data (solid line), (ii) a maximum thermal comfort control strategy (dashed line), and (iii) a CO_2 minimisation strategy that provides the same average thermal comfort as (i), but with minimum CO_2 emissions (dash-dot line). The plot also shows ambient temperature for reference (dotted line).

The most obvious feature of the optimised scenarios, is the apparent startup time optimisation– this is not an explicit feature of the system, but rather emerges from the optimisation process since our metric for PPD is only evaluated over business hours (8:30am to 5:00pm), so the optimised system does not run any longer than absolutely necessary to provide thermal comfort over this time interval. The comfort and CO_2 emissions improvements for the two scenarios are somewhat harder to see, though are clear from the metrics presented in Table 1.

Scenario	Average PPD	Daily CO_2 emissions	Daily Energy Costs
Baseline – as measured from existing BMS	5.2	44 kg	$6.23
PPD minimisation	5.06	40 kg	$6.74
CO_2 minimisation	5.2	31.4 kg	$5.38

Table 1: Comfort, CO_2 emissions and energy costs corresponding to Figure 4.

Of most interest here is that while maintaining identical thermal comfort to the existing BMS, we see that substantial savings on both energy costs & CO_2 emissions are feasible. (Note that although per zone savings seem small, there are around 100 zones throughout the building)

By allowing the building manager or user to determine the relative weightings given to the competing performance objectives, they are empowered with explicit knowledge of tradeoff being made when selecting a particular control strategy. This tradeoff is further explored in Fig. 4, where we show two scenarios of different energy cost structures and their effect on the optimisation process.

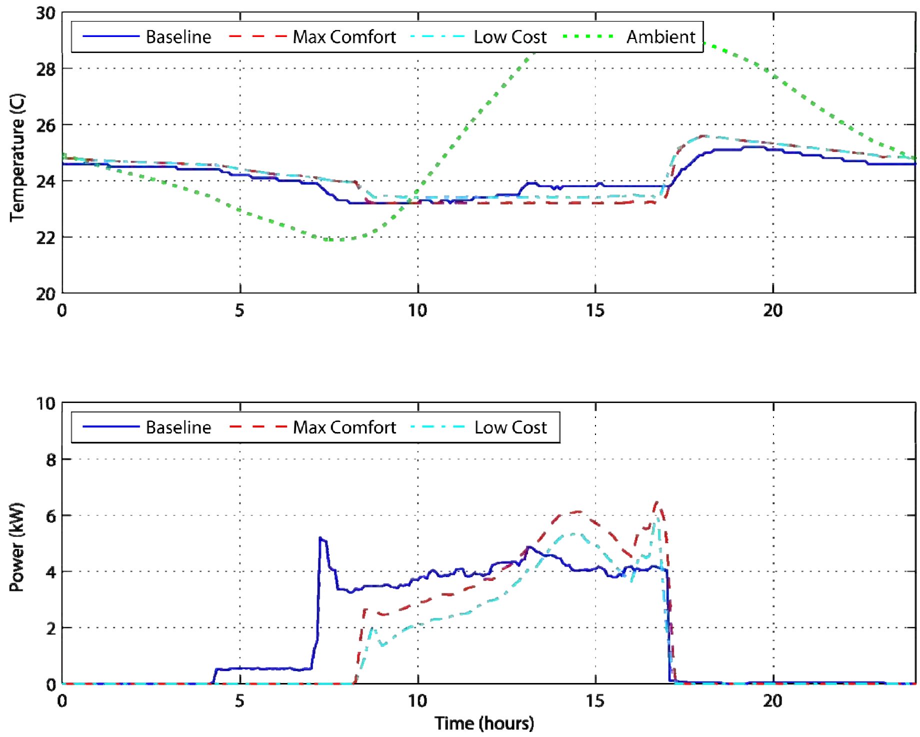

Fig. 4. Comparison of actual HVAC performance, and simulated performance under PPD & CO_2 minimisation strategies.

In Fig. 5, the baseline existing BMS strategy is shown (solid line) along with optimised scenarios for Time-Of-Use (TOU) energy pricing (dashed line), and the more novel Real-Time-Pricing (RTP) option where consumer prices are directly based on wholesale prices on the Australian National Energy Market. For these scenarios, the same optimisation objective function was utilised, though with the price spike on the energy market, significantly different behaviour is observed. As with the apparent start-up time optimisation previously noted, an electricity network demand response *emerges* from the optimisation rather than having to be explicitly programmed. Performance of these energy cost minimisation strategies are given in Table 2.

Scenario	Average PPD	Daily CO_2 emissions	Daily Energy Costs
Baseline – as measured from existing BMS	5.2	44 kg	$6.23
TOU cost minimisation	5.2	32.9 kg	$5.16
RTP cost minimisation	5.94	21.32 kg	$4.90

Table 2: Comfort, CO_2 emissions and energy costs corresponding to Figure 5.

As with the earlier comfort and CO_2 emissions, the multi-objective optimisation framework here allows direct evaluation and control of the tradeoffs being made, and so empowers the user with the knowledge to optimise their system according to their objectives.

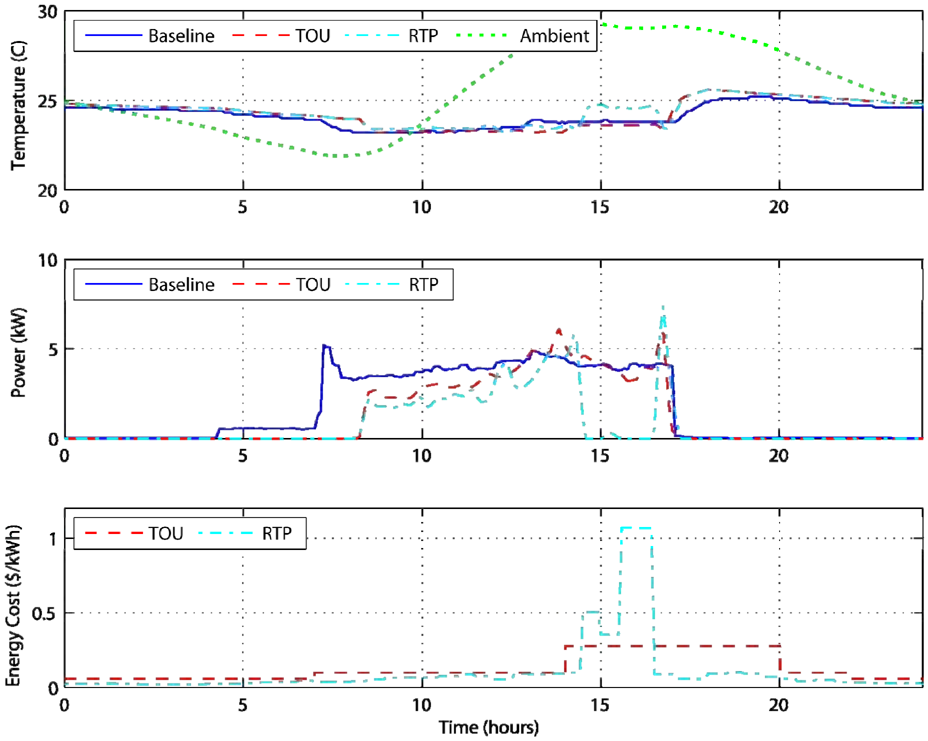

Fig. 5. Comparison of actual HVAC performance, and simulated performance under TOU & RTP cost minimisation strategies.

5. Conclusion

Using machine learning techniques and integrated enabling technologies, CSIRO is developing optimised HVAC supervisory control techniques applicable to both new and existing building stock for achieving increased end-use efficiency and peak demand reductions. Results from initial technology trials on two commercial office buildings show that reductions in HVAC energy and CO_2 in the order of 10-15% are achieved for a simple adaptive scheme without loss of thermal comfort. Theoretical performance analysis has shown potential energy and CO_2 reductions of up to 30% without loss of thermal comfort. Further savings are expected to follow current trials with full implementation of CSIRO's technology.

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GREEN ENGINEERING FOR HIGH RISE OFFICE BUILDING

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Keywords: Airflow Window, U-factor, Solar Heat Gain Coefficient, energy recovery, Thermal Image

Summary

This paper presents a system description and results of field measurements for two new energy recovery systems installed in a high-rise office building in Tokyo. The first is the new airflow window system in which air exhausted from a rotary heat exchanger is channeled between panes of a double-glazed window to improve fenestration performance. In this study, the U-factor and Solar Heat Gain Coefficient of this system were developed from measurements. The second is an “under floor cooling water i.e. a condensing water circulation system” for heating, in which cooling water is circulated through tubes laid in cinder concrete on the slab to reduce heating load of a public passage on the ground level of this building. Thermal comfort in the passage is improved by this system. This building requires cooling through the year, so heat can be provided by cooling water of a centrifugal refrigerator even during winter nights. This paper describes thermal images and heating load reduction achieved by this system. The U-factor and Solar Heat Gain Coefficient of this new airflow window system and heating load reduction by “the under floor cooling water circulation system” obtained through these measurements can be used for more accurate calculation of cooling and heating load for future projects.

1. INTRODUCTION

A high-rise headquarters building has been designed and constructed for “FUJI SOFT inc.” in Akihabara Tokyo. It incorporates various kinds of green engineering technologies in accordance with the owner’s requirements. This paper describes two systems developed using these technologies, called "EXAFW" and "UCCS."

When an airflow window and a rotary heat exchanger are used together, the rotary heat exchanger is usually installed downstream of the airflow window. However, EXAFW is a new system in which the rotary heat exchanger is installed upstream of the airflow window. This building has a refresh area at the south-west corner of the office floors. The exterior appearance of the corner facing the Akihabara station plaza was the most important point of the design. The architects required "transparency" using full-height, clear glazing. At the same time we needed to cut down the large air-conditioning load coming through the full height fenestration facing south-west and save energy. EXAFW was developed to resolve these two conflicting requirements. The air flow window is known as high energy performance fenestration. However, when a rotary heat exchanger is also used, the overall energy performance could drop. In a conventional airflow window system, room air is drawn between double panes, heated or cooled within them, led to a rotary heat exchanger, and discharged to the outside. The temperature of the air entering the rotary heat exchanger is higher in summer and lower in winter than room air temperature. It is inefficient to recover the exhaust air energy. Additionally in winter, when the dew point temperature of room air drawn between the double panes remains above the inner surface temperature of the outside pane, condensation will occur. Thus, the new airflow window system "EXAFW" was developed, in which exhaust air from the rotary heat exchanger flows between the double panes and is then exhausted. The U-Factor and SHGC of EXAFW were necessary to calculate the air-conditioning load. In the literature, Ishino et al. (1995) described the U-Factor and SC of conventional airflow windows. However, the U-Factor and SHGC of EXAFW were not available. The authors then carried out a full-size mockup experiment and estimated these values based on calorimetric measurement, as shown in the article by Numata et al. (2006). In 2007, the high-rise office building equipped with EXAFW’s was completed. In August 2007 summer peak field measurement, and in January 2008 winter peak field measurement were carried out. This paper provides calculated U-Factor and SHGC of EXAFW based on these field measurements.

“UCCS” is “the under floor cooling water circulation system”. In this building, there is a public passage leading through to the station. As this passage has frequent pedestrian traffic, infiltration through the entrance doors increased heating load. Energy and cost efficient equipment is required for this public space. Meanwhile the building is the head office of a software house, and the building has cooling demand through the year. The chillers are running through the year and condensing heat is discharged from the cooling tower even on winter nights. Since it is difficult to utilize such low potential condensing heat, we tried to use this cooling water directly to warm the floor structure of this passage. In this system, cooling water is circulated through tubes laid in the cinder concrete on the slab to reduce the heating capacity of the air-handling unit and to maintain thermal comfort for passengers. This paper provides thermal images comparing a UCCS equipped floor with a conventional floor, and estimates heating load reduction.

2. System Description

2.1 EXAFW

The full-height EXAFW is installed at the southwest corner of the office building, which has 31 floors and a gross floor area of 58,500m^2. Exterior and interior views of EXAFW are shown in Figure 1.

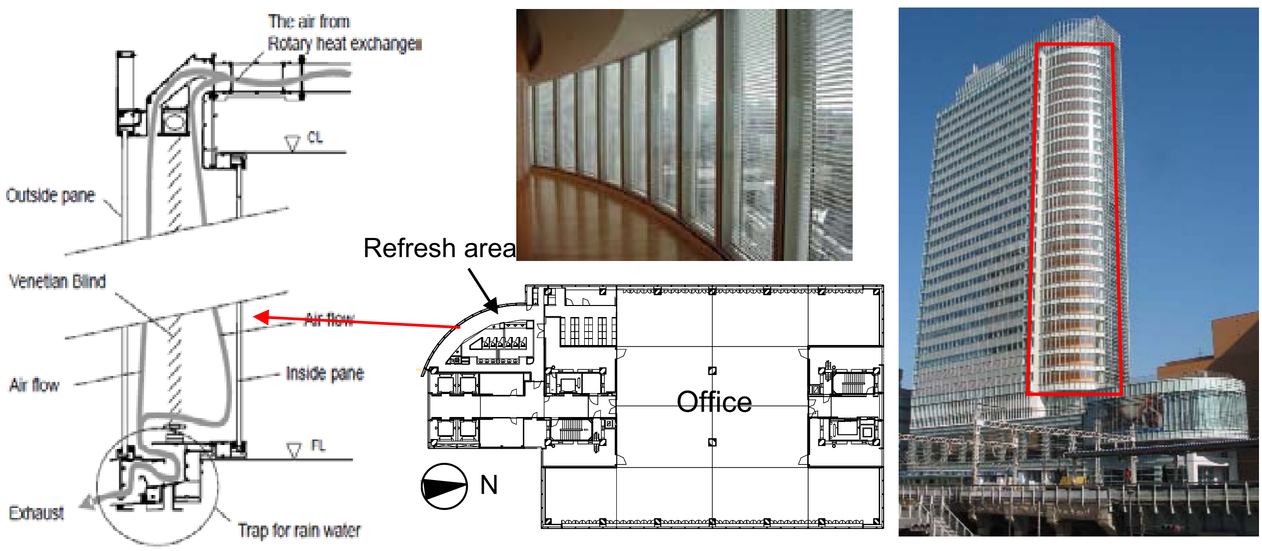

Figure 1. Exterior / interior view of EXAFW and typical floor plan

A schematic diagram of the EXAFW is shown in Figure 2. The return air from the room enters the rotary heat exchanger and passes heat to fresh outside air. The air leaving the rotary heat exchanger enters the double-glazed cavity and is then exhausted from the building. The flow rate of exhaust air is 290m^3/h per unit bay window (1100mm×2600mm). This flow rate is higher than that of a conventional airflow window. To obtain enough exhaust air for the EXAFW, the air exhausted from the office is used for the refresh area, as shown in Figure 1. The new system has the following features: (1) Since the exhaust air from the rotary heat exchanger is used, fresh air loads are reduced. (2) There is no condensation on widow panes in winter.

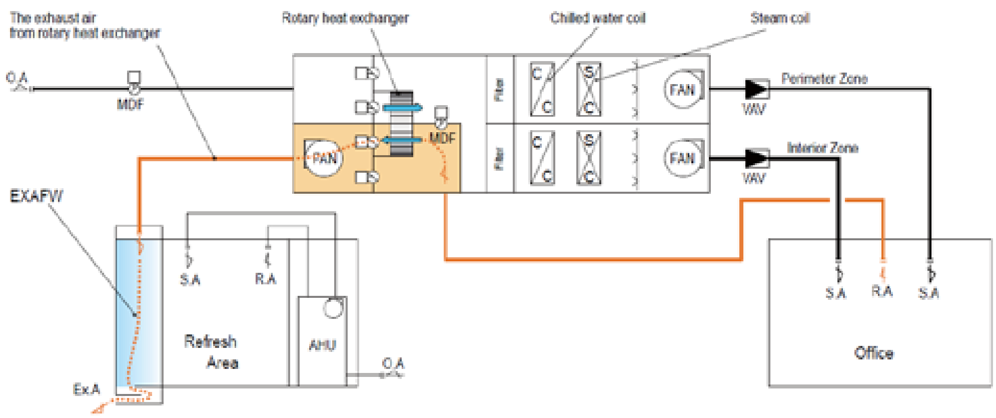

Figure 2. Schematic diagram of EXAFW

2.2 UCCS

The public passage on the ground level of the building has a large heating load due to intruding outside air. A moderate room temperature condition was adopted for a single-duct air-conditioning system. The UCCS was developed as the auxiliary system of this moderate air-conditioning system. Since the building has cooling demand through the year, cooling towers run even on winter nights. By channeling the cooling water returning to the cooling tower to the passage floor, the heat of cooling water, which is usually discharged to outside air, is utilized and the following benefits are achieved in winter. (1) Reduction of heating load of the moderate air-conditioning system. (2) Improvement of thermal condition by reducing cold radiation from the floor. A schematic diagram of the UCCS is shown in Figure 3 and the area of the UCCS is shown in Figure 4.

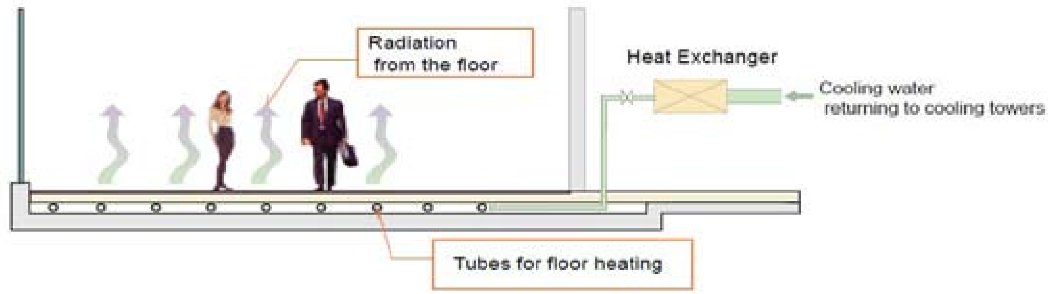

Figure 3. Schematic diagram of UCCS

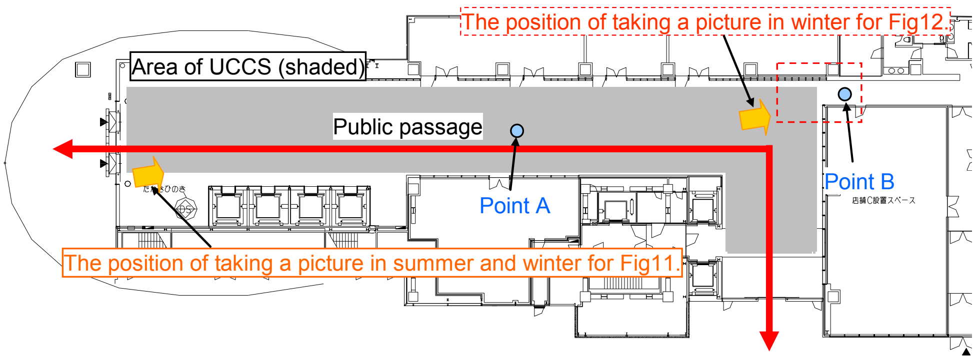

Figure 4. Area of UCCS (Shaded)

3. Measurements

3.1 Measurement of thermal performance for EXAFW

U-factor and Solar Heat Gain Coefficient of EXAFW are provided based on measurements as follows.

3.1.1 Night-time measurement

To avoid the influence of solar radiation, measurements for estimating U-factor were performed at night. The inner surface heat flux q_t (W/m^2) of EXAFW is calculated as:

$$q_t = q_c + q_r \qquad (1)$$

where q_r is measured inner surface heat flux caused by radiation (W/m^2) by a radiant temperature asymmetry transducer, as shown in Figure 5. Heat flux q_c caused by convection (W/m^2) is calculated as:

$$q_c = h_c(\theta s - \theta r) \qquad (2)$$

where hc is convection heat transfer coefficient (W/(m^2·K)), and θs, θr are surface and room air temperature(°C).

Henmi (2003) indicated hc as:

$$h_c = 1.98(\theta s - \theta r)^{1/4} \tag{3}$$

U-factor U (W/(m^2·K)) is calculated as:

$$U = \frac{q_t}{\theta o - \theta r} \tag{4}$$

We measured inner surface air temperature θs, room air temperature θr and ambient outside air temperature θo; calculated heat flux q_c caused by convection using equation (2); and also measured heat flux q_r caused by radiation. Inner surface heat flux q_t and U-factor are calculated by equations (1) and (4).

3.1.2 Multiple linear regression analysis

At night, the inner surface heat flux of EXAFW varies according to 4 parameters: (1) temperature of air entering EXAFW, (2) ambient outside air temperature, (3) room air temperature, and (4) air flow rate. The air flow rate is fixed. By night-time measurements we observed various sets of these values under real conditions. Using multiple linear regression analysis, the night-time (without solar radiation) heat flux $q_{t,night}$ (W/m^2) caused by three air temperatures θ_i, θ_r, θ_o (°C) can be expressed as:

$$q_{t,night} = f(\theta i, \theta r, \theta o) \tag{5}$$

$$f(\theta i, \theta r, \theta o) = a\theta i + b\theta r + c\theta o + d \tag{6}$$

where θ_i is the temperature of air entering EXAFW, $f(\theta_i, \theta_r, \theta_o)$ is a function for estimating the heat flux $q_{t,night}$ caused by three air temperatures θ_i, θ_r, θ_o, and a, b, c, d are coefficients of the multiple regression equation. We note that these values are not influenced by solar radiation.

3.1.3 Daytime measurement

During daytime, the inner surface heat flux is considered to consist of heat flux caused by solar radiation and heat flux caused by three air temperatures θ_i, θ_r, θ_o (without solar radiation). Solar heat gain coefficient (-) is given by:

$$SHGC = \frac{I_1 + q_C + q_r - f(\theta i, \theta r, \theta o)}{I_0} \tag{7}$$

where I_0 and I_1 are incident and transmitted vertical solar intensity(W/m^2). We measured the incident and transmitted vertical solar intensity at the outside and inside of EXAFW, and measured the inner surface heat flux q_r caused by long wave radiation as shown in Figure 5. We calculated the inner surface heat flux q_c caused by convection using equations (2) and (3). SHGC is calculated by equation (7). We note that the heat flux q_r caused by long wave radiation includes absorbed solar radiation, and transmitted solar radiation is expressed by I_1.

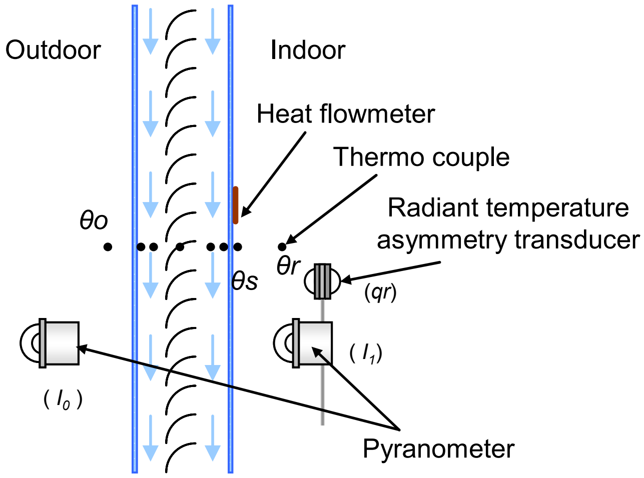

Figure 5. Measurement apparatus on EXAFW

3.2 Thermal imaging and temperature measurement of UCCS

Thermal images, floor surface temperature, air temperature and globe temperature in the public passage were measured as shown in Figure 6. Under floor sand temperature, flow rate and temperature of circulating cooling water were measured by BEMS of the building.

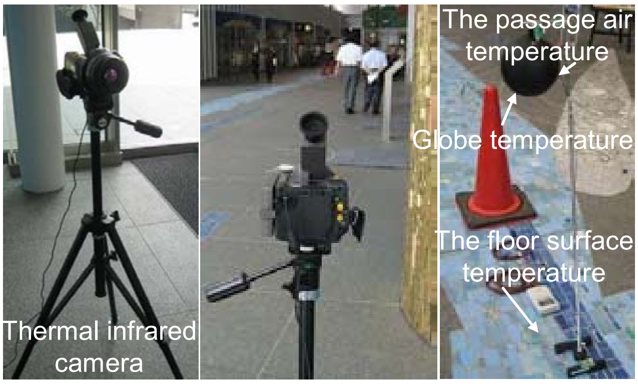

Figure 6. Measurement on UCCS

4. Results

4.1 Night-time inner-surface heat flux and U-factor of EXAFW

As the results of night-time measurement, U-factor, ambient outside air and room air temperature are shown in Figure 7. U-factor varied from 1.1 to 1.8 and averaged 1.6.

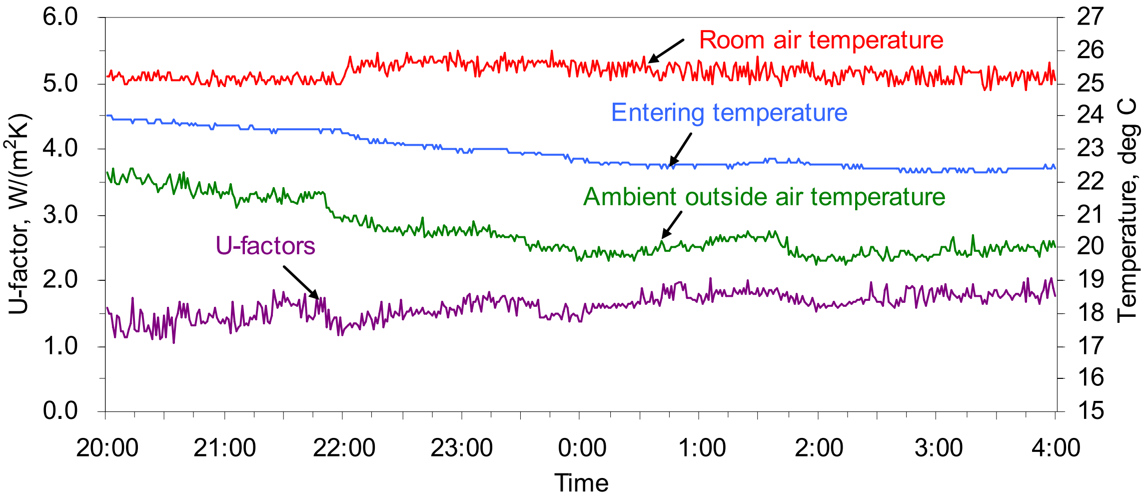

Figure 7. U-factor of EXAFW (July 30th and 31st, 2007)

We carried out a regression analysis using those measured data and the obtained model of "the heat flux caused by three air temperatures θ_i, θ_r, θ_o (without solar radiation)". $f(\theta_i,\theta_r,\theta_o)$ (W/m^2) is written as:

$$f(\theta i,\theta r,\theta o) = -2.86\times\theta i + 2.78\times\theta r - 0.11\times\theta o + 5.24 \quad (8)$$

4.2 Daytime inner surface heat gain and SHGC of EXAFW

Incoming vertical solar radiation and ambient outside temperature measured in a peak summer day are shown in Figure 8. The blind slat angle was kept vertical. Figure 9 shows daytime heat gain through EXAFW. Figure10 gives the SHGC of EXAFW. SHGC is approx. 0.05~0.10 and the mean value is 0.7 (blind at 90°). Long wave radiation, convection and solar radiation transmitted through EXAFW make up 58%, 30% and

12%, respectively. We can find an extremely large value of SHGC. This is because the response speed of the pyranometer is quicker than that of the thermocouple on the inner surface of EXAFW. When solar radiation sharply decreased, the change of the inner surface temperature was delayed by the thermal capacity of the window pane.

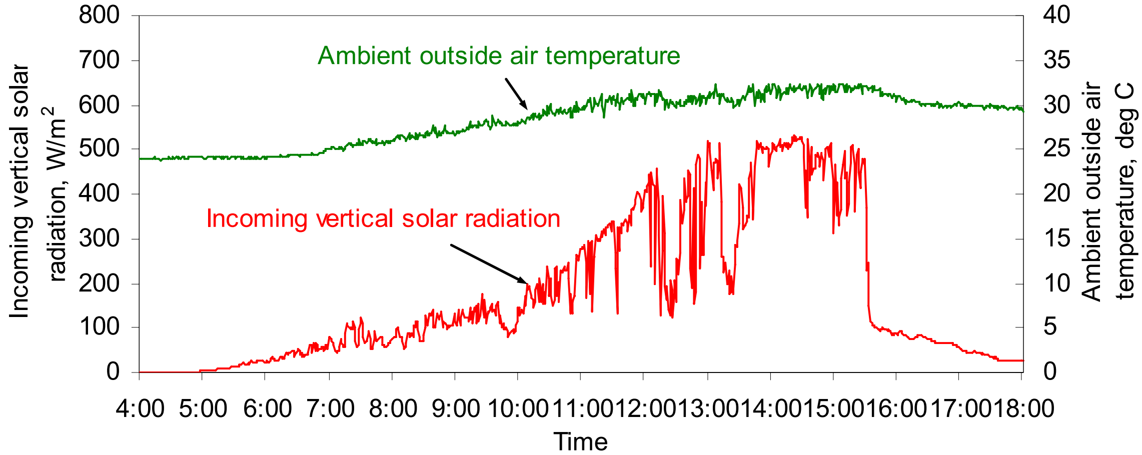

Figure 8. Incident vertical solar intensity and ambient outside temperature (August 1st, 2007)

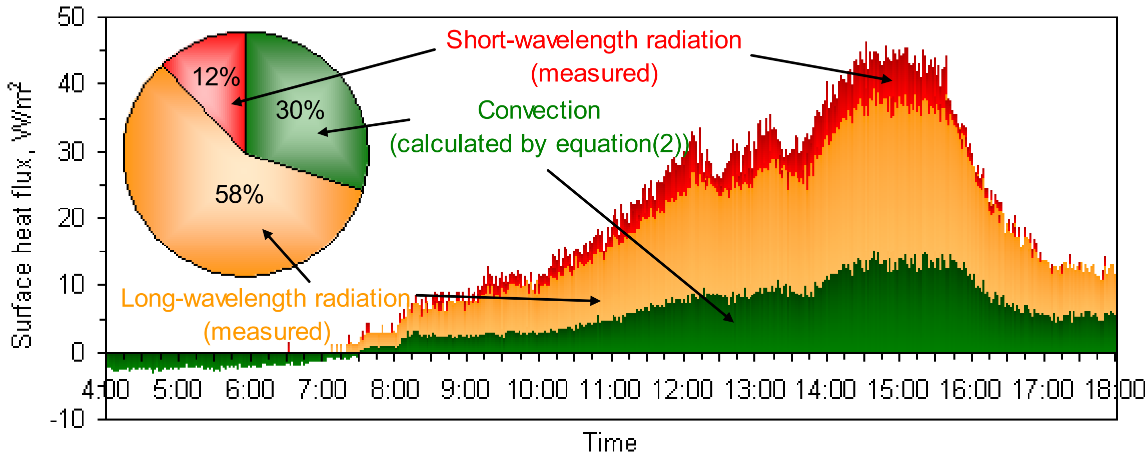

Figure 9. Daytime inner surface heat gain of EXAFW (August 1st, 2007)

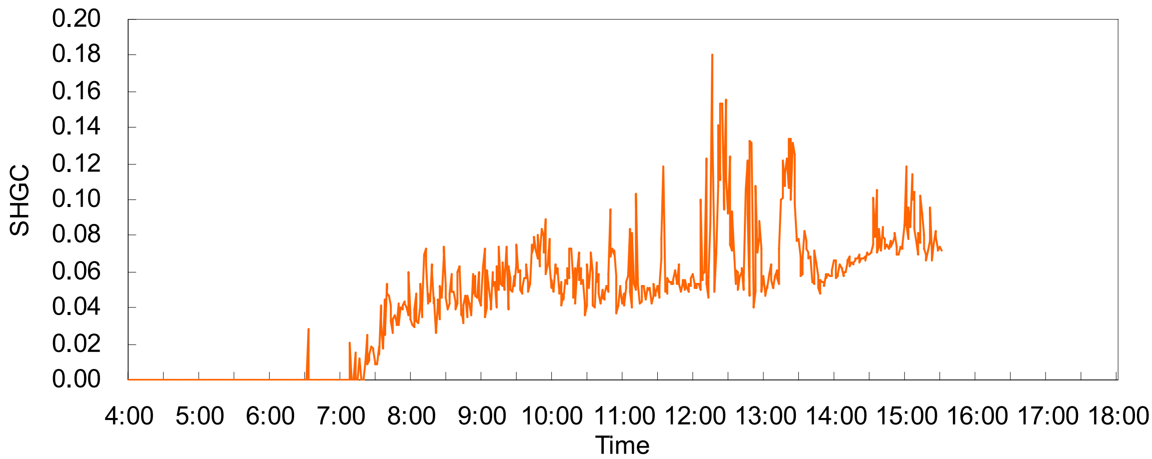

Figure 10. SHGC of EXAFW (August 1st, 2007)

4.3 Thermal images of UCCS

Figure 11 shows a thermal image of the UCCS, and Figure 12 and Figure13 compare the UCCS-equipped floor with the normal floor. The surface temperature difference between the UCCS-equipped floor and the normal floor is approx. 3K. When the heat transfer coefficient is assumed to be 8 W/(m^2.K), the heating load reduction of the air-handling unit for the passage is estimated to be 24 W/m^2.

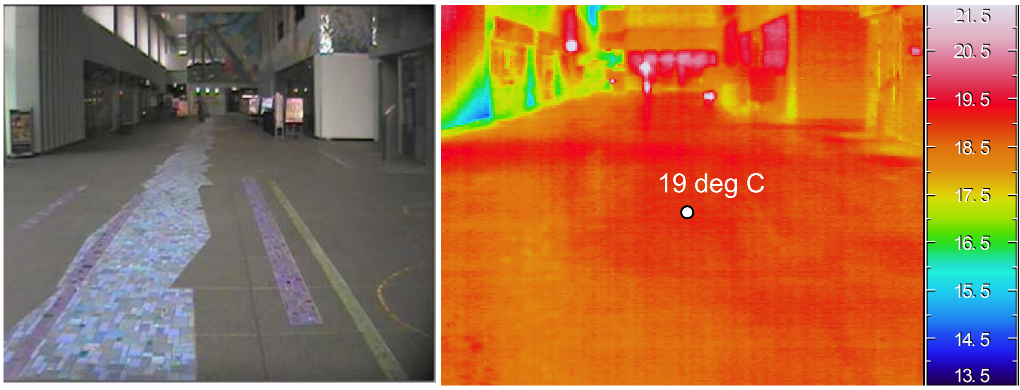

Figure 11. Thermal image of UCCS (10:40 February 2nd, 2008)

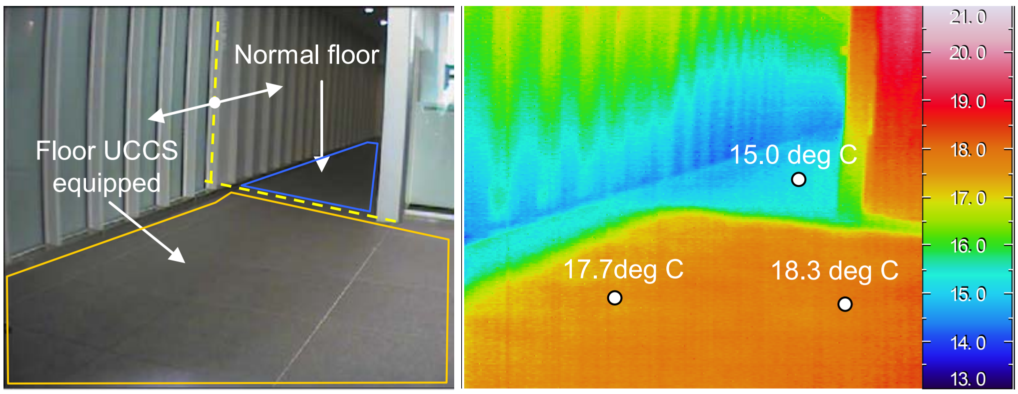

Figure 12. Comparison of UCCS-equipped floor with normal floor (10:40 February 2nd, 2008)

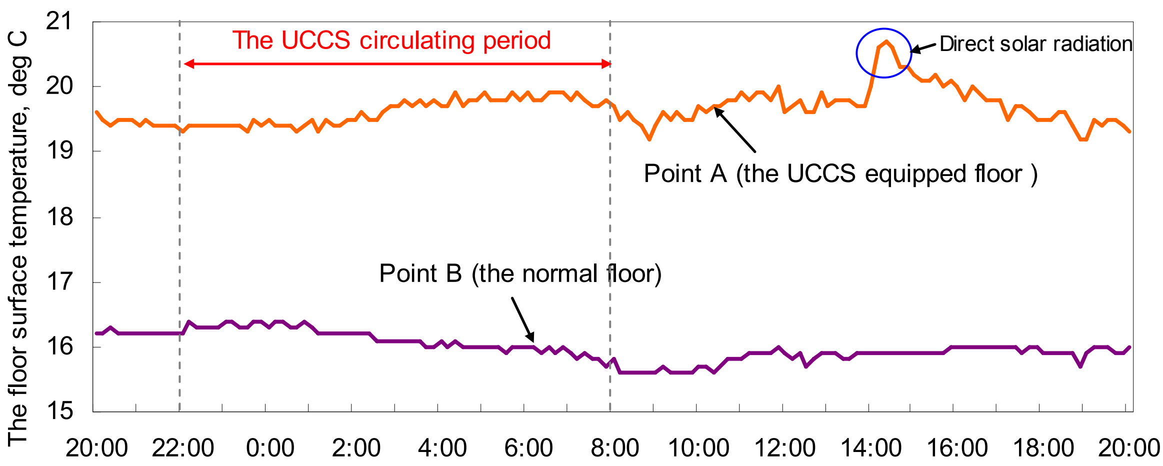

Figure 13. Comparison of floor surface temperature (February 14th and 15th, 2008)

5. Discussion

We estimated the U-factor and SHGC of EXAFW to be 1.6 and 0.07 (blind at 90°) based on field measurements. These performances are similar to those of conventional AFW (U=1.3, SHGF=0.17, 80m^3/h, blind at 45°). We note that the ventilating flow rate of EXAFW (290m^3/h) is 3.6 times that of the conventional AFW (80m^3/h). We tried to calculate and compare the cooling load of EXAFW against that of the conventional AFW using the above values. The load difference between these two systems comes up in heat gain through fenestration and in fresh air load. The EXAFW has 143% heat gain through fenestration and 93% of fresh air load compared with conventional AFW. Total cooling load of EXAFW is 5% less than that of conventional AFW (Figure 14)

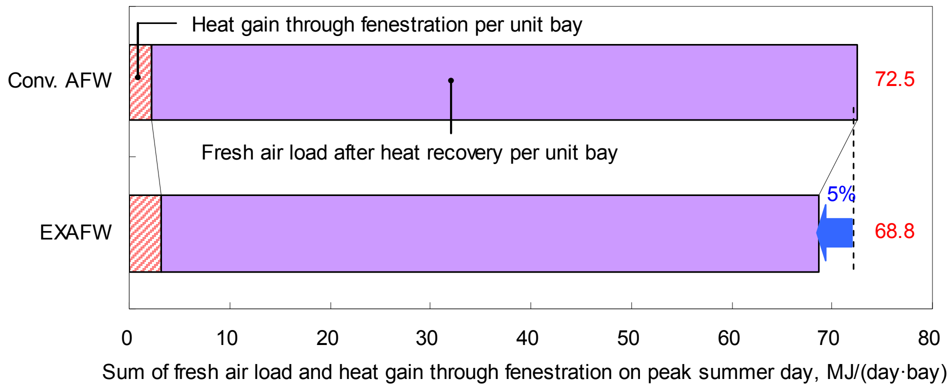

Figure 14. Comparison between EXAFW and conv.AFW

We measured the surface temperature difference between the UCCS-equipped floor and the normal floor. It is approx. 3K averaged over the peak winter day, as shown in Figure 13. The heating load (supplied by the air-handling unit) reduction is estimated to be 24 W/m^2. According to BEMS measurement data, averaged heating load over winter is 184 W/m^2. Thus, it is estimated that UCCS reduces the winter season heating load by13%.

6. Conclusion

We applied two new green technologies and produced the new airflow window system (EXAFW) and "the under floor cooling water circulation system"(UCCS), and applied them to a high rise office building. We measured the thermal performance of these systems, and determined the U-factor and SHGC of EXAFW and the heating load reduction by UCCS. We compared the cooling load of EXAFW including fresh air load against that of conventional AFW, and obtained a 5% reduction. The UCCS reduces heating load of the public passage by 13% and saves gas consumption of boilers. This information can be used for more accurate calculation of air conditioning load and for design of these new systems.

Acknowledgements

We thank Reiji YAMADA, Hitoshi TABEI, and Ichiro ISHII for permission to take measurements in the FUJISOFT Akihabara Building.

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HOLISTIC LIFE-CYCLE GHG EMISSIONS ASSOCIATED WITH BUILDINGS

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Keywords: Greenhouse gases, life-cycle, holistic, sustainable, building, accounting, planning tool

Summary

In this study we have developed a model to calculate greenhouse gas (GHG) emissions associated with buildings and development projects. The purpose of the study is to give property owners and managers a *GHG emission accounting tool* for existing buildings, which also can function as a planning tool for urban planners, architects and advisors in construction.

The model consists of four modules: 1. Embodied emissions from building materials, 2. Emissions from construction and earthwork, 3. Emissions from annual operational energy, 4. Emissions from use-phase transport.

The model has been tested on six Norwegian building projects, and the results have been compared with the results from two housing examples in Canada (Norman et al. 2006). The results from the Norwegian examples are in the same range as the Canadian findings, i.e. between approx. 40 and 90 kg CO_2 equiv. per m^2 per year.

The results demonstrate the importance of moving towards a more holistic life-cycle based understanding of GHG emissions associated with buildings. If we compare the buildings and the main sources, the results show that factors such as location, use of the building (function) and choice of energy solutions have the greatest impact on emissions. As emissions from operation-phase stationary energy use and transport are reduced, emissions from materials will become relatively more important.

The results show that the choices that give the lowest emissions of greenhouse gases are:

- Choice of energy-efficient design and renewable sources of energy and carriers can reduce emissions by more than 50 %.
- Central location and/or proximity to a good public transport system – emissions from transport linked to use of the building can be reduced by more than 50 %.
- Renovation and reuse of buildings – emissions can be reduced by 60–70 % compared with a new building.

It must be stressed that we need more examples and research to provide information about different types of building projects, architecture, location, public transport, etc., as well as further refinement of methods for comparing projects. As more examples become available calculated using the same method, it will be possible to set benchmarks for different types of buildings.

IPCC (2007) recommended global reductions by around 85 % against 2050. If we compare the preliminary results with this recommendation, the emissions from building projects ought to be lower than approx.10 – 15 kg CO_2 per m^2 per year (all sources of emissions).

1. Introduction

Climate change as a result of human emissions is probably the greatest challenge the global community has ever faced. All options must be explored to try to reduce emissions by as much as possible as quickly as possible.

Construction projects contribute to greenhouse gas emissions through the materials produced and transported, energy use during construction, energy consumption when the building is in use, energy use for maintenance, energy use for transport during operation of the building and emissions in connection with demolition and removal. According to the IEA (2005), construction and operation of buildings account for between 30 and 40 % of the world’s energy use. Transport during the operation phase of the building is in addition to this. Overall buildings are responsible for more than 40 – 50 % of the global emissions of greenhouse gases.

The EU and Norway have set themselves the goal that the global mean temperature will not rise by more than 2 °C. The IPCC has calculated that we can achieve this goal with a reasonable degree of certainty if global emissions in 2050 are 50 to 85 % lower than in 2000 (IPCC, 2007, Summary for Policy Makers, table SP.5.). This means an average emission of less than 0.5 tonnes of CO_2 per person per year, taking into account population growth. Today the global average is approx. 4 tonnes of CO_2 per person, and in Norway it is approx. 12 tonnes of CO_2 per person. All avenues for reducing emissions must be explored, and new solutions must be found, if we are going to get down to an individual emission rate of less than 0.5 tonnes of CO_2 per year.

Evaluating greenhouse gas emissions from a life-cycle perspective for building projects will indicate which aspects of the project are responsible for the most emissions; production of the materials used in the building, the construction phase, energy use for heating, cooling, etc. or transport to and from the building during daily operation.

Research from recent years generally only covers emissions from operation and the materials included in the building. The findings suggest that energy use for heating and cooling dominates (Junnila and Horvath 2003, Thormark 2002). It has been shown that the more energy-efficient buildings are, the greater the significance of emissions linked to choice of materials (e.g. Chen et al. 2001; Adalberth 1998).

At the same time, others have stressed that location and urban development are an integral part of a building project's total greenhouse gas emissions, and in many cases this factor can be the dominant one (Næss 2006; Anderson et al. 1996; Newman and Kenworthy 1999; Gurin 2003).

A study from Toronto compared two different types of housing developments: blocks of flats in the centre of town and detached houses in a suburb. The results underline the importance of location in reducing emissions from transport, but also that emission from stationary energy use is lowest in blocks of flats/urban developments. Emissions from use of materials were less significant (Norman et. al 2006).

Statsbygg is Norway's largest government property agency in the civil sector with a property portfolio of approx. 2.3 mills. square metres over 1500 properties in Norway and overseas. In 2007, Statsbygg completed 28 building projects. Statsbygg's main clients are central government agencies such as ministries, directorates, universities and colleges. Core activities are planning, providing advice on construction matters, property management and management of building projects. Statsbygg is a government corporation with 720 employees. Statsbygg wishes to lead the way in developing environmentally sustainable solutions.

Planning and developing from an environmental perspective, i.e. long-term ecologically sustainable development, is one of Statsbygg's priority areas. Low emissions of greenhouse gases has been a premise in connection with the transformation of Fornebu, the old main airport area, to a large housing and commercial area on the outskirts of Oslo, the capital of Norway. As part of the work the analysis model www.klimagassregnskap.no has been developed to calculate greenhouse gas emissions for building projects to ensure that greenhouse gas emissions from all phases of the projects can be documented.

The development and testing of the model has provided new knowledge about the importance of different sources of emissions in building projects. Greenhouse gas emissions have been calculated for six Norwegian building projects. These projects are planned and carried out by Statsbygg (4) and Bærum Municipality (2).

2. Calculation model www.klimagassutslipp.no

2.1 The main features of the model

The model for calculating greenhouse gas emissions www.klimagassregnskap.no consists of four modules and covers emissions from (1) production of materials used in the building, (2) transport of materials to the building site and energy use in the construction phase, (3) energy for use heating and cooling in connection with operation / use of the building and (4) energy use for transport in connection with operation / use of the building.

The calculation model has been designed in such a way that the emissions from the various different parts are calculated separately. The results are also summed up across the modules.

The basic principle for the calculations is:

Input factor/activity x emissions factor (CO_2, CH_4, N_2O) = greenhouse gas emission (CO_2 equiv.) (1)

The input factor / activity is a litre of fuel, a litre of heating oil, a kilogram of steel, a square metre of timber outside wall, the number of vehicle kilometres driven by lorry, energy need / use per square metre, etc.

Emissions factors for stationary energy consumption and transport are taken from national emissions accounts based on international sources (Statistics Norway, 2007). Emissions factors for materials have been calculated from a number of different references and are mean figures for European production, given as CO_2 equiv. per tonne of basic material. Emissions factors have been defined for 43 different building materials.

The building's lifetime has been set at 60 years.

2.2 The four modules

2.2.1 Materials, module 1.

The figures for greenhouse gas emissions from materials include extraction and transport of raw materials as well as the production process for the basic material. For some building materials, emissions have been calculated up until the final processed building product, for example plasterboard. Transport from the manufacturer to the building site is calculated in module 2 "Construction phase".

The material module contains emissions factors for 43 basic/building materials, and we estimate that this covers approx 80 % (weight) of the materials used in a building. The factors are taken from national and international studies and are given as emission per tonne or kg of a basic material. European average figures have been used.

Two sets of emissions factors have been established. One set includes emissions from electricity used in production; the other set does not. The emissions factor for electricity can be selected by the user of the model, but we recommend using the average value for the European OECD nations. In 2004 this was 357 g per kWh. This value has stayed relatively stable over time and corresponds roughly to a modern gas-powered power station that does not have CO_2 capture and storage.

Binding of CO_2 in the materials has not been included in the calculations. We are working on including a set of net emissions factors that take into account CO_2 binding and capture.

Different materials have very different life expectancies. So far, we have not included this in the calculations, but have assumed that all the parts of the building will last for the building's lifetime (60 years). This results in underestimation of the emissions from certain parts of the building. The error is probably not larger than the uncertainty in the overall calculations. We are working on including lifetime functions in the calculation model.

The material module is organised according to building components, Norwegian standard NS 3451. This makes it easier to gather input data from existing building documentation, as well as making the system recognisable.

The material quantities are entered using the units used in the industry i.e. m^2, m, per item, m^3, etc. The model includes an automatic conversion from commonly used units for material quantities (m^2, m^3, etc.) and for composite products (doors, windows, etc.) to kg of the individual basic materials.

In order to make conversion automatic, we have had to introduce some simplifications in terms of the density of the materials, a limited choice of dimensions, representative average values for composite products regardless of manufacturer, etc. This leads to and underlines the generic nature of the model.

We have only included values for construction work; i.e. the model does not yet include technical installations. It thus produces a rather simplified version of an emissions account; however, there is ample opportunity to further develop the model to include technical installations, to expand the number of basic materials and to include composite products directly. The module is going to be expanded to also include these parts.

We are currently working on integrating the module with building information models – BIM. Statsbygg is aiming to ensure that BIM also include a greenhouse gas module, so that greenhouse gases will become a premise when choosing materials.

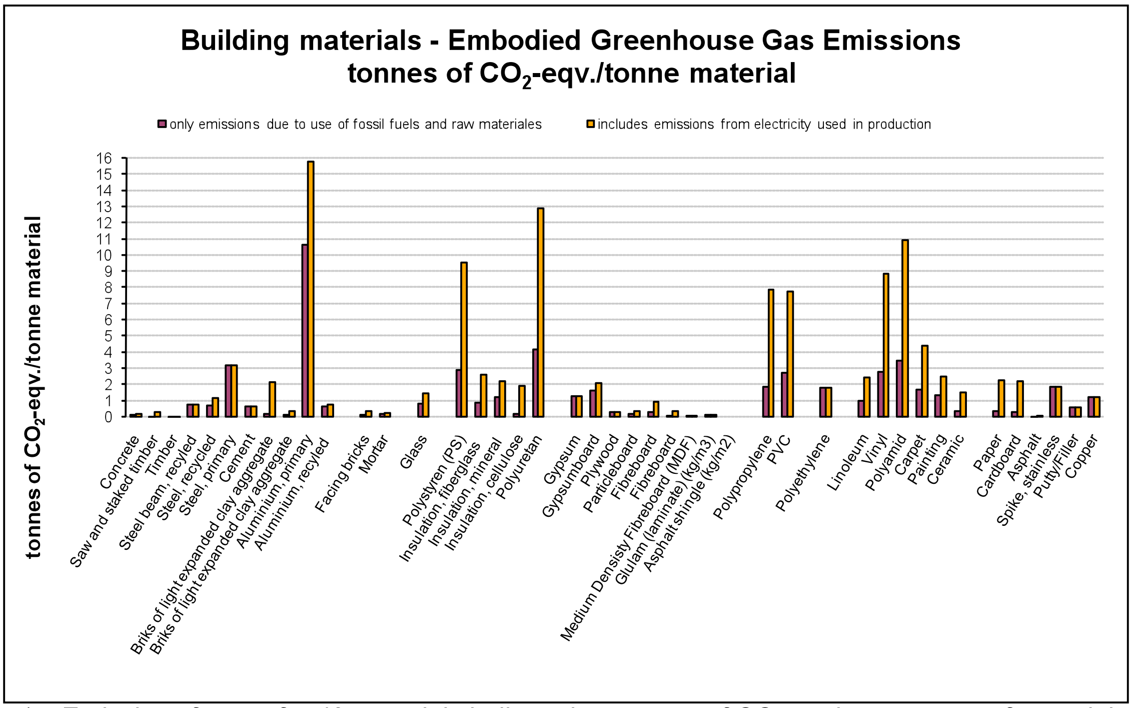


Figure 1 Emissions factors for 43 materials indicated as tonnes of CO_2 equiv. per tonne of material.

2.2.2 Transport of materials, site and construction, module 2

This module calculate GHG emissions from transport to and from the building site using light and heavy vehicles, use of construction machinery such as diggers, bulldozers, drills, cranes, etc. and stationary energy use such as diesel generators, building dryers, lighting, etc.

This requires reporting of data throughout the entire construction phase. Empirical data from similar projects can be used. Emissions factors are linked to the various sources of energy involved: auto-diesel, petrol, gas (LPG) and electricity.

2.2.3 Energy use in the operation phase, module 3

Emissions of GHG from stationary energy use depend on net energy need, the type of energy system and sources used in energy supply. A number of factors affect net energy need, including the design of the building, the thickness of the insulation in the walls, roof and floor, lighting and sun screening, the position of the building in relation to local topographical and climatic conditions, the function of the building, e.g. private home, hospital, etc.

The calculation model cannot assess the impact of these kinds of factors. The purpose of the model is to calculate emissions of greenhouse gases from stationary energy use based on input data on energy needs or measured energy use and chosen source of energy. The percentage of the energy need for electricity-specific purposes must be indicated. The remaining energy needs are hot water, heating and cooling.

The model allows you to specify energy solutions: electricity, district heating, oil boiler (light or heavy heating oil), natural-gas-fired boiler, LPG boiler, bio-boiler and wood-burning stove / open fire. Emissions factors for the different energy systems are given as defined in the Norwegian emissions accounts (Statistics Norway, 2007).

District heating is dealt with separately. The factors must be calculated individually for each project on the basis of information provided by the supplier of district heating to the building, i.e. information about the energy mix involved in production.

It is assumed that emissions factors and energy solutions remain stable throughout the building's lifetime of 60 years. In the event of remodelling or changes in the energy system, new calculations must be performed to find the greenhouse gas emissions from stationary energy use for the building project.

2.2.4 Transport, module 4

Emissions of greenhouse gases from transport come from combustion of fossil fuels such as petrol, diesel, natural gas, LPG, etc. In the event of a subsequent switch to another fuel based on renewable raw materials such as biodiesel, bioethanol, hydrogen, etc., emissions per vehicle kilometre will be reduced. The analysis model allows you to indicate share of carbon-neutral fuel.

The location of the building in relation to city-centre functions and collective transport is an important parameter that affects trip production rates and choice of means of transport. The functions within the building also affect the amount of transport.

The basis for establishing a calculation of the amount of transport from a building in use is empirical data collected in connection with Norwegian National Travel Survey (RVU). This survey has been undertaken several times and provides a good, broad picture of trip production rates, choice of means of transport, purpose of travel and distance travelled in different parts of the country, in different types of location and in different land-use categories.

Default data are used, but can be corrected in terms of the location of the building project in relation to urban centres and any concrete local travel surveys, choice of vehicle fleet policy, etc. Only daily travel is included, not long recreational trips.

Since a trip always has a starting point and a destination, only half of the travel activities are ascribed to the project. There are no grounds for choosing any other distribution of the length of the trip than ascribing equal parts to the point of departure and the destination.

The results are given as emissions distribution between private car, public transport and goods transport.

3. Results

3.1 Six Norwegian building projects

Six building projects that are in the design phase, under construction or recently completed and in use have been chosen; two day-care centres, two university extensions, renovation of a university building and construction of a block of flats.

The functions in the six buildings are so different that we expected to find large variations in construction and choice of materials, energy use, trip production / transport and in the calculated greenhouse gas emissions. The range in the examples provides new insight into the significance of the various different sources of emissions and the scope of the variation between different buildings.

With the exception of Bodø University College, all the projects use district heating, and emissions factors have been calculated for the individual district heating systems. We have calculated emissions from the electricity used for operation of the buildings and in production of the materials used in the construction. Table 1 indicates a number of details for the individual projects.

3.2 Greenhouse gas emissions in a holistic life-cycle based perspective

The model www.klimagassregnskap.no has been used to calculate emission of CO_2 equivalent for the life cycle of the six buildings. The emissions are annualised over 60 years and calculated per m^2 to allow comparison of the buildings. The emissions have been calculated for the three main sources: materials, operational energy use and transport during the operation phase. The results have been further broken down into different building components and personal transport – either public transport or private car.

Emissions from the construction phase and demolition (end-of-life) are not included in the GHG emissions calculations, because of insufficient data. Studies that have documented this have found that they have little impact in a life-cycle perspective. It probably constitutes less than 5 % of the total emissions (see for example Junnila and Horvath, 2003).

Traffic congestion as a result of new development projects, maintenance of infrastructure, changes in land-use (cutting down woodland), etc. are sources which have not been included in the model because of a lack of data and methods.

In the six Norwegian examples in figure 2, the annual emissions of greenhouse gases vary between approx. 40 kg CO_2 / m^2 / year and approx. 90 kg CO_2 / m^2 / year. Greenhouse gas emissions from the two examples from Canada in figure 2 have been re-calculated to approx. 65 and approx. 90 kg CO_2 equiv. / m^2 / year (Norman et al., 2006). All the examples have been calculated over a lifetime of 60 years. The calculated emissions from the projects are all within the same range. However, there are considerable variations; for example in terms of which of the main sources (materials, transport and energy use) dominate the emissions spectrum.

Table 1: Details of six building projects

Name	Year built (compl.)	Gross floor area m^2	Heated area m^2	Net energy needs kWh/m^2	No. of people (inhabitants, teachers / students)	Location
Fornebu Hage, Bærum Municipality	Under constr.[1)]	15,000	15,000	130	167 dw., average of 90 m^2, 2.1 p/dw.	12 km from central Oslo. Local service facilities, average public transport. Good access to parking
Storøya day-care centre, Bærum Municipality	Under constr.	1,000	1,000	65	110 p., approx. 9 m^2/p. (children,staff)	12 km from central Oslo. Local service facilities, average public transport. Good access to parking
Hundsund day-care centre, Bærum Municipality	Under constr.	1,100	1,100	120	134 people, approx. 8 m^2 / pers. (children,staff)	12 km from central Oslo. Local service facilities, average public transport. Good access to parking
The Norwegian Academy of Music (Oslo), Statsbygg	2007	8,000	5,700	222	198 p., approx. 29 m^2 /p. (student,staff)	Central Oslo / Majorstua, good public transport, poor access to parking
Bodø University College, Statsbygg	2004	12,150	11,000	166	1,183 p., approx 10 m^2/p. (student, staff)	5 km from central Bodø, local services, poor public transport, good access to parking
Sørhellinga, the Norwegian University of Life Sciences (UMB), Ås, Statsbygg	2007	11,000	10,000	132	406 p, approx. 25 m^2/p (student, staff)	3 km from Ås town centre, no local services, poor public transport, good access to parking

[1)] Under constr. = Under construction

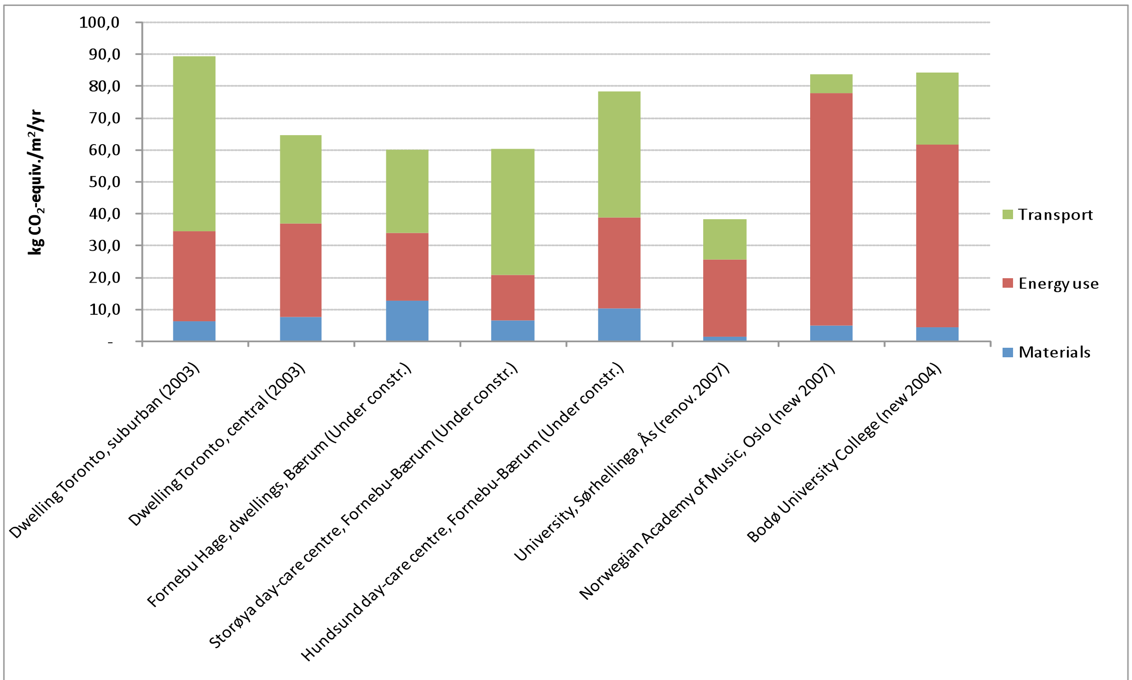


Figure 2: Greenhouse gas emissions from building projects calculated as CO_2 equiv. per m^2 per year. The examples from Norway have been calculated using the model www.klimagassregnskap.no. The examples from Canada (Toronto) re-calculated from Norman et al., 2006, 60 year life cycle.

3.3 Greenhouse gas emissions from transport

Variations in Transport volume can be explained by the function of the building; housing, day-care centre, office block, university or something else. Another important factor is its location in relation to urban functions and public transport. GHG emissions from transportation varies from approx. 6 to approx. 40 kg CO_2-eqv./m^2/year.

The two examples of housing projects in Toronto illustrate this clearly in that emissions from transport are much lower for the central location compared with the peripheral location. In this case, the difference is 40 %. The three Norwegian colleges demonstrate the same ratio: the emissions from transport are four times higher at the peripheral location (Bodø University College) than at a central location close to a major public transport hub (metro, trams and buses) (the Norwegian Academy of Music in Oslo).

The difference in emissions as a result of the different functions is demonstrated clearly if we compare the day-care centres with the housing development at Fornebu. All these three buildings are located in the same area, eliminating the impact of the location factor. The day-care centres appear to generate approx. 1.5 times as much greenhouse gas from transport as the dwellings, calculated per m^2 (see figure 2). The reason for this may be that there are more people (children and employees) per m^2 in the day-care centres, compared with a residential building.

3.4 Greenhouse gas emissions from stationary energy use

Emissions from stationary energy use are determined by the energy needs, energy system and choice of energy source / carrier. GHG emissions from stationary energy use in the Norwegian examples varies from approx. 14 to approx. 75 kg CO_2-eqv./m^2/year (figure 2).

The examples illustrate the importance of a good building envelope with little heat loss and low energy needs, and the significance of choosing a central heating system supplied by a district heating system based on water pumps or bio-energy (choice of primary energy).

The two day-care centres at Fornebu in Bærum Municipality have made different choices regarding energy efficiency. Storøya day-care centre is built according to the Passive House standard, whose requirements considerably lower than those in the Norwegian 2007 Technical Regulations (TEK07). The result is that emissions from energy use in Storøya day-care centre are half the emissions from Hundsund.

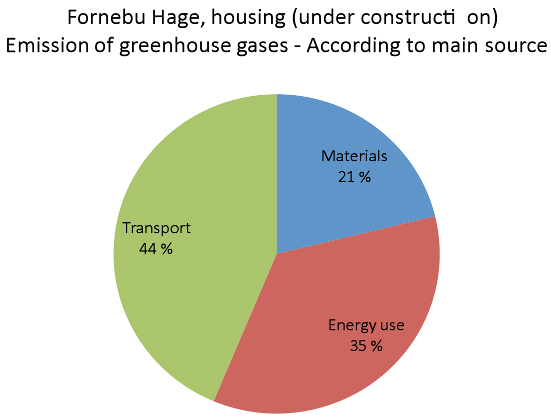
The two colleges, in Oslo and Bodø, have considerably higher emissions from stationary energy use than the other buildings. There are two reasons for this. The first is that they have been designed and built pursuant to old technical energy requirements (TEK97). This means a high specific energy use of 166 and 222 kWh/m^2. The second reason is that heating and hot water are based on electricity and not district heating. The other Norwegian projects use district-heating systems with bio-energy or heat pumps based on geothermal or seawater heat.

3.5 Embodied greenhouse gas emissions of building materials

Emissions linked to use of materials do not occur at the building site, but during production and transport of the materials. The results show that embodied emissions of materials range from approx. 1.5 – 13 kg CO_2-eqv./m^2/year, a share of approx. 5 – 20 % of the total emissions in a life-cycle perspective (figure 3)

The relative significance depends on the energy efficiency of the building and how transport-intensive the activities in the building are. As buildings are being designed to be more energy efficient, renewable energy supply and central location with good relation to service functions and public transport systems, emissions from materials will constitute a larger share of the overall emissions.

For some groups of materials, emissions from transport of the materials from the production place to the building site can be quite significant. These emissions are not yet included due to a lack of data for several of the groups of materials.



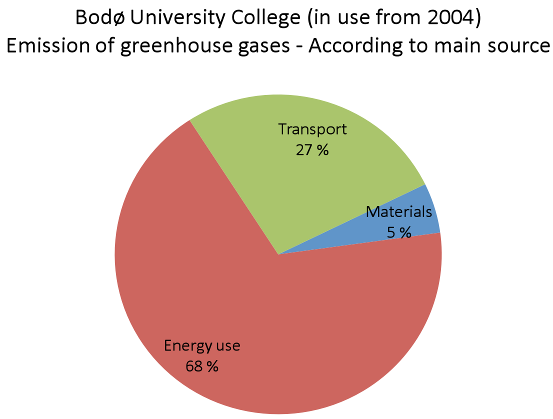


Figure 3: The emissions shares show the relative contribution from materials in a building project where energy efficiency has been given priority (Fornebu Hage) and one where it has not (Bodø University College).

The emissions calculations are based on European averages (generic data) for 43 groups of materials (see figure 1). Two sets of emissions factors have been established: one including emissions from electricity; the other only including emissions from fossil fuel consumption and process emissions. The user can decide which of these two sets of emissions factors to use. In the calculations presented in this paper, we have used the European OECD nations' average of 357 g CO_2/kWh (EEA, 2007). We recommend using this figure, as this factor has remained stable over time and reflects emissions in an integrated European energy market.

The emissions factors are gross factors, i.e. they do not take into account any binding of CO_2 in the materials in the building's lifetime. If binding is included, wood in particular will score better than the other groups of materials.

If we compare the buildings in more detail, we notice large differences in total emissions from materials and in which building components are responsible for the greatest emissions. Overall emissions from materials in the Norwegian examples vary from approx. 1.5 to 13 kg CO_2 eqv./m^2/year (see figure 4). The two Canadian examples are also in the same range, with approx. 6 and 8 kg CO_2/m^2/year (see figure 1).

The renovation of a university building at Sørhellinga (10,000 m^2) has the lowest emissions from materials. In this project, all the heavy, large materials are being reused, i.e. the load-bearing systems, ground and foundations, floors and ceilings, and large parts of the outside walls and roof. As a result, the overall emissions are only approx. 1.5 kg CO_2 eqv./m^2/year.

The three colleges have low emissions per m^2 compared with the housing projects and the smaller day-care buildings (see figures 1 and 4). And this is despite the fact that both the Norwegian Academy of Music in Oslo and Bodø University College have chosen to use concrete and steel in the load-bearing structures and a lot of glass in aluminium frames and bricks on the facades. The explanation for this is that these are huge buildings where the heavy structural elements constitute a relatively small part compared with the indoor area (surface area to volume ratio). Many of the rooms inside the buildings are also large (auditoria, classrooms, reading rooms, libraries, etc.), meaning there are fewer inside walls and surfaces than in a block of flats or a small day-care centre.

At present, we do not have a basis for setting a general score for greenhouse gas emissions from materials per m^2 pr year. The ratio between building volume and volume of materials in the ground and foundations and in outside walls and roofs has a major impact on emission level. However, there are clear tendencies concerning which options seem to yield the lowest emissions regardless of building volume. Renovation and reuse are best, followed by using timber instead of concrete, steel and glass.

Nevertheless, we must emphasise that these calculations are uncertain, and that there are other parameters and factors that need further investigation before we can start planning benchmarking of emissions from materials in buildings.

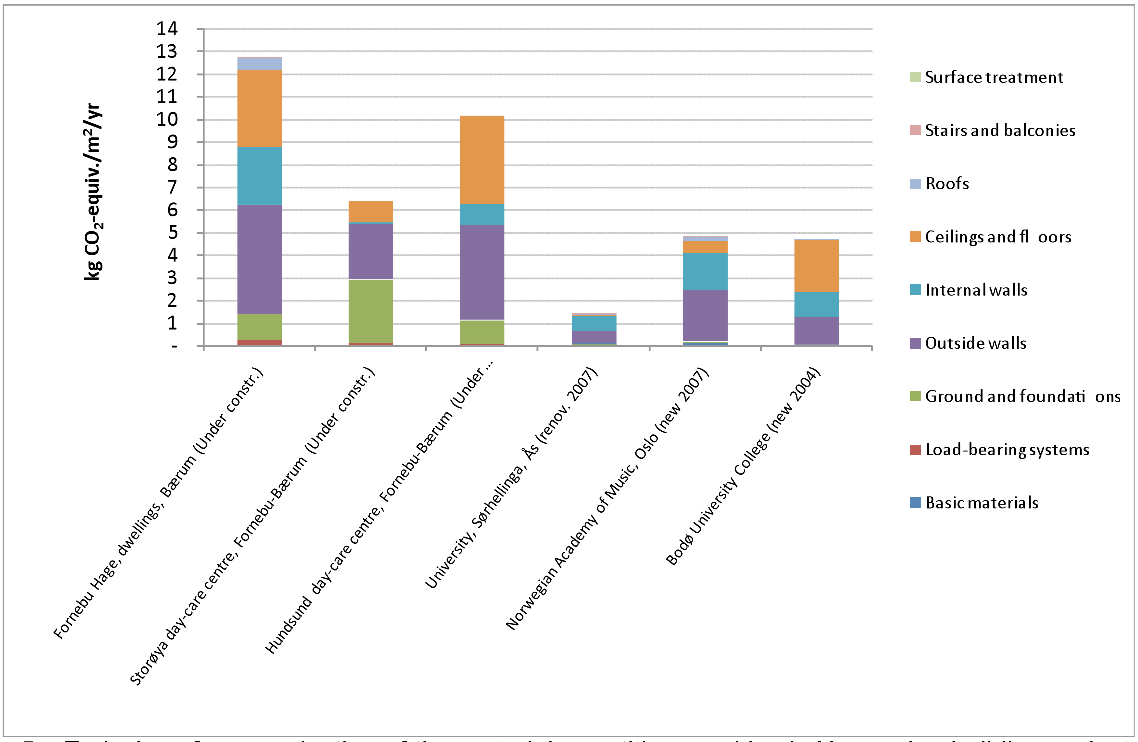


Figure 5: Emissions from production of the material quantities used in six Norwegian building projects.

4 Conclusions

The calculation model www.klimagassregnskap.no has been developed to enable systematic calculation of greenhouse gas emissions for building projects in a holistic, life-cycle perspective. The main sources included in the model are materials used in the structure of the building, operational energy use and operation-phase transport.

The calculation model has been tested on six Norwegian building projects, and the results have been compared with the results from two housing examples in Canada. The results from the Norwegian examples are in the same range as the Canadian findings, i.e. between approx. 40 and 90 kg CO_2 eqv./m^2 /year.

If we compare the buildings and the main sources, the results show that factors such as location, use of the building and choice of energy solutions have the greatest impact on emissions. As emissions from energy use and transport are reduced, emissions from materials will become relatively more important.

The results show that the choices that give the lowest emissions of greenhouse gases are:

- Choice of energy-efficient design and renewable sources of energy and carriers can reduce emissions by more than 50 %.
- Central location and/or proximity to a good public transport system – emissions from transport linked to use of the building can be reduced by more than 50 %.
- Renovation and reuse of buildings – emissions can be reduced by 60–70 % compared with a new building.

The calculation model is easy to use and represents a systematic calculation method that provides new insight into the significance of sources of emissions and measures that help reduce emissions. Integrated with building information models – BIM could the model also be a planning tool.

As more examples become available calculated using the same method, it will be possible to establish benchmarks for different types of building.

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LIFE CYCLE ENERGY PERFORMANCE: EXPLORING THE LIMITS OF PASSIVE "LOW ENERGY" BUILDINGS

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Summary

There is an increasing trend in reducing energy demand of buildings by improving building envelope thermal characteristics. Proven construction examples as used with the German PassivHaus standard achieve substantial reductions on the heating demand compared to mainstream construction, generally by using high levels of insulation together with ensuring excellent air tightness and minimizing of thermal bridges. However, the limits to which levels of insulation in a building can be increased and still represent overall life cycle energy savings are not clear. Particularly for temperate climates, adopting very-high insulation standards can lead to a danger of over specifying construction elements: once we reach certain levels of insulation, any extra material used can have larger energy costs or "embodied energy" than the energy it saves in the life cycle of the building. This paper presents the heating energy use of sample houses in the Irish maritime climate, and analyses the life cycle energy use including the embodied energy of the materials used. A 50-year perspective is presented, and conclusions about the limits to which the heating energy consumption can be lowered by "passive" means on a particular climate are drawn. This paper demonstrates the life-cycle benefits of optimizing the building design ensuring a correct orientation and sizing of the openings, but respecting certain limits when using energy intensive insulation materials.

1. Introduction

Reducing heating energy demand in buildings by means of insulation is recognized as one of the most cost-effective methods for saving energy and reducing CO2 emissions (COMMISSION OF THE EUROPEAN COMMUNITIES 2006). Building regulations around the world are changing to include more strict limitations of heat transfer on construction elements. Voluntary standards such as the PassiveHaus (Passive House Institute) introduced a more radical approach defining strict limits for the heating demand (15kWh/m2 per year), which are normally achieved by ensuring high levels of insulation, together with ensuring excellent air tightness and minimizing of thermal bridges. The potential savings of the application of these type of standards are very high, not only in colder countries but also in maritime climates such as in Ireland (Kondratenko, Brophy et al. 2006). However, as the building envelope performance improves, a higher amount of materials are generally needed, and some of the most commonly used materials like polystyrene have gone through a very energy intensive manufacturing process before they are installed in a buildings, which reduces the net energy savings achieved thorough its life cycle.

Some voluntary assessment methods such as LEED (US Green Building Council) or BREEAM (Building Research Establishment) do account for embodied energy issues, together with a wide range of other environmental impact issues. More detailed LCA tools as SIMAPRO (PRé Consultants) or ATHENA (ATHENA Institute) also offer the possibility of analyzing in detail a wide range of environmental aspects of materials including embodied energy. This paper focuses on a simplified assessment of heating energy demand including embodied energy of materials. While this is not as exhaustive an analysis as the above mentioned environmental assessment methodologies and LCA tools, the authors believe it provides a useful insight when applied with official calculation tools as part of building regulations or national rating systems. In this paper, the methodology is used to explore how far can the energy demand in a building be decreased by "passive" means, including the increase on the levels of insulation, to a level which is no longer a benefit from a life-cycle energy performance perspective, because the additional energy savings of any further improvements are counteracted by the embodied energy of the materials used.

2. Case Study

This case study analyzes the heating demand of a sample house in Ireland. The Irish climate could be classified as a mild climate, which under classifications such as the Köppen-Geiger system would correspond to a maritime temperate climate without a dry season and with reasonably warm climates (Peel, Finlayson et al. 2007). Figure 1 shows the annual solar radiation in Europe, where we can observe that levels in Ireland would have similar levels to those in Central and Northern Europe. This fact together with the mild temperatures means that in Ireland it should be possible to reduce the heating demand by passive strategies, and also might indicate that certain design strategies could be more useful than the mere increase of building envelope insulation levels.

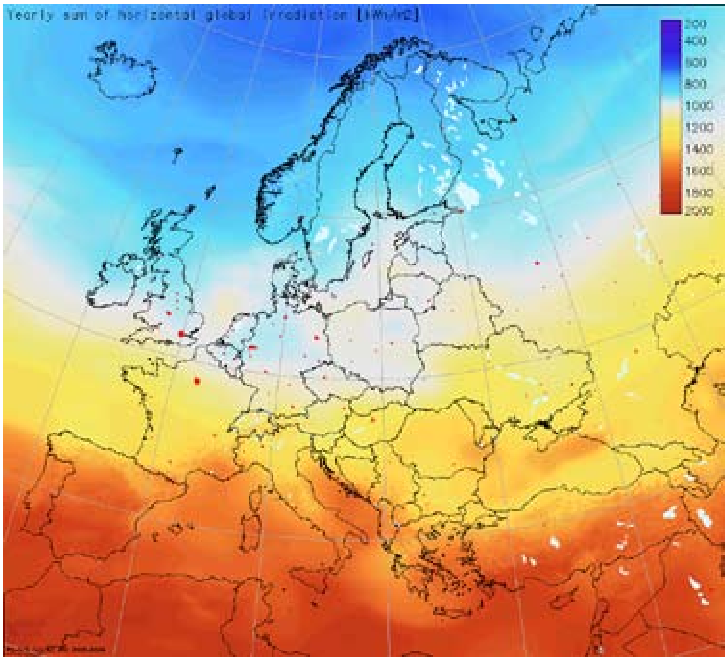

Figure 1. Yearly global irradiation on horizontal surface [kWh.m^{-2}] (Suri, Huld et al. 2007)

For this study the house size and type was selected from examples in the Irish Building Regulations Technical Guidance Document L (Minister for the Environment Heritage and Local Government 2006; Minister for the Environment Heritage and Local Government 2007).

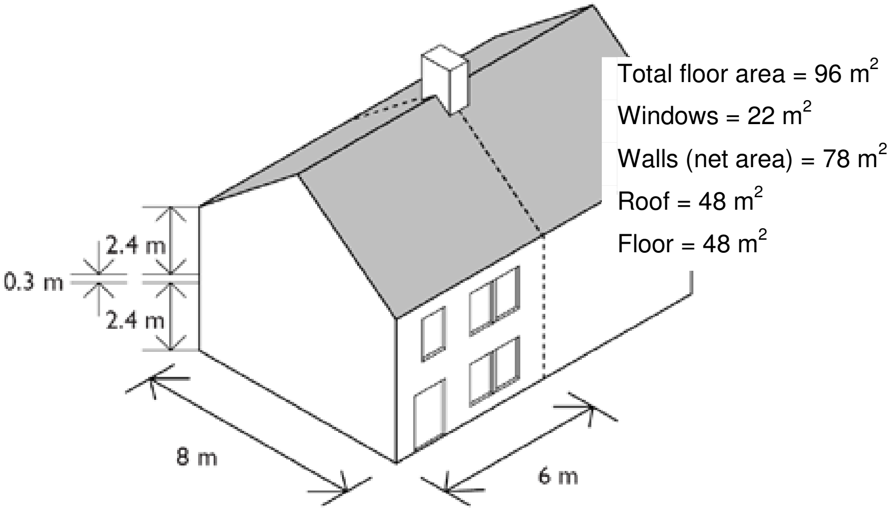

Figure 2. Case study semi-detached dwelling characteristics

These details of the house correspond to a semi semi-detached two storey house, which is the most common type in Ireland. Total area of the windows is set to 22 m^2 with an east-west orientation, which could also represent a typical situation

Our BASE CASE scenario for the case study corresponds to a house complying with the insulation levels from the 2006 Building Regulations, but including some additional energy efficient features such as the reduction of thermal bridging to a value of 87 W/K for the whole house, the limitation of infiltration and ventilation heat losses by air tightening the house (up to 0.60 ach at 50 Pa) and including mechanical heat recovery ventilation with an efficiency of 85% and an specific fan power of 1.0 W/ l *s.

A range of improved U values from the BASE CASE have been considered, the maximum upgrade achieving levels of 0.1 W/m2 K, which is a value already reached in some Irish Passive House constructions. Table 1 shows the different upgrades and U values considered:

Table 1. U values of construction elements for the five building envelope insulation options studied [W/m2 K]

	BASE CASE	UPGRADE 1	UPGRADE 2	UPGRADE 3	UPGRADE 4
Walls	0.27	0.21	0.15	0.12	0.1
Floor	0.25	0.2	0.15	0.12	0.1
Roof	0.16	0.14	0.12	0.11	0.1

Table 2 shows the thickness of the insulation layer needed to achieve the U values for each construction element. Calculations were carried according to the EN ISO 6946 (CEN 1997). The additional insulation material selected to lower U values was polystyrene, which is still one of the most widely used insulation materials in Irish construction. Physical properties of the polystyrene used in this case study are 20 kg/m3 density and 0.034 W/mK thermal conductivity.

Table 2. Thickness of insulation layer [mm]

	BASE CASE	UPGRADE 1	UPGRADE 2	UPGRADE 3	UPGRADE 4
Walls	115	150	210	265	315
Floor	85	120	170	215	270
Roof	255	285	325	365	425

Two options for windows are also considered, a first option is a double glazing unit with an U value of 2.2 W/ m^2 K, which would correspond to a typical window installed to comply with building regulations, and a second option of a triple glazed argon filled window with a U value of 1.0 W/m^2 K, which corresponds to current practice of Passive House designs in Ireland.

To account for the differences between typical and passive solar design strategies, different window sizes and orientation are also considered. The original option of 22 square meters of East / West oriented windows is compared with North/South orientations, and with an increase in windows areas on the south façade. This approach will serve to check benefits of window sizing and orientation on reduction of heating demand, while ruling out daylight issues, although it is understood that the use of daylight will improve with increasing window sizes. The following three additional sets of options are considered:

- A first set considers a change just on the orientation of the windows, maintaining the same house design and window area, but with an equal distribution of windows between south and north, instead of an East/West orientation.
- A second set of options considers an increase of 25% on the total window area, placing the additional area on the south façade.
- A third set of options considers an increase of 50% on the total window area, placing the additional area on the south façade.

As a result of the explained variations of building envelope, window type, and windows size and orientation, a total of 40 possible combinations of options are studied. Each option has been assigned an ID, with the following codes:

- Envelope insulation levels: BASE, UP1, UP2, UP3, UP4 for the 5 envelope insulation options.
- Glazing type : 2G for Double glazing, 3G for Triple glazing
- Glazing orientation: OR represents a North/South orientation
- Glazing area: +25%, +50% represents an increase to the total window area, added to the south façade

As an example, the option UP2_3G_OR_25% would correspond to the case study with the envelope UPGRADE 2, triple glazing, a north south orientation and with an additional 25% glazing area on the south façade.

3. Calculation Methodology for Heating Demand and Embodied Energy

3.1 Heating Demand

The heating demand for the different options was calculated with the DEAP Irish calculation methodology (Sustainable Energy Ireland 2007). Space heating demand in DEAP is calculated for an 8-hour daily heating schedule, between 7-9am and 5-11pm, which is considered a typical schedule. The setpoint temperature is considered 20 degrees Celsius for the living room area (which represents 30% of the total space) and 18 degrees for the rest of the occupied space. DEAP calculation of the heating demand is based on the European standard EN ISO 13790 (CEN 2004), and considering, on a monthly basis, only sensible heat and the following components of the energy balance:

- Transmission losses between heated space and external environment (including thermal bridging).
- Infiltration and Ventilation losses (accounting for air tightness of the house and the effect of heat recovery mechanical ventilation.)
- Internal heat gains
- Solar gains

The results for the monthly heating demand of three of the options, and of annual heating demand of the 40 options considered are displayed on Figures 3 and 4:

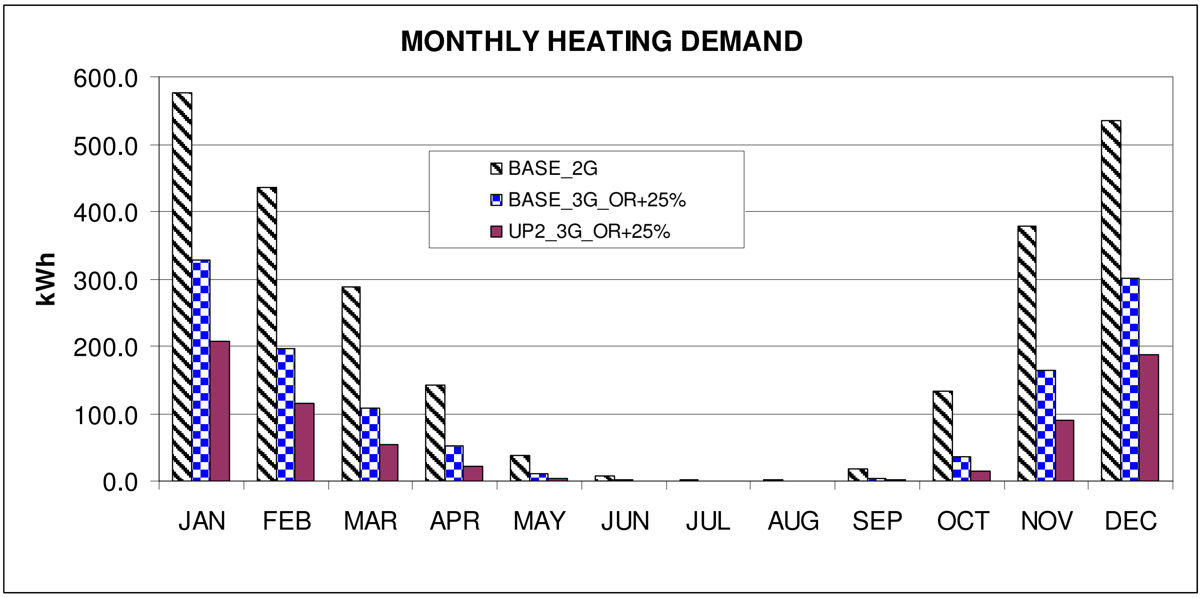

Figure 3. Comparison of monthly heating demand for three of the options

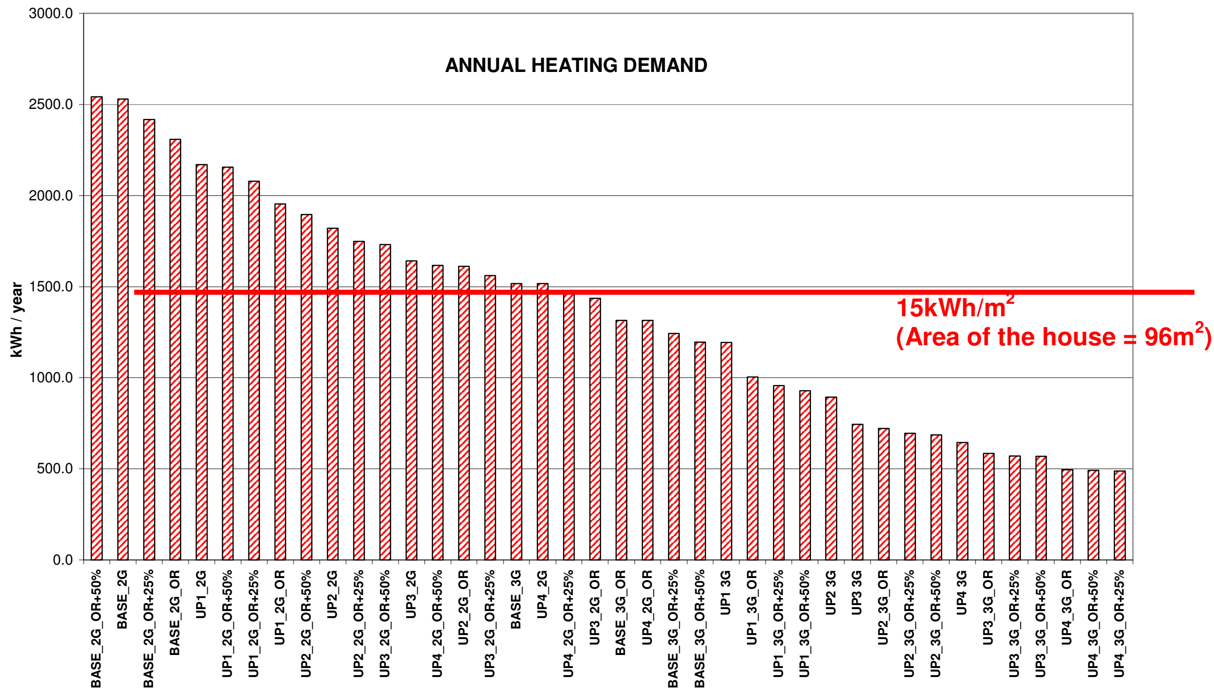

Figure 4. Comparison of heating demand for the 40 different options

From these se figures we can observe that the upgrade of insulation levels from the base case to UP1, UP2, UP3, UP4 has a progressive impact on the reduction of heating demand. It is also very noticeable the impact of the change in the glazing type, where the inclusion of the triple glazing windows has, in most cases, as much impact in terms of heating demand as it has the maximum upgrade of insulation levels. The options with a south/north orientation have a consistently lower heating demand as expected due to the higher solar gains. The increase in the areas of glazing on the south façade, when using the double glazing windows, in most cases increases the heating demand. For triple glazed windows, the annual heating demand slightly decreases when increasing window areas on the south facades, in all cases except for the most insulated option (UP4) where due to the super-insulation solar gains usage would not be enough to offset heat losses through the window.

These first results are what we would expect from an annual heating demand analysis. We can observe that more than half of the options considered will be for example below the threshold of 15 kWh/m^2 per annum which is one of the pre-requisites for PassivHaus standard, the progressive energy savings as we increase the insulation levels.

3.2 Consideration of embodied energy

To simplify the consideration of embodied energy, without the need of a full inventory of all building materials, we propose to use a differential comparison of the proposed building options from the initial base case (BASE_2G). The differential embodied energy referred to the BASE_2G is considered only for the construction elements most directly related to the energy performance, which for this study on heating demand will be the insulation of the building envelope and the windows. All other elements that are not directly related to the energy performance in use of the building or that can be considered the same as the reference base case are then neutralized.

The consideration of embodied energy of materials will be in all cases from “cradle to site”, which will consider all the energy used on from the extraction of raw materials, to manufacturing and transport to the building site.

To calculate the differential embodied energy of each of the options, information was sourced from the following references:

- The embodied energy of building envelope upgrade materials from the Inventory of Carbon and Energy ICE v1.5 (Geoff Hammond and Craig Jones 2006). For polystyrene insulation, a value of 88 MJ/kg was used.
- Embodied energy of upgrading windows was approximated from Weir and Muneer (1998) and Asif, Davidson et al. (2001). The upgrade of windows from double glazing with U value of 2.2 W/m2 K to triple glazed windows with a U value of 1.0 W/m2 K was considered as 500 MJ per m2.

The total differential embodied energy for each of the options, with relation to the basic case, was calculated. The values were annualized for a 50-year period which is a value widely used in literature as shown in a review of case studies by Sartori and Hestnes (2007), and representative for the life of the materials of a building before undergoing major renovations.

Figure 5 shows the comparison of energy options in the same way as Figure 4, but adding the annualized embodied energy for each of the options as calculated for the upgrade of insulation levels or of the windows as a differential from the option BASE_2G. This analysis will give an additional life-cycle perspective of the total energy use and another view on the limits of reduction of energy use by improving building envelope characteristics.

As a first observation, we can note that the differences in the overall energy use (space heating plus annualized embodied energy) between the options with the lower space heating demand is very small. The best option from this life cycle perspective would be the UP3_3G_OR, which is the second best insulation upgrade. That means that upgrading the insulation beyond the limits set on UP3 using polystyrene as the insulation material, would have a negative effect from a life cycle perspective for this case study dwelling in a temperate climate.

The high relative importance of orientation is also clear to observe, as insulating options UP4 with an East/West orientation will have a higher overall energy use (including embodied) than options with insulation two levels below (UP2) and a North/South orientation.

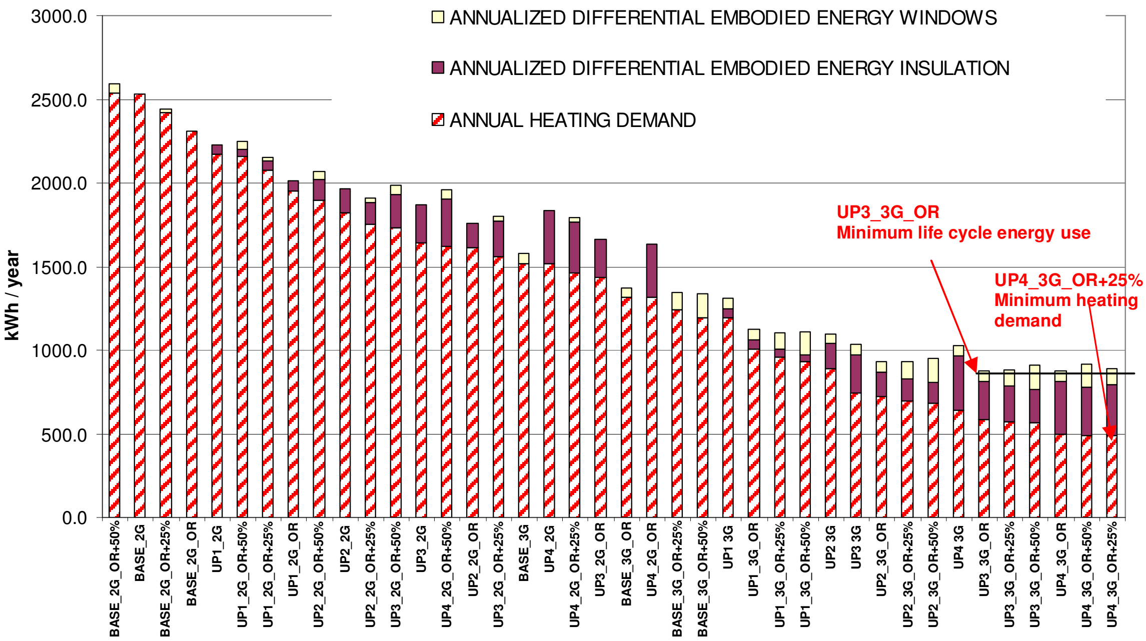

Figure 5. Comparison of heating demand and annualized differential embodied energy (related to the BASE_2G option) for the 40 different options

4. Conclusions

This paper has presented a very simplified approach to study the limits of reduction of heating demand from a life cycle perspective. The analysis added an annualized differential embodied energy factor to the space heating demand of different building design options. The heating demand was calculated according to the current official Irish calculation methodology for energy assessment of dwellings, while the embodied energy of materials was sourced from various references, annualized to a lifetime of 50 year and presented as a differential value related to the option BASE_2G.

The results show how high insulation levels using energy intensive materials such as polystyrene could lead to a higher overall life cycle energy use (over 50 years) than less insulating options. This aspect highlights the importance of choosing low energy intensive materials when pursuing extremely low energy demands, and also the need to carefully study the design alternatives for very low energy buildings, as aspects as orientation and opening sizing would have more beneficial effects from a life-cycle perspective than the mere upgrading of construction materials and elements.

As a final conclusion, this paper with its simplified inclusion of embodied energy adds a life-cycle perspective to the heating energy demand calculation, giving a hint to the dangers of over-specifying insulation levels, which is particularly relevant for mild climates such as that of Ireland and many parts of Western Europe.

The paper also exposes the need for methodologies to allow for this type of calculations in a simplified manner that could be readily available to architects, designers and engineers, perhaps together with official energy assessment tools, to avoid potential situations where no overall life-cycle energy benefits are being achieved by upgrading building envelopes with energy intensive materials.

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SUSTAINABILITY INDICATORS FOR THE BUILT ENVIRONMENT – THE CHALLENGES AHEAD

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Keywords: Sustainable development indicators, tools, stakeholder, construction, materials, buildings

Summary

Methods and tools including sustainable development indicators (SDIs) are important aids to the implementation of sustainable development in the construction industry. Through a qualitative analysis, a variety of methods which are widely used internationally can be assessed to establish their compliance with the general requirements of sustainable development. This paper looks at five fundamental criteria: holism, lifecycle assessment, directional certainty, traceability/transparency and local suitability. Most methods more or less meet these requirements, in which users play a central role in compliance. This paper identifies a number of remaining knowledge deficits: the recording and analysis of sociocultural indicators, additional environmental indicators such as land use, resource intensity, interior quality and usability, and a more detailed understanding of building usage and decommissioning costs. In addition to these knowledge deficits, and for a variety of reasons, there is also an implementation deficit: the practice of sustainable construction is lagging far behind the theory.

1. Introduction

Since its beginnings in the 1980s, the principle of sustainable development has become widespread in almost every section of society and area of the world (United Nations Commission for Environment and Development (UNCED) 1992 and (WSSD) 2002). Many governments, cities and companies have endorsed this principle and engaged in national and international dialogue concerning its implementation (Schweizerischer Bundesrat 2002, World Business Council for Sustainable Development). This follows a process of institutionalisation, for example incorporating the principle into federal law (Bundesverfassung der Schweizerischen Eidgenossenschaft vom 18. April 1999) and allocating responsibilities within and between ministries (Wachter 2006). It is usually then implemented within individual states or sectors such as business, transport and private households.

One example is the European Union's objective of reducing greenhouse gas emissions by 20% between 1990 and 2020 (EC 2008[1]) and the "burden sharing" of national targets between the twenty-seven EU member states. The latter has yet to be completed, and individual states are responsible for taking action to ensure that the national targets are met on time. The construction sector has an important part to play in meeting these targets, since it is responsible for some 40 percent of national greenhouse gas emissions in most industrialised countries (United Nations Environment Programme 2007.) However, the sector is very heterogeneous, with very different structures, standards (see Figure 1) and stakeholders such as private and institutional contractors, tenants and facility management companies.

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[1] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0017:FIN:EN:PDF

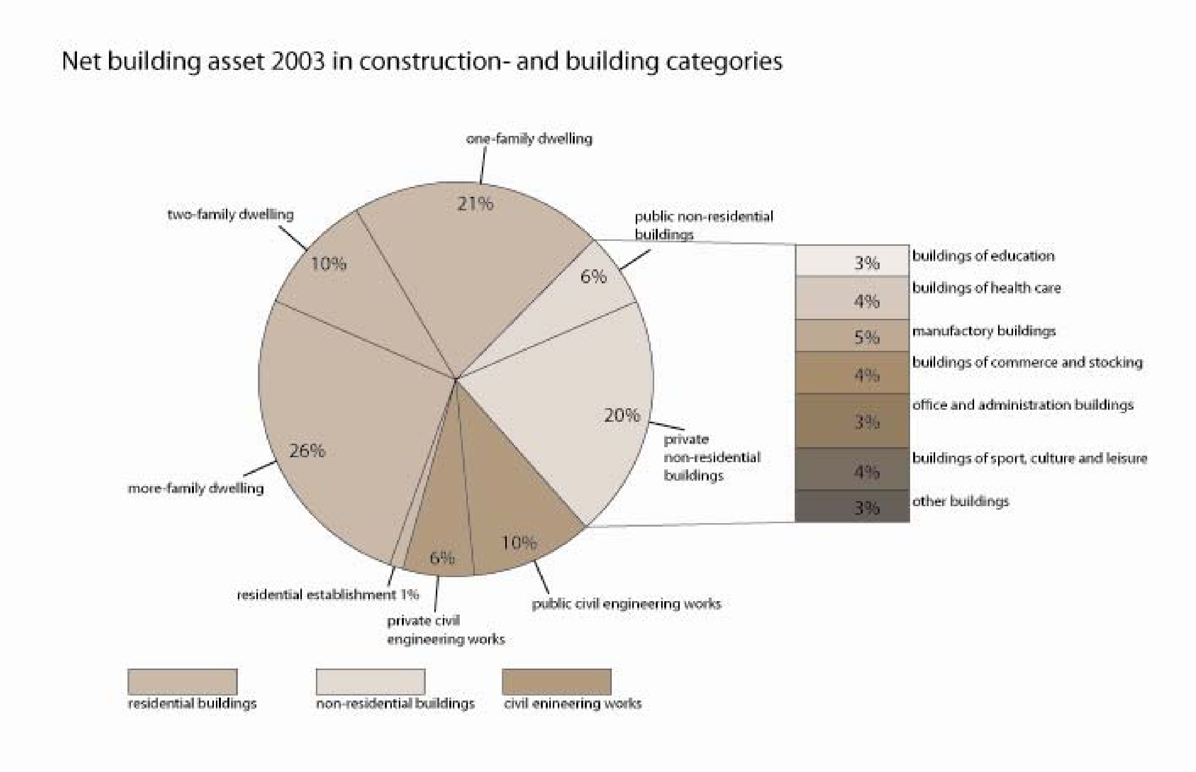

Figure 1 *Structural categories by net building assets in Germany, 2003 (Source: Zeitschrift für Immobilienökonomie, Sonderausgabe 2005; Data: Federal office for Statistic Germany (2004 - VGR); Euroconstruct 1999; Assumption by the ifo institute).*

Any strategies developed, for example to make new and existing buildings more energy efficient, must therefore reflect this diversity while focusing on national greenhouse gas emissions targets. Clearly, specific units of measurement are needed in order to aggregate the effects of what are sometimes localised measures and show these as a national contribution to the overall objective, in this case EU emissions targets. These units are also known as indicators (CO_2 or CO_2 equivalents in this example), and are the focus of this paper, which attempts to

- Formulate requirements for indicators used to assess and measure the construction industry's contribution to sustainable development
- Assess current progress in developing such indicators
- Assess the quality of the data on which the indicators are based, and how widely they are used
- Highlight further research needs

2. Sustainability Indicators

2.1 Definition and History

Indicators are a part of everyday life, often without our being aware of them. Units of measurement such as time, weight, temperature and price are used to describe the condition of anything from a simple object to a complex system. In terms of sustainable development, they allow the key components of the three-pillar approach – environment, business and society – to be converted into usable and relevant information. They can also be used to derive indices, which represent data in its most compressed form (see Figure 2).

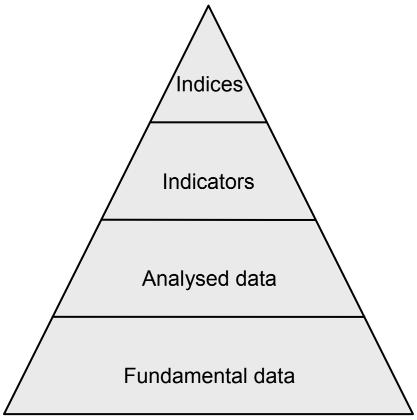

Figure 2 The stage model of information compression (Wallbaum 2002: 59)

In environmental terms, indicators can be defined as “measured, calculated, observable and quantifiable key figures forming part of a targeted system used to make statements about the state and development of the environment. The OECD pressure-state-response approach, for example, distinguishes between pressure, state and response indicators.

The historical background to the rise of sustainable development indicators (SDIs), which cover not only environmental but also economic and social development, is detailed in chapter 40 of Agenda 21 (United Nations, 1992). The first session of the United Nations Commission on Sustainable Development (UNCSD, 1993) expressed the need for a set of SDIs to measure progress in this direction. The first such set was introduced in 1995 and accepted by the UNCSD as a basis for evaluation, and the mandate was further confirmed by the Johannesburg Plan of Implementation, which called for

> …further work on indicators of sustainable development by countries at the national level, including integration of gender aspects, on a voluntary basis, in line with national conditions and priorities (World Summit on Sustainable Development 2002).

The report of the 13th session of the UNCSD on 11-12 April 2005 also pointed to the need for continuing work on SDIs at an international level (UNSCD 2005).

Alongside the more general efforts to develop SDIs, the construction industry has a long tradition of developing and using indicators. Table 1 below, which makes no claim to comprehensiveness, gives an idea of the many other tools and approaches used in an international context. These mainly differentiate between indicator-based analysis of materials, components, buildings and settlements. Towns and cities are not mentioned at this point since, to the best of the author's knowledge, the only comprehensive and specifically construction-related studies focus on individual aspects such as material flows and energy consumption rather than on the interaction between them.

Table 1 Use of SDIs in construction-related methods and tools, differentiated by level (in alphabetical order)

Materials	Components	Buildings	Settlements
Ecoinvent* (e), GaBi* (e, f, s), ixbau (e, s), OGIP (e, f), Simapro (e), Umberto* (e, f)	Bauteilkatalog (e, f), BEES (e, f), ecosoft (e), Ecoinvent* (e), GaBi* (e, f, s), Minergie-ECO (e), OGIP (e, f), Simapro* (e), Umberto* (e, f)	CASBEE (e), LEGEP (e, f), LEnSE (e, f. s), EPIQR (e, f), HQE (e, s), LEED (e, s), OGIP (e, f), SBTool07 (e, f, s), SNARC (e), Vitruvius (e, f)	COMPASS (e, f, s)

The letters in brackets refer to the main emphasis of the indicators used in the method or tool, as follows: (e) ecological, (f) financial, (s) societal.
*Not specifically developed for the construction sector

Table 1 is noticeably dominated by environmental indicators, which are used in all the methods cited. The second most common are financial indicators, and societal indicators appear only in a small number of methods.

Another noticeable feature is the large number of methods at the component and building levels, since these are used by planners and architects. The traditional environmental balancing tools at the component level require a very comprehensive knowledge of such areas as process technology and materials science, and are therefore not primarily aimed at these two professions.

Very few methods use SDIs at the settlement level. One current sustainability research programme being carried out by Novatlantis at the Swiss Federal Institute of Technology[2] deals with the development of sustainability criteria at district level. During the first stakeholder consultations, it became clear that settlements contain a more varied pattern of interests and stakeholders than other levels such as materials, components and buildings; stakeholders on the demand side, such as banks, contractors, tenants and local councils, do not yet have clearly localised interests and sometimes have to be served by target-group-specific SDI sets. Any meaningful set must also meet other requirements in terms of practicality and scientific rigour, and these are described below.

2.2 Fundamental Requirements

If SDIs are to serve their purpose, they must cover all dimensions of sustainable development; in other words, they must be **holistic**. These dimensions vary depending on the theoretical, social, political or cultural approach adopted, though most use the three-pillar model, comprising financial, environmental and social dimensions. Cultural and institutional dimensions may also be included, and individual dimensions may be further subdivided; the five-level model, for example, combines the environmental dimension with the chemical-physical and biological levels (Rauch-Schwegler 2005). Here, the challenge lies in implementing the selected dimensions for the construction industry. A view focusing primarily on ecological criteria does not meet the requirements for sustainable development, though the limited perspective in which ecology equals sustainability is still very widespread.

Secondly, SDIs must **cover the whole life cycle**, including all the various activities involved, such as raw materials extraction and processing, transport costs, and the construction, use and decommissioning of the building. Here, the challenge lies in selecting appropriate system boundaries so that the SDI set can still be used. Depending on the level at which the system is being examined, this also includes infrastructure such as water and sewage disposal.

System boundaries must be chosen in such a way that the significance of the elements being analysed is not consciously or unconsciously limited. The observed parameters or boundaries will need to be restricted on the grounds of practicality, but this should not be at the expense of **directional certainty**. SDIs should, if possible, be designed and used to ensure bottom-up and top-down compatibility, which can make the use of statistical data easier or more difficult.

Another requirement is **traceability and transparency** in terms of the dataset used, the assumptions made and the accounting and evaluation processes employed. This is important in ensuring scientific precision and as the basis for the intended communication to the target group.

In order to ensure transparency, SDI sets must be **adapted to local conditions**, at least in terms of the evaluation process used. For example, adequate supplies of fresh water are available in most north European countries, whereas in most southern European towns and cities it is a scarce commodity requiring particular attention.

3. Discussion

Most of the methods shown in table 1 are designed to meet pre-formulated requirements. Responsibility for the accurate use of SDIs lies primarily with users, so the conformity of these methods and tools has not been assessed here. However, in order to ensure that the analysis is holistic, it is possible to carry out an initial assessment based on the focus of each method

[2] http://www.novatlantis.ch/index.php?id=50&L=1, last checked April 8, 2008

shown in table 1. This clearly shows, for example, that societal indicators and evaluation processes must often be supplemented by others if the developer/seller intends to carry out any type of holistic sustainability assessment.

Although many methods deliberately do not assess holism, the dimensions depicted show room for improvement in terms of knowledge and implementation deficits. Table 1 shows that more research is undoubtedly required into the development and testing of social and cultural indicators. Some efforts have been made in this direction, such as SEEBalance, BASF AG's socio-efficiency assessment of products and processes,[3] or Sabento software for the biotechnology sector,[4] which make a valuable contribution when these dimensions have only just begun further development.

Even the environmental dimension, which has received a very great deal of international attention, requires further research. The knowledge deficits in this area include quantitative land use indicators, and qualitative indicators for construction sector activities. While some work has been carried out in this area,[5] there is still no conclusive analysis of the indicators' suitability and directional certainty. Most methods do not give sufficient attention to resource consumption throughout the life cycle in terms of energy sources and sustainable and non-sustainable raw materials (Wallbaum 2007), although the first tools are being developed.[6] More research is needed into the measurement and evaluation of sick building syndrome and other aspects of interior comfort, and in this respect there is considerable overlap with heating, ventilation and air conditioning. Here again, it is important to select appropriate system boundaries, since many contaminants are introduced into building interiors not from construction materials but from floor coverings and/or furniture.

More research is also needed into lifecycle costs, which are still often simplified to cover only capital costs. Some studies have been carried out into building usage costs (Stoy 2005), though these still have some gaps in terms of sample size and coverage of different types of building. They also highlight the fact that usage costs have traditionally been defined as operating costs (such as repairs, maintenance, electricity, water, and waste removal), and need to be extended to include capital costs and depreciation. This is the only way of monitoring and influencing construction-related decision-making by institutional investors and others; if costs are monitored throughout the lifecycle, it will undoubtedly be possible to develop financial indicators for decommissioning costs.

A specific challenge must be seen in the sustainable development of the building stock. Most of the listed tools in table 1 are not limited to new constructions but they are not specialized in the assessment of the building stock. First tools in this regard have been developed and approved in practice. One tool is "idi-al"[7], a tool developed by the Working Group on the renovation of the building stock (Bundesarbeitskreis Altbauerneuerung - BAKA) in Germany. idi-al assesses the physical situation of existing buildings and derives from this status quo study building appropriated refurbishment measurements. The proposed measurements include prices and the ecological optimisation potential, e.g. in terms of achievable energy savings. However this tool does not answer all the questions the issues of longevity and survival rates and their impact over the whole life cycle. But these issues are crucial to enable us to make a statement about the mix of new constructions, replacement buildings and the refurbishment of the building stock for a city to achieve the optimum in terms of economic, ecological and societal performance of the city building portfolio.

4. Conclusions

Although this paper has highlighted various knowledge deficits, the existing data and the large number of methods available can be described as very good. In most cases, if the methods were used accurately on this basis, they could make a substantial contribution to sustainable development in the construction industry. In practice this is very rarely the case, for a variety of reasons:

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[3] http://www.corporate.basf.com/en/sustainability/oekoeffizienz/seebalance.htm, April 8, 2008
[4] http://www.sabento.com/en/index.htm, last checked April 8, 2008
[5] See land use in GaBi; http://www.gabi-software.com/, last checked April 8, 2008
[6] http://www.holzwende2020.de/index.php?seite=319, last checked April 8, 2008
[7] http://www.idi-al.de/, last checked July 24, 2008

- limited awareness of sustainable construction (industry, politics and building owner/tenants),
- limited government enforcement and incentives,
- a lack of training within the sector,
- and the finance sector's lack of commitment to sustainable construction.

If the industry is to start becoming sustainable, the knowledge gaps must be filled and the existing knowledge implemented.

Creating a framework to make this possible is one of the key social challenges facing decision makers in the construction sector. This framework could be created by properly addressing the issues raised above. However, the most promising point, in terms of effectiveness of fostering sustainability in the construction sector, seems to be the stimulation through standards and regulations (UNEP SBCI 2007: 53) to overcome the most important barriers in this sector, i.e. hidden costs (transaction costs) and market failures.

Another promising approach could be the (additional) implementation of certain market driven incentives, like the implementation of a national rating and labelling system for sustainable buildings. To achieve a high degree of acceptance for such a rating and labelling system, it has to be developed in a participatory process that includes a broad variety of stakeholders. Furthermore this rating and labelling system should make use of existing data and information, e.g. to apply for a planning and building permission. Redundancy of data input from the side of the planer, architect or construction company has to be minimized as far as possible. At the best a planer will get with the rating certificate other supporting documents as "by-product" that are related to governmental requirements. Finally, this rating and labelling system should replace as much of the permissions and certificates that are needed at present.

The ongoing activities of the German chapter of the Green Building Council are currently running such a process[8]. The results and a first national rating and labelling system should be available at the end of the year 2008. To ensure the scientific accuracy of this sustainability rating and labelling system for buildings in terms of conformance with its goals it will be crucial to monitor the process, especially in the very beginning. Ecological and Economic Life Cycle Assessment that are conducted in parallel from case to case could contribute with results that indicate gaps or recommendations of adjustment within the rating system. Using a full Life Cycle Assessment it has been shown in the case of LEED that a better labelling grades does not necessarily correspond with a better ecological performance (Humbert et al. 2007).

Both filling knowledge gaps and implementing this knowledge need to go hand-in-hand if sustainable development in the construction industry is to be transformed from a utopia into a reality.

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BUILDINGS DESIGNED WITH AN ENERGY-EFFICIENT BUILDING ENVELOPE

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Keywords: air tightness, thermal bridge, leakage, sustainable, building envelope, heat loss, joints

Summary

In buildings the largest and most cost-effective potential for energy savings lies in reducing energy consumption. Reducing energy consumption in buildings for heating and comfort will lead to more sustainable buildings. Methods for reducing the energy consumption in buildings by reducing heat loss through the thermal envelope were discussed. In particular air tightening of the building envelope and superinsulated building components. Principles for air tightening of the building envelope were discussed and new principles for making superinsulated strip foundation of prefabricated lightweight elements were introduced and demonstrated as an alternative to strip foundation of concrete as traditionally used. The prefabricated elements, made of expanded polystyrene, were designed to be handled on site by one man. An area of non-freezing ground was established by using outer insulation located at the outer plinth. The element was integrated into the insulation located underneath the concrete floor slab, constructing a foundation system that allows very little energy to be lost through the joint that connects the concrete floor slab with the outer wall. The strip foundation allows for a full and continuous insulation cover against the heated part of the building.

1. Focus (2008)

The new Danish Building Regulations (Danish Enterprise and Construction Authority 2008) will have an impact on energy consumption in buildings, in that the regulations focus on the thermal envelope as well as individual building components. The aim is to reduce energy consumption for heating and comfort and that this will lead to more sustainable buildings. The new Danish Building Regulations entered into force on 1 February 2008.

One focus area was heat loss through the thermal envelope, in particular methods that ensure air tightening of the building envelope, eliminating thermal bridges and innovation of individual building components.

The new Building Regulations are part of a major action plan presented in 2005 by the Danish Government. The action plan aimed to promote significant results in the energy field. This action plan will have an impact on Danish energy-saving initiatives in years to come (Ministry of Transport 2005). The action plan includes a description of the Danish energy sector in the years leading up to 2025. One strategy of the action plan is the climate policy related to the Kyoto Protocol, United Nations (1998), which entered into force on 16 February 2005. As part of the internal distribution of obligations within the EU, Denmark must reduce its emissions of greenhouse gases by 21% compared with 1990 (Olesen, et al. 2004).

The action plan focuses on energy consumption in buildings, where the largest and most cost-effective potential for energy savings lies. The most important initiative is the tightening of the energy provisions in the new Danish Building Regulations.

The tightening of the energy provisions paves the way for further strengthening in 2010 and in 2015. The tightened energy provisions will result in an energy reduction of 25% for new buildings compared with buildings built in accordance with the former Building Regulations (Danish Enterprise and Construction Authority 1995).

2. Heat Loss through Leakages in the Building Envelope

Air tightness is an important property of building envelopes. It is a key factor for determining infiltration and related wall performance properties such as heat loss, indoor air quality, maintainability and moisture balance. Air leakage through the building envelope contributes to ventilation, heating and cooling costs and moisture migration. Air tightness is the property of building envelopes that is most important for understanding ventilation. It is quantified in a variety of ways, all of which typically go under the heading of “air leakage”. Air tightness is important from a variety of perspectives, but most of them relate to the fact that air tightness is the fundamental building property that impacts infiltration. There are a variety of definitions of infiltration, but fundamentally infiltration is the movement of air through leaks, cracks, or other unforeseen openings in the building envelope.

There is a direct connection between an airtight building envelope and a low consumption of energy in the building. In the North European countries, where outdoor air that seeps in through unforeseen leakages in the building envelope, infiltration increases the energy consumption for heating. It is estimated that infiltration increases the energy consumption by 20 to 30% compared with an airtight building envelope (Valdbjørn Rasmussen and Nicolajsen 2007). With regard to a better heat–insulated thermal envelope, the importance of an airtight building envelope becomes more pronounced in relation to the total energy consumption of the building. Furthermore, infiltration in the building envelope will result in both a less efficient heat exchanger if used for the ventilation system of the building and an increased risk of mould growth within the building envelope. However, a building must be ventilated. Fresh air should be provided to the building in an energy-efficient way that satisfies human needs for hygiene and comfort.

2.1 Air tightening of the building envelope

An airtight shell defined as that shell which encases the heated interior of a building and prevents infiltration in the thermal envelope is introduced, see figure 1.

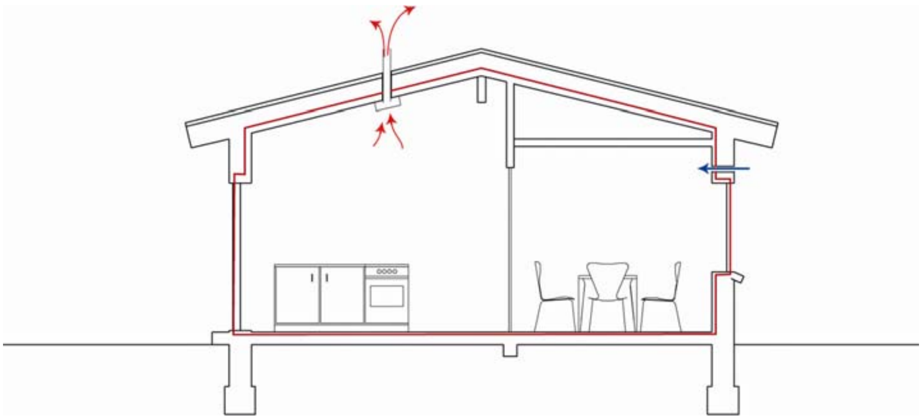

Figure 1 Location of the airtight shell in a building. The shell follows the building envelope, which consists of lightweight or heavy weight building components like wood-stud walls and concrete wall elements, respectively, combined with windows, doors, ceiling, roof and floor-slab constructions.

Typically the airtight shell follows the building envelope that consists of lightweight or heavy weight building components like wood-stud walls and concrete wall elements, respectively, combined with windows, doors, ceiling, roof and floor-slab constructions. Critical locations in the shell are located where building components are located in staggered levels, in joints between building components and at ductways, where installations are brought into the building. For lightweight building components such as wood-stud walls and ceilings, the airtight shell can be established by a 0.15 to 0.2 mm polyethylene foil additionally serving as the vapor barrier located within the insulation layer, e.g. placed between the wood trusses and the laths, see Figure 2. When the foil is used as a vapor barrier as well as an airtight shell, it is crucial that the foil is located at the warm side of the dew point and that the joints between the sheets of foils and joints facing other building components are securely fixed and airtight. Furthermore it is crucial that the joints keep their airtight properties during the lifetime of the construction, and are not damaged or decomposed during their service life. This entails a great deal of focus on how to establish the airtight shell on site during the design phase.

When preventing infiltration of the building envelope, a more efficient heat exchanger can be established, if used for the ventilation system of the building. A building should be ventilated to provide the building with fresh air to satisfy human needs for an indoor climate with a good hygiene and good comfort. When designing the ventilation system of a building, indoor air is primarily removed from rooms producing moisture and pollution from indoor activities, including rooms such as kitchens, utility rooms, bathrooms etc. Outdoor air supply is provided to living rooms and residential areas. The ventilation should not cause air velocities that locally exceed 0.15 m/s, which is normally considered to be the limit when humans feel a draft from airflow. Figure 2 shows a vent for ventilation mounted in the ceiling. The airtight shell was located in the ceiling and the vent was built into the shell. The vent was fixed to a wood support attached to the wooden trusses. The vent itself should be airtight and attached airtight to the airtight shell of the entire ceiling. The airtight shell of the ceiling was established by a polyethylene foil that also served as a vapor barrier. The polyethylene foil was placed between the wood trusses and the laths. The polyethylene foil was mounted on the frame of the vent and joint. The joint was secured and fixed in a way that ensured that it would perform and stay airtight during its service life.

Figure 3 shows a hatch for passage to the loft through the ceiling. Where the airtight shell was located within the ceiling, a hatch was mounted in the ceiling so it was built into the airtight shell. The hatch itself was airtight and the airtight shell of the hatch was extended to the airtight shell of the entire ceiling. By using a polyethylene foil as the airtight shell in the ceiling, the foil had to be securely attached to the frame of the hatch. A packing between the opening part of the hatch and the frame of the hatch ensured that the hatch was airtight when it was closed.

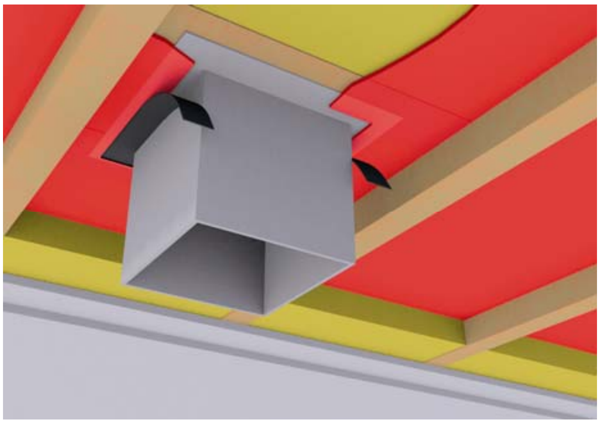

Figure 2 Ceiling-mounted vent for ventilation. The figure shows in detail how the airtight shell of the entire ceiling was attached to the vent. The airtight shell in the ceiling was established by a polyethylene foil, additionally serving as the vapor barrier. The polyethylene foil was placed between the wood trusses and the laths. The polyethylene foil was joined to the frame of the vent. The joint was secured and fixed in a way that ensured that it would perform and stay airtight during its service life.

Infiltration in the airtight shell was located by creating a pressure difference between the interior and the exterior of the building. By maintaining a pressure difference, infiltration would be revealed when designed openings in the building envelope were closed. Having lower outside temperatures compared with the temperature inside the building, infiltration was easily revealed by maintaining a low pressure inside and using thermograph equipment.

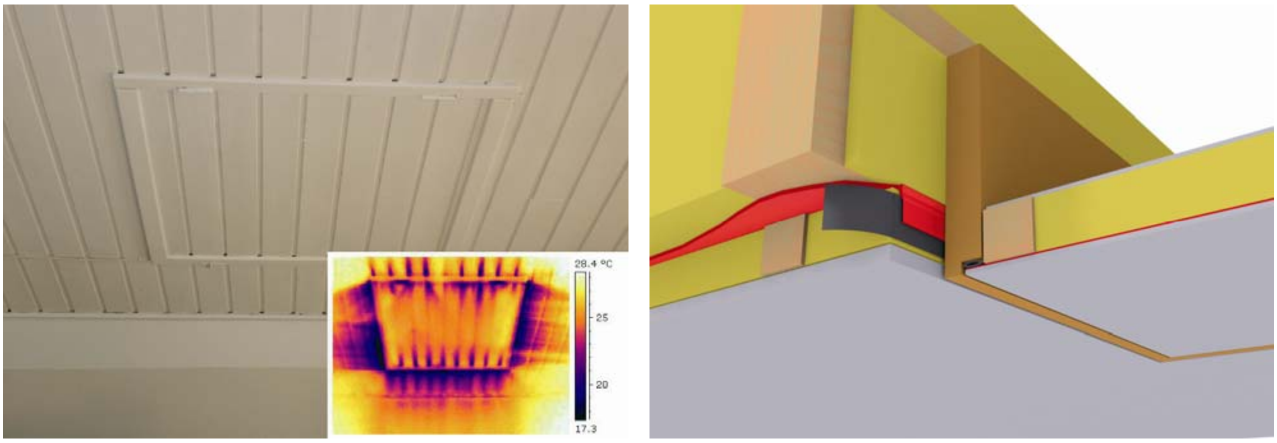

Figure 3 Ceiling with a hatch. The picture to the left shows an ordinary photo of a ceiling with a thermographich picture inserted at the lower right corner. The thermographic picture shows the infrared thermographic observation of a ceiling with a hatch. The colors on the infrared thermographic picture visualize the temperature of the ceiling. To the right, the figure shows in detailed how the airtight shell of the hatch was extended correctly to the airtight shell of the entire ceiling. The airtight shell in the ceiling was established by a polyethylene foil that also served as a vapor barrier. The polyethylene foil was placed between the wood trusses and the laths. The polyethylene foil was joined to the frame of the hatch. The joint was secured and fixed in a way that would ensure that it stayed airtight during its service life.

Thermograph equipment was used to show surface temperatures. Low temperatures inside a building reveal thermal bridges or locations of infiltration where cold air was sucked in when a low pressure was created inside. An infrared thermographic observation of a ceiling with a hatch is shown in Figure 3. The colors on the infrared thermographic picture visualize the temperature of the ceiling. The pictures to the left show an ordinary photo of the ceiling with the thermographic picture inserted at the lower right corner. To the right, the figure shows in detail how the airtight shell of the hatch was extended correctly to the airtight shell of the entire ceiling when fixed. The airtight shell in the ceiling was established by a polyethylene foil, additionally serving as the vapor barrier. The polyethylene foil was placed between the wood trusses and the laths. The polyethylene foil was mounted on the frame of the hatch and joint. The joint in particular was secured and fixed in a way that would ensure that it stayed airtight during its service life.

Heavy-weight building components such as concrete wall elements should themselves be airtight as well as being able to joint airtight for use in and as the airtight shell. Guidelines for establishing an airtight shell are given in Valdbjørn Rasmussen and Nicolajsen (2007).

2.2 Heat Loss through Thermal Bridges in the Building Envelope

A thermal bridge is defined as that a part of the building envelope where otherwise uniform thermal resistance is significantly changed. Typically by a full or partial penetration of the building envelope by materials with a different thermal conductivity, or by a change in thickness, discontinuation of the insulation material e.g. at wall, floor and ceiling joints. Typically such thermal bridges occur at the joints of different building components where it is difficult to achieve continuity in the thermal insulation layer. Thermal bridges give rise to two- or three-dimensional heat flows and have a major effect on the thermal performance of the building envelope. Thermal bridges decrease the internal surface temperature locally, thereby increasing the risk of mould growth at high humidity levels (Valdbjørn Rasmussen et al. 2006). The better the insulation of the building envelope, the larger the relative contributions of thermal bridges to the overall transmission heat loss of the building, and the more important it is to develop improved constructional details as well as improved buildings components. The effect of thermal bridges in the building envelope is significant, either due to the long length of joints per unit of the heat loss surface or due to joints with large thermal transmittance. It is estimated that thermal bridges in the building envelope increase the energy consumption by 13 to 17% compared with a continued homogenously insulated building. When attention is paid to avoiding thermal bridges in construction detailing, the contribution of building joints to the thermal transmittance may be minimized to less than 5% of the heat loss (Janssens et al. 2007). In low energy building design, this quality of detailing is certainly necessary to obtain a sufficiently low average thermal transmittance of the overall building envelope.

One focus area has been heat loss through the strip foundation of a building. In order to improve the joint between the exterior wall and the floor slab, a new solution was introduced as an alternative to the traditional Danish strip foundation of concrete. The new solution was a prefabricated lightweight element intended to meet the same performance requirements as the ones traditionally used.

2.2.1 Superinsulated strip foundation elements

The prefabricated elements were made of expanded polystyrene to form an element that could be used as the strip foundation of a house up to two storeys high. Elements were produced as one coherently shaped element through a production including an injection-molding process. The expanded polystyrene is produced from a mixture of about 5-10% gaseous blowing agent (most often pentane or carbon dioxide) and 90-95% polystyrene by weight. The solid plastic is expanded into a foam through the use of heat, usually from steam. The voids filled with trapped air give the element a low thermal conductivity. This makes it ideal as a construction material used as insulation in building systems. In the following the expanded polystyrene will be referred to as EPS. The calculated thermal conductance is 0.034 W/mK. The prefabricated element was specially designed to form the base for a house with an exterior wall of either a traditional double-brick wall, a traditional wood-stud wall, or combinations of lightweight concrete, brick and wood-stud walls with insulation. However, only when the strip foundation was fully integrated into the insulation located underneath the house, a foundation system was created that allowed very little energy to be lost through the foundation element that connected the concrete floor slab and the outer wall. In this case the strip foundation was to form the base for a house with an exterior wall made as a traditional wood-stud wall within insulation. The prefabricated EPS element was produced as units of 1.2 m in length and 0.6 m in width. The prefabricated element is 98% air by volume and has a density of 33.0 kg/m^3. The EPS has a characteristic short-term compressive strength equal to 250.0 kPa and long-term compressive strength equal to 75.0 kPa with a 2% strain, see Figure 4 a).

Figure 4 b) shows the prefabricated element made of EPS used as the strip foundation of a traditional wood-stud wall within mineral fiber insulation. When supporting a wood-stud wall, the insulation underneath the concrete floor slab can be of the same thickness throughout the concrete floor slab. The exterior wood-stud wall is supported by the concrete beam behind the outer plinth.

The prefabricated element of EPS was designed to form part of a foundation system that allows very little heat to be lost through the strip foundation, the joint between the ground deck and the exterior wall. The heat loss through the strip foundation will be referred to as the surplus heat loss, [W/mK] in the following. The surplus heat loss is defined as that heat loss which cannot be attributed to the one-dimensional heat loss through the ground deck and the exterior wall, individually. Surplus heat loss through the joint between the ground deck and the exterior wall is closely related to the design of the strip foundation.

Stainless steel rods of 5 mm in diameter were put through the EPS, every 0.6 m, forming the mechanical fastening point of the concrete for the outer plinth and the concrete floor slab. The mechanical fastening between the concrete for the outer plinth and the concrete floor slab contributes to the surplus heat loss through the strip foundation element. By using stainless steel rods, the contribution to the surplus heat loss is 0.002 W/mK (Danish Standards 2002, Table A.3.2). However, the contribution to the surplus heat loss decreases by using carbon fiber or other types of materials with a low coefficient of heat transmission to establish the mechanical fastening of the concrete for the outer plinth and the concrete floor slab.

The method calculating the surplus heat loss through the prefabricated strip foundation element is shown in Valdbjørn Rasmussen (2007 and 2008); a PC is used and the finite difference program HEAT2 version 5.0 in accordance with the method described in Danish Standards 2002. Calculations are dynamic with the outdoor temperature changing throughout the year.

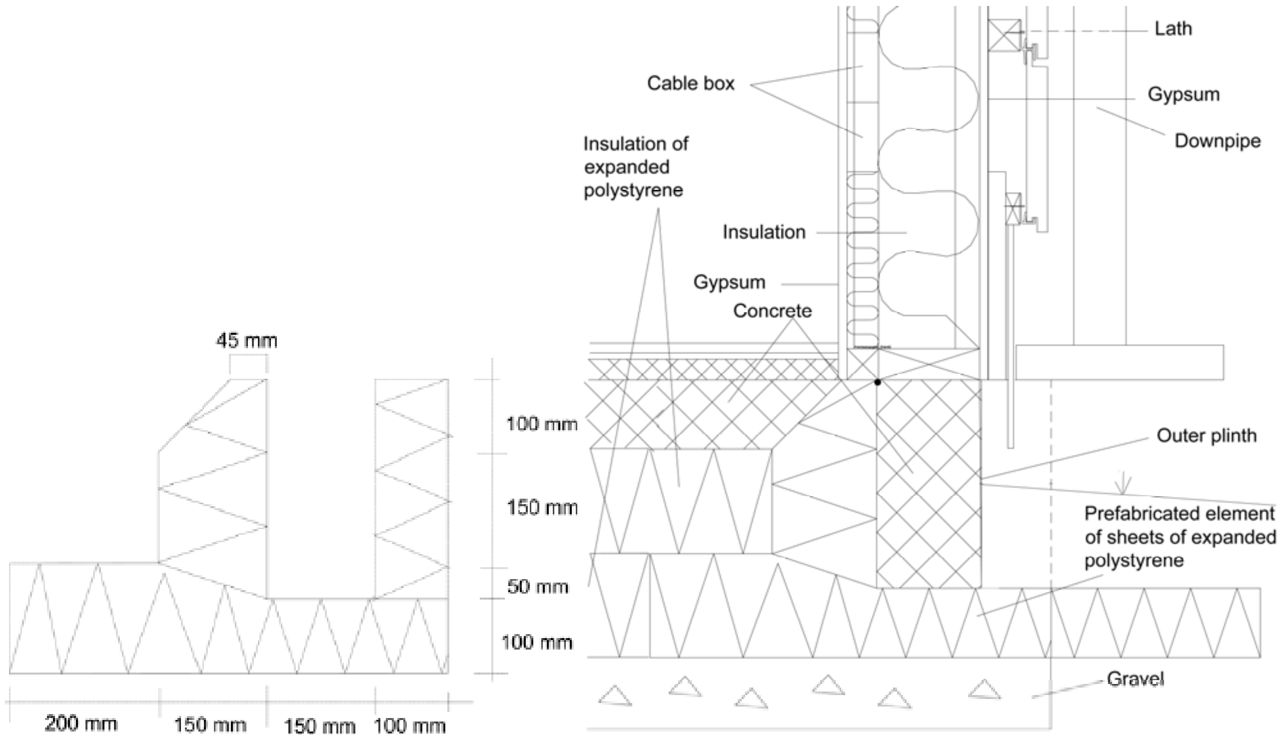

Figure 4 a): left, the prefabricated element made of EPS, b): right, the EPS element used as the strip foundation of a traditional wood-stud wall within mineral-based insulation.

2.2.2 Heat flow and temperatures in the strip-foundation system

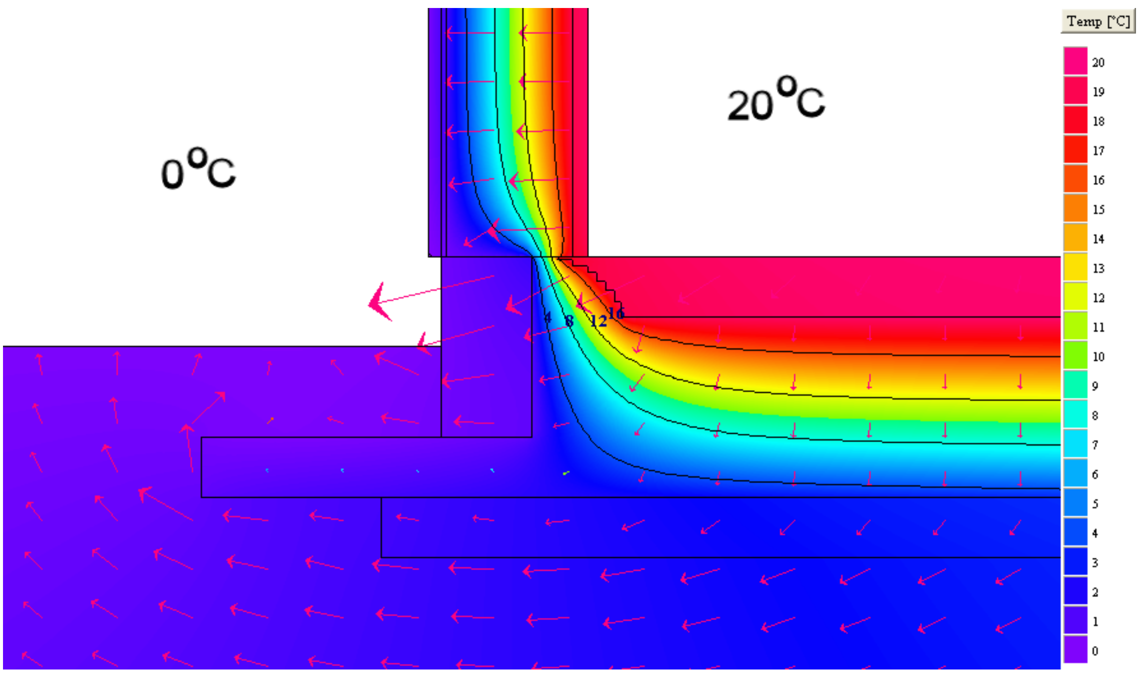

Figure 5. Temperature, isotherm curves and the heat flow through the prefabricated lightweight element used as strip foundation and the base for a traditional wood-stud exterior wall.

Ensuring stable non-freezing ground underneath the building was necessary for maintaining the stability of the structure and for avoiding settling cracks. To ensure stability of the strip foundation, it is important that temperatures lower than -1 °C do not occur in any frost-susceptible layer underneath the building during a cold winter (Danish Standards 2001). Temperatures below -1 °C underneath the capillary breaking layer could cause frost deformations of the soil underneath, which would in turn increase the risk of the strip foundation settling. Boards of EPS from the outer plinth of the strip foundation were used to form the element called the outer insulation. Design of the outer insulation was based on the descriptions given in the Danish Standards 2001, e.g. by using temperature characteristics for a cold winter, by using a design value of 100 years, where the lowest average outdoor temperature of a month decreases from -0.5 °C in a normal year to -7.3 °C in a cold year (Rose 2006).

Figure 5 shows the temperature, isotherm curves and the heat flow calculated for the prefabricated lightweight element, used as the strip foundation and the base for a traditional wood-stud wall within mineral fiber insulation. The average coefficient of heat transmission of the exterior wall was equal to 0.2 W/m^{2}K. For the calculations, the interim insulation to the ground deck and soil equaled 1.67 m^{2}K/W; the interim insulation to the soil itself equaled 1.5 m^{2}K/W, which allows the average coefficient of heat transmission of the ground deck to be 0.09 W/m^{2}K. Calculations were carried out with the specific heat capacity of the soil and the thermal conductivity of the soil set to 2.0 MJ/m^{3}K and 2.0 W/mK, respectively. Calculations were made for a building with conventional heating and for an outdoor temperature of 0 °C and an indoor temperature of 20 °C. The calculations were performed by using the PC program HEAT2 version 5.0 as a stationary calculation reaching thermal equilibrium between indoor and outdoor temperature. Arrows show the heat flow and the length of the arrows visualizes the relative heat flow. Isotherm curves are drawn as continuous lines with fixed indications of the temperature of the individual curve. Colors/grayscale used to visualize the temperatures are listed in the column to the right.

2.2.3 Building a strip foundation

Figure 6 a): Left, prefabricated leightweight elements, made of EPS, mounted as the strip foundation. The elemente were fixed together with large clamps of plastic, b): Right, 300 mm EPS, mounted as two layers on top of the base of stamped gravel bordered by the strip foundation that served as the insulation layer underneath the concrete floor slab. Iron was mounted as a net inside the strip foundation and as wires along the moat formed by the two vertical boards of EPS in the prefabricated elements, before concrete was cast and leveled.

At most locations in Denmark, a stable ground of glacial deposit (moraine) is present underneath a top soil layer of approximately 0.2 to 0.4 m in thickness. The top soil layer was removed in an area covering the area of the building. Material down to a depth of at least 0.35 m underneath the top soil surface had to be dug up. The excavated area was then covered with a capillary breaking layer of gravel, which was stamped in order to form the stable base for the building. The prefabricated EPS elements were mounted as the strip foundation, see Figure 6a). Fixed together with large clamps of plastic and with an outer support. 0.3 m of EPS in two layers, was mounted inside the strip foundation, served as insulation underneath the concrete floor slab. Before casting the concrete, an iron net was mounted to prevent cracks from developing due to shrinkage, inside the strip foundation and as wires along the moat formed by the two vertical boards of EPS in the prefabricated elements. Wires of stainless steel rods, 5 mm in diameter were put through the inner vertical boards of the prefabricated elements of EPS every 0.6 m, in order to connect the concrete in the moat to the concrete floor slab. Concrete was cast and leveled, see Figure 6b). After a few hours, when the concrete was dimensionally stable, the outer vertical boards of the prefabricated elements of EPS were removed, thus exposing the outer surface of the concrete moat as the outer plinth. The removed outer vertical boards of EPS were used as the outer insulation on the ground around the plinth.

3. Discussion

The tightened energy provisions included in the new Danish Building Regulations (Danish Enterprise and Construction Authority 2008) are intended to result in an energy reduction of 25% for new buildings compared with buildings built in accordance with the former Building Regulations. By focusing on the air tightening of the building envelope, the heat transmission of the thermal envelope and thermal bridges that cause heat transmission through individual building components and joints, more sustainable buildings are constructed with reduced energy consumption for heating and comfort.

This study focuses on two specifically important areas for the heat loss through the building envelope, in particular methods to ensure air tightening of the building envelope and thermal bridges. Thermal bridges are prevented by introducing a new building component for the strip foundation, ensuring continuity of the thermal insulation layer in the exterior wall and the insulation underneath the concrete floor slab. Furthermore, the on-site performance of the superinsulated strip foundation of prefabricated lightweight elements was introduced and demonstrated as an alternative to the traditionally used strip foundation of concrete.

3.1 Air Tightening

Infiltration in the building envelope causes unnecessary heat loss and a risk of mould growth. The water vapor content in the outdoor air is low in winter. When the cold air enters the heated rooms indoors, it will be heated up and the relative humidity of the indoor air will decrease as a consequence (Andersen et al. 1993). The indoor air will be altered by water vapor generated by occupants, plants and everyday activities such as cooking and washing. In this case the air in a heated occupied room will contain more water vapor than the outdoor air. In winter, air that leaks out through unforeseen leakages in the building envelope will decrease in temperature and rise in relative humidity. The air is likely to condense within the insulation, thus increasing the moisture content and the risk of mould growth and the decomposition of the building. By building airtight and ventilate well and controlled through vents, moisture and polluted air can be removed from the indoor environment. A certain amount of air change is necessary to keep the relative humidity of the indoor air at an acceptably low level.

Infiltration in the building envelope can easily be prevented. An airtight shell that encases the heated interior of a building should be introduced at the design phase. Typically the shell follows the building envelope that consists of lightweight or heavy weight building components. Often lightweight wood-stud walls or heavy weight concrete wall elements are used mounted with windows, doors, ceiling, roof and ground constructions. Critical locations in the shell are located where building components are located in staggered levels in between building components and at ductways, where installations are brought into the building.

For some building components the airtight shell can with advantage be established by a polyethylene foil that also serves as the vapor barrier placed within the building envelope. The foil serving as the vapor barrier should be placed in the insulation located at the warm side of the dew point in order to avoid condensation. For the airtight shell it is important that the joints between building components are securely fixed. Furthermore it is crucial that the joints keep their airtight properties during the lifetime of the construction, and are not damaged or decompose during their service life. This entails a great deal of focus on how to establish the airtight shell on site as well as during the design phase.

3.2 Superinsulated Strip Foundations

The prefabricated element was designed to comply with requirements of low energy consumption for buildings by lowering the heat loss through the thermal envelope. The surplus heat loss through the foundation element, the joint between the exterior wall and the floor slab, was partly secured by the geometrical continuity of the thermal insulation layer across the joint and partly by the overall design of the element. The prefabricated lightweight foundation element was designed to be integrated into the insulation layer located underneath the concrete floor slab at the ground deck and to face the insulation within the exterior wall. At the bottom of the exterior wall, the heat flow increase significantly changed thermal resistance regarding the change in the thickness of the insulation material towards the exterior wall, see Figure 5. Hence the geothermal heat is used to ensure that there is stable, ground not susceptible to frost underneath the building. Therefore it was necessary, for maintaining structural stability and to prevent settling cracks during cold winters, to establish outer insulation in front of the outer plinth.

The investigation covered a real life situation and use of a newly designed element to be used as the strip foundation of a single-family house. The house was a single-storey house with an exterior wall made as a traditional wood-stud wall within insulation. The performance of the element was observed and recorded on site. Ground conditions at the building site consisted of a stable ground of glacial deposit (moraine) covered with a capillary break layer of gravel, stamped to obtain stable base for the building. The base for the house was cast in one working operation and completed within two working days. The elements were adjusted on site and shown to be able to be handled by one man.

4. Conclusion

Air tightness of building envelopes is a key factor in determining infiltration, heat loss, indoor air quality, maintainability and moisture balance within the building envelope as indoors. Air leakages through the building envelope contribute to the cost of ventilation, heating and cooling and also to moisture migration.

Furthermore, air tightness is that property of building envelopes which is the most important for understanding ventilation. Air tightness is important from a variety of perspectives mostly from infiltration, movement of air through leaks, cracks, or other and unforeseen openings in the building envelope. There is a direct connection between an airtight building envelope and low energy consumption for heating in the building. With regard to a better heat-insulated building envelope, the importance of an airtight building envelope becomes more pronounced in relation to the total energy consumption of the building. If using a heat exchanger for the ventilation system of the building to ensure fresh air to fulfill human needs for hygiene and comfort, a less efficient system is provided decreasing in efficiency with less efficient air tightness of the building envelope.

Thermal bridges, parts of the building envelope where the otherwise uniform thermal resistance is significantly changed, and effects on heat loss has been ignored for many years. Full or partial penetration of the building envelope by materials with a different thermal conductivity, by a change in thickness or discontinuation of the insulation material is traditionally found at window, door, wall, floor, and ceiling joints. Such thermal bridges give rise to two- or three-dimensional heat flows and have a major effect on the thermal performance of the building envelope. Furthermore, thermal bridges locally decrease the surface temperature indoors, thus increasing the risk of mould growth at high humidity levels. As for a better heat-insulated building envelope the importance of avoiding thermal bridges becomes more pronounced in relation to the total energy consumption of the building. The effect of thermal bridges in the building envelope is significant, either due to the long length of joints per unit of the heat loss surface or due to joints with large thermal transmittance. When eliminating thermal bridges in the building envelope, it is important to design joints as well as new building component that ensure continuity of the thermal insulation layer of the building envelope.

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METHODOLOGY TO ASSESS THE COST-EFFECTIVENESS OF SUSTAINABLE MEASURES IN BUILDINGS

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Summary

Many recognize the value of sustainable construction as it reduces the negative impact on the environment and improves quality, accessibility and productivity for all of those who live and work inside buildings. However, economical advantages, which would help expand the concept in the marketplace, have not yet been established. The objective of this paper is to present a methodology to assess the cost-effectiveness of the application of sustainable measures in buildings through actions that establish a balance between environmental, economical and social factors. The methodology is based on the comparison of a case study (a building in which sustainable concepts were applied) with reference buildings making it possible to demonstrate triple bottom line added values. The aim is to achieve an optimum balance point, with an acceptable pay-back time and to provide evidence of good economic results in order to encourage the investment on sustainable construction.

1. Introduction

This paper was prepared with the objective of highlighting the concept of sustainable measures in building construction, a concept which has been commonly rejected for one main reason, its cost effectiveness. This problem is linked to some key issues:

- The lack of financial support, direct incentives and understanding of different advantages associated to sustainable buildings by governments, financial institutions and insurance companies.
- Builders and promoters in the real estate market have maintained a basic behaviour (and interest) to look for standard solutions that avoid an increase in the initial cost (investment) of new projects (construction phase). Thus they are transferring operational costs associated to the life cycle of the building to future owners.
- Finally, it is commonplace to observe the general conduct (building stakeholders) that is characterized by a restricted ability to consider the real costs generated during construction and operational phases in buildings. These costs are not considered or introduced in the market price formula, nor are they considered in the planning phase. Simply, they do not exist for building stakeholders. Some of these costs include: wastes, diseases and emissions (pollutants or CO2).

For this reason some countries have been trying to develop different tools for economical and financial feasibility as well as promote financial support, through incentives and subsidies that encourage the public and private investment onto Sustainable construction. These are recognized by their demand-efficiency in energy (25 to 30%) and water, less volume of construction residues and the use of durable materials (Kats, Gregory, 2003).

2. Tools to assess sustainable construction

Different countries have been developing studies and financial tools with the main purpose of implementing Sustainable Construction and disseminating a new mentality into the marketplace. Many of these studies are based on tools to assess sustainability which are divulged in a country and tailored to its reality, such as LEED (Leadership in Energy and Environmental Design) in the USA, Breeam (Building Research Establishment's Environmental Assessment Method) in the UK, Casbee (Comprehensive Assessment System for Building Environmental Efficiency) in Japan, among others.

Defined by a methodology and an evaluation system, these tools aim to classify and recognize a sustainable building, and at the same time, they work as a guideline for builders and project designers. A well-known example is the research carried out in the United States, where 33 buildings were compared (certified buildings or in the certification process, by LEED) with other conventional buildings. In this analysis, certain assumptions were used such as discount rates -5%; period of analysis - 20 years; annual inflation - 2%.

It was observed in " The costs and financial benefits of Green Buildings" report (Kats, Gregory 2003), that an investment of 2% (on average) over the initial cost (compared to a conventional building), produces financial benefits 10 times higher than the referred investment (for a period of 20 years), considering the analysis of some cost categories, such as consumptions, maintenance, emissions and productivity.

The same report gives us a simple example of how to evidence these benefits. Applied to a real case and assuming that the construction costs in California are about $150/ft2 to $250/ft2, increasing 2% to these values, it would be equal to $3/ft2 and $5/ft2, respectively. The cost effectiveness analyzed in 20 years would be equal to $48/ft2 and $75/ft2. If these values did not include the inherent benefits concerning CO2 emissions and productivity (just considering the reduction of energy and water demand, and less volume of waste) these would be around $6/ft2 (Kats, Gregory, 2003).

Another interesting study (also in the United States), prepared by David Langdon (2004), had the objective of analyzing costs linked to the construction phase of a "green building". This study showed that these costs (construction phase) drive the main decisions in sustainable projects (see figure 1). This report, which compared the construction cost per area in certified and non certified buildings by LEED, accounted for the cost of an information "database" of more than 600 projects (from 19 different States, typologies, locations, sizes and programs).

The referred study concluded that many projects reached the sustainability with their initial budgets or with a minimal additional increase (on average 2%).

In Europe, there are new incentives and legislation seeking to promote more aggressive policies in relation to the challenges of sustainable buildings. New studies have been carried out dedicated to cost effective buildings through sustainable construction concepts. These studies have been financed by the European Commission. Examples are the ASCOT model (Assessment of Sustainable Construction and Technologies Cost), a project carried out in 2004 by HQE2R and Cenergia. This tool helps users to implement a cost optimization of construction in which sustainability measures have been applied.

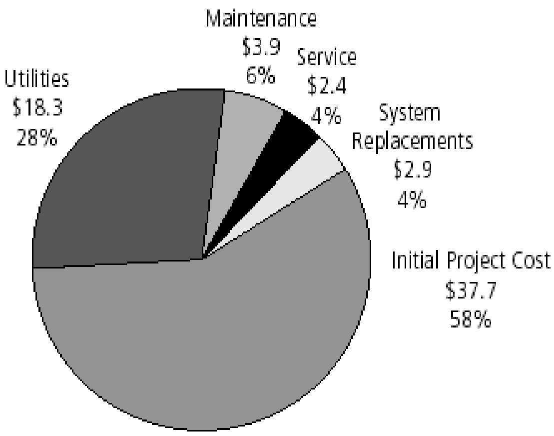

Figure 1 30 years Life Cycle Cost - Building example (Megan, Davis et. al, 2005)

There was also an increased interest in the subject of economic feasibility related to assessment tools and projects which can be applied to sustainable construction, such as SHE (Sustainable Housing in Europe): SHE has the main function of helping in the concept, cost analysis (initial cost and comparison to new buildings) and different options to obtain a higher viability of sustainable measures in projects. Another project, also co-financed by the European Commission, is the LCC-IP –"Guidebook-Integrated Planning for Building Refurbishment Taking Life- Cycle-Cost into Account". This project was constituted by several European case studies where an optimized relation between sustainable measures and cost – benefit analysis was demonstrated. Finally, it is important to make reference to the government calendar in the UK, regarding the new "Zero Carbon Emissions" program in new houses.

These studies demonstrated that a substantial amount of additional investments made in sustainable projects, are based on specific costs such as simulations, introduction of new technologies and integration of sustainable practices into the project. The studies also evidenced that it is always important to introduce these measures as soon as possible, mainly in the design phase.

3. Economic feasibility adapted to Portuguese reality

The above mentioned studies were carried out according to their national contexts. Thus, this paper intends to show a methodology that is being developed to assess the cost-effectiveness of some sustainable measures to be applied to commercial buildings, adapted to the Portuguese reality. The study will be carried out according to sustainability criteria based on two assessment tools:

- BREEAM (Building Research Establishment Environmental Assessment Method) (UK) – the first environmental assessment tool that was developed in the world;
- SBTool (Sustainable Building Tool) (Can) a tool which clearly identifies sustainable criteria (establishing environmental, social and economical criteria), and has been disseminated in several countries around the world (the Portuguese adaptation of the SBTool is in a pilot phase).

The various stages of this methodology are outlined in figure 2 and described below.

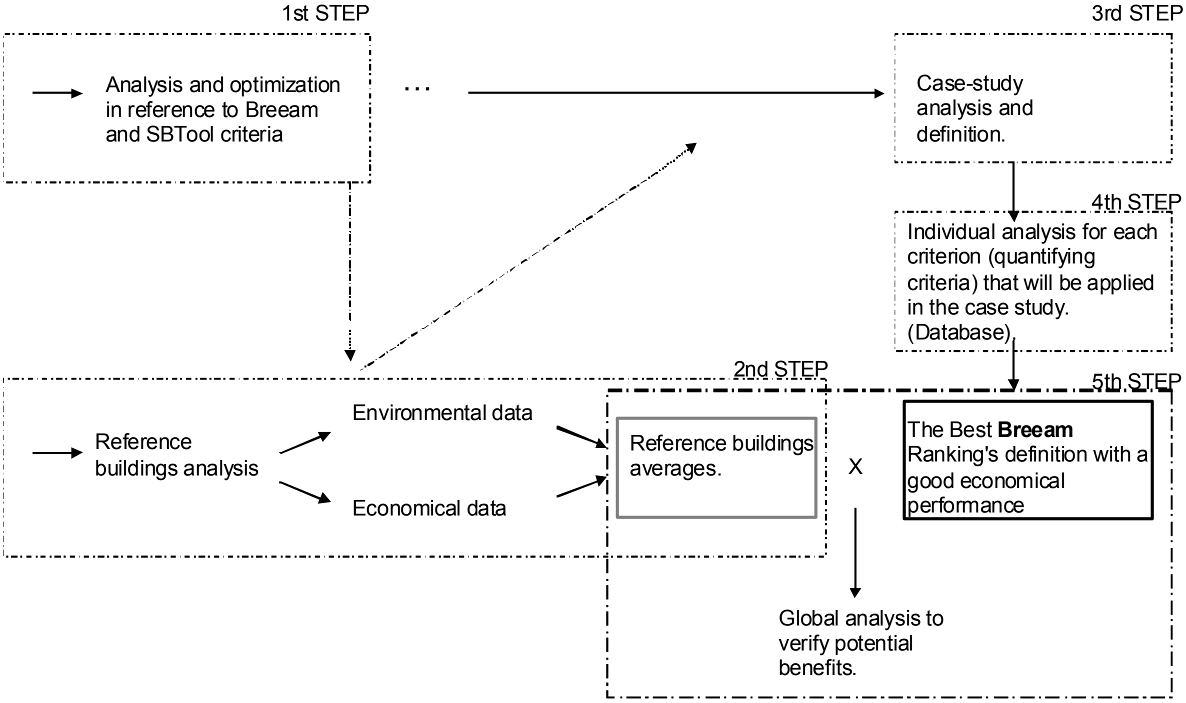

Figure 2 Structure of the proposed methodology

3.1 Guideline for sustainable construction and action analysis (1st step)

The first step of the proposed methodology is based on the criteria of analysis of a case study based on the previously mentioned tools (Breeam and SBTool), in which the criteria were identified and separated into different groups:

i) "Criteria of complex quantification", which produce indirect benefits, and are related to:

- Biodiversity;
- Measures with ethical values;
- Certain IEQ criteria (Indoor Environmental Quality);

ii) Sustainable criteria already covered by the Portuguese legislation. These are not considered in this research as they do not introduce any added value or differentiation for new challenges on Sustainable Buildings, as they are presently compulsory and related with:

- IEQ (Indoor Environmental Quality) covered by current legislation;
- Other criteria covered by current legislation.

iii) Quantified criteria through cost benefit analysis related to:

- Materials,
- Water management;
- Energy management.

These quantified criteria will be the main focus of this research. They may not be considered key elements but they can be directly quantified by cost benefit analysis, which allows for a binomial effect:

- Obtaining measurable results (direct benefits) for stakeholders - one of the main aspects for the decision-making of the project promoters and also the major contribution to the sustainable property/business value;
- Meet critical sustainable criteria based on international tools. These criteria are considered crucial to perform the best ranking proposed by these tools (See Figure 3).

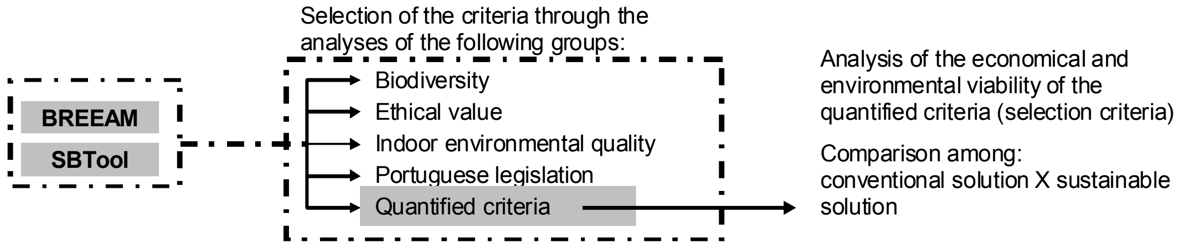

Figure 3 Selection procedures for the optimization of the criteria to be analyzed

Through this analysis it was possible to identify 116 SBTool criteria of which:

- 22% are already included in the Portuguese/ European legislation;
- 24% are related with quantified criteria.

and 72 existing criteria from the Breeam-Retail:

- 25% are already included in the Portuguese / European legislation (equivalent to the English legislation);
- 26% are quantified criteria (as above) of which a high incident is associated to profitability factors (of promoters or owners).

In spite of not being considered here, other indirect benefits may determine changes in the building performance related with economical results. An example is the IEQ (Indoor Environmental Quality) criteria which promotes excellent results in human and organizational productivity, when buildings are strongly related with services or commercial activities.

The profitability factor to owners and promoters must experience a cultural change in the interpretation of results to reflect a medium-long term perspective (positive balance between: Investment -first capital- cost, acceptable pay-back and higher cash flows during the lifecycle building or analysis period) as opposed to short term expectations (low investment cost -first capital- and comparable negative results during the building lifecycle).

The objective of this research is to recognize the evidence provided from the reduction of environmental impact when sustainable tools criteria are applied while at the same time demonstrate that these may lead to important economical advantages through direct benefits resulting from different actions on the reduction of consumption, conservation/maintenance effects and the added-value increase for Shopping Centers.

For an economical and environmental evaluation through this methodology, an individual application will be necessary. This will be demonstrated later in step 4.

3.2 Reference Building Definition (2nd step)

While actions were optimized through Breeam and SBTool criteria, environmental and economic data have been collected on three existing Shopping Centers in Portugal (which used equivalent construction methods) – Dolce Vita Porto (DVP), Dolce Vita Coimbra (DVC),Dolce Vita Douro (DVD). These commercial buildings belong to the Chamartín Real Estate Company.

Through the obtained data of those buildings, which will be referred to as “reference buildings”, it has been possible to establish efficiency indexes (consumption/m2/year and consumption /1000visitors/year) as can be seen in tables 1 and 2. In addition to these indexes (energy, water, CO2 emissions, recycled and non-recycled waste), global values will be compared with national and international "benchmarks" (see table 3). Nonetheless these can be analyzed according to the IEE (index of energy efficiency), specified for shopping centers, which is comprised by the law 79/2006 (that emerged from the transposition of the EPBD - Energy Performance Building Directive into the Portuguese law) which can be visualized in table 4.

It is important to point out that the values for the Portuguese reference building in table 3 are not directly comparable with the IEE values in table 4. To establish this comparison it would be necessary to separate the different types of consumption (heating, air conditioning and lighting) and to be identified along with the appropriate correction factors set out in the law 79/2006. The values listed in the previous tables (1, 2 and 3) represent actual and overall consumption from the different shopping centers.

Table 1 The efficiency index of the total demand (resources) and Chamartín's average per sqm (without climate correction).

DVS demand /sqm (construction area -GLA -Parking)							2006
Shopping Center	*Economical data*	*Environmental data*					
	Euros	Energy		Waste		CO_2emissions	Water
	Euros/m^2	kWh/m^2	Tep/1000m^2	Recycled /m^2	Non recycled / m^2	KgCO$_2$/ m^2	m^3/m^2
DVP	32.96	474.86	137.71	6.91	20.87	196.59	0.83
DVD	22.12	283.50	85.07	6.24	11.08	117.37	0.50
DVC	29.43	370.69	107.50	6.79	21.45	153.46	0.79
Average	28.17	376.35	110.09	6.65	17.80	155.81	0.71

Table 2 The efficiency index of the total demand (resources) and Chamartín's average per 1000 visitors.

DVS demand /1000visitors			2006
Shopping Center	*Environmental data*		
	Energy	CO_2emissions	Water
	KWh/1000visitors	KgCO$_2$/1000visitors	m^3/1000 visitors
DVP	1458.80	603.94	2.56
DVD	1265.24	523.81	2.24
DVC	1105.02	457.48	2.39
Average	1276.35	528.41	2.40

Table 3 The average efficiency index of Shopping Centers - International benchmarks. (Source: CIBEUS and other researches).

Annual Average energy Intensity (existent Shopping Centers)			
	GJ / sqm	KWh / sqm	Kgep / sqm or Tep / 1000sqm
Canadian Shopping Center average	1.30	361.40	**105**
UK Shopping Center average	1.04	290.00	**84**
Portuguese reference building	1.35	376.35	**110**

Table 4 The efficiency index, specified for the Shopping Centre in agreement with the decree-law 79/2006 (RSECE, 2006)

Existent buildings		
Activity types	Building typology	IEE (Kgep/ sqm.year)or (Tep/1000sqm.year)
Commercial	Commercial center	**190**
New buildings		
Activity types	Building typology	IEE (Kgep/ sqm.year) or (Tep/1000sqm.year)
Commercial	Commercial center	**95**

It is important to point out that the shopping centers are situated in different locations, thus different climatic factors were obtained for the "reference buildings". A basic comparison of the average values showed by the three buildings would be incoherent, as they would reflect the different climate features of the buildings performance.

With this in mind and influenced by the methodology used in the Decree-Law 79/2006 to define the IEE index (Energy Efficiency Index) for different building typologies, as referred above, climatic correction factors were applied to these shopping centers located in Coimbra (DVC), Porto (DVP) and Vila Real (DVD), when necessary.

Through these results, it will be possible to establish a comparison, on an economical and environmental level, between the “reference buildings” and a “case study”.

3.3 Case study definition (3rd step)

Following the analysis of the reference building and the verification of the selected criteria (from the sustainable tools), this methodology will be applied to a case study, the largest Iberian Shopping Center, which also belongs to “Chamartín Real Estate S.G.P.S., S.A”. The building is being constructed in Amadora, near Lisbon with a total construction area of 423.000 m2, including parking and 122.000 m2 of GLA (Gross Leasable Area). This project was designed with a new concept brand for Shopping Centers, named “Dolce Vita”, a world market reference. It will include wide reading spaces, stores, a food court, recreation areas and supermarkets.

The chosen typology is quite relevant (in relation to its dimension) since a commercial building of this size will have high environmental, social and economical impacts (Environmental impact, resulting from its construction and management, social and economical impacts, resulting from future changes in local reality, employment and road flow increases).

An evaluation of the shopping center, which is presently in the construction phase, has been carried out in order to verify if any sustainable criteria have already been applied. The measures which have already been applied will be compared (economic and environmental factors) with the reference building options, while the criteria which has not been applied will be compared with the present project options (considered less sustainable measures) of the case study.

The objective at this phase is to validate the selected criteria with an economical and environmental feasibility analysis.

3.4 Cost- effectiveness of sustainable construction indicators and database creation (4th step)

Only the Breeam tool will be used for evaluation during this stage. The final objective will be not only the analysis of the selected criteria but also to assess in which place of the ranking established by Breeam the case study results will be put on.

At this stage, the cost-benefit analysis of each sustainable measure (applied individually) will be analyzed through a simulation carried out in the selected commercial building previously mentioned.

First of all the information will be organized by categories that can be quantified (energy, water and material). This information will then be structured according to the organization schemes used in several sustainable tools.

The expected results are identified by environmental (CO2 emissions, consumption reductions and other important ecopoints) economical (investment cost, generated NPV (Net Present Value)) and payback period data. The database will be completed in the following steps:

1. Identification of BREEAM criteria that correspond to the project phase and that will be analyzed in the database. For each indicator, there are actions to reach objectives.

2. Identification of actions, which were already identified in the studied building, and which consider the Breeam criteria in the database. Analysis of actions should be accomplished through the comparison with conventional actions used in the reference buildings.

3. Identification of actions that were not found in the studied building and that should be filled out in the database. Analysis of these actions should be accomplished through the comparison with present existing measures in the studied building, regarding potential changes.

The final information will be organized in a database similar to the example shown in Table 5. Regarding outcomes from the implementation of 3 sustainable measures on the referred table, it can be demonstrated the following information.

- Energy example – Comparison between Installation of energy-efficient lifts with Regenerative system (SI –Sustainable Investment) and conventional lifts (CI - Conventional investment) – modification just applied in 30% of the lifts;
- Water example - Comparison between installation of dual flush WCs - 4,5 litres (SI- Sustainable Investment) and simple flush WCs (6 litres) (CI - Conventional investment);
- Materials example – Comparison between thermal insulation with low embodied impact (corkboard) (SI – Sustainable Investment) and thermal insulation with high embodied impact (extruded polystyrene - XPS) (CI – Conventional investment).

Presupposes considered: Inflation rate (year average) - 2, 5% Economic Cycle Analysis -20 years; Electricity price increases – Growth rate (year average) - 3%; Water price increases – Growth rate (year average) - 1%; Discount Rate for NPV (Net Present Value) – 6% (NPV - The present value of an investment's future net cash flows minus the initial investment).

For an additional Investment cost of € 72 198, 41 (SI- Sustainable Investment for the referred 3 examples), equivalent to 9,8% more than CI (Conventional Investment), It results on a total NPV of € 159 226,83 (equivalent to € 1, 31/sqm). The simple pay-back for the total investment is reached in 5 years.

Table 5 Database structure

Application example - Comparison result (conventional versus sustainable criteria)										
Case-study: DVT Shopping Center (Lisbon) Type occupancy: RETAIL Phase: Design Phase										
Breeam-Retail			Economical data			Environmental data				
Related category	Ref.	Criteria	Investment cost (€) and (%)	simple payback (years)	NPV (20yrs) (€)	KgCO2 reduction (per year)	Reduction consumption (%)(un/year)	embodied energy reduction	Breeam ranking
Energy	Ene8	Up to two credits are available where evidence provided demonstrates the installation of energy-efficient lift(s).	**29 799,00 (>14%)**	8	27407.60 (0.22€/sqm)	**< 12 709 (79.5%)**	**< 79.5%** (KWh)		2
Water	Wat1	1. All WCs have an effective flush volume of 4.5 litres or less. 2. Where dual flush toilets are specified they have guidance or symbols instructing the user on the appropriate operation of the flushing device.	**5 400,00** (13.4%)	1	168 818.64 (1.38€/sqm)		**<4 727 (m3) (<25 %)**		1
Materials	Mat6	1- Where evidence provided demonstrates that thermal insulation products used in the building have a low embodied impact relative to their thermal properties, determined by the Green Guide to Specification ratings.	**36 999,41 (>8 %)**	no payback	- 36 999,41 (-0.30€/sqm)			<7621 MWh (85%)	1
		total Investment (3 examples)	72 198,41 (0.59€/sqm)	5	159 226,83 (1.31€/sqm)				4

3.5 Defining the best Breeam ranking with a good economical performance

Following the analysis and the completion of the database with quantified criteria, the pre-assessment estimator (from the Breeam-retail) will permit the verification of rankings achieved in the case study. One of the aims of this work will be to compare and analyze the economical and environmental behaviour of three different scenarios (with different Breeam ranking) (See Figure 4). These are:

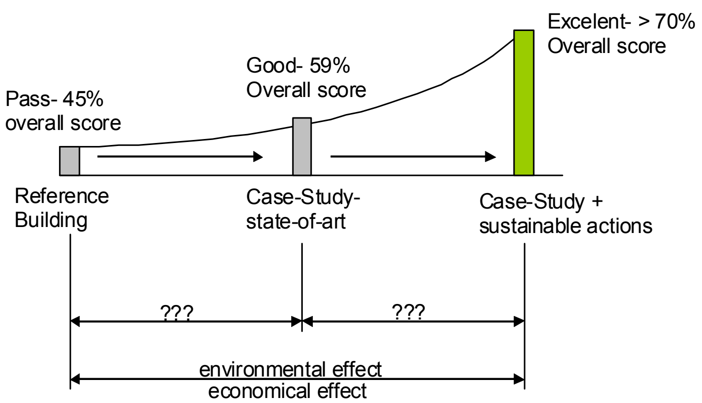

Figure 4 The comparison and analysis between different scenarios.

Scenario 1: The case study with approximately 45% overall score. (The same as Reference building)

Scenario 2: The case study with approximately 59% overall score (Actual situation of the case study with criteria already applied on the case study)

Scenario 3: The case study with >70% overall score (Breeam excellent ranking) (Case-study + criteria that were not considered in the case study at the time).

This process will be achieved by adding other Breeam criteria (referred above as “criteria of complex quantification”), which have solutions with low first capital impact.

The referred capital costs along with the new criteria will be considered as investment costs in both cases when totalizing the complete NPV and Payback effects on a global basis for the case study. Nonetheless the potential benefits of these criteria will not be considered as they provide “indirect benefits” and are difficult to quantify. This is the reason why the analysis (“Criteria of complex quantification”) will focus on solutions with a low investment cost impact. When this is not possible other solutions with a more economical impact will be used with the assurance that the expected NPV and payback results will not be negatively affected on a global basis, and at the same time capable of reaching the desirable overall ranking.

The explicitness and transparency that demonstrates efficiency benefits, and the way how to reach economic value in sustainable buildings, are a decisive incentive for stakeholders and for real estate market in general.

However, it is important to remember that this study will be defined for a specific typology in a certain area. Therefore the result will be conditional and will not allow a direct and immediate application of the best scenario methodology into other projects.

Nonetheless, through its main output information (costs definition, database output and new methodology), this study can serve as an important guideline to help different stakeholders involved in new sustainable building projects focused on economical benefits.

4. Conclusion

This paper seeks to define methodologies and objective contents to achieve newer and larger real estate projects (services /commercial), supported by sustainability concepts.

This study used the “Breeam and SBTool” tools as they are considered rigorous and are recognized among universities and academic environments and are essential resources for the study and development of Sustainable Building Evaluation.

Finally, this study seeks to define new methodologies and analysis aiming to integrate different action fields such as sustainability, functionality and economic feasibility (cost effectiveness) which more than often are used separately.

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THE NEGLECTED DIMENSION: SOCIO-CULTURAL INDICATORS IN THE ASSESSMENT OF SUSTAINABLE DEVELOPMENT IN MEGACITIES

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Summary

In the case of fast developing megacities of emerging countries, an integrated concept for the assessment of SUD, including the social and cultural dimensions comprehensively, is of particular need: Megacities are locations of polarization of people. Different cultural, social and income groups live closely together, thus opening an area of conflict. However, for the aspect of social sustainability, a theoretically stringent, systematic and comprehensive rationale which is translated into practical application does not yet exist.

The aim of the paper is to shed light on theories within the social and cultural dimensions of the sustainability assessment, on the specific socio-cultural challenges in megacities and on existing indicator systems possibly applicable in those megacities. Based on existing studies and expert interviews of local stakeholders, specific requirements for the assessment of the social and cultural dimensions are formulated for the emerging megacity Hyderabad (India). Following this analysis, both the gaps in research and practice as well as challenges and responses are pointed out.

1. Introduction

> *"There is almost complete unanimity among local and national governments and planning agencies that accurate, timely and policy-relevant data are a pre-requisite for good governance, good planning and good management."*
>
> State of the World's Cities Report 2001:114

As the citation from the State of the World's Cities Report 2001 points out, values of meaningful indicators are essential for authorities, both on urban, regional and national levels. Indicators, especially when compiled in indicator sets, help identifying the most critical issues for action. Furthermore, they provide transparency and feedback to both decision-makers and the civil society. In megacities of emerging countries indicators play a distinctive role as they increase rationality in governance[1].

Over the last years, a number of performance indicator sets[2] for the assessment of Sustainable Urban Development (SUD) have been developed. Yet, comprehensive concepts for the assessment of SUD are still lacking in most developing countries of Asia (Ooi 2007), where they would be much required: The concept of SUD poses a particular challenge to megacities[3] with their specific problems that are mainly due to their size, complexity and diversity. In the case of fast developing megacities of emerging countries, an integrated concept for the assessment of SUD, including the socio-cultural dimension comprehensively, is of particular need. Since different cultural, social and income groups live closely together, high potential for conflict is given (Laquian 2005:193-194).

The development of a megacity-specific indicator system by local bodies is typically preceded by a compilation of existing indicators. In a second step, a number of suitable indicators are chosen from this

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[1] Dr. Jo Santoso, expert interview (03.12.2007).

[2] An indicator is, according to the definition of OECD "a parameter, or a value derived from parameters, which points to, provides information about, describes the state of a phenomenon/environment/area, with a significance extending beyond that directly associated with a parameter value" (OECD 1994:9). If indicators are used for performance evaluation (like the here discussed Urban Performance Indicators), they are "selected and/or aggregated indicators" (ibid.) of the urban economic, ecological, social and cultural environment.

[3] A megacity is an urban area or an agglomeration with more than (varying in definition) five, eight or ten million inhabitants (Kraas 2007:82).

"long list". Thus, existing indicators serve as basis for practice-oriented new indicator developments. But are the existing indicators suitable for the adaptation to megacities in emerging countries?

The goal of the paper is to analyze the suitability of existing indicator sets and indices for Sustainable Development (SD) in megacities of emerging countries in view of the socio-cultural dimension. The general requirements of socio-cultural sustainability are pointed out and an overview of the needs of megacities of emerging Asian countries in the socio-cultural sector is given. The indicator sets and indices are analyzed in view of both these requirements. Finally, the challenges for the assessment of the socio-cultural dimension of SUD in (emerging) megacities is discussed in a detailed way and illustrated by the emerging megacity Hyderabad (India).

2. Materials and Methods

2.1 Socio-cultural Dimension of Sustainable Urban Development

Concepts for the operationalization of the rather abstract concept of SD break down its complexity into several subject areas, so called *pillars* or *dimensions*. Commonly, the concepts are based on the triangle of sustainability with the corners ecology, economy and society. Besides that, a variety of other definitions exists, including different factors for the description of the relationship between people and their built environment. Among those, sustainability models including the cultural dimension are of special interest, as they enlarge the definition of *built environment*. This paper draws upon a three-dimensional model of sustainability, where the social and cultural dimensions are coalesced to a socio-cultural dimension (cf. model of UNESCO 2005).

While the ecological and economic dimensions can be described rather intuitively, the definition of the socio-cultural dimension is more difficult. Therefore, a multiplicity of varied definitions exists. The Blackwell Dictionary of Sociology defines social as "anything that is related to social systems, their characteristics, and people's participation in them" (Johnson 2000:284). A social system can, in terms of the systems theorist Parsons, „refer to a stable relationship between two actors, to societies as a whole, to systems of societies, or indeed any level between these." (Scott et al. 2005:618). Accordingly, *social sustainability* describes two layers of social aspects which are included in the majority of concepts for social sustainability: The individual level, like the fulfillment of personal needs, and the level of society, like political participation and social peace (Empacher et al. 2002:13).

According to the definition of the *Mexico City Declaration on Cultural Policies*, "in its widest sense, culture may […] be said to be the whole complex of distinctive spiritual, material, intellectual and emotional features that characterize a society or social group. It includes not only the arts and letters, but also modes of life, the fundamental rights of the human being, value systems, traditions and beliefs" (UNESCO 1982). As culture includes both material and immaterial aspects, there is a disaccord amongst researchers about what cultural sustainability should be. *Cultural sustainability* commonly occurs to one of two different, but connected notions: Firstly, the claim for consistency of changes and core values, expectations and customs (Sachs 1999:32-33) and, secondly, a culture of decisions (Krainer et al. 2007:115).

Both social and cultural sustainability are also described in literature as dimensions having strong influences on the economic and ecological pillars of sustainability. Thus, the social and cultural dimensions consist supplementary in a second layer that lies crosswise on the four pillars of sustainability.

2.2 Assessment of the Socio-cultural Dimension of Sustainable Urban Development

In the last 20 years, a number of concepts for the assessment of SD have been created. Besides a number of integrated concepts considering several dimensions of SD, focused research has been carried out, which lead to specialized indicator sets and indices like the Ecological Footprint.

In the field of social indicators, first attempts go back to the 1960s, when social accounting was introduced, but certainly not yet linked to the concept of sustainability. "Social indicators relate to some area of social concern and they may serve the purposes of curiosity, understanding or action. They may take the form of simple data series or they may be synthetic series obtained by applying a greater or lesser amount of processing to data series. […] Social indicators form a subset of the data series and constructs actually or potentially available and are thus distinguished from other statistics only by their suitability and relevance for one of the purposes mentioned." (United Nations 1975:28) In this sense, social sustainability indicators serve the purpose of monitoring SD and apply thus the concept of the earlier social indicators. The most comprehensive investigations for sustainability indicators in the social dimension have consequently been carried out by social scientists with a broad knowledge of earlier attempts to compile social indicators.

In their review of existing indicator sets for social sustainability, Empacher et al. describe the multiplicity and variety in aims of different indicator sets. However, they also observe a condensation around several items: social justice with equitable distribution of income, access to resources and chances to live and act (Empacher et al. 2002). In their proposal for an indicator set, they include both "objective" and subjective indicators "since the perception of problematic areas is an important element of the social reality and moreover can differ as a matter of principal from the objective situation." (Empacher et al. 2002:68) This broad approach and its theoretical foundation distinguish the indicator concept from others and account for its attractiveness. Table 1 shows the dimensions and "Sub-Dimensions" of the indicator set, while the country-specific (Germany) indicators are not cited here.

Table 1 Proposal Indicators for social sustainability by Empacher et al. (2002:86)

Dimension	*“Sub-Dimension”*
Fulfillment of basic needs/ quality of living	Poverty
	Education
	Employment
	Dwelling
	Health
	Individual satisfaction
Social resources	Engagement for/interest in the community
	Social integration in the familiar surroundings
	Knowledge and human resources
	Tolerance
Equal opportunities/ social inclusion	Integration
	Social mobility
	Access to education
	Gender
Participation	Ethnic and other minorities
	Degree of participation
	Chances of participation

Table 2 Proposed dimensions for cultural indicators (Fukuda-Parr 2000)

Type of indicator	*“Sub-Dimension”*
Product Indicators	Cultural viability
	Cultural diversity
	Global ethics
Process Indicators	Participation in creative expression
	Access to culture
	Conviviality/ respect for cultural identity
	Chances of participation

It was as well in the 1960s, when the development of cultural indicators set off. Cultural indicators are commonly classified in *process-indicators* and *product-indicators*. Whereas *process-indicators* describe the costs (time, financial, etc.) for the use of cultural offers, “*product-indicators* deal with the way, in which on the one hand social fundamental values are communicated and on the other hand socially relevant problems and areas of life (“issues”) are placed by symbolic meanings“ (Deetjen 1989:285). This general meaning has to be filled with specific issues describing one or several areas of reality.

Concerning cultural indicators of development or sustainable development, research in this field is still in its infancy. One of the most comprehensive indicator proposals published so far is the compilation of the development economist Fukuda-Parr (2000). She combines the product-indicators of a conjointly held workshop by UNESCO and UNRISD with the process-related indicators proposed by Lourdes Arizpe (see table 2). Generally, the development of cultural indicators still lags behind the development of social indicators, both in general terms and especially with focus on sustainability.

2.3 Needs of Socio-cultural Sustainability in Megacities of Emerging Countries

In order to investigate indicator systems and their suitability for the socio-cultural dimension of sustainability assessments in megacities of emerging countries, light has to be shed on socio-cultural preconditions in this context.

The geographer Ehlers (2006:55) compiled a list of problems, risks and disadvantages of the global trend of mega-urbanization relevant to sustainable development. The list has been extended by Kraas (2006:22) who also added aspects of the political dimension to the before existing economic, ecological and social aspects. The social challenges and risks include the following issues:

- Loss of social coherence
- Growth of socio-economic disparities and of social fragmentation
- Reduced access to health care systems, educational and security infrastructure
- Informal, partly illegal settlements, urban decay
- Social disorganization: Conflicts, crime, riots, war
- Displacement processes
- Growing vulnerability of marginalized population groups
- Social injustice, abuse of social power
- Corruption, bribery, favoritism, nepotism
- Large-scale unemployment (“surplus labor force”)[4]
- Streams of migrants and commuters[4]

[4] Listed in Kraas’ “Economic Dimension”. Due to their close relation to and great importance for the social dimension, the two aspects are included in the present list.

Also investigating the most pressing challenges of megacities, MRC McLean Hazel and GlobeScan conducted a study amongst 522 stakeholders of 25 megacities (thereof nine Asian cities) (Economist Intelligence Unit 2007). The results show similar, though less detailed results, adding the challenge *population growth* (not only due to migration) as supplementary aspect.

While social challenges of megacities have been subject to detailed investigations, their cultural issues are rarely studied in a methodically sound way. The above mentioned work of MRC McLean Hazel et al. mentions *ethnic conflicts* as serious safety and security problem in megacities which point obviously at a cultural challenge (ibid:52). Another major issue in emerging and transitional cities is generally the *speed of change* and thus the risk of neglecting core values and customs in favor of copied "solutions" in various fields of other, successful urban agglomerations. Further immaterial aspects of cultural sustainability are already included in the aspects of the social dimension compiled earlier: Social coherence and integration are both major issues of social and cultural life.

2.4 Specific Needs of the Emerging Megacity Hyderabad

Hyderabad, the capital of the Indian state Andhra Pradesh, is a city branded by the current boom of the information technology. Since the last decade, the city's growing economic prosperity has caused an enormous increase in population: Between 1975 and 2000, the United Nations Population Division calculated an annual population growth of 3.84% in the agglomeration Hyderabad (United Nations 2001:97), up to 6.2 Mio inhabitants in 2007 (GHMC 2007).

In order to identify key challenges of Hyderabad, expert interviews have been conducted amongst local stakeholders, including researchers, representatives of urban and state planning authorities as well as NGO agents. Further challenges have been identified in the context of the City Development Strategy (CDS), initiated by the Municipal Cooperation Hyderabad and prepared in 2003 (Ramachandran 2004). The preliminary synthesis of interview findings and socio-cultural challenges highlighted in the CDS include:

- Limited transparency and accountability of government
- Inadequate security of tenure, housing and basic services
- Unequal livelihood and employment opportunities
- Increase in occurring infectious diseases
- Poor retention of students
- Inadequate health and education infrastructure/services
- Loss of built heritage and inherited immaterial culture

Even though the challenges mentioned are, as expected, very similar to the general needs of megacities in emerging countries, the city faces some specific characteristics, like the *loss of built heritage and inherited immaterial culture* as well as the *poor retention of students*. The above mentioned *displacement processes* are part of the broader Hyderabadi issue *inadequate security of tenure*.

2.5 Evaluation of Suitability of existing Indicator Systems

Existing indicator systems evaluated include both an international indicator system for SD in general, four indicator systems and an index for SUD chosen from a long list of 32 indicator sets and indices. Criteria for the selection of the indicator sets/index were their broad coverage of sustainability issues and the extension of acknowledgement/use of the sets. As described earlier, indicators of indicator sets and indices are typically classified into different dimensions. A first evaluation concerns the representation of these dimensions within the indicator sets/indices selected. Questions in this context are: Do the indicator sets include both social and cultural aspects of SD? How strong is their representation in comparison to the other dimensions? How inclusive are their indicators compared to the indicator sets proposed by researchers?

In order to evaluate the suitability of existing indicator systems in the socio-cultural dimension of sustainability in megacities of emerging countries, a comparative analysis is conducted. The selected international indicator sets/index are compared with the earlier identified socio-cultural challenges in megacities of emerging countries.

The international indicator systems evaluated include the UNCSD Indicators for Sustainable Development the Global Urban Indicators, the City Development Index, Healthy Cities Indicators, the ADB Urban Indicators and Urban Audit Indicators. The different indicator systems have been developed with different foci (e.g. sustainability, quality of living, health), but all of them are related to the field of sustainability. In the following, a short characterization of each indicator set is given.

Revised in 2007, the *UNCSD Indicators for Sustainable Development* (UNCSD 2007) are newly classified into 14 dimensions. They form the basis for a large number of national and organizational indicator sets.

The *Global Urban Indicators* of the third Global Urban Indicators Database (GUID III) are a set of indicators developed by UN Habitat in order to address both the Habitat Agenda key issues and the Millennium Development Goals on the urban level. Focus of the indicator set is the improvement of slum dwellers (UN-Habitat 2004:3-4).

It is an earlier version of this Global Urban Indicators Database from which the key indicators of the *City Development Index* are taken. Developed for the Habitat II Conference, the index aims at comparative analyses of the development level of cities (UN-Habitat 2001:116-120).

The third indicator system evaluated is the *Healthy Cities Indicators* developed by the World Health Organization. Aim of the system is “to describe the determinants of health in the cities of different countries” (Webster et al. 1998:1). After setting up the Healthy Cities Project in 1986 by the Regional Office for Europe, 53 indicators were chosen and tested in a pilot phase between 1992 and 1994. Drawing on the results of the pilot study, the indicator set has been modified to a tighter set of 32 indicators which forms the basis of the present investigation.

Prepared for the application to Asian Cities, the *ADB Urban Indicators* should serve the measurement of policy outcomes. Chosen by an expert group, the indicator system is the most comprehensive one (140 indicators) within this investigation, though the individual indicators included in this survey are the 112 indicators which are part of the ADB Cities Data Book 2001 (Westfall et al. 2001).

Focusing on the European level, the *Urban Audit Indicators* are aiming at the description of the quality of living of urban areas. Drawing on a study of Eurostat, 33 indicators were identified and refined during the pilot phase of the study. Today, the *Urban Audit Indicators* consist of 21 quality of life domains and a larger number of indicators. (The Urban Audit 2000)

3. Results

3.1 Representation of different Dimensions

The index and indicator sets surveyed are divided into a number of different dimensions as displayed in figure 1. The social dimension (health, shelter, education, migration, etc.) is represented in all sets surveyed, whereas it is only in the ADB Urban Indicators and in the Urban Audit Indicators where the cultural dimension is mentioned explicitly. In the ADB Indicators, the cultural dimension is represented through merely three (out of 112) indicators: Participation in sports, attendance at public events and at galleries/museums. These indicators would be located in the earlier described sub-dimensions *Participation in creative expression* and, partly, *Cultural viability* of Fukuda-Parr’s proposal as would be the cultural indicators of the Urban Audit Indicators. Concerning her additionally suggested sub-dimensions, *Cultural diversity* is addressed partly through the indicator *Minority groups* in the ADB Urban Indicators and *Nationality* in the Urban Audit Indicators. *Chances of participation are* often included in the indicator sets in relation to elections.

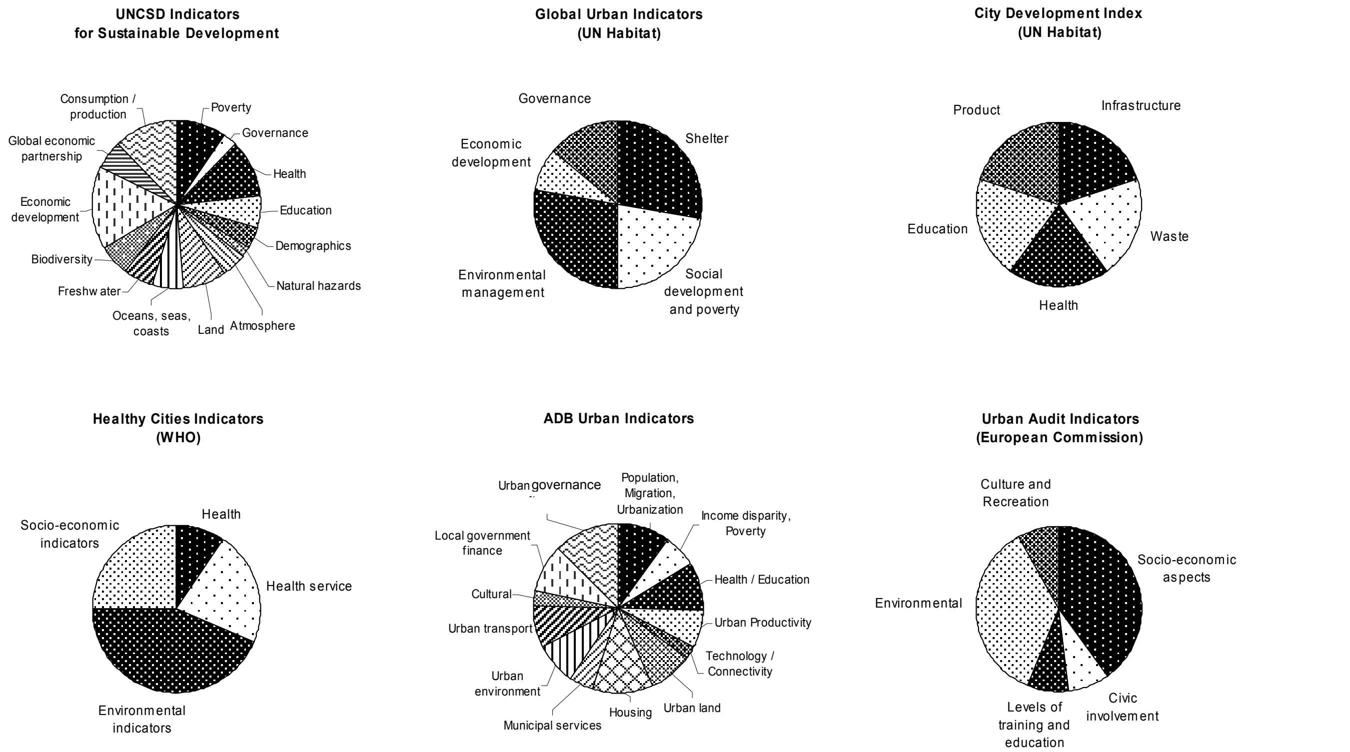

Figure 1 Quantitative representation of different dimensions within indicator sets/index surveyed

3.2. Indicator Systems by Dimensions

An overview on the results obtained from the comparative analysis is given in table 3. The listed challenges/risks are derived from the above described analysis on challenges in the socio-cultural dimension of megacity life. Solely the earlier identified aspect *Speed of change* is not included in the evaluation – if indicator systems are applied on a regularly basis, this aspect can be tracked for any indicator in use.

Table 3 Responses of existing indicator sets to the socio-cultural challenges of megacities in emerging countries

Challenges/risks of megacities	*UNCSD Indicators*	*Global Urban Indicators*	*CDI*	*Healthy Cities Indicators*	*ADB Urban Indicators*	*Urban Audit Indicators*
Loss of social coherence				(+)[5]	+	
Growth of socio-economic disparities and of social fragmentation	+	+		+	+	+
Reduced access to health care systems, educational and security infrastructure	+	+	+	+	+	+
Informal, partly illegal settlements, urban decay	+	+	+	+	+	+
Social disorganization: Conflicts, crime, riots, war	+	+			+	+
Displacement processes					+	
Growing vulnerability of marginalized population groups		+	+		+	
Social injustice, abuse of social power		+			+	+
Corruption, bribery, favoritism, nepotism	+	+				
Large-scale unemployment (“surplus labor force”)	+	+		+	+	+
Streams of migrants and commuters					+	+[6]
Population growth	+	+			+	+
Ethnic conflicts					+	

Overall, the ADB Urban Indicators seem to form the most suitable indicator set in order to address socio-cultural challenges and risks in megacities, closely followed by the Global Urban Indicators of UN Habitat. As both indicator sets have been developed for monitoring international cities of different sizes and income situations, this result has been expected.

It is only in the comprehensive indicator set of the ADB Urban Indicators, where the issue *ethnic conflicts* appears indirectly in form of an indicator (“representation of minorities” in the urban government/ management) and *displacement processes* in form of “squatter resettlement or normalization”. Waibel et al. (2007:62) describe the consequences of displacement in the case of Hanoi as follows: “Displacement processes have been common, as poorer inhabitants were out-priced, marginal settlements […] were demolished and the population was resettled to other areas […] Evidence from two inner-city upgrading programs shows that the resettlement process destroyed the inhabitants' social and economic networks in many cases and therefore often the basis of their income.” Thus, another possible future indicator for displacement processes might be the change in land prices in specific areas over time.

Another interesting aspect is *Loss of social coherence*, which also points at the integration of people. The WHO’s Healthy Cities Indicators include the “availability of primary health care services in foreign languages” which is an aspect of offering services for everybody. The only indicator set comprehending a non-specific indicator for social integration is, again, ADB’s Urban Indicators. They include “perception as a place to live” in the dimension “Urban Governance and Management”. Though, the respective descriptions of the indicator given in the ADB Cities Data Book do not clearly point out whose perspective is expressed. The *European Common Indicators* (Ambiente Italia 2003), an indicator set not included in the present review (as it has been developed as supplementary indicator set), offer a more suitable indicator in terms of inclusion of the citizens’ perspectives: Under the headline “Citizens’ satisfaction with the local community”, six different aspects are surveyed in a random sample population group: Level of social relationships, opportunities to do hobbies and enjoy leisure, level of basic services, natural and built environments, employment opportunities and opportunities to participate in local planning processes.

Streams of migrants are explicitly included in the ADB Urban Indicators (“Annual net migration”) and partially in an indirect way through the indicator “Nationality” in the Urban Audit Indicators of the European Commission. Even though the latter points at the phenomenon of migration in general, it cannot reveal the

[5] Integration of all in the healthcare systems.
[6] Indirectly and in parts measured through the Indicator “Nationality”.

time people have spent in an urban agglomeration and is thus not very helpful for the identification of possible integration difficulties. Concerning *streams of commuters*, there is a lack of indicators.

The challenge *corruption, bribery, favoritism, nepotism* is included in two sets of indicators: The UNCSD Indicators for Sustainable Development and the Global Urban Indicators. The latter includes a qualitative list on “transparency and accountability”. The check-list comprises six questions concerning the checking of municipal accounts, the publication of contracts/tenders as well as budgets/accounts, sanctions against misconduct of officials and instruments to both receive information on and investigate corruption (UN-Habitat 2004:54). The UNCSD Indicators report on the indicator “Percentage of population having paid bribes” to government officials (UNCSD 2007:50).

3.3 Challenges for the Assessment in the Indian Hyderabad

The city of Hyderabad faces, as described above, some specific challenges and risks. The comparative analysis displayed in table 4 shows the appropriateness of the surveyed indicator systems in responding to those specific challenges.

Table 4 Responses of existing indicator sets to the additional socio-cultural challenges of Hyderabad

Specific challenges/risks of Hyderabad	*UNCSD Indicators*	*Global Urban Indicators*	*CDI*	*Healthy Cities Indicators*	*ADB Urban Indicators*	*Urban Audit Indicators*
Loss of built heritage and immaterial inherited culture						
Poor retention of students						
Inadequate security of tenure	+	+			+	+

Whereas the *inadequate security of tenure* is addressed in several indicator sets, the *loss of built heritage and inherited culture* as well as *poor retention of students* are not included in any set. The specificity of the latter is suggested to provoke the absence of responding indicators. The challenge *loss of built heritage and inherited culture* would be included in Fukuda-Parr’s proposal both in form of a product indicator (*cultural diversity*) and a process indicator (*conviviality/respect for cultural identity*).

4. Discussion and Conclusions

Analyzing the suitability of existing indicator sets and indices for SD in megacities of emerging countries in view of the socio-cultural dimension, some deficiencies appear. Even relatively inclusive indicator sets like the ADB Urban Indicators lack a broad coverage of the cultural dimension of SD in comparison to the cultural indicator set proposed by Fukuda-Parr from the point of research. The social dimension is represented more comprehensively in most indicator sets even though it shows gaps in the coverage of relevant topics: The comparison of the indicator sets/index with the specific socio-cultural challenges in megacities of emerging countries showed that challenges like *displacement processes*, *loss of social coherence*, *corruption*, *streams of migrants/commuters* and *ethnic conflicts* should be addressed in a broader way. Generally, the ADB Urban Indicators and the Global Urban Indicators display a relatively good addressing of challenges. For the specific case of Hyderabad, two of the three specific challenges are not addressed.

The comparative analysis shows that the suitability of existing international indicator systems for the adaptation to megacities in emerging countries is limited in the socio-cultural dimension. Instead, proposed indicator systems from the point of research could bear an opportunity for the development of comprehensive megacity-specific indicator systems by local bodies. However, the availability of statistical data is limited, especially in developing countries. Working with relatively new indicators would imply alternative ways of data sources or collection.

Therefore, it is suggested that further research in the field of socio-cultural indicators in the assessment of SUD should not only include the development of indicators, but also try to facilitate low-cost, accurate and simple data collection.

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ENVIRODEVELOPMENT – INSPRIRING AND DELIVERING SUSTAINABLE DEVELOPMENTS

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Summary

EnviroDevelopment was developed by the Urban Development Institute of Australia – Queensland (UDIA (Qld)) to encourage more sustainable development. It is designed to reward high achieving developments and encourage others to achieve greater sustainability. It is also designed to clearly communicate to stakeholders and the public what developments have achieved in terms of sustainability.

EnviroDevelopment is performance based and applicable to a diverse range of development types and situations. It covers the broad spectrum of environmental and sustainability issues from the initial conceptual stages of a development, with elements devoted to ecosystems, water, energy, waste, materials and community. EnviroDevelopment is gathering strength and has already successfully enhanced sustainability of our future urban areas through its encouragement of industry champions.

1. The Context

Broad media coverage and credible scientific research of environmental issues has elevated community awareness in recent years. Climate change, pollution and resource scarcity (particularly water, fossil fuels, habitats and land) threaten biodiversity, human health and lifestyles. With rapid population growth in Queensland particularly, there is a need to develop our cities and towns carefully to reduce their environmental impact and conserve our resources.

The gradual recognition of the urgency of addressing these issues has seen a number of initiatives emerge. This has largely included regulation, exemplar projects, guidelines about some specific aspects of relevance to the building industry and a few rating tools. While some of these initiatives have enjoyed some success, they have had some limitations.

Environmental regulation is rapidly increasing, however regulation can generally only set minimum standards. Regulation offers no reward to high performers and its inflexibility can cause perverse outcomes. In 2002, UDIA and the Queensland Environmental Protection Agency formed a partnership to encourage and promote sustainable practices. The Sustainable Urban Development Program was able to inspire those already interested in sustainable development but had limited success in mainstreaming sustainability in on-the-ground projects as it did not sufficiently mainstream incentives.

Other tools have been limited in their scope, focussing on particular environmental elements and/or particular types of buildings and are often not applicable to the initial stages of planning or development. Many of these initiatives have been limited in their uptake and market recognition, due either to their complexity, cost, limited scope or lack of incentives for developers to implement.

UDIA recognised a need to develop a framework which would encourage and assist developers in the uptake of greater sustainability and which offered benefits to government, service providers and the community and gains for the environment.

2. EnviroDevelopment

The goal of EnviroDevelopment is to increase the uptake of sustainable urban development. To achieve this goal, implementation of the EnviroDevelopment Technical Standards must enhance sustainability i.e. it must deliver real achievements in terms of environmental and community outcomes. This must include the key concerns applicable to today's society such as reducing greenhouse gas emissions, water efficiency and protecting biodiversity. Importantly it must also motivate developers to implement sustainable development principles in their developments. The framework must be embraced by the industry, because if the program is not taken up by industry, it will have limited impact on the sustainability of the communities we live in.

The objective of EnviroDevelopment is to inspire and reward high performing developments in the field of sustainability. Designed to encourage flexibility and foster a proactive culture of innovation and environmental benevolence, it is performance-based and is adaptable to a range of development types and situations.

EnviroDevelopment is also designed to clarify the issue of sustainability in developments for local governments and consumers. It is imperative that it is clear what a particular development achieves. EnviroDevelopment also has a role in uniting sectors through partnerships based on benefits, incentives and common purpose.

To ensure the community understands what EnviroDevelopment certification represents, the message is kept simple yet meaningful through an innovative branding system. However, the system is supported by analysis using the best research available at the time and the scrutiny of professionals in the field.

3. The Journey

EnviroDevelopment has been developed in consultation with a range of stakeholders to ensure that the process of EnviroDevelopment certification is rigorous and maintains integrity. The Technical Standards Taskforce was formed at the beginning of the project to draft the technical standards of EnviroDevelopment. The Taskforce includes representatives from developers, consultants and state and local government. Careful balance was required during the formation of the concept and technical standards to ensure that EnviroDevelopment was flexible enough to encourage innovation and broad application, straightforward for consumers to understand with little interpretation and reliable enough to ensure its perennial integrity and achievement of enhanced sustainability outcomes.

The EnviroDevelopment Board of Management was established to oversee the operation of EnviroDevelopment at a strategic level and is responsible for overseeing the certification process. The Board consists of small, medium and large-scale developers, lawyers, and environmental consultants and also involves the Foundation Partners and Supporting Organisations as observers. The EnviroDevelopment concept has been supported by four Foundation Partners – St. George Bank, Boral, Brisbane City Council and GWA Caroma Dorf – with support also from the Queensland Environmental Protection Agency. Greening Australia and the Australian Green Development Forum have also provided support as Supporting Organisations.

4. EnviroDevelopment Technical Standards

EnviroDevelopment standards are structured to be substantially higher than standard practice and regulation. The standards have been set to recognise the performance of a development in achieving broad environmental goals, whilst facilitating the most appropriate or innovative method to be chosen for individual situations.

The level EnviroDevelopment is targeting is roughly such that the standards are set at a level that only the top 10-20% of developments are currently achieving. However, given sufficient encouragement and incentives, the level set by EnviroDevelopment should be within the grasp of many more developers. The Technical Standards Taskforce was mindful of not setting the standards so high that they would be perceived as too difficult or expensive to attempt compliance. Such a situation would see EnviroDevelopment become irrelevant and have little positive impact on industry performance or consumer awareness. The EnviroDevelopment Technical Standards draw together and build on the strengths of existing research and tools to provide a comprehensive system.

Table 1: Elements of EnviroDevelopment

Element	Objective	Target	Notes
ECOSYSTEMS	Healthy, sustainable ecosystems based on natural processes and rich with native biodiversity	Development that aims to protect and enhance existing native ecosystems and encourages natural systems and native biodiversity and rehabilitation of degraded sites.	Includes consideration of water quality, landform, flora and fauna.
WASTE	Reduce waste sent to landfill, more efficient use of resources	Development that includes better waste management procedures and practices and reduces the amount of waste that is disposed of to landfill.	Considers demolition and / or land clearing phases as well as construction and post-construction phases.
ENERGY	Reduce usage of polluting and non-renewable energy sources	Measures that achieve considerable reduction in greenhouse gas production from energy use across the development. As well as appropriate solar orientation and peak energy demand management.	Considers both energy efficiency measures and source substitution such as use of solar energy.
MATERIALS	Environmentally responsible material usage	Development that significantly ultilises environmentally responsible materials to lower environmental impacts in preference to other materials. There are also requirements for low toxicity material choices.	Encourages reuse of resources, materials with recycled content, materials from sustainable, renewable sources and non-toxic products.
WATER	Improve water use efficiency	Measures that achieve considerable reduction in potable water use across the development.	Considers both water efficiency mechanisms and/or source substitution such as water reuse facilities.
COMMUNITY	Vibrant, cohesive, healthy, happy, adaptable, sustainable communities	Development that encourages community spirit, sustainable local facilities, reduced use of private motor vehicles and accessible and flexible design that welcomes a diversity of people and adapts to their changing needs.	Includes consideration of consultation, transport, community design, local facilities, safe, accessible housing and indoor air quality.

The details of the standards of EnviroDevelopment and the evidence required, have been carefully set based on input from developers, a range of technical experts, local government, state government and green groups. The standards will be raised over time to set an appropriately high benchmark in light of changes in regulation, technology, expectations and industry practices. The standards will also be regularly reviewed to ensure improvements in technology and new relevant research are able to be incorporated and to ensure the EnviroDevelopment certification continues to represent a very high standard.

5. Certification Process

Developers wishing to apply to have a project certified as an EnviroDevelopment are required to demonstrate how they have met the EnviroDevelopment standards and submit the appropriate documentation as evidence of their achievement and ongoing commitment to the delivery and maintenance of the required sustainability and community attributes and features. Importantly, EnviroDevelopment is designed to minimise any additional cost burden to projects through prescriptive documentary requirements, high certification costs or additional professional fees. While protecting the integrity, to the greatest extent possible, EnviroDevelopment tries to minimise the need for reinventing or formatting existing documents and is designed to draw on existing documents prepared by experts for the purposes of development approvals or other purposes as well as appropriate additional evidence.

The EnviroDevelopment certification process has to withstand the scrutiny of the industry, government and community as well as EnviroDevelopment Foundation Partners and Supporting Organisations. The applications are initially assessed by EnviroDevelopment staff, however certification still requires the consideration and approval of the Board of Management. A site visit is also undertaken prior to certification being granted. EnviroDevelopment staff liaise with applicants during the certification process and provide feedback on strategies to improve their project's performance.

Certified EnviroDevelopments are subject to random site checks. Developers are required to advise UDIA within ten working days of any changes made or proposed to be made, to the proposed or existing EnviroDevelopment certified development which may affect eligibility for EnviroDevelopment certification.

EnviroDevelopment certification is valid for the period of twelve months from the date of approval, however it can be revoked within this timeframe for issues of non-compliance and failure to achieve commitments. Renewal of EnviroDevelopment certification is possible for a minimal fee through a review and renewal process.

6. Incentives

A key aspect of the EnviroDevelopment program is the incorporation of incentives to encourage more sustainable development. The EnviroDevelopment team can assist developers in evaluating which incentives are available and the best strategies to increase the sustainability of a particular project. The benefits and incentives offered by the EnviroDevelopment framework generally fall under two categories – the marketing benefits of EnviroDevelopment certification and the incentives facilitated by partnerships and EnviroDevelopment recognition by other organisations.

6.1 Marketing

If developers choose to have a project certified under EnviroDevelopment and are successful, they are awarded the right to use the appropriate logos for twelve months for elements for which they have been certified for. A suite of logos has been developed to facilitate this and works so that each 'leaf' represents an element of EnviroDevelopment, as detailed below in Figure 1. Developers who achieve the required performance standards in each of the elements of EnviroDevelopment are eligible to use the corresponding 'leaf'.

Figure 1: The six elements of EnviroDevelopment.

For example, Figure 2 below could be used by a development which has met the requirements for certification under each of the six EnviroDevelopment elements. Figure 3 offers the alternative logo, used to depict certification of a development that has achieved the standards for all six elements. This version may be more appropriate for other uses.

Figure 2: The certification logo for a development achieving all six EnviroDevelopment elements.

Figure 3: The alternative depiction of the certification logo for a development achieving all six EnviroDevelopment elements.

Correspondingly, Figure 4 would be able to be utilised in relation to a development that has met the standards for three of the six elements of EnviroDevelopment, namely water, materials and ecosystems. This could also be displayed in a format comparable to Figure 3 but with only the water, materials and ecosystems icons present. Figure 5 shows the generic marketing logo used only by UDIA (Qld) to promote the EnviroDevelopment concept and is primarily used for marketing and communication of the framework and for educational purposes. Foundation Partners are able to use a modified version of the generic marketing logo.

Figure 4: The certification logo for a development achieving three of the EnviroDevelopment elements (Ecosystems, Materials and Water)

Figure 5: The EnviroDevelopment marketing logo (UDIA use only)

Certified EnviroDevelopments are also featured on the EnviroDevelopment website (www.envirodevelopment.com.au) and in various related publications and media. Information about EnviroDevelopment itself and certified developments is also available at EnviroDevelopment stands at UDIA and other events. Through such mechanisms and responses to inquiries approximately 1750 hard copy EnviroDevelopment standards manuals have been disseminated to industry, in addition to those downloaded via the EnviroDevelopment website.

6.2 Partnerships and Mutual Benefit

The EnviroDevelopment concept has evolved on the basis of win-win partnerships. The uptake of EnviroDevelopment provides benefits for a range of stakeholders, given the mutual goal of enhanced sustainability of developments, although some stakeholders are particularly interested in specific components of EnviroDevelopment.

Home buyers, will be able to clearly identify which of these elements a particular development has excelled in. For instance, a development may be awarded recognition for its performance in the areas of water, energy and ecosystems or any combination of the six elements outlined above, if it meets the standards set by EnviroDevelopment for the particular elements. Purchasers of EnviroDevelopments will also have the benefit of any reduced operation costs, or enhanced liveability and lifestyle benefits resulting from the sustainable focus of the development, as well as peace of mind knowing that they have made an environmentally responsible selection. They may also have greater self-sufficiency of energy or water supply, improved access to local facilities and access to 'green loans' and rebates for example.

Similarly, local governments will be able to rapidly assess some of the likely benefits of a development application relating to an EnviroDevelopment project. There are also benefits to local authorities in terms of more efficient use of resources, more attractive and sustainable urban areas, benefits to the local environment and reduced infrastructure costs. For example, a particular development may be expected to reduce demand on potable water supplies by more than 40% or may undertaken significant efforts above and beyond the average, to protect biodiversity. Similarly, there are benefits for other levels of government, service providers and the community through the better outcomes and efficiencies inspired by EnviroDevelopment.

7. Implementation

Presently, there are nine certified developments, representing over 8,800 lots / units. At the time of writing, a number of developments were in the process of preparing applications. Interest from developers across Queensland has been significant and the EnviroDevelopment standards are being utilised by developers and consultants to guide future development plans.

Following the successful launch of EnviroDevelopment in Queensland in October 2006, and widespread industry acceptance, UDIA (Qld) has commenced a national rollout of EnviroDevelopment. At the time of writing, EnviroDevelopment was being trialled by three developments in South Australia and following significant interest from developers, a commitment has been made to also progressing EnviroDevelopment in Victoria and Western Australia where there is also a significant level of enthusiasm about EnviroDevelopment in the development industry.

Already EnviroDevelopment has achieved significant outcomes in terms of sustainability outcomes. Certified developments are saving more than 1,300ML/yr of potable water and 30,900 tonnes of greenhouse gas, compared to traditional standards.

In contrast to a weighted points-based system, EnviroDevelopment is target based, which sets required performance outcomes rather than prescribing solutions. Although this requires in-depth analysis of applications prior to certification, it has facilitated recognition of some great outcomes and minimised perverse outcomes and a ‘points chasing’ mentality. Each of the nine certified developments have achieved exemplary standards in the areas for which they have been certified. Innovative solutions employed include total water and energy self-sufficiency through the utilisation of onsite and renewable systems, extensive and cooperative community consultation programs and the delivery of extensive community facilities. Water treatment and reuse systems have also been pioneered. Despite a lack of information regarding full life cycle assessments and little market recognition, some certified EnviroDevelopments have also utilised environmentally responsible materials for a range of purposes including floor coverings, framing and to meet structural requirements. These projects have also utilised non-toxic paints, coverings and finishes. EnviroDevelopments have also delivered comprehensive waste management and minimisation programs for all stages of a development and contributed significant areas of green / conservation space for the purposes of species conservation and habitat enhancement, in addition to rehabilitation works. Certified EnviroDevelopments include detached greenfield, infill, medium density, masterplanned and mixed use developments and precincts. Applications are also be progressed for an industrial development and interest has been expressed from other sectors such as infrastructure projects and transportable homes. The application of a range of innovative sustainable development initiatives for different development types, scales and sites, promoted through EnviroDevelopment has played an important role in encouraging the industry to achieve greater sustainability.

8. Lessons Learnt

The level of interest EnviroDevelopment has received from both the industry and broader community suggests that sustainable development is becoming a key priority for a growing number of people and organisations. However, obstacles such as costs and delays still exist and impact on the industry’s ability to deliver more sustainable development. The industry is still experiencing some delays in the development approval process, particularly in instances where some local governments are nervous or unwilling to approve innovative systems such as on-site water treatment and re-use. This can result in some compromises and hindrance of sustainability achievements. The EnviroDevelopment process also highlights situations where regulation has not kept pace with science and technology and changes may be desirable.

Feedback to date indicates that developers of certified projects have found EnviroDevelopment to have merit and that the branding and independent certification has been valuable, and will of course increase further over time with growth in brand recognition so long as the integrity and meaning of EnviroDevelopment is maintained. The continued high level of interest in EnviroDevelopment and regular inquiries and website hits also indicates that there is growing interest in certifying new developments as EnviroDevelopments and in utilising the principles of EnviroDevelopment in designing new developments. This is expected to continue as the value of EnviroDevelopment certification will rise with increased brand use and recognition, and the provision of incentives from all levels of government.

EnviroDevelopment has also been recognised for its merit as an educational tool. As well as its assistance to industry and government in this regard, it has also been of interest to a number of universities and schools.

In addition to general learnings and research on the subject, the various EnviroDevelopment applications received and assessed have also highlighted instances where the lack of valid and reliable data can be problematic and further research would be of merit. This includes lifecycle assessment of materials, modelling of energy and water efficiencies in various scenarios, and understanding the benefits of various ecosystem and community attributes designed into developments. However, as further research is being conducted in many of these fields, further clarity may be achieved in future years.

9. Conclusion

EnviroDevelopment provides the effective interface between the real world and sustainability ideals. It offers a unique framework to bring together the multitude of piecemeal research, tools and general goodwill that actively promotes and rewards sustainable development. It is industry-led, revolutionary and practical.

The EnviroDevelopment system seeks to achieve meaningful outcomes which are easily recognised and understood by consumers. The integrity of a third party verification of a development's sustainability credentials, through an independent Board of Management and Technical Standards Taskforce, has been recognised by industry, government at all levels and other stakeholders.

MODELLING A SUSTAINABLE URBAN MANAGEMENT SYSTEM

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Keywords: Project management, urban scale, environmental performance.

Summary

After developing a methodological framework to model actions taken collectively and individually by the project group, we first established an inventory of research approaches. We then expanded our approach to professionals and future residents of an urban renewal neighbourhood in Aix-les-Bains. This methodology, while originating from the strategic analysis suggested by Crozier and Friedberg, should find new applications that complement the approach adopted for quantitative-qualitative comparative analysis.

1. Initial situation of the existing approaches

Our 'Habitat' can play a decisive role in the emergence of new forms of cooperation making it possible to reconcile in day to day life preservation of the environment, economic efficiency and social equality. The significance of these concerns falls completely within the framework of urban renewal operations to release certain areas from their decline, or even their complete exclusion from the development of our societies. 751 neighbourhoods are involved, classified as critical urban areas (zones urbaines sensibles, ZUS). The expectations of planners and the needs of public bodies have multiplied in the last few years, so a systematic methodological framework is proposed based on evaluation tools adapted to the context of each urban project.

1.1 The PASTILLE European project

Cofinanced within the 5th RDFP (Research and Development Framework Programme) by the European Commission and the Swiss government, the objective of the PASTILLE project (Promoting Action for Sustainability Through Indicators at the Local Level in Europe) was to develop an indicator base to assist public bodies to adjust their decisions, taking into account the criteria for sustainable development. The need to evaluate the policies applied involves public officials directly and leads to new forms of administration known as "New Public Management". These approaches notably reinforce the need to formulate precise objectives, evaluate the progress achieved, impose sanctions if necessary or at least corrective measures, etc.

Experiments carried out within the PASTILLE project has shown that using checklists of indicators overshadows the definition of a local policy that supports sustainable development, and therefore the priorities pointed up locally. The approach we habitually find to the indicators means they cannot be perceived as "endogenous elements of the dynamics of public action, in a particular context". On the contrary, the PASTILLE consortium[1] suggests the indicators be used as strategic tools for the governance process. Shared as the chief device for a perpetual forum between the different participants in urban governance, the indicators can create more cross-functionality, enabling better negotiation of often conflicting strategies and visions…

[1] http://www.lse.ac.uk/collections/pastille/test.xls

1.2 The European measure HQE2R

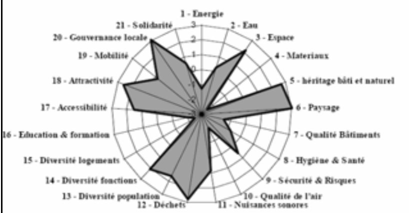
Under the coordination of the Centre Scientifique et Technique du Bâtiment (CSTB, Scientific and Technical Building Centre),the European project for research and demonstration known as " HQE2R"2 (Sustainable Renovation of Buildings for Sustainable Neighbourhoods) has between 2001 and 2004 brought together ten research organisations or centres and thirteen towns belonging to seven European countries. The HQE2R project has established as objectives the proposal of some tools, methods and guides containing recommendations or good practice for urban planning or renewal operations.

Three evaluation models have been developed by the members of the HQE2R project for evaluating urban projects: the ENVI model (Committee on the Environment, Public Health and Consumer Policy) on the environmental impact of projects or scenarios, the INDI model (INDicator based sustainability Impact assessment) for project evaluation and selection, the ASCOT simulation model (Assessment of Sustainable Construction and Technologies cost) that enables the comparison of a sustainable building with a benchmark building in terms of overall cost. These tools make it possible to meet respond to the requirements of European Directive 2001/42/CE pertaining to the environmental evaluation of programmes and plans.

1.3 The ADEQUA project

The purpose of the ADEQUA method3 is to create a tool to help in decision making during the rehabilitation of a residential quarter. The project consisted first of all of a classification of the criteria for sustainable development then secondly an inventory of the methods for their evaluation. The method was then validated using case studies chosen in partnership with the authorities.

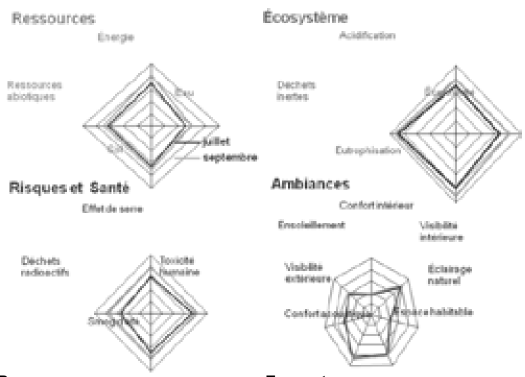
A final quantification of the indicators associated with the objectives enables construction professionals, the planner or the authority to evaluate quantitatively and to compare different planning alternatives for an area, with the aid of spidergrams. This quantification is based on the use of simulation tools and multi-criteria aggregation.



1 Energy 2 Water 3 Space 4 Materials 5 Built and natural heritage 6 Landscape 7 Building Quality 8 Hygiene & Public Health 9 Security & Risks 10 Air quality 11 Noise nuisance 12 Waste 13 Population diversity 14 Employment diversity 15 Accommodation diversity 16 Education & training 17 Accessibility 18 Attractiveness 19 Mobility 20 Local governance 21 Cooperation

Analysis of a quarter, INDI – HQE²R profile

Result from PASTILLE method



Resources
Energy
Abiotic resources Water
Sun **July**
September

Ecosystem
Acidification
Inert waste Ecotoxicity
Eutrophication

Risks and health
Greenhouse effect
Radioactive waste Toxicity to humans
Summer smog

Surroundings
Interior comfort
Sunshine Interior visibility
Exterior visibility Natural illumination
Acoustic comfort Habitable space

ADEQUA Indicators

Figure 1: Method of representing the results from different tools

2 http://hqe2r.cstb.fr

3 Frédéric CHERQUI, Méthodologie d'évaluation d'un projet d'aménagement durable d'un quartier – méthode ADEQUA, Laboratoire d'Étude des Phénomènes de Transfert Appliqué au Bâtiment, Université de La Rochelle, 2006.

2 A new Eco Obs approach to sustainable urban management

2.1 Concept

The research presented below clearly emphasizes the importance of developing in an often conflictive context the strategic tools to aid the public authority in their decisions or their negotiations. Here the concern is to examine, in a context of urban complexity[4], sustainable urban planning projects as a mode of organisation of the actions and the participants. Elsewhere we have observed, in the context of the ADEQUA project, the difficulties encountered in evaluating different urban project scenarios. This approach does not sufficiently respect habitual practices and the resources available to the participants. So it does not suffice on its own to favour the inclusion of sustainable development issues at this scale.

The methodology that we are currently developing aims at detecting objectively the convergences or "cooperation sets" and divergences or "conflict sets" between the participants in the urban planning operation. The project group, as a sociological system, exists because of the interdependence of the participants and actions, whose objectives may converge or diverge. Different strategies are analysed with the aim of encouraging the necessary collective actions for the success of the operation. The authority can then organise the conduct of the project in accordance with the supposed blockage points inherent to the participants. Our approach represents each participant in the environmental management of an operation. The tool which has been developed on this methodological basis makes it possible to create various sociograms representing the direct influences on the participants and the impact of each participant on the objectives of an operation. It is important to develop, in an often conflictive context, tools that assist the public authority in its decisions or its negotiations.

2.2 The use of MACTOR

In order to be able represent our results visually, we have had recourse initially to the MACTOR application. This illuminates the sets of alliances and potential conflicts between the actors and makes it possible to enquire about the possibilities of change in the relations between the different participants. So at first sight it is a suitable tool for the type of study desired, and for these reasons it has been used[5] on the Mérigotte mixed development zone (ZAC, zone d'aménagement concerté) and the Aix les Bains project today.

Analysis of the sets of participants is a crucial stage for the construction of a basis for reflection that then makes possible the construction of scenarios: without this precise analysis, the scenarios lack relevance and coherence, and very often analysis of the interplay of participants is preceded by a structural analysis to identify the key variables.

So the objective of using the MACTOR method is to provide to a participant an aid to decision making for establishing their policy on alliances and conflicts.

2.3 Creation of a new tool for observing eco-districts

The tool previously described and the use of MACTOR has made possible a real advance in the domain of sustainable urban management. However, the method of collecting data took a long time: all the participants had to be interviewed separately and the data then had to be captured to proceed with the analysis.

Now it is desired to attempt to set up an IT platform on which some questionnaires would be placed online, completed remotely and collected via the internet.

The approach adopted for the creation of the new tool breaks down into five stages. The first is the choice of IT system that best responds to our expectations. The second is the creation of 2 questionnaires aimed at users and professionals as well as a working framework to filter the data from the planning project's environmental chart. The third is collection of the responses. The fourth is the processing the data, with the establishment of sociograms (using MACTOR mathematical formulas) and statistical elements. The fifth and last stage is accumulation, interpretation and the creation of a database.

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[4] Marie FAUCONNET, Projet urbain et gestion durable de la Ville, in A DA CUNHA, P KNOEPFEL, JP LERESCHE, S NAHRATH, « Enjeux du développement Durable », PPPUR, 2005

[5] A preliminary set of results has notably been presented in ACHARD G, BUHE C, DUFRASNES E, WURTZ E, "*Environmental performance and management of sustainable urban projects*", IISBE, UNEP, CIB, Lisbon, 2007

3 Application to the Sierroz / Franklin district in Aix-les-Bains

The Urban Renewal of the Sierroz / Franklin Roosevelt district in the town of Aix-les-Bains is a project with the aim of transforming the area by opening it up to the rest of the town. Specifically, this is achieved by:

- dismantling 300 dwellings (4 x 14 floor towers)
- creating environmental quality (HQE® or similar approach)
- 311 dwellings in small collective homes
- shops
- premises for services
- the rehabilitation and residentialisation of 422 residences (creating defensible and 'owned' space, and/or installing security devices)
- reorganising the road network.

This project, extending over the period 2006-2012, falls very definitely into sustainable development practice. So protection of the environment, one of the components of sustainable development along with the economic and the social, must be exemplary. Like for the follow-up in the Mérigotte mixed development zone, we started by identifying several initial participants and objectives :

- The public authority and services associated with the Town of Aix les Bains;
- The town planner at Passagers des Villes architectural office

Each participant chosen has been identified based on a non-directive interview so that they can specify their goals and objectives, their strengths, their weaknesses. A single questionnaire enables us to grasp the position of each participant on the same basis. Just as we have established with MACTOR, we have been able to esta hows how closely the participants adhere to their obje

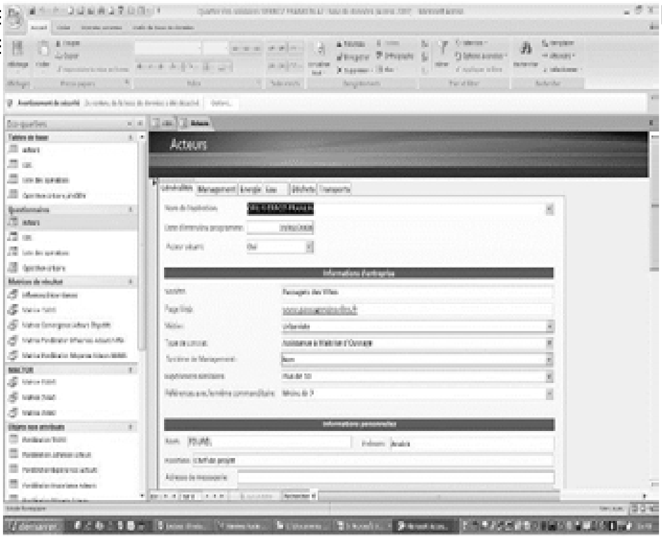

Figure 2: Eco-districts database

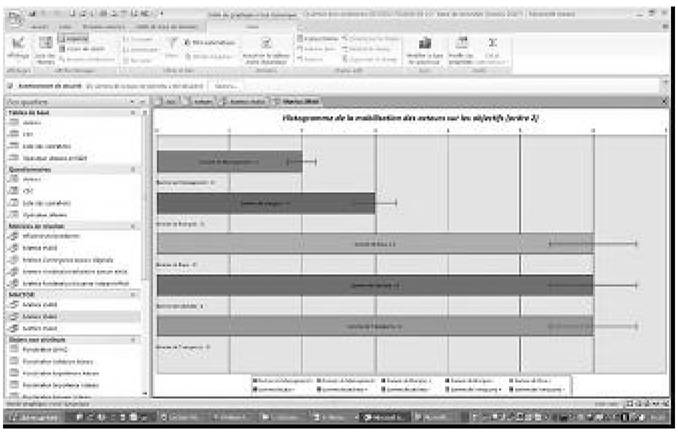

Figure 3: histogram of adherence of the participants to goals

4. Conclusions and prospects

Considering the significant number of urban rehabilitation operations sustained by ANRU (National Urban Renewal Agency), the ambitions of these programmes and the importance of the associated issue of urban sustainability, the need for evaluation and feedback is intensified and should intensify still more in the near future.

Our approach proposes to respond to this by making available, via a unit monitoring the energy efficiency integration practices in these "ANRU operations", a systematic framework based on evaluation tools adapted to the context of each urban project. So our work positions us at the intersection of these expectations in order to :

- Evaluate the practices applied to respond to the challenges of urban sustainability,
- Support exchanges between those running projects agreed by ANRU,
- Set up a monitoring centre based on the operational evaluation tools.

This monitoring centre will therefore monitor three types of indicators:

- Indicators of financial and economic incentive practices
- Indicators of performance or results
- Process or management indicators

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STRUCTURAL MODEL OF WATER AND ENERGY CONSUMPTION EFFICIENCY IN RESIDENTIAL BUILDINGS

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Keywords: Water Saving, Buildings Component, Planning, Tools and Methods

Summary

Supply of water in appropriate quantities and at the required pressure and temperature is the key criterion for any water consumer or user.

The criterion of the possible water consumption efficiency (and the efficient use of the energy required to ensure the water supply) is estimated cold and hot water more and more discussed and taken into consideration in the context of a water supply system operation.

A structural model has been used for recording the process of water consumption in residential buildings. Simulation models of the operation processes are of a functional character. The characteristic feature of those models is their operation in the cause-and effect chain which represents the reality.

The calculations of the cold and hot water consumption levels have been based on the data about the duration of individual activities (namely: how long does water flow out of tap batteries in individual types of activities) and their frequency (how many times during a day or a week etc.). The data used in the calculations have been based on a questionnaire survey focusing on the water consumption behaviours demonstrated by residents of buildings, and measurements taken by the author.

In line with the methodology developed for the purpose of this research the water consumption levels have been calculated for two identical buildings with different types of water system fittings installed therein, and the levels of pressure at individual storeys.

The structural model of water consumption presented herein illustrates the scale of the consumption efficiency improvements which can be achieved. The estimated cold and hot water consumption levels can be easily used for calculation of the operating costs connected with the consumed water and the energy required to heat it. In practice the system discussed in this paper can be effectively used for comparing various water supply system designs where the criterion of the operating costs generated by the proposed technical solutions is taken into consideration.

1. Introduction

The level of water consumption by a human being determines the proportional consumption of energy required to prepare that water in a proper way. From the water consumer's point of view it is important that water is supplied in adequate amount and at the required pressure and temperature. The aforementioned elements are closely related with the supply of energy necessary to overcome the resistance occurring in the process of transporting the water from the source to the consumer, create the required pressure at the water consumption points or – in case of hot water – heat the medium. The diversity of water consumption methods is reflected in the development of technological solutions employed in the production of taps designed for specific applications (e.g. thermostatic bathtub and shower taps for a household use or pushbutton or touch-free taps for public or industrial buildings).

The criterion of the possible water consumption efficiency (and the efficient use of the energy required to ensure the water supply) is more and more discussed and taken into consideration in the context of a water supply system operation. Investors and future occupants of residential buildings pay attention to the possible reduction of the operating costs connected with the residential units under construction or those they are planning to buy. Therefore the water consumption efficiency level of the offered design and constructional solutions of the water supply systems is used as the criterion of assessment.

This paper shows an attempt to build an assessment system for various possible water supply system solutions designed for residential buildings in the form of a structural model in order to compare them in terms of the water consumption economy opportunities they offer.

2. Theoretical Basics of Structural Modelling

The modelling of a technical facility operation and maintenance processes is used in the operation and maintenance tests along with the field surveys. A special category of models is used for this purpose, namely simulation models. The latter can cover the operation processes or the maintenance ones, or both.

The simulation models of the operation processes are or a functional character. So far they have been usually tried and developed as stochastic models in a form commonly known as the black box. The characteristic feature of those models is the modelling effect which ensures the cause-and-effect connection between the input and output signal consistent with the reality. The modelling effect is achieved by means of transforming the input signal into the output one in a way that differs from the performance which can be actually observed in the reality. The structural models commonly known as the transparent box are a much less popular category of models. The characteristic feature of those models is their operation in the cause-and effect chain which represents the reality accurately although the realisation differs from the real one – e.g. a computer-based numerical realisation. The use of those models in a simulation format makes it possible to monitor changes in the condition of the examined facilities in the course of their operation and maintenance.

3. Water Consumption Calculation Methodology

The following purposes which cold and hot water is used for in residential buildings can be distinguished (Fig. 1). In order to compare the water saving possibilities existing in the residential buildings some selected components have been taken into account: A, B, C, D, E, F, G. And to simplify the comparative calculations it has been assumed that the components E and F are independent of the pressure, the type of tap or the piece of equipment connected to the system.

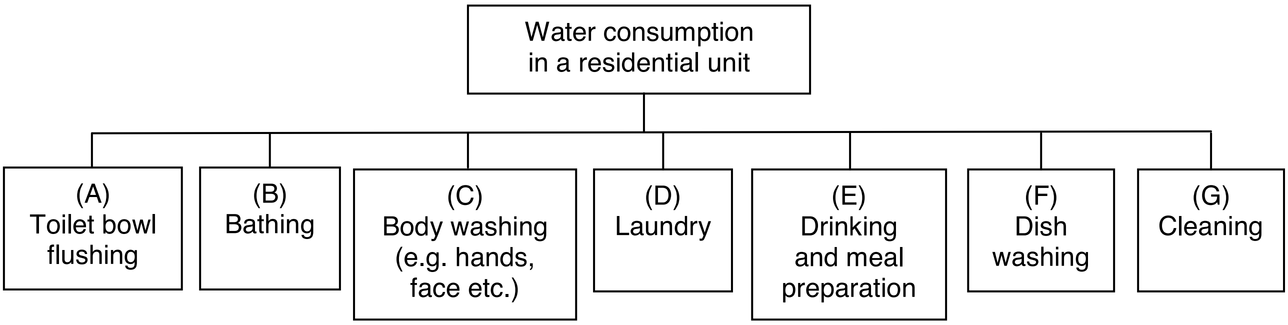

Figure 1 Purposes for which water is used in households.

It has been assumed that in case of the components A and D only cold water is used whereas in case of other components (i.e. B, C, E and G) mixed water is used (at the temperature of about 36÷40°C) in the proportion of 50% to 50% of the cold and hot water. The cold and hot water mixing ratio has been taken on the basis of the assumed cold water temperature of about 10°C and the hot water temperature of about 55÷60°C (in line with the requirements to be fulfilled in Poland and other European Countries).

The input data for the calculations are shown on Fig. 2. The water consumption for the purposes A, B, C, F and G has been calculated on the basis of the following assumptions:

- Water leakage in the water supply system, tap batteries, toilet cisterns, washing machines etc. is not taken into consideration;
- Water consumption in a toilet cistern does not depend on the pressure before the cold water feeding valve – the higher the pressure the faster the cistern is filled up;
- Water consumption during taking a shower depends on the type of the shower battery (the hydraulic characteristics of the battery are given in the form of the following function: P=f(Q)), its design characteristics which influence the way it is used and, in particular, how long the water flows during individual actions, and the pressure before the battery;
- The levels of water consumption for laundry washing purposes are important only in case of the systems which reuse the wastewater from bathing and laundry washing for flushing the toilet bowl (dual systems);

- In about 70% of cases a washbasin and a washbasin tap are used in the process of cleaning rooms in a residential unit and only in 30% of cases a sink unit and a sink tap are used for that purpose. To maintain the sanitary hygiene within a shower cabin and in a toilet bowl taps installed next to those facilities are also used;
- The levels of water consumption for the room cleaning purposes do not depend on the number of people occupying a residential unit;
- It is assumed that the basic body washing activities take place at a washbasin and the washbasin tap is used for that purpose;
- The aforementioned basic body washing activities include: hand washing, face washing and tooth brushing;
- Consumption of water during the basic body washing activities depends on the type of the washbasin battery (the hydraulic characteristics of the battery in the form of P=f(Q)), its design characteristics which influence the way it is used and, in particular, how long the water flows during individual actions connected with the use of water, and the pressure before the given battery (Fig. 3).

The calculation principles have been developed for each aforementioned water consumption purpose separately (A, B, C, D, E, F, G). The model algorithm includes the information about the frequency of using various sanitary facilities (Table 1) and the scenarios of activities involving the use of water developed for individual sanitary facilities and taps/batteries (Tables 2, 3 and 4). The calculations for other discussed water consumption purposes marked with letters A, D, E, F and G have been made in a similar way.

In case of the tap batteries their hydraulic characteristics (showing the correlation between the water flow levels and the pressure in the water supply system before the given tap) have been used.

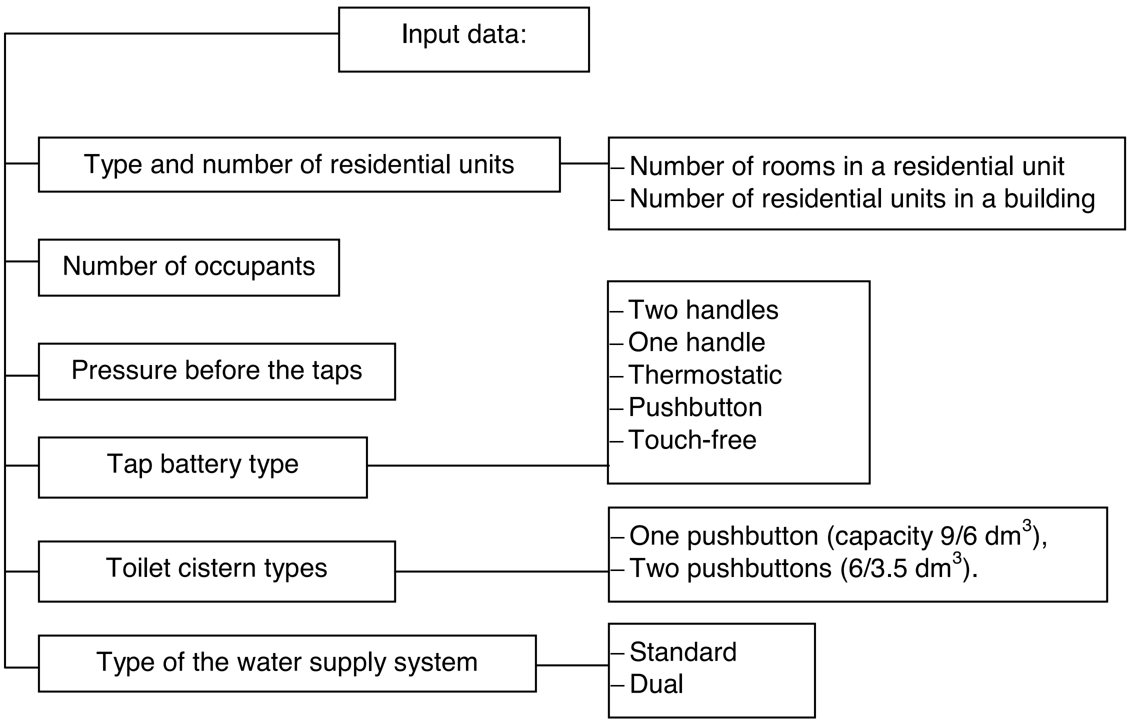

Figure 2 Breakdown of input data for a structural model.

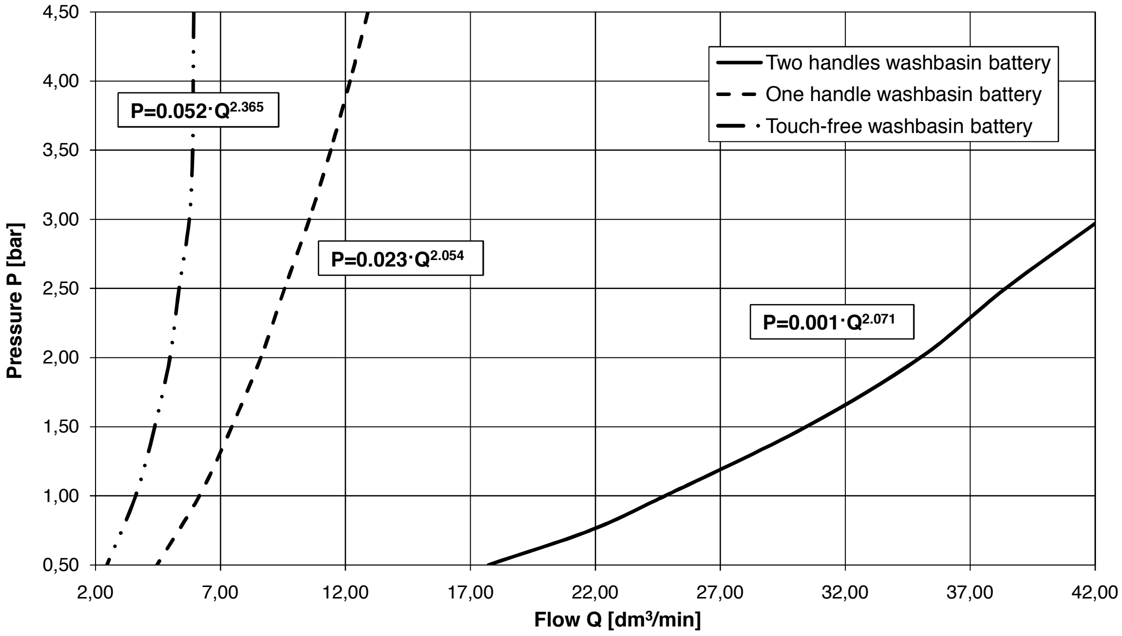

Figure 3 Example of hydraulic characteristics various types of washbasin batteries.

Table 1 Frequency of water consumption for various purposes taken into account in the algorithm of the structural model.

Actions related with and purposes of water consumption				Unit	Frequency of consumption (average value)
A	WC	Toilet bowl flushing	Large	$[(d \cdot person)^{-1}]$	1
			Small	$[(d \cdot person)^{-1}]$	3
B	Bathing	Bathtub		$[(week \cdot person)^{-1}]$	1
		Shower		$[(d \cdot person)^{-1}]$	1
C	Washbasin	Hand washing		$[(d \cdot person)^{-1}]$	2
		Tooth brushing		$[(d \cdot person)^{-1}]$	2
		Face washing		$[(d \cdot person)^{-1}]$	2
		Hand washing in the washbasin in WC		$[(d \cdot person)^{-1}]$	3
D	Laundry washing	Manual laundry washing/using a washing machine		$[(week \cdot person)^{-1}]$	1
E	Sink unit	Drinking and preparation of meals		$[(d \cdot person)^{-1}]$	0.5
F	Dish washing	Manual dish washing or using a dishwasher		$[(d \cdot person)^{-1}]$	0.7
G	House cleaning	Sink unit		$[(week)^{-1}]$	0.5
		Washbasin		$[(week)^{-1}]$	1
		Washbasin in WC		$[(week)^{-1}]$	1
		Bathtub		$[(week)^{-1}]$	0.5
		Shower		$[(week)^{-1}]$	1
		WC		$[(week)^{-1}]$	1

Table 2 Example of a taking-a-shower scenario (B) broken down into individual actions for various types of taps.

Individual actions	Duration of the action [min.]				
	Two-handle tap battery	One-handle tap battery	One-handle tap battery with eco-pushbutton	Thermo-static tap battery	Pushbutton (or touch-free) tap battery
Setting suitable water temperature	0.5	0.1	0.1	0.0	0.0
Rinsing the head and the body	1.5	1.5	1.5	1.5	1.5
Soaping the head	1.0	1.0	1.0	1.0	0.0
Rinsing the head	1.0	1.0	1.0	1.0	1.0
Soaping the body	1.5	1.5	1.5	1.5	0.0
Rinsing the body	2.0	2.0	2.0	2.0	2.0
Total water flow time:	7.5	7.1	7.1	7.0	4.5

Table 3 Example of a hand-washing scenario (C) broken down into individual actions for various types of taps.

Individual actions	Duration [sec.]				
	Two-handle tap battery	One-handle tap battery	One-handle tap battery with eco-pushbutton	Thermo-static tap battery	Pushbutton (or touch-free) tap battery
Setting suitable water temperature	8	2	2	0	0
Rinsing the hands	5	5	5	5	5
Soaping the hands	15	15	15	15	0
Rinsing the hands	10	10	10	10	10
Total water flow time:	38	32	32	30	15

In the calculation algorithm applied in the structural model two types of water supply systems existing in buildings have been taken into account in terms of the water saving opportunities they offer:

– A standard type: a system fed from the external water supply network, with a lower distribution and centralised production of hot water, where the entire used water is piped off, in the form of wastewater, into the sewage system;

– A dual type where some portion of the wastewater from bathing and laundry washing can be reused (following a preliminary treatment) for flushing the toilet (Fig. 4).

The calculations based on the algorithm included in the structural model produce the results which show the water consumption in a predefined period of time (e.g. a day, a week, a month, a year) for individual flats or for the entire building, or the unit water consumption values expressed e.g. in $dm^3/(Person \cdot d)$. The results can be broken down into the consumption of cold water, hot water and the total consumption, as well as into individual types of the declared water supply system (the standard of the dual one).

4. Examples of Calculations

In accordance with the methodology presented above the water consumption has been calculated for two identical buildings with different types of tap batteries and toilet cisterns installed therein, and the levels of pressure at individual storeys. In order to compare the water consumption levels selected purposes which water is used for in households (A, B, C, D and G) have been taken for calculations. Moreover, versions based on the standard water supply system and the dual one have been calculated for each variant. The results of the calculations can be found in Tables 4 and 5.

The functional characteristics of the buildings No 1 and 2 is as follows:

- Multifamily 4-storey building;
- 55 residential units, 1, 2 or 3 rooms each, 165 occupants.

Water-tapping points in the sanitary rooms in the building No 1 are equipped as follows:

- Toilet cisterns with the cubic capacity of 9 dm^3 each;
- All tap batteries of the standard two-handle type;
- The pressure level at the connection to the water supply system: 3.0 bar.

Water-tapping points in the sanitary rooms in the building No 2 are equipped as follows:

- Toilet cisterns with the cubic capacity of 6/3.5 dm^3 each;
- Thermostatic shower batteries with eco-pushbutton, touch-free washbasin batteries with flow limiter, sink unit one-handle batteries with eco-pushbutton;
- The pressure level at the connection to the water supply system: 3.0 bar;
- Pressure reducers which ensure the pressure equal to 1.0 bar before every water-tapping point in the building are installed on every storey before the connection between the water supply system and the water-tapping points.

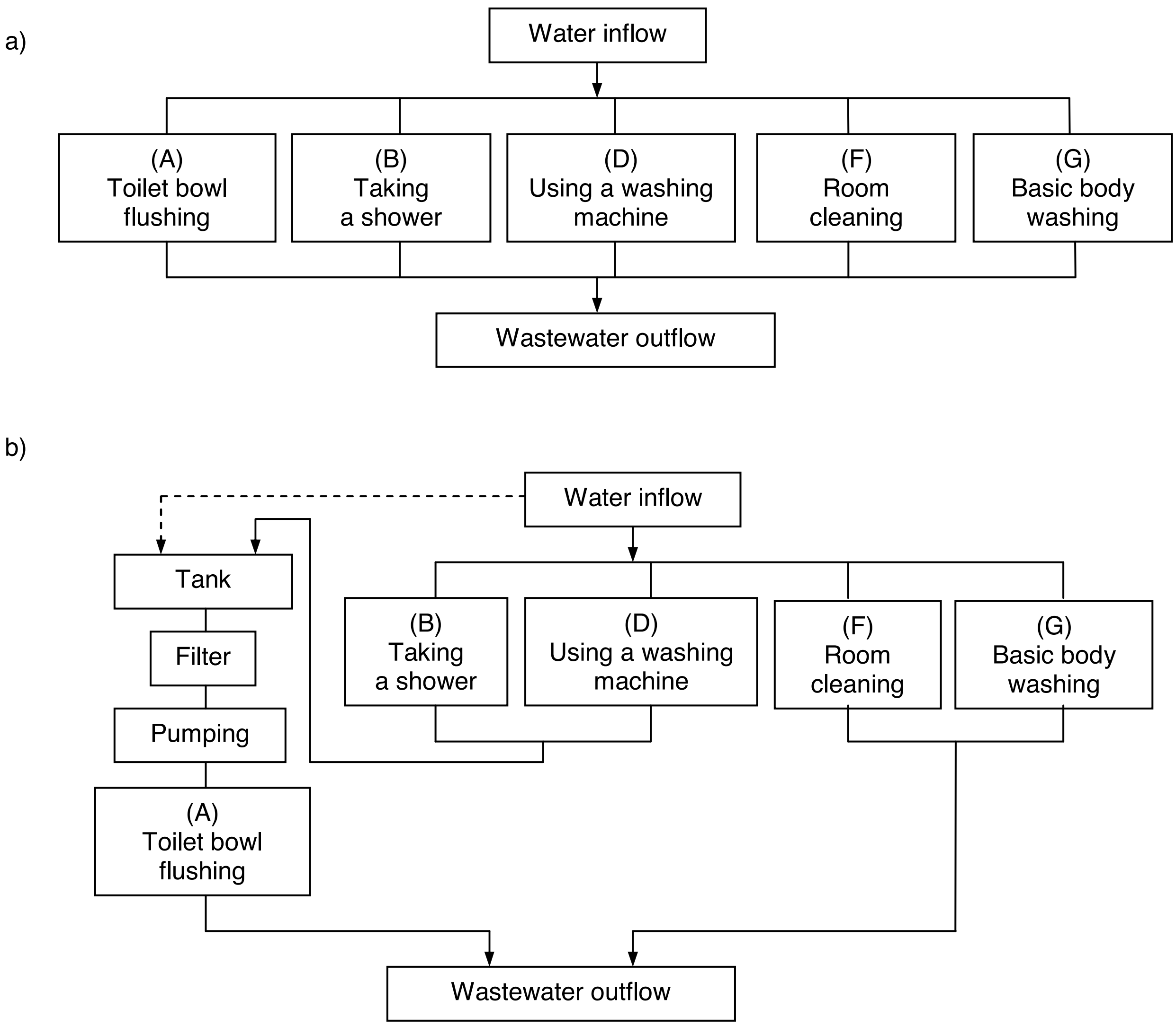

Figure 4 Diagrams of various water supply system types: a) standard type, b) dual type with a partial recycling of the used water.

Table 4 Results of water consumption calculations in the building No 1.

Type of water consumption:		Cold water	Hot water
		dm^3/(Person·d)	dm^3/(Person·d)
A	Toilet bowl flushing	45.0	-
B	Taking a shower	20.2	20.2
C	Hand washing	8.5	8.5
	Face washing	5.2	5.2
	Tooth brushing	16.8	16.8
D	Laundry washing	21.5	-
G	Room cleaning	4.2	1.4
Total:		121.4	52.1
Total cold and hot water for the standard water supply system:		173.5	
Total cold and hot water for the dual water supply system:		128.5	

Table 5. Results of water consumption calculations in the building No 2.

Type of water consumption:		Cold water	Hot water
		dm^3/(Person·d)	dm^3/(Person·d)
A	Toilet bowl flushing	22.5	-
B	Taking a shower	8.2	8.2
C	Hand washing	2.2	2.2
	Face washing	2.0	2.0
	Tooth brushing	3.5	3.5
D	Laundry washing	21.5	-
G	Room cleaning	2.8	2.1
Total:		62.7	18.0
Total cold and hot water for the standard water supply system:		80.7	
Total cold and hot water for the dual water supply system:		58.1	

The results presented in Tables 4 and 5 can be used for comparing the solutions applied in the water supply systems in both buildings in terms of the future water consumption levels and the costs of the tapped cold and hot water. Those figures should not be unambiguously interpreted as the actual water consumption levels due to the fact that some portion of the water-consumption-related needs of the occupants can be underestimated (e.g. as a result of the existing differences in habits, traditions, behaviours, and division into individual gender, age or other groups) and because of the limitations of the assumptions made for the calculations (e.g. unavailability of bathtubs and bathtub tap batteries in bathrooms).

In case of a standard water supply system the economy on the water consumption in the building No 2 amounts to as much as 53% as compared with the same type of the water supply system operated in the building No 1. This economy has been achieved as a result of using toilet cisterns with smaller cubic capacity (it is possible to use 6 or only 3.5 dm^3 of water depending on the need) and replacement of standard two-handle tap batteries with water-saving ones, and installation of pressure reducers on every storey of the building.

The upgrade of the water supply system to a dual one where the wastewater from shower cabins and washing machines is reused for flushing toilet bowls can generate the water consumption economy of about 26-28%.

The modernisation of the building No 1 (equipped with a standard water supply system and traditional tap batteries and toilet cisterns, without any pressure reducers), consisting in replacement of the whole system with a dual one and the upgrade of the water-tapping accessories, and introduction of pressure reducers, can generate the water consumption economy of 66%.

5. Conclusion

Introduction of water-saving technologies, even those which improve the water consumption efficiency only slightly but are applied directly in users' (consumers') homes i.e. within the interior water supply systems in the buildings, contributes directly to the actual reduction of the water consumption levels and this reduction is reflected in lower charges collected from the users for consumed water and energy (the energy used for heating the water and generating an appropriate pressure in the water supply system).

On the other hand the reduced water consumption in individual buildings connected to the municipal water supply system has a substantial influence on the actual amount of water taken from the given water line and, consequently, it may have a direct impact on how individual elements of the water supply system are designed and on the costs of their construction and operation.

The structural model presented herein, designed to calculate the water consumption levels, illustrates the scale of the consumption efficiency improvements to be achieved. The estimated cold and hot water consumption levels can be easily used for calculation of the operating costs connected with the consumed water and the energy required to heat it. In practice the system discussed in this paper can be effectively used for comparing various water supply system designs where the criterion of the operating costs generated by the proposed technical solutions is taken into consideration.

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RAINWATER HARVESTING SYSTEM DESIGN BASED ON RAIN GUAGE TIME SERIES

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Keywords: risk assessment, sustainable design, rain harvesting

Summary

Rainwater harvesting/storage systems should be evaluated with respect to historic patterns of drought. Patched-point rain guage time series have been used to simulate the performance of rainwater harvesting in seventeen Australian locations as an example of a methodology that could be applied at thousands of other places. The key to sizing rainwater harvesting systems was found to be average daily rainfall (ranging from 0.6 mm/d in Port Augusta to 5.7 mm/d in Cairns), being the annual average divided by 365 days. To further develop rainwater harvesting design, it was assumed that 250 litres of water per day is the nominal household demand, and that an effective roof catchment area (ranging from 87m² in Cairns to 806m² in Port Augusta) is found from twice the ratio of average daily rainfall rate (mm) divided by demand (L/d). The longest drought in 118 years of daily rainfall time-series (1889-2007) was found at each location as the longest sequence of days without a single day experiencing a threshold trigger of at least half of the average daily rainfall (ranging from 58 days in Melbourne to 292 days in Exmouth). The nominal rain water storage requirement was then taken as the product of the daily demand and the number of days of the longest drought (ranging from 14,500 L in Melbourne to 73,000 L in Exmouth). Finally the catchment-storage system was simulated in the seventeen location for the 118 year period of time-series, finding a failure rate ranging from 0.2% in Melbourne to 4.6% in Exmouth. Failure was measured as the number of days that the rainwater harvest system ran dry, and so import of water would be required to meet demand in extreme drought.

1 Background

The Australian Bureau of Meteorology maintains Australia's climate record, including daily rainfall records, some dating back to the early 19th Century, plus other climate observations (temperature etc) which have been computerized from 1957 [1]. The Queensland Climate Change Centre of Excellence's (QCCCE) SILO data service integrates all observations from more than 10,000 rain guages[2] into interpolated daily gridded datasets of Australian rainfall spanning from the late 19th century to the present day in a daily timestep. Similarly, data drom approximately 500 evaporation reporting locations have been interpolated from 1970 onwards. All SILO interpolated datasets have a spatial resolution of 0.05 degree (~5km), from which hundreds of thousands of point time series can be extracted using the Silo datadrill. Other parameters such as temperature, solar radiation, and vapour pressure are computerised since the International Geophysical Year (1957), and these data are most relevant to the analysis of climate influenced design of the built environment [2]. Data for this project has been provided through the SILO datadrill facility [1] http://www.nrw.qld.gov.au/silo/. In the present paper we show how SILO can be applied to size rainwater harvesting system to suit local climate based on over one century of rainfall records. We employ a simplified rainfall/building simulation assumption that personal water requirements are low [3] such that garden use can be meet by grey water recycling.

1.1 Water demand

Australian household usage has decreased with restrictions [4, 5] and so 250 l/d is reasonable household use in drought [2].

[1] Some pre 1957 data have been computerised in the CLIMARC project, http://www.nrw.qld.gov.au/silo/CLIMARC/
[2] Data courtesy of the Australian Bureau of Meteorology

1.2 Storage Capacity

Australian rainwater harvesting generally directs rainfall into storage tanks at a maximum of one litre of harvesting per mm rainfall per square meter of roof provided with guttering. First flush diverters may dump a few lites per event, but well maintained systems may have operational efficiencies approaching 100%. Reliability is not ensured with 100% efficient harvesting unless the storage capacity is large enough to carry the household through the longest drought. There being finite limits to practical storage, there will eventually be droughts when the storage tank runs dry and external supplies must be trucked in. In the present paper it is assumed that a small non-zero failure rate is acceptable compromise against unrealistic desire for tank capacity. There tends to be a “law of diminishing return” by preparing for extremely rare droughts, in which case trucking contractors are prepared to cart water from aquifers and/or desalination facilities.

2. Simulation Methodology

2.1 SILO

Figure 1 shows the map of Australian climate[3] observation network with number of years of continuous daily records from which QCCCE derives its interpolated datasets. SILO Patched Point Dataset delivers a timeseries for any of 4729 selected stations, and these are not shown in Figure 1 as they would overwhelm the map. Additionally, the SILO datadrill provides data for estimating rain water harvesting capabilities at all points across the Australian landscape.

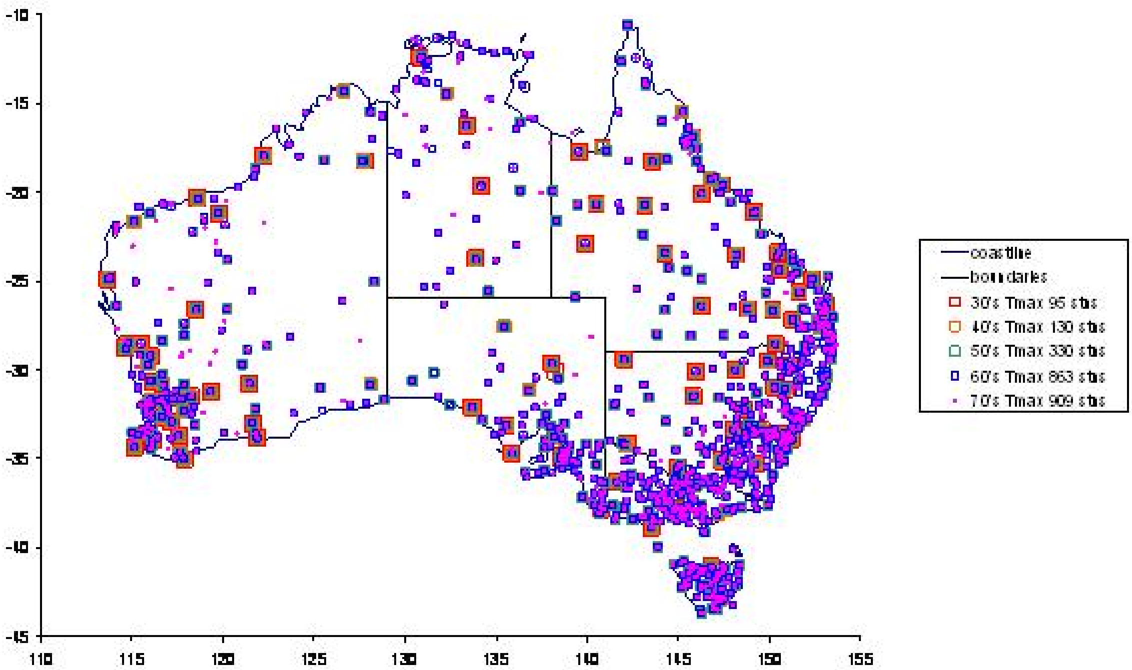

Figure 1 *Observation network employed by SILO includes over 1200 stations covering temperature, rainfall, and generally other coincident meteorological parameters in daily time series*.

[3] ‘Climate’ records are non-rainfall observations of temperature, wet and dry bulb temperatures, evaporation, cloud oktas etc. Not all climate stations report all of these observations.

2.2 Analysis of time series

In the present paper a detailed study was made of rainfall harvesting capability at seventeen location in Australia, but first a case-study of rainwater tank reliability was conducted at Somerset Dam Township, 40 km NW of Brisbane, to explore various combinations of rainwater harvest design.

3 Case Study

The drought stricken township of Somerset Dam, inland from Brisbane, Queensland was chosen to explore the result of combined factors of tank size and roof catchment area. In the end it was decided to find a simple rule of thumb to size rainwater harvesting to meet demand, and then to size the appropriate storage capacity to provide reliable supply without unreasonable demand for external water supplies. One of many simulated daily storage tank levels in the years 2000-2007 are displayed in Figure 2. Numerous combinations of tank size and catchment area were simulated with fifty-year time series, summarized in Figure 3 with the vertical y-axis is the failure rate of the alternative harvest/storage systems.

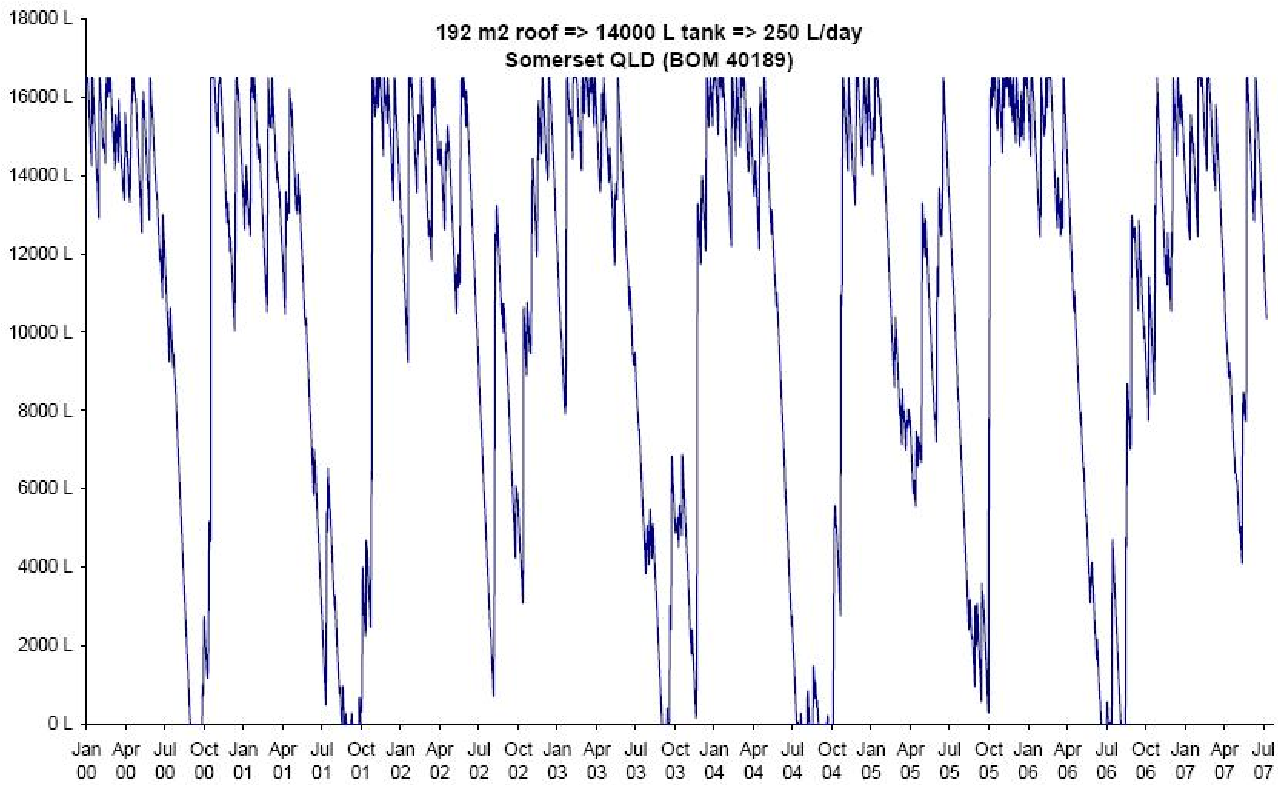

Figure 2 Simulation results for a location inland of Brisbane, Somerset Dam, Queensland.

The effect of changing storage capacity (1, 2, 5, 10, 20, 50, 60, 70, 100, 200 days) is displayed on the left of Figure 3, where the x-axis is the ratio of demand/rainfall. The effect of the ratio of demand/rainfall (1,2,5,10) is displayed on the right side of Figure 3, where the x-axis is the storage capacity measured in days. Inspection of these parametric curves on the right side indicated that sizing roof harvest area in direct proportion to average rainfall would require something on the order of 1000 days storage capacity to achieve low-failure rate system performance, while two times the indicated roof area brings the storage requirement down and order of magnitude to maintain the desired low failure rate. Looking at the left side figures it appears that the 1, 2, 5, 10, and 20 day storages could never achieve the desirable low-failure performance, no matter how much roof catchment could be harvested. It appears that the 50 day storage was wavering on the verge of being able to utilize a large catchment to achieve the desired low-failure rate, and that performance looked to be substantially more stable at 60 day storage and greater.

So we nominal harvest area as twice the ratio of demand over rainfall 2×(250 Litres / 2.7mm) = 185 m² and found that the longest period of time without as much as half of 2.7 mm rain in any one day was 110 days (7 April – 25 June 1946 had a total rainfall of only3.4 mm). From the length of drought we nominated the storage capacity as 110 days × 250 L/day = 27,500 L. Finally we simulated the system performance in (Figure 4) and found the failure rate of 0.7%. A failure demerit is scored for each day that the simulated rainwater harvesting system runs dry.

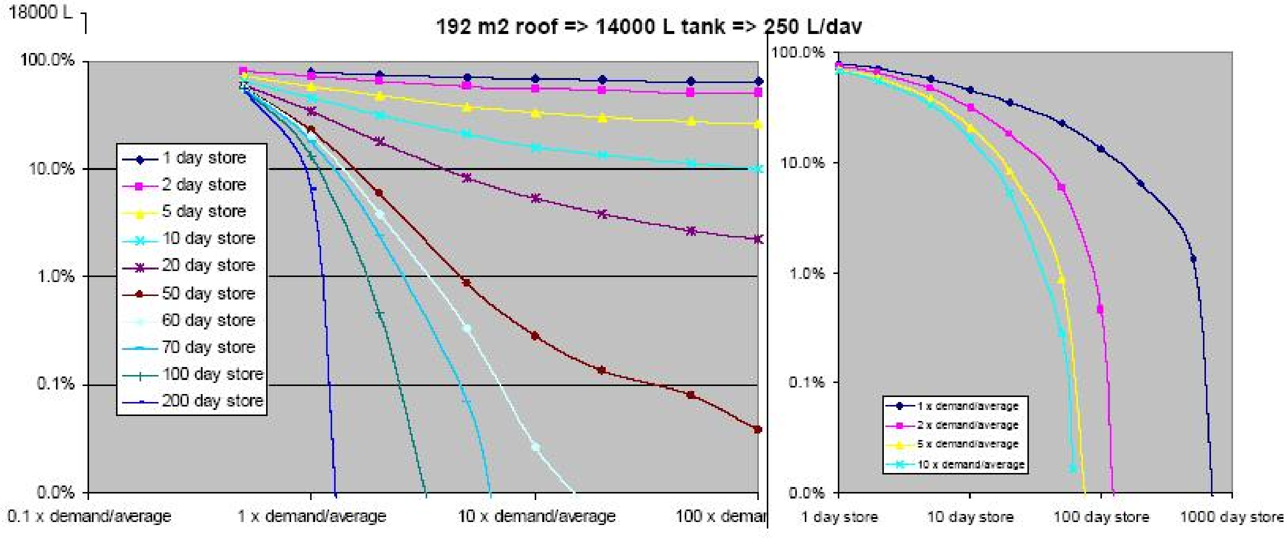

Figure 3 Summary of simulation results various tank capacities and roof catchments areas for the case study of Somerset Dam township, Queensland.

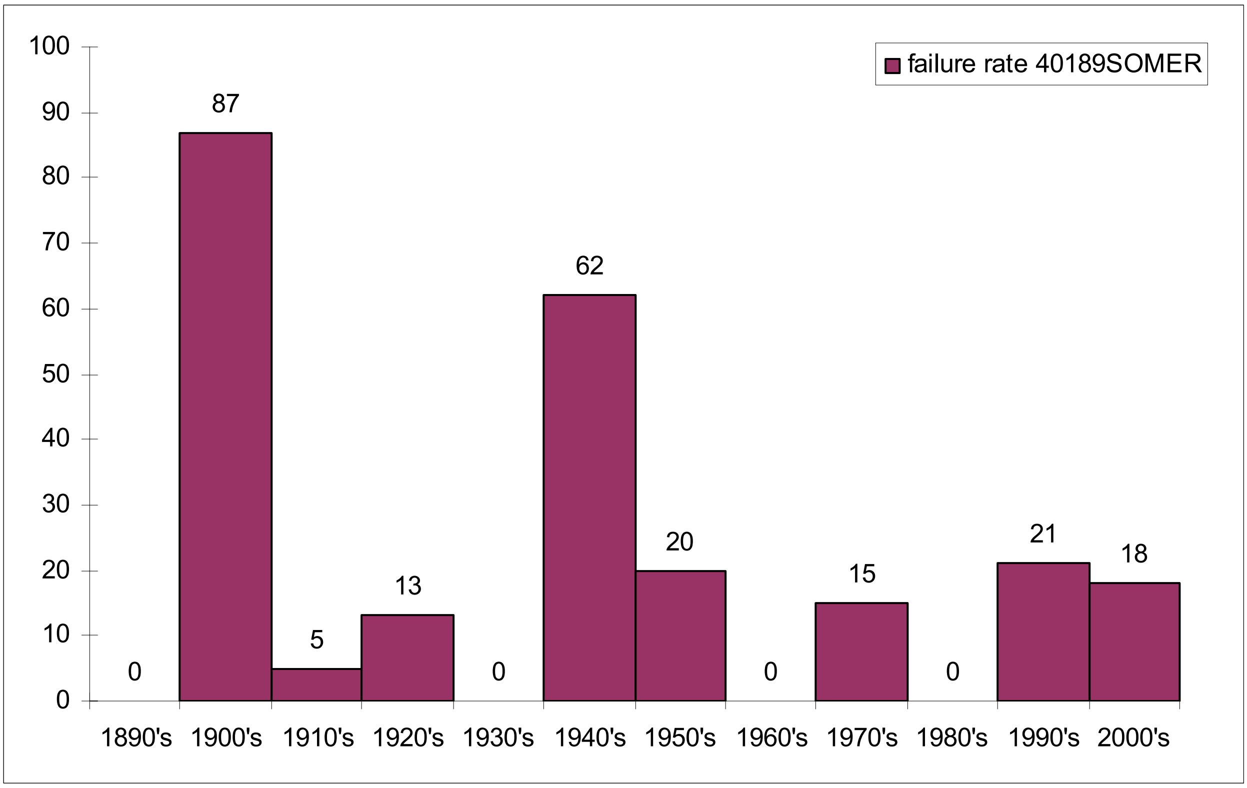

Figure 4 Simulated number of failures per decade serving 250 litres per day for nominated 27,500 L tank capacity and 185 m² roof catchment area for the case study of Somerset Dam township, Queensland. Note that the 2000's bin includes only 8 years of simulation output, and so more failures are possible by the end of this decade.

Having developed a workable model for Somerset, it was implemented as a nominal sizing methodology in sixteen other localities, and their failure rates were simulated and reported herein. A summary of the rainwater harvesting potential of Australian locations is presented in Table 1. The entire premise is that a constant household water demand of 250 litres per day would be met with the rainwater system. In practice there would be a variable rate of demand for garden watering, and so subsequent models of rainwater tank systems should be developed to exploit the SILO estimates of evaporation. This is particularly important since rainwater harvested in urban areas is not suitable for drinking water.

Table 1 Analysis of rainwater tank sizing for Australian locations, based on SILO data drills 1957-2007

location	BOM ID	average daily rain (mm) pa/365	needed area of catchment (m²)	longest period below half of daily average	suggested tank capacity (litres)	empty rate (supplement required)
Western Australia						
Exmouth Town	05051	0.7	675 m²	292 days	73,000	4.6%
Perth Airport	09021	2.2	225 m²	145 days	36,250	1.5%
Albany	09500	2.5	197 m²	62 days	15,500	4.2%
Northern Territory			m²			
Darwin	14015	4.3	116 m²	250 days	52,250	0.2%
Alice Springs	15540	0.8	654 m²	187 days	46,750	3.3%
South Australia						
Port Augusta PO	19036	0.6	806 m²	119 days	29,750	1.1%
Adelaide W Tce	23000	1.3	396 m²	104 days	26,000	0.6%
Queensland						
Cairns PO	31010	5.7	87 m²	133 days	33,250	3.1 %
Townsville	32040	3.2	157 m²	270 days	67,500	0.7%
Rockhampton Air	39083	2.3	217 m²	159 days	39,500	1.0%
Brisbane RO	40214	3.0	168 m²	80 days	20,000	3.4%
Somerset Dam	40189	2.7	185 m²	110 days	27,500	0.7%
New South Wales						
Sydney Airport	66037	2.7	184 m²	68 days	17,000	2.5%
Wollongong	68188	3.9	128 m²	81 days	20,250	1.7%
ACT						
Canberra	70014	1.8	277 m²	64 days	16,000	1.7%
Victoria						
Melbourne RO	86071	1.6	312 m²	58 days	14,500	0.2%
Tasmania			m²			
Hobart Airport	94008	1.4	356 m²	58 days	14,500	0.2%

Mathematical statement of the nominal sizing scheme is presented in the remainder of this section.

The needed catchment area A is proposed to be estimated with equation 1 to recommend the appropriate roof catchment is estimated as twice the daily water demand D divided by the average daily rainfall rate R

$$A = 2\frac{D}{R} \qquad (1)$$

The needed storage tank volume V is from equation is estimated as twice the product of daily water demand D and longest period of time on record where there are no rainfall events greater than half the average daily rainfall rate R for that time, $\max(t_{event} - t_{next\_event})$.

$$V = D \cdot \max(t_{event} - t_{next\_event}) \qquad (2)$$

Supplementary water will need to be delivered by tanker truck or other means is the rainwater harvesting system fails to meet the demand. The failure rate of the nominated rainwater system is determined by measuring the number of days that the tank is dry, divided by the number of days of rainfall records for the location in question. The calculation of tank storage S is determined by equation 3 within the limits of zero and the capacity of the tank V (force to zero if storage is negative, force to rated capacity if overflowing).

$$S_t = S_{t-1} + R \cdot A - D \qquad (3)$$

Conclusion

We find that reasonably reliable rainwater tank performance is expected if roof catchment area is sized from twice the ratio of demand divided by rainfall. Further we nominate a storage tank size large enough to carry demand in the longest consecutive period without any rainfall greater than a threshold of half the average daily rainfall. Unfortunately there will be events when the nominated harvesting system runs dry, and water must be imported to meet demand. The forgoing is an optimistic assessment, and ignores losses from the harvest and storage processes. Harvest area and storage capacity should be scaled up or down with respect to the nominal 250 litre daily demand assumption.

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TITLE: MAKING NEW ZEALAND POLICY, WATER CONSERVATION FRIENDLY

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Keywords: water, conservation, demand management, policy, regulations

Abstract

As the global shortage for water worsens, domestic water use efficiency becomes more critical. Urban dwellers need to play their part through embracing demand management and using supplementary water supply. However, domestic water supply in New Zealand is a neglected aspect of sustainable development, with much of the population believing that water is a free good. In most of New Zealand there isn't political willingness to take a different message to the electorate with water pricing, even metering being a hotly contested issue.

Of the various factors that influence water use efficiency, well targeted policy and regulation offers most chance of affecting change. Technologies are already available which could reduce mains water use but incentives; cash, carrots or sticks have rarely been used strategically and have had limited success, except in a few cases.

This research has explored all avenues of mains water demand management to determine what policy may be most effective and to work with water supply authorities to assist them to put demand management into practice. International and national water policy best practice has been trawled for successful approaches and it is clear that the inter-relationship between local context, water efficient technologies and appropriate policy and planning is critical and that solutions, designed to be applied by local water supply authorities, should be tailored to the specific context of each location and fine-tuned as each water use efficiency strategy unfolds. One size doesn't fit all.

Introduction

New Zealanders' domestic water consumption is highly variable around the country and with water metering only available in some areas, an accurate figure for domestic water usage for many regions or for the country as a whole, is not available. Reported figures range from a domestic water usage figure of 160 litres/per person/per day in Nelson at the top of the South Island or 167 litres/per person/ per day in Waitakere, a city within the Auckland region, to an average 750 litres per person per day in the Queenstown Lakes District. Table 1 shows the variability of water use reported throughout the country and demonstrates that in general, those places with water metering plus volumetric charging are lower than those without. This is consistent with a UK research study that shows a significant reduction in water use once metering and volumetric charging, often with well crafted tariffs, are introduced, Pezzey (1998).

Table 1 Per capita average domestic water use in New Zealand towns

Water supply authority	Liters per person per day
Nelson	160*
Waitakere	167*
Rodney	179*
Metrowater	184*
Manukau	189*
Papakura	190*
Tauranga	214*
Upper Hutt	227
Christchurch	333
South Taranaki	450
Kaikoura	648
Kapiti	650
Queenstown	750

*Metering with volumetric charging

Most of the interest in water in New Zealand has been on irrigation for rural use which uses 78% of water abstracted, Lincoln Environmental (2000). Overlaid is the issue of water quality and again the rural sector has had most of the focus with some of the North Island Lakes showing eutrophication with toxic algae blooms rendering them unsafe for swimming. For the majority of New Zealanders domestic water supply is not high on their agenda. There is a general view that water is a free good and a lack of understanding of the costs associated with delivering water to the home. There is also a concern about the possibility of privatization of water supply and any move to meter water and pay on a volume basis, in those areas currently paying for water as part of their general rates, is seen as one nail in the coffin towards privatization, even though the Local Government Act (2002) requires a local council to maintain strategic control of water supply.

In New Zealand there is no one over-riding reason why consumers should be concerned about the amount of water they use. There is not the same level of drought as in some countries, especially Australia, where the population can see first hand the severity of the lack of rainfall and its impact on domestic water supply. The rationale for demand management is based on a number of premises, which taken collectively make a strong and logical argument for water use efficiency. Those key drivers are:

- Capital cost savings through delaying or eliminating infrastructure development, both for more supply and increased wastewater services. The national level of estimated investment required is approximately $5 billion over a 20 year period to upgrade water supply, wastewater and stormwater infrastructure. Ultimately that cost would be borne by the consumers.
- Reducing infrastructure operating and consumer costs for water and energy. Consumers do not necessarily link water use efficiency with lower energy costs but energy is consumed in the supply, treatment, removal and heating of water.
- Reducing ecological impacts. Ensuring there are sufficient residual flows in rivers that groundwater supplies are not adversely impacted and that wastewater doesn't leak form pipes into local waterways and estuaries.
- Addressing climate change issues and the need to improve the resilience of the water supply system. For New Zealand, climate change is anticipated to mean more dry weather on the East, wet on the West and more frequent storm events overall.

Water policy in New Zealand currently focuses on education, some social marketing and little else while the range of water demand features available includes:

- Economic Tools; pricing tariffs, incentives/rebates
- Improving technology; water efficient fitments, fixtures and appliances
- Education, awareness and social marketing; promotional material and education programmes
- Regulation and Legislation; the Building Code and various Acts.
- Synergies between combinations of the above approaches.

There is no central water authority in New Zealand responsible for domestic water services, nor any one Act which provides overall guidance. The present regulatory responsibilities are shared between four main Acts being: the Building Act (2004), the Resource Management Act (1991), the Local Government Act (2002) and the Health Act (1956). These Acts can, through their interpretation, appear to provide conflicting requirements so that in general there is wariness about using regulatory routes to implement demand management.

Instead water supply authorities, mainly councils and their water supply authorities (WSAs) have implemented innovative educational approaches which include specified water advisors for indoor or outdoor use; free indoor minor pipe or water fixtures maintenance, school programmes, open days, and a suite of internet advice. Some councils also have financial incentives, mainly rebates or special promotions in association with retailers. These approaches are useful and a necessary element of encouraging water demand management but without education as to why reducing demand is necessary, consumers may neutralise the efficiency of better technology by using water more profligately. Yet education on water use in New Zealand is rarely enough on its own, as exemplified by one of the largest WSAs that has excelled in its attempts to encourage less domestic water use but has had little impact on its ultimate water use reduction goal, with per person water consumption remaining virtually static over the last thirteen years. Clearly more than education is required to get the desired change that the WSA requires to negate the need to contribute to the costs of a major water supply upgrade in the future. In many New Zealand cities and towns with growing populations, the goal could be to keep overall water consumption static while the population rises. What policy and regulatory changes are required to bring about the desired change?

Research approach and methodology

Beacon's research is at the applied end of the spectrum. Beacon Pathway is a research consortium, established in May 2004 with the aim of encouraging and improving New Zealand's sustainability in the residential built environment. It intends to improve the sustainability of the New Zealand housing stock, both new and existing homes, primarily using existing technologies and/or building systems which are currently underutilized. It also aims to keep the dwellings affordable. Reducing the level of water use in homes is part of that challenge.

The hypothesis for our research was that "barriers to water use efficiency can be overcome by well designed policy and regulatory approaches, specific to end-user requirements."

To test the hypothesis policy and regulation relating to demand management approaches both in New Zealand and overseas, were investigated for their effectiveness.

The investigations included the following components:

- A nationwide survey of territorial authorities or associated water supply authorities to establish the extent of water conservation programmes across the country and the key drivers for those programmes
- Four case studies of New Zealand councils that have demonstrated results attributable to demand management approaches including the use of voluntary programmes, water metering and volumetric user charges, changes to district plan rules to achieve water conservation outcomes, leak reduction programmes, and other methods of demand management such as education and training.
- An international literature search then identified policy approaches in other countries that could be applied to the New Zealand context.

The findings of that work was summarised by Lawton (2008) and provided input into the next research component which was to utilise the information in workshops with water supply authorities that wished to introduce a demand management strategy. Critical to the success of these workshops was having a range of people from across the water supply service, eg engineers, policy planners, educationalists, consents officers, all in the room together to start the development of a water demand management strategy that was applicable to their specific circumstances. The workshops were in part designed to inform, encourage and develop a consensus on an agreed plan of action. The workshops also provided material for the research through a discussion on how demand management approaches may best be tailored for any given water supply authority. The interaction between context, at the global, national and local scale, demand management approaches or packages of approaches and the policy and regulations needed to support those approaches is conceptualised in Figure 1.

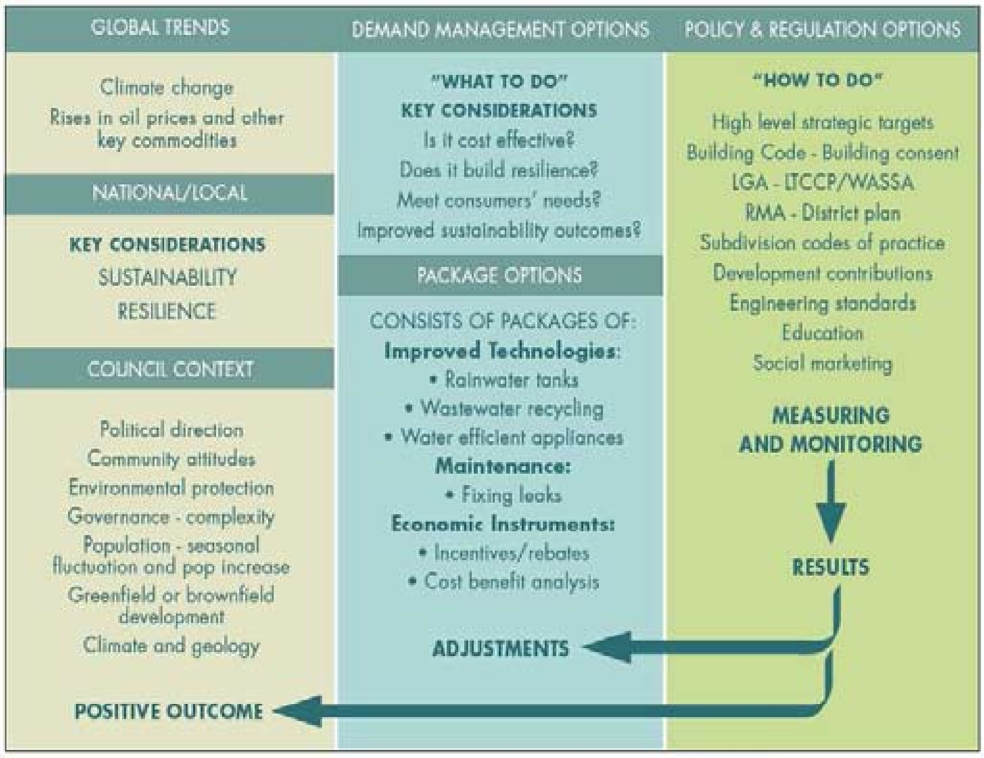

Figure 1 Interactions between context, water demand approaches and policy instruments

The collective results of the research and workshops discussion will be collated to provide a resource for all water supply authorities, guidelines on best practice for water demand management that could be applied to the range of contexts found throughout New Zealand under our current regulatory framework.

Results

The response rate to our questionnaire was 55% of the 76 water supply authorities in New Zealand. From the responses it was obvious that the majority were considering how to implement or increase their level of water demand management. In general they did not need to be persuaded that demand management was desirable, despite their need to balance their financial targets through water sales. The over-riding issue was that they had not managed to convince the consumers of the need for demand management. Additionally in some cases the local politicians had stood for council on a ticket of not implementing metering and without metering, it is difficult to manage the resource effectively, understand the leakage rate or apply incentives to reduce demand.

Many authorities are facing growing population and will have supply constraints in the near to middle future. Due to the long planning horizon needed for major infrastructure anticipated increased supply would need to be considered 10 to 20 years or more before it is required. The case for reducing demand instead of increasing supply must be strong and ideally shown to work prior to committing to that approach. With the need for new supplies looming to match the anticipated population needs, it is critical that demand management practices are implemented swiftly if large capital investments with consequent ecological consequences are to be avoided.

The four New Zealand case studies that were examined in detail provided a wealth of examples of educational approaches which was of general interest throughout the country. It was clear from workshop feedback that a mechanism to share these stories and successes would be a useful role for an industry agency, research provider or government agency. However the educational approaches that offered the best success were hands on, with practical one on one advice sometimes supplemented with in-house water services maintenance. While internet advice may reach the masses it doesn't appear to have the same impact as the personal approach.

Those water supply authorities that had implemented water metering with volumetric pricing had an immediate drop in water use, dramatic in the case of Tauranga where is was reported as being reduced by over 25%. Introducing water metering was considered to be more difficult since the introduction of the LGA which strongly promoted a public consultation process for local authorities. The process known as the Long Term Council Community Plan (LTCCP) with a ten year horizon and three yearly refinements should have been a good opportunity to discuss water management issues with the community but instead appeared by some to be viewed as a barrier, an indication maybe that the current approach to community participation is not working well.

Outdoor water use in gardens for irrigation was a key differentiator of water use between communities. In general those areas with low rainfall and/or sandy soils used significantly more water than those where rainfall was evenly spread throughout the year. While not a surprising result it did emphaise the value of addressing indoor and outdoor use separately and how the use of rainwater tanks and/or grey-water recycling came into their own, especially in high outdoor water use areas. Unfortunately the current application of both those technologies is clouded by Health requirements which, even though they can be technically addressed, can push the use of rainwater tanks and grey-water recycling into the too hard basket.

While local authorities have tended to value their independence a suggestion that came through our workshops was that national legislation which supported water demand management would assist WSAs, especially in considering regulatory routes. They wanted stronger signals from national levels which still allowed enough flexibility to implement those requirements according to their local context although in general they would have welcomed simple requirements such as dual flush toilets and low flow shower heads to be mandatory across the country. Similarly, mandating for metering at a national level would have been welcomed by some WSAs as it would have removed the decision from the local arena where it has become in many cases, a political football.

Legislation in New Zealand is not enabling when it comes to reducing domestic water use. There are a number of Acts which help determine the water use of a home but none of them are provide a clear path to water use efficiency. The Acts are inter-related as shown in figure 3. There are two immediate improvements that need to be made. The first is to make better use of the Resource Management Act, 1991 (RMA) through emphasising the need to conserve water at the national level in a National Policy Statement (NPS) and bringing that principle through the Regional level so that where required, they can direct rules or methods in the District Plan.

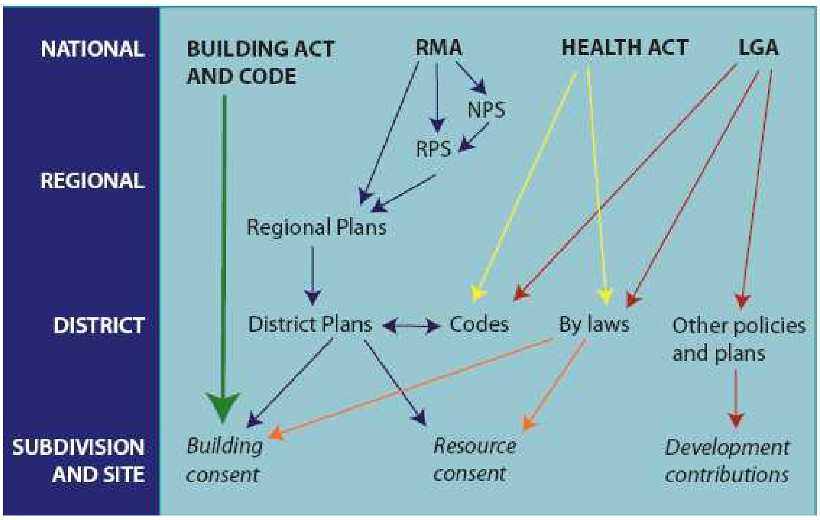

Figure 3: The Acts that impact on urban water use efficiency and their interaction.

The next change is to clarify a conflict which exists between the Building Act, 2004 and the RMA. At present"

"Section 18 of the Building Act 2004 precludes the imposition of performance standards for building work additional to or more restrictive than those specified in the Building Code. Therefore a person who carries out any building work is not required by this Act to:

- achieve performance criteria that are additional to, or more restrictive than, the performance criteria prescribed in the building code in relation to that building work: or
- take any action in respect of that building work if it complies with the building code. (2) Subsection (1) is subject to any express provision to the contrary in any Act".

While there is some ambiguity as to whether this section can over-rule the ability of the RMA to perform its prime function of resource management, the lack of certainty was found to be considered a deterrent by some councils who were not prepared to risk the cost faced by litigation if a legal approach which contested. This affected their ability to mandate for water efficient products from dual flush toilets to requiring rainwater tanks with all new homes.

Despite the lack of legislative encouragement one of the smaller case study authorities has been prepared to try the regulatory route. Despite and maybe because they have not run the metering gauntlet with their community they have implemented a number of other demand management approaches which are leading up to significant regulatory changes at a local level. Kapiti Coast District Council has used a wide range of approaches and brought them together as a model package. The processes include:

- Education packages including a "green gardener" to assist with the choice of plants and irrigation
- A substantial communication process using the Long Term Council Community Plan under the LGA (2002) to discuss demand management requirements with the community
- A sub-division Code of Practice which promotes low impact urban design
- Advertising on local radio and newspapers and websites
- Modeling using PURRS developed by Coombes (2002), which indicated that for Kapiti District Council dual flush toilets can save between 20 and 31% of toilet water use and low water use washing machines reduce water use for that purpose by 50% giving c.15% reduction in household water use. PURRS modeling was also used to identify the optimal size of rainwater tanks that corresponded to Kapiti's annual rainfall distribution.
- What sets Kapiti apart from other councils is that it was the first council to try to introduce a district plan change under the RMA (1991) which will mean that rainwater tanks become mandatory for all new homes or a mix of a rainwater tank with a grey-water recycling system for garden irrigation will be required.

While those actions may not seem revolutionary in some countries, in New Zealand, Kapiti a relatively small community of 46,000 has gone where so far, larger councils have feared to tread. The lack of willingness to push the legal boundaries is in no small part because the process is long and fraught with potential legal challenge, there is little case law to support them and the cost is not insignificant. If successful, they will, given the interest shown in this approach at the demand management workshops, be the first of many to apply for such a Plan change. Given that the RMA provides for a hierarchy of regulatory processes, it would be helpful if water demand management was signaled as a desirable approach in a national policy statement and/or regional policy statements which sit over the District Plans.

Our international literature survey identified a wealth of information on demand management approaches and policy approaches. It shed light on the type of regulatory approaches that work well, again confirming the value of nationally based performance standards or requirements. The introduction of a mandatory labeling scheme, Water Efficiency Labeling System (WELS), when it comes into effect in New Zealand, will undoubtedly also assist in raising both the awareness of and availability of water efficient appliances. It is a national led intervention that will have impact.

The workshops are confirming that differing approaches are required between councils to take account of their individual contexts. Lack of discretionary income in smaller councils calls for more innovative use of community volunteers. Some water supply authorities will focus on retrofitting with low cost water efficient fitments while others will have greenfield opportunities and local developers willing to assist with major changes in their approach. Some councils will be the leaders and others will follow suite. It seems likely however that there is a major shift in willingness to engage and our research results will provide guidelines for differing contexts that ensure we don't have to try and make one shoe to fit all.

Discussion

Through the surveys, case study analysis, overseas literature research and workshops some key findings are emerging.

Consumer acceptance and political willingness will play a major role in how far and how fast water managers and politicians are prepared to promote water use efficiency. The issue of water metering and volumetric pricing is a point of contention in many districts. One perception within the community is that access to "free" water is a right for all people and shouldn't have a charge attached. This completely overlooks the cost of supply and the fact that people have always paid for water in their general rates. Education and awareness raising will in part help dispel the free good argument but it is unlikely that this will affect a wholesale change of attitude without other policy interventions. In addition the value case for demand management for each of its stakeholder groupings, needs to clearly articulate the benefits based on sound data.

The understanding of "water as a necessity" is undoubtedly more pronounced in those areas of the country that have experienced periods of drought in more recent years. It is yet to be tested whether those areas are more likely to offer support for mandatory water conservation approaches and volumetric pricing based on consumption. The degree of necessity relates substantially to water access and climate. Some parts of the country have low rainfall but still enjoy a plentiful supply. Other parts are more obviously short of water with most of the available supply already allocated to hydro, agriculture, industry as well as domestic use.

Councils are in general keen to adopt demand management and recognize the value of conserving water, especially where it will result in the delay or removal of the necessity to find a new water supply source. Councils make most progress when they understand their own context and develop a strategic approach to water demand management which involves a package of interventions. Often demand management was found to be associated with a champion within the organisation, notably a new council employee who was keen to take a fresh approach. Councils in general recognized the benefits of learning from each other and welcomed the idea of a network which focused on demand management and provided for a sharing of resources and experiences.

The degree to which current policy and regulation is helpful or provides barriers will undoubtedly impact on the route of uptake of water use efficiency. The current regulatory route can be long and often needs to be addressed on multiple fronts. Without strong national legislation promoting water use efficiency it is left to councils or water supply authorities to individually determine their policy or regulatory route. Hence there is massive replication of effort, some of which could be avoided by national level guidance or legislation.

In fact New Zealand legislation does not respond well to the need for water use efficiency. Current conflicts exist between the role of the RMA, which as the name suggests is responsible for resource management, and the Local Government Act, which should result in good governance, an approach which incorporates all aspects of sustainability and strong consultative processes but as yet has not delivered anything innovative in terms of water conservation. Then the issues with on-site water supply and water recycling in relation to the Health Act must be clarified and if there are real conflicts, they need to be resolved as the perception of those barriers currently provides a deterrent to using on-site supplementary water supply.

There has been some call for a national structure to oversee and promote water use efficiency initiatives. New Zealand has acknowledged the benefits of an organisation focused on energy efficiency, the Energy Efficiency Conservation Authority (EECA); water is arguably an even more essential resource than power given its status as a resource that is essential for all life and a similar organisation to EECA but focused on water should be created immediately. Australia has introduced the National Water Initiative which provides a potential model for New Zealand.

While national guidance and legislative support is important there will still need to be local solutions, specific to the variables of each water supply authority's context. They reflect the differences in climate, population, socio-economic groupings, local political viewpoints and development opportunities. The suite or package of interventions and the policy to implement them will have considerable site specificity.

Nobody wants a prolonged drought as we have seen in Australia. It has however galvanized the country into a major focus on preserving the irreplaceable resource that is water. Without such a crisis it is likely that New Zealand will take longer to respond to what is now recognized as a global need to carefully manage water use. The regulatory building blocks are there but they could be remodeled and their performance criteria improved. There is a willingness amongst water supply authorities to be proactive but they require support form national and regional levels, a move which would also gain efficiencies through providing model examples of how to reduce water demand. Consumers have a way to go in understanding our water supply but financial instruments will play an increasing role as energy costs linked to water supply and heating continue to rise. Domestic water supply in New Zealand is at the beginning of a major period of change to embrace sustainability which will in turn contribute to reaching Beacon's goal of creating "sustainable homes that don't cost the earth."

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CREATING PRODUCTS FOR SUSTAINABLE PROPERTY INVESTMENT - A BLUEPRINT FOR GREEN PROPERTY INVESTMENT FUNDS FROM GERMANY

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Summary

The interest in more sustainable properties has risen strongly in the recent past since the so-called business case for implementing sustainable development principles within property-related decision making processes has been powerfully made during recent years. There has been a shift from anecdotal evidence to well-documented case studies and comparative analyses of environmental, social and economic performance of buildings from around the world clearly indicating that sustainable building is a highly profitable exercise. However, the implementation of sustainable development principles does not only serve the industry's actors to safeguard and increase competitiveness and long-term profit but is required because of the huge responsibility that the property industry is taking towards society and the environment. The development and provisioning of sustainable property investment products and related consulting services offers a major opportunity for property professionals to increase both, financial returns as well as their standing within society and the business world. Yet, this opportunity remains largely untapped due to various reasons. In response to this situation the present paper sets out a strategy for the development, implementation and widespread dissemination of sustainable investment products for the property industry. This is seen as an additional and potentially powerful approach to stimulate demand for sustainable buildings.

1. Status quo & the way ahead

The growing acceptance of social responsibility by organisations, corporations and other actors across all business sectors creates a demand for investment opportunities and products that adhere to the principles of sustainable development. This demand is further strengthened by the growing body of academic research evidencing that socially responsible investing (SRI) and corporate social responsibility (CSR) programmes do not result in inferior financial performance compared to conventional investment and business practices (see: UNEP FI, 2007a). In this context the questions arise whether there are any sustainable property investment options available for institutional and private investors and whether these investment options are in line with the Principles for Responsible Investment ruled out by the UN Environment Programme Finance Initiative (PRI, 2006) as well as with the responsible investment guidelines formulated by the European Social Investment Forum (EUROSIF, 2007)? Besides the products and services offered by a small number of leaders in the field of sustainable property investment and management (see: UNEP FI, 2007b) the answer to these questions is clear: not yet.

Planners, construction firms and facility mangers are able to design, realize and operate sustainable buildings today. However, it apparently requires innovative approaches to increase the demand for buildings that are – at the same time – energy-, resource- and cost-efficient, healthy, and more resistant to obsolescence and offer higher aesthetic, urban as well as technical and functional qualities. Besides informing and taking influence on awarding authorities and clients of direct property investments, an additional approach is seen in the development of new products for indirect property investments. This is the starting point for the authors' research project on the basics of sustainable property investment. The project took place within the research initiative "Zukunft Bau" and has been funded by the German Federal Office for Building and Regional Planning. The project investigated whether, how and which property investment products are appropriate for strengthening the demand for sustainable buildings and which general framework and preconditions would favor such developments. Within this paper the authors report on selected findings.

In 2007 about € 20 billion (10^9) were invested in 110 public SRI funds in Germany – with a growing trend. Across Europe more than € 1 trillion (10^{12}) is invested in this sector and in the USA assets under management in the SRI sector amount up to US$ 2.3 trillion. However, until now property represents an almost entirely neglected asset class within the SRI sector. At the moment only a very limited number of property investment firms or funds make sustainability an explicit goal; in addition, existing SRI funds in the USA as well as across Europe do not offer investors screened and professionally managed property portfolios. If these funds exist, they are simply too hard to find. Given that property improves the risk-return ratio of any mixed-asset portfolio and that an optimal share of property (direct or indirect investment) lies between 10 and 20% (see: Sirmans and Worzala, 2003; Worzala and Sirmans, 2003), the SRI market as a whole is significantly under-allocated from the perspective of optimal asset allocation. Consequently, the untapped market potential for publicly offered sustainable property investment products is immense. The authors assume that this untapped market potential still exists due to an underdeveloped market for certified sustainable buildings, information and knowledge deficits among private and institutional investors and a lack of proactive fund developers and initiators. In order to overcome this situation and for the development, implementation and widespread dissemination of sustainable investment products for the property industry the following steps are recommended of which a selection is further discussed below:

a) Description and analysis of relevant constellations of actors;
b) Description and analysis of the information and cash flows between these actors;
c) Analysis of the interests and motivations on the demand side;
d) Estimation of the market potential for sustainable property investment products;
e) Discussion of appropriate 'designs' and types of investment products;
f) Development of suitable assessment-, rating- and certification-approaches;
g) Strategy development for the development of property fund products; and
h) Development of appropriate marketing and reporting instruments.

2. Steps to sustainable property investment products

2.1 Constellations of actors, information and cash flows

The typical constellation of actors in financial markets in terms of cash flows and value creation regarding financial products can be – in principle – transferred to both, the processes of value creation regarding sustainable property investment products and the relevant groups of actors in property and construction markets. A core element in the constellation of actors is seen in the linkage between planners and construction industry on the one hand (referred to as the 'physical side') and the financial and banking industry on the other hand (referred to as the 'monetary side'). In the process of value creation the monetary side is responsible for granting the financial capital required for carrying out construction works. Identifying incentive-structures for allocating further investment capital from the financial market to the funding of sustainable buildings creates additional impulses for the construction industry. A crucial point, however, is that these impulses for the construction industry are clearly focused on property projects only that adhere to the requirements for sustainable buildings (i.e. 'additional investment capital for sustainable buildings only'). This can create an additional demand for sustainable buildings. The linkages between the physical and the monetary side are provided through financial intermediaries and service providers such product developers and suppliers, rating agencies and institutional funds that collect capital.

Figure 1 provides a simplified description of relevant constellations of actors. The starting point is the demand side; i.e. those institutional and private investors interested in SRI products. Actors on the demand side select an appropriate investment product (i.e. a sustainable property investment product) from one of the available suppliers/initiators in the market by relying on consulting service providers and rating results. The supplier/initiator either acts as a property developer or identifies and buys appropriate property assets in the marketplace.

Figure 1 shows a 'product-level' (left side) as well as an 'assessment/information level' (right side). It is clear that both investors (e.g. pension funds) and suppliers/initiators can be subject to so-called sustainability reporting requirements. In this regard, first labels for SRI-products as well as for 'sustainable buildings' already exist. However, approaches for the certification of sustainable property investment products are yet missing. Nonetheless, such certification schemes would be the logical consequence if property assets are to play a role within the SRI-market. Labels and certification schemes for sustainable property investment products would have to combine assessment criteria from the SRI-sector and from the sustainable building area. In addition, sustainability issues would have to be integrated into accounting and financial reporting requirements for property funds.

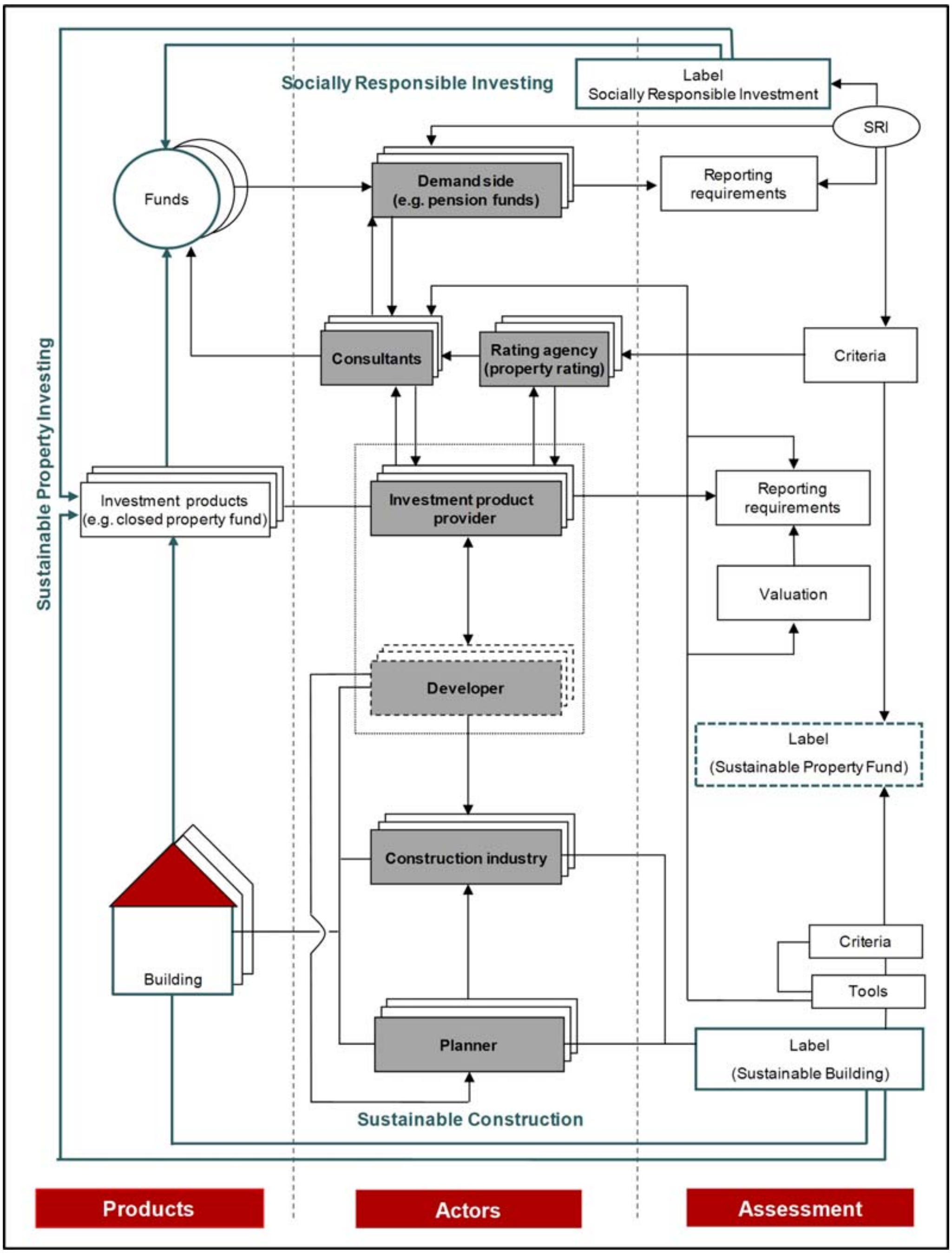

Figure 1 Constellations of actors for the development of sustainable property investment products

2.2 Interests and motivations on the demand side

A major problem in property economic research is the unsatisfactory situation regarding data availability; concerning both, transaction data and information and market participants' motivations and goals. Empirical surveys investigating the interests and motivations of selected groups of actors regarding the issue of sustainable building and property investment are rare (Pivo, 2007). So it does not come as a surprise that the situation regarding sustainable property investments in Germany has not yet been subject to investigation and inquiry.

Therefore, a survey was carried out among German institutional investors in order to gain insight into their interests, motivations, and level of awareness and knowledge regarding SRI-products in general as well as sustainable property investment products in particular. During September and October 2007 a total of 848 institutional investors have been contacted within the scope of a survey; 116 of them (response rate: 13%) responded either by telephone interview or through a web-based questionnaire survey to the following topics: organization and financial structures; importance of property assets in general; importance of socially responsible investing; importance of sustainable property investment. Among the 116 participants of the survey were 13 capital investment companies, 59 precautionary institutions (such as pension funds and life insurance companies) and 34 non-profit-organisations (including foundations, churches and charities aid organisations).

a) Importance of property within the portfolio

Capital investment companies usually diversify their portfolios. The survey showed that stocks, bonds and property make up for about 1/3 of assets under management each. About 69% of assets under management have a planned holding period of at least 5 years. The remaining 31% are split between assets with a medium-term (18%) and a short-term (13%) holding period. The inclusion of different asset classes with different holding periods leads to a broad diversification of investment risk, which is typically for capital investment companies. The exact share of property within the surveyed companies' portfolios is 34%.

Regarding precautionary institutions the survey revealed a risk-averse and long-term oriented investment strategy. On average, bonds have a share of about 60% of all assets under management. In the case of pension funds and life insurance companies the share of bonds is even higher: 70% due to legal requirements. About 3/4 of all assets have a planned holding period of more than 5 years. The share of property within precautionary institutions' portfolios is 13%.

Within the third group of surveyed investors, non-profit-organizations, the survey showed that they also have a longer-term oriented investment strategy. The share of property within their portfolios is 16%.

b) Level of knowledge regarding SRI

The majority of surveyed investors judged their level of knowledge and awareness regarding socially responsible investments as 'very good' or 'good'. A particularly high level of knowledge was reported among the capital investment companies of which 45% judged their level of knowledge as 'very good' (see Figure 2). The following relationships have been identified by making use of correlation analysis of some of the survey's results: (1) The level of knowledge regarding SRI-products increases if investors already have SRI-assets within their portfolios; (2) the higher the share of SRI-assets within the portfolio, the higher the level of knowledge; however, this relationship does not apply to the knowledge regarding sustainable property investments; and (3) the higher the share of property assets within the portfolio the higher the knowledge regarding sustainable property investments.

Given that the overall share of SRI-assets within the surveyed investors' portfolios is rather low (capital investment companies: 4%, precautionary institutions: 5% and non-profit-organisations: 13%), the high level of knowledge reported among investors is, indeed, remarkable.

c) Importance of Sustainable Property Investments

About 50% of the surveyed investors showed a moderate interest in sustainability-oriented open- or closed-end property funds. Among the surveyed investors the group of capital investment companies showed the largest interest. The remaining half of the surveyed investors stated that sustainable property investment funds are not on their 'radar' or that they are not considering this type of investment respectively. Further survey results are as follows:

- The different groups of institutional investors have different perceptions on what product forms would be of interest for sustainable property investment. The preferred forms are direct property investment and closed-end property funds. Capitals investment companies also showed an interest in property stock corporations and real estate investment trusts (REITs). Non-profit-organisations show a tendency to prefer open-end property funds.
- The majority of surveyed investors expect that the rates of return from sustainable property investments are comparable to those of conventional property investments.
- In addition to sustainability certificates for the property assets in question almost all investors argued that continuous sustainability reporting of fund companies and/or initiators would be an important characteristic of a sustainable property investment product. In this context it is interesting to note that 31% of the surveyed investors are already subject to sustainability reporting requirements; this means that if those investors would like to engage in sustainable property investments, the availability of sustainability performance information would be a precondition for such engagement.
- Compared to the level of knowledge regarding SRI products and issues in general the level of knowledge regarding sustainable property investments is judged considerably lower (see Figure 2).

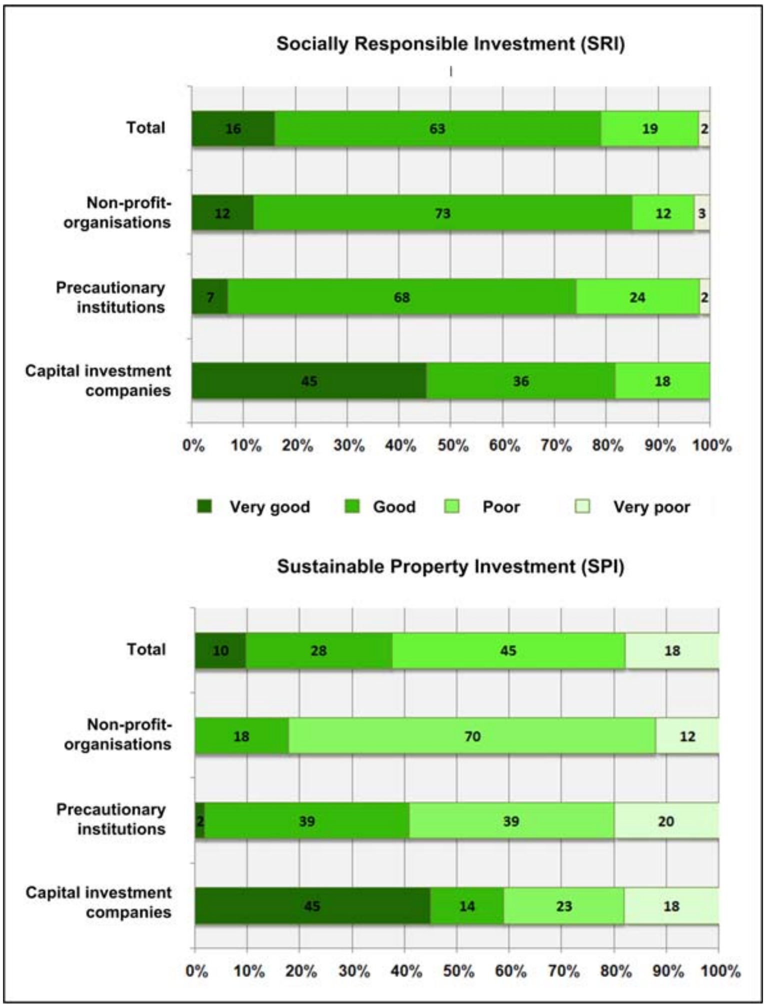

Figure 2 Investors' level of knowledge regarding SRI and sustainable property investment issues

In summary, there is moderate interest among institutional investors regarding sustainable property investment options in Germany. Clearly, this interest is greatest among those investors that are already engaged in SRI and that already have larger shares of property assets within their portfolios. However, these investors must be intensively advised and actively provided with detailed information on new SRI options and products in the property sector. This requires the development of appropriate marketing and reporting instruments.

2.3 Market potential for sustainable property investment products in Germany

The untapped market potential for sustainable property investment products can be estimated by using two different approaches: (1) estimation based on the share of SRI in the total investment universe; and (2) estimation based on optimal asset allocation considerations within the SRI market.

At the moment the share of SRI in total assets under professional management in Germany is roughly 1% (see also: Schäfer, 2005). In 2006 the total volume of property assets under professional management of institutional investors in Germany has been on the order of € 394.8 billion. Consequently, it can be argued that the market potential for sustainable property investment products is about 1% of the volume of property assets of institutional investors; this corresponds with a market potential of about € 4 billion in Germany.

The second approach for calculating the market potential is based on the consideration that from the viewpoint of optimal asset allocation the share of property within a mixed-asset portfolio is somewhere between 10% and 20% (Sirmans and Worzala, 2003; Worzala and Sirmans, 2003). In 2007 about € 20 billion were invested in 110 public SRI funds in Germany (Imug, 2007). As result, the market potential for sustainable properties within the public SRI sector is between € 2 and 4 billion.

The figure of € 4 billion market potential translates into a floor area of about 3 million square metres of office space; this estimate is based on an average price for gross floor area of about 1,400 €/m² for office buildings in average quality (see: BKI, 2007).

For reasons of comparison the following data is worthwhile mentioning: the market for office space in Frankfurt currently has a size of about 12 million square metres; in Germany the overall volume for construction works was ca. € 237 billion by 2004 and about € 5 billion of this sum have been spent for the construction of new office buildings.

2.4 Existing market & discussion of appropriate types of investment products

Although a negligible number of sustainability-oriented developments (closed-end property funds with very small volume only) could have been identified within the scope of the research project, the market for sustainable property investment products is virtually non-existent in Germany. Regarding the market in the USA the Responsible Property Investment Center (see: http://www.responsibleproperty.net) provides an overview on existing products and firms. Additional outstanding examples can be found in a recent publication of the UNEP FI's Property Working Group (UNEP FI, 2007b). For the German property market the following types of investment products are recommend (given that the basic framework for the development and establishment of REITs in Germany are not yet fully sorted, the development of a 'green' REIT appears unrealistic at the moment):

a) Development of smaller closed-end property funds for private investors

An appropriate strategy for new fund initiators is seen in the development of closed-end funds. These can comprise one or more property assets which have been certified with the national sustainable building certification scheme. As this certification scheme is still under development at the moment the idea of developing and marketing 'hot-topic-funds' appears attractive: possibilities are 'climate-protection property funds' and 'energy-efficiency property funds' comprised of net-zero-emission-buildings. The typical fund volume for closed-end property funds in Germany is between € 5 and 250 million; the duration usually is between 10 and 20 years.

b) Development of special open-end property funds for institutional investors

Due to distinct reporting requirements towards investors and possibilities for active portfolio management the investment type of special open-end property funds particularly lends itself for the development of sustainable property investment products. With this type of investment the number of investors, duration and volume is unlimited; typically the volume is at least € 250 million. Given the lack of comparability between different sustainability assessment and certification schemes it is recommend to select properties from regions within the coverage of one certification system only (questions concerning comparability and acceptance of different certification systems are currently intensively discussed in Europe).

2.5 Investment strategies

Sometimes it is argued that one problem for the development and establishment of sustainable property investment products lies in the difficulty of identifying an appropriate number of property assets that would qualify for such treatment. However, the following investment strategies can be applied:

a) "Build, Operate (and sell)" – Project development

If there is a shortage of sustainable buildings in the marketplace fund developers/initiators can act as a project developer and guarantee this way that the property assets are designed, constructed and subsequently managed according to the requirements of sustainable building.

b) "*Modernisation & Refurbishment" – Improving sustainability performance of the existing stock*

Investments into the existing building stock can extend or restart the life-cycle of buildings and improve the buildings' environmental and social performance. In particular in Europe carrying out extensive revitalisation works is partly regarded superior than building new.

c) Cause-based investment – Fostering more sustainable communities and cities

This strategy comprises investments into community projects such as affordable housing and urban revitalisation in order to foster a more sustainability society.

Pursuing the aforementioned strategies leads to additional demand for more sustainable planning and construction works. An additional investment strategy without this effect is:

d) "Screening & Selection" – Portfolio optimisation

Comprises the purchase and/or disposal of property assets (e.g. for portfolio selection or portfolio optimization purposes) that meet / don't meet preset minimum environmental and social performance requirements.

It also includes active portfolio management in order to develop the existing stock towards a more sustainable asset. Almost certainly the quality of the applied management practice will become – besides the quality of the buildings within the portfolio – a criteria for assessing and certifying sustainable property investment products.

2.6 Reporting: Requirements & Possibilities

An essential feature of a sustainable property investment product is the availability and regular updating of a sustainability report. This is because many institutional investors (in particular, pension funds) are already subject to sustainability reporting requirements. For example, in their statement of investment principles trustees in the UK must give (according to the Occupational Pension Schemes Regulations) information about (a) the extent (if at all) to which social, environmental or ethical considerations are taken into account in the selection, retention and realisation of investments, and (b) their policy (if any) in relation to the exercise of the rights (including voting rights) attaching to investments. Similar reporting requirements apply in Germany.

Sustainability reporting is a critical area as there exists a general 'ethical, social and environmental reporting-performance portrayal gap'. This gap has been identified by Adams (2004) and by Hummels and Timmer (2004). It is argued that current ethical and social reporting practice does not provide investors and other stakeholders with appropriate information to assess the material consequences of company activities and behaviour in socially or politically sensitive areas. "Until reports that compare sustainability performance are freely available, as ubiquitous as financial reports, we will remain lost in the quagmire of intriguing anecdotes, unable to determine who performs better […]. In a world with comparable reports, sustainability reporting can fulfil its true potential: providing concise, transparent information that clearly reflects the reality of environmental and social issues, allows for benchmarking, highlights long-term risk and opportunities, and contributes to improved levels of public and investor confidence. […] Otherwise sustainability reporting will remain an exercise in creative writing …" (Rogers, 2005, p. 39).

In fact, the reporting requirements for an innovative product with which the market is unfamiliar with are even harder as for already established investment products. In this regard, it is important to realise that acceptance of and trust in new property investment products will only be achieved by striving for the highest degree of transparency possible and, in doing so, not only delivering attractive products to investors but also the information necessary to meet investors' reporting requirements. Thus, a sustainability report for sustainable property investment products should, at least, contain information on the following issues:

- Impacts on the environment through emissions; expressed through the CO2-equivalent;
- Energetic quality / energy efficiency;
- Amount of drinking and waste water during occupation;
- Waste volume;
- User satisfaction; based on post-occupancy evaluations;
- Existence of local risks through flooding, extreme weather, large-scale catastrophes in adjunct industries, etc.; and
- Extent and manner of regular inspection and maintenance works.

It has to be note that this information refers to the property assets only; more general reporting requirements for the fund companies/initiators are laid down in detail here: AccountAbility, 2003 and GRI, 2006. The information on the property-related issues should be expressed (1) in absolute values, (2) as a trend, (3) in comparison to selected benchmarks, and (4) by indicating appropriate reference values (such as m^2, m^3, number of occupants/employees, etc.). The annual sustainability report of the UK-based fund company Hermes serves as an outstanding example in this regard (see: Hermes, 2007).

3. Conclusion & Outlook

The interest in socially responsible investment and corporate governance issues has risen dramatically in recent years; and so has the availability of SRI products. However, this trend has not yet led to comparable developments within the property industry. This assertion applies to both, the demand side (investors) and the supply side (fund developers and initiators). As a consequence, the current challenge lies in aligning the goals and motivations of socially responsible investing with efforts to increase the share of property assets within investment portfolios. This will create a demand for sustainable property investment products and thus, strengthen the demand for sustainable buildings in general. Coping with this challenge requires (1) increasing the awareness level of such investment products through systematic marketing; (2) delivering more scientifically robust evidence regarding the economic advantageousness of sustainable property investments; and (3) purposefully serving investors' existing sustainability reporting requirements.

The research carried out on the situation in Germany revealed that institutional investors which are already engaged in the SRI market represent a most promising target group for sustainable property investment products. But even though there is market demand and the untapped market potential can be estimated most existing property fund providers/initiators are reluctant in developing appropriate investment products. As a result, there are opportunities for both, fund initiators aiming to enter the property sector as well as for established property fund initiators to successfully extend their product range. These opportunities are major, but they have to be taken, now.

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NEXT GENERATION DECISION SUPPORT INSTRUMENTS FOR THE PROPERTY INDUSTRY − UNDERSTANDING THE FINANCIAL IMPLICATIONS OF SUSTAINABLE BUILDING

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Summary

The mainstreaming of sustainable development in property and construction is not only possible but realistic, even in the short to medium term. But for this to happen, a fundamental change to how we understand and value our built environment has to be achieved and the feedback-mechanisms within the property and construction industry have to be altered. This requires the development and application of new decision support instruments capable of bridging the gap between economic, environmental, social and cultural measures and components of property value. The paper investigates the basis for improved decision support by referring to three deep-seated obstacles currently hampering the implementation of sustainable development principles within the industry which are: (1) the increased application of financial modelling within a property context without taking into account the major differences between financial and property assets, (2) a fundamentally flawed understanding of the concept of property value, and (3) the absence of feedback-mechanisms that incentivise change. It is argued that the prerequisites for the development of new decision support instruments are (1) a sensible integration of property as a distinct asset class within portfolio theory, (2) further development of the understanding of the concept of property value, and (3) an improvement of the information flows between actors of property markets on the basis of building files. Such a framework would provide the basis for more scientific market analysis and would allow developing and applying new instruments for valuation, risk assessment, and overall quality assurance.

1. Introduction

Due to the shift in public perception of climate change and environmental degradation as real phenomena, recently the interest in sustainability has risen almost exponentially; both outside and within the property and construction industry where the topic is now sometimes being marketed as if it were new. The central importance of buildings in achieving sustainable development goals has been well-established for many years; as well as the knowledge with regard to the methods and financial benefits of more sustainable design, construction and management of buildings. What has been missing so far was awareness among market participants that sustainable property investment and management is, indeed, a highly profitable exercise and that refurbishing the existing building stock represents the most cost-effective solution available for tackling the looming environmental crisis. The current situation which sees all major actors more or less concerned with sustainability issues and the pressure for action constantly rising creates a real opportunity for achieving a broad market penetration for sustainable buildings and respective investment and management strategies. But this major opportunity will pass by unused if a restructured approach to how we understand and value our built environment cannot be achieved and if the informational basis and information links (i.e. the feedback structure) within the property and construction industry remain unchanged. Failure in this regard will result in 'greenwashing' the industry without addressing the roots of the problem. To be more precise: any effort solely focused on limiting the negative impacts of poor design and unsustainable property investment and management practices (i.e. anti-social behaviour, hostile public spaces, social conflicts, occupational diseases, contaminated land, contribution to climate change and biodiversity loss, urban sprawl, and the urbanisation of the countryside) without addressing the underlying value-systems and the feedback-mechanisms that motivate behaviour will remain insufficient. Instead, these efforts are "only trying to keep the old world ticking for as long as possible" as du Plessis (2003, p. 2) expressed it while having the majority of current sustainable construction solutions in mind. This diagnosis also applies to narrow-minded endeavours to implement sustainable development principles within the wider and highly influential property and interlinked financial markets.

2. Basics for improved decision support

Sustainable development in property and construction can no longer be perceived as mostly a technical matter of improving buildings' or the construction industry's performance. Sustainable development will not flourish if it is narrowly conceived and executed in a sectoral manner. Linkages need to be drawn with the investment, lending and insurance industries, with the larger social and economic agendas and policies, and between the different jurisdictions of responsibility at the governance level. The sheer complexity of this task requires, amongst other issues, new decision support instruments and information systems. It also requires 'hybrid' qualifications among professionals combining, for example, technical, economic, ecological and sociological expertise. The nature or 'design' of these decision support instruments as well as the necessary information links that have to be established can best be explained by referring to some of the major obstacles currently hampering the implementation of sustainable development principles within the industry.

2.1 Mathematical modelling & the concept of property value

Property is increasingly being seen as a distinct assets class besides stocks and bonds. This is due to an ongoing consolidation of financial and property markets and because it has been demonstrated that property improves the risk-return ratio of mixed-asset portfolios. For this reason, financial modelling and investment analysis practices are now extensively applied within the property industry to problems of risk premium determination and valuation with a constantly growing interest in financial valuation techniques and models such as discounted cash flow analysis, capital asset pricing, so called multi-factor models or real options theory. The aforesaid has been described as "the intrusion of the financial method in the real estate field" (d'Amato, 2008). Although property valuation and investment analysis represent the major mechanisms that allow environmental and social considerations to be aligned with economic return (Lützkendorf and Lorenz, 2005), the problem is that mainstream property valuation and investment counselling practice increasingly treats property as an asset class with just another degree of liquidity, even if we do not have a deep knowledge of the value of liquidity. This practice rests on a dangerous illusion since it fails taking into account that property assets do have major environmental and social impact with tangible consequences for our everyday life and well-being (d'Amato, 2008). Consequently, whenever these techniques are applied without taking into account the specific nature of property assets and investments and without prior adjustment to the subject matter of investigation and inquiry, the advice given on that basis is likely to be misleading.

So it does not come as a surprise that the role of mathematical modelling in a property context is a controversial one: On the one hand, it appears that the 'mathematization' of property economics and investment analysis has 'gone a bit far'; i.e. financial modelling in a property context is sometimes being carried out as an art for art's sake by transforming the original property problems into pure mathematical ones. Within this practice it is the mathematics theory and formal language that forms the subject matter and problem to be analysed and not the real-life problems of property investment, ownership and management. With a focus on economics in general Dillmann et al. (2000) argue that mathematics is a valuable and useful tool which economists should and must apply as long as its use is economically sensible. However, "the dangers of going beyond the 'frontier' of what is economically sensible occur when economists depart from the actual (empirical) subject matter because of the applied mathematical instruments, when the underlying value judgments are not, or only insufficiently, taken into consideration, when the recording and measurement of empirical magnitudes as an economic problem is underestimated or is even subordinate under the requirements of the formal language, and when the process of mathematization is considered as a substitute for the process of 'Verstehen' [i.e. understanding]" (Dillmann et al., 2000, p. 260). This frontier is crossed by the application of mathematical modelling in the property industry whenever it departs from and disregards the subject matter. As a consequence, mathematical modelling in a property context should be regarded meaningful (or even permissible) only in cases when the limits and conditions of validity – such as the underlying value-systems – are clearly displayed (see also: Szira, 2000). On the other hand, however, mathematical modelling is seen as the essential tool for analysing non-economic components of property value in economic contexts. There has recently been a shift away from 'modelling tools' towards the 'market itself' or, to be more precise, towards a better understanding of the market base of property value and the processes shaping it (see: Kauko, 2008). Unfortunately, the theory and concept of property value has been an almost entirely neglected area of property related research and education.

The value of a thing consists in its recognized fitness for attaining an end, or in its recognized utility. Utility can be defined as the capacity of a thing to serve for the satisfaction of human needs. According to Menger (1871, p. 120) the value of goods is always "the necessary consequence of human knowledge that the maintenance of life, of well-being, or of some ever so insignificant part of them, depends upon control of a good or a quantity of goods. […] The value of goods arises from their relationship to our needs, and is not inherent in the goods themselves. With changes in this relationship, value arises and disappears." The basic goal of property valuation is to provide a measure of the utility derived through the access to and control of property. The value of property is determined through the flow of services it is capable to provide for the satisfaction of human needs; i.e. the increment in well-being dependent upon it, or – what is the same – the impairment of well-being which its loss must bring about (see: von Mises, 1949, p. 120). However, the isolated analysis of financial variables and their subsequent transformation into a one-sided understanding of the economic value of property has lead to an artificial separation of economic, environmental, social and cultural measures and components of property value. This understanding is fundamentally wrong and misleading since it fails recognising that, in truth, the different components of property value are intrinsically linked and non-divisible (see Figure 1). Property, or the process of investment and management, has the capacity to create (or destroy) value consisting of different components. A fixation on economic value alone and an understanding of economic value as the end of all things does not make a great deal of sense. The increasing recognition among the wider public but also within parts of the property and construction industry that the maintenance of life and well-being depends – to a significant degree – on the environmental and social performance of buildings and the built environment means that the current understanding of property value needs major revision. In fact, it is becoming evident that a property's economic value also depends on the building's capability to create and protect environmental, social and cultural values and that an isolated analysis of mere financial variables is no longer (and has never been) adequate for capturing the apparently re-discovered concept of property value.

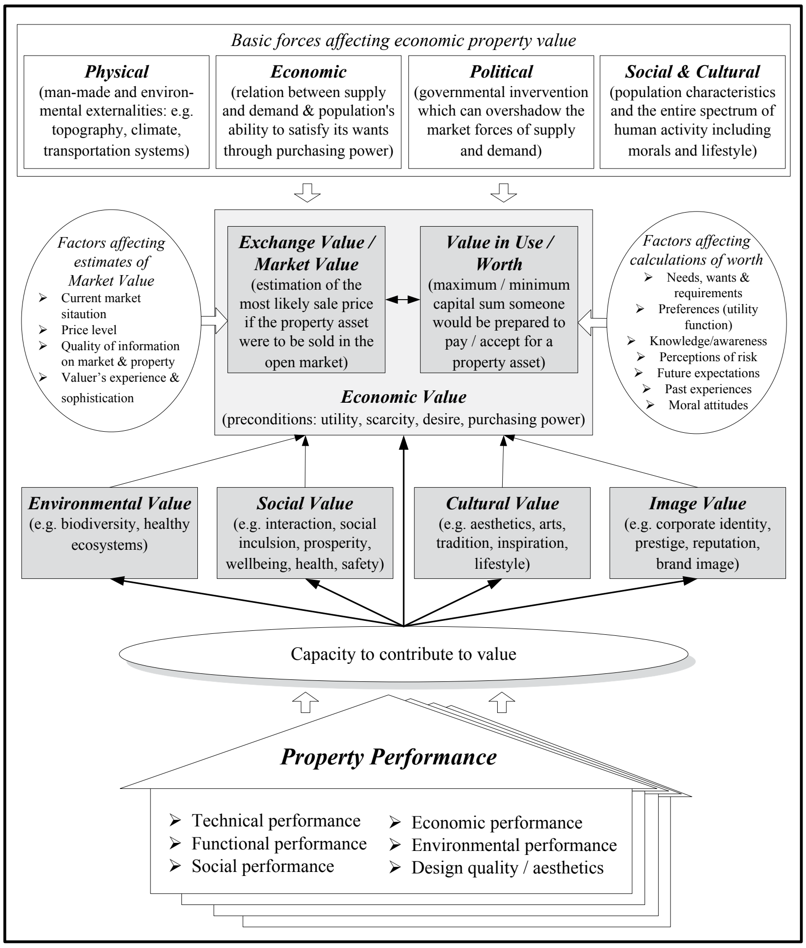

Figure 1 Property value map

In addition, there is an emerging concern that property valuations are conducted without appropriate value theory in place; i.e. a lack of professional foundation. Canonne and Macdonald (2003) investigated in detail the extent to which over 100 major North American textbooks on property valuation as well as a wide number of property valuation manuals, treaties and anthologies cover the theory of economic value and its history. They come to a sobering conclusion: "the theory of value […] is systematically neglected" (Canonne and Macdonald, 2003, p. 113). This is due to the fact that economists in the twentieth century have turned away from the analytical study of value to concentrate on the apparently more tangible econometrical analysis of prices. "To positivists, empiricists and others who value 'fact and logic' over 'vagueness and ambiguity,' any theory of value is vague and ill-determined. For this reason neoclassical economists have given up the notion altogether" (Klamer, 2003, p. 192). It appears that the property profession has put aside the theory of value not because the issue had already been solved but because the issue had appeared too complicated. "It is much more comfortable to technically concentrate on prices and price models than to go into the domain of deductive speculation and intellectual conceptualization, which is prerequisite to the study of the nature of value, and this is quite contrary to the usual inductive nature of economics" (Canonne and Macdonald, 2003, p. 116). However, this is a critical issue because future progress in the field of valuation does not lie in the further development of mathematical modelling techniques but lies in the discovery of the relation between man and his environment (Schmutz, 1948). Given the dearth of valuation literature addressing the theory and concept of property value as well as the links to sustainable development issues it does not come as a surprise that contemporary property valuation practice fails to account for all the factors that determine the competitive position of property assets in the changing marketplace. Consequently, contemporary valuation practice bears the risk that estimates of property values are being distorted and that misinformed and unsound decisions are being made on the basis of these valuations. This may be one of the deeper causes for unsustainable behaviour in property and construction markets.

2.2 Loops of feedback and adaptation & information exchange

It is important to realise that the mainstreaming of sustainable property investment and management is constrained by a misalignment between suppliers and those demanding property assets for occupation and/or investment. This misalignment became known as the *vicious circle of blame*. However, the circle can be broken by providing actors with appropriate feedback on both the environmental and social aspects of building performance as well as on its various interrelations with financial performance and property value. In this regard, the traditional focus on those actors directly involved in construction has certainly been helpful but not sufficient. The involvement of additional groups of actors such as property professionals, banks, assessors and certifiers as well as research and educational institutions is an absolute necessity (see Figure 2).

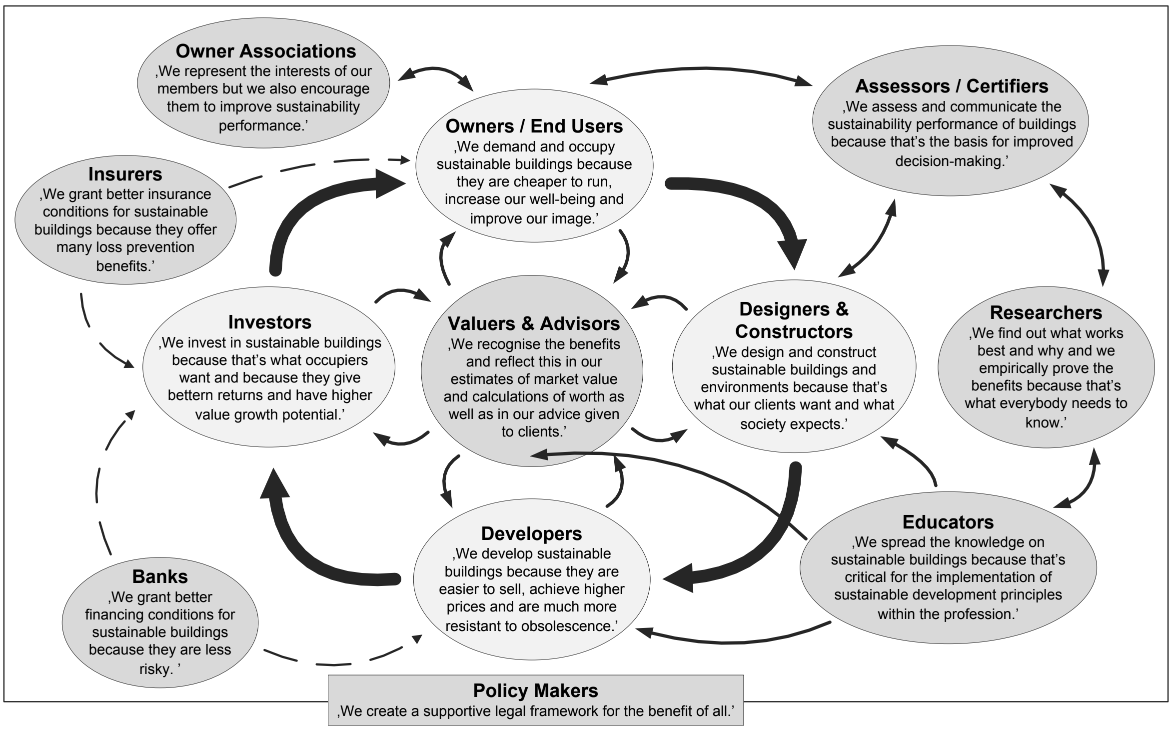

Figure 2 Virtuous loops of feedback and adaptation

The interplay between all these different actors as well as the information flow needs to be organised in such a way that the knowledge regarding the benefits of sustainable buildings pervades all areas and is accounted for within the highly influential processes of valuation, investment counselling and risk analysis. At the moment, the problem is that the feedback-mechanisms that motivate and incentivise change are not yet fully in place. One principle of sustainable development is that measures and actions within all sectors and at all levels of society are adjusted and re-calibrated through loops of feedback and adaptation. However, actors across all business sectors and also in property and construction markets are cut-off from feedback. "They know nothing of their impacts on people, culture, health, or the environment. They subsist only on the shallowest feedback: direct internal financial returns" (Kiuchi, 2003). This is dangerous and leads to a false statement of corporate accounts since huge and growing external cost categories are ignored. Shareholders may not notice these unstated costs while in contrast stakeholders do (Kiuchi, 2003). Expressing this in the property context: if building owners and investors know nothing or very little about the real performance of the buildings they buy, use and operate, (i.e. if they are cut off from feedback delivered by triple bottom line monitoring), then these buildings cannot be improved systematically in pursuit of both individual and collective well-being. The alternative is for property professionals to begin assessing and reporting value creation through sustainable design, incentivising change and more sustainable behaviour. The added value appropriated to sustainable design will underwrite a restructured approach and a radical change to how we understand and value our built environment. The end result is the emergence of a pro-active, self-perpetuating loop driving further change and even more sustainable behaviour.

A precondition for assessing and reporting value creation through sustainable design and for installing appropriate feedback-mechanisms within the property industry lies in overcoming existing information asymmetries. What is needed is a systematic description of major characteristics and attributes of buildings for various purposes such as valuation, risk assessment and certification; i.e. a reliable and cost-effective source of information for property professionals. An appropriate source of information in this regard are building passports or building files which have been discussed in Europe since a considerable period of time. However, building files are yet only issued occasionally on a voluntary basis. In addition, building files are not yet standardised. The introduction and dissemination of building files in property markets is currently hampered by ambiguous and unclear perceptions regarding their informational content and function. Usually building files are either seen as a kind of building manual, as an extended construction and building specification, as a quality assurance system or even as a label or certificate. However, the interpretation of building files put forward in this paper is that of an 'information container' which supports the exchange of information between actors in property and construction markets (see Figure 3).

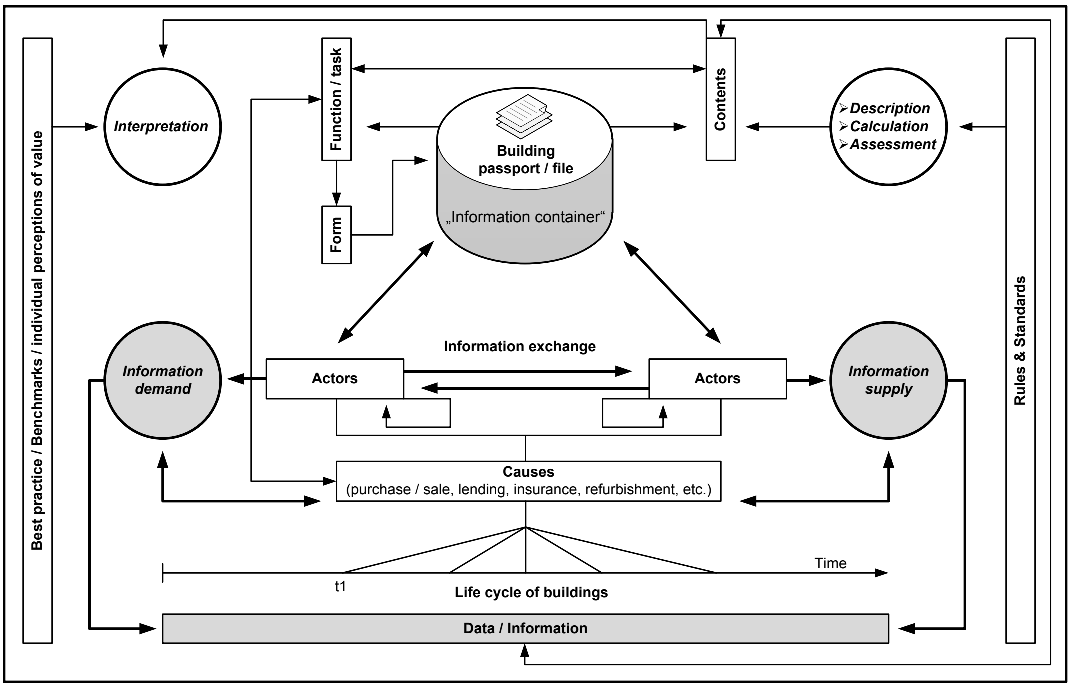

Figure 3 Information flows between actors of property markets on the basis of building files

There exists a clear need for provisioning, extending and updating building related information along the life cycle of property assets. This information has to be gathered and compiled on a scientifically robust basis during the planning phase as well as during the subsequent phases of operation and refurbishment. In this regard it is important to realise that different actors fulfil different roles and have different standpoints and goals. They therefore need different kinds of information in different formats tailored to the requirements of specific decision making problems accompanying the life of buildings. Building files can be used to serve this informational demand as they are capable of providing different kinds of information for different actors. They could contain information on the following issues: construction method; building materials; statics; heat and sound insulation; fire safety; operating costs; maintenance and repair; demand for and consumption of different resources/media; etc. For the further development of the informational content of building files it is recommended to foster the development towards performance-based building information as well as to compile a list of key characteristics and attributes which would best serve different actors in different decision-making contexts. The latter issue could be addressed through efforts undertaken by the large organisations for property professionals such as the Royal Institution of Chartered Surveyors (RICS).

3. Next generation decision support instruments

Next generation decision support instruments for the property industry will have to fulfil a variety of roles and purposes. First, they will have to address the imperfection and asymmetry of information. In today's property markets investors and their professional advisors are forced to analyse and evaluate various aspects of building performance and the attractiveness of a particular location in great detail while they are simultaneously required to take into account a variety of complex institutional influences and externalities at global, regional and national level. The success of property investments and the competitiveness of investors and their professional advisors strongly depends upon knowledge and on the capabilities and sophistication to assess, interpret and understand the increasing complexity of factors from diverse sources of real estate information (see: Castells, 1996). This means that decision support instruments will have to allow for interlinking information from sources such as market and transaction databases, building files, sales portals, land registers, geographical information systems, national statistics bureaus, etc. in order to enable property professionals to fulfill their role as 'information managers' in a market where the distribution of information is traditionally considered asymmetrical. Second, decision support instrument will have to allow professionals to assess and communicate (in understandable formats) the accuracy and reliability of both their estimates of values, risks and costs as well as of the quality of the applied valuation, risk analysis, management, construction and refurbishment processes. This will involve addressing notions of uncertainty and probability as well as the issue of traceability (see: Lorenz et al., 2006). As there has already been a lot of loss of both credibility and faith in the property and finance industry in general and in the valuation and counselling profession in particular (due to overvaluation, misleading advice and speculative behaviour that has recently led, amongst other issues, to a global crisis in property and interlinked financial markets), professionals will have to apply tools and measures not only for 'quality assurance' of products and processes (see Figure 4) but also to make their 'thought processes' explicit and to give clients a better understanding of the nature and risks of property investment and financing.

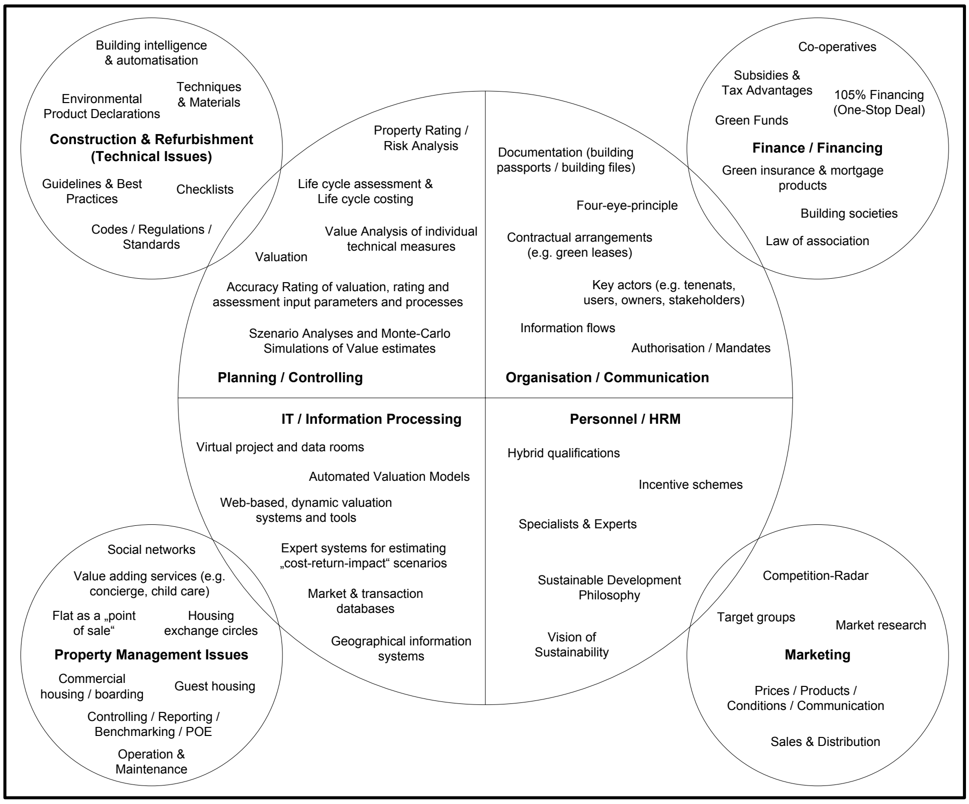

Figure 4 Overview on instruments, tools, measures and key issues for Overall Quality Assurance

Finally and most importantly, decision support instruments will have to bridge the gap between economic, environmental, social and cultural measures and components of property value and help to establish the necessary feedback-mechanisms that incentivise and drive change in the property industry. This requires a synergy we have not seen so far; i.e. an integration of the traditional methods and tools for valuation, risk analysis and cost estimation with the methods and tools developed by the sustainable building community for assessing and communicating the contribution of buildings to sustainable development. The connection, though yet missing, between these two kinds of methods and tools is seen in the introduction and wide-spread dissemination of building files within the property and construction industry. The challenges and difficulties in creating next generating decision support instruments lie as much in the further development of IT-systems and tools as in the improvement of the informational data basis available in the property industry. This will be shown by briefly referring to the development of new instruments for the following areas: valuation and risk assessment.

As the perception of property as a commodity is currently changing to emphasize sustainability-related building characteristics and performance aspects as important determinants of a property's worth and market value, valuation practice must change accordingly. It has therefore been argued that advanced valuation methodology – like hedonic pricing techniques – can and must be applied in order to continuously monitor market behavior and shifts in value perceptions in order to provide a more scientific basis for the price or value adjustments that have to be made to account for the benefits of sustainable design features not solely reliant upon the knowledge, judgment and experience (or inexperience) of the individual valuer alone (Lorenz et al., 2007). But the application of advanced valuation methodology can only provide meaningful results on the relationships between environmental, social and financial building performance if the quality of building descriptions contained in property transaction databases does allow drawing such conclusions. Unfortunately, at the moment this is not the case since we do not yet have performance-based building descriptions in property transactions databases. This issue has been investigated in more detail by a recent survey carried out at the University of Karlsruhe on the content and scope of transaction databases in Germany. The survey comes to sobering conclusions: Only a minority (8%) of valuation expert committees (the major source of property transaction information in Germany) has made preparations to extend the scope of transaction databases by including information from the recently introduced energy performance certificates while the majority is still considering this issue or does not even know about the relevance of the information contained within these certificates (Kertes et al., 2008). However, the state of affairs may not be much better in other countries where property markets are considered to be much more transparent and price information is more readily available; performance-based building descriptions are arguably missing in almost all transaction databases. So valuers are left alone when forming an opinion of value for the foreseeable future as it will take years to accumulate the informational data basis necessary to empirically underpin a valuer's decision to provide a 'valuation bonus' for a sustainable building or a 'valuation reduction' for a conventional one.

The situation is very similar with regard to the further development of instruments for assessing property risk (so-called property ratings). Developers of property rating systems (mainly banks and rating agencies) have started creating links for the direct and indirect integration of sustainability issues within rating methodologies and processes. But if the results of building assessment tools are to be used to support the rating process, then the flow of information can be organized in different ways and the question arises whether partial results of building performance assessments should be used to provide the informational basis for certain aspects of property ratings, or if the overall building assessment result should be integrated into property ratings as a separate rating category? Nonetheless, the use of property ratings in their current form already allows distinguishing more clearly between conventional buildings and more sustainable ones within property financing and risk-analysis processes (Lützkendorf and Lorenz, 2007). But if financial intermediaries acknowledge the economic impact of sustainable design, such acknowledgment will be credible in the longer term only if the sustainability performance of a building is reflected in the lending terms. Some banks are already offering special lending terms for energy-efficient, environmentally sound and/or sustainable buildings. However, there is a need to verify whether this is the result of marketing activities or certain grants-in-aid, or whether it is in fact due to a better understanding of the correlation between risk assessments and lending terms? Only in the last case would this represent a breakthrough with wide-ranging implications. And again, such conclusions can be drawn only on the basis of data combining performance-based building descriptions on the one hand and financial performance information (in this case: loan default rates) on the other hand.

4. Outlook

The challenges imposed by sustainable development for property professionals, their professional bodies and their educational institutions are unprecedented – in terms of importance, urgency and scale. And as the concerns are slowly changing from worries about environmental degradation and loosing species to fears about losing the services that keep our own species – and its civilization – thriving (WBCSD, 2007), the solutions and actions undertaken to address this challenge are likely to be entirely different from current ‘best practice’ in construction, property investment and management. Addressing this challenge will require as much a ‘technical solution’ (in terms of developing new decision support instruments, building knowledge, and establishing new information links) as it will require a ‘moral solution’. Is it so difficult to realise that due to information asymmetries actors in property and construction markets operate in a permanent prisoner’s dilemma and that we would all benefit from more agreeable behaviour (see: Hume, 1751 and Kuhn, 2003)? Apparently, the profession stands at the crossroads of deciding between travelling along ‘the road of value and agreeableness’ (which involves acknowledging the principle of enlightened self-interest which states that individuals who act to also further the interests of others ultimately serve their own self-interest) or pursuing business-as-usual and experiencing the ‘tragedy of the commons’ (see: Lloyd, 1833), a social trap that involves a conflict over finite resources between individual interests and common goods which finally dooms the resources in question.

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ENERGY - 'FROM SERIAL RENOVATOR TO SENSIBLE RETROFITTER'

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Summary

When people move home they often bring with them exciting plans to 'improve' their property. The focus is often on marble bench tops and luxury bathrooms at the cost of improving the energy performance of the home and hence, the comfort and health of the occupants. Why do we place such a high value on aesthetic 'renovation' whilst we ignore the real benefits that can accrue from energy efficient 'retrofit'? Beacon Pathway, a research consortium with the aim of bringing 90% of New Zealand's homes to a "high standard of sustainability" by 2012, is helping to define best practice in the provision of retrofit solutions. Beacon seeks to understand what New Zealanders value when thinking of 'renovating' their home, what people understand and value about 'retrofitting', and how the two can be aligned to raise the value case for energy efficient renovation. Beacon has developed a framework for decision making to analyse the best retrofit solutions for a range of New Zealand housing typologies and specific options for targeted users and consumers. The research is helping to determine the technical feasibility of improving the energy performance in existing stock and quantified the energy efficiency gains possible within the constraints of individual dwelling typologies. The research is also helping Beacon develop a range of appropriate delivery processes and marketing approaches for dwellings with different household and tenure characteristics, including owner-occupied dwellings / rental dwellings; high energy users and recent home buyers.

1. Introduction

Beacon Pathway Ltd (Beacon) is a research consortium that seeks to radically change the design, construction and renovation of New Zealand's homes and neighbourhoods. Beacon aims to bring about a significant improvement in the sustainability of the residential built environment in New Zealand through science-based New Zealand research.

Beacon's current research on energy is directed to a market transformation that will ensure that both suppliers and consumers act to improve the energy efficiency of New Zealand's housing stock. Beacon recognises that improving the energy performance of New Zealand's housing stock is primarily a matter of changing the performance of the existing stock through retrofitting. The issue for New Zealand's retrofitting initiatives, whether publicly funded or privately initiated by householders, is how to develop energy retrofit packages that most effectively improve dwelling performance and fall within the constraints of household affordability and willingness to pay. Beacon intends to use the findings of this research to develop a study of retrofit performance and take-up among 1000 New Zealand dwellings.

Beacon is addressing the problem of developing effective retrofit packages by a three pronged research stream that is directed to:

- establishing the relationship between retrofit and building typology
- identifying how to stimulate take-up among key consumers in the housing market, and
- identifying a set of evidence-based, robust promotional approaches, packages and tools to retrofit existing houses.

In this paper we present the findings from the second of those research prongs. That research has been concerned with four key questions. They are:

- What user/consumer segments are best targeted to achieve maximum take-up of energy efficiency retrofits of New Zealand homes?
- What are the motivations of these user segments and how should they be targeted?
- Are there common features of building typology of the priority user segments?
- What benefits do other end-users in the supply chain gain through retrofit?

Those questions have been explored through two surveys. One survey has focused on households that are high energy users and the second survey has involved households that have recently moved from one house to another. In the following discussion, we:

- set out the rationale for surveying those two sets of consumers
- provide the survey method and comment on the focus and rationale of the questionnaire
- present some of the key findings from the surveys, and
- comment on the implications of the findings for the development of effective retrofit packages and the potential for market transformation and stock sustainability.

2. Recent Movers and High Energy Users

New Zealand is an enormously mobile society. The 2006 census found that 57.7 percent of the population had changed place of residence in the previous five years. Young people and tenants tend to be the most mobile. Nevertheless, approximately 140,000 dwellings change hands annually. Recent Movers are unique in two ways. Firstly, home buyers have immediate selection choices. The factors that inform those choices regarding the energy efficiency and their assessment of the performance of their new home give a very real insight into: the value home owners place on energy efficiency, warmth and healthy living conditions; the characteristics of homes that home buyers use to assess the likely performance of a dwelling; and the probability of accurate assessments by buyers of the performance of a new dwelling. Secondly, home buyers are often in situations in which they chose a home which requires renovation and they finance their purchase to allow for renovation. That tendency allows us to better understand the extent to which energy and associated dwelling performance and retrofitting are elements within any renovation planning and financing.

High Energy Users are also an important group of householders. Energy use by high users dominates the aggregate energy patterns of New Zealand households. Increasing their energy efficiency and, preferably decreasing their aggregate energy use, is critical to improving the overall energy performance of the residential housing stock in New Zealand. The Centre for Research, Evaluation and Social Assessment (CRESA) has established in a recent survey for the Energy Efficiency and Conservation Authority (EECA) that those households that see themselves as high or very high energy users generally are so. High energy use households may make up between 15 and 25 percent of households. That is, between 200,000 and 350,000 households in New Zealand (Saville-Smith, K. and R. Fraser, 2007). High Energy Users have the potential to reap the greatest returns on investment from increasing the energy efficiency of their dwellings. Understanding their patterns of renovation and their perspectives on retrofit is, consequently, critical to developing effective market transformation and a sustainable housing stock.

3. The Research Method

Both groups were surveyed using largely similar questionnaires. The High User Survey, however, was implemented through telephone interviewing and the Recent Mover Survey was a postal survey requiring the participant to self-complete and post back the questionnaire. Although there were some differences between the questionnaires to take account of the different population profiles of the participants and data collection, both questionnaires involved primarily closed-ended, pre-coded questionnaires with some opportunities for the participants to convey information in free-form. The latter were subsequently content analysed and coded.

The questionnaires focused on eliciting information from participants about the: size and physical characteristics of their current dwelling; renovation and retrofit activities in the year prior to surveying and associated costs; intended renovation and retrofit activities in the coming year and intended expenditure; energy consumption patterns and their perceptions of the drivers of their energy consumption; condition and performance of the dwelling in winter and summer including incidence of damp and mould; householders' understanding of retrofit and the impacts of various retrofit components; and the householders' attitudes to retrofit, the benefits they associated with retrofit and willingness to pay. The survey participants were also asked to report a limited set of socio-demographic information around household income, life stage and household size.

For the High Energy User Survey, data was collected from self-identified high energy use households. Participants for the survey were selected randomly from throughout New Zealand using telephone numbers extracted from white pages listings. Interviewing was undertaken over a two week period from 12 October 2007 to 26 October 2007. An initial screening question asked respondents to estimate their energy consumption compared to other households – only those respondents who estimated their household energy consumption as high or very high were eligible to complete an interview. In all 700 interviews were completed and assuming that the sample has captured high energy users, it provides a margin of error of ± 3.8 percentage points at the 95 percent confidence interval.

Participants for the Recent Movers Survey were selected randomly from a data extract of recent movers generated from the New Zealand Post Household Postal Address Directory. A 'recent mover' was defined as someone who had changed address between 1 April 2006 and 31 March 2007. The data extract was also limited to those households who identified themselves as owner occupiers. The data extract included some 33,700 households, divided into 11 broad regions using post code data. The final sample of 3,000 households was a stratified random sample where the number of households included in the sample from each region was intended to be broadly proportional to the total number of recent mover households in that region for the survey period. Surveying took place over a four week period beginning late September 2007. In all 724 completed surveys were received before the due date of 19 October 2007. The margin of error for the recent mover dwelling population is 3.7 percentage points at the 95 percent confidence interval.

The data from the surveys have been entered and analysed in the Statistical Package for the Social Sciences (SPSS) and subject to univariate and bivariate analysis. Statistical testing – usually chi-square tests – was also undertaken to establish whether there was systematic and statistically significant relationships between selected key variables.

4. Dwellings, Energy Use and Dwelling Performance

New Zealand has a homogenous dwelling stock in terms of dwelling size and type. This is evident in the dwellings occupied by the High Energy Users and the dwellings occupied by Recent Movers. The majority of dwellings are three bedroom dwellings and there is a strong preponderance of detached single-storey dwellings (Table 1).

Table 1: Dwelling Size and Type

Dwelling Characteristics	% Recent Movers		% High Energy Users	
	n	%	n	%
1 bedroom	10	1.4	16	2.3
2 bedrooms	104	14.4	75	10.7
3 bedrooms	354	49.0	300	42.9
4 bedrooms	212	29.4	210	30.0
5+ bedrooms	42	5.7	99	14.1
Total	***722***	***99.9***	***700***	***100***
A detached single-storey house	443	61.7	450	64.4
A detached multi-storey house	190	26.5	185	26.5
A semi-detached single-storey house	18	2.5	20	2.9
A purpose built flat or a flat in a converted building	19	2.6	18	2.6
A semi-detached multi-storey house	16	2.2	8	1.1
Other	19	2.6	8	1.1
An apartment (in a block two or more storeys high)	7	1.0	6	0.9
A terrace house	6	0.8	4	0.6
Total	***718***	***99.9***	***699***	***100***

The participants in the High Energy User Survey, by definition, saw their energy use as above average. However, around a fifth (21.5 percent) of the Recent Movers Survey participants also described themselves as high energy users. When compared to the Recent Movers, the High Energy User Survey participants tend towards simplistic explanations for their high energy use. The high energy users among the Recent Movers Survey participants have multi-dimensional explanations. Among the High Energy User Survey participants the common explanations for high energy use refer to having a large number of household appliances, while among the Recent Movers the most common explanation is around the amount of energy their house takes to heat (Table 2). The Recent Movers (including those of them who are high energy users) are much more concerned about the energy efficiency of their homes than the High Energy Users. Recent Movers are also considerably more concerned with the comfort or warmth provided by a dwelling (Table 3).

Table 2: Assessment of Likely Reasons for Their Households High Energy Use

Explanations for High Energy Use	% Recent Movers with High Energy Use (n=156)	% High Energy Users (n=700)
Our house takes a lot of energy to heat	60.3	35.3
House has many lights	44.2	6.6
Large number of appliances	42.3	37.1
Household members are wasteful with energy	31.4	18.0
We have old hot water tanks	25.6	4.3
We have many hot water tanks	3.8	2.9
Our house takes a lot of energy to cool	2.6	0.7

* Multiple Response

Table 3: Considerations of Energy Issues when Acquiring Current House

Energy Issues Considered	% Recent Movers (n=724)	% High Energy Users (n=700)
Comfort or warmth within the house	83.4	59.9
Whether house had insulation in the roof space or under the floor	64.8	47.4
Whether the windows and doors were tight fitting or draught-proofed	44.3	35.0
What the energy bill might be like	35.9	22.4
Whether the house had double glazing	25.4	15.3

* Multiple Response

This concern with warmth and comfort does generate a somewhat different insulation profile in the dwellings reported on by Recent Movers and High Energy Users respectively. Recent Movers are less likely to report dwellings with no insulation. They are more likely to report that their dwellings are fully or substantially insulated (Table 4). Notably, only 6.4 percent of Recent Movers report no insulation compared to 13.3 percent of High Energy Users. There is not, however, a strongly pronounced difference in the appliances that Recent Users and High Energy Users mainly use for heating (Table 4), although the latter show a slightly lower use of woodburners and heat pumps and a higher reliance of electric heaters and portable gas heaters than Recent Movers.

Table 4: Reported Insulation Profile of Recent Movers' and High Energy Users' Dwellings

Insulation	% Recent Movers (n=724)	% High Energy Users (n=700)
No insulation	6.4	13.3
Roof space only	25.8	25.9
Floors only	1.2	1.1
External walls only	3.5	2.7
Roof space and floor	6.9	8.3
Roof space and exterior walls	32.6	27.1
Floor and exterior walls	0.4	1.4
Fully insulated	16.3	15.9
Not sure	6.9	4.3
Total	***100***	***100***

Table 5: Main Space Heating Used

Heater Type	% Recent Movers (n=724)		% High Energy Users (n=700)	
	n	%	n	%
Enclosed woodburner	168	25.9	158	22.6
Heat pump	144	22.2	109	15.6
Electric heater e.g. fan, bar, convection heater	68	10.5	105	15.0
Fixed electric radiator or oil column heater	65	10.0	80	11.4
Fixed and flued gas heater	58	8.9	66	9.4
Portable gas heater e.g. LPG	50	7.7	64	9.1
Open fire	26	5.7	40	5.7
Underfloor heating	15	4.0	21	3.0
Fixed unflued gas heater	17	3.3	23	3.3
Other	35	2.6	25	3.6
No heating used	*3*	*1.3*	*9*	*1.3*
Total	***649***	***100.0***	***700***	***100***

It is notable that, while only a very small proportion of High energy Users Survey participants explain their high energy use in terms of the age of their hot water cylinders their hot water cylinders have a distinctly older profile than the hot water cylinders in the houses of recent movers. Almost half the hot water cylinders of High Energy Users are aged more than 10 years and less than a third (28.4 percent) of hot water cylinders are less than five years old. In addition, 51.4 percent of High Energy Users report that the pipes from their hot water cylinders are not lagged at all. By way of comparison, 38.4 percent of hot water cylinders in the houses of recent movers are less than five years old and 38.9 percent of the Recent Movers report that their hot pipes are unlagged.

Both household sets report similar patterns of efficient light bulb use. Two-thirds (66.1 percent) of High Users reported using energy efficient light bulbs. However, only around a fifth (21.6 percent) reported that energy efficient light bulbs make up 76 percent or more of the light bulbs in their dwelling with a little over two-thirds (67.3 percent) of High Users reporting that half or less of their light bulbs are energy efficient. Similarly, 70.4 percent of Recent Movers reported using energy efficient light bulbs, but only 14.9 percent reported that energy efficient light bulbs make up 76 percent or more of the light bulbs in their dwelling. Almost two-thirds (61.4 percent) of Recent Movers report that half or less of their light bulbs are energy efficient

5. Renovation and Retrofitting

It appears that both the energy and thermal performance of dwellings of High Energy Users and the dwellings of Recent Movers could be significantly improved through quite simple retrofitting interventions. It is of enormous importance that a considerable proportion of dwellings have been exposed to significant investments in renovation in the year prior to surveying, but few of those renovations have actually involved retrofitting for higher levels of energy efficiency.

Among the Recent Movers, 46.3 percent they have undertaken renovation or retrofit work in excess of $2,000. 43.6 percent of Recent Movers also report intending to expend more than $2,000 on renovations and retrofitting in the coming year. The average reported expenditure on renovations/retrofit is $22,477 and the median is $7,000. Among the High Energy Users, a third (33.3 percent) report renovation or retrofit work in excess of $2,000. 35.9 percent of High Energy Users intend to expend more than $2,000 on renovations and retrofitting in the coming year. The average reported expenditure by High Energy Users on renovations/retrofit is $25,284 and the median is $9,500. Table 6 sets out the renovation activities reported by High Energy Users and Recent Movers.

Most of this renovation work is not prompted by a belief that their dwellings are in poor condition. Among the High Energy Users, 43.4 percent reported that their dwelling was in good condition only needing minor maintenance. Nevertheless, High Users made up 51.7 percent of the High Energy Users intending to undertake substantial renovations, repairs or retrofitting in the coming year. Among the Recent Movers the group that reported that their dwelling is in good condition are also over-represented among those intending to expend more than $2,000 in the coming year on renovations, repairs or retrofitting. This does not mean, however, that renovations do not include attempts to deal with dwelling performance problems.

43.6 percent of High Energy User reported that their dwelling had problems of mould or damp and over a third (36 percent) of High Energy Users and 31.9 percent of Recent Movers reported on ways they have tried to address mould, cold and damp problems in their houses through repairs or renovation or acquisition of appliances. Their strategies are almost entirely dominated by the installation of Heat Recovery Ventilation (HRV), Distributed Ventilation System (DVS), or similar systems with installation of heat pumps and dehumidifiers not far behind. 46 percent of the High Energy Users that reported attempting to address mould and damp in their houses put in HRV/DVS systems, but less than 4 percent installed insulation. Similarly, 28.6 percent of Recent Movers used dehumidifiers while 19.5 percent installed HRV/DVS systems and 17.7 percent installed heat pumps to deal with mould, damp and cold. Less than 8 percent installed some form of insulation despite 83.7 percent of the Recent Movers dwellings having only partial or no insulation.

Table 6: Renovation & Retrofitting Activities

Renovation or Retrofit	Recent Movers (n=724)		High Energy Users (n=700)	
	n	%	n	%
Interior repainting and/or wallpapering	155	45.7	46	19.7
Replacement of kitchen appliances	117	34.5	22	9.4
Carpeting	104	30.7	31	13.3
Replacement of kitchen cabinetry	90	26.5	19	8.2
Installing a heat pump	81	23.8	23	9.9
Replacement of bathroom whiteware	77	22.7	37	15.9
Replumbing	66	19.5	8	3.4
Installing an extractor fan in the bathroom	64	18.9	3	1.3
Installing a rangehood/extractor fan in the kitchen	64	18.9	1	0.4
Full exterior re-paint	63	18.6	28	12.0
Replacement of bathroom cabinetry	62	18.3	15	6.4
Rewiring full or significant part of the dwelling	54	15.9	5	2.1
Installing ceiling insulation	46	13.6	13	5.6
Installing wall insulation	46	13.6	7	3.0
Installing a new hot water cylinder	44	13.0	7	3.0
Replacement of interior cladding	41	12.1	15	6.4
Installing a ventilation system e.g. HRV, DVS	40	11.8	17	7.3
Installing underfloor insulation	35	10.3	8	3.4
Adding rooms	31	9.1	16	6.9
Installing a wood burner	26	7.7	6	2.6
Roof replacement	25	7.4	15	6.4
Polishing floors	24	7.1	3	1.3
Upgrading hot water systems to instant gas	24	7.1	1	0.4
Venting drier to the outside	23	6.8	1	0.4
Installing a low flow showerhead	21	6.2	1	0.4
Replacement of significant amounts of exterior cladding	20	5.9	7	3.0
Installing double glazing	17	5.0	4	1.7
Installing a rainwater tank	11	3.2	1	0.4
Installing a pellet burner	7	2.1	1	0.4
Installing a solar hot water system	6	1.8	4	1.7
Installing a wet back hot water system	3	0.9	1	0.4
Installing a heat pump hot water system	2	0.6	4	1.7
Installing passive vents in windows	1	0.3	0	0.0

* Multiple response

Not surprisingly, considerable proportions of householders find that they continue to have mould, damp and cold problems. Among the High Energy Users, for instance, of the 313 householders reporting they have a mould in their dwelling, 45.4 percent have previously attempted to address the problem through renovation, retrofit or appliance use. Similarly, of the 252 High Energy Users who have taken measures to rectify problems with mould, 56.3 percent report still having mould problems.

Not only do the participants in the High Energy User Survey and the Recent Movers Survey appear to be misdirected in their efforts to improve dwelling performance, many are unaware of the term ‘retrofit’. Only 28 percent of High Energy Users and 41 percent of the Recent Movers reported that they had heard of the term. In both surveys, the participants showed considerable variation as to the activities they identified as retrofit. As Table 7 shows, installation of ceiling insulation is associated with retrofitting by substantial proportions but many of the lowest cost and most basic options such as use of curtains are less likely to be associated by householders with retrofitting.

Table 7: Activities Identified by Recent Movers and High Energy Users as Retrofit*

Activities	Recent Movers (n=296)		High Energy Users (n=252)	
	n	%	n	%
Installing insulation/batts in the ceiling	238	80.4	66	33.7
Installing double glazing	220	74.3	44	22.4
Installing underfloor insulation	218	73.6	57	29.1
Installing insulation in the walls	213	72.0	46	23.5
Draught stopping the doors and windows	192	64.9	11	5.6
Installing heat pump	167	56.4	19	9.7
Putting in an HRV/DVS or similar ventilation system	158	53.4	11	5.6
Upgrading hot water systems to solar hot water	148	50.0	12	6.1
Installing an extractor fan in the bathroom	148	50.0	4	2.0
Venting the drier to the outside	143	48.3	0	0.0
Installing efficient wood burner	143	48.3	6	3.1
Installing a low flow shower head	139	47.0	0	0.0
Putting heavy thermal curtains with pelmets	139	47.0	4	2.0
Installing a rangehood/extractor fan in the kitchen	133	44.9	3	1.5
Installing passive vents on the windows	121	40.9	2	1.0
Upgrading hot water systems to instant gas	121	40.9	5	2.6
Putting in a wetback hot water system	113	38.2	2	0.0

* Multiple response

6. Wanting Retrofit and Willingness to Pay

There are considerable differences between High Energy Users and Recent Movers in relation to their expressed desire for retrofits. As Table 8 shows, the High Energy Users are strongly oriented towards associating comfort and health benefits with reduced energy costs. Among the Recent Movers, however, over a quarter see comfort and health benefits as being attractive in themselves irrespective of energy cost savings. This is despite the fact that High Energy Users show a substantially higher monthly expenditure than Recent Movers. The average electricity bill for the previous month was $194 for Recent Movers but $282 for High Energy Users. The median electricity bill for Recent Movers for the previous month was $170 compared to a median for High Energy Users of $250. Just as the Recent Movers appear more amenable to retrofitting for comfort without the added incentive of energy cost savings, so too are Recent Movers less likely than High Energy Users to report that expense is a barrier to retrofit (Table 9).

Table 8: Attitudes to Retrofitting Current Houses among Recent Movers and High Energy Users

Attitude Statement	Recent Movers (n=724)	High Energy Users (n=700)
Retrofit for comfort, warmth and health if power bill savings	38.3	46.0
Retrofit for comfort, warmth and health even if no power bill savings	26.9	17.6
Will not retrofit current house	22.0	21.9
Already retrofitted	7.9	8.0
Don't know	5.0	6.6
Total	***100.0***	***100.0***

Table 9: Barriers to Undertaking Retrofit (n= 670)*

Attitude Statement	Recent Movers (n=724)	High Energy Users (n=700)
Too expensive	41.2	50.8
I don't know what my particular house needs and/or how to get the best value for money from a retrofit	27.9	2.6
I don't know how to do it myself	9.4	0.5
I can't get access to credible information	5.7	2.5
It would be inconvenient	4.9	13.5
I can't get trades people	2.5	1.1
I have other priorities	0	4.8

* Multiple response

This is not to suggest that expense and affordability are unimportant. Even among Recent Movers, expense is the most commonly cited barrier to retrofit. However, for Recent Movers, the inability to assess value for money is a strong barrier to retrofit take-up. Financial preoccupations are also evident among both High Energy Users and Recent Movers when they reflect on their willingness to pay for retrofit activities. In Table 10, Recent Movers appear less likely to be prepared to take-up retrofit recommendations than High Energy Users. This may indicate that Recent Movers have selected dwellings to a level of performance and comfort that suits them. Overall, both sets of households are characterised by the low investment that they are willing to make in retrofit. Over a quarter of High Energy Users reported that they might act on retrofit recommendations that cost less than $500. Around another quarter reported that they were either unlikely to take up recommendations or did not know how they would respond, while 18 percent of High Energy Users reported that they would take up measures costing between one to three thousand dollars. Among the Recent Movers, almost two-thirds (63.9 percent) would spend less than $5,000 on recommended measures.

Table 10: Amount Willing to Spend on Recommended Measures for Improved Energy Efficiency

Willing Investment	Recent Movers (n=724)	High Energy Users (n=700)
Less than $100	7.3	15.0
$101-$500	8.4	11.4
$501-$1,000	16.0	11.7
$1,001 to $3,000	19.9	18.1
$3,001 to $5,000	12.3	10.9
$5,001 to $8,000	4.0	3.9
$8,001 to $10,000	2.9	3.4
$10,001 to $15,000	1.7	1.0
$15,001 to $20,000	0.8	0.4
More than $20,000	1.4	2.4
I am unlikely to act on recommended measures	17.4	11.7
Unsure	7.9	10.0
Total	***100***	***100***

7. Getting a Sustainable Stock through Householder Take-Up

It is clear that both Recent Movers and High Energy Users are resistant to investment in retrofitting. High Energy Users show little interest or ability to select dwellings that are likely to be resource efficient. Recent Movers are more likely to seek dwellings that are warm and comfortable, but even their newly acquired dwellings still have very basic sustainability features missing. This data suggests that achieving high standards of sustainability in future housing stock is critically dependent on ensuring that any new housing stock is built to optimise energy, thermal and other resource performance. Rather than being satisfied with minimal standards, the difficulties in getting reinvestment in retrofit suggest that sustainable new housing is a fundamental pathway for the future.

Notwithstanding, the fact is that existing housing stock in New Zealand does not perform well. If that is to be remedied we need to give up on our desire to transform serial renovators into sensible retrofitters. Retrofitting has no resonance. Certainly some householders want to reduce exposure to energy costs and others want improved comfort. But the reality is that while these households are prepared to pay for renovation, they do not do retrofit despite many of their dwellings having basic energy deficiencies easily retrofitted at low cost. Basic deficiencies include draughty doors and windows; poor insulation of hot water cylinders and pipes; partial roof and underfloor insulation, and inefficient heating and lighting. Indeed, it appears that where householders do undertake work that might be considered ‘retrofit’ they undertake to put in complex systems rather than address basic issues of thermal performance.

The data shows that willingness to pay for energy performance improvement is complex among these high energy user dwellings. Less than a third of high energy users reported that they would pay more than $5,000 for measures that would improve the energy efficiency of their homes. However, the median expenditure on renovations in the previous year was $9,500. Nevertheless, High Energy Users and Recent Movers both reported making renovations and appliance investments directed specifically to address mould, cold and damp problems. This suggests that the pathway to improved energy, and probably other resource efficiency lies in: connecting retrofitting to the renovation decisions and investments that high user households make in relation to their dwellings; developing a range of low cost retrofit packages; aligning renovation solutions that improve the thermal envelope to addressing concerns about cold, dampness and mould; and providing advice on the relative impacts and appropriate sequencing of retrofit products and packages.

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COSTS AND BENEFITS OF A GREEN VILLAGE: DEMONSTRATING LOCHIEL PARK'S VALUE

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Summary

This paper presents the results of a study of costs and benefits of sustainability initiatives currently being implemented in the Lochiel Park green village development project in South Australia (SA). An alternative assessment methodology to that offered by a conventional cost-benefit analysis was developed that considers costs and benefits with reference to a framework of sustainability indicators, both quantitative and qualitative, with a particular focus on the operational phase of urban development. Principles reflected in the approach include considering costs and benefits across the life-cycle of sustainability initiatives, taking into account multiple stakeholder perspectives on costs and accommodating both monetised and non-monetised indicators of cost and benefit. An important finding of the study is that analysis of costs and benefits informed by these principles offers a valuable approach by which to consider investment in sustainable building. Applying the framework to Lochiel Park, the costs and benefits of various water and energy sustainability initiatives were assessed and compared, with results indicating that Lochiel Park initiatives are making an important contribution to sustainable urban development. A number of lessons can be derived from the study to inform future investment in green development.

1. Introduction

The South Australian Land Management Corporation (LMC) is responsible for delivering Lochiel Park, an ambitious green village development located in Campbelltown near the Adelaide CBD. In 2007, LMC commissioned the Institute for Sustainable Futures (ISF) at the University of Technology, Sydney to undertake a study to assess the likely costs and benefits of sustainability initiatives being implemented at Lochiel Park.

An approach to identifying and communicating costs and benefits of sustainability initiatives was developed. The approach drew on the principles and tools of cost-benefit analysis, tailored to meet study objectives in terms of assessing both environmental and social values of Lochiel Park and adapted to make best use of available data. Principles reflected in the approach include: consideration of costs and benefits over the life-cycle of sustainability initiatives (in this case explicitly focusing on the operational phase due to scope and data limitations); assessment of multiple cost perspectives including those of Lochiel Park residents and wider society; and consideration of both monetised and non-monetised costs and benefits. Sustainability initiatives were assessed with reference to a set of indicators developed by ISF in collaboration with LMC and other stakeholders involved in Lochiel Park design and construction. The indicators approach was complemented by a survey of government and private agencies with an interest in Lochiel Park to gauge perspectives on the costs and benefits to each organisation of being involved in the development of a landmark green village.

This paper outlines the approach and results of the ISF study and situates the study in the context of wider questions about valuing sustainability in the urban development sector. Challenges associated with undertaking analysis of costs and benefits in the green building sector are discussed and the approach to valuing sustainable building taken by ISF/LMC is described. Results of the analysis are presented, including water and energy resource savings, costs associated with selected initiatives and implications for future urban green development.

2. Lochiel Park Green Village

In March 2004, the South Australian Premier Mike Rann announced the development of a 'nation leading' green village at Lochiel Park, a site 8 kilometres north east of the Adelaide CBD. The site comprises fifteen hectares of land and is located adjacent to the River Torrens Linear Park.

Lochiel Park is being developed during a period of rapid change, in both the residential development sector generally and in community perceptions about the urgent need for action on critical sustainability issues such as water and climate change. The South Australian Government has invested significantly in Lochiel Park with the aim of ensuring that dwellings are affordable and price-competitive, while at the same time demonstrating sustainability potential of green building, particularly in the areas of water and energy conservation. Recognising that cutting edge technology in the early stages of development can be expensive relative to existing technology, and that there is significant demonstration value in building sustainability into Lochiel Park, the South Australian Government has provided a substantial subsidy that is to be passed on to householders to offset the costs of sustainability initiatives.

Initiatives for achieving water and energy savings at Lochiel Park are outlined in a comprehensive Urban Design Guideline document that requires, among other things, achievement of a minimum 7.5 star design using the AccuRate House Energy Rating tool (AccuRate is the second generation version of NatHERS), photovoltaic panels, electricity demand-limiting devices and a triple pipe system for delivering potable, rain and recycled water to Lochiel Park households. LMC has set an overall energy saving target of 66% and a potable water saving target of almost 80% compared with current Adelaide housing stock.

To achieve the ambitious water saving targets, LMC is implementing a broad suite of initiatives including reducing household water demand, installing raintanks to supply hot water and reusing stormwater to supply non-potable water for a number of household end uses. The overall approach to water management in Lochiel Park is to use fit for purpose water, supplying water of a sufficient quality for different end uses.

The 66% energy saving target will be achieved through increased thermal performance, energy efficient appliances and photovoltaic (PV) systems (Blaess et al. 2006). Dwelling designs submitted by LMC building contractors are required to meet a set of specifications that are described in the UDG and quantified through star ratings and targets embedded in a sustainability rating tool designed specifically for the Lochiel Park development. The Lochiel Park energy initiatives intend to push boundaries well beyond the minimum standards required in regulation. For example, the mandated 7.5 star AccuRate rating for dwellings, is significantly higher than the current South Australian 5 star rating requirement.

Based on the outcomes of an earlier scoping study undertaken by ISF and discussions with LMC, it was agreed that the analysis of costs and benefits would focus on the operational phase of a prioritised list of water and energy initiatives. Ideally, an assessment of costs and benefits would consider the full life cycle of sustainability initiatives from pre-production through to disposal. In this instance, the operational phase was selected for analysis due to scope and data limitations. It should be noted that impacts associated with manufacturing and disposal, for example embodied energy, were therefore excluded from the analysis.

Initiatives selected were those that would best demonstrate the value of investment in sustainability at Lochiel Park, and for which sufficient data was likely to be available to provide a realistic assessment of cost and benefits. The initiatives included in the study were:

- Household water demand management including the installation of efficient fixtures and appliances
- Raintanks to be installed for each Lochiel Park house and plumbed to supply hot water
- Stormwater reuse system supplying non-potable water for irrigation, toilet flushing and clothes washing
- Whole of house energy demand management measures including dwelling design and appliance efficiency
- 7.5 star AccuRate rating dwelling design compared to 5 star dwelling design (incorporating a common air conditioning appliance efficiency in both the base case and Lochiel Park)
- 7.5 star AccuRate rating dwelling design plus 6 star efficiency rating air conditioning appliances compared to 5 star dwelling design plus 5 star efficiency rating air conditioning
- Residential photovoltaic systems

3. Cost Benefit Analysis and Sustainable Urban Development

Cost-benefit analysis (CBA) is an analytical tool widely used to assist decision-makers to prioritise investment of public resources between different projects, programmes, policies or activities. It is based on the theoretical premise that if benefits are defined as impacts that increase human wellbeing and costs are those impacts that reduce wellbeing, then aggregating costs and benefits to all individuals will determine whether there is an overall gain or loss in wellbeing to society. This "social net benefit" test, used by governments to determine whether an option qualifies for investment of public money, is also predicated on the idea that even if some individuals may be worse off as a result of a project or policy, in theory the winners' gains could be redistributed to the losers in a way which benefits all individuals – a principle not without its critics (see e.g. Arrow, 1951; Gowdy, 2004).

The Lochiel Park green village residential development represents a new and exciting avenue for governments to invest in promoting sustainable outcomes. However, the application of cost-benefit analysis (CBA) in the area of public investment in privately-owned and constructed residential building developments is less established than other areas of public investment in services or sustainability outcomes. Particular concerns about the application of the "social net benefit" test implicit in CBA for initiatives such as Lochiel Park reflect the limitations of CBA more generally (Pearce et. al. 2006):

- A dollar does not have the same value to all individuals.
- The distribution of impacts is no less relevant than the aggregate net impact.
- CBA results can be biased by omission of key costs or benefits e.g. environmental and other externalities.
- There are challenges associated with the measurement of costs and benefits, mechanisms for taking into account uncertainty and methods for reflecting individual preferences and values.

4. A Stakeholder Approach to Valuing Lochiel Park

In light of the limitations inherent in applying traditional CBA to sustainable urban development, ISF and LMC developed an alternative approach to measuring the costs and benefits of Lochiel Park sustainability initiatives. The approach was informed by the principles and tools of cost-benefit analysis, adapted to make best use of available data and to enable meaningful communication of the value of the water and energy saving efforts.

One of the principles informing the ISF/LMC approach was the importance of considering the multiple cost perspectives inherent in a development such as Lochiel Park, where private and public agencies as well as residents and wider society have a stake in the investment and its returns.

An initial step in developing an approach to valuing sustainability at Lochiel Park was therefore to undertake a stakeholder analysis, identifying the various cost/benefit perspectives relevant to investment in sustainability. There are two ways in which Lochiel Park stakeholders are affected by housing development – firstly, through market exchanges (goods and services, in exchange for money) and, secondly, non-market impacts (externalities that affect stakeholders, but are not monetised or traded in markets). The stakeholder analysis, shows market exchanges and changes to the traditional distribution of money, goods, services and externalities between the various actors and organisations involved in urban development (Figure 1).

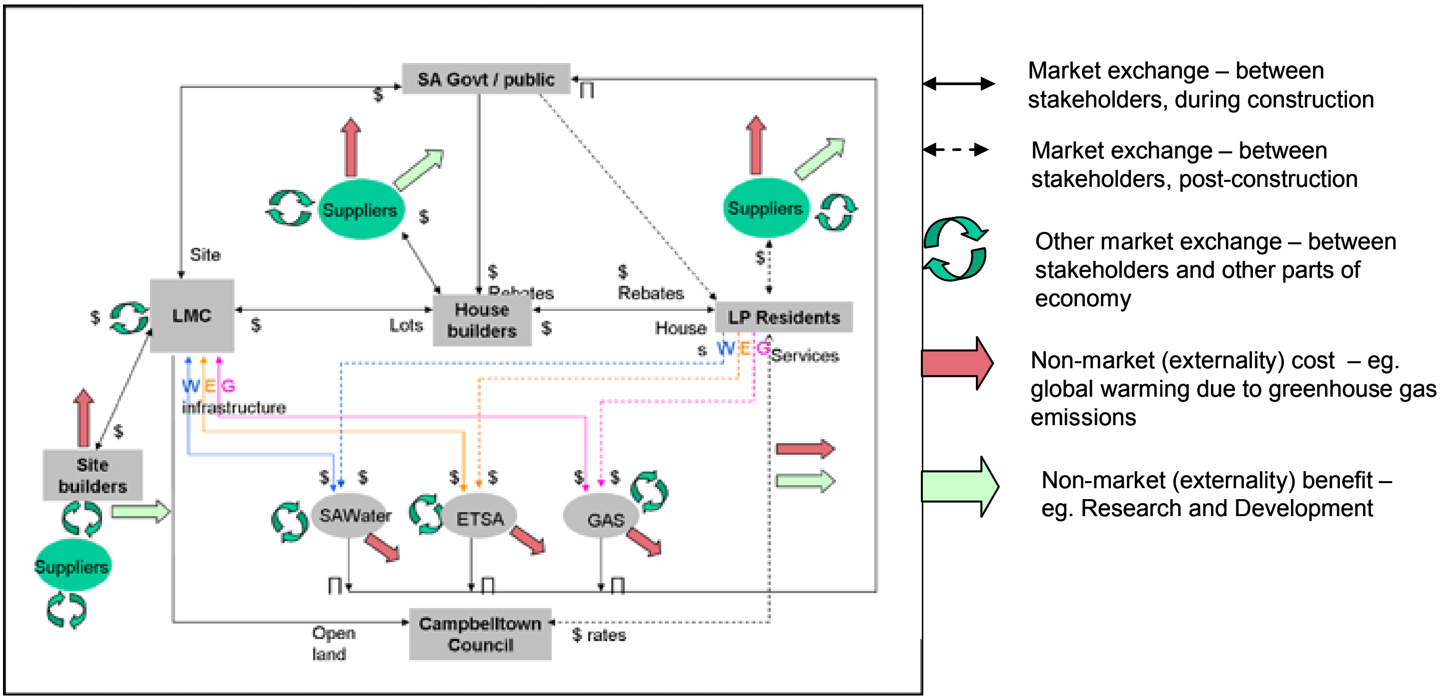

Figure 1 Stakeholder mapping of the distribution of costs and benefits related to Lochiel Park

5. Indicators of Lochiel Park Value

Drawing on the stakeholder mapping exercise, and in discussions with LMC and other organisations involved in the design and/or construction of Lochiel Park, categories for assessment of the benefits of Lochiel Park sustainability initiatives were identified. Categories of indicators selected were those considered to best reflect the range of impacts of sustainability initiatives across the operational life-cycle phase. They were also selected for their capacity to enable consideration of the spectrum of values associated with sustainability initiatives - both monetised and non-monetised. The categories of indicators are:

Resources saved - delivery of services with fewer resources is one of the most effective ways to improve sustainability and a reduction in resource (water and energy) consumption therefore represents a benefit for Lochiel Park residents and for the wider community.

Reduction in household bills - reduced resource consumption results in reduced household spending on water and energy bills and delivers direct financial benefits for Lochiel Park residents.

Greenhouse gas emission reductions - anthropogenic climate change, attributed to increased concentrations of greenhouse gases in the earth's atmosphere arising from human activities, has been identified as one of the greatest challenges faced by humankind. Scientific consensus, as demonstrated through the Intergovernmental Panel on Climate Change, is that there is an urgent need to dramatically reduce greenhouse gas emissions. There is therefore a societal (and global) benefit from initiatives that reduce consumption of fossil fuel-based energy, and thereby greenhouse emissions, in a residential development.

Value for money - an important indicator for assessing the relative costs and benefits associated with sustainability initiatives is value for money or the return on investment in Lochiel Park sustainability initiatives. Value for money is significant for residents (both Lochiel Park and elsewhere) when determining how to invest in sustainable living and also for guiding decision making about public policies, programs and investments for sustainability.

Ecosystem and community services - in addition to quantifiable benefits relating to resource and bill savings, Lochiel Park sustainability initiatives will contribute to the improvement of ecosystem services such as stormwater filtration and increased/improved habitat for birds and other wildlife and also the provision of community amenities such as open public space.

Cultural change towards sustainable living - there are indirect benefits associated with green development in terms of its contribution to a wider societal shift towards sustainability. The cultural and practical considerations associated with sustainable housing and sustainable living are widely promoted through high profile green development initiatives.

These six indicator categories convey the spectrum of ways in which Lochiel Park sustainability initiatives could add value from the perspective of different stakeholders. These were considered with reference to costs, using actual cost data provided by LMC. Where actual cost data was unavailable, best estimates were used based on information from industry sources about costs associated with various fixtures, appliances and design features.

Values relating to resources saved, bill savings, GHG reductions and value for money were assessed with reference to a set of quantitative indicators, as outlined in Table 1. Values associated with ecosystem and community services and cultural change towards sustainable living were assessed qualitatively through a stakeholder survey.

Table 1 Quantitative indicators for measuring the value of sustainability initiatives at Lochiel Park

Resources saved	Resource savings in kL or kWh for an individual Lochiel Park household and for the whole of Lochiel Park (106 households plus water used for park irrigation).
Reduction in household bills	Bill savings as a result of energy or water saved over a 10 year period from the perspective of an individual Lochiel Park household.
Greenhouse gas emission reductions	Avoided greenhouse gas emissions due to Lochiel Park energy initiatives calculated by applying a greenhouse gas conversion factor (in CO_2 equivalents) to the energy savings and an "avoided social damage cost" value to the avoided greenhouse gas emissions.
Value for money	Net present value of each sustainability initiative reported on a per-household basis based on capital costs and discounted operating costs and bill savings associated with the selected initiatives. Cost per unit of resource saved expressed as $/kL or $/kWh saved over a 10 year period.

Modelling exercises, which estimate future energy and water savings and their value necessarily, make a number of assumptions about the future. For example, although site construction had commenced at the time of the study, not all key parameters were yet known with certainty. Modelling also includes assumptions about the choices of future residents, such as technology, and the efficiency of designs, appliances and fittings. Most significantly, all modelling explicitly or implicitly includes assumptions about the behaviour of future residents.

Finding appropriate data, and in particular baseline data against which to compare sustainability costs and benefits was a constant challenge during the study. To resolve data issues and to ensure that the final outcomes of the study were accepted by all participants, a collaborative approach was taken to developing the study parameters and establishing inputs. A two day workshop was held with LMC, Lochiel Park builders and water and energy consultants and ISF worked closely with LMC in all aspects of study design and data collection. This approach meant that LMC was engaged in the process and had a clear understanding of the outputs, outcomes and limitations of the study. The process emphasised the importance of understanding non-financial impacts that are difficult to assess, as well as the monetised costs and benefits of the assessed initiatives. In both respects, the study was different to more traditional cost-benefit or cost-effectiveness analysis.

6. Findings and lessons

The primary conclusion of the study was that LMC and the South Australian government are making an important contribution to change towards sustainable living through investment in the Lochiel Park development. Quantified costs and benefits differed for each of the initiatives considered in the analysis, and some presented a more positive picture than others, as would be expected when dealing with a rapidly evolving field in technological, social and economic terms. The qualitative analysis complemented quantitative indicators of value, suggesting that the long-term impacts of the cultural change potential of the development in the building industry and the wider South Australian community are important. This section outlines some of the findings of the analysis of water and energy saving initiatives and describes results of the stakeholder survey as a means to identify some of the less tangible benefits and costs associated with Lochiel Park.

6.1 Water initiatives

As a result of investment in innovative water infrastructure and improvements in household water use efficiency, Lochiel Park households will use on average 75% less mains potable water than an average Adelaide household. This is an impressive saving, largely due to using recycled stormwater for non-potable needs including clothes washing, toilets and irrigation. Bill savings for residents are also significant, with Lochiel Park residents saving approximately 40% on water bills over 10 years. The most notable bill savings result from household demand management initiatives including the mandating of 4 star WELS rated toilets and 3 star washing machines and showers.

Analysis of bill savings associated with water initiatives in the study was undertaken using a 10 year price path with water prices increasing in real terms by 3% per annum (as advised by SA Water). More recently, with the announcement that a desalination plant will form part of the water supply system for Adelaide, it seems likely that water prices will rise at a much faster rate – a planned price increase of 42% in one year has been reported (Faulkner, 2007). If this increase occurs, bill savings resulting from Lochiel Park water initiatives would almost certainly be higher than those reported in this study.

The cost effectiveness of Lochiel Park water initiatives differs considerably as shown in Figure 2. Household demand management is by far the best value for money, with a cost per kL of water saved of $0.15 over a 10 year period. Raintanks are relatively expensive at around $18/kL. The cost of the stormwater reuse system is about $6/kL including the significant portion of water which will be used for park irrigation and comparable to raintanks at $19/kL when irrigation water is excluded. The analysis shows that investing in household efficiency is a cheap and effective measure for improving water sustainability, while raintank installation and stormwater recycling are relatively expensive resource saving options. However, the magnitude of total water savings in Lochiel Park would not be possible from efficiency alone. To achieve the percentage reduction in household water use the stormwater reuse system is particularly important. There are also additional benefits resulting from the stormwater system in that the constructed wetlands will provide a stormwater treatment service for two sub-catchments, thereby improving the quality of water discharged into the Torrens. Similarly, it is important to acknowledge that there would be additional costs associated with water initiatives such as energy use, which were beyond the scope of consideration for this study.

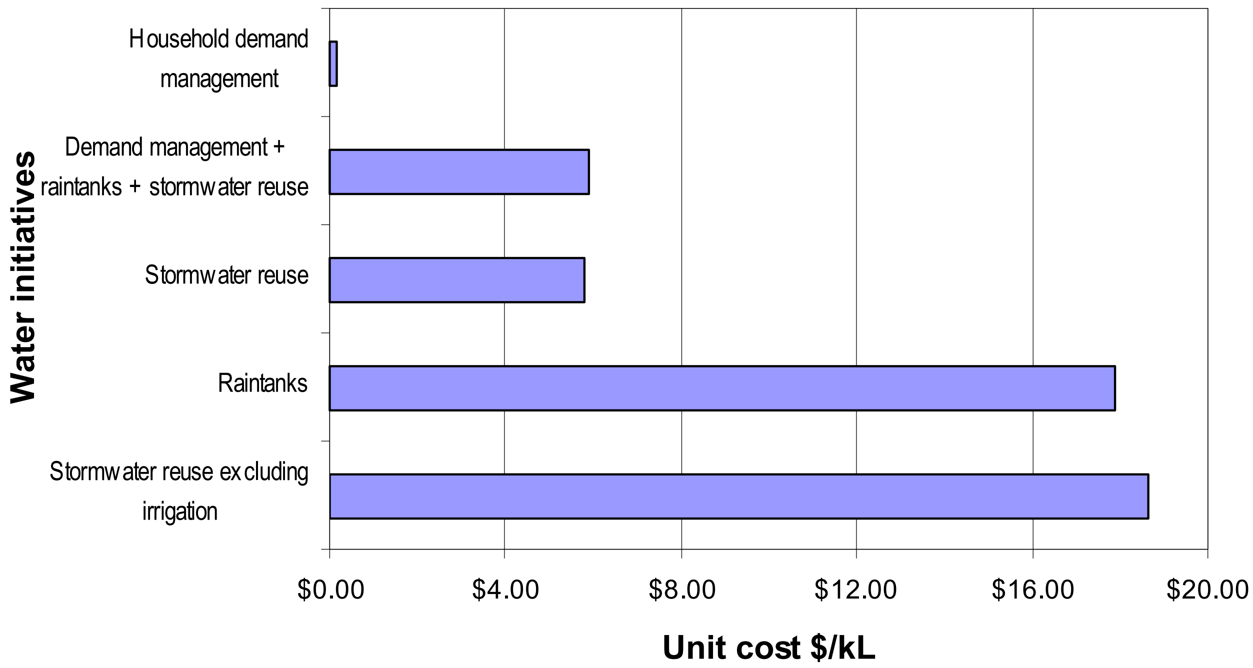

Figure 2 Relative cost effectiveness of Lochiel Park water initiatives

6.2 Energy initiatives

The study indicated that measures implemented to achieve very high energy efficiency in Lochiel Park dwellings are expensive – the marginal net cost to a resident elsewhere of moving from a 5 star to a 7.5 star rating is close to $18,000 over 10 years. There may be more cost-effective ways to achieve the same dwelling efficiency outcomes, however the ability of builders to achieve the rating cost-effectively is highly impacted by client preferences. For example, client preference for large windows leads to a requirement for expensive shading to achieve the necessary efficiency.

Figure 3 shows the results of comparison of unit cost (present value of upfront costs and operational costs, per kWh saved over 10 years and 25 years for PV systems) of PV systems, additional 2.5 star dwelling design efficiency to achieve 7.5 star, and the same design efficiency plus 6 star air conditioning.

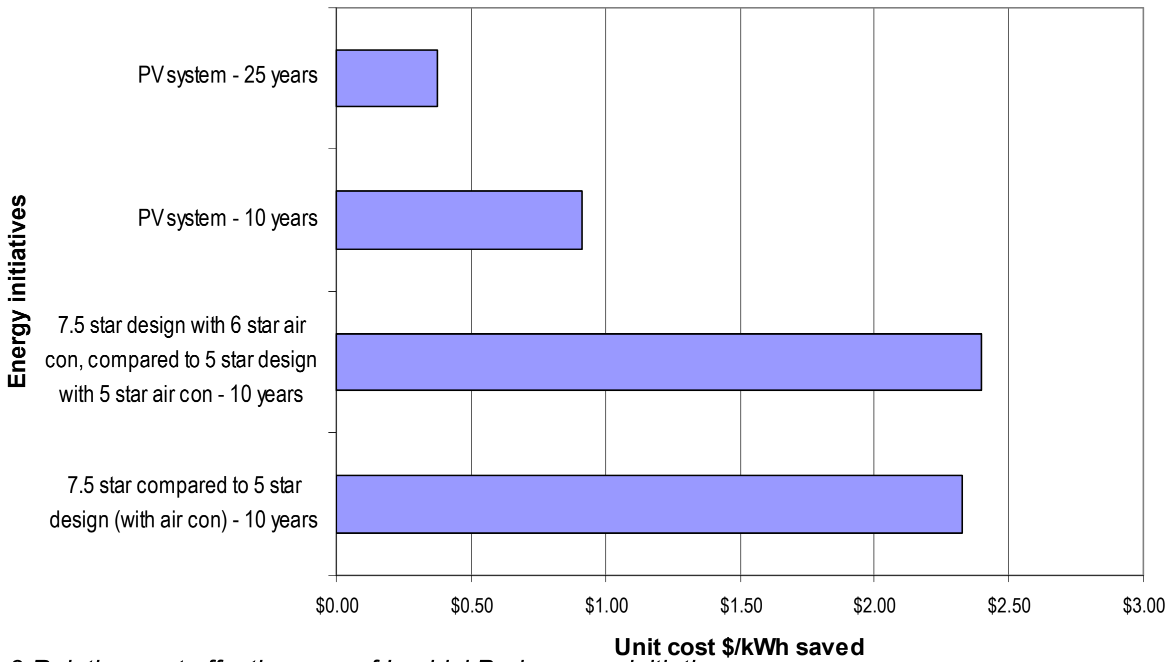

Figure 3 Relative cost effectiveness of Lochiel Park energy initiatives

Overall in this analysis, PV systems appear to be the most cost-effective option with a unit cost of $0.90 over 10 years, compared to $2.30 over 10 years for a 2.5 star increase in dwelling design efficiency from 5 to 7.5 star. PV cells are compared in this study to top-end efficiency measures i.e. the difference between 5 and 7.5 star dwelling efficiency. It is highly likely that more basic efficiency measures, for example dwelling orientation, could contribute to a 5 star dwelling with marginal upfront costs close to zero. These basic measures would be highly cost effective compared to PV systems. The substantial rebates available for PV systems also improve their cost effectiveness from a resident perspective compared to high-end dwelling design efficiency in this analysis.

The absolute marginal resource (and financial) savings of the shift from 5 to 7.5 star rating are small compared to the absolute energy supply from PV cells – 8,000 kWh per household over 10 years saved through the additional 2.5 star dwelling design efficiency, compared to 22,000 kWh of electricity supplied by PV cells over 10 years. There may therefore be an 'efficiency threshold' beyond which further investment in efficiency is less cost-effective than alternatives to achieve a given level of reduction in fossil fuel-based energy consumption. It should be noted that PV systems currently incorporate significant embodied energy and this should be factored into a full comparative life-cycle analysis of alternative energy supply/demand management options.

A further factor affecting the cost effectiveness of all options is the low retail price of electricity and gas – around 18c per kWh for electricity and 1c per MJ for gas. This means that even where resource savings (for example from PV cells) are higher, the financial benefits to residents in terms of household bill savings are not great. Analysis of the impact of a potential feed-in tariff of 44c per kWh for export of PV electricity generation to the electricity grid shows that increasing the financial return (savings) to residents for electricity export increases the private return on investment to residents. The broader implication of this finding is that increases in retail energy tariffs brought about through, for example carbon pricing, are likely to improve the cost effectiveness of the options considered in this analysis. Carbon pricing effectively begins to factor into tariffs externalities associated with greenhouse gas emissions that are currently and have previously not been taken into account.

The study quantified the likely greenhouse gas emissions reductions and associated avoided social damage costs from Lochiel Park energy initiatives. The predicted greenhouse emissions reductions associated with Lochiel Park energy initiatives, in the order of 40-50% per household from energy demand management measures, demonstrate the potential for substantial absolute reductions if the initiatives were scaled up to larger developments. Social damage costs of carbon are an indicator of externalities that are currently not factored into energy tariffs. Using a social damage cost of carbon from the Stern Review of the Economic Costs of Climate Change (Stern 2006), the study quantified likely damage costs avoided as a result of Lochiel Park energy initiatives. The avoided damage costs from all houses collectively through dwelling design and PV systems could be as much as $35,000 per annum. This demonstrates that Lochiel Park energy initiatives may result in important societal benefits that go beyond the level of residential bill savings.

6.3 Qualitative analysis – costs and benefits to stakeholders

A stakeholder workshop and survey was used to assess perceptions of costs and benefits associated with involvement in Lochiel Park design/construction with a view to capturing some of the less tangible outcomes of Lochiel Park, for example benefits related to research and development. Results indicated that a perceived value of Lochiel Park was the opportunity to test cutting-edge technologies, in order to provide valuable information that will enhance the future potential for builders at other developments or applications.

Discussions and surveys of builders' organisations revealed a perception that involvement in Lochiel Park had led to substantial benefits in terms of learning about sustainable new products, technologies and building methodologies, new market opportunities for individual companies, and the opportunity to "lead" the sector as a whole. Builders also identified that they believed that the wider community would benefit by the demonstration of cost-effective sustainability initiatives. However, as supported by the evidence from the quantitative analysis, one respondent noted that the overall demonstration effect of Lochiel Park might be dampened, because the relative incremental cost of building a 7.5 star house over a 6 star house might be disproportionately high compared to the energy savings achieved.

Although surveys of residents and the community was beyond the scope of this study, some stakeholders noted that they expected general benefits for the wider community, in terms of sustainability outcomes of future developments. The visibility of the Lochiel Park development, promotion of the sustainability benefits during the remainder of construction and beyond to broader South Australian and Australian communities has the potential to encourage wide-ranging behaviour and attitudinal change towards sustainable living.

Some sustainability initiatives excluded from this study are likely to contribute significantly to the sustainability value of Lochiel Park. For example, wetlands, a key feature of the stormwater management system, combined with an urban forest, could add significantly to the amenity value not only for residents of Lochiel Park but also potentially for the local community. There is potential for this benefit of Lochiel Park to the local community to be explored through further qualitative research, for example in exploring links between green space and health.

7. Conclusion

Lochiel Park is being developed to demonstrate significant reductions in energy and water use to become a nation leading green village. It has raised the bar. There are a number of lessons from the Lochiel Park study that can inform investment in future sustainable urban development. An important finding is that analysis of costs and benefits that accounts for multiple cost perspectives and addresses both monetised and non-monetised values offers a valuable method by which to assess investment in sustainable building. It enables comparison of various options for achieving sustainability outcomes and ensures that costs and benefits and their distribution are made explicit.

Analysis of costs and benefits of various sustainability initiatives should ideally be considered during the design phase of development to enable comparison of options and to ensure the most context-appropriate initiatives are selected. This would be best done with reference to a sustainable building framework that identifies principles and desired outcomes for green building on a case by case basis, to facilitate transparent decision making informed by consideration of the multiple relevant perspectives on costs and benefits.

The ISF/LMC approach to assessing costs and benefits of Lochiel Park represents an alternative means for determining the value of green development based on sustainability indicators, comparative assessment of initiatives and stakeholder analysis. The approach builds on conventional cost-benefit methodologies by enabling consideration of different stakeholder perspectives and incorporation of some of the less tangible benefits and costs associated with sustainable urban development.

In the case of Lochiel Park green village, the assessment of costs and benefits associated with water and energy saving initiatives indicated that LMC and the South Australian government are making an important contribution to urban sustainability. Quantified costs and benefits differ for each initiative considered in the analysis, and as expected some present a more positive picture than others, however it is clear that LMC is achieving substantial resource savings for the South Australian community by investing in water and energy saving initiatives. With expected increase in water and energy prices in the shadow of carbon emission trading scheme the benefits of the initiatives are likely to increase in value for residents and society as a whole The less tangible values of Lochiel Park – including its provision of ecosystem services and contribution to mainstreaming sustainability in the urban development sector – are difficult to capture comprehensively, but the study suggested that there are long-term benefits associated with cultural change in the building industry and the wider community that will be realised when the development is completed and the community has developed.

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A SERIES OF DESIGN METHOD AND MEASUREMENT RESULTS OF OFFICE BUILDINGS UTILIZING NATURAL VENTILATION IN CENTRAL TOKYO

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Keywords: Natural Ventilation, Night purge, sustainable building, Energy saving

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Abstract

In recent 10 years in Tokyo Japan, the idea of HVAC design for office in Tokyo has drastically changed: from the previous idea of actively air-conditioning super-insulated space, to energy saving air-conditioning using natural ventilation during relatively cool seasons. Detailed planning such as site location, expected wind characteristics around the building, shape of the building and its air inlets/outlets positions, are needed for designing l ventilation for every single building.

This paper reports four office buildings introducing natural ventilation with their design method and observation results of indoor environment and energy consumption. The design methods vary wide in range: under floor air-conditioning in combination with natural ventilation, hybrid air-conditioning system using natural ventilation and air-conditioning machine simultaneously, and natural ventilation applied to super high-rise building.

From the results we have obtained, there was considerable variation of air change rate from 1 to 6 times/hour depending on difference in size of opening for ventilation or effectiveness of ventilator. In addition, it was determined that by using hybrid air conditioning system using natural ventilation and air-conditioning machine simultaneously, for air-conditioning load that were not eliminated only by natural ventilation, to effectively lengthen natural ventilation operation of air-conditioner. As for natural ventilation for super high-rise building, utilizing wind around the building will take in enough air volume by natural ventilation into the building.

1. Outdoor Condition of Tokyo and Possibility of Natural Ventilation

Considering heating in winter, and cooling in other seasons for HVAC system in an office building in Tokyo was common until late 1980. However, due to improvement of thermal insulation and increment of internal heat inside the building, cooling throughout the year became general after 1990. These transition of design condition caused building with super-insulation and fixed window to change into building with openings for ventilation, natural ventilation and night purge in early 1990.

Outside air temperature through the year in Tokyo is shown as figure 1, absolute humidity condition through the year in Tokyo is shown as figure 2. Natural ventilation is effective during seasons except between July to end of September which outside air temperature is higher than 25• •and absolute humidity is higher than dew point of 19• ÐB. Since air-conditioning in the office has changed to cooling for most of the year in recent years, natural ventilation is also effective even during winter seasons to maintain inside thermal environment sound by using outside air.

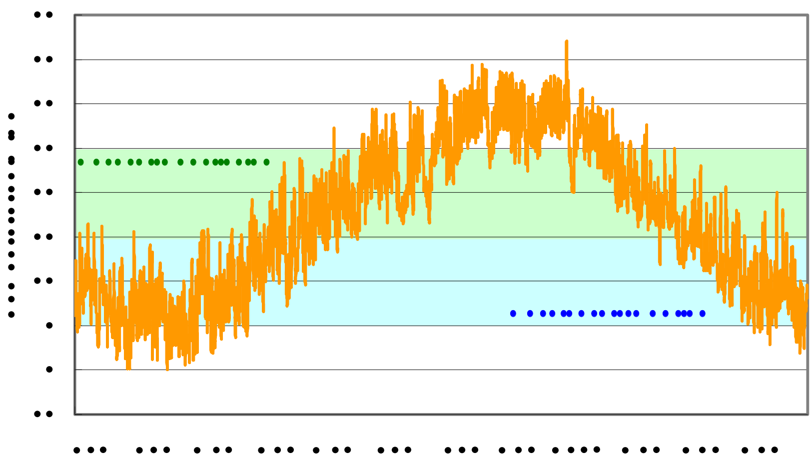

Figure 1 Outside air Temperature, Tokyo 2000.

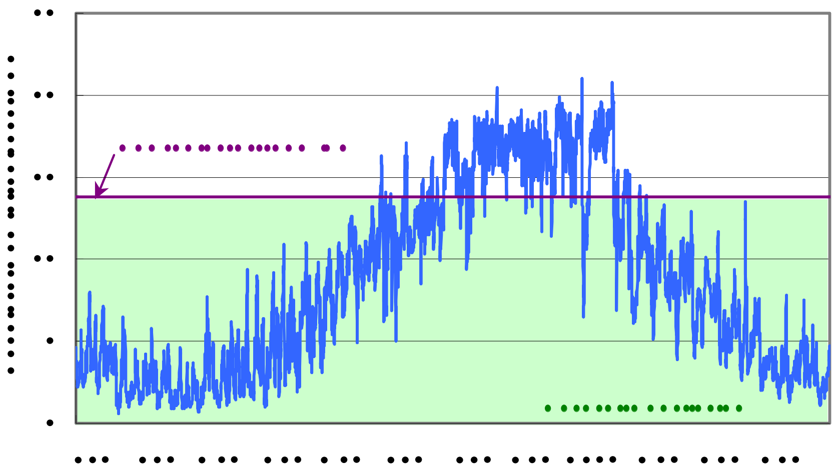

Figure 2 Outside air Absolute humidity, Tokyo 2000.

Outside air temperature-annual rate during air-conditioning hours of 8:00 to 20:00 is shown as figure 3. It shows that natural ventilation is effective during 3/4 of daily hours in a year.

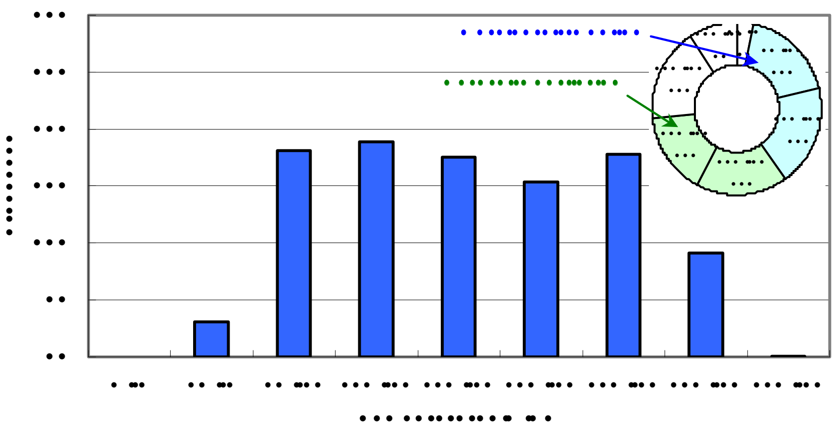

Figure 3 Outside air Temperature-Annual rate, Tokyo 2000

2. Outline of a Building Introducing Natural Ventilation

Outlines of four buildings, which introduced natural ventilation, and methods of natural ventilation are shown in table 1, control point setting is shown in table 2, and comparison of energy saving effect by natural ventilation is shown in table 3. These four office buildings are all built in central Tokyo.

Size of one floor area of building with natural ventilation varies from 476m^2 to 1080m^2. Only building D is high-rise building, with the rest be considered as medium sized building. Building A and B has natural ventilation at the intermediate story, adopting gravity ventilation using temperature difference. Building C adopts combination of gravity ventilation and prevailing wind for natural ventilation since it has floor area of 3,250m^2, which is quite large. High-rise building D is utilizing pressure difference of wind pressure to take natural ventilation horizontally. Opening ratio of natural ventilation (total areas of openings for natural supply and exhaust air per floor divided by area subject to natural ventilation) for all building is listed at last row. Building A shows 99cm^2/m^2 which is quite large while building C and D shows 55cm^2/m^2 and 27cm^2/m^2 which seem quite limited.

Table 1 Building summary and method of Natural ventilation

		A	B	C	D
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Total Area	m2	16,567	5,357	29,747	35,015
Total Floor	F	10	9	7	21
[illegible]	F	3-7	2-5	2-7	5-20
Building height	m	39.6	39.8	31.0	112.8
[illegible]	m2/FL	640	476	3,250	1,080
[illegible]	m3/FL	1,728	1,499	9,750	3,240
[illegible]	cm2/FL	99.4	60.5	54.7	26.6

The feature of building A lies on combination of under floor air-conditioning and natural ventilation/night purge. Just like figure 4 shows, outside air is taken inside from external wall into OA floor directly, then delivered to office by fan. The outside air is heated inside and then extracted through vertical shaft by chimney effect.

Building B has concert hall just above the office introducing natural ventilation. Therefore by making vertical shaft taller to create neutral plane at higher location enhancing effectiveness of gravity ventilation.

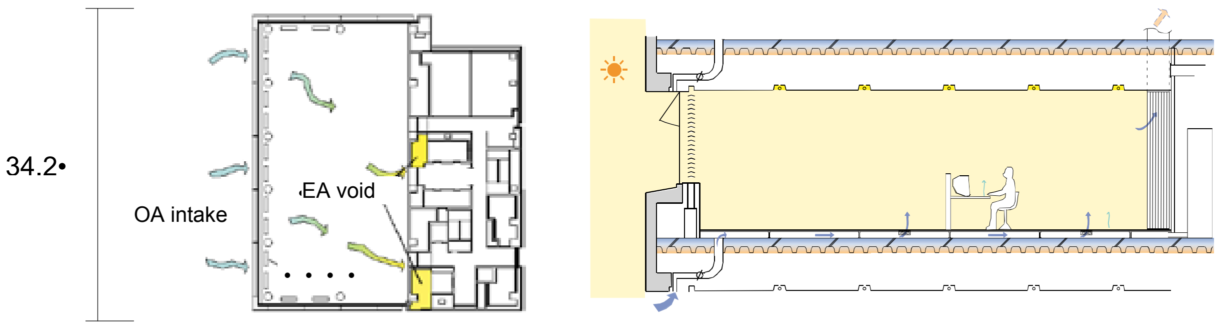

Figure 3 Plan and section of A building

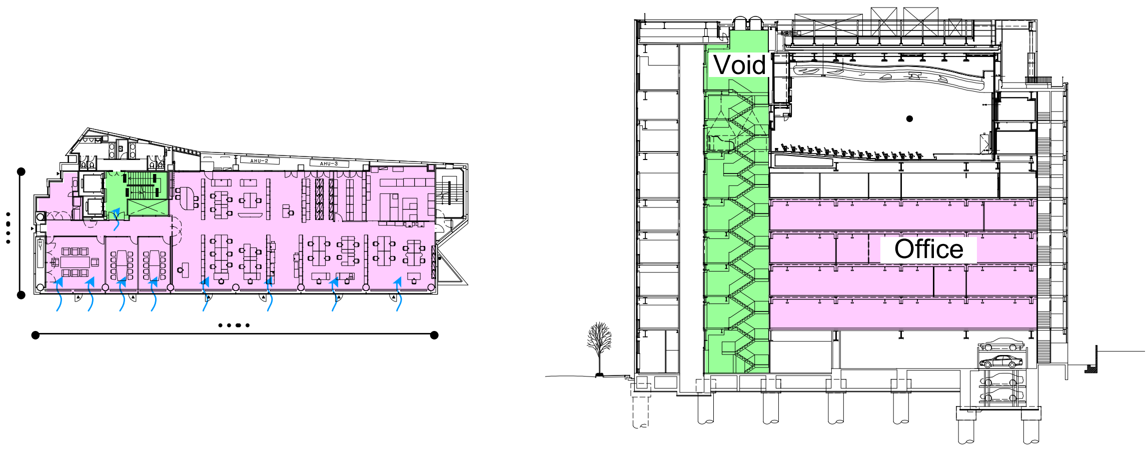

Figure 4 Plan and section of B building

Since building C has large floor area, in addition to natural ventilation introduced at perimeter of the building, allocating a light court at the center of the building for airflow to make vertical route for natural ventilation. Utilizing pressure difference caused by prevailing wind from the sea above natural exhaust also enhances effectiveness of natural ventilation.

Building D is a high-rise building located just by Tokyo bay, prevailing wind is purposely taken inside through the building on horizontal plane. As a countermeasure for pressure caused by the wind, outside air intake ducts are bent several times to absorb the pressure.

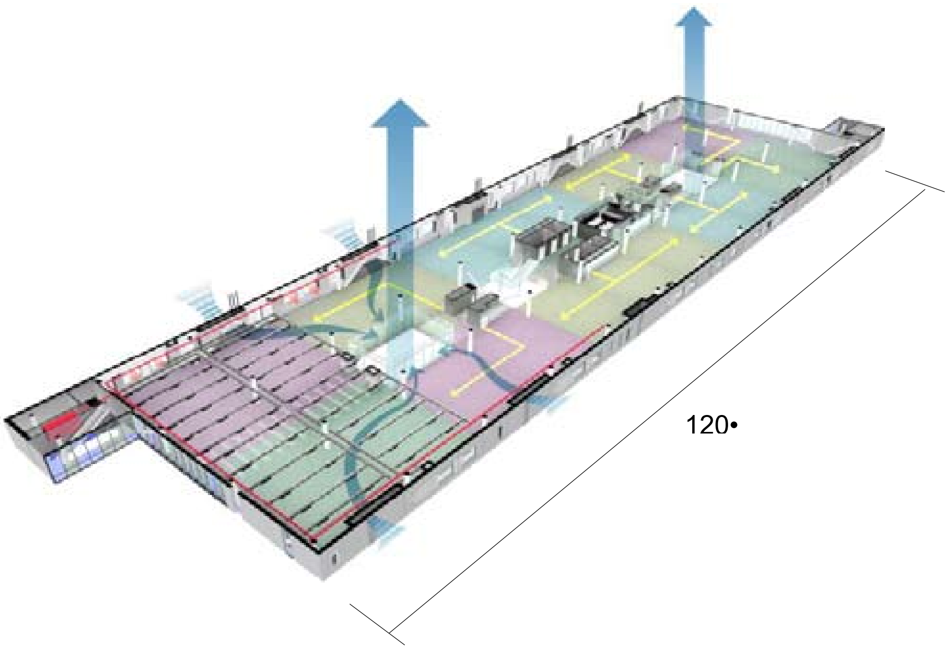

Figure 5 Plan of C building

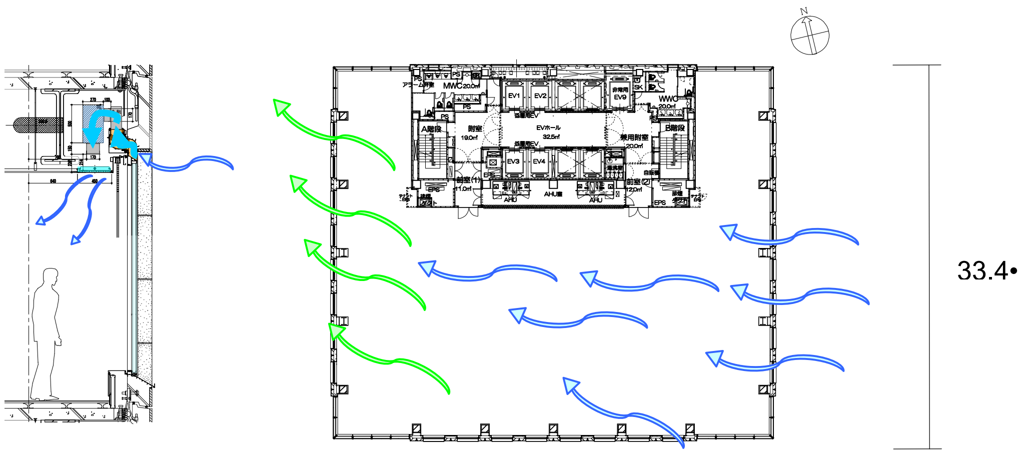

Figure 6 Plan and detail section of D building

3. Controlling Condition and Effectiveness of Natural Ventilation

Conditions for automatic control for natural ventilation is shown as table 2. Building fulfilled conditions determined at table 2 automatically opens natural ventilation damper to start natural ventilation. Since building A and B utilize gravity ventilation, they starts natural ventilation when outside air temperature is 2• • lower than inside air temperature, and when outside air temperature is lower than 15• •they switches from natural ventilation to outside Air-conditioning. Building C and D conducts ventilation by wind pressure, so they starts natural ventilation when outside air temperature is lower than inside air temperature, and like building A and B they switches from natural ventilation to outside Air-conditioning when outside air temperature is under 15• :

Table 2 conditions for Natural ventilation

		A	B	C	D
Outside air temperature for NV	• DB	15<To<Tr-3.5	15<To<23	15<To<Tr	15<To<Tr
Outside air temperature for Night Purge (NP)	• DB	15<To<Tr-2.0	15<To<23	15<To<Tr	15<To<Tr
Outside air temperature for Outside air cooling	• DB	5<To	5<To	11<To<15	10<To
Other Condition		Outside air Velocity<10m/s, No rain			Outside air Velocity <15m/s, No rain

Observation results of natural ventilation are shown as table 3. Air change rate is about 3• 4 times/h when outside air temperature is 18• 19• •for building A and B. Room temperature during natural ventilation is about the same as settings of air-conditioning system of comfortable temperature of 24• 25• • Annual thermal load handled by natural ventilation and night purge for Building A and B are about 60MJ/Am^2• year and 43MJ/Am^2• year. Air change rate of building C is about 1time/h, which is induced from its small opening area for natural ventilation compared to other buildings. Also since it is low-rise building, effectiveness of gravity ventilation is no much to building A and B. However, by operating air-conditioner as supplemental role during natural ventilation (hybrid air-conditioning), thermal environment is maintained at comfortable state. Building D shows good performance of natural ventilation utilizing wind pressure archiving air change rate of about 1• 6 times/h.

Though there are some difference in amount of internal heat generation and ventilation volume, the observed result showed that room temperature during natural ventilation is about the same as air-conditioned temperature of 22• 27.5• CD. Building A had highest value for cooling load handled by yearly natural ventilation of 60MJ/m2• year with large opening area for ventilation with more air change rate. Following building A is building B and C with also fairly large opening area for ventilation. Building A also has thermal storage effect to structure by night purge with a value of 260KJ/m2• day which contributes enhancing effectiveness of natural ventilation and night purge greatly.

Table 3 Measurement result of Natural ventilation

		A	B	C	D
• ••••••• •••••••••••• •••••••• ••	• DB or m/s	17-21	•••••	••••••	• •••••• ••••••• •• ••••• ••
ACR• By• Natural Ventilation)	N/h	2.8-3.3	3.8-4.6	0.5-1.7	1.2-6.0
Measurement Room Air temperature	• DB	25-26	22-24	26-27.5	unknown
• ••••••• •••••••••••• •••••••• ••	• DB	•••••	••	•••	unknown
ACR• By• Night purge)	N/h	2.3-3.0	4.6	2.1	unknown
Energy saving (Treated thermal load By NV, NP)	MJ/Am2year	60	43	7	unknown
••••• •••••••••••••••••••••••	kJ/m2• day	260	••	••	••

4. Conclusion

- • By utilizing prevailing wind or in case of gravity ventilation by elevating neutral plane higher, natural ventilation has potential of having air change rate of 1times/h• 6times/h.
- • Gravity ventilation affects natural ventilation effectiveness with its size of opening for ventilation and neutral plane.
- • Air change rate of wind ventilation differs drastically depending on outside wind condition.
- • To further improve effectiveness of natural ventilation, outside air with 15• DB or lower be taken inside directly into the room, not through air-conditioner, without disturbing temperature distribution.

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• FACTOR4 DWELLING" IN THE NEXT21, EXPERIMENTAL HOUSING OF OSAKA GAS

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Keywords: energy saving, house remodelling, heat insulation, factor4, renewable energy, SOFC

Summary

This paper outlines an experimental project for drastically reducing the environmental impact of home energy consumption whilst assuring a high level of living comfort. The project has been applied to an existing dwelling unit within NEXT21, which is the experimental apartment housing in Osaka, Japan owned and managed by the Osaka Gas Company.

The main approaches for achieving the objective of the project have been,

1) To remodel an existing dwelling unit,

2) To improve thermal insulation and shading,

3) To introduce efficient equipment for energy conversion and consumption,

4) To make possible the use of renewable energies and

5) To change the behaviour of the residents related to energy consumption.

The technical items include photovoltaic power generation, condensing gas boiler, hot water floor heating, home-size solid oxide fuel cell (SOFC) and semi-automatic shading / ventilation control system.

The simulation analysis gives figures, evaluated in terms of primary energy, for the expected effect. Compared to the reference model, the heating and cooling load will be lowered by 45% through architectural improvement. New efficient equipment will produce a further reduction of 15% and solar energy 13% of the original consumption. In total, the energy load may be lowered by 78%, including the efforts of residents to change part of their lifestyle.

1. Introduction

It is claimed that to prevent global warming greenhouse gases need to be reduced in the long term by 75 to 82%[1]. These figures might seem unrealistic in relationship to the pessimistic opinion that Japan could not meet the Kyoto Protocol promise to reduce greenhouse gases (GHG) by 6% in the year 2010 (average between 2008 and 2012, compared to 1990). However, the above-mentioned targets are essential to keep the average rise of atmosphere temperature to within 3.5/2.5 degrees Celsius respectively. Therefore, it is acceptable to consider them as the target for the advanced low- energy dwelling of today.

The majority of GHG is carbon dioxide (CO_2) caused mainly by the consumption of conventional energies, not only fossil fuels but electricity. To find effective solutions in the field of urban housing, an experimental project was launched in June 2005, the target for which has been to reduce the energy-based environmental impact to a quarter of the original amount by remodelling an existing apartment dwelling and comparing it with a basic apartment. This could be realised through reducing energy consumption and wherever possible using sources of locally available renewable energy.

The project has taken place within Osaka Gas Company's experimental housing, "NEXT21", which was built in 1993 for the purpose of experimenting with gas equipment within a highly durable "open building" structure and flexible "infill".

Dwelling no.301 was selected for the project. This dwelling unit was originally designed by architect Naomi Tachibana as a "Garden House", which aimed at living in harmony with the natural environment. It enjoyed plenty of indoor / outdoor greenery, day-lighting and natural ventilation.

Many alternatives were examined from the available techniques. This paper describes the methods to remodel the dwelling to consume less energy as follows: • •

Figure.01 NEXT21 in Osaka

[1] Ministry of Environment Brochure based on IPCC 3rd Report

1) Improving the building envelope to reduce the heating and cooling load.

2) Introducing highly efficient equipment and new systems for energy conversion,

3) Incorporating renewable energy, namely solar energy and

4) Reviewing and changing the occupants' lifestyle in terms of energy consumption.

The estimated effect of these methods was examined through simulation analysis.

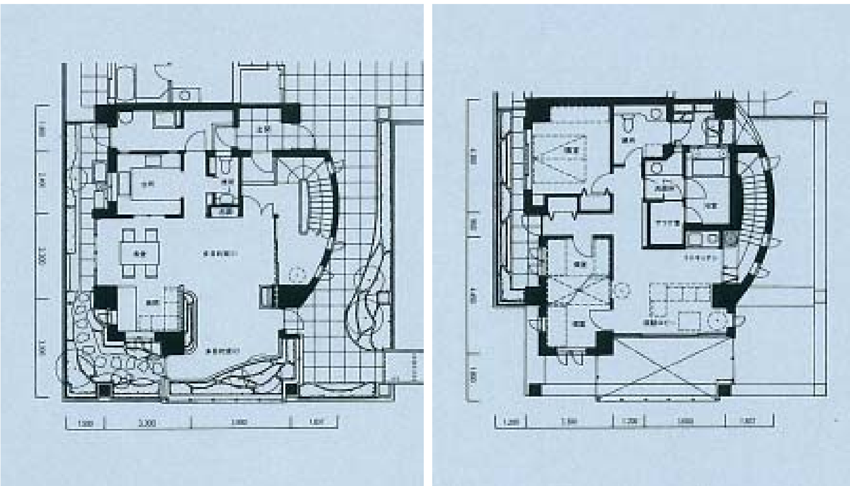
The target of reducing energy to a quarter of the original might appear over-ambitious but the intention of the project was to show people and the company that it was realistic for a household to achieve such an environmental impact. By early 2007 the remodelling work was complete and Unit 301 was given the name "Factor4 Dwelling", after the book "Factor Four, Doubling Wealth - Halving Resource Use" by Ernst von Weizsacker and others.

2. Improvement of Building Envelope

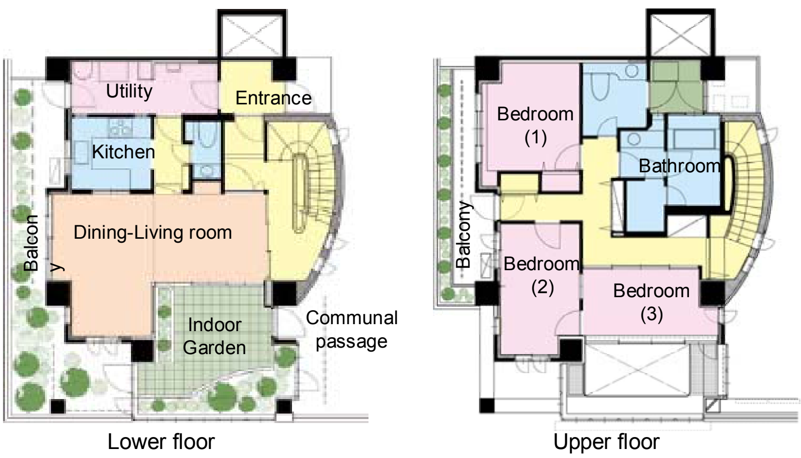
Unit No.301 is a maisonette apartment with external walls and openings on 3 sides, facing east, south and west. Its total floor area is approximately 150 sqm. The improvement of the building envelope has reduced the heating and cooling load. The unit had a relatively high ratio of external wall length to floor area. The total areas of windows were also considerable (Fig.-1). Therefore the heating and cooling load prior to remodelling was similar to that of an average detached house.

The first improvement to be made to the walls and floors was to add thermal insulation in the voids within the walls and the space under the lowest level flooring. In addition the total length of the external wall was reduced by enclosing the set-back porch and a balcony with additional doors / panels, which made these spaces internal. The second improvement was to add internal window sashes to change the glazing from double to triple. Shutters in the form of insulating panels were also provided to put over some small windows during winter. The third method was to reduce the heating load by maximising solar gain from the windows.

The original southern façade was a large area of glass, which created an interior space that had the feel of a conservatory but was effectively part of the living space. In addition the heat loss was greater than the solar gain from the glass so measures were taken to divide the space into separate living room and conservatory. This would prevent heat loss in the winter, and good shading would prevent heat penetration in summer. The actual remodelling method is discussed later. In the intermediate seasons, there would be little difficulty in controlling the indoor climate at the optimal level by closing and opening the windows and shading. The conservatory with internal planting would also be useful for cooling the atmosphere.



Figures.02, 03 Floor plans before renovation



Figures.04, 05 Floor plans after renovation

2.1 Thermal Insulation and Shading

The main objects and methods of insulation to the envelope were:

2.1.1 External walls: There was void between the external panels, backed up with foam polyurethane, and internal panels of gypsum board. It was totally filled with cellulose fibre made from recycled paper. The material was inserted though holes in the gypsum boards, which were finally covered with thin plywood and finished. Fortunately the void width was varied between 140 and 150mm, which enabled a good quantity of cellulose fibre to be inserted. These methods could reduce the heat loss, in terms of U-value, of a typical external wall from 0.62W/m2K to 0.20W/m2K.

2.1.2 Lower level floor: The space under the lower floor of the dwelling is a small auditorium, air-conditioned only occasionally when used. The floor was not insulated except where it was needed to prevent heat-bridging from outside. The former residents had complained about the cold floor. The void between floor slab and the flooring board was therefore filled with 190mm thick cellulose fibre, which was beneficial in terms of thermal insulation and energy saving and also for providing greater comfort.

2.1.3 Windows and doors (except conservatory): The following four methods were applied.

a) Internal sashes, wooden with single glazing, were added to the main windows. The glazing was converted from double to triple in total.

b) The small windows were fitted with insulated shutters to close them off during the winter seasons.

c) The windows in the stair well were fitted with interior Venetian blinds.

d) External Venetian blinds were installed on the western balcony.

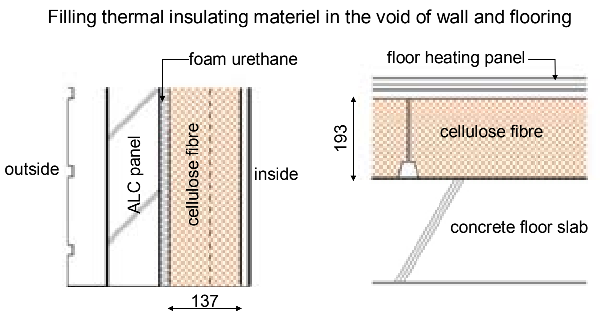


Figure.06 (left) Wall cross-section

Figure.07 (right) Under the floor (lower level) cross-section

2.2 Conservatory (Indoor Garden)

The southern part of the original living room was converted into the conservatory by dividing the space by new sliding doors. The conservatory will serve as the heat collecting space and buffer zone between the living area and the outside. This measure made it possible for the heating and cooling load to be drastically reduced because the conservatory is a semi-external space not part of the air-conditioned zone. The glazing planes separating exterior and interior space were designed so that heat gain, shading, ventilation and closing could be smoothly operated according to the seasons and other situations.

For shading, most of the glazing was covered with external roll-screens, which could be automatically closed and opened according to the strength of sunlight. The special swinging windows for ventilation "Swindows" were introduced for automatically controlling the ventilation. Four were fitted in the top and the bottom parts of the plane (8 sets in total). On sunny winter days, the screens are kept open for taking advantage of solar heat gain. The ceiling fan helps introduce warm air from the conservatory into the living space. The interior sliding doors are closed during the night. During the summer days, on the other hand, the shading screen and sliding doors are both closed and the "Swindows" open or closed dependent upon the indoor / outdoor temperature.

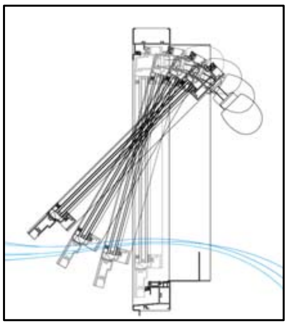


Figure.08 "Swindow" cross-section (product of Sankyo Tateyama Aluminium, Inc.)

The conservatory not only retained the original concept for the apartment to create an indoor green but also enhanced it by creating a secure intermediate space between outside and inside. The depth of conservatory could have been as little as 2m but to make the space a semi-external living area, it has become as large as the remaining living room.

Figure.09 Conservatory

Figure.10 Indoor Garden

The planting zones in the conservatory were filled with light soil and filled with greenery which was anticipated would lower the temperature in summer through water evaporation from soil and plants. The floor finish has been converted from wood to soil-ceramic tile suitable for semi-outdoor living. Eventually the conservatory area was named “Indoor Garden”.

The upper part of the high conservatory was difficult to clean and maintain. A new catwalk has been provided to solve this problem. A ceiling fan has also been installed to carry the warmed air into the lower level living space.

The shading screen can be controlled both by automatic and manual modes. It closes when the solar luminance or wind velocity exceeds a designated level. The “Swindows” can also be operated automatically and manually dependent upon controlling factors such as the combination of indoor and outdoor temperatures and high wind speeds.

2.3 Reducing external wall length

The entrance porch and the upper level service balcony had the shape of a (set back) bay. These were made into internal spaces by adding new doors, which reduced the total length of external wall and created smaller but thermally intermediate spaces. This lowered the heat load whilst the internal floor area increased. As this is effective only in winter, the doors can be left open in other seasons.

Comprising all the measures mentioned above, the Q-value (total heat loss per unit floor area) was to be improved to 2.52W/m2K after remodelling compared to 9.12W/m2K beforehand.

2.4 Greening

As unit no.301 had the name “Garden House”, greening the dwelling was the main design theme. The concept was characterised by interior plants. Besides conserving planting zones in the “Indoor Garden”, the western balconies are intended to have creeping plants for shading in summer using the existing metal trellis. Good maintenance and watering depend on resident participation.

2.5 Additional change in floor plan

2.5.1 Adding a bedroom

The dwelling had only 2 bedrooms although the floor area is more than150m2. The family size had been four throughout the early phases of the project and a regular complaint was that they needed an additional bedroom. This problem has been resolved by converting the upper level lounge into another bedroom. In addition, the kitchenette was abolished and converted into a closet for the newly created bedroom.

2.5.2 Change in staircase

The interior staircase is not within the heating / cooling zone. For preventing the heat transfer from the lower to upper level, however, the gaps between steps, which were intended to allow natural ventilation, have been closed. In this way, the energy saving concept has been given priority over the original design concept.

3. Improvement of Utility and Equipment

High efficiency is one of the most important considerations for saving energy in the home. Therefore the engineers have extra responsibility for equipment that the residents cannot change. The former air-conditioning system was no longer efficient. It has therefore been totally changed from a system serving the whole NEXT21 building to one for an individual dwelling. This has been made possible by the improvement in the quality of heat-pump for individual home use in the last 10 years. In addition, the energy systems have been chosen primarily for their efficiency and not necessarily their saving on the use of city gas.

3.1 Hot water supply and Combined Heat and Power

The solar heating to be installed still required an efficient boiler to cover the amount of heat needed to meet demand. On the other hand, a combined heat and power (CHP) system was to be tested in this experimental dwelling by introducing a developing fuel cell (FC) system. With two systems coexisting in one dwelling, I was possible to run them either separately or simultaneously. The comparison of these could be an interesting theme in terms of use practice and energy efficiency. (Solar heat utilisation will be discussed in the section of renewable energy. As of March 2008, the solar system was not yet installed.)

3.1.1 Condensing Gas Boiler

A condensing gas boiler has the function of absorbing exhaust heat by condensing the vapour into water to gain the latent heat. A latest condensing boiler has been installed. Its heat efficiency is 95% for hot water supply and 85% for floor heating (LHV[2]). This adds extra heat to the amount provided by solar collectors and fuel cell system. A mixing unit has been added to control the highest temperature of incoming hot water.

For the moment, only the hot water tank for fuel cell (FC) has been installed. There will be 2 tanks and the choice between them will be either automatic or manually done by the residents who can watch the temperature of each tank. When the temperature is high enough, they can use hot water directly from a tank instead of taking it through the boiler.

[2] Low Heat Value

3.1.2 Solid Oxide Fuel Cell (SOFC)

Among the developing fuel cell systems, solid oxide fuel cell (SOFC) is the most promising one for apartment houses or small households. The main reasons are the compactness and its high generating efficiency up to 45% (HHV[3]), which is higher than that of ordinary thermal power generation. The rate of usable exhaust heat from SOFC is relatively low up to 30% but it can be used for hot water supply. The dwelling unit No. 301 is one of the testing fields for improvement.

Figure.11 SOFC (Kyocera / Osaka Gas) right

3.2 Space Heating

The former heating/cooling system was a central VAV[4] air-conditioning. Hot water was generated from waste heat from the central CHP system and distributed to each dwelling. The efficiency was not high enough to meet the current target. The newly installed systems therefore include the following:

3.2.1 Floor heating by gas-heated hot water

One of the complaints from the past occupants was about the coldness of the floor at the lowest residential level, below which the space was non-residential and not sufficiently insulated. The heating efficiency of floor heating is lower than that of gas fan-heater and air-conditioning by electric heat pump. As for comfort and healthiness, however, floor heating is an ideal method. The level of comfort is higher because of the radiation from the floor and the direct touch of the feet on a warm surface. The vertical temperature distribution is almost even whilst air conditioning alone could only warm up upper part of the room.

The new system was aimed at lowering energy consumption compared with the existing system. Lower water temperature through larger pipes loses less heat during travel and reduces pumping power. Because of the sub-flooring system, however, there was no choice but to introduce a ready-made floor heating system in the remodelling.

3.2.2 Air conditioning

Air conditioning system for cooling can automatically be applied for space heating. There was no intention to introduce floor heating on the upper level. When the envelope heat loss has become very low, the excess heat at the lower level could warm the upper level. Hence a medium size air conditioning unit (2.8kW) seemed to be sufficient to keep the whole floor warm enough.

3.2.3 Gas cocks for eventual use

A newly installed heating facility does not require gas cocks but there could be a possibility of fault or insufficiency of heat distribution. Gas cocks in each room have been provided just for these cases.

3.3 Space Cooling

The former cooling system was also a central VAV air-conditioning. Cold water was prepared in a heat absorption chiller set in the basement of the building, transferred to dwellings, converted into cold air and finally distributed through duct to each room. The main shortcoming was high electricity consumption for the pump and fan.

However, the efficiency of electric air-conditioning units for home use has been remarkably improved in the last 10 years. Therefore it was decided to change the system from central to individual and adopt the highest performance model in the market. The coefficient of performance COP[5] exceeds 6.

The cooling load could be reduced by a half through the combination of high insulation and effective shading. Then only one system of 2.8kW in each level was estimated sufficient for keeping the room cool in summer.

3.4 Ventilation System

The use of a ventilation system conflicts with aspects of energy saving. For example, when increasing the volume of air ventilated, not only is lost but electricity consumption rises as a result of running the fan. In the remodelled apartment a heat exchanging ventilation system was installed on each level and the air ducts of the former VAV system re-used. In respect of seasonal operation, the compulsory ventilation level stipulated in the Building Standard Law, will be applied flexibly for energy saving. That is to say the mechanical ventilation system in the living space can be cut off during the non-cooling/heating seasons where a number of windows are usually kept open.

3.5 Lighting

[3] High Heat Value
[4] Variable Air Volume: an air-conditioning method manageable under partial load
[5] Coefficient Of Performance

Each light fitting was examined to decide how to improve it. A typical method of reducing electric consumption for lighting is to replace conventional bulbs with bulb-shaped fluorescent lamps, which use only one fifth of electricity to provide equal luminance. In addition, unnecessary lighting should be removed totally or just the bulbs taken out. Where sufficient luminance is achieved, the number of fluorescent lamps can be reduced.

In this way, unnecessary or surplus lamps and fixtures have been changed. The original condition was extravagant and far from the energy-saving concept. There were 49 lighting fixtures in total in the dwelling. The total capacity, according to the design document, reached 3.0kW when all were switched on. However, the length of time the lighting is switched on is unknown so the effect of energy saving is therefore difficult to determine.

3.6 Cooking

Energy saving in cooking could be improved through considering changing ways of daily life. In particular, it has direct effect to minimise the use of electricity for heating food and keeping it warm, because only 40% of the energy consumed in thermal power station reaches home. Although each action is small, there is a considerable room for reducing energy consumption in cooking. This might include the choice of cooking apparatus, developing methods of low energy cooking and other more ingenious cooking methods.

The only change made in the remodelled apartment was to introduce a modern gas cooking table, the heat efficiency of which reaches 56%, compared to 50% of a conventional model.

3.7 Other use of electricity

To stop using “stand-by mode” on equipment is one of the essential methods to reduce domestic electricity consumption. This can be realised with a small amount of investment or conscious efforts by the occupants. In the remodelled apartment, half a dozen electric sockets (taps) with switches have been provided. A small neon lamp indicates the main switch is not cut off and induces the users to cut the electricity from the socket to eliminate stand-by electricity.

4. Solar Energy Utilisation

However hard efforts are made to save energy, it is practically impossible to reduce domestic energy consumption to a quarter of the original amount. It is therefore paramount to take advantage of renewable sources of energy as a means of drastically reducing conventional energy consumption - which is the main cause of global warming. The typical renewable energy for home use is light and heat from solar energy.

4.1 Photovoltaic System

The photovoltaic (PV) system is most promising as a clean and quiet system for renewable power generation applicable to individual houses and low-rise blocks of housing. In the case of “NEXT21”, a PV module of 7.5kW has been set symbolically on the rooftop to generate electricity for use in common areas. One third of the existing PV module (2.5kW) has been switched exclusively to unit 301 for the experiment. A new power conditioner has also been installed.

The surplus electricity, i.e., the electricity that unit 301 does not consume, is transmitted to the electrical grid within the NEXT21 building. The 2.5kW is practically a maximum capacity for five-storey apartment block because the roof area per dwelling is limited to 20m2.

Figure.12 PV module, one third of it serves for the dwelling 301

4.2 Solar Hot Water Supply

If global warming is to be avoided, it is most important to use solar heat to cover a large part of the domestic hot water supply. In Japan, hot water constitutes about one third of the domestic energy consumption. Solar heating is classified into the following categories: 1) natural circulation type, 2) forced circulation type and 3) water storage type. The collector in this instance is a flat type set almost vertically within the concrete framework. The heat is collected in liquid medium then transferred to and stored in the hot water tank through heat exchanger.

5. Pre-evaluations

The effects of the various measures are evaluated through simulation both in terms of energy saving and gaining renewable energy. The first step is to establish the basic model against which the findings of the study will be compared. Standard energy use is calculated according to the energy use categories, which is based on standard data already available and actual data from the previous occupation.

All the energy use is converted into mega-joule (Mj) on a primary energy basis. As the electricity that has reached the users is roughly 40% of the energy consumed in thermal power plants, it is multiplied by 2.5 to give it a primary energy rating. Then, the reduction of each measure in each category is evaluated one by one, which is explained below. Finally, gain from renewable sources of energy, in this case PV for electric power and solar heat for hot water, is deducted from the total amount of energy required, on the premise that PV power and solar heat utilisation has negligible impact to the environment.

5.1 Basic Energy Consumption (Reference Data)

There are several sources of calculation to provide reference data. They are:

(1) Actual energy consumption during the early phases of occupation,

(2) Model data in Osaka from The Institute of Energy Economics Japan (IEEJ), and

(3) Simulation by SMASH[6] modelling for heating and cooling load only.

The adopted method consists of two of the above:

(1) Simulation by SMASH modelling for heating / cooling load, and

(2) Simple average of the actual consumption volume, using average data for a detached home. The Osaka average data from the IEEJ has been adjusted for the project to a household of four persons.

5.2 Effect of Energy Saving

The energy saving results listed below includes effects that have been verified through simulation analysis. Instead of solar heat gain for hot water, the waste heat from the SOFC system is included.

Assuming a basic level 100 (167.2Gj), the energy load has been calculated to be lowered through each measure as follows:

(1) Through architectural improvement (resulting better heating/cooling performance), the energy consumption will be reduced to 55% (92.1Gj),

(2) Through refurbishment or replacement of built-in facilities, to 48% (80.8Gj)

(3) Through replacement of home electrical appliances, to 44% (72.9Gj)

(4) Through expected change in lifestyle of the occupants, to 39% (64.7Gj)

(5) Through utilising the waste heat gained from the SOFC, to 35% (59.3Gj)

Finally, deducing the PV generated power from the residue of energy saving mentioned above, the total consumption was estimated to be 22% (36.8Gj, reduction rate of 78%). These figures represent the consumption level of conventional energy in terms of primary energy, which is comparable to the alleviation of the environmental impact.

Thus, although some presumptions are included, the target of “reducing energy load to a quarter of the original amount” seemed realisable when every measure was taken into account.

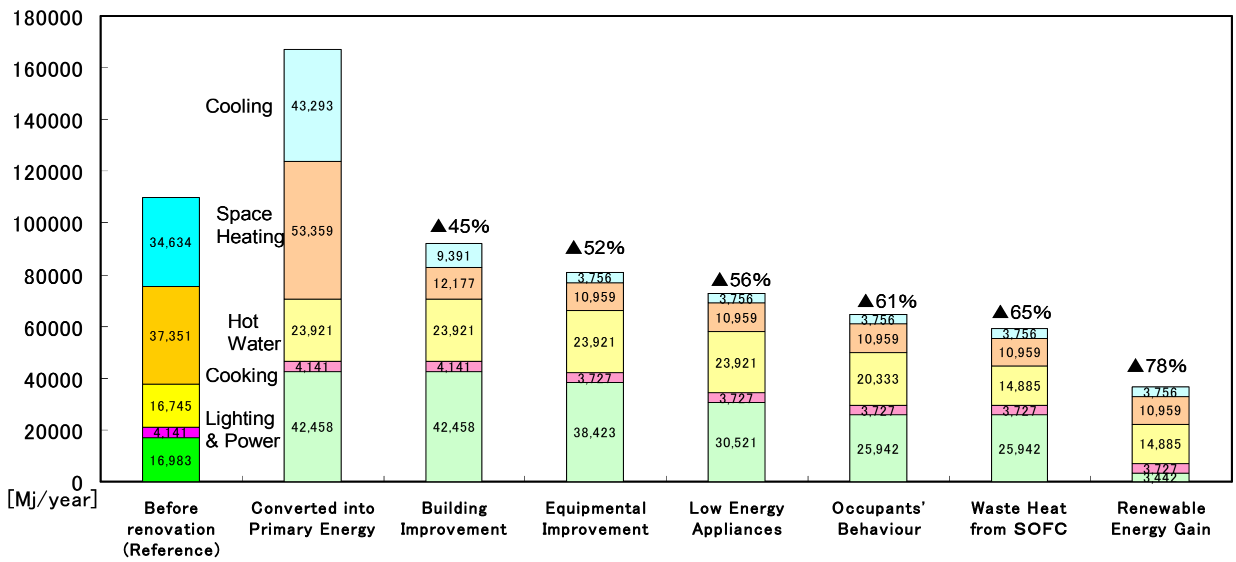


Figure.13 Expected process of Energy Impact Reduction (figures in Mj per year)

5.3 Effectiveness per Invested Cost

The energy reduction or gain of each measure, in term of Mj in primary energy per 1000 yen, was calculated to compare their effectiveness. After every measure, with its performance, had been assessed, the cost effectiveness was prioritised.

[6] Simplified Analysis System for Housing Air Conditioning, IBEC Japan

5.4 Data to be measured

Finally, it is necessary to compare the expected targets against actual data after occupation. This includes indoor/outdoor temperature, electric consumption, gas consumption, PV power generation and heat gain from either SOFC or solar collector. Sensors and meters were installed at suitable locations and the data have been transmitted to the logger installed in the basement of the building. They have been collected regularly and analysed.

6. Experiment through occupied condition

Once the energy saving/gaining measures were ready in April 2007, a family moved into the dwelling. The family consisted of a married couple with two daughters both in junior high school that year. Although the age of children is different, the family size is the same as the ones in previous phases (1st and 2nd).

A study group for "Experiment of Factor4 Dwelling Low Energy Living" has been set up. It has actively watched over the process, analysed the results and determined additional measures to fill the gap between the target and the outcome. This study is to continue for 5 years.

In the first fiscal year, April 2007 to March 2008, the family was not requested to make efforts to reduce energy consumption. The home electrical appliances remained as they had been brought in. The intention was to have basic data for comparison with the later energy saving behaviour.

The data from the first year has been collected sufficiently in spite of some errors and mistakes. At the same time, the weak points of remodelling have also been clarified. Following is a list of the main findings from the first year of occupation. The Fig.14 shows the energy consumption/gain results through the FY 2007 in comparison with the reference and the actual data in previous occupation.

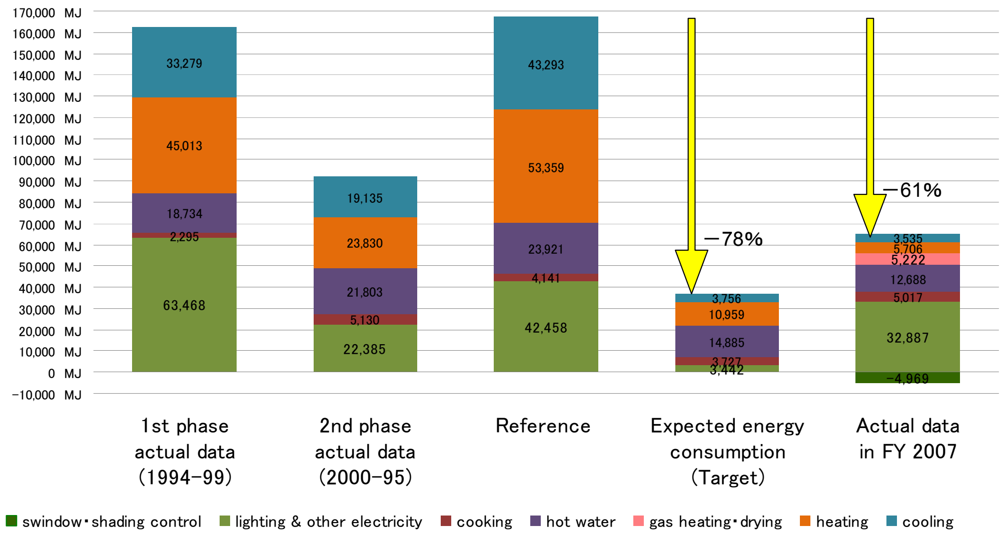


Figure.14 Results of energy consumption in comparison with target, reference and previous cases

Heating: The energy consumption for heating space was as low as expected. The effect of better insulation has been clearly proven.

Cooling: The cooling energy was 6% lower than expected but the way of using air-conditioner was intermittent which is not equal to the presumption.

Hot water supply: The waste heat from the fuel cell seems to have been well utilised. The energy use for this purpose was 16% lower than expected.

Cooking: The energy for cooking was 35% greater than expected but not as significant as other uses. The data during winter is estimated from the other seasons because it is only available for non-heating season.

Lighting and other electric use: This section has been the most difficult part of the project to analyse. The main reasons for the high-level consumption cannot be explained beyond the two old refrigerators in use. More detailed examination is required.

The total reduction rate for the first year was approximately 61%. That figure is still far behind the target of 78%. The electric consumption in particular has been much higher than expected. Patient watch, further improvement of equipment and good guidance to the occupants are required for attaining the target.

PREDICTED IMPROVEMENT OF ENERGY EFFICIENCY FOLLOWING TERRACE HOUSE RENOVATION

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Keywords: energy efficiency, renovation, housing, sustainable building, energy simulations

Summary

This research is concerned with the energy demands of terrace houses before and after renovation. The studied terrace houses are built in 1968 and situated in Lund in southern Sweden. They are technically outdated. Several possibilities for renovation, inspired by the IEA Task 28 Lindås Park project, are discussed and analyzed from an energy performance point of view. Energy performance is predicted using the DEROB-LTH computer program. An important aspect for the design is the minimal disturbance for the occupant of the house. The renovation concept is divided in four steps; (1) applying additional thermal insulation in the roof, (2) replacing the windows, (3) improving the ventilation system and creating an air tight building envelope and (4) applying additional thermal insulation in the walls. The combined effects of these four renovation steps is predicted to reduce heating demands from 15700 kWh/a to 6000 kWh/a, a reduction of 61.8%. Energy demands of dwellings can be considerably reduced by means of renovation, with minimal hindrance for the occupants.

1. Introduction

The terrace houses that are analyzed and discussed are situated in the Gilleskroken neighbourhood in Lund, Sweden (Fig. 1). The Gilleskroken terrace houses were designed by the Danish architect Bent Jørgen Jørgensen and built in 1968-1969. The terrace houses have high architectural qualities. They do however require renovation. In total 22 terrace houses were constructed. The footprint of an individual dwelling is 8.0 m. wide and 10.3 m. deep. The living area is divided over three floors: a basement with laundry and storage facilities, ground floor with entry, kitchen and toilet, living room and extra room and first floor with bathroom and bedrooms. There is no accessible attic. The walls dividing the dwellings are constructed in brick, facades are constructed in wooden frames with wooden façade panelling.

Dwellings that are built today are more energy efficient than older dwellings. Building energy efficient dwellings have only limited effects on the reduction of the current energy use because new dwellings represent only 1 or 2 percent of the total housing stock. The majority of dwellings is already built and will continue their (high) energy consumption. Renovation of existing housing and making them more energy efficient will have a much higher impact on energy consumption reduction. Finding smart ways to change energy demands of the many existing dwellings can bring about a substantial decrease of current fossil energy use and related CO_2 emissions.

The focus in this project is to develop a renovation method that results in more energy efficient terrace houses. The heating demands of the Gilleskroken dwellings before renovation were measured by asking the occupants for their energy bill. Heating demands upon renovation were predicted using the computer program DEROB-LTH, provided by the Division of Energy and Building Design at Lund's Institute of Technology, Lund.

1.1. Analysis of the Gilleskroken dwellings.

The Gilleskroken dwellings are built in a traditional fashion using different materials for the structure, facades and foundation. For the foundation the top layer of soil was removed after which the foundation was constructed straight on the ground. On top of this foundation the dwellings are erected. The floors were constructed in concrete. Interior walls were built up of wooden studs with gypsum board panels. Walls between the dwellings consist of two brick walls, with 60 mm mineral wool for sound insulation in the cavity. There is a load bearing interior wall that has round steel columns as structural elements. The wooden outer walls consist of wooden studs and rails. Between the studs there is 95 mm of mineral wool thermal insulation. The facades are made up of horizontal wooden panels. Wooden trusses are used as structural elements for the construction of the roof. These trusses span 7.62 meters from wall to wall and are placed at 1200 mm centre to centre. Inside the roof there is a total of 150 mm mineral wool thermal insulation.

The Gilleskroken dwellings are connected to a district heating system. Water is heated centrally in a large heating plant. This water is transported to the dwellings through underground insulated heating pipes. The system is well maintained and very efficient. In the dwellings there are heat exchangers that transfer the heat to the dwellings' heating system which consists of radiators that are placed under the windows in each room. These radiators are heated with hot water that is heated by means of district heating.

Interviews were held with 13 of the total 23 households at Gilleskroken (56%). These interviews provided a clearer picture of the occupants' opinion on their dwellings plus useful information regarding the technology and construction of the dwellings. The usage of household electricity averages 4600 kWh/a for the 13 interviewed households. From a technical point of view the opinions of the occupants regarding the quality of their homes varied. However, many respondents claim that their dwelling requires regular maintenance. The wood needs to be painted every three to five years. Also, many of the occupants had changed the roof covering more than once. Some respondents mentioned the use of cast concrete in the dwelling as a positive feature. Others said that the use of the different materials such as wood, brick, and concrete appealed to them aesthetically. In several dwellings there were ruptures in the brick on the exterior. Nonetheless, on the whole the respondents are very content with their homes.

Figure 1 Gilleskroken gable dwelling

Figure 2 Lindås Park project

2. Materials and Methods

In this research a proposal is made for the renovation of the Gilleskroken terrace houses. This proposal is based on an analysis of energy efficient terrace houses at Lindås Park, near Gothenburg, Sweden. The Lindås Park project was used as an exemplary model for the Gilleskroken renovation. Data is collected from various publications (Wall, 2006; Ruud and Lundin, 2004). Calculations to determine energy use before and after renovation of the Gilleskroken dwellings are done in the computer program DEROB-LTH.

2.1. Reference Project Lindås Park

The Lindås Park project, started in 1997, and designed by EFEM Architects is located 20 km south of Gothenburg, Sweden. The project was part of the IEA Task 28 and sets a good example as energy efficient terrace housing. The project consists of 20 houses, of which 8 are gable houses, which were built in 2001. Heating demands have been monitored continually over the years. The dwellings have an average total energy demand of 7,000 kWh/a. The gable houses use an additional 1,500 kWh/a. This is the equivalent of 58 kWh/m²·a for an average terrace house, and 71 kWh/m²·a for a gable house. These figures show the advantage of the integral approach as an average Swedish dwelling uses 150 kWh/m²·a on heating alone.

The 20 dwellings at Lindås Park use an average of 4020 kWh/a for lighting and household appliances, 1848 kWh/a for domestic hot water, 1742 kWh/a on heating of space and ventilation air, and 668 kWh/a for fans and pumps. The energy efficiency of the dwellings at Lindås Park was achieved by implementing the following measures;

- Very thick thermal insulation of the building envelope
- Air-tight building envelope
- Mechanical ventilation system with heat recovery
- Solar water heater for domestic hot water

The building envelope is insulated extensively in order to reduce transmission losses. There is a minimum of 435 mm thermal insulation in outer walls, roofs and floors. There is little heat transfer through the building envelope, see Table 1. Windows contain three panes of glass with two metallic coats in combination with a Krypton or Argon gas fill.

Table 1 Heat Transfer in the Building Envelope of Dwellings at Lindås Park

Building component	Heat transfer (U) (W/m²·K)
Exterior walls	0.10
Roof	0.08
Ground floor	0.09

The dwellings have been made as airtight as possible to reduce infiltration losses. This has been achieved by overlaps in the vapour barrier, and by placing the vapour barrier at 100 mm from the interior so that nails do not puncture the vapour barrier.

The dwellings are equipped with an air-to-air heat exchanger in order to reduce ventilation heat losses. The heat recovery efficiency is approximately 83%. In summer this heat exchanger is by-passed. The heat recovery heat exchanger forms a very important element of the chain resulting in low energy consumption. Special attention is given to the well-functioning of this ventilation system, as it is there to provide optimal air quality and high comfort.

Each dwelling has a 5 m^2 solar collector facing south and 40% of the domestic hot water is provided by the solar water heaters.

2.2. DEROB-LTH model

The DEROB-LTH computer program a model of a Gilleskroken dwelling was generated. Energy demands for heating before renovation were calculated, and found to be 15700 kWh/a. The model was altered step by step, based on the Lindås Park project. The four steps of renovation are as follows:

1. Roof (Additional thermal insulation in the roof)
2. Windows (Change to energy efficient windows)
3. Ventilation/infiltration (Air tightness in combination with a mechanical ventilation system)
4. Walls (Additional thermal insulation in the walls)

The four steps were implemented in the DEROB-LTH model one by one. Energy demands for heating are calculated for each step and for the cumulative steps.

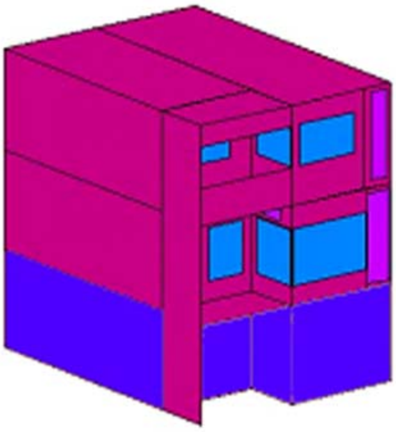

Figure 3 Model of a Gilleskroken dwelling in DEROB-LTH.

2.3. Renovation of the Gilleskroken Dwellings

The Gilleskroken dwellings are quite spacious with living areas divided over three floors. The plans of the dwellings are well thought out and functional. However, all this space is not always used because of the small household sizes, e.g. one or two persons. New plans were made for the dwellings focusing on the elderly, with a proper bathroom and bedroom at ground floor level. Part of the first floor can be used to house a student. A small apartment was created on the first floor, see Figure 4.

Apart from the spatial renovation, the dwellings also underwent some improvements from a technical point of view. The primary issue is that the dwellings have poor thermal insulation. Currently this is 95 mm of mineral wool for the walls. Also, the original windows are no longer sufficient. Secondly, the roof needs revising.

Figure 4 Gilleskroken ground floor level, left the existing situation, right the proposed new situation.

Thirdly, there is the existing ventilation situation in the dwelling. Ventilation takes place by simply opening windows. In winter this is not an optimal solution. Use of passive and active solar energy in the dwellings will cut down energy demands. The varying orientations of the dwellings (north-sound and east-west) require a number of solutions on how to optimally use solar energy in the dwellings. The abundance of space in the dwelling is a positive aspect of the dwelling that should remain even after renovation. The dwellings have plans that are both practical and functional, which is a quality that should remain. The use of different materials gives the dwellings their own character; the combination of wood, brick and concrete makes the dwellings stand out.

3. Results and Discussion

3.1. New architectural designs

A new architectural design for the Gilleskroken dwellings was proposed (Fig. 4 and 5). This design lives up to present-day demands and provides with new possibilities for use of the dwellings and the neighbourhood. The new design can be implemented while renovating the Gilleskroken dwellings for energy purposes.

The dwelling is not only renovated but also transformed into several new dwellings. On the ground floor an apartment can be created for the current, senior-occupants, as is illustrated in Figure 3. This apartment has a floor area of 50 m². It contains a hall, living room, kitchen and bedroom. It also has easy access to the garden. The apartment is very accessible as it is on ground level.

On the first floor two independent student apartments are created. They both have a kitchenette and a bathroom. The two student rooms have floor areas of 30 and 31 m² respectively. The staircase is a common staircase. A shared storage space for bicycles, lawn mover, e.g. is situated next to the entrance. The room in the basement is owned by the occupants of the ground floor apartment. They can use it as a guest room or hobby room. All other storage space is owned by the current occupants.

The Gilleskroken dwellings have two different orientations; some dwellings have a North-South orientation, others an East-West. A sun room was designed for the dwellings that have their entrance on the north side and their living room on the south side. In the DEROB-LTH model a glass wall was constructed in front of the terrace and balcony, creating a sun room at the back of the dwelling. The sun room cuts down the heating demands for space heating. It can be used from early spring to late autumn, and is not heated. Cooling in summer can be done by opening windows both at ground level and near the roof, and by using shadings.

3.2. DEROB-LTH Calculations

Energy demands for heating of the Gilleskroken dwellings was reduced drastically when implementing all the renovation steps as proposed in this research. From the original 15700 kWh/a needed for heating for a Gilleskroken dwelling, energy demands were reduced to as little as 6000 kWh/a. Each of the individual renovation steps will be discussed.

Figure 5 First floor; left the existing situation, right the proposed new situation.

Applying additional roof insulation does not require a complete renovation. This measure can be taken without causing much disturbance for the occupants. An additional 50 mm thermal insulation to the existent 150 mm already cuts down heating demands with 400 kWh/a (Table 2). Because of the available space inside the roof construction the maximum insulation thickness is 400 mm. This decreases heating demands with 1100 kWh/a. This is as much as 7% of the annual heating demands.

Table 2 Thickness of Roof Insulation in relation to Heating Demands
(Calculations in DEROB-LTH on Model of Gilleskroken Dwelling)

Roof Insulation (mm)	Heating Demands (kWh/a)
150	15,700
200	15,300
300	14,800
400	14,600

Replacing the existent double pane windows by triple pane low energy windows filled with Argon gas cuts approximately 3300 kWh/a of the total heating demands. When both the first two steps (400 mm roof insulation and triple pane windows with Argon fill) are implemented 4300 kWh/a can be saved compared to the existing situation.

Ventilation rate and the heat recovery system have a substantial effect on the heating demands of the Gilleskroken dwelling model. Where heating demands are as much as 18000 kWh/a in a model with 1.0 ac/h (air change per hour), this figure is as low as 6000 kWh/a at 0.1 ac/h. Mechanical ventilation rate in practice is 0.5 ac/h, infiltration rate is assumed to be 0.1 ac/h. In the model the ventilation rates after renovation are assumed to be a theoretical 0.15 ac/h. This is possible to achieve using a heat exchanger with 85% efficiency and by making the dwelling as airtight as possible as is done in the Lindås Park project.

At present, the Gilleskroken dwellings have only 95 mm of thermal wall insulation. It is presumed that when the walls are renovated the above mentioned three renovation steps are carried out as well. In the DEROB computer model it was found that applying only an additional 100 mm of thermal insulation cuts back heating demands substantially.

As could be expected from the Lindås characteristics the optimal thermal insulation situation can be found at an additional 200 mm (a total of 290 mm), see Table 3. Applying more insulation material than this would only slightly decrease energy demands whereas it could not compensate for the energy it takes to produce, transport and later demolish and recycle the additional insulation material. Dimensions of thermal insulation are bound to limits and applying lots of thermal insulation does not improve the thermal insulation of the dwelling limitless. Thermal insulation thickness of more than 400 mm is superfluous and hardly contributes to further energy reduction (Sanjee and Ham, 2006). The solution chosen in this research is 195 mm of insulation for the walls.

Table 3 Thickness of Wall Insulation in relation to Heating Demands
(Calculations in DEROB-LTH on Model of Gilleskroken Dwelling)

Wall Insulation (mm)	Heating Demands (kWh/a)
95	7,000
195	6,000
290	5,700
390	5,600

The combined effects of the four renovation steps reduced heating demands from 15700 kWh/a to 6000 kWh/a, a reduction of 61.8% (Fig. 6). The impact on energy use of the individual renovation measures depends on which measure is taken first. If for example only walls are insulated, this measure would have a higher impact on total energy reduction than it has in this research where it is the last applied step in the model.

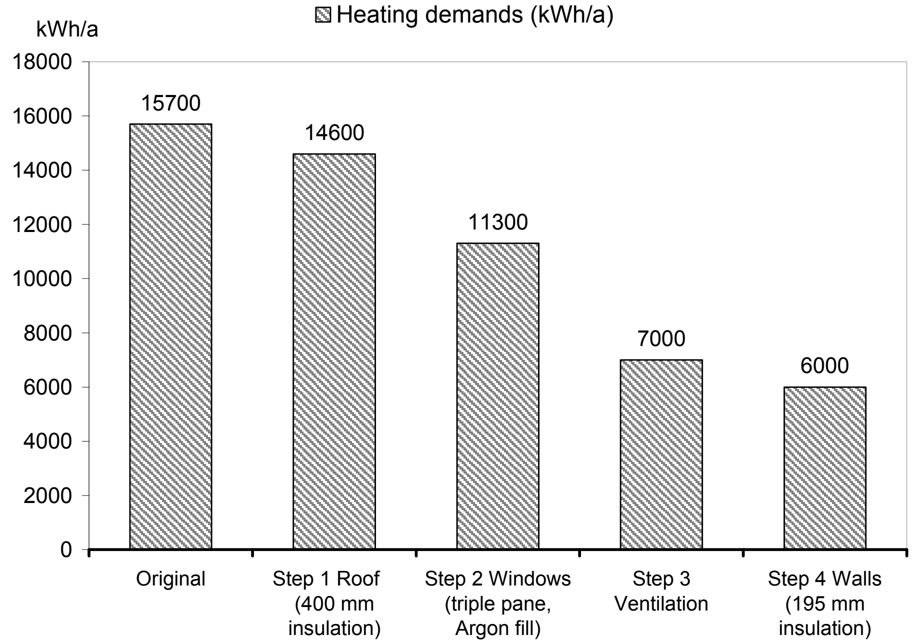

Figure 6 Renovation steps and heating demands for Gilleskroken model in DEROB-LTH

4. Conclusion

This analysis suggests that energy demands of dwellings can be considerably reduced by renovation. In a renovation program many different aspects have to be taken into account and decreasing energy demands of the dwellings is only one aspect. Putting the focus on reducing energy demands of the built environment and showing that this can be achieved with rather average renovation measures could consequentially improve our living environment. This research shows that implementing relatively simple renovation measures such as applying additional roof insulation can decrease heating demands of dwellings substantially.

One of the advantages using the DEROB-LTH computer model is that many situations can be calculated easily and quickly. Varying the thickness of the thermal insulation shows that thermal insulation does not need to be applied endlessly. A thermal insulation layer of 300 mm is sufficient in both walls and roof. However, when carrying out a renovation project, a close eye has to be kept on the right use of materials and renovation measures. Creating an airtight dwelling without providing with a well-functioning ventilation system will cause considerable problem for occupants. Competent builders should be contracted and renovation experts should be consulted before undertaking a renovation project.

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DEVELOPMENT AND TESTING ON THE HYBRID LIGHTING SYSTEM COUPLED DAYLIGHT WITH ARTIFICIAL LIGHTS

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Keywords: daylight use, symbiotic environment, energy saving, daylight pipe

Summary

The plant always exchanges the energy and material from the environment interactively (the photosynthesis effect and breathing effect) to supply the nutrient for maintaining the life of itself. The “heat” and “light” from sun are the key factors. This study, was attempted to analyze the characteristics of sunlight (illumination and wavelength on the leaf surface), and then to develop a hybrid lighting system, which connected the daylight with some artificial lights, to mimic the characteristics of sunlight. The fuzzy-control interface for the composition of the light sources was implemented. This device can be utilized in the living space which is intended to green plants but without depending on the sufficient daylight. The performances of energy consumption in various scenarios are also addressed..

1. Introduction

It has been reported that daylight illumination schemes provide the potential for significant energy savings in buildings. For example, Bodart and Herde estimated that the implementation of appropriate daylight access devices can reduce artificial lighting power costs from 50~80% [1]. Previous researchers have explored the feasibility of using daylight illumination schemes to reduce building energy costs in a variety of indoor environments, including hotels [2], apartments [3], offices [1], large atrium spaces [4], daylight-illuminated corridors [5], and classrooms in the tropics [6]. In subtropical climates such as that found in Taiwan, the major sources of power consumption include lighting, air conditioning and automotive power. Of these three sources, the lighting load can account for as much as 88% of the total energy consumption [7].

Hybrid Energy Systems have become one of the major technologies developed recently. Most of them involve engine systems for vehicles. There were few researches and developments of hybrid energy systems in living space. This study which utilized daylight pipes and auxiliary artificial light was attempted to construct a hybrid lighting system for mimicking the characteristics of sunlight. A fuzzy-control interface for composing the light sources was implemented. This device can be utilized in the living space which is intended to grow green plants without strong daylight. The performances of energy consumption in various lighting conditions are also investigated.

2. System Design

To grow plants in living space, the irradiation of four ranges in the light spectrum is the most important: 400-450 nm, 500-550 nm, 600-650 nm and 700-750 nm. To investigate the influence of four ranges of spectrum on plant growing, the study optimizes the light strength ratio of the sunlight guided from the pipes and the artificial light. Different lighting modules are constructed depending on the actual natural lighting condition in Taiwan.

2.1 Daylight Pipes

Aluminum plates with mirror faces and high reflectivity, the coefficient of reflection is 0.85, are used and rolled up to form a section of the daylight pipe. To effectively guide the sunlight into the indoor space and optimize the experimental requirement, the daylight pipes can be disassembled and reassembled section by section into different shapes, named from module A to module E (Figure 1). To assess the performances of the daylight pipes and to compare with the measured results, a software of “Lightscape” was used to simulate the light distribution indoors through the pipes (Figure 2).

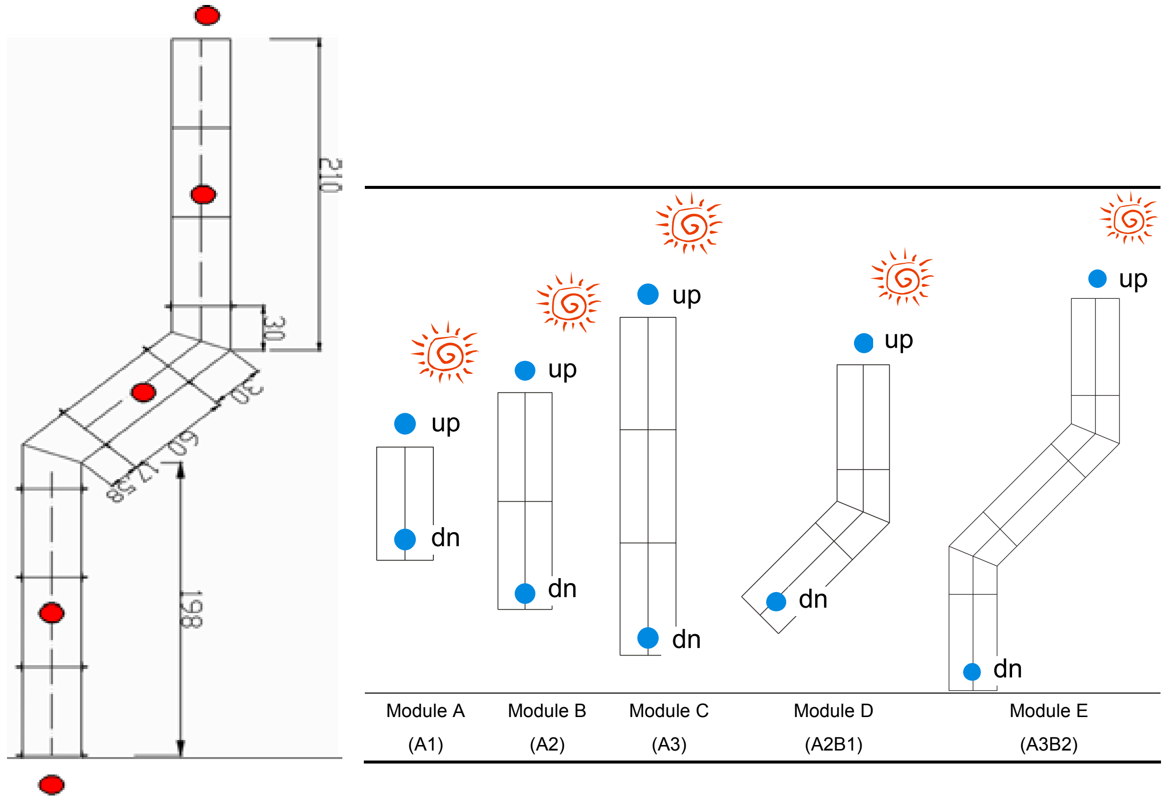

Figure 1 Dimensions and types of daylight pipes.

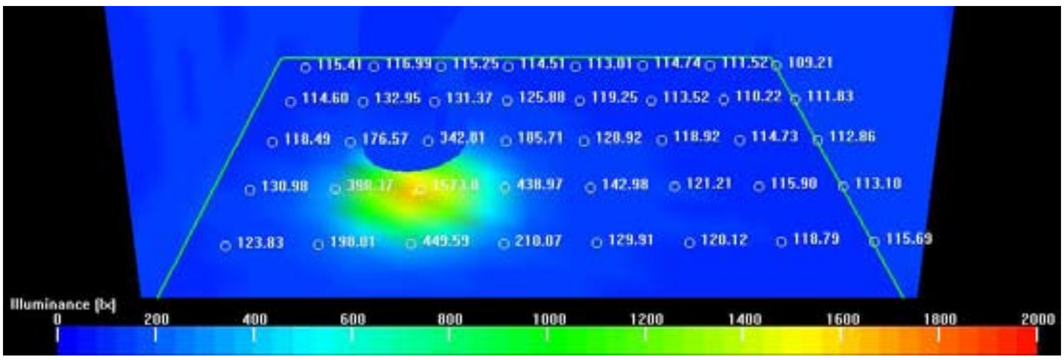

Figure 2 Post-process of simulated result on the light distribution through the daylight pipe.

2.2 Fuzzy control program

To compensate and improve the sunlight introduced into the living space and to construct the independent ecological system with the same physical conditions of the natural environment, a fuzzy control program is designed to make the lighting distribution in the system approach the corresponding environment. The fuzzy control module written and edited by LabView software was constructed to suitably trun on and off the artificial lights in the indoor space.

"If…., then…." is the main rule to state the operation of the fuzzy control program, which was developed by Prof. E. H. Namdani in University of London at Queen Mary, U.K. in 1974. A mathematical model should be constructed before the system is applied through overall investigation of the input and output conditions. In the current study, different lighting distribution from various modules of artificial lighting systems was investigated and analyzed to construct the database of the fuzzy control (Figure 3 and 4). To reduce the error percentage in the lighting performance, detailed investigations of natural and artificial lights were required in the study.

2.3 Calculation of energy saving of the hybrid lighting system

It is reasonable that a large amount of effort is necessary to simulate natural light by artificial lightings. Therefore, it is beneficial to develop a hybrid system to achieve the high fidelity and energy saving. Therefore, we define a factor of energy saving rate (ESR) to assess the reducing rate of power consumption between artificial lighting and hybrid lighting (Figure 5).

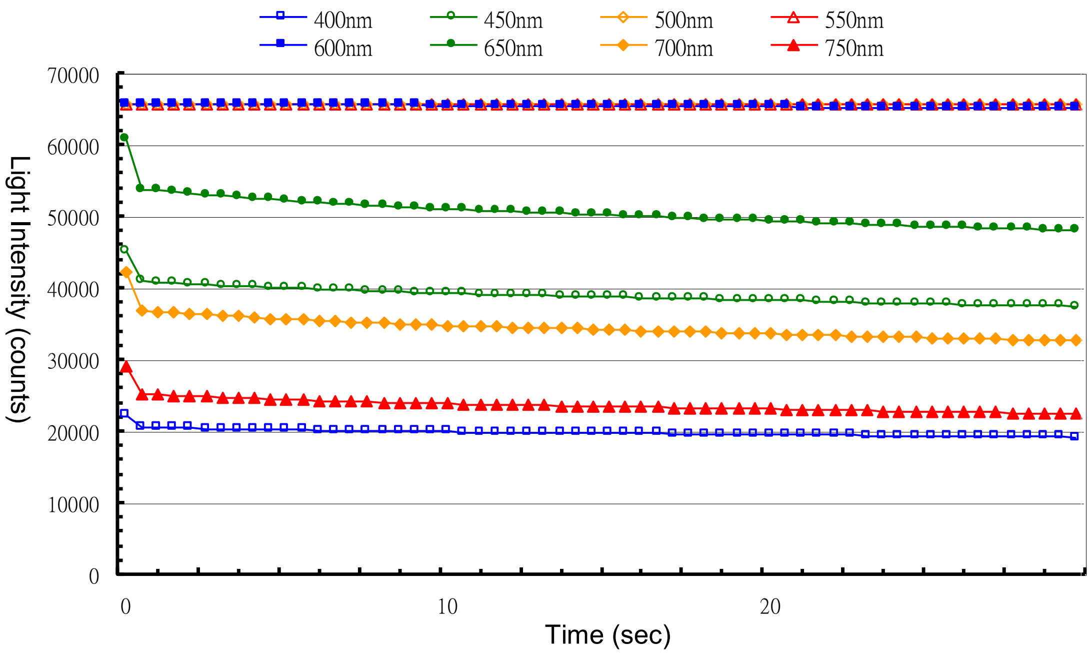

Figure 3 Field Measurement of natural sunlight at 9:00 am Jan. 1st, 2007 in Fulong, Tiawan.

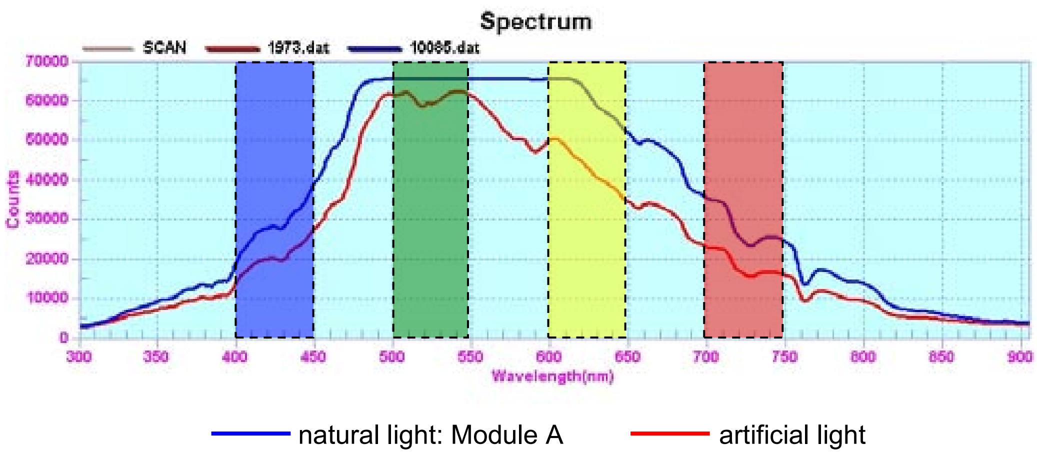

Figure 4 Comparison of the natural and the artificial light.

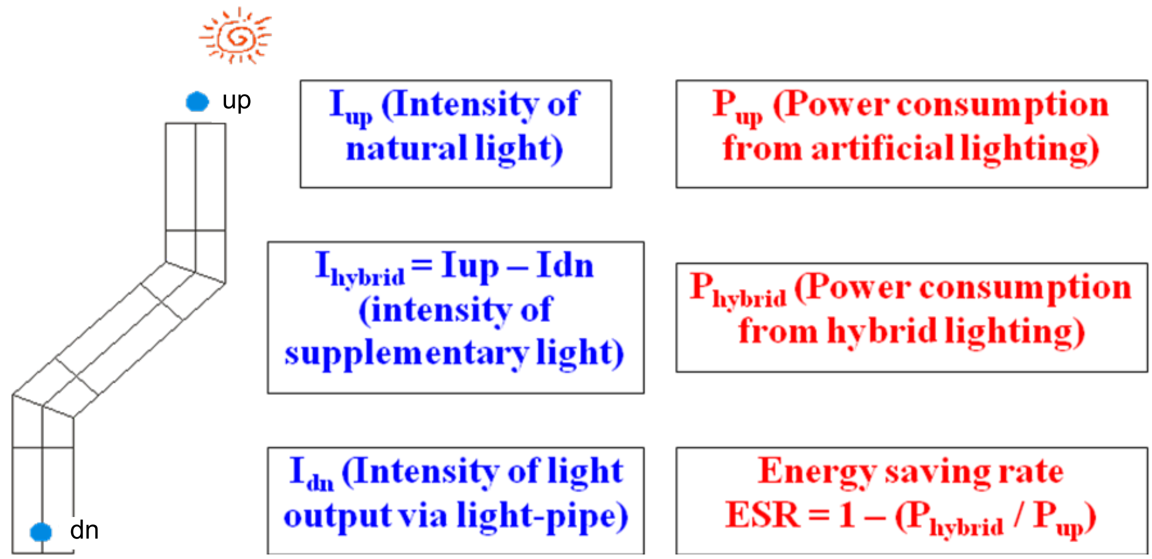

Figure 5 Structure of energy-saving calculation of the hybrid lighting system.

3. Experimental Results

3.1 Comparisons of different daylight pipes

In Figure 6, the sectional pipes are successfully assembled. A detailed investigation of the sunlight strength before and after the sunlight go through the pipe was done (Table 1).

Figure 6 Photographs of field measurements of the daylight pipes.

Table 1 Light strength before and after the sunlight go through the pipe.

Season	Time	Items	Modules				
			A (A1)	B (A2)	C (A3)	D (A2B1)	E (A3B2)
Winter	10：00	Weather*	cloudy	cloudy	cloudy	cloudy	cloudy
		Up spot**	48700	47100	56600	31200	37300
		Dn spot	35600	23080	13110	6880	4300
		D/U ratio	73.1%	49.0%	23.1%	22.0%	11.5%
	12：00	Weather	cloudy	cloudy	cloudy	cloudy	cloudy
		Up spot	55800	76500	53100	66600	46400
		Dn spot	32200	37100	16880	13130	5230
		D/U ratio	57.7%	48.4%	31.7%	19.7%	11.2%
	14：00	Weather	cloudy	cloudy	cloudy	cloudy	cloudy
		Up spot	43700	63000	44600	63200	43300
		Dn spot	30100	22510	12620	13360	4790
		D/U ratio	68.8%	35.7%	28.2%	21.1%	11.0%
	16：00	Weather	cloudy	cloudy	cloudy	cloudy	cloudy
		Up spot	15360	24740	23480	16540	15410
		Dn spot	6580	5840	4370	2240	1106
		D/U ratio	42.8%	23.6%	18.6%	13.5%	7.1%
Spring	15：00	Weather	partly cld.	partly cld.	partly cld.	partly cld.	partly cld.
		Up spot	12750	12643	12712	11423	12121
		Dn spot	12100	9136	8200	3432	2590
		D/U ratio	94.9%	72.2%	64.5%	30.0%	21.3%
	16：00	Weather	partly cld.	partly cld.	partly cld.	partly cld.	partly cld.
		Up spot	12040	10794	11210	12031	11778
		Dn spot	7297	4935	4392	2379	1389
		D/U ratio	60.6%	45.7%	39.1%	19.7%	11.7%
	17：00	Weather	partly cld.	partly cld.	partly cld.	partly cld.	partly cld.
		Up spot	4907	4872	4791	4631	4711
		Dn spot	2721	2622	2615	767.7	284.9
		D/U ratio	55.4%	53.8%	54.5%	16.5%	06.0%

* Measured from northern Taiwan in Winter and southern Taiwan in Spring.

** Unit: lx (illumination).

To compare the D/U ratios shown in Table 1, the measured results showed that the ratios from the southern Taiwan in Spring represent better performance than the ratios from the northern Taiwan in Winter at the same time period. The Up-spot and Dn-spot of every case are also measured the light intensity of the spectrum from the wavelength of 300 nm to 900 nm (Figure 7). The reduced parts of daylight intensity can be realized to be supplied by the artificial lighting properly.

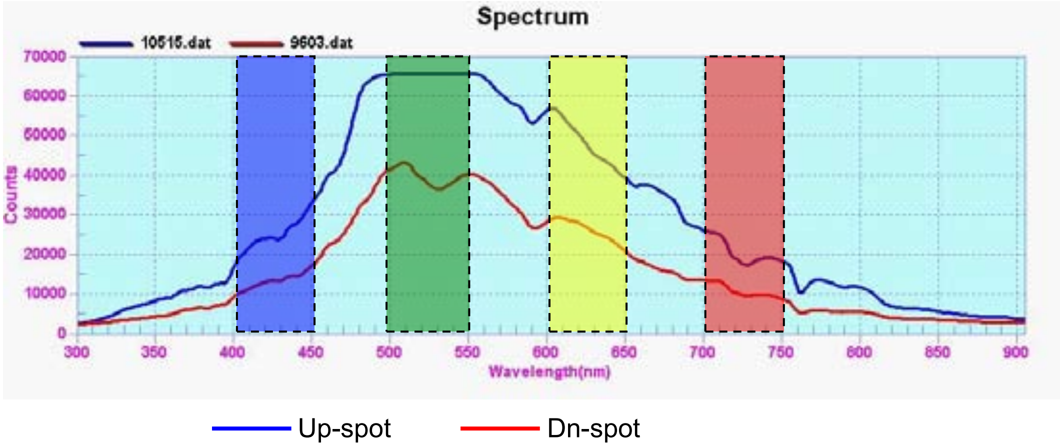

Figure 7 Comparison of light spectrums between the up-spot and the dn-spot: take Module C as an example.

3.2 Output of fuzzy control module

The maximum value of the insufficient light can be obtained by the measured results. This insufficiency can be supplied from several kinds of lamps which can be chosen to perform various spectrums separately. Hybrid module can be calculated by inputting the supplementary intensity (Figure 8). The fuzzy-control module will output the one of the lamp compositions with minimum error.

3.3 Calculation of energy saving of the hybrid lighting system

When we input the set of intensity values measured from Up-spot, The output of lamps module represents that the artificial lighting can perform as natural daylight. Therefore, the power consumption of this lighting scenario can be compared with hybrid lighting system (Table 2). Results show that this system is valuable.

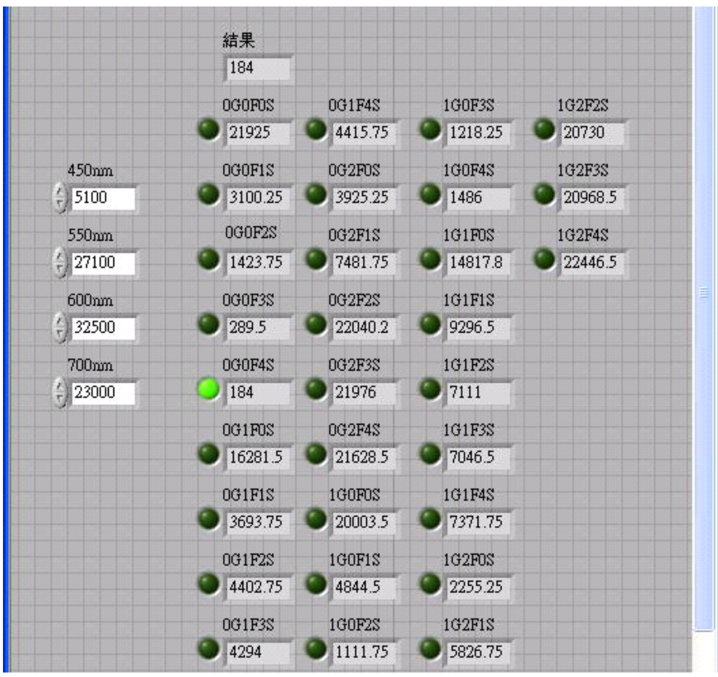

Figure 8 Calculated output by fuzzy control module.

4. Conclusions

The developed lighting system utilizing the daylight pipes and the artificial lighting is an essential element for growing plants in an independent ecological system. With the current system, an optimized lighting system can be realized with low power consumption. The measured results are beneficial for designing the hybrid system to perform vividly the daylight of the site we select for the plants indoor, especially for the eatable greens. The automatic fuzzy control program is introduced in developing.

Table 2 Calculation of energy-saving rate of hybrid lighting system: Module E.

Time	Artificial lighting to simulate the daylight		Hybrid lighting		Energy saving rate
	Lamps module	Power consumption	Lamps module	Power consumption	
9 : 00	0G2F3S*	4000 W	1G1F0S	580 W	85.5 %
10 : 00	0G2F3S	4000 W	1G1F1S	1580 W	60.5 %
11 : 00	1G1F2S	2580 W	1G1F0S	580 W	77.6 %
12 : 00	0G0F2S	2000 W	1G1F1S	1580 W	21.0 %

* G: 80 W per one; F: 500 W per one; S: 1000 W per one.

The reflection of sun-pipe is reasonable with 10-50 % of the remnant intensity but slight spectrum shift. This might be introducing the useful waveband for the growth of plants. A novel light control system which combines the artificial lights and outdoor daylight is under developing. The calculated result will also provide a set of data to suggest the optimum lamplight while renewal.

Acknowledgements

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PASSIVE HOUSES IN AUSTRIA - SUSTAINABILITY MONITORING OF STUDENTS' HOSTEL MOLKEREISTRASSE, VIENNA

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Keywords: students hostel, passive house, sustainable building, green building, energy monitoring, primary energy, greenhouse gas emissions, user satisfaction, electrical energy

Summary

Austria has a diversified know-how concerning sustainable buildings and the highest rate of passive houses per resident. The students' hostel Molkereistrasse in Vienna was the largest passive house worldwide, when it was opened in Sept. 2005. The facility performance evaluation gave evidence for an extremely high user satisfaction and a very good energy performance and climate protection performance concerning space heating and hot water generation. Further measurements for the improvement of the energy performance and the user satisfaction have been derived from the monitoring project. Future realizations of students' hostels can benefit from studying the successful pilot project in Vienna. And an additional attention should be laid to reduce the energy consumption for hot water generation and for electrical appliances.

1. Sustainable buildings in Austria

Austria has been a pioneer in the realization of eco-friendly and energy efficient houses and has accumulated substantial practical know how concerning passive houses, solar heating systems, and biomass energy production systems (Treberspurg + Smutny, 2005). Currently, it can claim twice as many sustainable settlements per resident as Germany (Wolpensinger, 2008). The following figure shows the development of passive houses in Austria. A passive house is designed to be heated with less than 15 kWh useful energy per treated floor area and year. Austria has the highest number of passive houses per resident worldwide with 200 objects per 1 Mio. residents in the end of 2006 (Lang, 2008). In the last three years, the cumulated total floor area has doubled each year.

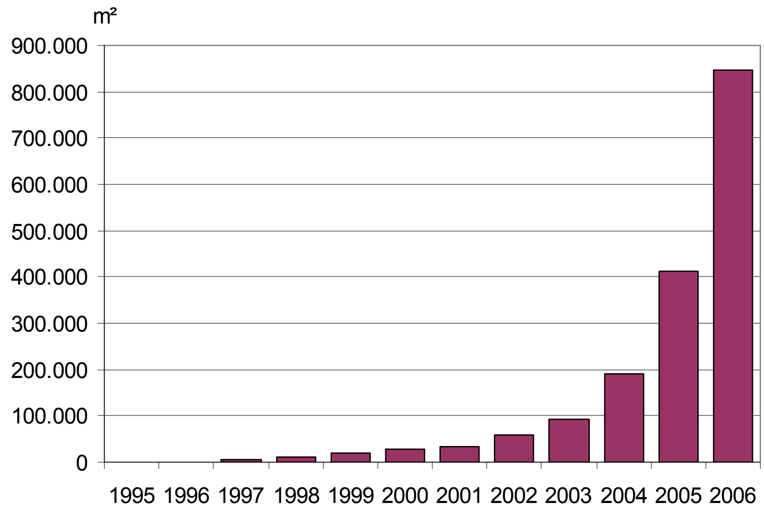


Figure 1: Accumulated total usable floor area [m²] of existing passive houses in Austria (Lang, 2008)

1.1 Presentation of specific passive houses

Approx. 45 % of the documented usable floor area of passive houses is provided by apartment houses, 22 % by one-family and two-family houses and 33 % by other buildings (Lang, 2008). The following pictures provide an overview on selected Austrian passive houses.

Figure 2: Housing estates in passive house standard. From left to right: Mühlweg-Vienna (Source: Bruno Klomfar, Dietrich I Untertrifaller Architects), EBS-solarCity-Linz (Source: Treberspurg & Partner Architects, EBS Linz,), Roschégasse-Vienna (Source: Treberspurg&Partner Architects)

Figure 3: Office buildings in passive house standard. From left to right: SOL4, Mödling (Source: Thomas Kirschner, SOL4), Adobe-Passive-House Tattendorf (Source: Meingast, natur&lehm, Reinberg Architects), Christophorushaus, Stadl-Paura (Source: BBM)

Figure 4: Special buildings in passive house standard. From left to right: S-house (Wimmer, 2005) (Source: GrAt, Schleicher Architects), Gemeindezentrum Ludesch (Source: Gebhard Bertsch, Hermann Kaufmann Architects), Schiestl House alpine refuge at Hochschwab 2154 m above see level (Source: Treberspurg & Partner Architects, pos Architects)

Figure 5: Buildings with thermal retrofit measures that meet the passive house standard. Left: Housing estate Makartstrasse-Linz (Source: Robert Freund, Arch+More Architects), Right: School Schwanenstadt (Source: PAUAT Architects)

A passive house can be designed in different ways. Austrian passive houses have been built in light-frame timber construction, in massive timber construction, and in massive construction with concrete or bricks. There are also some examples of thermal retrofit of existing buildings into passive houses. The renovation of

Makartstrasse, a 50 unit housing estate in Linz, used a super-insulated passive solar façade with integrated decentralized ventilation systems. This resulted in 90 percent savings in heating energy and operational costs. It is obvious, that Austria currently has a lot of diversified planning expertise in the field of passive houses which can be a valuable resource for foreign architects, building engineers, and planners of building services.

1.2 Sustainable energy supply

Austria currently has the highest rate of installed solar collectors per resident in Europe besides Cyprus and Greece (Weiss et al., 2007). The total area of installed solar collectors is 3.3 million m² and is increasing by approximately 0.3 million m² per year (Faninger 2007). To grasp these figures they are compared with the situation in Australia. Even with Austria's much smaller population (8.3 Mio. versus 20.7 Mio. in 2007) and less solar radiation, the annual sales as well as the total installed capacity of glazed solar collector area are about 43 % higher than in Australia (Weiss et al., 2007). This is also an important factor for the economy: More jobs are generated by the solar thermal energy industry than by the Austrian ski producers.

Table 1 Solar heat markets in Austria and Australia according to IEA (Weiss et al., 2007)

Solar Heat Worldwide	Collector Yield 2005 [GWh/a]		Total capacity installed at the end of 2005 [MW_{th}]		Annual installed capacity 2005 [MW_{th}]	
	Hot water, space heating	Total (incl. pools)	Glazed collectors	All collectors	Glazed collectors	All collectors
Austria	860	995	1690	2106	163	168
Australia	701	1971	1192	3605	114	385

Solar thermal energy concepts have been optimized by simulation with TRNSYS and successfully tested in practice. Online monitoring of solar systems has proved to be valuable for owners and occupants, providing safeguards against failure and malfunction and helping to adjust the control settings and thereby increase solar gains. Experience and planning competence are available especially for large volume houses – housing estates, office buildings, hotels, and business/industrial facilities.

Biomass is also an important energy source for heating. About 43 percent of the land area in Austria is forested. Biomass resources are used from forestry, agriculture, and the food industry and timber industries. Since biomass heating has been continuously supported, the regional economy has been strengthened. Meanwhile, Austria is one of the technology leaders in the production of boilers for split logs, wood chips, and pellets.

1.3 Success factors for the realization of sustainable building in Austria

Austria has an effective housing subsidy scheme. High income taxes (30–40 percent) enable several steering mechanisms. About 1.3 percent of the gross domestic product is used for housing subsidies. This stabilizes the building industry and has positive impact on social integration, the overall quality of buildings, and especially the ecological building performance. In early 2006, the housing subsidy scheme in the federal state Vorarlberg was revised. Passive House Standards are now mandatory for subsidized housing estates. As of October 1, 2006, a solar heating system is mandatory for subsidized housing estates in the federal state Styria.

Building laws with mandatory values for thermal insulation. Thermal resistance limits for the building envelope have been increased several times during recent decades and will be further decreased.

A law banning nuclear power plants (Atomsperrgesetz, BGBl. Nr. 676/1978). The use of nuclear power as an energy supply was prohibited after a plebiscite in 1978. This has been an early success on the road to a sustainable energy supply.

Initiatives of individuals had a relevant impact on the development of green buildings. The passive house movement started in the federal state Vorarlberg because of the commitment of individuals. Vorarlberg still has the highest density of passive houses. In the federal state Styria the use of solar collectors has started in the 70ies. Individuals who provided guidance in building the first solar collectors for private homes formed the AEE INTEC, now one of the leading R&D companies for solar heating systems. Meanwhile, individual housing developers who build each new housing estate with a solar thermal system tend to build passive housing estates only.

Funding of research and development: The R&D-impulse-program "Building of Tomorrow" of the Austrian Federal Ministry of Transport, Innovation and Technology (BMVIT) on "technologies for sustainable development" (at:sd) has a focus on sustainable buildings and has supported approximately 200 projects (Paula+Bauer, 2005). Core projects are innovative building and reconstruction concepts and their realization.

Several demonstration buildings already draw international interest, e.g. the S-house that has been presented on SB05 in Tokyo (Wimmer, 2005).

2. Passive house students' hostel Molkereistrasse in Vienna

2.1 Building concept

The building was planned by Baumschlager Eberle P.ARC architects and Team GMI passive house engineers. At the time of completion in September 2005 it was the largest passive house worldwide with a gross floor area of 10 527 m² - this corresponds to a treated floor area of 7 715 m² according to the calculation by PHPP (PHI, 2007). The building holds 280 beds in 133 apartments on seven floors.

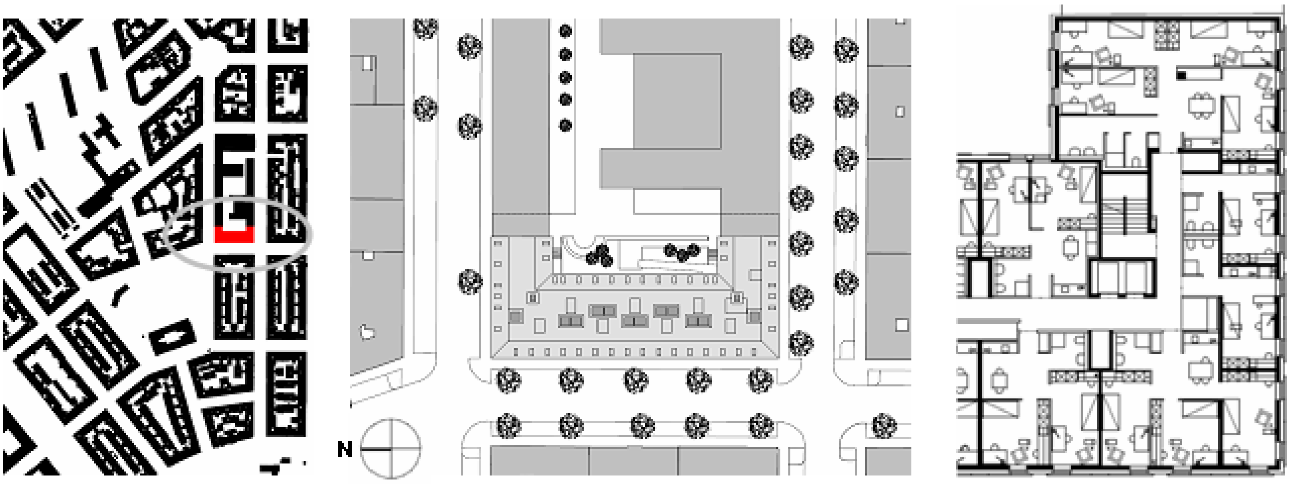


Figure 6: Site plan and floor plan of Students' Hostel Molkereistrasse. Source: Baumschlager Eberle P.ARC

The architects realized several innovative components within the strict financial regulations of the subsidy scheme. Each student has a single room with approx. 14 m² useable floor space and high quality interior equipment (wooden parquet floor, television sets, internet connection, etc.). The brass shadings act as attractive and varying structure for the façade. The shadings are manually operated and can provide a high thermal comfort during heat waves. Due to the high compactness of the building - 18 m depth of building wing -, central corridors are provided with a sophisticated daylight concept. Seven light wells have been optimized by simulation and supply daylight throughout seven floor levels.

The building has an active heating system - supplied with district heating - with mini-radiators in each room that are located above the doors near the supply air opening. Space heating and ventilation are thus separate systems with the advantage that the temperature can be regulated individually for each room by a room thermostat. A window contact automatically switches the thermostat to the lowest level (16 °C) if the windows are opened or tilted.

The distribution of warm water is done by one pipe system instead of a two pipe system (closed circuit). This concept reduces the pipeline length and therefore reduces thermal losses by more than 50 % compared to closed circuit system with the same insulation level.

The controlled ventilation with fresh air is done by small decentral ventilation units - one unit per two apartments. About 30 m³/h air is supplied per person. During cold periods with exterior temperature below 0 °C the air flow is reduced to 20 m³/h to avoid low air humidity. The fresh air is pre-heated or pre-cooled by ground-coupled heat exchangers.

2.2 Facility performance evaluation

Since February 2007 the energy consumption and user satisfaction have been measured. The first research period was analyzed and interpreted in the end of March 2008 (Smutny+Treberspurg, 2008), (Treberspurg et al., 2008). The survey is planned to go on until end of 2009. The aim of this study was to gain experience for future building projects and to improve the ecological and social performance if possible and necessary. The research project examined the actual energy consumption and the wellbeing of the occupants by means of a post-occupancy-evaluation (POE).

The survey concerned the comfort of ventilation, heating and noise and also included the associated needs and requirements of the occupants. Preliminary evaluation results showed good marks for the thermal comfort and the wellbeing of the occupants. More than 80 % of the occupants felt comfortable in the hostel.

The preliminary results were used to intensify the information on special topics (e.g. heating regulation, shading panels, window ventilation, building manual, etc.) that have been appeared to be unclear. A detailed analysis of the user satisfaction is planned to be carried out in the second investigation period. A comparison of 26 Viennese students' hostels showed that the general user satisfaction in the Molkereistrasse is very high. Only one hostel - the recently renovated Albert-Schweizer-Haus - showed better marks, but had a much lower rate of return of the questionnaires (15 %) compared to Molkereistrasse (66 %).

Heat meters and electric meters with electronically data transfer (M-Bus system) have been installed to investigate the site energy for space heating, water heating and ventilating. The site energy is the amount of energy that the user pays to the energy supplier. The calculation of useful energy for heating was done by determining the energy losses of heat distribution with the detailed information of the building services consultant Team GMI. These energy losses accounted for approx. 8 kWh/(m²·a) per gross floor area (GFA).

Useful energy consumption for heating was further converted according to actual climate and actual room temperature with the purpose of comparing it with the planned heating energy demand under standard reference conditions for temperature. The median of the indoor air temperature of 20 rooms was 23.2 °C (standard deviation 1.7 K), putting the transmission and ventilation losses 22 % higher than under design conditions of 20 °C.

The following figure shows the savings of useful heating energy and interrelated operational costs and greenhouse gas emissions compared to conventional Viennese housing estates of the same size with district heating supply. The referenced value is based on the actual heating energy consumption of a high amount of buildings and has been determined by (Hofbauer, 1998). The medium value of 50 kWh/(m²·a) is related to dwellings with more than 10 apartments that have been built about the year 2000. This is already a relatively good energy performance compared to older housing estates (80 kWh/(m²·a); built in 1980) or compared to conventional single family houses (70-100 kWh/(m²·a); built in 2000). Nevertheless, the successfully realized passive house concept showed to reduce this value by approximately factor five to a level of 11 kWh/(m²·a) per gross floor area. This corresponds to approximately 15 kWh/(m²·a) per treated floor area which is the limiting value according to the passive house concept.

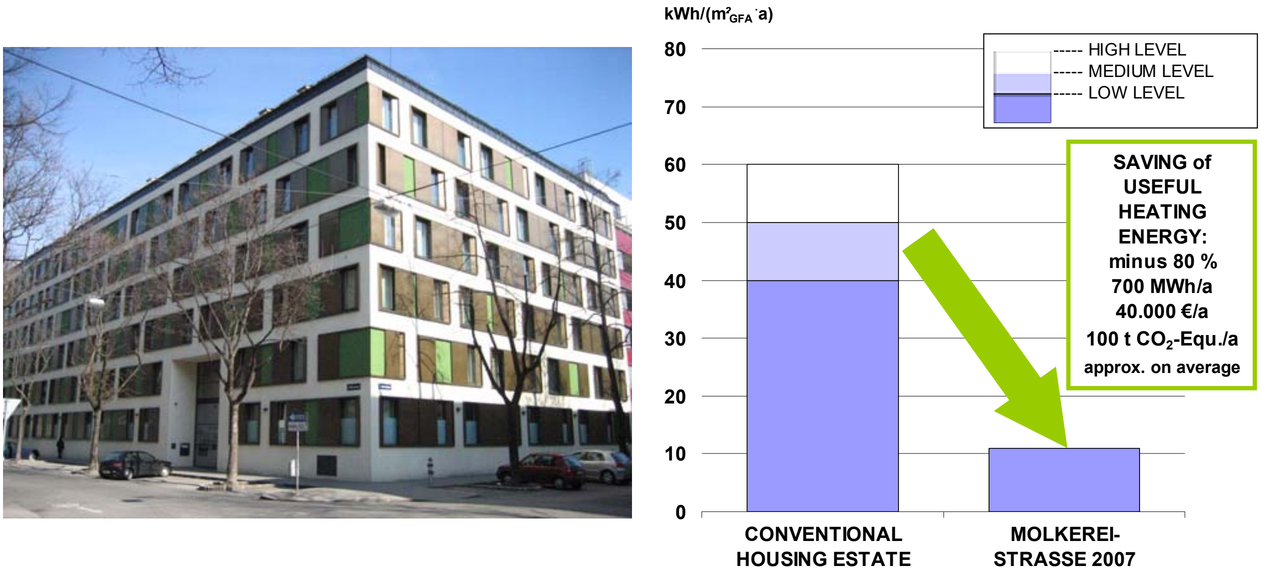
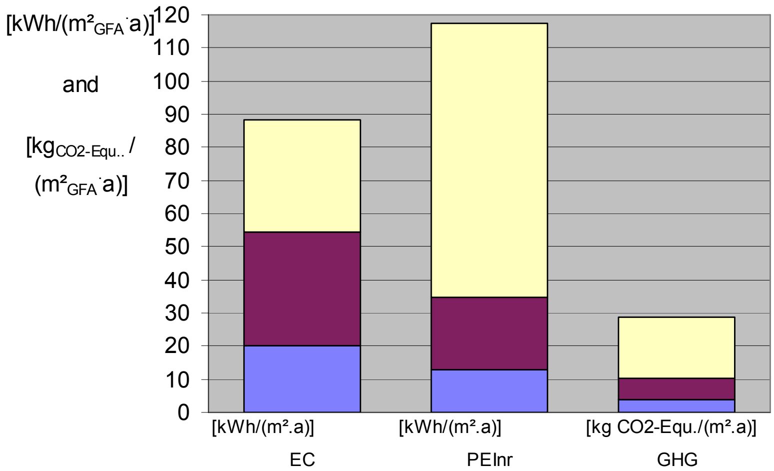


Figure 7: Useful energy consumption for space heating per gross floor area (GFA) under standard reference conditions for temperature. Passive house hostel Molkereistrasse compared to conventional Viennese housing estates built in approximately the year 2000. Foto: Roman Smutny

The second criterion for passive houses concerns the total energy consumption including electricity for household appliances, indicated by the non-renewable primary energy input (PEI_{nr}) with a limiting value of 120 kWh/(m²·a) per treated floor area, calculated with factors from the GEMIS-database. GEMIS includes the total life-cycle in its calculation of impacts - i.e. fuel delivery, materials used for construction, waste treatment, and transports/auxiliaries. With the primary energy factor for the Viennese electricity supply including imports - 2.43 kWh/kWh which equals approximately the average value for Europe according to GEMIS 4.42 (UBA-AT, 2007) - the primary energy consumption of the hostel is 160 kWh/(m²·a) per treated floor area. Measurements have been derived from the monitoring to reduce this value under the limiting value for passive houses in the following years.

The following figure shows the total site energy consumption (EC) per gross floor area, which has been assessed by the total non-renewable primary energy consumption (PEI_{nr}) and the total greenhouse gas emissions (GHG) using the corresponding factors for Viennese energy supply including imports (UBA-AT, 2007). The total values for these three energy services are 88 kWh/(m²·a) EC, 117 kWh/(m²·a) PEI_{nr} and 29 kg/(m²·a) of CO_2-Equivalents GHG. Please note that these values can not be compared to the passive house criteria, because of the different reference floor area. By the way, there is no criterion for GHG in the passive house concept.



	EC	PEInr	GHG
Electrical Energy, total	34	83	18,1
District heating, Hot water	34	22	6,6
District heating, Space heating	20	13	3,8

Figure 8: Site energy consumption (EC), non-renewable primary energy consumption (PEI_{nr}) and greenhouse gas emissions (GHG) for space heating (not standardized), hot water and electrical appliances per gross floor area (GFA) and year. Medium values of the period 09.2005 - 08.2007.

The analysis of the total energy consumption showed the importance of hot water generation for the overall performance, which was underestimated in the planning stage. The design value for water heating (25 litres with 60 °C per person and day as an ordinary value for conventional housing estates) is approximately half of the actual consumption value. The comparison with four other students' hostels (see *Figure 9* and (Engelmann et al., 2008)) surprisingly showed that the hostel in Molkereistrasse had the lowest value.

The analysis of the primary energy input and the greenhouse gas emissions showed the importance of electricity consumption for the overall performance. Electricity consumption causes 71 % of the total PEI_{nr} and 62 % of the total GHG.

2.3 Comparison with other Viennese students' hostels

In order to evaluate the energy performance and climate protection performance of the hostel in Molkereistrasse, three other Viennese students' hostels have been analysed that had been built in the period 1996 to 2005 and are also supplied with district heating. It is important to keep in mind that a direct comparison of the ecological performance of different buildings has only a limited significance due to methodological frameworks. According to the ISO standards for life cycle assessment (ISO 14040 - 14043) the same functional unit has to be used for comparisons of products or processes. The functional unit of buildings should respect the benefit and comfort of the apartments and therefore has to take into account the quality of the building services and equipment as well as the overall quality of the indoor environment. The passive house concept aims at optimising the thermal and hygrical comfort, the air quality and the daylight quality. For that reason it can be assumed, that the indoor environment in the hostel Molkereistrasse has a higher benefit for the students than in the other hostels, which has been verified by the survey of 26 students' hostels in Vienna. Furthermore the hostel Molkereistrasse offers single rooms only with television sets and internet connection, which is not the fact for the other hostels. Nevertheless, the useful floor area has been preferred as functional unit of the comparison due to practical reasons. The difference in the benefit is expressed qualitatively in addition and has to be kept in mind for the interpretation of the results.

The following figures show the comparison of the energy performance and climate protection performance of four Viennese students' hostels per useful floor area (UFA).

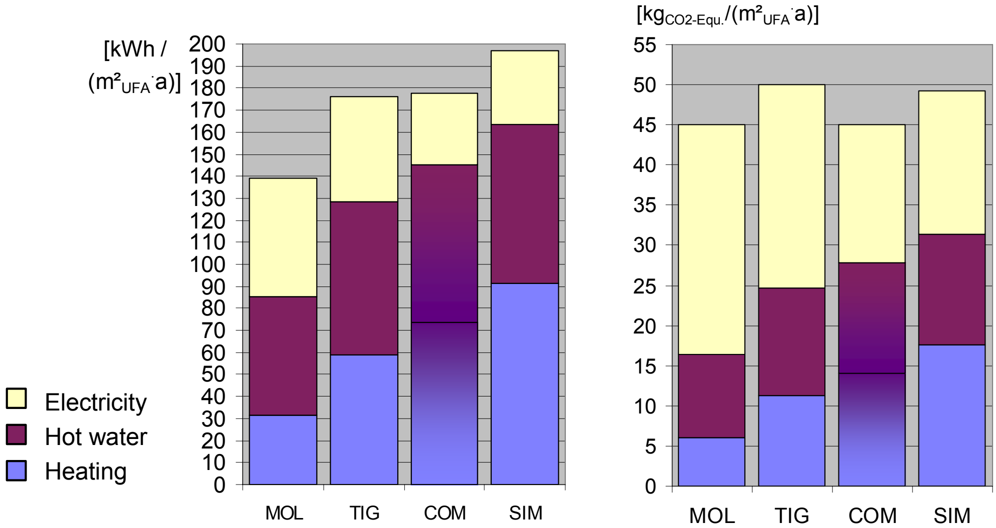


Figure 9: Total site energy consumption (left chart) and greenhouse gas emissions (right chart, factors for Viennese energy supply including imports). Space heating (not standardized), hot water generation and electrical appliances per useful floor area (UFA) and year. Four Viennese students' hostels Molkereistrasse built in 2005 (MOL), Tigergasse built in 2000 (TIG), Comeniusgasse built in 1996 (COM) and Simmeringer Hauptstrasse built in 2005 (SIM). All supplied with district heating. Medium values of the period 09.2005 - 08.2007.

Remark: For the interpretation of the results it is important to take into account the higher benefit of the passive house Molkereistrasse (MOL) concerning thermal comfort, hygrical comfort, air quality, daylight quality, summerly comfort, available TV-Sets, available internet connection, other qualities of the building services and equipment.

The oldest of the four hostels (Comeniusgasse, built in 1996) had the lowest electricity consumption The comparative values of Tigergasse and Simmeringer Hauptstrasse were approximately 50 % higher and of Molkereistrasse approximately 100 % higher. In the survey of the user satisfaction the hostel Comeniusgasse was on 25th position of 26 investigated Viennese hostels. This result can also be referred to the very low building services and equipment quality that causes low electricity consumption. The greenhouse gas emissions (GHG) are dominated by the electricity consumption due to a higher GHG-Factor (533 kg/MWh) compared to district heating (192 kg/MWh) according to GEMIS-Austria (UBA-AT, 2007).

The added value of the hostel Molkereistrasse compared to the hostel Simmeringer Hauptstrasse - with the most similar benefit and quality per usable floor area - is a saving of the total energy consumption of approx. 60 kWh/(m^2_{UFA}·a) - minus 29 % - and a saving of GHG-Emissions of 4.2 kg/(m^2_{UFA}·a) - minus 9 %. With the assumption of the same useful floor area (6 687 m²) the annual savings of district heating amount 520 MWh (78 kWh/(m^2_{UFA}·a)) which corresponds to 34 000 € (5.1 €/(m^2_{UFA}·a) and 100 t CO_2-Equivalents (15 kg/(m^2_{UFA}·a)).

3. Conclusions

The passive house students' hostel Molkereistrasse offers a very good energy performance and climate change performance regarding space heating and hot water generation. The user satisfaction is extremely high. Savings in operational costs for space heating and hot water generation amount approximately 34 000 € per year.

An appropriate design value for water heating in students' hostels is 50 litres with 60 °C per person and day, which corresponds to a low value for hotels with shower (Recknagel et al., 1997). The hostel in Molkereistrasse had the lowest energy consumption for hot water compared with 4 other hostels, which is likely to be caused by the efficient hot water distribution (one-pipe-distribution).

The results of a direct comparison of the ecological performance of passive houses with other buildings have only a limited significance due to a different benefit and comfort of the apartments. The benefit of passive houses is higher (or should be higher if designed and built accurately) regarding thermal comfort, hygrical comfort, daylight comfort, summerly comfort, air quality and larger useable floor area (because of less lost area for radiators and more comfortable area beside windows).

Recommendations are derived to improve the energy performance and the user satisfaction in the students' hostel Molkereistrasse. The consumption of electric energy can be reduced by energy efficient equipment, by a more frequent change of filters in the ventilation units, by a reduction of the ventilation in summer season and other measurements.

For the realization of sustainable students' hostels the passive house concept should be implemented comprehensively including concepts to reduce the consumption of energy for hot water generation and electrical energy, e.g. photovoltaic, energy efficient household appliances and lighting and others.

The passive house concept has proven to be effective to reduce the energy consumption and the fossil energy carriers for space heating and hot water generation. However, it is difficult to reduce the electricity consumption due to increasing comfort requirements regarding electrical equipment (e.g. tumbler, internet usage) and due to more powerful technical equipment (e.g. computer, larger TV-Sets, etc.). An increasing electricity demand has to be avoided to avert new power plants and to protect the climate. Therefore space heating and hot water generation should minimize electrical energy consumption and concepts to reduce electricity should be intensified and promoted.

Acknowledgements

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"BOTTOM UP" MODEL TO ESTIMATE ENERGY USE IN AUSTRALIA'S RESIDENTIAL SECTOR

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Summary

In 2006, Energy Efficient Strategies (EES) was commissioned by the Department of the Environment, Water, Heritage and the Arts to determine baseline energy consumption estimates attributable to Australia's residential sector. The study, completed in early 2008, quantitatively benchmarks current and future residential energy consumption by end use, which allows the development of specific greenhouse response measures by industry and government.

For the project, EES developed a "bottom up" end-use model that tracked, at a state level, energy consumption from 1986 to 2005 with projections to 2020. The model predicted that residential energy consumption will increase by about 62% from 1990 to 2020.

The model separately tracked four main categories of end use; space conditioning (11 product sub-types), water heaters (9 product sub-types), cooking products (6 product sub-types) and appliances (major and minor – 32 product sub-types). In addition, the four main fuel types of electricity, mains (natural) gas, LPG and wood were also tracked, this allows for future greenhouse gas emissions to be estimated.

The end-use model developed by EES includes complex stock models of each end use, covering ownership, technical attributes and usage patterns. For example, the model for space conditioning appliance stock was linked to a housing stock model and a space conditioning load module. Space conditioning loads are based on simulation modelling of typical building shells combined with 20 years of historical weather data across 10 climate zones. The complexity of the model is also demonstrated by the water heating stock model, which was able to explicitly model solar contributions in addition to boosting fuels.

The EES model can now be used to evaluate the impacts of a wide range of policy options at a state or national level, ranging from minimum energy performance standards (MEPS) for televisions to retrofitting of ceiling insulation in existing dwellings.

1 Background

The report titled *Australian Residential Sector Baseline Energy Estimates 1986-2020* (EES 2008) published in June 2008 was commissioned by the Department of the Environment, Water, Heritage and the Arts (DEHWA) to determine end use energy consumption estimates in the residential sector and to provide a quantitative foundation for the development of greenhouse response measures by industry and government. The study is an update of the first baseline study that was commissioned by the Australian Greenhouse Office (AGO) and published in 1999 (EES 1999). This paper summarises the bottom up modelling approach developed under this project. The published report (EES 2008) provides detailed documentation model inputs and outputs and associated assumptions.

The study covers Class 1 and Class 2 buildings as defined by the Building Code of Australia - this primarily includes private residential dwellings that are separate (e.g. stand-alone houses) and attached (e.g. blocks of flats, town houses, terrace houses). Energy use by appliances and equipment in households is covered in the study. Minor commercial activities that were undertaken in the home such as home offices were also included. However, residential components of commercial establishments were not included.

The study estimates energy consumption in the residential sector from 1986 to 2020. The study examines all major stationary energy end uses including electrical appliances and equipment, heating/cooling, water heating and cooking. There is particular attention given to space heating and cooling in residential buildings:

the interaction of the thermal performance of the building shell, heating and cooling regimes and the product type, fuel mix and energy efficiency of space heating and cooling equipment together with actual climate data. Fuels covered include electricity, mains gas (reticulated natural gas which is primarily methane), LPG (primarily propane) and wood for space heating. The energy contribution of solar water heating to total water heating energy requirements was also explicitly estimated in this study. Fuels not covered by this study include black coal, coke, brown coal briquettes, kerosene, heating oil, automotive diesel oil (ADO) or industrial diesel fuel (IDF). Wood for cooking and hot water was not estimated, but were considered to be negligible. Energy consumption of vehicles or engines was also not covered in this study.

2 Methodology Outline

The end-use model was developed using a wide range of data sources and provides estimates at a state level for all major energy sources. The model takes the following factors into account when estimating energy consumption by end use, fuel, state and year:

- Number of households over time and the average size of these households.
- Number of each appliance type per household over time (ownership and penetration).
- Key characteristics of new appliances entering the market each year, plus average appliance life and associated retirements, which were used to generate a stock-weighted average value in each year.
- Data on usage patterns and other aspects of user behaviour and interaction that impact on energy consumption of appliances (applied to the stock present in each year).
- Impact of climate on space heating and cooling requirements (all households were divided into one of 10 national climate zones – most states were covered by several climate zones).
- Information on new house construction at a state level (e.g. materials, construction type, size).
- Interactions of climate on water heater energy such as hot water requirements, cold water temperatures and the performance of solar systems.

In all, nearly 60 different end use and fuel combinations were separately modelled using this approach.

Data was synthesised by means of an end-use model to estimate energy consumption from 1986 to 2020 under a base-case scenario (Business as Usual (BAU) with existing energy program measures). The BAU scenario incorporates the impact of Australian energy policy programs that were already in place up to mid 2007 or finalised and scheduled to be introduced before 2009 (e.g. minimum energy performance standards (MEPS) for air conditioners in 2007).

The end use model is based on a series of stock models which accounts for the average technical characteristics of both new appliances and buildings entering the stock and old ones leaving the stock to provide a stock-weighted average from 1986 to 2020.

The main inputs into the appliance end-use model are:

- Appliance attributes – these are typically capacity or other attributes that affect energy consumption, including energy efficiency.
- Ownership – this is data on the presence of the total number of products that consume energy in households.
- Determination of appliance usage parameters (e.g. frequency and duration of use, climate impacts, temperature settings for washers etc).

The housing stock model was complex as it accounted for the key attributes of the building shell stock in each state as well as considering climatic data. Dwellings in each state were allocated into one of 10 climate zones, that were selected to cover the major climate zones/population centres in Australia. Dwellings in each state were apportioned to the relevant climate zone on the basis of the number of households in each postcode area as reported by Australia Post. Appliance ownership data and occupancy information together with estimated zoning within the residential stock was applied to the Building Shell simulation software (a modified version of AccuRate© (www.nathers.gov.au) to generate heating and cooling demand. One of the limitations of the study related to the fragmented nature of regional data on appliance ownership and fuel availability, which meant that it was considered to be uniform across each state.

Having completed the setup and operation of all the end use modules, a calibration check was undertaken. This check involved the collation of all of the energy consumption estimates for each year, fuel type and each state and territory. This was followed by a comparison against actual top down data for the same period. In all cases Australian Bureau of Agricultural and Resource Economics (ABARE) data has been used as the primary top down source. Where possible published data from the Energy Supply Association of Australia (ESAA, formerly Electricity Supply Association of Australia) and the Australian Gas Association

(AGA) was also used for some state-level comparisons. In some cases, state utility data was made available as part of the review process. Some small adjustments to some stock model parameters were required to calibrate the model estimates with actual energy consumption data.

3 Main Findings

3.1 Overall Trends

The study estimated that the residential sector energy consumption in 1990 was about 299 PJ (electricity, gas, LPG and wood) and that by 2008 this had grown to about 402 PJ and is projected to increase to 467 PJ by 2020 (Figure 1). The residential energy consumption is estimated to increase during the Kyoto commitment period (2008-12) by between 135% and 141% compared to 1990 levels. This increase coincides with a continuing trend towards an increased proportion of the total residential energy demand being met by electricity (high greenhouse gas intensity) and a decrease in the use of wood (low greenhouse gas intensity). It is likely that this predicted growth in energy use in the residential sector will be at least matched by the growth in greenhouse gas emissions (ie at least 135% above 1990 levels by 2008). On the basis of these estimates it could be argued that the residential sector will fail to make an equitable contribution to the Kyoto emissions target of 108% above 1990 emissions levels.

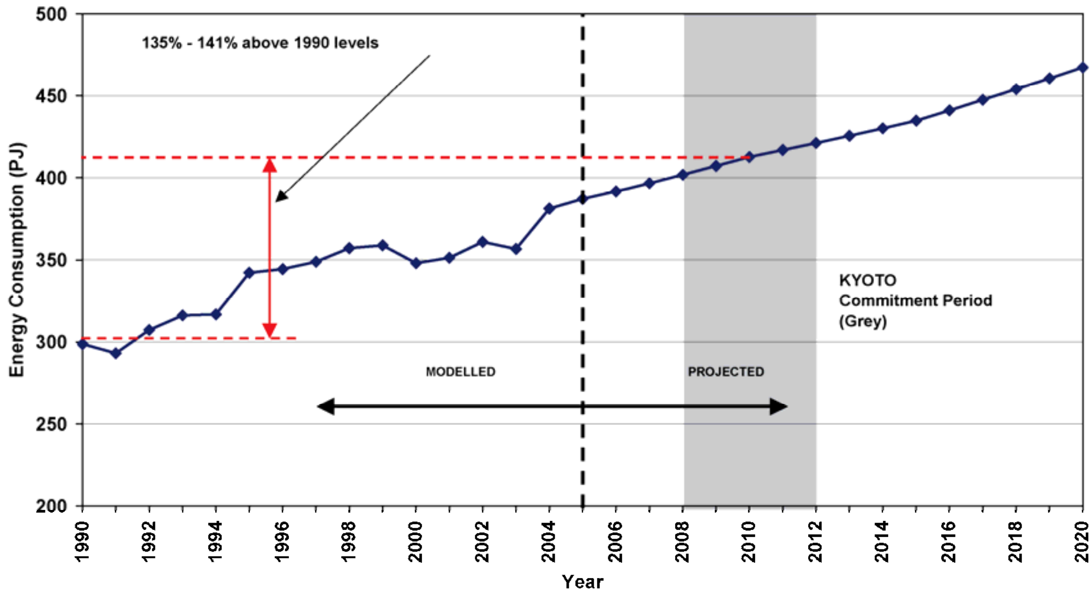

Figure 1 Trends in Energy Consumption in Australia's Residential Sector from 1990 to 2020. The Kyoto commitment period of 2008-12 is shaded grey. (EES 2008)

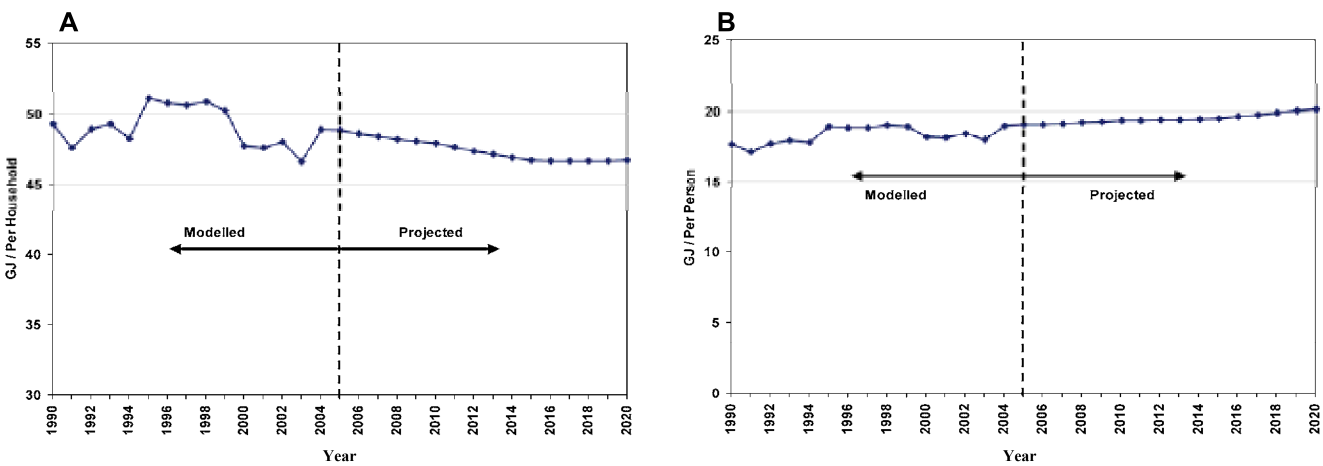

Figure 2 Trends in Australia's Residential Energy Use a) per household and b) per person– from 1990 to 2020 (EES 2008)

Dividing the total residential energy consumption by the estimated number of households in the corresponding year, enabled the energy consumption per household to be estimated. Since 1990 the average energy consumption per Australian household has remained relatively constant apart from the influence of year-to-year climatic variations that impact significantly on space conditioning energy demand (Figure 2a).

Projecting forward to 2020 there is expected to be about a 6% decline in energy consumption per household compared to 1990 levels. This decline is achieved despite expected increases in service deliveries to households, particularly in space conditioning and in a diverse range of appliance types such as larger more power-intensive televisions and an increase in standby energy consumption, lighting, computers and other home entertainment. The decline in energy consumption per household is primarily being driven by existing and planned energy programs designed to improve energy efficiency of appliances and the building shell.

By dividing the total residential energy consumption by the population in the corresponding year, the trend in per person residential energy consumption shows a steady but modest increase from 17 GJ/person in 1990 to 20 GJ/person in 2020, or a 20% increase over the study period (Figure 2b). This increase in energy consumption per person is partly being driven by a decline in persons per household, as there are some forms of fixed energy consumption that are associated with each household.

3.2 Trends By Fuel Type

The contribution of electricity to residential energy consumption is predicted to increase from 46% in 1990 to 53% in 2020 (Figure 3). Gas consumption is also expected to increase from 30% of total energy consumption in 1990 to 37% in 2020 while wood is predicted to decease from 21% to only 8% over the same period. LPG use will remain relatively unchanged and is expected to contribute to 2% of energy use in 2020.

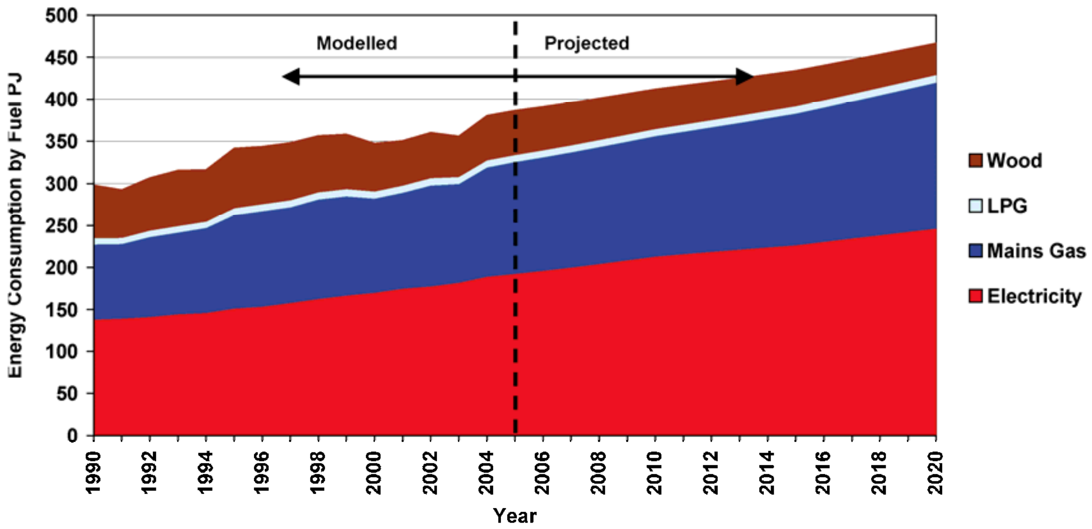

Figure 3 Trends in Residential Energy Consumption by Fuel Type – Australia 1990 to 2020 (EES 2008)

3.3 Trends By End Use

The national trends in energy consumption by each major end use from 1990 to 2020 are presented in Figure 4. Growth in electrical appliance energy consumption was the largest among major end-uses and was estimated to increase from 70.5 PJ in 1990 to 169.4 PJ in 2020, which represents an increase of 4.7% per annum. By 2020 energy use by electrical appliance is forecast to almost match space heating as the largest single energy use in the average Australian household. Energy demand for space heating is forecast to continue to rise but not at the same rate as for appliances (1.3% average growth per annum, 1990 to 2020).

Water heating was the other major energy use and after plateauing in 2004 is expected to decline slowly to 2020. Water heating is the only major energy use predicted to decline over the study period, principally as a result of various energy programs undertaken by Commonwealth and State/Territory Governments. The key drivers for changes in water heating energy are an increase in gas and solar technologies with a corresponding decrease in electric storage hot water. The declining demand for hot water has also resulted from an increase in water efficient appliances such as front loading washing machines and low-flow shower heads combined with a decline in the number of people per household.

Cooking energy is forecast to undergo slow but steady growth of approximately 1.8% per annum over the study period, roughly in line with the growth in the number of households. There is a trend towards gas cook tops and electric ovens, which is driven by consumer preference and overall performance. Cooking energy consumption remains a modest share of total energy consumption.

Of all the major end uses, space cooling is forecast to show the most rapid growth over the study period with an average growth of 16.1% per annum. This growth comes off a very low energy base of 3.0 PJ in 1990, so even with this high rate of growth in total energy terms by 2020 energy consumption for space cooling is only 17.7 PJ or 4% of total residential energy consumption in that year. However, despite its low contribution to total energy consumption, space cooling is an end use that attracts considerable political and policy attention due to its very poor load factor and the potential to create major problems for the electricity generation, transmission and distribution systems on peak summer days.

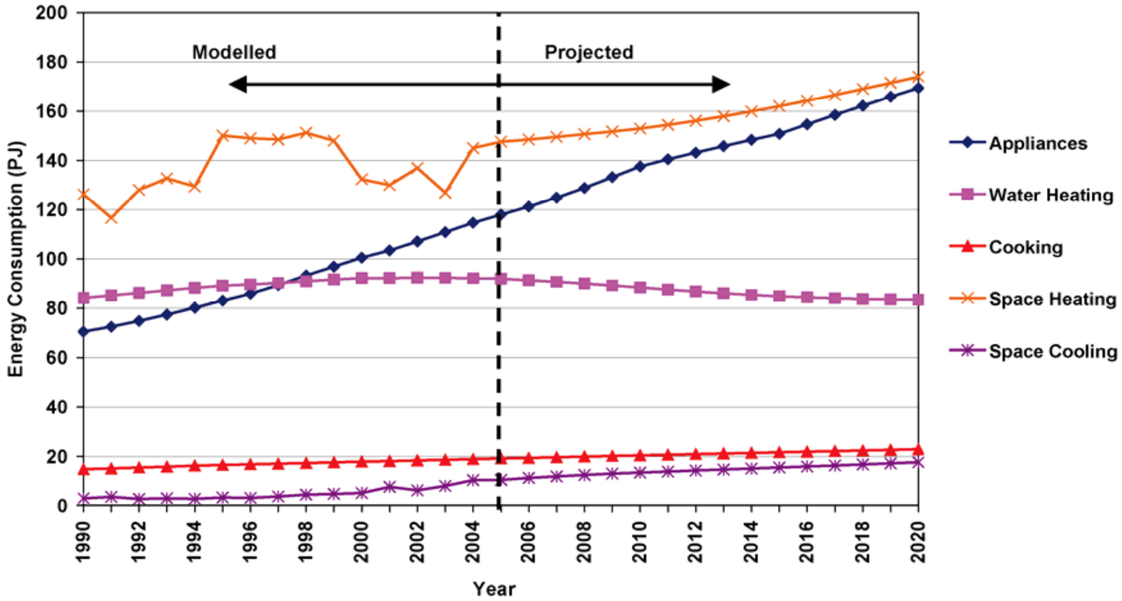

Figure 4 Trends in Total Energy Consumption in Australia's Residential Sector by End Use from 1990 to 2020 (EES 2008).

3.4 Trends in Building Shell Efficiency

Analysis of the building approval data has revealed that the average size of new dwellings is increasing rapidly. To illustrate this, the total number of households and the total floor area of the housing stock is presented in Figure 5. From 1986 to 2020 the total floor area of residential dwellings is expected to increase by 280% and the number of households is projected to increase by 177% over the same period.

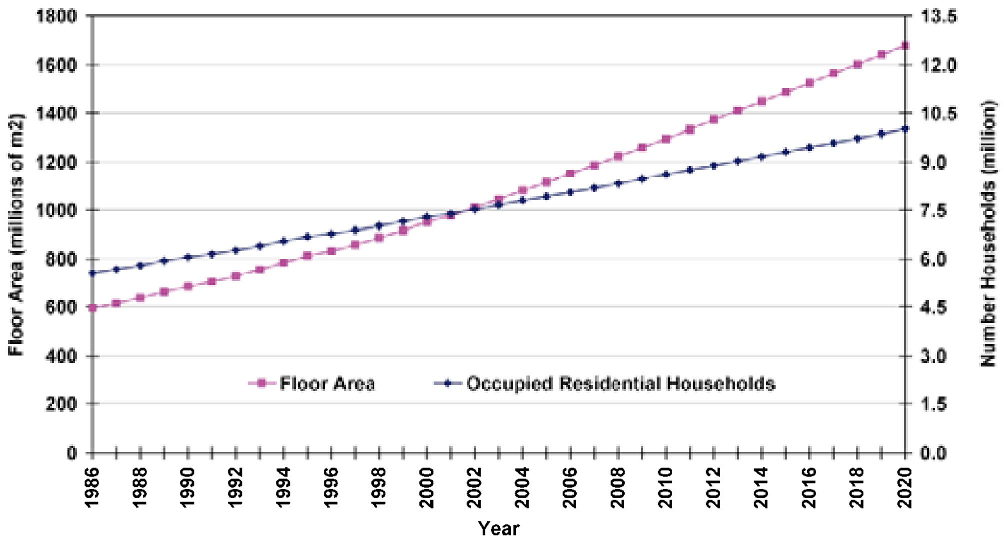

Figure 5 Trends in Floor Area and Number of Occupied Households in Australia's Residential Sector from 1986 to 2020 (EES 2008).

The national trend for building shell efficiency (i.e. total potential space conditioning load per square metre of floor area), shows a modest but steady improvement over the study period, down from 280 MJ/m^2 to approximately 200 MJ/m^2 (Figure 6). This improvement is being driven by policy initiatives that commenced in Victoria and the ACT in 1990 and by 2005 had expanded to include all states through the Building Code of Australia (BCA). Unfortunately the improvement in building shell efficiency over the study period has been outpaced by the rate of increase in average floor area. This has occurred to the extent that on a per household basis the potential space conditioning load (i.e. whole house heating and cooling in accordance with the default schedules of operation in the Nationwide House Energy Rating software - AccuRate) is projected to increase from about 30 GJ to 35 GJ per household per annum from 1986 to 2005 (Figure 6 - secondary "y" axis, blue line). Post 2005, where a standardised climate has been assumed the trend is reasonably steady suggesting that efficiency improvements are offsetting increases in average floor areas.

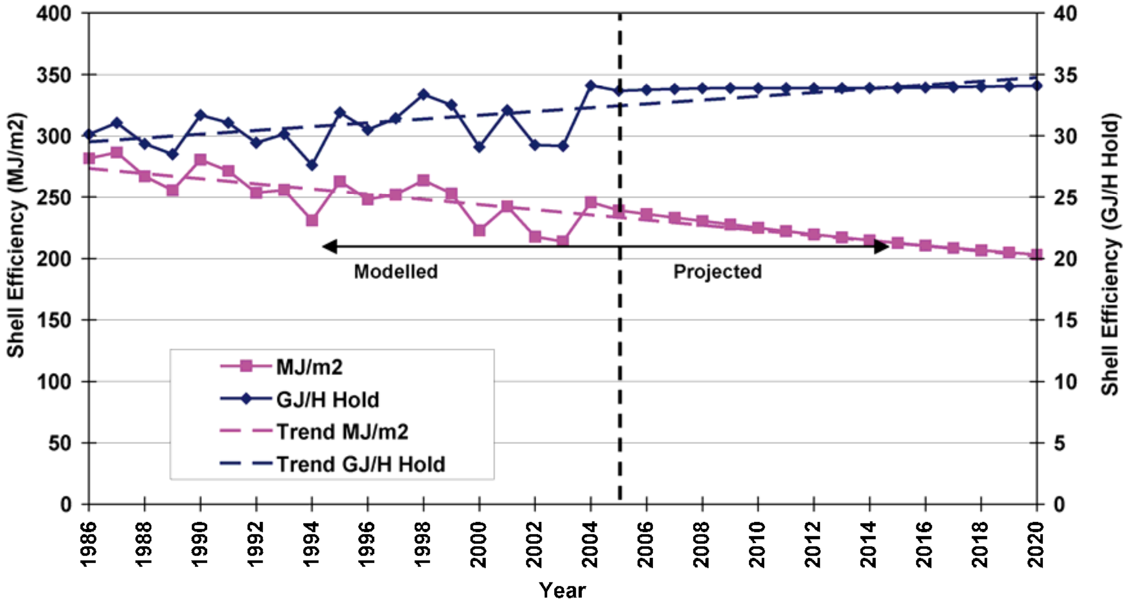

Figure 6 Trends in building shell efficiency in Australia's Residential Sector from 1986 to 2020 (EES 2008)

4 Emerging Trends

Space Conditioning

Energy demand for heating and cooling is projected to increase despite the introduction of minimum building shell performance standards in all jurisdictions. The main factors driving this trend are:

- The floor area of the average new dwelling continues to significantly exceed that of the stock average, thereby driving up the average floor area of the stock of dwellings as a whole over time. In addition householders continue to undertake renovations that increase the floor areas of their existing dwellings, particularly the older detached dwellings.
- The share of dwellings with whole house heating systems, particularly gas heating, is projected to rise significantly over the remainder of the study period, especially in the colder states.
- The share of dwellings with space cooling installed is projected to continue to rise significantly over the remainder of the study period – penetration of air conditioners has more than doubled in the past 10 years to around 65%. While the energy consumption for cooling is still relatively modest, this will have increased by a factor of five from 1990 to 2020 under current trends.
- The relatively recently introduced building shell performance standards only affect approximately 2% of the total stock per annum and in reality provide only a modest level of improvement compared to the BAU case in terms of total energy consumption projections to 2020. Nonetheless, stringent standards for new dwellings will have significant long-term energy impacts, which will continue to accrue beyond 2020. New housing built now with poor building shell efficiency will be a large long-term liability for future generations.

Additional analysis was undertaken for space conditioning loads using actual weather data over the past 20 years. The objective was to simulate energy demand in a set of dwellings where the housing stock characteristics were constant so that the only variable influencing space conditioning was the weather conditions. This type of analysis was designed to reveal the trends in potential space conditioning demand driven by climate variability independently from trends in housing stock type and numbers. Interestingly in all parts of Australia except the tropical north, the trend in predicted potential heating load over the study period was downward and the trend in cooling load was upwards as shown for South Australia(Figure 7). This trend is broadly consistent with predictions for climate impacts associated with global warming.

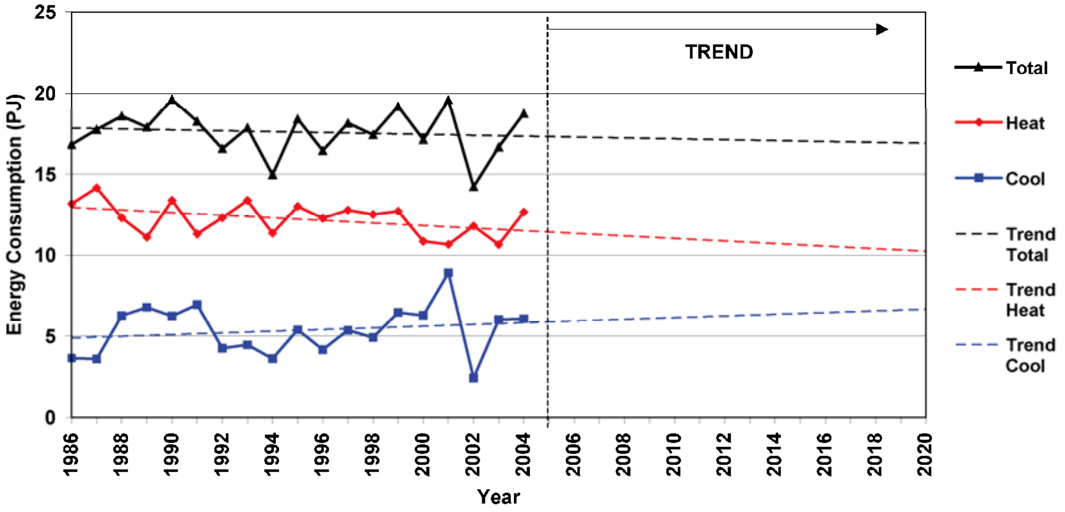

Figure 7 Space Conditioning Loads for Total, Heating and Cooling for Fixed Stock in the Residential Sector in South Australia from 1986 to 2020 (EES 2008).

Water Heating

In 1990 water heater usage accounted for approximately 84 PJ, this is estimated to have peaked at approximately 92 PJ in 2002 but is projected to slowly decline to 84 PJ by 2020, despite an increase in household numbers. The most significant trend over the study period for water heater energy use is the shift away from resistive electric heating (primarily storage systems) towards natural gas or combinations of solar with gas or electric boosting.

Increased natural gas use has coincided with the expansion of the natural gas network, which is growing steadily, but still only covers 46% of Australian households. Instantaneous gas units have also gained favour because of their compact size and their capacity to provide a continuous flow of hot water. Solar boosted water heating has also gained popularity over recent years (although the installed base was relatively small up to 2003 with a national average of about 4%). This increasing trend is being driven largely by initiatives at the state level, particularly the provision of rebate schemes and requirements for new homes to exclude or discourage electric storage water heaters. Some of these schemes are also boosting the stock of heat pump “solar” water heaters, which may become more significant over time as the capital costs are likely to fall.

The application of minimum energy performance standards (MEPS) (1999 and 2005 for electric and 2009 for gas), existing and emerging state and BCA requirements mandating the use of lower greenhouse intensive technologies (GWA 2007) and the various incentive schemes designed to encourage greater use of solar and heat pump technologies all combine to result in an overall downward trend in total energy consumption for water heaters from 2002 to 2020.

Refrigerators/Freezers

Refrigerator and freezer energy use grew slowly at start of the study period but has been in decline since 2004. In 1986 refrigerators and freezers usage combined accounted for approximately 26 PJ and by 2020 this is projected to have decreased to approximately 24 PJ. This decrease is predicted to occur despite an increase in total stock (refrigerators and freezers) from approximately 10 million units in 1986 to an estimated 17 million units by 2020 (70% increase).

Since the early 1990s the average energy consumption of new refrigerators and freezers has improved significantly, with a 40% reduction from 1993 to 2006 (EES 2006). These improvements have been driven by both the energy labelling program and by the introduction of MEPS requirements in 1999 followed by more stringent levels in 2005. The 2005 MEPS levels will continue to place downward pressure on energy growth for these products over the study period.

IT Equipment

Energy use of personal computers, laptops, monitors and miscellaneous Information Technology (IT) equipment has been growing rapidly since the start of the study period. In 1986 energy use of IT equipment was negligible, this was estimated to have increased to nearly 7.9 PJ by 2005 and is projected to continue to rise to almost 15 PJ by 2020.

The main drivers for the increase in energy consumption have been:

- An increase in the total number of households.
- A rapid increase in ownership of personal computer laptops and related equipment over the study period. Since 1986 ownership of personal computers has risen from virtually zero to 0.87 by 2005. Ownership is projected to rise to nominally 1.25 for personal computers and 0.65 for laptops by 2020.
- For personal computers, on-mode power consumption has virtually doubled from approximately 50W to more than 100W at present.
- Hours of use have almost doubled since the early 1990s from approximately 500 hours per annum to more than 900 hours per annum. This is projected to continue to rise to approximately 1200 hours per annum by 2020. There is a large potential for energy management of these products to reduce energy consumption.

Entertainment (Games, STB and TVs)

Games consoles, set top boxes and television energy use has been growing significantly in recent years.

In particular, television energy use has been growing steadily since the start of the study period but is now projected to grow more rapidly over the remainder of the study period. In 1986 TV usage accounted for approximately 3 PJ and in 2005 was estimated to have increased to approximately 12 PJ and is projected to exceed 45 PJ by 2020 (without the introduction of MEPS and energy labelling which is being finalised).

The main drivers for the projected rapid increase in energy consumption are as follows:

- The average number of televisions per household is projected to increase from approximately 1.5 in 1986 to a projected 2.1 by 2020. One in 4 households now buy a new television each year.
- Hours of viewing have been rising steadily over the study period from approximately 1500 per annum in 1986 to a projected 2800 hours by 2020 per TV.
- Newer technologies such as Plasma and LCD have been driving a trend towards a very rapid increase in average screen size. This trend has resulted in a rapid rise in energy consumption from an average on-mode consumption of approximately 65W in 1986 to 100W in 2005 and continuing to grow to an estimated 230W by 2020.

Lighting

Lighting energy use had shown steady and relatively strong growth since the start of the study period but is expected to decline from 2010 to 2015 then begin to rise again for the remainder of the study period. In 1986 lighting energy usage was approximately 13 PJ and by 2005 this is estimated to have increased to nearly 25 PJ with a peak of just over 27 PJ in 2010. Following a dip in energy consumption post 2010, consumption is projected to rise again to approximately 25 PJ by 2020.

Apart from the growth in the number of households and the increase in floor areas of those households the main drivers influencing the general upward trend in lighting energy consumption are:

- Since the early 1990's there has been a strong growth in the use of quartz halogen (QH) low voltage lighting. This change in technology is doubling the power density of these types through increased illumination levels.
- Compact fluorescent lamps have been slowly gaining market share since their introduction in the late 1980's. The penetration of this relatively efficient technology (approximately 50-65 lumens per watt) is expected to increase rapidly with the announced phase out of incandescent lamps in 2009. This is expected to drive lighting energy consumption downwards for the following 5 years.
- By 2015 it is expected that practically all standard incandescent lamps will have been removed from the stock (largely replaced by CFLs). Beyond 2015, increases in household numbers and the expected continuing popularity of QH lamps is projected to drive energy consumption upwards again. However, future regulatory proposals may ameliorate these trends.

5 Conclusions

The titled *Australian Residential Sector Baseline Energy Estimates 1986-2020* (EES 2008) provides one of the most detailed assessments of residential end use energy consumption ever undertaken in Australia. The "bottom up" end use modelling approach, while by no means unique or radical, has been applied in a comprehensive and systematic fashion to the residential sector to cover nearly all significant end uses. The bottom up estimates have been reconciled with state level top down data and there is generally good agreement, although the data suggests that there may be some questions regarding the reliability of national energy data share by sector which has been compiled since 2000.

Due to concerted efforts over many years, many areas now have rich data sets for modelling and therefore good modelling inputs can be developed. Areas such as ownership and attributes for new appliances and equipment are generally well documented. Despite the detailed modelling undertaken, the study revealed that there is a paucity of data in some areas. In particular, there is little individual product end use metering data which is critical to quantify the impacts of human interactions (frequency and duration of use) and climate and weather related impacts. This is one area where data collection efforts need to be expanded. Another area with poor data is average age and the distribution of age – very little documentation on retirements for either appliances or buildings exists. Lighting is another area where there is poor data on the stock and energy consumption.

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HOW 'ZERO' IS A 'ZERO CARBON' HOME?- A COMPREHENSIVE ASSESSMENT OF A 'ZERO CARBON' HOME

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Keywords: zero carbon, policy, building energy life cycle, microgeneration technologies

Summary

The UK government's domestic 'zero carbon' policy is incredibly challenging, requiring a vastly improved energy efficient home as well as introduction of microgeneration technologies into the dwellings in order to meet the target. However, by achieving the zero carbon status, it neglects the potential increase in the embodied carbon resulting from the increased insulation and microgeneration technologies being implemented. This paper evaluated the life cycle of the zero carbon homes through comparison of three eco-home (energy efficient home and two alternative zero carbon home) against a normal base case dwelling. It found that the additional embodied carbon can account for up to 32% of the total life cycle carbon compared with the base case (40 year life cycle with technology replacement rate of 20 years). The results also showed that different technologies performed better than others, wind turbine for example are less carbon intensive than photovoltaics. The research also highlights the lack of research as well as the difficulties in measuring the embodied carbon of microgeneration technologies. Nonetheless, despite the limitations it is important that the carbon emissions should be accounted for holistically in the policy development and in the zero carbon definition. However, more research should be carried out into life cycle carbon assessment of the eco-homes and the microgeneration technologies in order to substantiate the findings from this paper.

1 Introduction

Buildings consume large amount of energy over its life cycle and hence one of the biggest emitters of carbon dioxide and contributor to climate change. It has therefore been a key target sector for government in their energy and climate strategies initiatives. With UK's reserves of oil and gas declining, reducing energy consumption and energy independence has also been high on the political agenda.

The demand for heat and electricity directly contributes to our carbon impact. Our homes are largely heated and powered by fossil fuels (gas, oil, electricity) with 80% of electricity itself created by fossil fuels (coal, gas, oil) (SDC 2007). Carbon emissions from the domestic housing sector represent around 27% of the total UK emission (41.2MtC), with 73% of the emissions dominated by space and water heating (Figure 1).

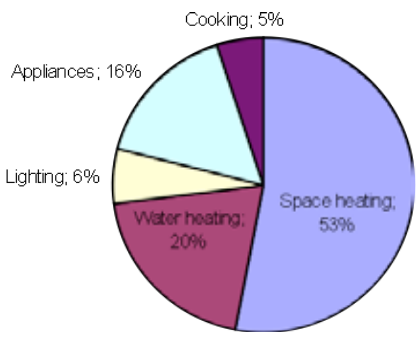
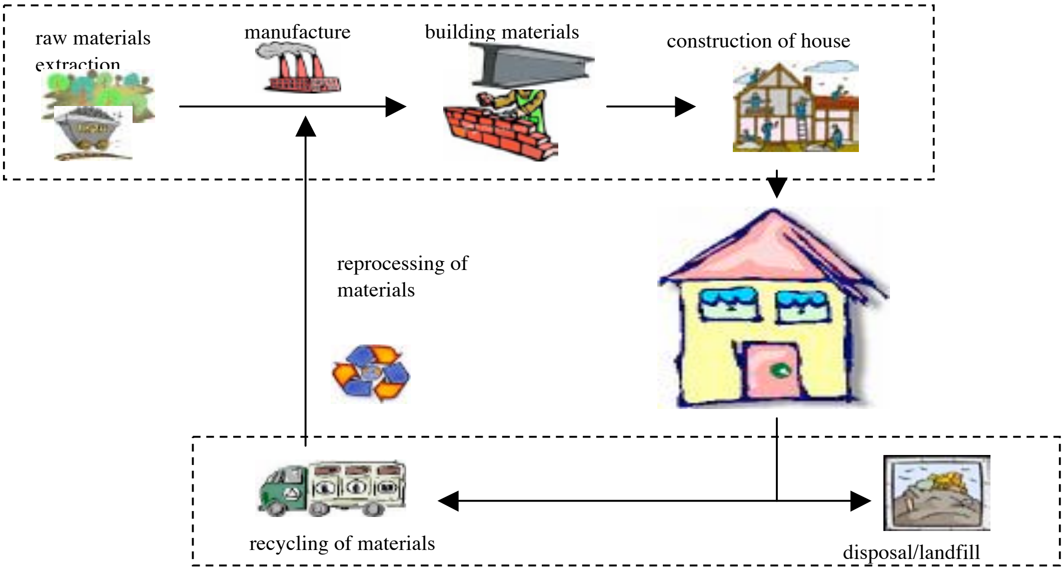


Figure 1: Domestic carbon emissions by end use. Average household emissions 1.54 tonnes carbon per year (DEFRA 2006)

1.1 Building Life Cycle

To evaluate the zero carbon policy it is important to review the building life cycle and appreciate the carbon emissions from the entire life cycle. The environmental impacts associated with each component of the building life cycle vary between different stages. In terms of energy use and carbon emissions, the operation phase account for the largest proportion with the material production phase constituting a significant proportion of energy use as well. The emissions from Figure 1 relates to only the operational phase of the life cycle. However, the embodied carbon has not been factored but can account for a significant proportion of the life cycle carbon of a dwelling, typically up to 20% in a conventional dwelling. More details of the embodied energy/carbon aspects of the building life cycle is detailed in Section 2.2.



1.2 'Zero carbon' policy

The zero carbon policy was announced in December 2006 as a key government initiative to address carbon and sustainability issues in the housing sector. The policy only covers the new build housing. Although, new housing currently represents only 1% of the total housing stock, it is expected to increase to constitute 25% of all housing stocks by 2050 (Barker 2004). Since the possibilities for achieving early improvements in environmental performance are particularly good in new housing (WWF 2003), there is clearly an opportunity to make a significant contribution by incorporating carbon reducing measures at the design and build stage.

The Code for Sustainable Homes, which became effective since April 2007, is the main policy vehicle from which the zero carbon targets will be achieved. It is widely regarded as one of the key government policy initiative to drive forward sustainability in new housing developments. The Code introduces a six star rating scheme similar to that of electrical white goods, and is designed to provide a marketing tool for developers and consumers. The Code sets minimum standards of carbon emissions for each Code level as indicated as follows:

Table 1: Government proposed energy/carbon performance targets over time (DCLG 2006)

Date	2010	2013	2016
Energy/carbon improvement as compared to Part L (Building Regulations 2006)	25%	44%	Zero carbon
Equivalent energy/carbon standard in Code	Code Level 3	Code Level 4	Code Level 6

The Code technical guidance defined a zero carbon home as one with 'zero net emissions of carbon dioxide (CO_2) from all energy use in the home'. The definition encompasses all energy use in the home (including energy for cooking, TVs, computers and other appliances) rather than just those energy uses that are currently part of building regulations (space heating, hot water, ventilation and some lighting) (DCLG 2006).

The precise definition of what is meant by zero carbon is unclear at the moment, and the government is currently in the process of defining what would constitute the definition, for example, whether offsite renewables offset would be allowed under the definition. This has significant implications in terms of how the energy of the dwelling is supplied, and in turn has implications on the embodied carbon of the building life cycle.

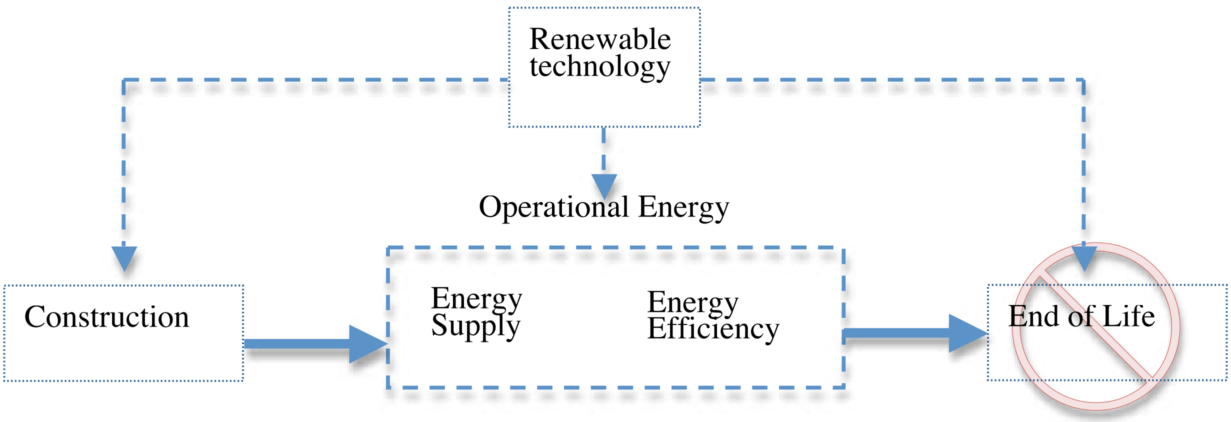
The zero carbon policy also only covers the carbon emissions resulting from the operational phase of the dwelling. It does not account for the embodied carbon from manufacture, transportation and construction of the house and its components.

The aim of this paper is to evaluate the zero carbon policy by assessing the carbon performance of a zero carbon home over its life cycle. It will compare the components of meeting zero carbon through implementation of a range of technological measures, and assess their performance against a base case conventional dwelling. It is intended that the results would provide a more holistic life cycle carbon assessment of a zero carbon home, and hopes that it will help inform policy makers and housing developers on the most efficient ways of achieving the zero carbon targets.

It is important to note that the aim of the paper is not to provide accurate energy and carbon figures, but rather to provide an indication of the rough requirements in order to meet the zero carbon targets and to appraise the zero carbon policy. Nevertheless, the modelling will encompass as much features and details as possible to produce reasonably accurate and confident results.

2 Methodology

A model has been developed to model the life cycle energy requirements of a typical home, including the embodied energy/carbon, operational energy and energy offset from microgeneration technologies. Energy relating to end of life has not been factored into the model as it is quite difficult to model the impacts and in any case, it is assumed that it will not have a significant impact over the building life cycle.



Sections 2.1 – 2.3 describes each stages of the life cycle model and the main parameters and assumptions used in the modelling.

2.1 Operational energy

A simplified operational energy demand model has been developed. The purpose of this model is to obtain a general indication of the energy demand of a typical home that is being modelled. It is not intended to provide an accurate representation of the energy use of a home. As such, only the major energy usage of the home has been modelled, i.e. energy for space heating, water heating and electricity consumption.

The energy demand for hot water has been estimated with a function based on the floor area expressed in Standard Assessment Procedure (SAP) 2005. Estimation of electricity consumption has been calculated based on the assumptions described in Building Research Establishment Domestic Energy Model (BREDEM). Low energy lighting and appliances has been assumed with a consumption level of 40% lower than average electricity usage by normal households. The space heating demand has been estimated based on the degree day method described in BREDEM and SAP 2005 (Mortal 2007). Description of the dwelling modelled is provided in the model parameters in Section 3.

2.2 Technological requirements to meet zero carbon

Meeting zero carbon is incredibly challenging. Previous work (Chow 2008, Mortal *et al* 2007) have identified the most cost effective measures in meeting the zero carbon requirements. The most efficient and cost effective way is to reduce the initial base line energy demand of the dwelling through measures such as increase insulation and use of energy efficient fittings, followed by provision of microgeneration energy technologies

There are a number of microgeneration technologies suitable for reducing the operational energy and carbon emissions of a building. However, the technologies vary considerably in terms of their energy and carbon performance, reliability, and cost effectiveness. A feasibility study of the renewable technologies from previous research identified biomass, photovoltaics (PV) and wind turbine as the best options to meet zero carbon for a domestic dwelling.

Ground source heat pumps (GSHP) was deemed unsuitable due to the substantial additional electricity requirement and therefore requiring additional electricity capacity to be generated from other technologies. Solar hot water was considered suitable, although they are limited to a fixed proportion of annual hot water demand it is able to offset, and therefore it was deemed more economical to have a larger biomass boiler to supply all the space and hot water demand of the dwelling.

Biomass is not considered carbon neutral due to the manufacturing, processing and transportation of the fuel, and therefore additional energy from PV or wind will be required to offset the additional carbon emission. This has been factored into the energy model.

2.3 Embodied energy

The embodied energy refers to all the energy required to produce, manufacture and install/construct a particular product. The most common methodology used for determining the embodied energy/carbon of a product is the life cycle assessment methodology.

Research has shown that the embodied energy of a building can account for a significant proportion of the life cycle energy use. However, in this assessment, only the additional embodied energy/carbon resulting from increase in materials and technological systems will be considered. The assessment will be based on the additional embodied carbon requirements over a defined base case (standard building regulation). It will therefore exclude all the main embodied carbon associated with the basic building materials required for construction of the structure and foundations of the house. However, the additional insulation for a low energy home will be factored into the model.

Measuring the embodied energy/carbon of the technologies is extremely difficult. The life cycle methodologies are dependent upon a number of factors and assumptions used within the system boundary:

- Variation of production methods of the technologies, impacting the quantity of energy required.
- Variation in the transportation requirements
- Variation in the raw materials used for production of the technologies by different manufacturers
- Location of the processing plants, and suppliers, again impacting the transportation requirements
- System boundary definition, for example, whether to include the energy required from the technology installers travelling to the dwellings.

In addition, the carbon intensity of the energy mix varies between different countries, and this will have an impact on the embodied carbon of the technologies. Embodied CO_2 is not directly proportional to embodied energy. Electricity generation generally has efficiencies of around 30%, as compared with heat generation efficiencies of around 80%. Processes that require high grade electrical energy will result in higher CO_2 emissions than those that run on low grade heat energy. It also depends on the energy source for that particular process. In Scandinavia for example, most of the power used in the aluminium industry comes from hydro-electric schemes and therefore has no embodied CO_2 in its manufacture (Bioregional 2008).

Embodied Carbon of Microgeneration technologies

The data used in calculating the embodied energy of the microgeneration technologies have been based on secondary research that has been carried out previously. Little work has been done to determine the embodied impacts of microgeneration technologies and therefore large assumptions are made about the embodied energy figures used in the model.

Photovoltaic cells are considerably energy intensive to produce. Substantial research has been done on the different photovoltaic manufacturers and types of photovoltaic cells (e.g. Wilson Young 1995, Knapp Jester 2001, Alsema Niuwlaar 2000). One of the most comprehensive work on photovoltaic cells have been from Bankier & Gale 2006, where they compared and reviewed some 16 previous research done on photovoltaics. Their research found that the total energy requirement for producing and installing a monocrystalline PV module was 6,400 MJ/m^2 (Bankier Gale 2006).

Comparatively few research has been done on domestic micro-wind turbines. There has been some research on larger scale turbines, particularly from Danish research. They estimated a large scale wind turbine to have an energy payback of a year. However, they are far more efficient than domestic sized turbines and therefore it had been assumed that the energy payback period for a 6kW turbine is a conservative 3 years. A Cambridge-MIT research estimated the embodied energy to be 13,000kWh per turbine (Woolf 2002).

There has been little or no research work done on biomass boilers. However, as this assessment is only focused on comparing the additional embodied energy, it has been assumed that the embodied carbon of a biomass boiler system is equivalent to that of a conventional boiler system. A biomass boiler requires additional infrastructure in terms of storage facilities, additional pipework, flue extractor, but these have been considered to be negligible in this assessment. Some embodied energy have also been allocated to the manufacture of biomass wood pellets. These have been provided by the Standard Assessment Procedure (SAP 2005).

There has been some research into embodied energy of insulation materials. These vary considerably between types of insulant used. Polystyrene insulation has the highest embodied energy (3770MJ/m^3) compared to natural materials such as mineral wool which only has an embodied energy of 970 MJ/m^3) (Canadian Architect 2000). For this assessment fibreglass insulation have been assumed for the model.

In summary, the figures used for the embodied energy calculations are as follows:

Technology	**Embodied energy (converted to kWh/unit)**	**Embodied carbon (carbon intensity assumed 0.083kgC/kWh)**
Photovoltaic (Monocrsytalline)	1,777 kWh/m^2	147 kgC/m^2
Wind turbine (6kW turbine)	13,000 kWh/turbine (6kW)	1,079 kgC/turbine (6kW)
Biomass boiler	Considered similar to conventional gas boiler with negligible increase in embodied energy. However, carbon emissions from biomass fuel have been accounted for.	Wood pellets- 0.007 kgC/kWh
Insulation (fibreglass)	270 kWh/m^3	22.4 kgC/m^3

3 Model Parameters

A simple model was developed to evaluate the life cycle energy consumption of a typical domestic home. Section 2.1 described the basic assumptions used in the model. To compare the impacts of the embodied energy resulting from reaching zero carbon, a case study of four identical homes each with varying energy performance features will be used. The four homes are identical in terms of their specifications but differ in their space heating energy demand and types of microgeneration technologies used.

The base case dwelling will resemble the current UK Building Regulation standards, and is based on the requirements under the 2005 Standard Assessment Procedure (SAP) for calculating energy demand for a domestic dwelling. Table 2 describes the basic reference values for the base case dwelling being modelled.

Table 2: Reference values of base case dwelling

Element or system	Value
House type	Two storey detached house
Total floor area	$128m^2$
Windows	25% of the total floor area
Walls	U=0.35 W/m^2K
Floors	U=0.25 W/m^2K
Roofs	U=0.16 W/m^2K
Thermal bridging	0.11 x total exposed surface area (W/K)
Windows	U=2.0 W/m^2K Double glazed, Frame factor 0.7, Solar energy transmittance 0.72 Light transmittance 0.08
Infiltration	0.5 Air changes per hour

The other three homes modelled against the base case will be significantly more energy efficient consisting of comparatively lower U-Values for the building elements. To achieve the U-values as specified, the insulation of the building elements were increased by 150mm to 200mm thick. Table 3 summarises the different reference values used compared with the base case dwelling.

The increase in embodied carbon in the insulation throughout the building elements has been factored into the model. However, the increase in other building structural elements to accommodate the increased width and associated structural requirements has not been included. It was deemed difficult to estimate the additional requirements and was also deemed negligible. This home will be referred to as an 'eco-home' in the context of this paper.

Table 3: Reference values of eco-home

Element or system	Value
Walls	U=0.13 W/m^2K
Floors	U=0.12 W/m^2K
Roofs	U=0.10 W/m^2K
Windows	U=1.0 W/m^2K Triple glazed

Modelling of the base case and 'eco-home' dwelling produced an estimated of the space and water heating and electrical energy demand, as summarised in Table 4.

Table 4: Estimated energy demand of base case and eco-home dwelling

	Base Case	Eco-Home
Space heating	11,880 kWh/yr	6,850 kWh/yr
Water heating	3,373 kWh/yr	2,867 kWh/yr
Electricity	4,157 kWh/yr	4,157 kWh/yr
Total	**19,410 kWh/yr**	**13,874 kWh/yr**

4 Results

Using the energy demand modelled, the appropriate microgeneration technologies were specified. There are a number of ways to meet all the energy demand to achieve zero carbon in a dwelling. Two options have been presented and analysed in this assessment.

Option 1- It was estimated that 41m^2 of PV panels with an output of 600 kWh/yr/m^2 and 10kW of biomass boiler with a 90% efficiency is required to supply all the energy required

Option 2- Alternatively a 6kW wind turbine with an annual energy output of 3,397 kWh/year and 13m^2 of PV panels are also able to supply all the electrical demand of the dwelling.

Table summarises the estimated energy demand and carbon emissions of the four case study modelled.

Table 5: Summary of energy demand and carbon emissions of the four dwelling type.

	Base Case (Building Regulations Part L)	**Eco-home (energy efficient home)**	**Eco-Home + Option 1 (biomass boiler and 41m^2 of PV panels)**	**Eco-Home + Option 2 (biomass boiler, 13m^2 PV panels and one 6kW wind turbine)**
Space heating	11,880 kWh/yr	6,850 kWh/yr	6,850 kWh/yr	6,850 kWh/yr
Water heating	3,373 kWh/yr	2,867 kWh/yr	2,867 kWh/yr	2,867 kWh/yr
Electricity	4,157 kWh/yr	4,157 kWh/yr	4,157 kWh/yr	4,157 kWh/yr
Annual carbon emissions				
Space heating	629.64 kgC/yr	363.05 kgC/yr	47.95 kgC/yr	47.95 kgC/yr
Water heating	178.77 kgC/yr	151.95 kgC/yr	20.07 kgC/yr	20.07 kgC/yr
Electricity	469.74 kgC/yr	469.74 kgC/yr	0 kgC/yr	0 kgC/yr
Additional embodied carbon over base case	0	573 kgC	6,623 kgC	3,570 kgC

4.1 Life cycle carbon analysis

The results showed that the different features of the homes and microgeneration technologies used result in varying levels of embodied carbon and operational carbon emissions. In order to provide a better and more holistic comparison of the carbon performance of the different dwelling types, a life cycle carbon assessment is performed.

The calculations of the life cycle carbon analysis is based on the following assumptions:

- The microgeneration technologies have been assumed to have a lifespan of 20 years.
- No carbon emissions associated with maintenance and repairs have been assumed.
- No discounting of the initial embodied carbon have been applied to the modelling.
- No change in carbon intensity have been assumed for the primary energy supply for the base case dwelling, i.e. gas and electricity. The same is true for biomass wood pellets.

Figure 2 displays the total cumulative carbon emissions of the four dwelling types over a 40 year life cycle. It shows that despite the initial increase in embodied carbon of the eco-homes due to the increased insulation and microgeneration technologies, the dwellings are still able to save significant amount quantity of carbon over the life cycle. However, the proportion of carbon saved differs depending on the type of microgeneration technology used.

Table 6: Summary of the potential carbon savings of the dwellings over the base case

	Base Case (Building Regulations Part L)	**Eco-home (energy efficient home)**	**Eco-Home + Option 1 (biomass boiler and 41m² of PV panels)**	**Eco-Home + Option 2 (biomass boiler, 13m² PV panels and one 6kW wind turbine)**
40 year life cycle carbon savings over base case (percentage)		22%	68%	80%

Table 6 summarised the potential carbon savings over the base case and showed that a home with energy efficiency measures and microgeneration technologies can reduce carbon emissions by up to 80% compared with the base case dwelling over a 40 year life cycle. However, these 'zero carbon' homes still account for a significant proportion of carbon emissions, up to 15,000 kgC more in embodied carbon.

The results also showed that insulation are very efficient in reducing carbon emissions, being able to reduce a significant proportion of carbon emissions over its life cycle with a little increase in embodied carbon (over 10 tons can be saved over a 40 year life cycle with just a 500 kg increase in embodied carbon).

Sensitivity

The results from this paper have been calculated based on a number of key assumptions made on the embodied carbon of the microgeneration technologies and their life span. These assumptions have been described throughout Sections 2 and 3. Changes in these factors are likely to affect the life cycle carbon performances significantly. As such, it is difficult to evaluate the performance of the microgeneration technologies with any significant amount of confidence. Nonetheless, it indicates that embodied carbon associated with the zero carbon homes can account for a substantial increase in the proportion of the life cycle carbon emissions.

The life cycle carbon calculations are also dependent upon the system boundary of the study and whether indirect embodied carbon, such as those resulting from operation, maintenance and transport of the microgeneration technology industry, have been considered. These can contribute significantly to the embodied impacts of the technologies.

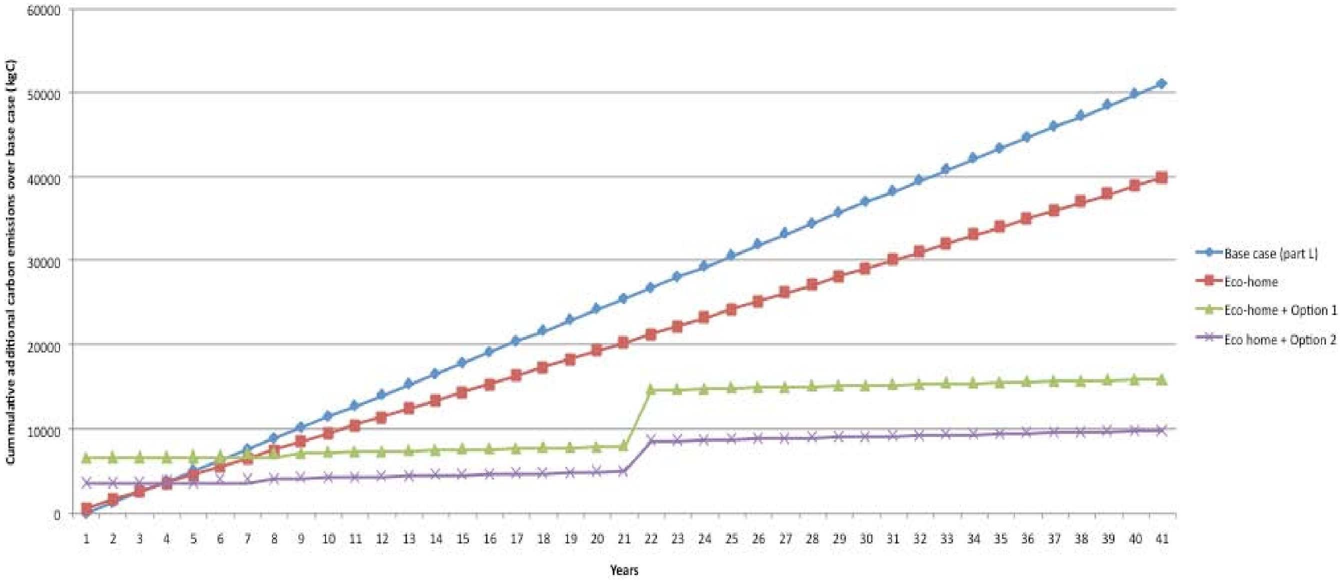


Figure 2: Cumulative additional carbon emissions over a 40 year life cycle for four different dwellings modelled

5 Discussion

The purpose of this paper is to evaluate the zero carbon policy by assessing the embodied implications of meeting the zero carbon targets over the building life cycle. The results have shown that the embodied carbon resulting from increased insulation and implementing microgeneration technologies can account for a significant increase in the proportion of the life cycle impacts, which have been excluded by the official 'zero carbon' definition. Estimates from the research suggest that using energy intensive microgeneration technologies such as photovoltaic panels can account for up to 22% of more carbon emissions compared to a base case normal dwelling. It therefore argues that a more holistic accountability of the life cycle carbon should form some part of the zero carbon definition.

The research also highlighted that different microgeneration technologies perform better than others e.g. wind turbines are more effective than photovoltaics. Again, this is not accounted for in the zero carbon policy which would not differentiate between higher embodied carbon technologies.

However, the research also highlights the potential difficulties in accounting for the embodied impacts of microgeneration technologies as they differ significantly depending on the production processes, location, transportation requirements and carbon intensity of the energy mix of the country. It is therefore essential that a systematic methodology for accounting for these impacts are developed and addressed in the life cycle assessment methodologies, as well as in the definition of zero carbon.

The significant increase in capital costs for incorporating these technologies have also not been considered. Previous research (Mortal et al 2007, Chow 2007, Chow 2008, Kingspan 2007) have concluded that capital costs can add up to 30% to the overall build costs. The relative efficiencies of reducing carbon emissions become more significant if embodied carbon are to be factored into the assessment. Nevertheless, it is still worthwhile over the life cycle of the building to incorporate microgeneration but these have to be considered along with higher embodied carbon technologies and cost implications.

In terms of the carbon and cost benefit of setting and striving towards zero carbon targets, the research suggests that it is perhaps more efficient to reduce demand through better building fabric and to decrease consumption of electricity and hot water than to require implementation of microgeneration technologies into domestic dwellings. The research indicated a significant proportion of carbon can be mitigated with better thermal performance building envelope. Passive house standards, for example, can reduce the space heating requirement dramatically at significantly less costs than integrating microgeneration technologies. It is still able to perform comparatively in terms of its life cycle carbon compared to a zero carbon home if the additional embodied carbon of the technologies are also considered. Therefore, government policies should perhaps focus more on achieving higher standards of building construction with minimal carbon emissions resulting from the operation of the dwelling, while at the same time strive towards reducing the carbon intensity of the national grid energy, than to set zero carbon standards which are relatively inefficient. However, substantial further research would need to be carried out to substantiate the findings from this paper.

Other considerations such as district energy supply or offsite renewables might also impact the embodied carbon and life cycle carbon substantially, and could potentially provide a more suitable and efficient route to achieving zero carbon levels.

6 Conclusion

Meeting the UK government's zero carbon policy is incredibly challenging, and require domestic dwellings to be built to higher energy efficient standards as well as requiring implementation of microgeneration technologies. While the policy is certainly commendable and will substantially reduce the carbon emissions over the operational phase, it does not however, account for the relatively significant increase in the embodied carbon resulting from the additional measures to reach zero carbon. This paper assessed two different zero carbon home and highlighted the substantial increase in embodied carbon, primarily due to the high carbon intensity of the photovoltaic panels.

The research also highlighted the difficulty in measuring embodied carbon of the technologies and more research would be required to develop a more comprehensive methodology for accounting the complete life cycle carbon emissions of buildings. This paper argues for a more holistic accounting of carbon emissions over the building life cycle rather than focusing on operational phase and the inclusion of the embodied elements to the definition of zero carbon.

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RATE ABSORPTION APPROACH FOR BUSINESS SECTOR ADOPTION OF ENERGY CONSERVATION MEASURES (ECMs)

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Summary

Utilizing publicly available utility and property tax records, the energy use of more than 13,000 U.S. commercial businesses from 1994-2006 were analyzed by twelve (12) primary submarkets. Energy use intensity (kWh/m^2/yr) and other energy characteristics were determined for each market. The energy savings and added first cost of viable energy conservation measures (ECMs) were compared to minimally code-compliant HVAC and lighting alternatives in each market. A rate absorption program was devised that offered utility-provided rebates ranging from 15% to 65% of the added first cost of each ECM. The cost of each rebate and corresponding rate of adoption, administrative costs, lost energy sales revenue and utility variable cost savings were absorbed by changes in energy rates. Results indicate that a 65% ECM rebate and 25% market adoption would require a $US 0.043/kWh (50%) rate increase for the utility to remain cost neutral. Businesses choosing not to implement conservation measures (e.g. "non-adopters") would realize an increase in energy costs of between 7%-50%, depending on the level of rebate and percentage of market adoption. In contrast, those businesses choosing to implement conservation measures (e.g. "adopters") could realize net savings of up to 14.4% in spite of higher energy rates. On average, the energy costs for adopters is 19.9% less than non-adopters or, between $US 2,897.00 and 4,094.00 less each year for the average business. The subsequent reduction of 31,900kWh/yr in energy consumption could on average, eliminate the release of 18,821kg of CO_2 emissions each year for each business.

The objective of this study is to demonstrate a methodology for energy utilities to develop market-based conservation programs that produce the greatest energy reductions and carbon offset for the lowest program cost. By conserving energy, the consumer reduces operating costs and improves production efficiency and competitiveness. Similarly, the utility reduces the need for costly peak load generation, capacity expansion and wholesale power purchasing.

1. Introduction

Global warming is the increase in the Earth's near surface atmosphere and ocean temperature. Although climate change is a natural and cyclical process, much debate now focuses on the human contribution to global warming caused by the use of fossil fuels for energy and subsequent release of carbon dioxide and other "greenhouse" gases into the atmosphere. According to former U.S. Vice President Albert Gore in his Nobel Prize winning documentary "*An Inconvenient Truth*", global warming has caused the number of major hurricanes to double in the last 30 years and, the rate of glacial flow in Greenland to double in only the past 10 years. Gore further contends that deaths from global warming will likewise double in the next 25 years to more than 300,000 per year as a result of climate change induced heat, flooding and drought.

The U.S. represents roughly 5% of the world's population, yet, 23% of its fossil fuel consumption. Approximately one-third of all energy in the U.S. is consumed within the built environment, and more than one-third of this energy is used by the commercial business sector (DOE, 2004). Commercial buildings in the U.S. number more than 4,859,000 and occupy more than 6.7 billion square meters of floor area. The average commercial building in the U.S. is approximately 1,300m^2, yet nearly three-fourths (73%) of all buildings are 930m^2 or smaller. Although only two-percent of U.S. buildings are larger than 9,300m^2, these buildings account for 35% of total U.S. commercial floor space. In 2003, the average U.S. commercial building consumed 577kWh/m^2/yr (EIA, 2006).

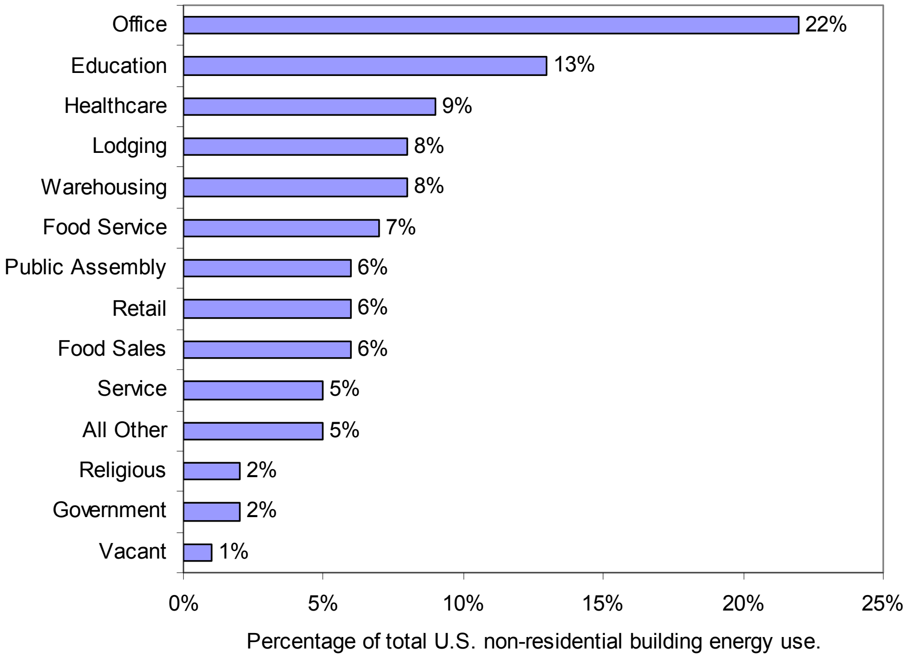

Figure 1. Percentage of U.S. non-residential energy use by market sector (EIA, 2006).

Commercial buildings consist of a variety of building types including offices, retail, service, education, food service and sales, healthcare, government and public assembly, and many other non-residential uses. The commercial office market occupies the largest share of non-residential floor area (17%). With an average energy use intensity of 667kWh/m^2/yr, the office market is the largest U.S. energy user (Figure 1). Combined, office, retail, education and warehousing comprise 60% of the total commercial floor space, 51% of buildings and, 49% of total non-residential energy use in the U.S. However, food service and sales are among the most energy intensive, consuming on average, between 1,646-1,687kWh/m^2/yr (Figure 2). Each of these markets has unique energy needs, but as a whole, more than half of all energy used by commercial buildings is dedicated to space conditioning and lighting (Grosskopf, 2007).

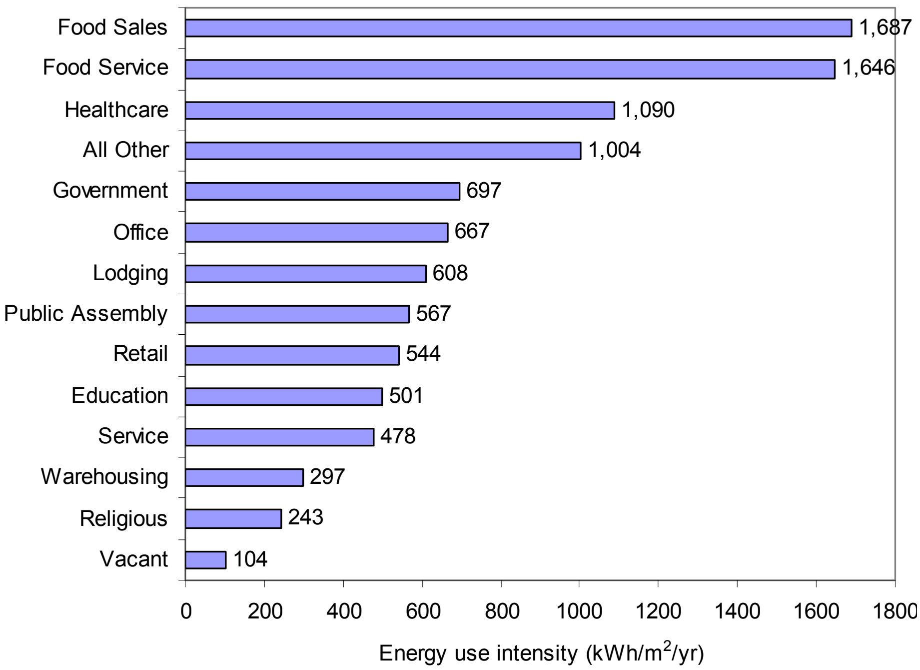

Figure 2. U.S. energy use intensity of non-residential buildings by market sector (EIA, 2006).

2. Traditional Market Barriers

Of 262 utilities selling 75% of all power produced in the U.S., 55% have commercial energy conservation programs. In spite of the namesake, the focus of many programs however, is to reduce peak energy demand (kW) while maintaining energy consumption (kWh). By doing this, utilities are able to reduce supply costs and defer new electric generation capacity while minimizing lost electric sales. As proof, U.S. utilities reduced peak demand 5.3% through "energy conservation" programs in 2000 while reducing net energy consumption only 1.1% (DSM, 2000). The consumer however, is motivated to minimize the added initial costs of implementing energy conservation measures while maximizing energy savings (kWh). Because most ECMs reduce energy consumption evenly throughout the day and throughout the year, most contribute significantly more toward energy reduction than demand reduction. Although many ECMs are cost effective for the consumer, most are not cost effective for the utility. As a result, many U.S. utilities have divested from energy conservation programs. Following years of growth, program expenditures fell from USD 2.74 billion in 1993 to USD 2.5 billion in 1999. From the height of U.S. program investment in 1993, incremental energy savings fell 8.4% from 8,980 million kilowatt-hours (kWh) to 8,229 million kWh in less than 12 months, a trend that continues today (EIA, 2006).

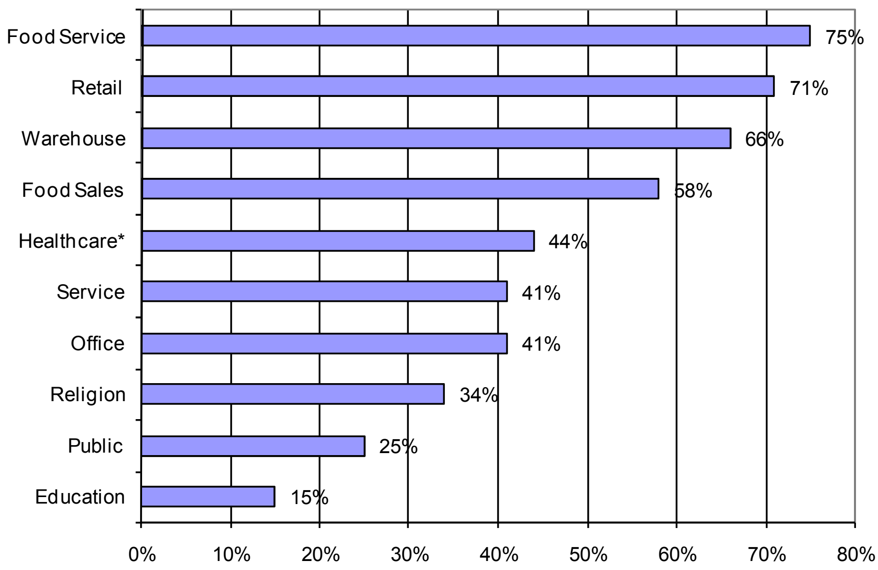

Figure 3. Percentage of space leased by number of U.S. commercial buildings (EIA, 2006).

Another significant market barrier for energy conservation is the disproportionately high percentage of non-residential lease space (Figure 3). More than half of all commercial floor area in the U.S. is leased. Developers of commercial lease space in the U.S. often require tenant businesses to pay their own utility costs. As a result, the developer has little financial incentive to implement energy conservation measures during building design and construction. Unless the leaser is a major "anchor" tenant negotiating a long-term lease, the leaser has very little or no control over building design or performance specifications. Furthermore, tenants generally place a greater premium on location, lease rates and aesthetics when selecting lease space. On average, commercial tenants change lease space every 3-5 years, creating additional barriers to conservation product and service adoption, as businesses with high turnover are unlikely to remain in spaces long enough to realize an energy savings return on investment (e.g. "payback").

Even for owner-occupants, discretionary investments into energy efficiency beyond minimum building code requirements usually require a return on investment that is competitive with other investment choices available to the business. Unlike the residential market, where nearly all housing is roughly the same size, serves the same function, has the same relative occupancy and hours of operation, commercial buildings are considerably more diverse. Therefore, it is more difficult to determine "payback" of conservation investments with any degree of certainty. In addition, many sustainable building practices have competing objectives. Improved indoor air quality (IAQ) that is achieved by introducing added fresh air ventilation into the building for example, often results in added energy to heat, cool, humidify or dehumidify the outside air. Given these and many other market barriers, most U.S. businesses are unwilling implement energy efficiency beyond minimum building or energy code requirements.

3. New Market Enablers

To overcome the market barriers imposed on traditional energy conservation programs, a rate absorption program is proposed that allows the utility to pass along the cost of energy conservation rebates and other incentives to the consumer. In other words, the cost of the incentive program, as well as the utilities' administrative costs and lost revenue are absorbed by increases in energy rates. Reductions in utility supply costs or deferred capital costs may either be credited back to the program or retained by the utility. In theory, businesses choosing not to implement conservation measures (e.g. "non-adopters") would realize an increase in energy costs. In contrast, those businesses choosing to implement conservation measures (e.g. "adopters") would realize an energy savings in spite of higher energy rates. By conserving energy, the "adopter" reduces operating costs and improves production efficiency and competitiveness over the "non-adopter". Similarly, the utility reduces the need for costly peak load generation, capacity expansion and wholesale power purchasing. The goal of this "win-win" market-based approach is to maximize energy conservation and carbon offset at the lowest program cost.

3.1 Case study

To test the rate absorption approach, a case study was developed using a small-to-medium sized city of approximately 200,000 residents in the southeast U.S. A total of 13,827 commercial and industrial (C&I) account records from roughly 4,700 businesses were obtained from a 610MW utility serving this community. North American Industrial Code System (NAICS) identification numbers, which were used to categorize each account by market, were matched to 12,188 (88.1%) records using available utility account information. A confidence code ranging from 1 (low) to 10 (high) was assigned to each NAICS match. Accounts that did not achieve NAICS assignments with a confidence code of "6" or greater were eliminated. A total of 9,650 (69.8%) commercial accounts were assigned a NAICS identification number with confidence code of "6" or greater. Of those records successfully matched with a NAICS identification number, inactive electric accounts were eliminated, resulting in a total of 7,048 (51.0%) remaining accounts. Of 7,048 active electric accounts successfully assigned a NAICS identification number, 4,917 (35.6%) were matched by customer name, service address and other account information to a parcel that had a valid county property appraiser tax identification number. Of those, 4,162 (30.1%) accounts matched parcels having summarized total floor area for that parcel.

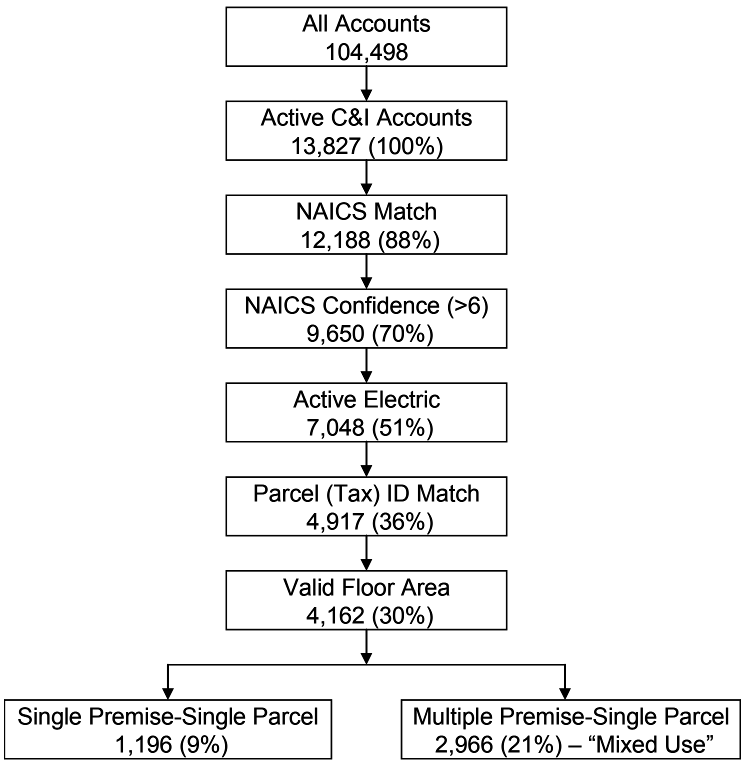

Figure 4. Methodology used to determine energy use intensity (kWh/m^2/yr) by market.

The remaining 4,162 records were distributed across 1,844 unique parcels. Of these, 1,197 (28.8%) were single accounts located on single parcels. The remaining 2,965 (71.2%) accounts were located on 647 parcels having between 2 and 115 accounts each. Since floor area could not be readily unbundled and allocated to multiple accounts, each having different use, NAICS designation and energy use history, a "mixed-use" NAICS designation was created to represent the combined floor area and energy use history for these largely "strip mall" businesses aggregated on a single parcel. The number of account records remaining in each NAICS market segment was compared to the number of pre-filter account records to determine if any NAICS market segment experienced a disproportionately high rate of attrition.

Next, monthly energy use records dating from January 1994 to December 2006 for each account were merged with building floor area data. Inactive billing periods resulting from building vacancy or transition of ownership (e.g. customer account changes) were identified and excluded from the analysis. Since energy use intensity was measured by the total energy use of the building in relation to its floor area, natural gas consumption (if any) was converted to equivalent units of electrical energy (kWh). The total annual energy consumption of each account was divided by total floor area to determine the average annual energy use intensity (kWh/sf/yr) for each account in each market. For the purposes of this study, it was assumed that the same (or similar) type of business occupied each building space from 1994 to 2006, and that no significant changes to building area or composition had been made during this time.

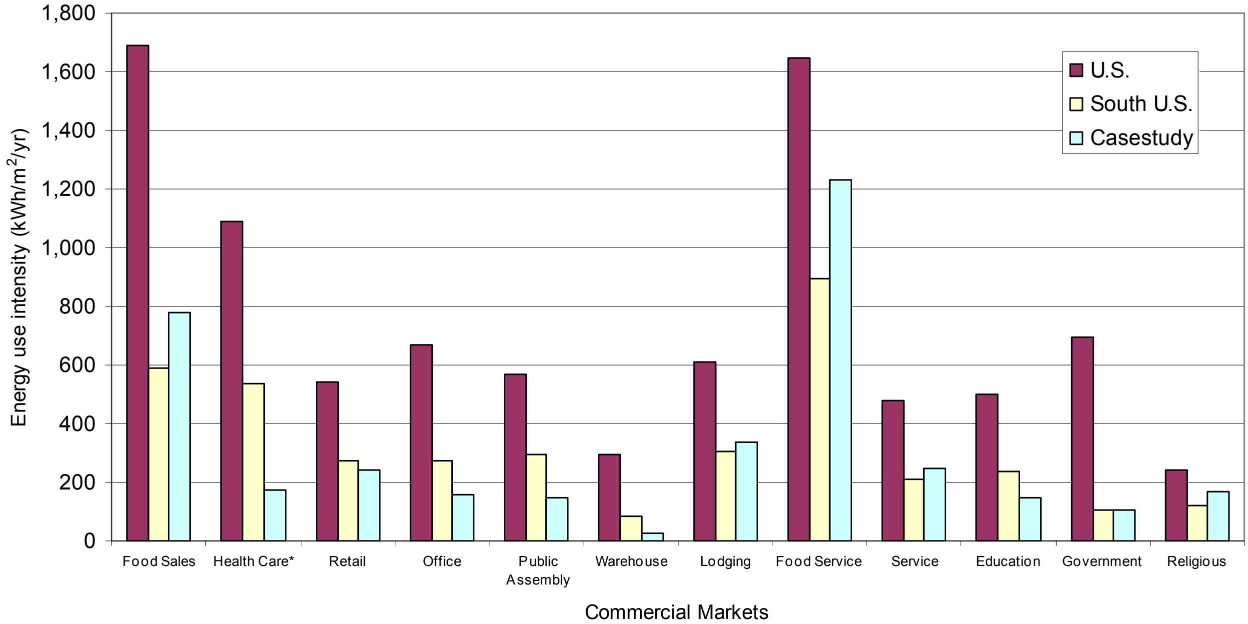

Figure 5. Comparison of U.S. and case study energy use intensity (kWh/m^2/yr) by market.

The average annual energy use intensity of buildings within the case study region was 301kWh/m^2/yr, nearly half (52%) the U.S. average, yet somewhat consistent with similar market sectors in the southeast U.S. having an average energy use intensity of 360kWh/m^2/yr. Other market specific findings include:

- Office and retail markets comprised roughly one-quarter of all accounts. Office, retail, food service (restaurants) and food sales (grocery stores) comprised more than half (53%) of the total commercial market energy demand (kW).
- Food service and food sales were consistently 3-5 times more energy use intensive compared to the aggregate commercial market, ranging between 7.9-20.9kW/100m^2 energy demand and 729-1,252kWh/m^2/yr energy consumption.
- Healthcare stores and gasoline stations were the 2-3 times more energy demand intensive (8.7-11.0kW/100m^2) compared to the aggregate retail market from 1994-2006. Gasoline stations were more than twice as energy use intensive (420-480kWh/m^2/yr) as the rest of the retail market.

- The "bottom 10%" (worst) energy performers in each market were 3-7 times more energy use intensive than the market average. The greatest ratio disparities were found in religious (7.1:1.0), services (6.3:1.0) and lodging (4.8:1.0) sectors. The greatest numerical disparities were found in food sales (1,746kWh/m^2/yr) and food service (1,604kWh/m^2/yr) markets. The "bottom 10%" of accounts in each market were among the largest by size and consumption, averaging 146,053kWh per account per month from 1994-2006.

- Electric load factors (the percentage of average demand relative to peak demand) for food service, food sales and lodging averaged between 40%-50%. Load factors for service, religious and education were among the poorest, averaging less than 20%. Load factor for retail averaged roughly 35%, although load factors for gasoline stations and healthcare stores exceeded 45% and 70% respectively due in large part to continuous hours of operation. Load factors for postal services and assisted living exceeded 50% and 60% respectively.

- Lodging, food service, food sales and retail were on average, among the largest individual connected electric loads (57.4-109.2kW per account) and largest electric energy users (averaging 40,061kWh per account per month).

- Individual building material, sporting goods and general store retailers as well as assisted living, lodging, postal service and entertainment accounts all averaged 100kW demand or greater and consumed between 22,596-62,651kWh per account per month.

- No significant differences in energy use intensity with respect to building age or building size were found when compared by market, except for buildings over 9,000m^2. For all markets, buildings greater than 9,000m^2 had 2-3 times the energy use intensity of the market average.

- Service markets were found to have the highest account turnover rate with a customer change every 2.9 years on average. Education had the lowest turnover rates with a customer change every 14.3 years. The core of the C&I market, office, food service and sales, retail, and healthcare, experienced account turnover every 3.9-4.8 years on average.

Next, the energy savings and added first cost of energy efficient HVAC and lighting alternatives were compared to minimally code-compliant alternatives in each market. The scope of this investigation was limited to only HVAC and lighting alternatives since roughly half of all energy consumed in U.S. commercial buildings is used for thermal comfort and lighting. For measures likely to have the same or similar energy use impacts regardless of location or climate, energy use data from the following resources were used:

- 2004-05 Database of Energy Efficient Resources (DEER), version 2.01, California Public Utilities Commission, http://eega.cpuc.ca.gov.deer
- 2006-08 Demand Side Management (DSM) Program, Pacific Gas & Electric and Southern California Edison, http://www.californiaenergyefficiency.com/matrix.html
- 2007 Integrated Resource Plan, Appendix K, Puget Sound Energy, http://www.pse.com/energyEnvironment/pse2007irpView.aspx

For measures likely to be affected by climate, energy use data from the following source representative of the study area was used:

- 2007 Potential for Energy Efficiency and Renewable Energy to Meet Florida's Growing Energy Demands, Report Number E072, American Council for an Energy Efficient Economy.

HVAC alternatives evaluated included unitary (packaged) systems and water and air-cooled chillers of various types, efficiencies, capacities and control capabilities. Lighting alternatives evaluated included T-5, T-8 and compact fluorescent (CFL) lighting, pulse-start metal halide, high pressure sodium (HPS) and light emitting diode (LED) technologies and control systems used in place of less efficient incandescent and mercury vapor technologies with limited or no control capabilities. The performance of each of these energy efficient alternatives was characterized for buildings of varying sizes in each of the twelve (12) markets. The minimum and maximum energy savings and added first cost for HVAC and lighting upgrades are presented for the commercial market in the study region (Tables 1 and 2). The market most representative of the average energy savings and added first cost for HVAC and lighting upgrades is also presented.

Table 1. Investment costs and annual energy savings for select lighting upgrades.

	Min	Max	Avg	Market	Upgrade	Base
	292			N/A[2]	T-8, 34w	T-12, 60w
Added first cost		1,930		N/A[2]	CFL, 13w	Incand, 60w
($US/100$m^2$)			1,001	Food sales	MHalide, 175w	Incand, 500w
	474			Education	T-8, 34w	T-12, 60w
Energy savings		11,693		Retail	CFL, 13w	Incand, 60w
(kWh/100m^2/yr)			5,483	Food sales	MHalide, 175w	Incand, 500w
	0.03			Education	T-8, 34w	T-12, 60w
Demand savings		1.53		Retail	CFL, 13w	Incand, 60w
(kW/100m^2)			0.71	Warehouse	MHalide, 175w	Incand, 500w
	0.06			Food sales	MHalide, 320w	Incand, 1000w
Energy SIR[1]		0.61		Education	T-8, 34w	T-12, 60w
($US/kWh/yr)			0.22	Healthcare	CFL, 13w	Incand, 60w
	478			Retail	MHalide, 320w	Incand, 1000w
Demand SIR[1]		10,567		Education	T-8, 34w	T-12, 60w
($US/kW)			2,180	Office	T-8, 34w	T-12, 60w
	7.9			Education	T-8, 34w	T-12, 60w
Simple payback[3]		0.7		Retail	MHalide, 320w	Incand, 1000w
(yrs)			2.5	N/A[2]	N/A[2]	N/A[2]

[1] SIR, savings to investment ratio
[2] N/A, multiple or varies by market, building characteristics or other attributes
[3] 12-16 year service life, $US 0.085/kWh "blended" energy rate (energy, demand, account fees, etc.)

Table 2. Investment costs and annual energy savings for select HVAC upgrades.

	Min	Max	Avg	Market	Upgrade	Base
	33.36			Lodging	Screw 2.1COP	1.9 COP
Added first cost		694.50		Food Service	Unit 11.0EER	9.5 EER
($US/100$m^2$)			283.92	Office, Retail	Unit 11.0EER	10.0 EER
	186.18			Office	Unit 11.0EER	9.5 EER
Energy savings		1,495.86		Food Service	Unit 11.0EER	9.5 EER
(kWh/100m^2/yr)			517.88	Retail	Unit 11.0EER	9.5 EER
	0.06			Education	Unit 11.0EER	10.0 EER
Demand savings		0.64		Food Service	Unit 11.0EER	9.5 EER
(kW/100m^2)			0.27	Retail	Screw 2.0COP	1.7 COP
	0.08			Healthcare	Screw 2.1COP	1.9 COP
Energy SIR[1]		1.51		Office	Unit 11.0EER	10.0 EER
($US/kWh/yr)			0.65	Retail	Unit 11.0EER	9.5 EER
	93.91			Lodging	Screw 2.1COP	1.9 COP
Demand SIR[1]		5,833.64		Education	Unit 11.0EER	10.0 EER
($US/kW)			1,552	Food Service	Unit 11.0EER	10.0 EER
	18.6			Office	Unit 11.0EER	10.0 EER
Simple payback[2]		0.9		Healthcare	Screw 2.1COP	1.9 COP
(yrs)			4.3	Retail	Unit 11.0EER	9.5 EER

[1] SIR, savings to investment ratio
[2] Unitary systems - 15 year service life, chillers - 20 year service life, $US 0.085/kWh "blended" energy rate (energy, demand, account fees, etc.)

Using market specific energy use intensity data and, the average costs and energy savings of lighting and HVAC upgrades for the commercial market as a whole, a rate absorption program was devised. Rebates ranging from 15% to 65% of the added first cost of each upgrade were factored into the analysis. Corresponding rates of adoption from 5% to 25% of the total commercial market were used. Multiplying the average added first cost ($US/$m^2$) for an HVAC and lighting system upgrade by the rebate (%), and again by the total commercial market adoption (m^2), the one-time, total rebate program cost was calculated. Next, lost sales revenue resulting from the conservation effort was calculated by factoring the average energy savings (kWh/100m^2/yr) for an HVAC and lighting upgrade by a "blended" commercial rate of $US 0.085/kWh, inclusive of all energy, demand and account fees. These values were weighted by the average energy use intensity of each market (Figure 5) and, the size of the market by floor area (m^2) relative to the entire commercial market. Administration costs for staffing to coordinate and monitor the rebate program were assumed to be 20% of the rebate cost each year.

Table 3. Casestudy electric generation, transmission and distribution supply costs. (Regan, 2004)

Cost	Cost Component	Value of Reduction (USD)
Avoided T&D Facilities	Fixed	104.94/kW
Avoided T&D Personnel	Fixed	6.15/kW/Yr
Avoided Generation Unit	Fixed	1,452.00/kW
Avoided Generation Personnel	Fixed	5.52/kW/Yr
Avoided Generation O&M	Variable	0.0049/kWh
Avoided Generation Fuel	Variable	0.01864/kWh
Fuel Cost Escalation		3.9%/Yr
Inflation		4.0%/Yr
Line Loss Percentage		6.0%
Cost of Capital		8.75%

Avoided utility supply costs resulting from the conservation effort were credited back to the program. For conservancy, only avoided variable operating and maintenance costs ($US 0.024/kWh) were considered. Avoided fixed costs, such as deferred infrastructure expansion costs, personnel, etc., were not considered since the electric generation, transmission and distribution (T&D) capacity to meet (and in most cases, exceed) the pre-conservation effort demand would have already been in place. Avoidance or delay of capital expenses, if any, would likely occur many years into the future and only if a significant demand reduction (50MW or greater) were to occur as a result of the conservation program.

Next, the present value (PV) of the initial rebate program and, future lost sales revenue and administrative costs were calculated using an average service life of HVAC and lighting upgrades equal to 15 years. A discount rate of 8.75% factoring the utility's cost of capital, inflation, energy costs, risk and uncertainty was used. The present value of avoided supply cost benefits was credited back to the program under the same constraints. The net present value (NPV) of total program costs was then calculated for rebates ranging from 15% to 65% and, corresponding adoption rates ranging from 5% to 25% of the total commercial market. The resulting NPV of program costs for each rebate and corresponding level of adoption was divided by total commercial energy sales for (MWh/yr) to determine the required energy rate adjustment necessary for the utility to remain cost neutral.

Table 4. Rate absorption schedule.

Rebate (%)	Market Adoption (%)	Energy Savings (MWh/yr)	Rebate Cost ($US)	Admin Cost ($US/yr)	Lost Sales ($US)	Avoided Cost ($US)	NPV of Costs ($US)	Rate Change ($US/kWh)
15	5	6,219	199,804	39,961	528,636	146,401	3,653,807	0.006
25	10	12,438	666,015	133,203	1,057,272	292,802	8,009,915	0.013
35	15	18,658	1,398,631	279,726	1,585,908	439,203	13,068,325	0.021
50	20	24,877	2,664,059	532,812	2,114,544	585,604	19,531,338	0.031
65	25	31,096	4,329,097	865,819	2,643,180	732,005	27,047,804	0.043

* Discount period, 15 years; discount rate, 8.75%

Results indicate that 15%-65% rebates on HVAC and lighting upgrades and 5%-25% market adoption would require a $US 0.006-0.043/kWh (7.1%-50.6%) rate increase for the utility on a base rate of $0.085/kWh to remain cost neutral. Businesses choosing not to implement conservation measures (e.g. "non-adopters") would similarly realize a 7-50% increase in energy costs. In contrast, those businesses choosing to implement conservation measures (e.g. "adopters") could realize net savings of up to 14.4% in spite of higher energy rates. On average, the energy costs for adopters is 19.9% less than non-adopters or, $US 2,897.00-4,094.00 less each year for the average business. For simplicity, this analysis assumes that the total implementation process and, present value of all current and future program costs are recovered within the same year. To lessen the financial burden on the consumer, this cost may be spread over several years.

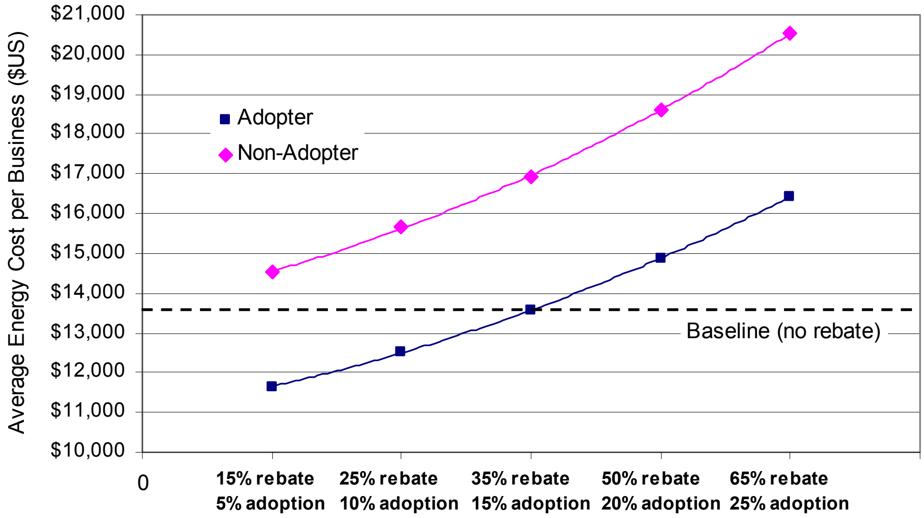

Figure 6. Rate absorption impact on average consumer energy costs.

The uncontrolled release of NO_x, SO_2 and CO_2 emissions alone contribute significantly to the global greenhouse effect. Aggregating emissions proportionately across Florida's coal, petroleum, gas and nuclear generation output, it is estimated that 0.0036kg of SO_2, 0.0023 kg of NO_x and 0.59kg of CO_2 are released for every kilowatt-hour of energy used by the consumer (U.S. DOE, 1995). The reduction of 31,900kWh/yr of energy use per business in the study area could on average, eliminate the release of 18,821kg of CO_2 emissions each year. Depending on rates of adoption (5%-25%), the study market consisting of 4,700 businesses each averaging 70m^2 of useable floor space and having an average energy use intensity of approximately 301kWh/m^2/yr, could reduce up to 18.4 million kilograms of CO_2 emissions each year.

4. Conclusions

The objective of this study was to demonstrate a rate absorption approach where the risks, costs and benefits of a conservation program, traditionally borne by the utility, shifts to the consumer. Adopters of the HVAC and lighting upgrades evaluated in this study achieved an average savings-to-investment ratio of 6.5 and a simple return on added first cost investment within 1.9-2.5 years. The implementation cost of the energy efficiency upgrades was absorbed by incremental increases in energy rates, which were disproportionately passed along to non-adopters, or those businesses choosing not to improve their energy efficiency. In essence, non-adopters financed the costs of production efficiency improvements for their competitors, or those businesses choosing to improve their energy efficiency.

4.1 Limitations

Although the results of this particular study show that energy use is most closely correlated to type of market (e.g. type of use), the energy use variance of buildings within the each market was found to be very high. Combined with other building characteristics (e.g., size, age, climate, changes in use, etc.) the task of estimating energy savings from even a limited number of HVAC and lighting upgrade options is extremely complex. Although the methodology developed herein may be applicable and replicable in other study regions, the results should not be generalized to any other study area.

4.2 Further Research

The rates of consumer adoption corresponding to the levels of rebate incentives in this study are hypothetical. Although the author(s) have performed research in the U.S. residential market identifying levels of market adoption relative to varying levels of incentives, no similar research for the commercial market has been completed to date. There exists a critical need to assess the "tipping points" necessary to stimulate the greatest level of market adoption for the lowest program cost, and, to separate true adopters from "free riders" or those individuals and businesses who would have implemented energy efficient upgrades with little or no incentives.

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TITLE: GOVT³: HELPING THE NEW ZEALAND GOVERNMENT GET SUSTAINABLE BUILDING

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Summary

The Ministry for the Environment's Govt³ programme has been working with core Departments and Ministries to encourage sustainable practices since 2003. One area of sustainability these government agencies are now starting to embrace, and is being reflected in their building projects, is sustainable building practices. The Govt³ programme helps and supports these agencies by working with other government agencies on policies that support sustainable building objectives, and with industry to develop the products and services required to make sustainable buildings possible. This paper highlights what the Govt³ agencies are currently doing and to meet the programme's requirements of 'best practice' sustainable building and what the Leading Government Sustainability (LGS) team is planning to develop to help them. The support shown for the Govt³ programme also highlights the New Zealand Government's commitment to 'walk the talk' on sustainability.

The '*Value Case for Sustainable Building in New Zealand*' has shown that sustainable buildings need not cost much more up front and any premium will be paid back many times over during the life of the building. Using whole-of-life costing, Govt³ agencies are able to lease, or own buildings with dramatically reduced environmental impacts. These buildings also provide healthier more pleasant working environments for their staff. Examples include the Department of Conservation's new head office that has converted a former cinema into one of New Zealand's best performing office buildings. However, reducing impact, although noble in its self, will not get us to true sustainability let alone start to restore the damage caused by our past short-sighted development practices. There is now a conversation developing that looks beyond reduction to neutral, restorative, or even regenerative development strategies. It will require a collective approach from industry and government to achieve. If this happens New Zealand could be on the way to being the first truly sustainable nation.

Introduction: environmental concerns with the built environment

Governments around the world are waking up to the environmental impacts associated with the built environment. Globally these impacts are immense. According to the United Nations, the building and construction sector is becoming known as "the 40% industry". This is because 40% of all energy and material resources globally are used to build and operate buildings, 40% of CO_2 releases come from building construction and operation, and 40% of total waste results from construction and demolition activities (United Nations, 2007). On top of these figures are the impacts of buildings construction, operation, maintenance and demolition on land, water, air quality and human health.

In 2003 the United Nations warned that if current patterns do not change the expansion of the built environment will destroy or disturb natural habitats and wildlife on over 70% of the Earth's land surface by 2032 (UNEP, 2003). It is not surprising then that the United Nations Environment Protection programme sees the building and construction sector has having more potential to contribute to the achievement of sustainable development than any other sector (UNEP, 2007).

The environmental performance of New Zealand's building and construction sector varies from global averages due to local resource availability, climatic conditions, and the fact that the majority of New Zealand's electricity is generated by hydroelectric power schemes. Although variable to global averages the impacts remain immense. Therefore it is not surprising that a growing number of public sector agencies, private sector organisations, and individuals are calling for a change in the way New Zealand's buildings are designed, constructed, operated and demolished.

This call for change has been greatly bolstered by the New Zealand Prime Minister's February 2007 announcement that "New Zealand can aim to be the first nation to be truly sustainable". The New Zealand Government also acknowledged that "it is important that government shows leadership on sustainability, and gets its own house in order when it is encouraging individuals and business to take actions for sustainability".

As government undertakes approximately 30% of all new construction in New Zealand, it has the ability to influence the market from a demand side. It has signalled its intention, through government procurement, to improve the sustainability of a growing number of sectors, including the wider building and construction sector. The main focus of this paper is how the New Zealand governments Govt^3 programme is going about empowering its members to achieve more environmentally sustainable building results. The paper also looks at the programme's inspirational goal of going beyond reducing impacts to how we can build truly sustainable buildings in the New Zealand context.

The Govt^3 programme

In September 2003 the Ministry for the Environment started the Govt^3 programme with the aim of increasing capacity and knowledge on environmental sustainability within government agencies. The name Govt^3, meaning government and "3" - the three pillars of sustainability: economic, social and environmental. The Ministry for the Environment's Leading Government Sustainability (LGS) team, leads and manages the Govt^3 programme and have been working with the programme's 57 government agencies to assist them to "walk the talk" on sustainability. The programme does this by identifying best practice and promoting practical solutions to achieving it.

One topic area of sustainability these agencies are now starting to embrace, and is beginning to be reflected in their building projects is the use of sustainable building practices. The LGS team assists and supports these agencies by working with them directly to encourage and support their efforts. The LGS team also works with other government agencies, and wider industry to encourage the development the policies, products, and services that make sustainable buildings possible. The LGS team provides Govt^3 agencies, and the professionals working for them, with tools, recourses, and guidance to make the process of getting sustainable buildings easier.

Value case for sustainable building

One of the obstacles the LGS team identified as needing to be challenged was a perception that sustainable buildings cost a lot more than conventional buildings. A value case was commissioned to look at local case studies to quantify whether there was any substance to the 20 plus percent premium being talked about by the New Zealand building industry. The resulting '*Value Case for Sustainable Building in New Zealand'* identified that although there was a premium it was more likely to be between

2-6 percent (Fullbrook et al, 2006). It also showed that buildings with lower environment impacts need not cost much more in upfront capital costs and any premium would be paid back many times over during the life of the building. One of the main reasons for this premium was attributed to the extra time and resources the building and construction industry needed to become accustomed to a different way of doing things. This is in line with the finding from other developed countries that have introduced environmental considerations to building projects.

In December 2007 the New Zealand Treasury launched its new Capital Asset Management (CAM) framework that requires government agencies to take a longer-term view of their assets. This means Govt[3] members are now able to use whole-of-life costing to make asset decisions over a forty-year timeframe. This will foster the use of practices and technologies that have better sustainability outcomes, as they are paid for over a timeframe that is more conducive to their use.

What constitutes a sustainable building?

Another hurdle government agencies have had to overcome is the question of 'what constitutes a more sustainable building' and what level of performance should these buildings be achieving. It should be made clear that in New Zealand we are currently not building sustainable buildings, but use the term "sustainable building" to indicate an intention to do so in the future. To this end, the Govt[3] programme adopted a variation of the Sustainable Building Centre's definition as it reflects a changing view of the environmental impacts associated with buildings.

Buildings are "sustainable" when they are designed, built and operated with low environmental impacts (or actually start to have a positive environmental impact) while enhancing the health, welfare and quality of life of the people that live and work in them.

(Variation on that used by British Columbia's Sustainable Building Centre)

Most of the earlier definitions of sustainable building only focused on reducing impacts. Whereas, the Sustainable Building Centre's definition hints at the possibility of using building developments to improve environmental and human impacts and outcomes. Putting this definition into a commercial procurement context however, would have proved difficult without some associated performance indicators. The New Zealand Government recognised this and in May 2006 directed the Govt[3] members to accelerate the adoption of sustainable building practices. This was to be achieved by specifying best practice sustainable building indicators (performance standards) for government building tender documents for new and existing buildings.

Environmental rating tools

After looking at what other governments had done to set best-practice sustainable building standards, it was decided to engage the newly formed New Zealand Green Building Council (NZGBC) to select a sustainable building assessment scheme appropriate for a New Zealand context. The project's purpose was to identify, and then develop a project plan to implement the selected scheme. As government agencies occupy a large amount of the office accommodation the LGS team were particularly interested in the development of environmental rating tools for the commercial office-building sector. The LGS team realised that industry would need to be encouraged in come up with solutions to the environmental issues associated with the building and construction sector. Therefore, a key component of the project's brief was to engage with the wider building and construction sector and gain their support for the chosen rating scheme. The NZGBC developed the Green Star New Zealand rating scheme with the input of almost 500 people from New Zealand's wider building and construction sector.

Although based on the Australian Green Star rating scheme the New Zealand scheme was the first rating scheme of its type to base final certification on a building's actual performance. Most other rating schemes base certification on a buildings predicted performance at the design stage. This result is a tribute to the collaborative working style of NZGBC and the support shown by the wider building and construction sector. It also reflects the importance and value of involving the users of these tools in the decision making process as it was industry that felt the tools short acknowledge actual, rather than predicted performance. The resulting Green Star New Zealand commercial office-building rating tool was adopted by the government for all new government commercial office building, owned or leased, from 1 July 2007.

The NZGBC is currently working with a number of Govt[3] agencies to investigate the possibility of rating tools for their specific building needs. Examples include the Ministry of Education, which is working with the NZGBC to develop rating tools for schools and the Housing New Zealand Corporation, which is assessing the need for a residential rating tool(s). The Ministry of Education had already required the inclusion of environmentally sustainable design practices for all new schools. The use of rating tools will offer a more consistent way of gauging a school building's performance against a set of known environmental performance criteria. One of the criteria being trailed on four new schools under development is educational value, whereby the building's design is awarded credits if it contributes to the education of the user.

In October 2007 the New Zealand Government further acknowledged the value of using the NZGBC's Green Star New Zealand rating tools by setting a target that all new government buildings are to meet a minimum 5 star rating (New Zealand excellence) from 2012. This was a suggestion put forward by the LGS team as a key means of setting targets that would lead to operational changes. The LGS team will continue working with the NZGBC and the wider building and construction sector to ensure rating tools are available for all major government building types by this date.

In the LGS team's opinion rating tools are best used to verify a buildings environmental performance rather than to determine a buildings design. In this way the Green Star New Zealand rating tools have become the government's eco-verification tools for government buildings environmental performance.

Building design through to commissioning

The best time to incorporate sustainability into a project is before the design process even starts. This is because by the time the first 1% of a project's upfront costs are spent, up to 70% of its lifecycle costs may already be committed (Fullbrook, et al, 2006). Pre-design therefore takes on increased importance and requires a new set of skills for those typically involved in a conventional building project. Ideally the pre-design period would have the involvement of the users, developer, investor, design team, builders, and facilities management team. This collaborative approach is known as an 'integrated whole building design process' and is a prerequisite for achieving better environmentally performing buildings.

The LSG team is currently developing a sustainable building toolkit that includes guidance in a number of areas such as integrated whole building design, and passive solar design, principles. The toolkit covers the life-cycle of a building from pre-design through to deconstruction. Govt[3] members, or the professionals working for them, will provide evidence on how they have incorporated sustainable building design considerations (figure 1). It is hoped that the toolkit will become a requirement for all government commercial building projects. It will be targeted at commercial buildings. Over time the toolkits can be extended to include topics such as distributed renewable energy technologies, green roofs, regenerative design, and other positive environmental design principles.

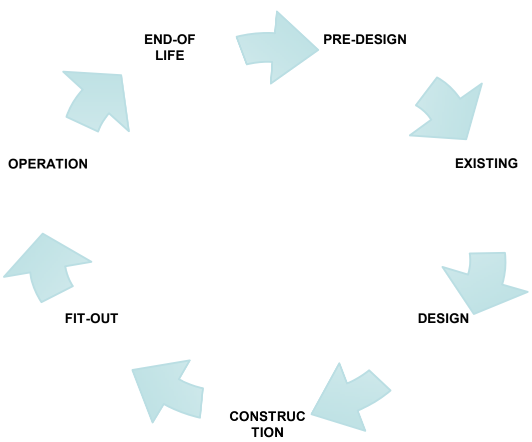

Figure 1: Sustainable Building Toolkit life-cycle topics

The best-designed building however, will not achieve its performance potential without proper commissioning. Proper commissioning of buildings has historically had a very low profile and priority in the construction industry and is often done poorly, if at all. Sustainable buildings by their very nature require a high level of performance (Fullbrook, 2007a), and they're commissioning and management therefore requires extra focus. When the LGS team looked for guidance on how to undertake best-practice commissioning there were few examples available. It was decided to commission 'A Best Practice Approach to Building Commissioning, Completing and Ongoing Operation' to fill this gap and ensure new government buildings operated as intended. The commissioning guidelines became mandatory for government buildings over 2000m^2 as of 1 July 2007. Given that government is a significant tenant of commercial buildings in New Zealand it is hoped that these guidelines will act as a catalyst to improve the building and construction sector's overall commissioning practices.

The importance of education

One area that the LGS team is focusing a lot of time on is educating the Govt^3 members on the opportunities that sustainable building can offer them. A small, but very experienced group of sustainable building practitioners have volunteered their time to help the LGS team to inform and educate these agencies about best-practice sustainable building practices. An important component of this education has been up-skilling and empowering these agencies so they are able to use what they are learning in real-life building project situations. Individual member of the Govt^3 programme sharing their achievements in the area of sustainable building has also proved important. Seeing others achieve positive results justifies the extra time and effort put into these projects. It also shows that individuals in organisation similar to their own can do it so why cant I. The Govt^3 programme now holds regular sustainable building network meeting so that members can share their experiences. The power of this kind of networking should not be undervalued, particularly if the members are encouraged to personalise what they are doing to their own organisational needs.

An example of a government building that utilised sustainable building principles

The Department of Conservation's new head office in Wellington is a good example of what is possible when you combine sustainable building principles with an organisations purpose. The Department of Conservation's mission is "to conserve New Zealand's natural and historic heritage for all to enjoy now and in the future". So when the Department of Conservation started looking for new accommodation, it saw an opportunity to express these values in its new building.

The Department of Conservation approached the LGS team early on to help with the preparation of their request for proposal documents to consolidate their Wellington staff into on site. They had already done a lot of preliminary work that included extensively surveying their staff to ensure their needs were understood and reflected in the new buildings design brief.
The Department of Conservation's new home is a retrofit of an existing cinema into a commercial office building which:

- Utilises rainwater storage and efficient fixtures and fitting that have reduced water use from the town supply by 60%;
- Has achieved a 40% reduction in energy use through the use of natural day-lighting, an efficient lighting system - including the use of motion sensors to turn off unused lighting, and a modern building management system;
- Has automatically opening windows and a highly efficient ventilation system that combines passive ventilation with chilled beams;
- Has inbuilt recycling facilities on each floor, and recycled much of the construction and demolition waste materials during the construction process;
- Has cycling facilities to encourage staff to the use of alternative transport options. The building is also located on Wellington's main bus route.

Figures 1 and 2: Pictures of the Department of Conservation's new head office with the atrium on the left and chilled beams on the right (Source: Pictures courtesy of the Department of Conservation)

Although the Department of Conservation had a number of new building options to chose from it took the riskier, and ultimately more sustainable option of using an exist building that was not ideally suited for use as an office building.

The future direction of the Govt^3 programme

During the latter half of 2007 the LGS team undertook a strategic review of the Govt^3 programme. This was the first major review of the programme since its start in November 2003. During the intervening years the programme had evolved from voluntary to mandatory participation. It has also moved from looking at improving the corporate functions of government agencies to include operational elements. An example is the requirement that all government buildings meet a minimum 5 star Green Star rating from 2012.

What was lacking from the programme was 'where were we collectively going with sustainability'. The Govt^3 agencies were starting to ask 'how can we use our collective good will and effort in the area of sustainability to have a wider positive effect on the New Zealand as a whole'. Therefore the strategic direction for the Govt3 programme now looks at the linkages on wider society including the built environment.

From individual buildings to the wider built environment

There is growing recognition that the environmental impacts of a building go far beyond the site boundary (Fullbrook, 2007b). Figure 3 shows the impacts that include transport, emissions, material manufacture, waste, public health, land use and ecology. Many of the projects Govt^3 members undertake are large in scale and require connection with sustainable infrastructure – urban design, transport and community – to realise their full sustainability potential.

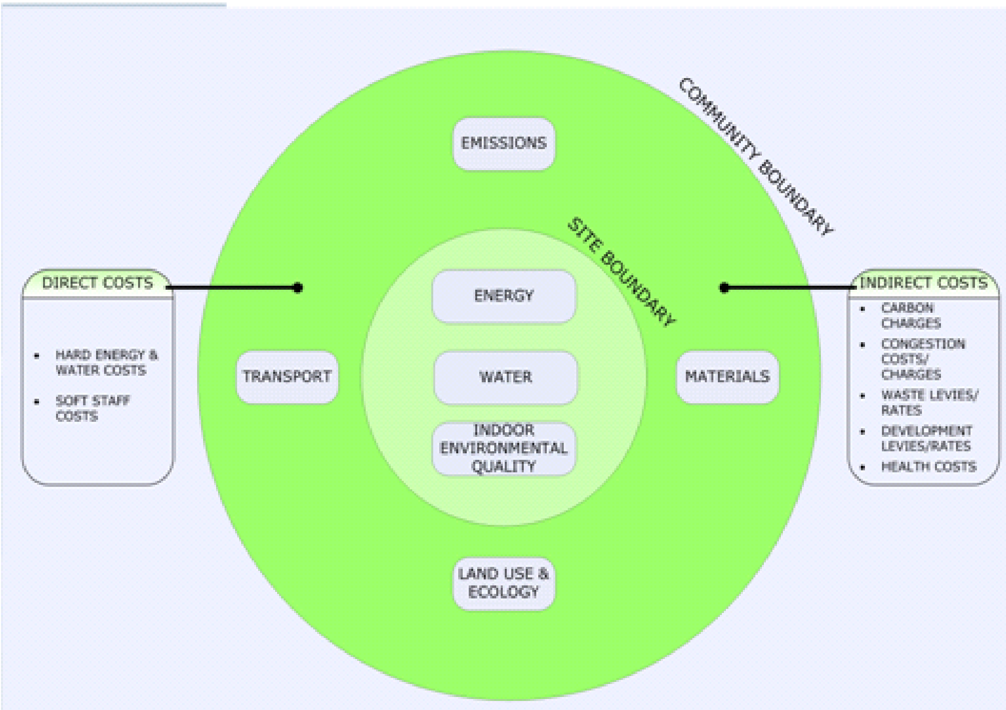

Figure 3: Environmental impacts beyond a building's site boundary.
(Source: Fullbrook, 2007, unpublished)

The current sustainable building topic area of the programme has been expanded to include these other topic areas. The phrase "built environment" refers to the manmade surroundings that provide the setting for human activity, ranging from the large-scale civic surroundings to the personal places. Buildings, transport, infrastructure, and urban design now all fall under the new title of "sustainable built environment". The Govt[3] team will continue to develop guidance on sustainable building but also now works with other government agencies and industry to develop guidance on sustainable infrastructure, transport, and urban design.

Decisions about sustainable development however, are more often that not done in isolation from one another. Many scientists, economists, and planners have started to recognise that integrated approaches to problem solving lead to more efficient, cost effective solutions when developed with natural principals and elements in mind (Centre for Sustainable Community Development, 2004).

From green to sustainable and beyond
By signing up to the Govt[3] programme the members have agreed to use 'best practice' sustainable building practices. Yet the current usage of the term 'environmental sustainability' is arguably framed in the context of reduced environmental impacts as opposed to long-term environmental balance. Although reducing environmental impacts is a worthy goal and an important discipline it is far from striving for sustainability (Nicholson, 2005).

In 2006 the New Zealand architect Graeme Finlay presented a challenge to some of the Govt[3] agencies at a network meeting designed to inform them of emerging sustainable building issues. Graeme asked why we, as participants in the building industry, are not designing New Zealand buildings as net GENERATORS of energy, as CARBON sinks, manufactured from WASTE materials, and improving BIODIVERSITY. Internationally, there is a call by those who have mastered the basics to go further. In the area of the built environment a 'low environmental impact design approach' by itself cannot achieve sustainable development over the long term. It could be argued that a broader and more sustainable design approach must move beyond simply avoiding environmental damage to embrace environmental positives.

Taking a long-term view of the impacts on the ecological health of ecosystems it could also be argued that sustainability, even true sustainability, is only part of the answer. This is because sustainability is fundamentally about creating a steady state that still leads to degeneration of the system, as a whole, over time. New Zealand's biodiversity has been adversely affected by the actions of people and these effects are continuing (Craig, et al, 2000). But what if sustainable development was good for the environment? Figure 4 showcases a trajectory of environmentally responsible design that describes the transition from conventional practice and green architecture (negative environmental impact), to sustainable architecture (zero impact), through to design with positive environmental impact (Reed, 2007).

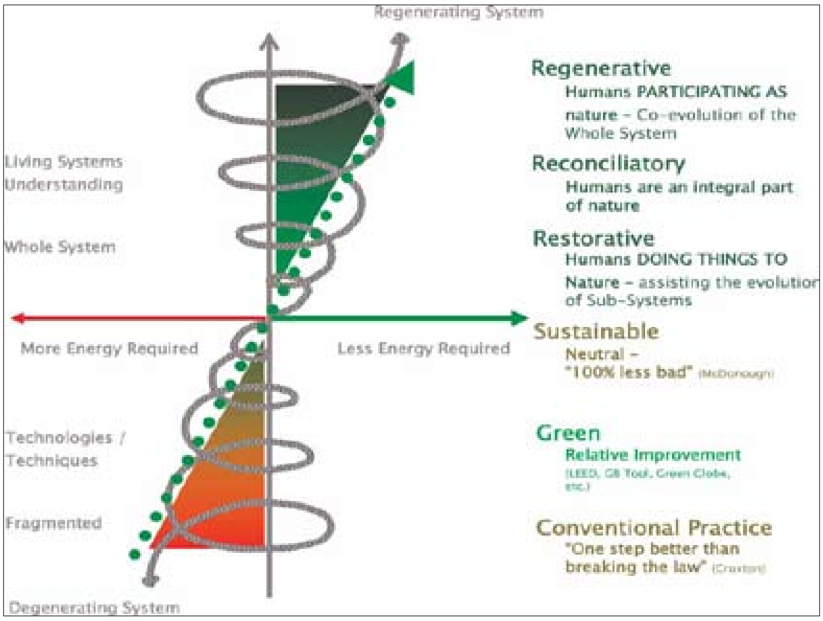

Figure 4: Trajectory of environmentally responsible design (Source: Reed, 2007)

From uniformity to a distinctive New Zealand building style

In the past a regions buildings were a reflection of the local culture, resource availability, and building traditions. What we have today is an "international style that has evolved into something less ambitious: a bland, uniform structure isolated from the particulars of place – from local culture, nature, energy, and material flows" (McDonough and Braungart, 2002). Apart from these buildings reflect little, if any, of a regions distinctness or style they are not intimately connected to the natural flows of the 'place' they are suppose to be a part of. Is it any surprise then that development has all the negative environmental baggage associated with it?

The prevailing approaches to building design also rarely, if ever, address the human biological and ecological need for contact with nature that has been increasingly identified as a prerequisite of human physical and mental health and productivity (Kellert, 2004). Given the imperative of reducing the continued loss of New Zealand's biodiversity and the recognition that contact with nature is good for us why not combine these two needs. The programme has therefore set an aspirational goal of regenerative design that promotes the co-evolution of the whole system. Over time the LGS team may also develop a regional approach to the delivery the Govt^3 programme which will foster difference - individual solutions - sense of place - and a connectedness with a regions natural resources and ecology. The LGS team will also play a leadership role by facilitating connections and collaboration between stakeholders that lead to the promotion of an integrated sustainable built environment design approach.

Bring industry on the journey

Making these changes to the Govt^3 programme however, will not be possible without the industry's goodwill and active participation. This is because although governments are expected to take the lead, other stakeholders are just as important to ensuring success in achieving sustainable development (UNEP, 2007b). At a workshop In February 2007 the LGS team brought together thirty organisations representing a large part of the building and construction sector to map their sustainability initiatives. The intention was to show that by working more closely together, government and industry organisations could leverage off each other's sustainability initiatives. At this workshop the group identified the development of a clear vision for improving the sustainability of the building and construction sector, and leadership to drive these improvements as priorities going forward.

The interest shown at this workshop led to further discussions during the remainder of 2007 to develop a mechanism that would coordinate and foster a shared industry/government vision for a sustainable building and construction sector. The management group currently includes Building Research (BR), the New Zealand Green Building Council, the Department of Building and Housing, and the Ministry for the Environment. The Ministry for the Environment is currently talking to other relevant government agencies and key industry stakeholders to find out what they would like to see happen and what their motivators for involvement might be.

There is general agreement within industry and government that there is a pressing need to improve the environmental performance of the building and construction sector. There has also been general agreement that what is currently lacking is a mechanism to coordinate and drive these improvements. A Sustainable Building Pathway (working title) could provide an opportunity to foster and coordinate these improvements and provide a feedback mechanism whereby the whole sector and relevant government agencies can learn from each others experiences.

It is envisaged the Sustainable Building Pathway would focus on fostering and coordinating environmental improvements of the wider sector but will also develop strategies that help to accelerate these improvements. Whilst the Sustainable Building Pathway will look at the wider built environment to ensure an holistic view is taken it could also allow the investigation of specific topics (examples could include education, water, energy, buildings, infrastructure etc). If industry and government are to be true partners in this initiative there needs to be plenty of flexibility to incorporate their respective views into the overall shape and direction of the pathway. The success of the Sustainable Building Pathway depends on gaining both government and the building and construction sector's buy-in and support. Work is currently underway to establish government's role in this initiative thereby ensuring an appropriate and integrated policy approach.

Conclusion

There is no disputing the environmental impacts of the building environment are immense and it is time to change our building and construction practices to reduce, even reverse them. The adoption of sustainable building practices is still relatively new in New Zealand but is gaining traction at a relatively quick pace. The Govt^3 members have started to use sustainable building practices to reduce the impacts associated with their building projects, and there is now a cross-fertilisation of these ideas between members. The governments adopting of the NZGBC's Green Star New Zealand rating tools and general consumer interest in green building has regenerated the demand needed to convince the market to improve the environmental performance of the commercial building industry.

However, if New Zealand is to become the first truly sustainable nation we will need to make a step change in the way we design our buildings rather than taking a slow transition approach. The Govt^3 programme has adopted an aspirational goal of regenerative design not just for buildings in isolation but as part of a wider sustainable built environment approach. Bu using an integrated design and local context approach it is hoped that Govt^3 members building projects can act as a catalyst to transform New Zealand's built environment. This will require a collaborative approach that includes the active participation of the whole building and construction sector. The possibility of developing a shared vision and strategy for sustainable building in New Zealand will be an import step in gaining this support.

Acknowledgments

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DECISION MAKING PROCESSES AND THE ADOPTION OF ENERGY SAVING TECHNIQUES IN RESIDENTIAL AND COMMERCIAL REAL ESTATE

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Keywords: stakeholders, decision making, energy saving, real estate

Summary

In this paper a research framework is presented for a better understanding of how actors take decisions on adopting and applying energy saving techniques in an inter-organisational context. Based on a literature study these actors are expected to be influenced by the network in which they operate during different phases of building projects and their expectations, partially based on experiences in the past, regarding the feasibility of the project's objectives. Because of different degrees of experience and social responsibility or accountability of individual actors in building projects, four different types of building projects are distinguished that cover a large part of all the building projects conducted. The characteristics of these four types are described for the Dutch situation. For two of them some first empirical results are given.

1. Introduction

The energy consumption in the built environment accounts for more than forty per cent of the total energy consumption in Europe (EC, 2002). Improving the energy performance of the built environment is an important issue to come to sustainable development and to reduce carbon dioxide emissions. Particularly after the first oil crisis, many innovative techniques have been introduced to lower the energy consumption or to use renewable energy sources, but not all techniques have been broadly adopted. The differences between these innovative techniques are large. An energy saving technique can be relatively simple or rather complex and in some cases it can directly replace the conventional product or large adjustments in the building design must be made.

Energy saving techniques and the use of renewables can reduce costs and society in general agrees upon the necessity of adopting them. Although high ambitions regarding the energy performance of the forthcoming building are often expressed during the initial phase of a building project, these ambitions are only in a few cases resulting in buildings incorporating many energy saving or renewable techniques. In this paper we intend to make a contribution to the knowledge on decision making processes on adopting energy saving techniques by identifying the relations between stakeholders involved in building processes. The framework is based on decision making theory and innovation adoption theory in order to generate insights in the influences of the organisational environment, in which different types of building processes take place. The central question is:

How can the adoption process of innovative techniques that lower the energy consumption or use renewable energy sources in the building industry be positively influenced?

It is expected that the organisations or persons involved in the building process are of influence on the adoption process, whereby the ambitions stated by the principal before construction and the actual energy performance after construction often do not correspond with each other. In a building process some organisations or persons are only for a limited timepath involved and all have different interests and targets. Therefore, many reasons to install or to reject energy techniques can exist, but they do not always coincide.

Firstly, the theoretical framework will be formulated in which the innovation adoption theory of Rogers (2003), Dieperink et al. (2004), and Hartmann et al. (2008) play an important role. Secondly, the research framework will be explained. Thirdly, the basic characteristics of the main types of building projects will be addressed. The research methodology is described in section five and, finally, in section six the first empirical results are discussed.

2. Theoretical framework

Rogers (2003, pp. 12) states that: *an innovation is an idea, practice, or object that is perceived as new by an individual or other unit of adoption*. In this paper the *idea, practice, or object* are techniques that lower the energy consumption or techniques that make it possible to fulfil the need for energy in a renewable way. The *individual or other unit of adoption* will be looked for within building projects and will in this paper be called actors. The diffusion (*the process in which an innovation is communicated through certain channels over time among the members of a social system,* Rogers, 2003, pp. 5) and rate of adoption (*the relative speed with which an innovation is adopted by members of a social system*, ibid, pp. 23) can differ strongly per technique. *The rate of adoption is the relative speed with which an innovation is adopted by members of a social system* (ibid., pp. 221). Five variables are distinguished which determine this rate of adoption. The first variable, perceived attributes of innovations, brings five attributes together, which are:

1. Relative advantage: the degree to which an innovation is perceived as being better than the idea it supersedes. The relative advantage of an innovation, as perceived by the members of a social system, is positively related to its rate of adoption (ibid., pp. 229, 233);
2. Compatibility: the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters. The compatibility of an innovation, as perceived by members of a social system, is positively related to its rate of adoption (ibid., pp. 240, 249);
3. Complexity: the degree to which an innovation is perceived as relatively difficult to understand and use. The complexity of an innovation, as perceived by members of a social system, is negatively related to its rate of adoption (ibid., pp. 257);
4. Trialability: the degree to which an innovation may be experimented with on a limited basis. The trialability of an innovation, as perceived by members of a social system, is positively related to its rate of adoption (ibid., pp. 258).
5. Observability: the degree to which the results of an innovation are visible to others. The observability of an innovation, as perceived by members of a social system, is positively related to its rate of adoption (ibid., pp. 258).

The five attributes all join the same aspect "as perceived by members of a social system". A social system is defined by Rogers as a set of interrelated units that are engaged in joint problem solving to accomplish a common goal. The members or units of a social system may be individuals, informal groups, organizations, and/or subsystems (ibid., pp. 23). In this research the social system consists of stakeholders of building processes. Therefore, a stakeholder is in this case a person with an interest or concern in a building project. Not all stakeholders can exert influence on the progress and outcomes of a building project. The particular group of stakeholders that can exert influence is called actors. This research will focus on them.

These actors or the organizations they operate in are influenced not only by the characteristics of the innovative technique itself, like expressed by the five attributes of Rogers, but are also influenced by the context in which the decision making process has to be taken. Dieperink et al. (2004) stresses the importance of studying adoption in its context. The framework of these authors links companies' characteristics and the decision making process & assessments on the one hand with macro developments, technical aspects, economic aspects and the company's context on the other hand. Especially in building projects, where organisational connections exist adjacent to inter-organisational connections, decisions are taken in a complex context. Insights in these structures can contribute to decision making theory.

Vermeulen et al. (2006) have translated the framework of Dieperink et al. (2004) to specify first and second level variables, which explain the adoption of energy innovations for new office buildings. They mention that the actor's characteristics and the networks in which the actor participates have impact on the decision making process and therefore on the rate of adoption. But in their research only the adoption in commercial real estate has been addressed and not the adoption in residential real estate. In residential real estate installations account for a much smaller part of the building costs. This offers interesting opportunities for further research, because the energy consumption is in residential real estate as high as in commercial real estate (PEGO et al., 2007).

Besides the fact that variables and attributes are defined that can accelerate the adoption process, there also exists a perspective in which barriers are defined that decelerate or block adoption processes. By debating on these barriers these scholars (e.g. De Man, 1983; Painuly, 2001) also address the need to include variables that can explain the influence of the context in which innovations are introduced to the potential adopter. Painuly (2001) states on barriers to renewable energy penetration for example that *there are different barriers that need to be overcome…through various actions by stakeholders and governmental policy measures* (ibid, pp. 77). Research of DeCanio (1998) also showed that *data on the profitability of lighting upgrades…strongly support the conclusion that organizational and institutional factors are important determinants of firms' investment behaviour and outcomes* (ibid, pp. 453). Furthermore, it is stated that profitable investments to save energy are possibly not implemented, because of internal barriers in private and public organizations. To be able to understand adoption of energy saving techniques the specific context has to be taken into account. Regarding public organizations Hartmann et al. (2008) offer a model of the adoption process that links the public dimension and professional dimension of the client with the innovation perception (see Figure 1). However, the fact that different levels of public involvement are present (for example because of building regulations on energy performance) has, as far as we know, not been included in existing innovation adoption theories. In general public involvement takes place on two different levels:

- Micro: Individual building projects where the government is involved by means of regulation and inspection. In some situations local governments can be more actively involved or even be the principal or user;
- Macro: Many decisions to stimulate the adoption of techniques that reduce the energy consumption are taken on a national level or supra-national level.

This research distinguishes four different clients and two sorts of buildings to come to a meso scale:

1. Residential real estate developed by social housing corporations;
2. Residential real estate developed by private ownership;
3. Commercial real estate developed by investors;
4. Commercial real estate developed by the government.

Every type of building process needs to be analysed regarding decision-maker, underlying motivations and moment of decision-making in adopting or rejecting energy saving techniques in a project specific context.

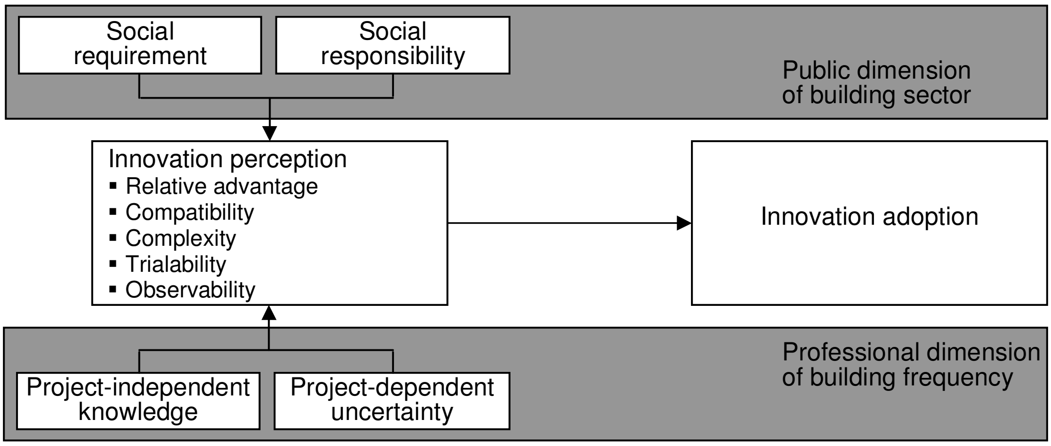

Figure 1: Influences on the innovation adoption of professional public clients (Hartmann, et al., 2008)

3. Research framework

In analyzing the four building projects three research questions reflecting on the deciding actor, underlying motivations and timepath of involvement are formulated:

1. Which actors decide on the adoption and application of energy saving techniques?
2. Which arguments and motivations are underlying their decisions?
3. When and how are adoption decisions taken in the design and construction process?

3.1 Allocating decisions to actors

In the construction industry the social system consists of a great variety of stakeholders related by one or more specific building processes. As mentioned before, a stakeholder is in general a person or organization with an interest or concern in a building project. In a research on the perceptions of stakeholders on alternative energy technologies in buildings, Cooke et al. (2007) distinguish eight different stakeholders: architects, building service engineers, clients, specialist consultants, planners, project managers or quantity surveyors, technology suppliers and contractors. Based on forty-one interviews Cooke et al. (2007) drew up the perceptions of stakeholders on alternative energy technologies. These stakeholders could be so called potential adopters. Vermeulen et al. (2006, pp. 2720) explain what potential adopters are: …*by 'potential adopters' we mean those persons in a decision making position in a project development organization who decide what technological innovations to incorporate in the construction of a new office building.* In this research this select group of stakeholders is called actors.

Besides the term stakeholders another term, "building professionals", is often deployed. Lo et al. (2006) use it for addressing practicing construction engineers, civil engineers, and architects, who are qualified and have at least three years of working experience. However, within the development of residential real estate by private ownership the client can not be expected to be qualified or to have at least three years of experience, therefore in this research the term building professionals is probably not appropriate for all stakeholders or respondents, especially those involved in developing privately owned residential real estate.

Furthermore, it is necessary to be aware of the differences between the communication process and the actual decision process. Rogers clearly addresses the communication process as a preliminary phase. Lo et al. (2006) speak of the influence of building professionals in the decision-making process without giving more insights in which consultation took place before adoption or who exactly took the decision. In this paper the term actor will be used to refer to the specific group of stakeholders that can directly influence the building project and its result. In this research nine different actors are distinguished, which are described in Table 1. It could be that two actors in one project do not have direct communication, but that one of the two still strongly is influenced by the estimated needs of the other. For example an architect will probably give thought to how a building is going to be used.

Table 1: Descriptions of the nine actors regarded in this research

	Actor	Description
Granters	Client – Principal (Cl)	Person or organisation requesting the constructive service of a professional person or organisation
Granters	Customer- User (Cu)	Person or organisation making use of the provided building
Granters	Warden (W)	Person or organisation responsible for the supervision of and maintenance on the building and its location
Granters	Property developer (PD)	Person or organisation that converts land to a new purpose, especially by constructing buildings
	Municipality (Mu)	A town or district having a local government that enforces building regulations
Takers	Architect (A)	Person who designs buildings and in most cases supervises their construction
Takers	Consultant (Cs)	Person who or organisation that provides expert advice professionally
Takers	Contractor (Co)	Person who or organisation that undertakes a contract to provide materials and/or labour for a construction project
Takers	Subcontractor (Sc)	Firm or person that carries out work for a company as part of a larger project
Takers	Manufacturer (Ma)	Firm that fabricates construction components and/or materials

3.2 Arguments and motivations

The reasons to adopt or reject certain energy saving techniques can have a broad background. Past research addresses the use of multicriteria decision-making frameworks (e.g. Haralambopoulos et al., 2003; Banaitiene et al., 2006) and the role of decision support systems (e.g. Hersch, 1999) to chose for the adoption of a specific technique out of a range of alternatives. However, in that case the actors of the building project should already be familiar with all existing alternatives.

Rogers' attribute "relative advantage" often gets more attention than the other attributes when in the social system known energy saving techniques are compared. The final choice for an energy saving technique can then be based on variables like fuel saved, return on investment, number of created jobs, environmental contribution and involved risks (Haralambopoulos et al., 2003). In this research attention will be paid to the preliminary phase of becoming familiar with the existence of energy saving techniques by addressing the five mentioned attributes of Rogers that influence the rate of adoption and by setting an environmental context in line with the model of Hartmann et al. (2008).

3.3 Design and construction processes

This paragraph addresses the different phases of the design and construction process, because *it should … be recognized that any given decision is likely to be part of a series of decisions or decision processes rather than occurring in isolation* (Hersh, 1999, pp. 397). In other words preceding and following phases can be of influence on the phase in which decisions are made. By using a scheme of the phases in a standard building process it will be possible to get more insights in when the decisions are taken. Process schemes of Arditi & Gunaydin (1997) and Turin (2003) link actors and phases of the building project directly, but by insinuating these relations in advance, different process schemes need to be prepared reflecting on different project organisation forms. Therefore a process scheme will be used of the University of Salford (Kagioglou et al., 1998), that does not mention any actors or stakeholders yet.

Decisions on the adoption of complex energy saving techniques can be taken in early phases of the building process to minimize efforts and costs of installation. It is expected that the early phases in construction projects are in general most suitable to address rigorous energetic requirements, because…*the early phase of a project development is the most important time for innovative activities and for planning a project execution that will optimise project value generation* (Kolltveit et al, 2004, pp. 545).

4. Characteristics decision making processes in building projects

We are aware that the list with the four types of building projects, mentioned in section 2, is not complete regarding construction types and possible ways to come to project development. We use this distinction because of the different levels of expertise, accountability of the principals, and the specific energy consumption patterns of the regarded objects. In this section some characteristics of these kinds of real estate and the actors involved in the building processes will be mentioned regarding the Dutch situation.

4.1 Residential real estate developed by social housing corporations

Social housing corporations own more than one third of the Dutch houses. By the end of 2003 the total number of houses owned by corporations was 2,420,500 (Dekker, 2004). The objective of these corporations is to provide affordable housing of a proper quality even for households with a minimum income. It is hard to achieve this objective in a market with relatively high land prices of € 341.- /m^2 on average. Besides, the average building costs of a rented house are € 86,000.- (excluding VAT) (Bouwend Nederland, 2007) and the adoption of energy saving techniques makes even higher investments necessary.

A subsidy on the rent is provided for the tenants of this type of residential real estate, when their income minus the cost of renting are below certain thresholds. These thresholds are solely based on the basic costs of hiring without service costs or energy costs. On average the basic costs are € 402.- per month (Bouwend Nederland, 2007). This means that extra investments that go beyond the basic regulations of the Building Code[1], can not be earned back by raising the monthly rent, because an increase will result in a subsidy stop for the tenant. However, the tenant does receive a lower energy bill and therefore will benefit from the investment done by the housing corporation.

De Man (1983) specified certain barriers that obstruct the adoption of energy saving techniques in the social housing sector. He distinguished structural, regulatory, and interpretive barriers. These barriers only addressed misfits in the relation between the national government and the social housing sector, but the organisation of the building process itself was not addressed. Nowadays social housing corporations are considered to be highly experienced principals or property developers regarding real estate, but based on the investments costs less experience is expected to exist on the adoption of innovative techniques.

4.2 Residential real estate developed by private ownership

In recent years the Dutch government stimulated the development of residential real estate by private ownership. This type of development is considered to be favourable because of the higher level of differentiation in building designs and of customer satisfaction. In most cases these houses are detached and are middle to high-priced. Regarding the adoption of energy saving techniques the financial aspect could form a smaller barrier compared to the development of social housing, but the principal’s acquaintance with existing energy saving techniques is expected to be a bigger barrier.

In developing residential real estate by private ownership the role of the principal is only in some cases ascribed to environmentalists that wish to adopt several energy saving techniques. However, in most cases the Building Code will be used to specify the quality level and just some basic energy saving techniques are applied. When the principal is not familiar with the broad range of energy saving techniques that is available nowadays, an important role can be played by the other actors that are involved in the project. Some architects for example are specialists in sustainable building and have progressive designs of houses available. In other cases it is the municipality that stimulates the adoption of energy saving techniques by offering information, subsidies or certificates. In these projects macro, meso and micro scale considerations can have an interesting overlap.

4.3 Commercial real estate developed by investors

The development of commercial real estate can take place on demand of a company that is in need of work space to provide service to its customers. However, in this research the development of real estate by (institutional) investors will be regarded, because in this design and building process the principal and user are not one and the same actor.

In the Netherlands the total number of offices is approximately 60.000 (Prendergast et al., 2006) with a value of 250 billion Euro (DTZ Zadelhoff, 2007). Although commercial real estate uses large quantities of energy, the building regulation on the energy consumption of commercial real estate is not as hard to comply with as the regulation for residential real estate. An obstacle in adopting energy saving techniques forms the fact that in many projects the future user of the building is not known yet. Therefore, the investor does not know what the energy consumption of user pattern will be, and if the future user is willingly to pay for the extra energy saving techniques in exchange for lower energy bills.

[1] The Dutch Building Code specifies the minimum quality of new buildings, among the prescripts is an Energy Performance Coefficient that specifies a maximum energy consumption per object.

4.4 Commercial real estate developed by the government

In many countries governments play an important role in developing commercial real estate. In the Netherlands the national government alone owns offices with a gross surface of 3,2 million m^2 (Min. VROM, 2007). By being principal and (dedicated) user at the same time a government (department) should be able to benefit from the investments during their whole lifespan. Furthermore, it is assumed that governmental principals set an example for the building industry by adopting state of the art energy saving techniques or by adopting energy saving techniques that are not profitable yet, but are considered to be sustainable. The government could be an experienced client (like Hartmann et al. (2008) already mentioned) with a strong social responsibility.

5. Methodology for future research

The research will be conducted by using structured questionnaires. The respondents will be chosen in such a way that they can reflect on one or more of the four building processes specified. Seven preliminary interviews among a social housing corporation, municipality, province, architect agency, and project developer demonstrated the need for a structured questionnaire, but with the possibility to include personal reflections on the questions and on the answer options. A scheme (see Figure 2) reflecting on the roles of the actors within the decision making process will be used to structure the answers regarding the first and third research question. The second research question on arguments and motivations is expected to result in figures comparable to Figure 1 of Hartman et al. (2008).

Furthermore, the first few interviews already demonstrated the relevance of financial aspects of energy saving and the necessity to operate demand based. This means that the client or user needs be willing to pay for the techniques. Without this willingness the Building Code and local regulations form the basics to achieve a certain energy performance.

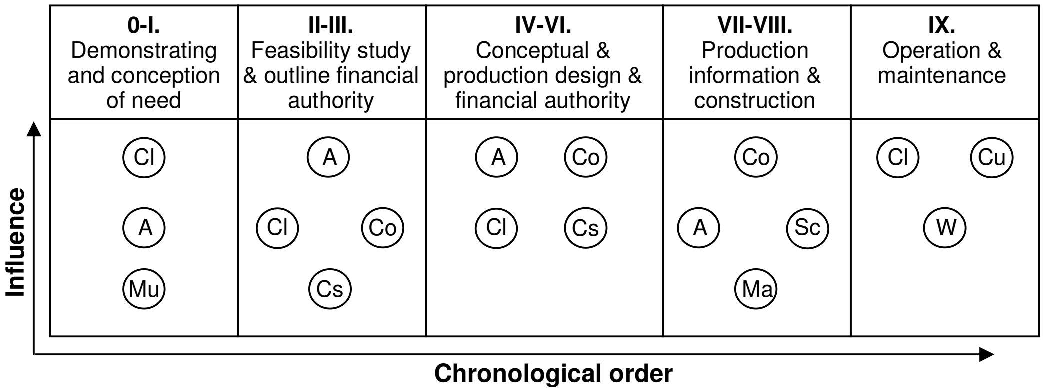

Figure 2 Possible representations of empirical data resulting from research on decision making actors in different phases of a building process.

6. First empirical results

Two preliminary projects had taken place to get insights in the adoption of energy saving and renewable energy techniques in the four building processes. The first project consisted of a research among social housing corporations regarding the decision to adopt or reject passive house designs. This research was conducted to reflect on the first phases (0-III) of buildings projects of the first category "residential real estate developed by social housing corporations" The second project focused on the possibilities to reduce Life Cycle Costs (LCC) by using Service Level Agreements (SLA) in commercial real estate. The LCC and SLA included among others heating systems and energy costs. This project considered commercial real estate in the existing building stock (phase IX) developed by investors.

6.1 Adoption of the passive house concept by social housing corporations

By using the integrative framework of Dieperink et al. (2004) research was conducted on which factors are of influence on the decision making process on adopting passiv houses by social housing corporations. In general the main categories that influence these processes were: government, market & society, company's characteristics, economic aspects, technical aspects, and macro developments. A methodology of reviewed surveying was used in which surveys were preceding extensive interviews among ten respondents of different housing corporations in the eastern part of The Netherlands.

Although these corporations have a strong social responsibility within the Dutch community, the surveys made clear that the economic aspects were considered to be the most important drivers to implement energy saving techniques (Dekker, 2008). The respondents could define, within the main categories, which aspects surrounding a project are influencing the decision making process most strongly. The results are given in Table 2. Furthermore, the results of the interviews showed that the corporations are well-disposed towards innovations that can reduce the energy consumption. One of the reasons for this sympathy is the rising energy price that increases living costs of their tenants.

Table 2: Relevance of aspects within main categories that influence the decision making process on adopting passiv houses according to respondents (Dekker, 2008).

Government	Market & society	Economic aspects	Technical aspects	Macro developments
1. Policy & regulations	1. Demand	1. Investment costs	1. Reliability	1. Energy prices
2. Incentive programs	2. Vertical collaboration	2. Pay back period	2. User-friendliness	2. Environmental considerations
3. Subsidies & credits	3. Influence of suppliers	3. Efficiency	3. Complexity	3. State of economy
4. Support	4. Rate of R&D		4. Technical practicability	4. Developments involving energy supply
5. Knowledge transfer	5. Union		5. Alternative options	
6. Convenants			6. Organisational practicability	
			7. Problems at startup	

6.2 Importance of life cycle costs and service level agreements among investors

In the research of Lenters (2008) the acquaintance with LCC and SLA among Dutch and German commercial companies and their vision on the possibilities to reduce costs by using SLA were revealed. Six Dutch and six German respondents have been interviewed. The interviews were again preceded by surveys.

Two out of twelve respondents were unacquainted with LCC. Five of the respondents indicated to be able to compute LCC themselves. Six persons mentioned that they were already familiar with the concept for more than five years. Regarding the energy consumption of commercial real estate SLA are used in the field of maintenance of building installations, climate control systems, heating systems, and electric equipment. In these situations the respondents state that these services are in most situations provided to the owner of the real estate object and not to the user. Services involving the maintenance of building installations and climate control systems are more often incorporated in SLA than services involving heating systems and electric equipment. These results are relevant to gain insights on how actors involved during design & construction phases of the building process and actors involved during operation & maintenance can match there interests.

7. Conclusions

This research aims at improving the understanding on how actors are involved in the processes of adopting and applying energy saving techniques. Interviews and structured questionnaires among social housing corporations shows that the bottom line for the energy performance of buildings given by the national Building Code or in some cases given by additional regulations provided by the municipality, and not surpassed willingly because of the involved investment costs. However, these regulations make sure that the corporations are requesting for energy saving techniques in an early stage of the building project. Furthermore, it seems at this moment that these regulations are their strongest motivation in applying energy saving techniques.

The foreseen methodology of structured questionnaires will give direct insights on micro scale. Insights on meso scale, reflected by the four distinguished building processes, can be generated by using a) a process protocol that specifies actor involvement in combination with b) a higher number of respondents than in former research was done. In the end we expect to be able to provide multi-actors strategies to enhance the adoption of energy saving techniques.

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THE PHILOSOPHY OF "SUFFICIENCY ECONOMY" AND SUSTAINABLE SUBURBAN COMMUNITY DEVELOPMENT IN THAILAND

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Keywords: sustainability, suburbia, Thailand, self-sufficiency, self-reliance.

Summary

Sufficiency Economy is one of the major goals for sustainable national development in Thailand, initiated by the present King of Thailand, along with a people-centred approach. New Theory Agriculture, the most famous and practical implementation of the philosophy of Sufficiency Economy has also proven useful among Thai farmers in rural areas. One of the major successes is the achievement of the key principles regarding self-reliance and self-sufficiency. Its implementation plays an important part in encouraging a better lifestyle, physical and emotional wellbeing, and resource management, specifically land. It helps to harmonise simultaneously individual, social, economic, and environmental development.

As New Theory Agriculture sets a good example of a move towards sustainable development in Thailand another step forward would be to apply it to a more complex scale of community such as suburbia. This paper investigates the importance of the philosophy for sustainable suburban development in Thailand and the possibility for its implementation and application, as well as benefits that might come from this. Case studies have been chosen to illustrate a clearer view of the current situation and present capabilities. The findings should encourage adjustments ranging from individual lifestyle, household planning, better relationships in the community, to those with the environment, as well as contributing to sustainable suburban community development in Thailand.

1. Introduction

Sufficiency Economy has been used as a Thai version of sustainable development and is meant to serve as an underlying principle to all activities for a sustainable future. Even though there is not enough evidence of comparative study between sustainable development approaches and Sufficiency Economy, which have similarities, it is possible to point out the potential sharing of key interests. The main idea of Sufficiency Economy; to live with what one can have and not be extravagant, suggesting that when one only has what one should the sharing of resources is fairer, will greatly contribute to a sustainable future. The philosophy of Sufficiency Economy is believed to be leading the nation to develop in a more secure way, producing a more resilient and sustainable economy, better able to meet the challenges arising from globalization and other changes (NESDB, n.d.: 1). The concept of this philosophy is understood to be capable of application to all people in society (NESDB, n.d.: 2). However, there is still little evidence of its practical implementation except for the famous New Theory Agriculture, a theory aimed at farmers in rural areas.

New Theory Agriculture has proven successful among rural communities, so it would be reasonable to take the further step of its implementation in a more complex society as found in suburbia, as this should be significant for overall national performance in the direction of sustainable development. Moreover, an earlier study (Hengrasmee and Vale, 2007) which tested the benefits of suburban agriculture to the Thai economy concluded that agricultural activity in suburban areas is necessary to maintain Thailand's economic status. Because New Theory Agriculture is aimed at meeting family consumption needs before providing goods for sale, the study hypothetically investigated the situation of national food supply and export capacity under the circumstance that all farmers practice New Theory Agriculture. It appears that surpluses produced by farmers are enough to sustain Thai national consumption. However, there would not be enough food for export which is one of the main sources of income for the country. Therefore, suburban agriculture could be a solution. When suburban people are partially responsible for food production it would lessen the farmers' burden of feeding the whole country and provide goods for export at the same time. This involvement would leave farmers with the job of feeding themselves, producing some foods that cannot be grown in suburbia, and investing their available land, labour, and time in other cash crops.

Accepting the need for food production in suburban areas and the need to establish the next step forward for the implementation of the philosophy of Sufficiency Economy, this paper explores the possibility of implementing the philosophy in suburban areas. The current capabilities of the selected areas are tested to see to what extent Sufficiency Economy can be applied into the suburban situation in Thailand.

2. Sufficiency Economy and New Theory Agriculture

The philosophy of Sufficiency Economy has been bestowed by His Majesty King Bhumibol Adulyadej (Rama IX) to his subjects through royal remarks on many occasions, and the origin can be traced back to the year 1974, even though only later in 1997 was it known as "Sufficiency Economy" (NESDB, n.d.: 1). The philosophy has been officially adopted as a vision for national development since production of the Ninth National Economic and Social Development Plan (2002-2006) (NESDB, 2002).

The concept of a Sufficiency Economy is adapted from Buddhism by stressing the "Middle Path" as an overriding principle for appropriate conduct by the populace at all levels (NESDB, n.d.: 2). According to the "Middle Path", "Sufficiency" is implemented as the three significant parameters of moderation, reasonableness, and the need for self-immunity for sufficient protection from impacts arising from internal and external changes (NESDB, n.d.: 2). So, in short, Sufficiency Economy is about encouraging people to know what is enough for each person, learn to be satisfied with what each can have, and try to be more self-reliant and self-sufficient without being too extravagant. This principle applies to all conduct starting from the level of families and communities, up to the whole nation (NESDB, n.d.: 2).

In terms of practice, the most important example of the implementation of the philosophy to date in Thailand is the famous "New Theory Agriculture" also given by King Rama IX in 1994. The emphasis is on practical implementation and has proved successful among rural communities. The theory recognises land capital and uses it as the basis of resource availability. The key idea is to make the most of the immediate environment at a manageable scale as well as maintaining harmony with it at all levels. It outlines the idea of what one can have. New Theory Agriculture is aimed to help people to have the ability to provide themselves with enough food to eat and enough essentials for everyday life, with much less dependency on outside factors. Then the surpluses can be exchanged or sold. The theory consists of three steps to be completed, from the smallest scale of a step to be taken by a family to the third step for the wider community. The essential part of the theory is about proper management of land use and how to develop the economy. The three steps of the theory are briefly described below.

The first step is based on producing enough products to be consumed in the family with some extra products to sell. This step is about the agricultural system, and encourages farmers to grow a diversity of plants to balance the ecological system and the needs of everyday life. The Theory suggests farmers proportionally manage their land by divided it into the four parts of a rice field, a pond, a farm plants/crops part, and a part for housing and other necessary buildings. An approximate proportion was suggested, but the key is for the farmer to divide the land reasonably according to individual needs, ability and available labour.

After successful practice of the first step, it is expected there will be enough food for each family. The second step is to pool efforts and look for co-operation within a community. The co-operative setting suggested by the second step will help to create a strong relationship based on interdependence in a community. Every family gets a reasonable benefit and a well planned society is created. In short, the second step of the New Theory is aimed at co-operation between people at every level in a community. The third step is creating a relationship to the outside community for improving local economic status. This step can help a community to reduce its capital costs and progress into a stronger position in the production and marketing field. This step will lead farmers to be more efficient and have an economic marketing operation.

New Theory Agriculture is not only well known as a theory, but has already been proven useful for farmers who are practising it. There is evidence of farmers having a better family life in terms of a well-fed family, less expenses, more income from selling their surpluses, and the family has work to do all year round, thus reducing the need for family members to migrate to find jobs in the city outside planting seasons (Promthong, 2001; The Chaipattana Foundation, 1997; 1998; 1999). It can be inferred from New Theory Agriculture that if the smallest scale of society, the family, especially in a rural area, can improve their economic position by trying to supply their own needs at less cost or undertake agricultural activities with far less capital cost than before, this might be the beginning of creating a sustained life for them and their community. The successful practice of New Theory Agriculture lies deeply in the self-reliant lifestyle and consciousness of self-sufficiency adopted by rural people. A major lesson drawn from the successful experiences of the farmers is that the combination of a self-reliant and self-sufficient attitude and practical arrangement of available land to suit the lifestyle is the key to success.

3. Process of the Study

This study aims to explore the possibility of implementing the Sufficiency Economy into suburban areas of Thailand. The process chosen for the task consists of four stages. The first stage is to identify the key ideas from Sufficiency Economy and New Theory Agriculture suitable for suburban implementation. Then an investigation of the general characteristics of an average household in suburbia will be undertaken. Stage three involves a series of investigations into the average consumption by a family, which will help to set a standard for demand. The last stage is to test the physical ability of average suburban households to supply the estimated demand.

3.1 Stage One: Key Issues for Implementation

This first stage is to identify the key areas of the philosophy that can be implemented in suburban areas. The successful implementation of the philosophy for rural areas in New Theory Agriculture was taken as the basis for this. The main idea behind the application of the first step of New Theory Agriculture is the method of land management, with the following steps being about building relationships within and between communities. The theory first suggests farmers divide their land into several parts with each having a different purpose and producing different products. Since New Theory Agriculture is an implementation of Sufficiency Economy, the main idea is also that the farmer, whose work is to provide food for others, should be able to provide his family members with their basic food needs. The suggestion for land arrangement is based on the amount of food each family needs to consume each year as well as the need for water for food production and family consumption, especially during the dry season. Surplus land can be used for producing extra products for sale, but only if the family can do this without overstretching themselves. The recognition of the Middle Path or moderation and self-sufficiency play an important role in the farmer's decision making. So, to be successful in practicing New Theory Agriculture, as well as building a good foundation for the family's economic status, the basic requirements are a combination of good judgment in terms of self-sufficiency as well as good practice in land management.

Implementation of Sufficiency Economy for a rural community using New Theory Agriculture suggests three scales of application, these being family, community, and national. Implementation of the philosophy in suburban areas can also use this structure. According to New Theory Agriculture, focus on the family is the first step before moving on to the second and third steps. The family level is centred on a self-sufficient lifestyle and practical land management that will enhance the ability to have a self-reliant lifestyle. This study investigates the possibility of applying the first step of the implementation process to suburban areas, so the physical characteristics of suburban households and the ability to support such a lifestyle will be tested.

3.2 Stage Two: Suburban Household Characteristics

In this study, implementation is focused on the first step, at family level. The physical characteristics of a representative residential area in suburban Thailand are needed for testing the capability for implementation. A suitable definition of Thai suburban areas is also needed, in order to identify the physical characteristics of average suburban households. The characteristics of average land holdings and housing footprints are identified for testing against consumption levels. This also means that any households outside the identified suburban areas but having equivalent characteristics should be able to comply with the study findings.

After careful consideration, two Tesban Thambol in Phitsanulok province were selected as examples of representative Thai suburban areas. According to the investigation, the most common areas for land holdings in the case studies range from 200-400 m^2 with an average 50-100 m^2 building footprint. In addition to the average range, six more housing models were selected from the standard housing plans provided in 2004 by the Department of Public Works and Town and Country Planning (n.d.) as these have footprints related in size to the averages discovered in the case studies. These also represent the average number of family members in suburban households and show a general understanding of contemporary housing trends for Thai people. These housing styles provide a foundation to work from, especially in terms of roof styles, when considering the potential for energy production and water collection.

3.3 Stage Three: Levels of Consumption

The average household size for the whole country when surveyed in 2004 was 3.4 people/family, so four family members (two parents and two children) have been assumed in this study (NSO, 2005). In general, suburban people will probably not be familiar with the idea of self-reliance, since the location of suburbia is normally close enough to facilities so people can buy all they need. However, better practice of self-reliance in suburbia or other places will support sustainable development in Thailand. A series of investigations into suburban consumption examined three areas of basic consumption for a family living in a suburban house. As New Theory Agriculture suggests farmers should live with less dependency on others for food and water, the basic needs for a suburban family which will increase their self-reliant lifestyle are assumed to be in the areas of food, energy, and water.

3.3.1 Food Consumption

How much a person eats is actually a personal issue. However, average consumption for Thai people can be estimated by using the average diet suggested by the Nutrition Division, Department of Health (2003). From the fact that suburban households have limited land, complete self-reliance in food will not be possible. Fruit and vegetables are seen as the most suitable types of food for home production on limited land as well as being appropriate in terms of the level of skill involved. Accordingly, only the consumption of fruit and vegetables will be presented here. The level of fruit and vegetable consumption suggested by FAO and WHO (2004) is a minimum of around 400g/person/day. More fruit and fewer vegetables are also mentioned. As a result, in this study it is assumed a family of four people will need 350kg of fruit and 234kg of vegetables each year.

3.3.2 Energy Consumption

Average energy consumption for Thai households can be traced from several national statistical data sets provided by government authorities. For example, data for different types of energy consumption in the residential sector are provided annually by the Department of Alternative Energy Development and Efficiency (DEDE, 2005b). Average electricity consumption for a household can also be traced by using data drawn from payment of electricity bills, with the latest data of this type in 2004 coming from a survey by the National Statistical Office (NSO, 2005). Along with information on the average price per kWh (unit) from the DEDE (2005a) in the same year, a rough picture of average electricity use per household per month can be built up.

However, in this study, estimation of energy consumption for a family is based on demand, and calculated from the types of appliance and period of use in a household with four people. The study also chose to use only electricity as the source of energy, in order to avoid complication. Two examples, one of low users and the second of intermediate/high users were created based on different types of appliance ownership and levels of use. Types of appliance selected in this study[1] are from a series of ownership surveys done by NSO (1996; 1998; 2000; 2002; 2004). The study estimated use of 5.9 kWh/day for a low user household and 18 kWh/day for an intermediate/high user household.

3.3.2 Water Consumption

Average water consumption data at national level is regularly provided by both Metropolitan Waterworks Authority (MWA) and Provincial Waterworks Authority (PWA). Water consumption per capita from 1997 to 2006 reported by MWA (2006) and PWA (n.d.) revealed that around 240 litres/person/day is used within MWA areas, and 150 litres/person/day in PWA areas. So, average water consumption in Thailand turns out to be around 200 litres/person/day. Even though the suburban example chosen for this study is inside a PWA area, a more generalised 200 litres/person/day is used to account for rising aspirations in suburbia.

In general, water is used for drinking, sanitation, and washing in a household as well as for outside activities such as watering plants and car washing. Average water consumption for different activities (Manager Online, 2003; Energy World Journal, 2003) in Thai households is shown in Table 1. The table also provides two alternative sets of consumption values based on water conservation practice appropriate for suburban households aiming for greater self-reliance. The first is based on installing better fixtures and the second on using greywater for the out-of-house use. In fact more actions involving behavioural changes can be done to reduce water consumption, but the two alternatives represent water conservation methods that can be easily achieved by all.

The study concludes that a family with conventional fixtures will require around 292,000 litres/year, a family with water conservation fixtures who are not using their greywater will use 208,780 litres/year, and a family with both water conservation fixtures and greywater use will need only 122,640 litres/year.

Table 1 Estimation of household water consumption per person

Types of use	Proportion (%)	Consumption per capita					
		Conventional fixtures		Water conservation fixtures			
				Without reusing greywater		Reusing greywater	
		litre/day	litre/year	litre/day	litre/year	litre/day	litre/year
Household cleaning	2	4	1,460	4	1,460	4	1,460
Kitchen use	5	10	3,650	10	3,650	10	3,650
Washing clothes	9	18	6,570	18	6,570	18	6,570
Wash basin and shower	23	46	16,790	27.6	10,074	27.6	10,074
Flushing toilet	26	52	18,980	13.5	4,928	13.5	4,928
Out-of-house use	35	70	25,550	70	25,550	10.4	3,796
Total	100	200	73,000	143	52,232	84	30,478

3.4 Stage Four: Potential for Self-reliance in Suburban Thailand

The physical characteristics of current suburban household models selected in stage two have been tested to see to what extent they can provide the basic needs for a family of four people as estimated in stage three. First, the ability to supply food is tested based on available land areas and appropriate levels of fruit and vegetable production. The capability for energy production and water collection is based on the size and type of roof from the selected housing models.

3.4.1 Potential for Food Production

The study selected three types of fruit[2], 13 vegetables[3], and 10 herbs[4] to represent the types of fruit and vegetables to be produced in suburban Thailand. The investigation involved the area needed for each plant, and length of time of growth and production on a monthly basis, to allow for the family being able to plant and harvest all year round. An area between 133 m^2 and 150 m^2 is needed for all plants. The different areas come from shifting plots between short-life plants.

Using the average range of current plot sizes (from stage two), the housing footprints of six standard housing models provided by the Thai government as well as two average housing footprints from the chosen suburban case study were calculated, with an allowance for a driveway. This was done to find out how much unbuilt area is left for food production. It is assumed vegetables are planted first due to their higher

[1] Types of appliance owned by a low user number 11, these being a television, electric fans, electric pot, rice cooker, lighting, washing machine, electric cooker, refrigerator, water pump, radio, and video player. For the intermediate/ higher user, 15 appliances were chosen including all of the appliances owned by the low users and four extra, these being air conditioners, water heater/boiler, microwave oven, and a computer.
[2] Guava, papaya, and banana.
[3] Cabbage, cauliflower, Chinese kale, Chinese flowering cabbage, leaf lettuce, Chinese cabbage, water spinach, yard long bean, cucumber, pumpkin, tomato, angled gourd, and okra.
[4] Coriander, long coriander, kitchen mint, galangal, ginger, chili, lime, lemon grass, sweet basil, and holy basil.

productivity compared to fruit for the same area. As a result, as shown in Table 2, the minimum that can be produced is 50% of yearly household consumption. When the housing plot reaches 350 m^2, all housing models can reach the stage of complete self-reliance for fruit and vegetables.

Table 2 Productivity levels of selected housing models on different plot sizes

Plot size	Productivity levels							
	Housing Type 2	Housing Type 3	Housing Type 4	Housing Type 5	Housing Type 6	Housing Type 7	50 m^2 footprint house	100 m^2 footprint house
200 m^2	N/A	50%	N/A	50%	N/A	N/A	60%	N/A
300 m^2	100%	100%	70%	100%	80%	70%	100%	80%
350 m^2	100%	100%	100%	100%	100%	100%	100%	100%
400 m^2	100%	100%	100%	100%	100%	100%	100%	100%

3.4.2 Potential for Energy Production

The potential for energy production in suburban areas is investigated by assuming all electricity generation comes from natural resources. The location of Thailand provides a good opportunity for exploiting solar radiation using photovoltaic (PV) cells for electricity generation. The average solar radiation for the whole country is 18.2 MJ/m^2-day (Janjai, Laksanaboonsong, and DEDE, 1999). For Phitsanulok, data obtained from the Regional Office of Energy Development and Promotion 9 shows average global solar radiation for the province ranges between 15.8-22.3 MJ/m^2-day and average insolation is 4.4-6.2 kWh/m^2-day.

The estimation of energy consumption presented earlier in stage two shows that 5.9 kWh/day is required for a low user household and 18 kWh/day for the intermediate/high user. The two systems for using PV panels for electricity generation are stand-alone and grid-connected. However, suburban areas are normally located where necessary facilities, such as electricity infrastructure, are already in place, so the stand-alone system does not seem appropriate. A grid-connected system would be a better choice in terms of smaller area requirement and less capital cost, as well not needing batteries for energy storage in the system. This paper presents the areas needed for PV grid-connected systems, which are also likely to be the main choice of suburban people due to the support for them given by Metropolitan Electricity Authority (MEA) and Provincial Electrical Authority (PEA) through the Very Small Power Producer program (VSPP) (MEA, n.d.; PEA, n.d.). The grid will act as the backup system for the house with surpluses put into the grid as necessary.

The investigation into using a grid-connected system is based on average insolation (5.2 kWh/m^2-day). In general an installation with a nominal power of 1kW_p requires an area of 9-20 m^2 (Hermannsdörfer and Rüb, 2005) depending on the type of photovoltaic cell. A project carried out by the Electric Generating Authority of Thailand (EGAT) and DEDE, which started phase one in 1997 with 10 houses and later expanded in 2002 with 50 houses, introduced the use of several types of PV panel to the general public (EGAT, 1998; 2004). Experiences of the project give a rough estimation of the relationship between PV nominal power and installation area. It appears from the project that the average area for a nominal power of 1kW_p using monocrystalline silicon or polycrystalline silicon is around 9 m^2, while an amorphous PV panel system requires 15 m^2.

The potentials for electricity generation for each housing type for a grid-connected system are listed in Table 3. Note that the southern side of the roof is used in this investigation, since it is the most suitable for PV installation in Thailand. Almost all roof types of the standard models provided by the government are hipped, so only around 1/3 of each roof is available for the installation. With a gable roof, there will be more area for PV installation, so both types of roof (hipped and gable) were applied to the 50 m^2 and 100 m^2 footprint houses in the investigation. It can be seen that nearly all housing models can produce enough electricity for a low user household whatever types of PV panel they use. The use of monocrystalline or polycrystalline panels allows the intermediate/ higher users to produce at least 60% from a grid-connected system. The amorphous type needs more area, so it is harder for the intermediate/ higher users to produce enough electricity with the current hipped roofs. The use of a gable roof would give more roof area and therefore more electricity.

Table 3 Potential for electricity generation of the selected housing models for a grid-connected system

Description	Housing Type 2	Housing Type 3	Housing Type 4	Housing Type 5	Housing Type 6	Housing Type 7	50 m^2 footprint house		100 m^2 footprint house	
Available roof area (m^2)	55	37	47	36	40	53	32 hipped	48 Gable	53 hipped	80 Gable
Monocrystalline Silicon/ Polycrystalline Silicon: 9m^2/1 kW_p										
-Low user (1.75 kWp)	≥100%	≥100%	≥100%	≥100%	≥100%	≥100%	≥100%	≥100%	≥100%	≥100%
-Intermediate/high user (5.37 kWp)	≥100%	77%	98%	75%	83%	≥100%	67%	100%	≥100%	≥100%
Amorphous Silicon: 15 m^2/1 kW_p										
-Low user (1.75 kWp)	≥100%	≥100%	≥100%	≥100%	≥100%	≥100%	≥100%	≥100%	≥100%	≥100%
-Intermediate/high user (5.37 kWp)	68%	46%	58%	44%	49%	65%	40%	59%	65%	99%

3.4.3 Potential for Water Collection and Storage

Investigation into the potential for water collection was divided into two parts. The first tested the estimated out-of-house water requirement (shown in stage three; 3.3.2) against the possible collection. The second compared rainwater harvested from the available roof area against total water requirement.

An area of 150 m^2 is needed for fruit, herbs, and vegetable production at home. An estimate from the New Theory (Promthong, 2001) of water needed for these plants other than natural rainfall is equal to 625 litres of water per square metre of productive garden. A 150 m^2 garden will, therefore, need 93,750 l/ year. The current 70 l/ person/ day for out-of-house use would give 102,200 liters of water for watering the plants each year. It is, therefore, assumed that 102,220 litres/year will be sufficient for all out-of-house use including growing the fruit and vegetables for home consumption.

Currently in Thailand rainwater remains one of the main sources of drinking water for many people even though there is much concern about human health and poor water quality because of the increase in pollution, causing alarm to many Thai people living in urban or industrial areas (Department of Health, 2007). The main reason for impurities is understood to be from improper design of collection and storage systems, as well as lack of maintenance, rather than the quality of rainwater itself (Department of Health, 2007). If rainwater is used as an alternative water supply, it can be treated appropriately either by boiling or passing through filters, especially if used for drinking. (Food and Water Sanitation Division, n.d.).

Phitsanulok has an annual average rainfall of 1,300 mm. Using the available roof areas of the housing models, the potential rainwater harvest is shown in Table 4. Only the household using water conservation practices involving water saving fixtures and reusing greywater can harvest enough rainwater for their annual consumption. The others will have to combine rainwater collection with conventional water supply.

Table 4 Potential rainwater harvest and levels of water use

Description	Housing Type 2	Housing Type 3	Housing Type 4	Housing Type 5	Housing Type 6	Housing Type 7	50 m^2 footprint house	100 m^2 footprint house
Catchment area (m^2)	166	110	142	109	121	160	96	159
Amount of rain harvested (litre)	215,800	143,000	184,600	159,900	185,900	208,000	124,800	206,700
Conventional consumption	74%	49%	63%	55%	64%	71%	43%	71%
Water conservation fixtures	≥100%	68%	88%	77%	89%	≤100%	62%	99%
Water conservation fixtures and reusing greywater	≥100%	≥100%	≥100%	≥100%	≥100%	≥100%	≥100%	≥100%

It is possible to harvest enough rainwater for family consumption. However, a container for rainwater storage is also required. Even though the average rainfall of Phitsanulok is quite high, the dry season is quite long. Rainwater storage would have to be big enough to hold between 38-48 m^3 depending on the roof area available even for the family with water conservation fixtures and greywater reuse. This size of water storage will greatly affect the land area available for food production if it is intended to install storage tanks above ground. In general, Thai people normally store water sufficient for up to two day's consumption as a general precaution in case of water cuts. Water tanks commonly used in the residential sector are, therefore, normally 1.5-4 m^3. Bigger water tanks are intended for use in public buildings and are harder to obtain for individual households. However, if collecting rainwater is seen as an appropriate practice by the majority of people, bigger water tanks would be more common.

4. Sufficiency Economy and Sustainable Suburban Community Development in Thailand

The first step of the implementation of Sufficiency Economy through the guidelines of New Theory Agriculture suggests self-sufficient lifestyle and practical land management are needed. These have been used as the key for testing the ability of current Thai suburban areas to become more self-reliant. The study shows that the current sizes of suburban property in Thailand have the ability to provide at least some of the basic needs of food, energy, and water. The overall results of the study show what is needed to achieve complete self-reliance in all areas. Current suburban households in Thailand could implement the idea of Sufficiency Economy and make a suburban version of New Theory Agriculture a reality. However, the major key to success lies in change in behaviour.

For example, the investigation into fruit and vegetable production shows that a sufficient amount of fruit and vegetables could be produced, if a family adopts agricultural activity as part of their normal routine. Similarly, a reasonable amount of electricity can also be harvested from the current available roof area, but, instead of installing enough PV panels to meet current energy demand, a family can also choose to reduce their energy use to match the roof area available, which will be a cheaper option. Moreover, the study shows Thai people use a lot of water, as much as 200 litres/person/day. In addition to the two technical alternatives for water conservation used in this study, more can be done to reduce water consumption by change in behaviour. For example, the time for showering could be reduced, and water supply can be turned off when soaping or brushing teeth. Even though total independence from the central water supply is not necessarily a goal because there is access to a water supply in suburban Thailand, some use of rainwater would help lessen impacts on the environment from the process of supplying water centrally. A life cycle study of residential water supply in New Zealand by Mithraratne and Vale (2007) suggests use of a rain harvesting system with a concrete rain tank can significantly reduce the life cycle energy and CO_2 emissions compared to the central supply. Moreover, in the case of newly developed areas with limited access to infrastructure, an increase in self-reliance could be seen as more appropriate practice than expansion of the central supply. The same study found that a concrete rain tank also has lower life cycle costs compared to the reticulated supply. However, the initial cost is much higher, which may be a discouragement. This condition is related to the situation in Thailand where bigger water tanks are not common for family use and are therefore more expensive. Promotion of the idea of rainwater collection or subsidy from the government instead of investment in expansion of public infrastructure and services would be a helpful support.

By practising self-reliance, a family would directly benefit from having fresher food, better economic status by less expense, and more understanding about their resource consumption. Even though the aim of this study is to test physical capability, which is only related to the first stage involving the individual or family level, when considering implementation of Sufficiency Economy and New Theory Agriculture for suburban areas as a whole, complete individual or family self-reliant lifestyle would not seen as necessary as for rural communities where access to infrastructure is limited. Reasonable implementation is required depending on each family and community condition. Co-operation within a neighbourhood and beyond, as in the second and third stages of New Theory Agriculture, would be a support for a self-reliant lifestyle for all individuals. A co-operative community would effectively provide assistance for exchanging products, labour, and services as well as strengthening relationships within the community and with other communities.

Community scale co-operation over basic needs, such as providing a community reservoir, local electricity service, community kitchen garden, and local market, could be managed so all community members can participate and benefit. In addition to these basic demands, services such as waste management could be a next step for all community members. After co-operative practice in this step is achieved, strong community building based on having strong families is established. The community will be related to the idea of sustainable development through the self-reliance rooted at family level. Wider connection to other communities as the last step in the implementation will build a network of services between communities as well spreading the ideas and practices through the connections.

5. Conclusion

The investigation into the possibility of implementing the philosophy of Sufficiency Economy through the guidelines suggested by New Theory Agriculture into suburban communities in Thailand proved that a self-reliant lifestyle in three basic needs, food (fruit and vegetables), energy, and water can be achieved. This paper shows that housing styles and plot sizes of current suburban households in Thailand can produce enough fruit and vegetables, electricity, and water for an average rate of consumption by a family of four. From the location and lifestyles of suburban people, a complete self-reliant lifestyle should not be necessary. The study cannot suggest how much each family should produce, because self-sufficiency as the main criteria for decision making is subjective and depends on each individual, but if practiced widely it will benefit households directly and contribute to sustainable suburban and national development as a whole.

The idea behind implementation of the philosophy is intended to encourage individuals in terms of adjustments to lifestyle and behaviour. It also provides a rough idea of what households in Thailand with the same physical characteristics could achieve. According to the three steps of implementation, successful application of the first step will contribute to a strong foundation for community. Further steps with the individual and community working alongside each other will help to build stronger and more sustainable community development as well as a better environment.

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HOW THE RESULTS OF THE EQUILIBRIUM™ INITIATIVE COULD AFFECT THE FUTURE OF CANADIAN HOUSING

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Summary

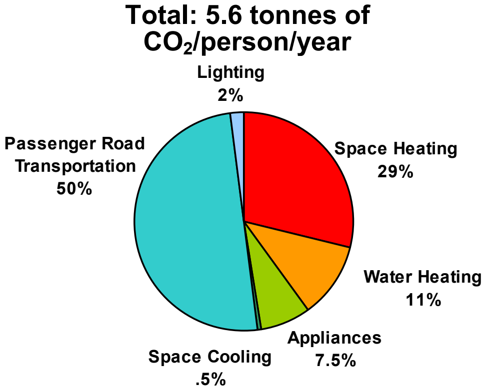
Faced with rising energy costs, environmental and health problems, Canadians are beginning to consider housing options that are healthy, energy-efficient, durable, environmentally friendly and less expensive to operate and maintain. This paper provides an overview of how Canada attempts to balance all those aspects while trying to introduce the sustainability principles for both housing and communities. In view of past and future scenarios of the environmental impact of housing, the Canada Mortgage and Housing Corporation (CMHC), a national housing agency, created the EQuilibrium™ Sustainable Housing Initiative to encourage a move towards sustainability across Canada. Projects including both new and retrofits in urban, suburban and rural environments were selected in 2007and 2008. Several have already been finished providing invaluable data. The technical requirements specified that the housing be healthy, energy and resource efficient, affordable, and with a low environmental impact all the while producing as much energy as it uses on an annual basis. This paper provides various Canadian housing scenarios followed by a short analysis of EQ approaches, focusing particularly on energy performance. It also provides the overview of used technologies offering possible solutions to sustainable living and, in the long term, optimization of future Canadian housing.

1. Environmental Impact of Residential Sector in Canada - Rationale for Action

In order to understand the rationale behind the EQuilibrium™ Initiative one must look at the reality of all aspects of environmental impact associated with past and current housing developments. The truth is that for the entire world to live as an American or Canadian two more earths would be required. The average Canadian footprint is approximately 8.5 hectares per person (it almost doubled over last 15 years) while there are only 2 productive hectares available for each person on the planet. A recent study led by Marbek Consultants for CMHC related to the environmental impact of housing in Canada (up to year 2025) had several findings. Residential sector environmental outputs have regional and global environmental consequences - the magnitude of environmental outputs to air, water, soils and land alterations of this sector are significant enough that they can be expected to contribute to broader environmental impacts including acid rain, smog, climate change, biodiversity decline, and Arctic contamination. The implications of different scenarios for dwellings, neighbourhoods, and infrastructure were evaluated to develop the future mechanisms for establishing long term goals and objectives.

1.1 The Relevant Housing Data Findings *(Marbek et al 2007)*

- There were 12 million dwelling units in Canada in 2004, with single detached houses accounting for about 57% of the total. They will continue as the dominant dwelling type until at least 2025.
- Only 25% of the estimated 16 million dwellings projected for the 2025 will be built after 2004. Reductions in environmental impacts would be limited unless the condition of existing dwelling stock is upgraded.
- There are significant opportunities in new housing in terms of “getting it right the first time”.



According to a Natural Resources Canada report on energy efficiency trends published in 2006, GHG emissions from the residential sector were up 10 per cent in 2004 (76.7 Mt) compared to 1990 (69.5 Mt). Without the energy efficiency improvements made in that time span, energy use would have risen by 31 percent.

Note: one transcontinental flight can add as much as 5-10 tonnes to the production of CO_2

Figure 1. Emissions of CO_2 per capita

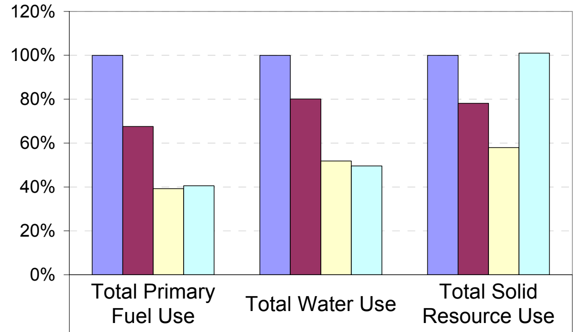
1.2 Residential sector - overall resource use and environmental outputs:

- The operating stage dominates overall environmental outputs consisting of roughly 75%–95% of the total life-cycle environmental outputs during 2004–2025.
- Operation of dwellings and residential transportation dominate life-cycle energy use accounting (for over 50% and almost 45% respectively) of the total life-cycle primary energy use during 2004–2025. Choices such as neighbourhood and dwelling, dwelling conditions (e.g., envelope, equipment), and daily behaviours (e.g., heating/cooling, hot water use, etc.) have a huge influence over how much life-cycle energy is needed.

1.3 Residential Sector Impacts *(Marbek et al 2007)*

- A single detached house has the highest environmental outputs per dwelling, requiring significantly more life-cycle resources and producing significantly more life-cycle air, water, and soil pollutants. On a per-dwelling basis, single detached house would require roughly 30% more life-cycle resources than row/town house, and roughly double that of low-rise apartment/condo unit, as shown in Figure 2. These increased environmental outputs could be assumed to result in higher environmental impacts than other dwelling types.

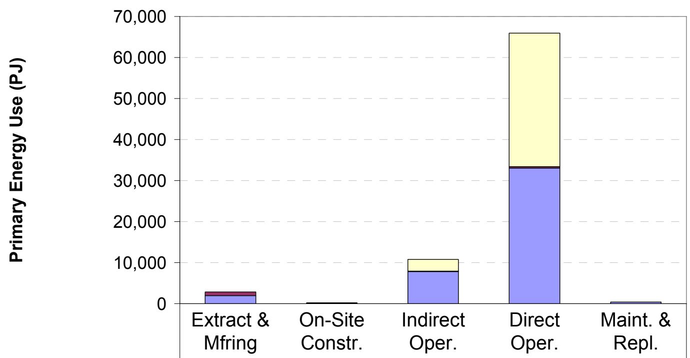
Impacts to Resources:



	Total Primary Fuel Use	Total Water Use	Total Solid Resource Use
Single	100%	100%	100%
Row/Town	68%	80%	78%
Low-rise MURB	39%	52%	58%
High-rise MURB	41%	50%	101%

Figure 2: Life-cycle Resource Use per Dwelling during 2004–2025, by Dwelling Type, Normalized to Single Detached *(Marbek et al 2007)*

- The location of dwellings and our associated behaviors have tremendous impacts requiring solutions to reduce impacts through good design and construction practices and operational stage behaviors in order to reduce these impacts.



	Extract & Mfring	On-Site Constr.	Indirect Oper.	Direct Oper.	Maint. & Repl.
Res. Transp.			2.9E+03	3.3E+04	
Road, Water & Wastewater Infra.	8.9E+02	5.9E+01	1.3E+02	3.1E+02	
Dwellings	2.0E+03	1.4E+02	7.8E+03	3.3E+04	3.9E+02

Housing accounts for 17 per cent of secondary energy use in Canada and 16 per cent of the country's greenhouse gas (GHG) emissions (Natural Resources Canada, Energy Use Data Handbook August 2006).

Figure 3: Life-cycle Primary Energy Use by the Residential Sector during 2004–2025, by Life-cycle Stage & Structure/Activity[1] *(Marbek et al 2007)*

Impacts to Air:

[1] *Secondary energy* includes only the energy commodities paid for by end users (e.g., electricity, natural gas, propane, fuel oil, diesel, gasoline, wood, etc.), while *primary energy* also includes all raw energy resources (e.g., crude oil, coal, etc.) used to produce and distribute that secondary energy

- Annual carbon monoxide (CO) emissions from the residential sector are about eight times higher than the total of the industrial sectors for which data were available (not all of sectors release that information).

Impacts to Water
- Annual water use in existing dwellings is expected to decline by 20% during the study period primarily due to improved plumbing fixtures installed during kitchen and bathroom renovations. However, water use in new dwellings more than makes up the difference.
- In 2004, Canadians consumed 335 litres of water per person per day, at 65% above the Organisation for Economic Co-operation and Development (OECD) average totalling 3.7 teralitres — equivalent to about 15 days of water flow over Niagara Falls and representing 60% of total annual water use in the country.

Impacts to Land and Soil:
- With expected neighbourhood development patterns, such as significant decline of suburban expansion and associated consumption of land, the effects of housing development and use in existing neighbourhoods have to be mitigated even if existing neighbourhoods will absorb most of the new dwelling stock to 2025.

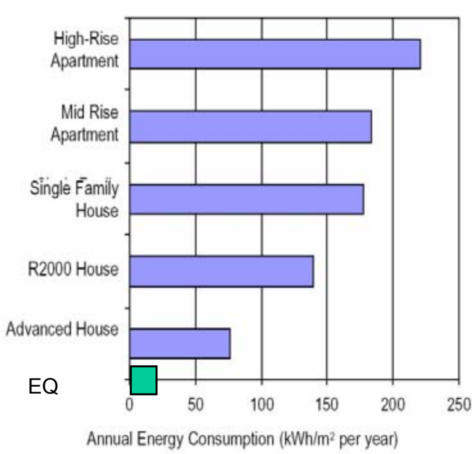
2. EQuilibrium™ Initiative

The word "Sustainability" tells us about the possible equilibrium - balance between 3 pillars / principles of sustainability: ecological, economical and societal (social, cultural, ethical etc, while social itself = health/safety, neighborhood impact, quality of life etc.) - the balance in high performance housing within sustainable community where all principles would be applied and where people could enjoy healthy lives while their impact on nature, including all developments, would be minimal.

2.1 EQuilibriumtm Housing Definition

EQuilibrium™ (EQ™) is a Canadian housing initiative, led by CMHC. The initiative evolved from the initial Net Zero Energy Healthy Housing with the ultimate goal of developing demonstration housing that would produce as much energy on-site as it consumes on an annual basis by applying measures of energy efficiency and using renewable energy. The housing is to also provide safe, comfortable and healthy living spaces for occupants, resource conservation and reduced environmental impact on land, water and air.

A (net) zero energy building can be defined in several ways *(Crawley et al, 2006)* and different definitions depend on factors such as the project goals set by the design team and by relevant legislation or guidelines. Different stakeholders have different perspectives: for example government is interested mainly in primary energy that provides national energy numbers, while building owners are usually thinking about energy costs and measures to reduce them, and designers are dealing with on-site energy use and energy code requirements. Others may be interested in reducing emissions from power plants.
There are four commonly used "net zero" definitions such as: net zero site energy, net zero primary energy, net zero energy costs, and net zero energy emissions. The EQuilibrium™ initiative is based on the net zero site energy meaning that an EQ™ site produces over the year at least as much energy as it uses and it can be monitored on-site, while source energy or emissions cannot be measured directly due to site-to-source factors, or too much oscillation such as in case of net zero energy costs.
The secondary and primary types of energy play a major role in environmental impact analysis and the country performance in that area is a good indicator about the current "state of affairs" and about intentions. The *Figure 4* below indicates the problem in Canada.



The Government of Canada's 20 plus years old R2000 Program for energy efficient housing has never reached its intended market share, while the Advanced Houses Program was only a one-time initiative to demonstrate and monitor new technologies needed to achieve levels higher than R2000.
Thus came a need for a tangible program with aspects of both house and community, which would achieve much better performance while its results, after being monitored closely for a year, will create a base for a country large House/Community program.

Figure 4. Annual Energy consumption in residential sector in Canada with the predicted EQ™ performance.

Peter Pfeiffer, a "green architect" from Austin, Texas, said:

"Using energy production strategies before energy conservation strategies is like (smoking) a vitamin-enriched cigarette – a house should be green by design instead of green by device".

2.2 Features and Advantages of EQuilibrium™ Housing

The EQ™ teams were asked to design the best housing to minimize energy (and resource) consumption and only then use the appropriate technologies to achieve the goal of balancing optimized energy use with its production on site. The concept integrates climate specific issues, energy efficient construction, reduced energy use, passive solar design, indoor environmental quality, grid interconnected renewable energy systems, water, land and natural habitat conservation and strong community context to reduce home's environmental impact to an absolute minimum.
The intention of EQuilibrium™ initiative is to combine and integrate these design and building practices into practical solutions that meet the needs of both occupants and builders alike.
The benefits and advantages offered to owners include:

- ***Lower energy bills*** – net zero energy consumption annually means dramatically lower energy bills and protection from fluctuations and increases in future energy prices.
- ***A reliable source of energy*** – integrated on-site renewable energy systems can be designed to continue functioning even during blackouts.
- ***Healthier living*** –better indoor air quality and non-toxic, healthy materials and finishes.
- ***Greater comfort all year*** – an energy-efficient building envelope, more natural light and better acoustics.
- ***Reduced pollution and CO2 emissions*** – with better building design and reduced energy demand.
- ***Affordable sustainable development –*** vital and healthy communities with efficient infrastructure, attractive green spaces and vibrant neighborhoods that combine places to work, live and play. Initially, houses are expected to cost more than conventional housing. But a higher purchase price will be offset, depending on ever increasing energy prices, by the significantly lower energy and operating costs.

Subsequent to Request for Proposals, CMHC selected 12 winning projects in 2007 and 2008 to build EQuilibrium™ demonstration homes in all regions while giving them technical, marketing and financial support. The builders will acquire the experience and expertise to access new business opportunities and to promote such homes across Canada.

Six examples of EQ™ homes below represent rural, suburban and urban settings

Figure 5 Eco-Terra, Eastman, Quebec

Figure 6 Avalon Dicovery III - Red Deer, Alberta

Figure 7 Riverdale, Edmonton, Alberta

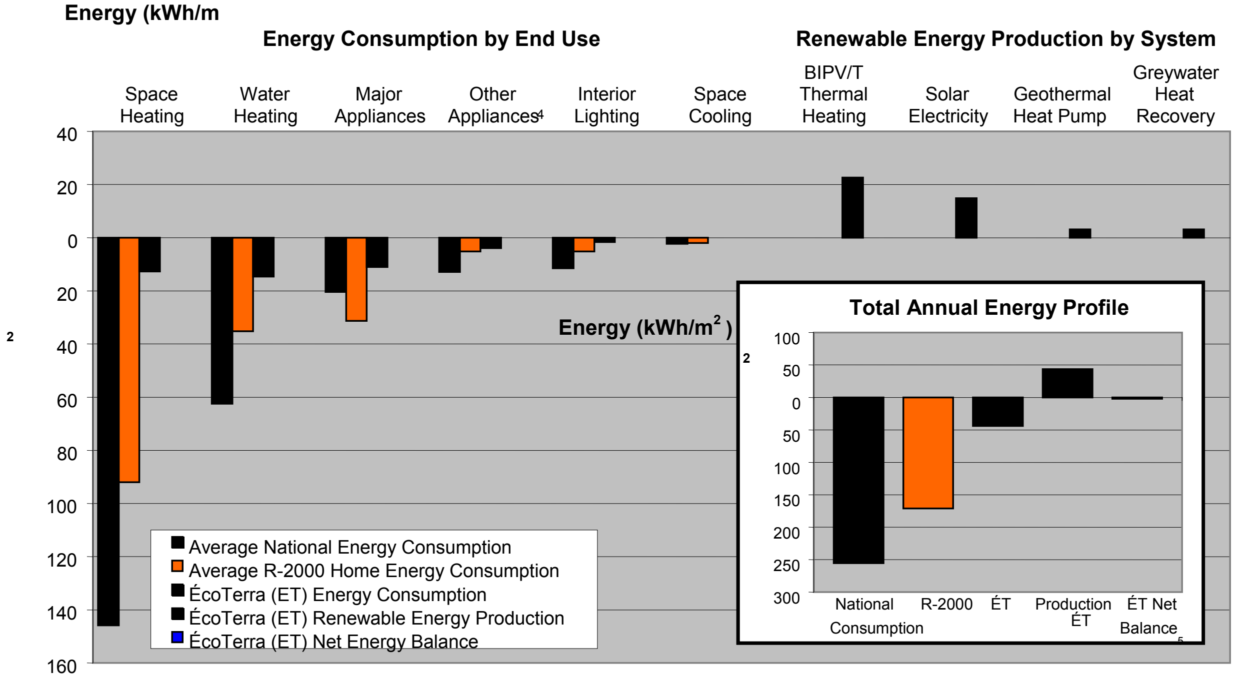
Figure 8 Annex Townhomes, Toronto, Ontario

Figure 9 Minto EcoHome, Ottawa, Ontario

Figure 10 CHESS, Red Deer, Alberta

In their original submissions most of the EQtm teams show very high average levels of insulation in walls and roofs of R52 and R65 respectively (R value; 1 R = 0.176 RSI) despite the decreasing efficiency and significant increase in cost in relation to heating energy savings. Several teams however, such as for example EcoTerra, with energy consumption data shown in *Figure 11* below, achieved good enough results looking instead for energy efficiency and savings in other areas like very strict passive solar design and high quality of construction, equipment, appliances and materials.
Average use of PVs (photovolaics) reached approximately 5.5 kW per project, which meant that teams attained the initial requirement for a very good envelope performance. The design's pre-requisite was to achieve a higher level of performance than current R-2000 standards, which has set the bar for many years. For example, all finalists had to pass the computer simulations on HOT2000 program to verify the required values above R2000 in envelope design. The net energy performance achieved average of 98.8 with a 100 established as a net zero energy performance over a year as per definition.

Figure 11 - Comparison of Canadian National Average , R-2000 Home and Predicted ÉcoTerra (ÉT) Annual Residential Energy Consumption and Production (Sources: NRCan, ET)



Profiles of most other houses show similar relative energy values, but all of them are still based on predicted yearly design values and not the operational data. The mandatory monitoring during the first year of occupancy will ensure that the final project evaluation will be based on actual performance.

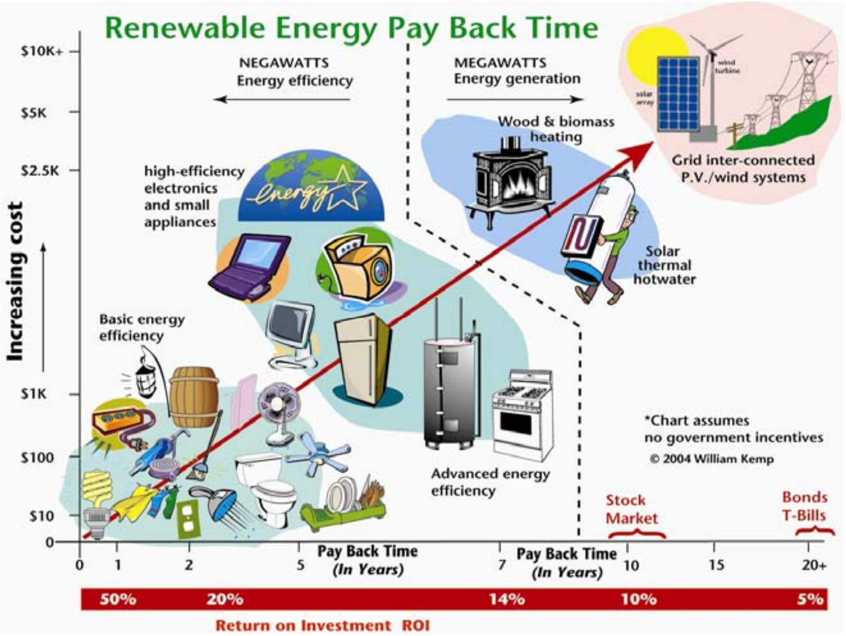
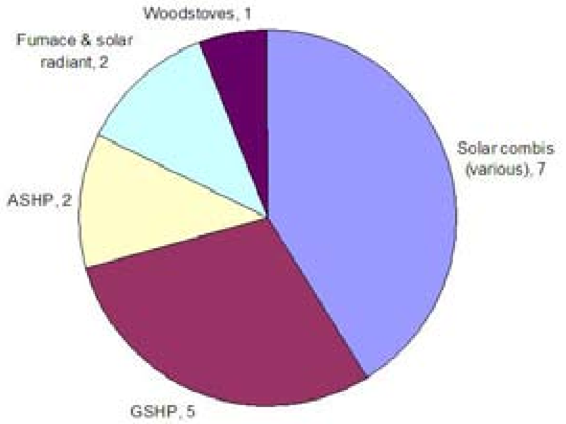


Figure 12. Renewable energy payback time *Source: Natural Resources Canada, 2007*

Another very important aspect is the payback time for necessary investments in technologies.
As the Figure 12 shows, the payback period for items such as solar thermal hot water and photovoltaics are still beyond what average people consider reasonable.
There are also many institutional barriers, codes and regulations which, while not being updated for decades, are blocking use of efficient technologies. Very often by-laws go to the anecdotal levels like for example one in major Canadian city banning use of PVs on residential buildings due to "(energy) manufacturing process" for which re-zoning to industrial would be necessary.



ASHP- Air Source Heat Pump
GSHP- Ground Source Heat Pump
Solar combi- solar heating system that provides both space heating and hot water heating. The primary heat source is solar energy with the balance provided by backup heater(s) fuelled by gas, oil, electricity or biomass.

Sources: Natural Resources Canada, 2007; CMHC

Figure 13. Heating system types in EQ^{TM} projects as shown in original submissions - some projects utilize more than one type.

The proposed heating systems reflected the willingness to use (and pay for) any system which would improve the performance and help achieve a Net Zero Energy goal, thus underlining the research purposes more than affordability, required to a certain extent by the design guidelines.
It was clear that the task to promote the "solar" challenge will be very difficult and mainly due to incorrect perception that in Canada as a Northern country, no solar technologies would ever work well enough. However, the latitude of Ottawa (45° 25') is close to that of Nice in France(43° 42') and Canada's most populated areas along the US border enjoy much more sun that the solar leader – Germany.

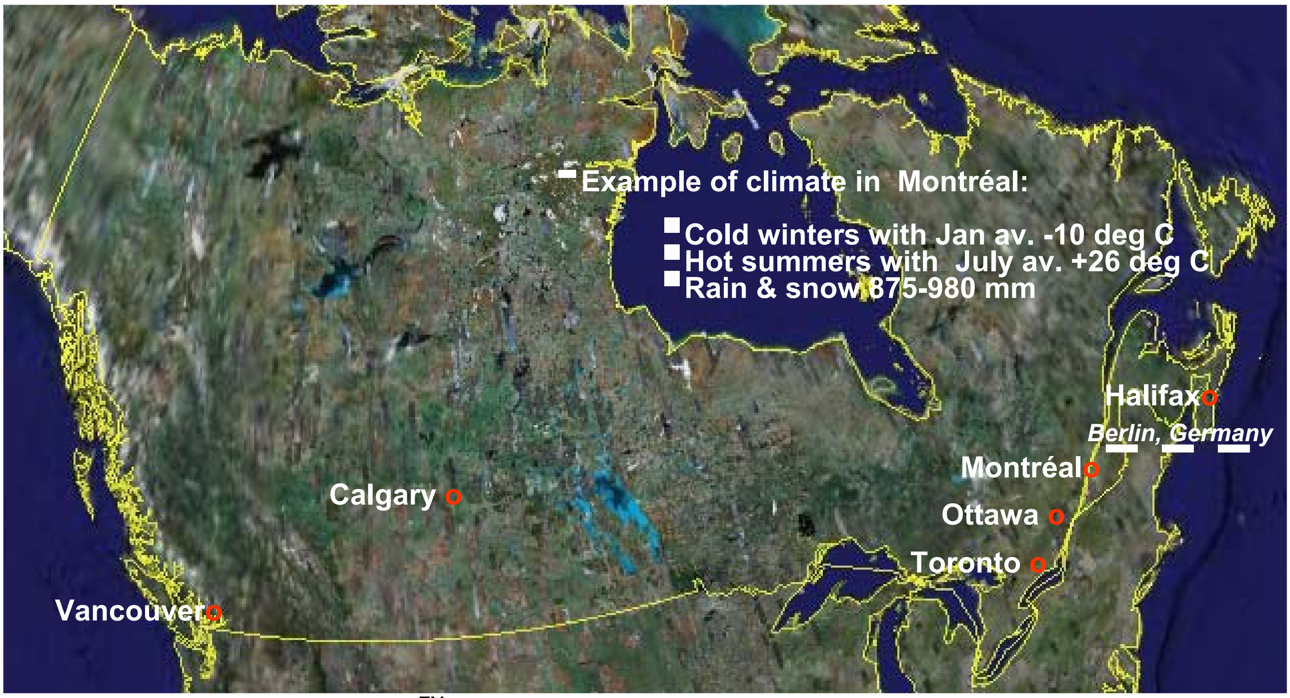


Figure 14. Map of Canada with EQ^{TM} approximate locations and latitude of Berlin, Germany for comparison

Process conclusions

After several homes have been started and one finished, preliminary conclusions started to emerge such as:

- The public was afraid of too much technology versus "equally good, but simpler" approach
- Large scale builders use of "regular" workers is not enough and professional teams are required with the necessity to market good workmanship and an explanation of the approach without compromising community and health issues.

- Too much faith was put into increased insulation without an extensive "building as a system" analysis, especially in regards to building envelope and leakage control.
- Education of consumers and professionals is crucial to future follow up especially in areas such as passive solar design concepts for house and community, basic definitions of energies, renewable technologies (solar heating and solar electrical energy) use and installation.
- Necessity of life cycle cost analysis combined with mortgage payments and with respective energy cost saving - the optimization of investment with specifics such as current energy price, availability of fuels, price and predictions of renewable energy technologies. windows technologies
- Understanding of sustainable community, public transportation, necessity of large scale, high performance retrofits as a main component of the future in housing

The goal of the EQuilibrium™ Housing initiative in limiting resources use is directly related to the looming climate change or in other words, to the ever increasing destruction of our planet, if the current *Business As Usual* building practices are not adjusted to the fact that the resources are not limitless and that life for future generations will be endangered. It is a small, but a significant, step to develop a vision and approach to build capacity and to lower or eliminate existing barriers for Canada's future residential and renewable energy industry sectors. It will soon be followed by the creation of sustainable EQ™ communities across the country with demonstrations of 1500 houses by 2010 and achievement of market acceptance of such communities with highly energy-efficient healthy houses.

3. Conclusions

Thus the EQuilibrium™ housing initiative represents a significant step forward in the future reduction of the energy intensity of Canada's housing sector, supporting the growing need for renewable energy solutions and it is also an ambitious attempt at applying high performance, healthy housing principles to reduce the future environmental impacts of an entire sector.
Some of these leading-edge EQuilibrium™ Initiative houses are clearly winners in a design stage, but none have yet been verified in the real world over an extended period of time. We can expect however, that most of them, if not all, will achieve a site Net Zero Energy goal and that the results from this initiative will help Canadians plan further research and explore appropriate solutions to properly address the ever increasing environmental impact of the residential sector. Canada is the fourth largest producer of GHG emissions per capita and it is getting worse.The long term EQ™ initiative's goal to build all houses as Net Zero Energy in 2030 will probably be revised to much earlier years. It is enough to look at the European Union to see how the immediate action could be implemented. The value of research coming in the next few years from monitored homes will be priceless in many technical aspects however, the barriers such as conservatism and fear of anything new, constrains from financial institutions and market confidence can only be achieved through education on all levels and assistance through regulatory frameworks.

There is a lot of interest for EQuilibrium™ Initiative coming from builders, developers and architects, and from progressive government agencies as well as from regular people not interested in just "building the best", but also looking for answers why to do it in a first place. The results of that interest vary from a change of regulation, a new university curriculum, educated builder to more tangible outcomes, such as energy efficient subdivisions and even Net Zero component in the Olympic Village in Vancouver being built for the 2010 Games. These results show that maybe we can slow down our insatiable expansion where it is still possible, and limit our impacts on nature, which is (repeating after P.Curry in *"Ecological Ethics"): "…an ultimate source of all value. Unless it gets our consideration, the richest and most wonderful places and most of the mankind probably will not survive this century and that will be our great crime against our children and grandchildren".*

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Some Websites

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http://www.avalonmasterbuilder.com/net_zero.html
http://www.echohaven.ca/net-zero.html
http://www.ecocite.ca/projects_abondance.html
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http://www.nowhouseproject.com/
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http://www.sui-toronto.com/

SUSTAINABILITY INDICATORS FOR BUILDINGS: STATE OF THE ART AND CHALLENGES FOR DEVELOPMENT IN BRAZIL

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Key-words: sustainability, indicators, assessment, buildings, built environment.

Summary

Sustainability indicators of the built environment describe its environmental, economic and social impacts for designers, owners, users, managers, policy makers and other stakeholders in the building sector. Such indicators capture trends to inform decision agents, guide policies and strategies development and monitoring, and to facilitate sustainability reporting. An indicator therefore has, three major functions: quantify, simplify and communicate.

Sustainability indicators rose initially at the nations' sphere, most of them in response to Agenda 21, but sustainability metrics are necessary at all levels. In Brazil, there are several efforts to define sustainability metrics for the built environment at its different scales that, however, vary greatly and are defined by criteria and methodologies not necessarily replicable. This paper has four major goals: to revise international literature and define sustainability indicators; to stimulate a strategic reflection on difficulties and barriers for the establishment of indicators of sustainability of the built environment in Brazil; to identify research needs to promote effective advance in this field; and to discuss methodological procedures to develop indicators at the building level.

To advance on the development of sustainability indicators for the built environment in Brazil it is necessary to: (1) define a framework and methodology for developing sustainability indicators, (2) define common indicators to be monitored at national level, as well as groups of local indicators, selected as appropriate; (3) create a national database; and (4) make these data publicly available and up-to-date. A network effort at national level is needed and should be specially considered by R&D funding agencies.

1. Introduction

Indicators are parameters (measured or observed property) or values derived from parameters that provide information on a given phenomenon (OECD, 1993). An indicator has synthetic meaning and is developed for a specific purpose. These two characteristics make their meaning transcend the properties directly associated to the parameter value, as the number or measurements and needed parameters to describe a given situation is reduced, and the information process that deliver the results of such measurements to the final user, simplified.

The establishment of sustainability assessment supposes the use of reliable, representative, comparable and traceable indicators. To be useful, and indicator should, therefore, allow for an explanation of the reason of changes in its value through time, be sufficiently simple in the way it describes problems usually complex, and use common definitions of key-components and normalization to enable comparisons (COLE, 2002).

Sustainability indicators were created first at nation's level, noticeably as a response for Agenda 21. However, metrics are needed at all levels (Figure 1), as they can not only show the way, but also show if and how occurs the movement of the society, the construction industry, an organization or the production of buildings in relation of national sustainable development goals (SILVA, 2003). At building/built environment level, such metrics are necessary to simplify and communicate complex information, and can be used for (ISO, 2005):

- Evaluation (against reference values or performance targets);
- Diagnosis (to identify factors affecting sustainability);
- Comparison (among alternatives and buildings); and
- Monitoring (change across time).

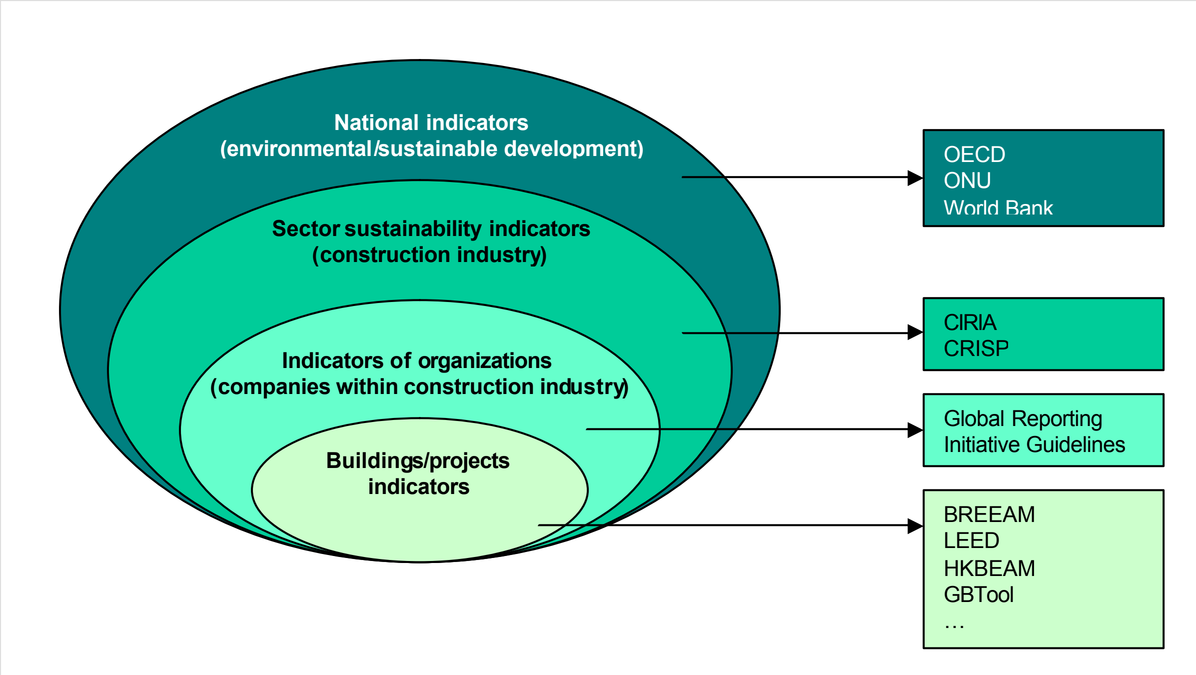

Figure 1 - Scales of action of major initiatives on sustainable development/environmental indicators.

Despite being fundamental to help unifying economic, social, environmental and institutional decision-making, indicators *per si* are not capable to promote performance improvement. Performance targets and benchmarks, for each indicator, are equally necessary to, at one's hand, calibrate the analysis (i.e. define performance scale) and evaluate progress (SILVA, 2003) and, on the other, encourage appropriate resource allocation to reach the aimed progress rate (CIRIA, 2001).

Next sections present a panorama of the major international initiatives as well as of the challenges posed to advance in the development of sustainability indicators of the built environment in Brazil.

1.1. Goals and methods

This paper aims at (1) stimulating a strategic reflection regarding barriers and challenges for the establishment of national indicators of sustainability of building and the built environment; (2) identify research needs to promote effective advances in this field; and (3) discuss methodological procedures for definition of sustainability indicators of the built environment in Brazil.

Study and discussion methodology is based on a broad review of national and international literature and previous initiatives, and analysis of (1) the relationship between application of environmental/sustainability assessment, projects life-cycle and users needs and expectations; (2) perspectives adopted by existing assessment methods, regarding use of indicators; and (3) recommendations and approaches internationally accepted for the establishment of sustainability indicators.

2. Initiatives at national, construction sector and building levels

At nation's level, the Organization for Economic Co-operation and Development (OECD) pioneered the development of indicators in 1989, and started regular publication of environmental indicators in 1991. UN involvement dates back to 1972, when the Stockholm UN Summit made evident that environmental issues had steadily become object of social/economic international policies. Twenty years later, in the UNCED at Rio de Janeiro, it was consensually agreed that (1) strategies for sustainable development should integrate environmental aspects in development policy and plans and (2) for that purpose, such instruments would require support of environmental and social/economical data. Published at the very UNCED, Agenda 21 (United Nations, 1992) listed specific recommendations for the development and implementation of environmental and economic accounting, and of sustainable development indicators (UNSTAT, 2002b).

The United Nations Commission for Sustainable Development (UN CSD) was another Rio 92's result, and carried out a vast work program on sustainable development indicators between 1995 and 2000 (DESA, 1999a). OECD and UN paths crossed after 1993, when OECD published its core set of indicators (OECD, 1993). This was the major inspiration for sustainable indicators lists published by UN CSD in 1996 (DESA, 1996), as a first response to Agenda 21 demand, and in 1999 (DESA, 1999b).

From mid 80's on, several frameworks were developed to organize nation-level indicators, particularly environmental indicators. Most of the initial work on environmental indicators focused on the state of the environment, through monitoring of physical alterations of the natural environment. To explicit the causes of the identified problems and what could be done to solve them, gradually more encompassing pressure-response models were developed like pressure-state-response (PSR) model, adopted by OECD and its variations: driving force–state-response (DSR), adopted by UN CSD; driving force–pressure-state-impact-response (DPSIR), adopted by the European Environment Agency (EIA) and by Statistical Office of the European Communities (EUROSTAT). Combinations of media and pressure-response approaches were used by the Environment Statistics Section of UNSTAT (UNSTAT, 1984) and by the CSD Theme Indicator Framework (DESA, 1999b), which organizes indicators according to four major dimensions (social, environmental, economic and institutional indicators), divided in themes and sub-themes. The structure of the Agenda 21 was no more strictly followed, but the themes/sub-themes refer to the appropriate chapters. This framework formed the basis for development of several works, like the European networks BEQUEST and CRISP, and SILVA (2003), a discussion for the Brazilian context.

The most relevant initiatives to be highlighted at sectorial level are probably the work carried out by the Construction Industry Research and Information Association (CIRIA) for the United Kingdom (CIRIA, 2001) and by CIB W82 Construction Related Sustainability Indicators – CRISP (June 2000 and August 2003) at European level, partnering with four other countries, captured in publications like Bourdeau et al (1998), CIB W82 (1999), CRISP Network (2001) and Häkkinen et al (2002). At building level, studies at University of Michigan (REPPE, 1999), and within Green Building Challenge (GBC) scope to analyze and compare buildings across different national contexts (COLE;LARSSON (2000); TODD;JOHN (2001)) and within ISO/TC59/SC17/WG2 (ISO, 2005b) effort for specific standardization framework deserve recognition.

There are fundamental distinctions between the pure concept of sustainability indicators and the indicators used – or possible to be presently used – in building assessment systems. Assessment methods currently available typically do not consider social and economic aspects of sustainability and are directed to individual buildings, while the broad discussion on sustainability indicators refers to more general measures of society, that are not easily related to the scales of organizations or buildings (COLE, 2002; TODD;JOHN, 2001). A last significant difference in approaches is the crescent trend of assessment methods aggregate performance metrics to summarize a building's global performance, while sustainability indicators are usually kept as discrete entities (COLE, 2002). COLE (2002) also points out the limitations imposed by time, first, because of the different time scales as sustainability is a concept based on equilibrium on the long-term and building effects are perceived in a much shorter timeframe; secondly because assessments are valid only for the particular point in time in which they were carried out, as environmental performance of buildings is – explicitly or not - relative to a typical performance level and are not able to capture continuous improvements on individual buildings and both cutting-edge and typical practices.

For all these obstacles and also due to the difficulties to access accurate and continuous data necessary to formulate and maintain indicators, existing building rating systems refer to (environmental) sustainability targets theoretically or empirically established. Empirical indicators have been adopted and later on validated or excluded, based on practical experience on implementation in the cases assessed by each system

3. Methodological challenges and research needs identified

Use of indicators basically consists of three major steps:

1. Choice of relevant indicators that should reflect needs and concerns of stakeholders (sectorial agenda) and the adequate representation of the assessed object. Such selection depends on decision limits, of the object and construction context and of practical availability of information.
2. Research of adequate methods and information to evaluate indicators values;
3. Information collection and use of relevant methods to attribute value to the selected indicators.

In Brazil, several efforts are noticeable for definition of indicators of sustainability of the built environment that, however, vary largely and are defined according criteria and methodologies not necessarily replicable. This work suggests six steps to methodological development for creation and validation of sustainability indicators of the Brazilian built environment:

1) Delineation of the state-of-the-art on sustainability indicators of the built environment

CRISP Network carried out a unique work on identification and systematization of sustainability indicators for the European construction industry, including some non-European methods. SILVA (2003) carefully review existing sustainability indicators and added some reflection as to their applicability in the peculiar Brazilian context. Such initiatives configure an encompassing state-of-the-art and lay the foundations for future development.

2) Definition of a methodology for data collection and organization

Even more important than the numbers attributed to indicators is to have accurate control over what the indicator effectively describes and the circumstances in which the values were obtained or attributed. This control provides traceability and reproducibility and allows for value adjustment or refinement according to scenario alterations and available data across time.

To build upon previous research efforts, and for international comparability purposes, it is suggested that the indicators characterization charts developed under CRISP's auspices are tested, at the possible extent and at the different scales, observing eventual data availability limitations in Brazil.

3) Creation of a sustainability indicators database applicable to the built environment

Besides describing the nature of the different sustainability indicators of the built environment, the approach given by ISO presents four main requirements for indicators systems:

- Sustainability should be described based on an encompassing set of indicators expressing environmental, social and economic aspects, as well as their relationship;
- Selected indicators should describe essential (environmental, social and economic) building impacts;
- Relevance of selected indicators should be justified and, when necessary, validated;
- Indicators development and application processes should be transparently reported.

Consideration of potential final users' feedback is a powerful instrument for validating indicators. Selection of most relevant indicators from cited reference lists should be therefore done considering compliance with the essential requisites that validate a good indicator (relevance, objectivity, accessibility, range, measurability, sensibility and traceability) and aiming at answering questions such as the following:

- Who are the final users?
- For which purpose will the indicator be used?
- How to proceed in relation to contradictory indicators?
- How to use the indicators?
- Is it possible to measure? If not, how to attribute a value for the indicator?

As indicators are needed in decision-making processes of several agents, the starting point for their development is the identification of the main users, their information expectancies and needs. The intended use for an assessment system may therefore vary according to the life-cycle stage it is intended to be applied in. Information character, quality and availability also depend of the project life-cycle stage. Indicators that describe the same aspects can be initially related to values estimated in design stage that, during operation, would be replaced by real-time measurements, satisfaction surveys or other performance evaluation instruments. Consequently, indicators used to characterize building performance in each application should be adjusted to the proposed end use.

While individual indicators should be the most independent possible, practice has shown that it is more efficient to employ indicators sets, on their turn dependent of the user's perspective and of a certain life-cycle stage, able to include a broad representation of sustainability aspects.

4) Definition of a set of indicators for national monitoring, complemented by core set of relevant local indicators

Assessment methods of buildings intend, at the extent possible, to link the building contribution for achievement of broader sectorial and national targets. Definition of an agenda for the Brazilian construction sector is, therefore, the initial basis for proposition of a sustainability assessment framework, finely tuned to national context and aspirations.

JOHN et al. (2000) and JOHN;SILVA;AGOPYAN (2001) initiated the discussion on an Agenda 21 for the Brazilian civil construction, pretty much like the original structure used by CIB (1999). In posterior contributions SILVA et al. (2002) e SILVA (2003) proposed an sectorial agenda organized according to the international molds for sustainability reporting, given by UN's Agenda 21, in which the triple bottom line is complemented by an institutional dimension, related to provision and strengthening of intra and cross-sectorial platforms. The institutional agenda was proposed due to the lack of sufficient normative instruments, governmental policies, articulation of sectorial strategies pro sustainability and or sustainability report of construction-related organizations and products.

The indicators list proposed by Silva (2003) follows CRISP's format general lines. ISO TS 21.929 recommendations (ISO, 2005b) could be used for screening and selecting the set of national indicators.

5) Creation of a database of indicator values (local, but able to be regionally and nationally aggregated)

Database construction is a labor-intensive, long-term work. It is important to highlight that, the CRISP network, taken here as a methodological reference, had the goal to systematically register currently used construction industry-related sustainability indicators, but not the values measured or attributed to them. The creation of a benchmark database for each relevant indicator is fundamental to provide meaningful assessment results and to drive establishment and updating of sustainability goals. In the Brazilian case, this gap that can only be bridged through gradual refining or substitution of the values initially extracted from literature and research, as a considerable number of assessments and measurements are carried out and following a consensual, replicable methodology.

6) Continuous update and broad data dissemination

As assessments only make sense when the performance reference is explicitly defined, it is necessary to keep the database continuously updated, to lead to more reliable numbers and evaluations and more realistic target setting. Dissemination of reference values is important to make the assessment procedure replicable within the country, while recognizing regional peculiarities that interfere in result interpretation.

4. Final remarks

Indicators are sought to clarify national and international trends of social, economic and environmental development and to closely chart progress towards sustainable life patterns.

Performance indicators are also used by environmental assessment methods to demonstrate improvement in – and allow for comparisons among – individual buildings. In both applications, indicators provide their users with the necessary feedback through performance benchmarking and illustration of progress rate and extent, helping to raise awareness regarding environmental issues and their social and economic (or vive-versa) reflexes, and level a comparison basis between decision-making and strategic planning.

Most identified metrics in the review of international initiatives for development of sustainability indicators focus on the environmental dimension of sustainability and is more appropriate to measure health and sustainability of ecosystems, communities or specific environmental components, such as water or air. Most of these metrics can not be applied to the building scale, or is effects, as they do not distinguish between the relative contribution of buildings or the built environment to health and sustainability of a certain ecosystem, community or environmental component of interest. It is therefore recognized in this work the difficulty of relating information obtained at the building scale to progress of the construction sector or of a country in any of sustainability dimensions. It is advocated, though, the validity of extracting relevant indicators for buildings, even though their immediate aggregation is not yet possible to form a global metric of society, indicate the path for cooperation in compliance with sectorial or national goals of producing a built environment driven by more responsible attitudes, based on the reflection on their long term effects.

CRISP network began the organization of sustainability indicators for the built environment used in different countries. Similar efforts will probably be impelled by the implementation of specific ISO standard. Even though generic, ISO recommendations shed some light on the need for standardization of definitions and methodologies for data collection and aggregation, and for indicators interpretation.

Brazil already counts on some efforts to establish sustainability indicators that, however, vary largely and are defined according criteria and methodologies not necessarily replicable. In order to advance in the development of sustainability indicators of the built environment, it is paramount that the country defines consensual framework to structure indicators, and methods for data gathering, definition of national indicators (aligned to international trends and experience) as well as of a core of local indicators relevant for each case and typology; value measurement or attribution, and for interpretation and aggregation of indicators. A robust database should be created and kept updated and broadly accessible.

DAC/FEC/UNICAMP began the creation of an environment for housing and monitoring of indicators of sustainability of the built environment. First figures available at the database refer to office buildings. School buildings will be added across the next two years. Part of them are applicable to other parts of the country, but it should be kept in mind that some of these data are unavoidably regional in essence (parts of the State of São Paulo) and could result in misleading conclusion without previous definition of equivalent figures for other regions. An effort with national range is needed and should be carefully considered by research funding agencies.

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Certification In The Hotel Sector; Does It Actually Reduce Global CO_2 Emissions?

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Summary

The research poses a simple question, ‘Does Certification in the hotel sector signify lower CO_2 emissions per guest night?' The research examines whether certification schemes are rigorous and whether the results are credible. The paper discusses climate change and global tourism, the issue of ‘green’ electricity and carbon offsetting, provides a critique of current methods of certification used in the hotel sector and examines the environmental impact and the accounting method used.

Global CO_2 emissions were compared and calculated from the delivered electricity and fuels consumption data from seventy selected certified hotels worldwide. No corrections were made in the calculations for climate, quality of services, existence of services etc. The performance indicator used is $kgCO_2$ per guest night.

The analyses shows no clear pattern. In some cases emissions reduced after certification in others no change. Certified hotels do not necessarily have lower emissions than uncertified hotels and a comparison of before – and after – certification shows no significant improvement. Most dramatically emissions from certified hotels widely vary by a factor of 7. Although it is arguable a number of corrections should be made to account for different climates, the research highlights that hotels with high CO_2 emissions are being awarded certification and it questions what message ‘certification’ gives to guests and other stakeholders. At worst it appears ‘business as usual’ can achieve certification with no obvious improvement in performance. The authors conclude a simple, accurate method of CO_2 emissions calculation needs to be developed which can be adopted universally.

1. Introduction

The scientific community is unequivocal in its acceptance of the connection between climate change and green house gas emissions yet there are no international benchmarks for CO_2 emissions in hotels although there are in existence published energy benchmarks. Although transport is commonly identified as a major emitter, accommodation receives much less attention, in spite of the fact that it typically accounts for 1/4 of the total emissions from global tourism (Table 1).

We estimate hotels are five times more CO_2 intensive than people living at home yet CO_2 emissions are not accounted for in audits and are not included as a mandatory category in certification. There is a widespread problem of false accounting in certification. Hotels are claiming reduced or zero CO_2 emissions through ‘green’ electricity deals and carbon offsetting schemes.

1.1 Climate Change and Global Tourism CO_2 emissions

International arrivals are expected to reach nearly 1.6 billion by the year 2020 from 25 million in 1950. (WTO) Tourism growing at such a rate affects both transport and accommodation equally. If carbon intensive transport reduces then this proportion could become much higher as the focus will tend to shift onto accommodation.

Table 1: Emissions from Global Tourism in 2005 including same day visitors (DAVOS, 2007)

	CO2 (Mt)
Air transport	517
Other transport	468
Accommodation	274
Activities	45
TOTAL	**1,304**
Total world	**26,400**
Share (%)	4.94

1.2 Carbon Offsetting

Carbon offsetting is the act of mitigating greenhouse gas emissions. It involves calculating emissions and then purchasing 'credits' from emission reduction projects which would prevent or remove an equivalent amount of carbon dioxide elsewhere. Due to its indirect nature, carbon offsetting is difficult to verify. Hotels were found to be making false CO_2 claims. For example, a major chain hotel in London markets itself as being 'carbon-free' and 'offsets all its emissions' yet the results of our analysis indicate its emissions to be 20 kgCO_2 per guest night which even increased after certification. The extra cost to the guest of offsetting their stay was 2 Australian dollars (less than 1% of the cost of a room for one night).

1.3 'Green' Electricity – How green is it?

In response to growing climate and environmental concerns, certification and self-certification of "green" electricity (with different and often conflicting definitions) have proliferated in the marketplace. Many products do not contribute to *additionality* (i.e. the development of new low or zero-carbon generation) but instead favour double selling of electricity already paid off by consumers. The lack of minimum common standards cause significant confusion in the public and undermines the future uptake of green electricity. (CLEAN-E, 2006)

It would be expected that if the price charged by green providers were significantly higher than fossil-electricity, then increasing the demand for green electricity might generate extra cash for investment in more green power. A believable increase would be a 50% to 150%, whereas extra costs for green electricity are typically 10% and sometimes significantly lower. This unrealistic extra cost is almost proof that it is only a marketing exercise.

1.3.1 Additionality and The Eugene Standard

Green power consumption can only lead to additional low or zero carbon power generation if *additionality* is proven. The Eugene Green Energy Standard is an international standard to which national or international green electricity labeling schemes can be accredited. It confirms that energy supplied under the accredited schemes: 1) Is produced from genuinely sustainable energy sources; 2) Will result in a real increase in renewable generation beyond the requirements imposed by government ('additionality'); 3) That the demand from consumers is matched by renewable generation. Two variations of the standard, 'gold' and 'silver', differentiate between schemes depending on the additionality of new renewable energy supplied. Currently only two national labels (German *ok-power* and Swiss *Naturemade)* are accredited by the Eugene Standard. out of one hundred and ten European labels listed on Eugene website(Eugene, 2005) Despite this fact, it has been found many certified hotels rely on claims of zero carbon or neutrality based on purchasing 'green' electricity, which is not accredited.

2. Certification and Benchmarking

Certification schemes are created by privately operated companies and NGO's and are based on voluntary initiatives by the hotels themselves. Around the world, there are some 260 voluntary initiatives, including tourism codes of conduct, labels, awards, benchmarking and "best practices." Of these, 104 are ecolabelling and certification programmes offering logos, seals of approval, or awards designed to signify socially and/or environmentally superior tourism practices. (Honey, 2002)Certification delivers a certificate which claims the participant is "green", sometimes that is done by looking at processes. A benchmark measures something quantitatively with a view to comparing it to a given value regarded as a datum. Most certification schemes can be categorized and analyzed by their methodology – as performance-based (using benchmarks) or process based (using environmental management systems) and by sector of the tourism industry they cover (conventional tourism, sustainable tourism or ecotourism). A hybrid of process-based environmental management systems and performance benchmarks are more effective. (Honey, 2002)

There is a confusing proliferation of a wide range of certification schemes with varying criteria, which is compounded by the overuse of 'eco-terminology' for marketing purposes. In most cases methods of calculation, data about baseline indicators and algorithms for use in the performance assessment are not disclosed to the hotel operator or available in the public domain. There is concern that the complexity and cost of certification systems preclude smaller businesses.

Certification of a *design* represents a *potential* for a building and does not indicate how that building is going to actually perform. Even that potential is open to question as much of the performance of a building depends upon things that are uncertain or do not perform as well in reality as assumed in the model that predicts energy use. There is no correlation between the two and on no account should there be any confusion between certification that goes to design.

2.1 Accountability of CO_2 emissions in schemes and tools

Only one certification scheme calculates CO_2 emissions but this is included in a non-mandatory category for certification. As a result, a hotel could in fact have low energy consumption and high CO_2 emissions yet still become certified. Differences were found between our CO_2 emissions calculations and those reported in the benchmarking assessment report. Since the accounting method was not disclosed it was not possible to verify the differences in calculations of emissions.

It was found that the actual calculations of CO_2 emissions are dependant on the assumptions about electricity production emissions. In our CO_2 emissions calculations, the figure of 0.48 kg CO_2/kWh (BERR) has been quoted for the UK average electricity production but it should be noted that this figure may be 0.52 kg CO_2/kWh. (DTI – DUKES, 2006) Although even these figures are debatable because if we were reducing energy use then we would clearly be aiming at the marginal effect and could reasonably apply the highest emissions intensity of 0.67 kg CO_2/kWh corresponding to the least efficient power stations.

2.2 Adding delivered units of electricity to delivered fuels

The most serious error in all schemes analysed is the adding together of delivered electricity to heating without first converting the figures to primary energy (or CO_2 emissions) before adding together. As a result, the energy performance indicators used by the majority of hotels and certification schemes are erroneous. In many cases, when asked for raw data, the only figures provided by a hotel were these performance indicators with no separate breakdown for delivered electricity or heating in which case neither the performance nor the CO_2 emissions of the hotel could be reliably calculated.

2.3 Weighting of categories in awarding credits for certification

Most schemes involve five or more assessment categories yet success in only one or two categories (energy is not always mandatory) enables a hotel to become certified despite having poor environmental performance. In 2007, Nordic Swan made energy performance a compulsory category. Green Globe includes an indicator for CO_2 emissions and Renewable energy (percentage) used but does not affect the overall benchmarking evaluation. In LEED, it was found that five of the ten LEAST popular (and most difficult to achieve) credits were made up entirely from the Energy & Atmosphere category, which deals directly with CO_2 emissions. (Kramer, 2006) Where LEED has been used for hotels there is some uncertainty as to what building type is being used to establish the benchmarks against which the subject hotel is being judged.

3. Method

Four analyses were made; a time series analysis of CO_2 emissions per guest night for chosen fuel mix for a selected certified hotel before and after certification; the same as previous but including delivered energy; an example of CO_2 emissions for 2006 for six certified hotels in different schemes and finally, an example of CO_2 emissions for 2006 for 29 hotels certified within the same scheme.

The consumption data for delivered fuels, electricity and heat was extracted from invoices, meter readings, monitoring data in excel files, intranet access of hotel databases and benchmarking assessment reports. The delivered fuels consumption data differed in units and was converted to CO_2 emissions using the conversion factors from The Carbon Trust and IPCC. The national average electricity fuel mix breakdown and conversion factor was collected from BERR for UK, government and academic sources for each respective country. In order to know which conversion factor to apply for, the district heating information was collected from the supplier about how the heating was generated.

Information was also collected on the physical and operational parameters of the building including: date of certification, total number of guest nights, size, structure, age, orientation and design of the building, number of bedrooms, floors, total area, number of facilities and level of services offered, geographical and climatic location, the type of energy system installed and how they are operated and maintained.

3.1. Dependency of CO_2 emissions calculations to chosen fuel mix: Sweden

Sweden is connected to the other Nordic countries through the Nordic electricity market, NordPool, which also has connections to the European continent. The energy production mix in these three areas is very different as seen below. The collected heating and delivered electricity consumption data for a selected certified chain hotel located in Stockholm, Sweden was using three methods of accounting. The first scenario is where we accept the argument that the electricity is 'green', i.e. 100% renewable. The second scenario assumes an average Nordic electricity mix and the third scenario assumes an average European mix which is more diversified with mainly nuclear, coal, hydro and natural gas fired power production (as shown in Fig. 1). The district heating is supplied by CHP so the CO_2 emissions have already accounted for in electricity production and shall therefore be considered zero.

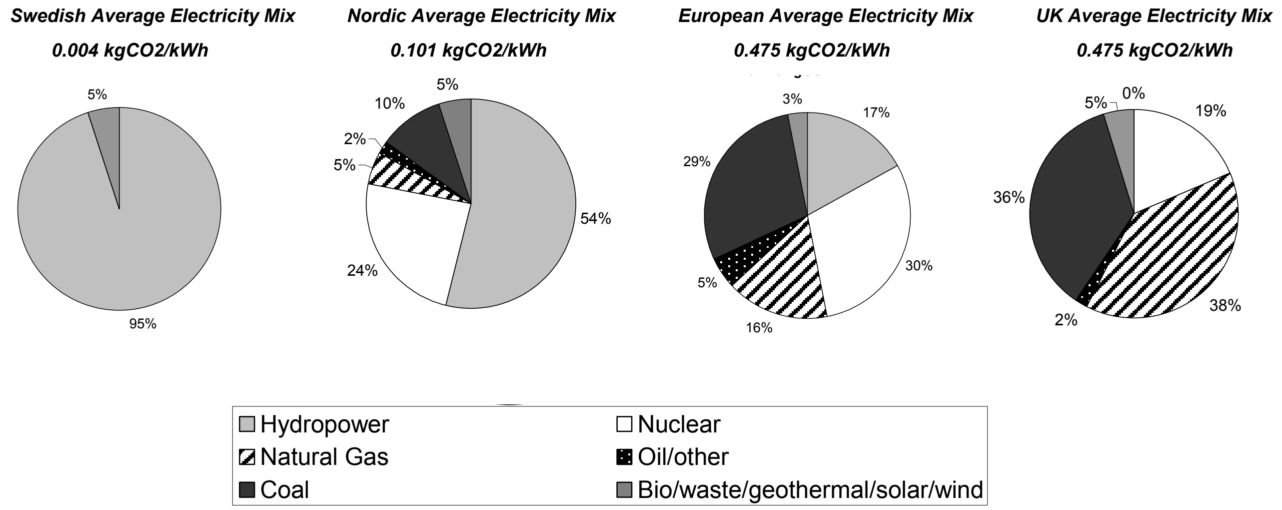


Figure 1 Fuels used in "Green", European and National (Nordic / UK) electricity power production

3.2 Time series analysis of CO_2 emissions per guest night for chosen fuel mix for a selected certified hotel before and after certification.

The graph below (as shown in figure 2) shows a more significant reduction in emissions attributable to switching to ‘green’ electricity rather than to certification alone. However it is acknowledged there is a 10-15% reduction in emissions after the hotel became certified which may be explained by the skilled expertise of the newly appointed environmental manager around the time of certification. The graph clearly shows the significant impact on emissions of the choice of fuel mix chosen. The CO_2 emissions have been calculated in kg CO_2 per guest night.

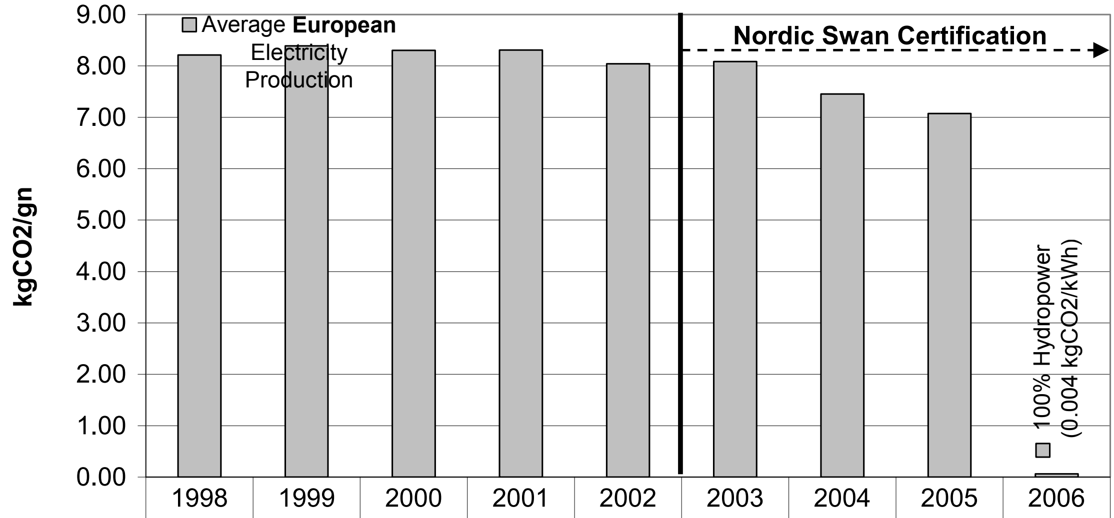
The graph below shows the results of the third scenario which uses the average European electricity mix (0.475 kg CO_2 /kwh) before the hotel switched to ‘Bra Miljövil’ green certified electricity in 2006. Heating is supplied by district heating (CHP) and is considered to have zero emissions. By selecting the average European electricity mix, we are presenting the worst-case scenario, which we consider to be reasonably justified due to Sweden’s connection to the European continent via Nordpool compared to the totally unjustified switch to ‘green’ electricity as demonstrated by the graph below.

The marketing of the hotel implies that its remarkable reduction in CO_2 emissions are a result of being certified yet the graph shows that until the switch to a different electricity supplier in 2006, certification has had very little effect on reducing CO_2 emissions.The graph also shows despite all the hype surrounding certification it has been shown to have no real effect on reducing CO_2 emissions, irrespective of whether or not the carbon emissions can be decimated overnight by simply switching to a different power company.

CO_2 Emissions per guest night (kgCO2/gn)

Pre-switch - Average European Electricity Production (0.475 kgCO_2/kWh)

District Heating (CHP) - assumption zero CO2 emissions



	1998	1999	2000	2001	2002	2003	2004	2005	2006
kgCO2/gn	8.21	8.39	8.30	8.31	8.04	8.09	7.45	7.07	0.06

Figure 2 Time series analysis of claimed CO_2 emissions for chosen fuel mix for a selected chain hotel in Stockholm, Sweden before and after certification (kg CO_2 per guest night) Note reduction after switch to “green” electricity.

3.3 Time series analysis of CO_2 emissions and energy consumption per guest night for a selected certified hotel, before - and after - certification.

The purpose of the two graph’s below shown below is to establish if certification has directly resulted in reduced energy consumption and/or CO_2 emissions per guest night. Heating is supplied by gas and delivered electricity is supplied from the grid (EDF). The hotel does not purchase ‘green’ electricity. The graph shows that certification has had no effect on either energy consumption or CO_2 emissions, which has in fact increased. It should be acknowledged that a consistent reduction in emissions is recorded from 2002 to 2005 after which the emissions increase. The reduction may be explained by the drive to achieve certification as well as to the individual expertise of a skilled environmental a manager who then left in 2006. He was then replaced by a new less skilled manager who has now since left. The marketing for the selected hotel implies the hotel is ‘carbon free’ and ‘to offset all its emissions’ yet only the conference facilities have been ‘offset’. Furthermore, due to the lack of transparency in accounting methods, it is impossible to validate the claims made for that improvement and to explain how the energy consumption and CO_2 emissions of that area has been distinguished from the overall area (if there is no sub-metering.)

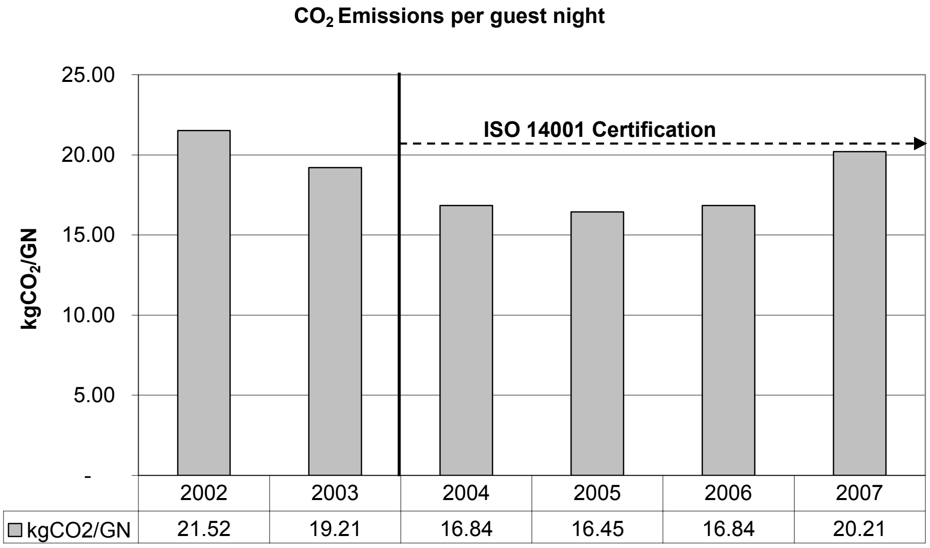


Figure 3 Time series analysis of CO_2 emissions per guest night for a selected chain hotel in London, UK, before and after certification.

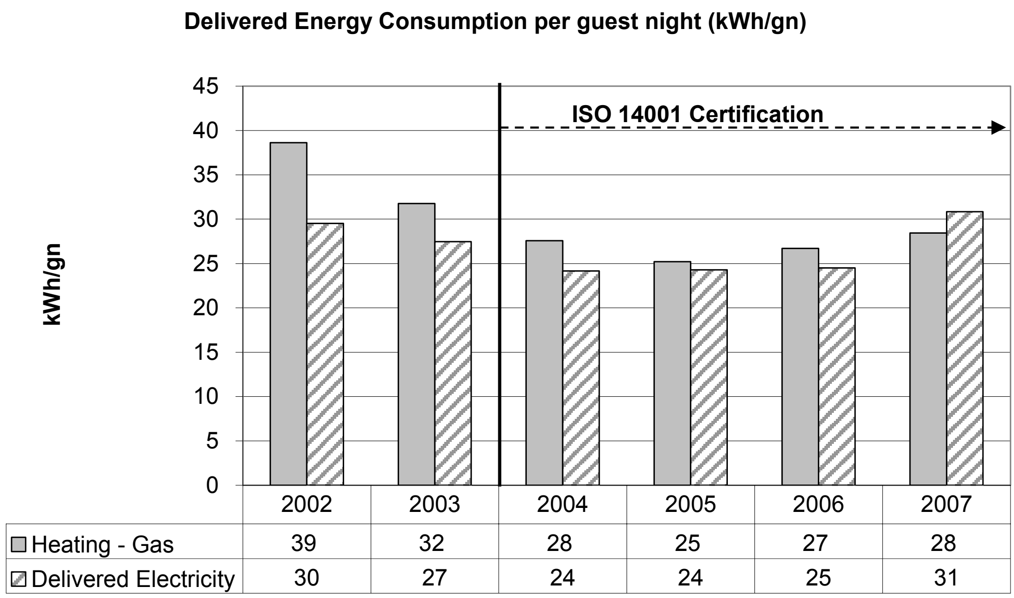
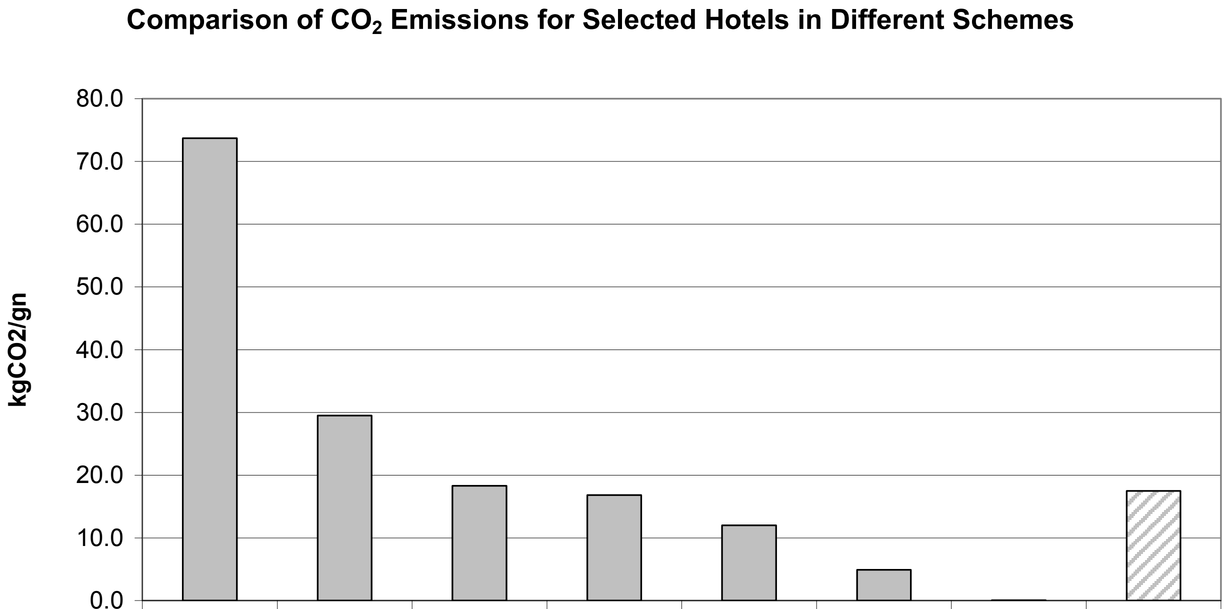


Figure 4 Time series analysis of CO_2 emissions and energy consumption per guest night for a selected chain hotel in London, UK, before and after certification.

3.4 An example of CO_2 emissions for 2006 for eight certified hotels in different schemes

The purpose of the graph below is to compare the CO_2 emissions per guest night for a series of certified hotels for a particular year. Despite the wide range in CO_2 emissions, all have been awarded certification. In one case, there is almost no difference in emissions between a certified and non-certified city hotel located in the same country. In another case, a city hotel having achieved gold certification actually emits almost double the CO_2 emissions than a non-certified city hotel in the same country. Based on the figures given and the assumption made in the calculations, is it justified to certify a hotel sustainable that emits 73.7kg CO_2 per guest night as another certified hotel that claims to have zero CO_2 emissions? Is it justified that some certified hotels are decimating their CO_2 emissions overnight by simply buying non-accredited, "green" electricity certificates yet still awarded certification?



	Green Globe, Australia	GTBS GOLD, Scotland	LEED-NC (av. US) SF	ISO 14001, UK	Nordic Swan (av. EU) Oslo,	EU Flower (av.EU), Greece	Nordic Swan (HEP)	Not Certified, UK
kgCO2/gn	73.7	29.5	18.3	16.8	12.0	4.9	0.1	17.5

Figure 5 A series of certified hotels claimed CO_2 emissions within different certification schemes for 2006.

3.5 An example of CO_2 emissions for 2006 for 29 hotels certified within the same scheme

The graph below shows the range of CO_2 emissions within the same scheme and have received the same level of certification. Based on the figures given in the graph, is it justified to certify a hotel sustainable that emits over 70 kg CO_2 per guest night and moreover, to give it the same level of certification as a hotel that emits only 1 kg CO_2 per guest night?

The calculated CO_2 emissions are based on the figures given in the certification benchmarking assessment report sent to the respective hotels. However, it should be noted that numerical errors in reporting have been found between the CO_2 emissions calculations provided by the benchmarking assessment report and our calculations. For example, in one of the hotels quoted in the graph above, the reported CO_2 emissions were 73 kg CO_2 /GN but by our calculations this should be 30 kg CO_2 /GN. In addition, there may of course be some that are declared low in the graph below but by our calculations should be three times higher. These numerical errors in reporting undermine confidence in the scheme.

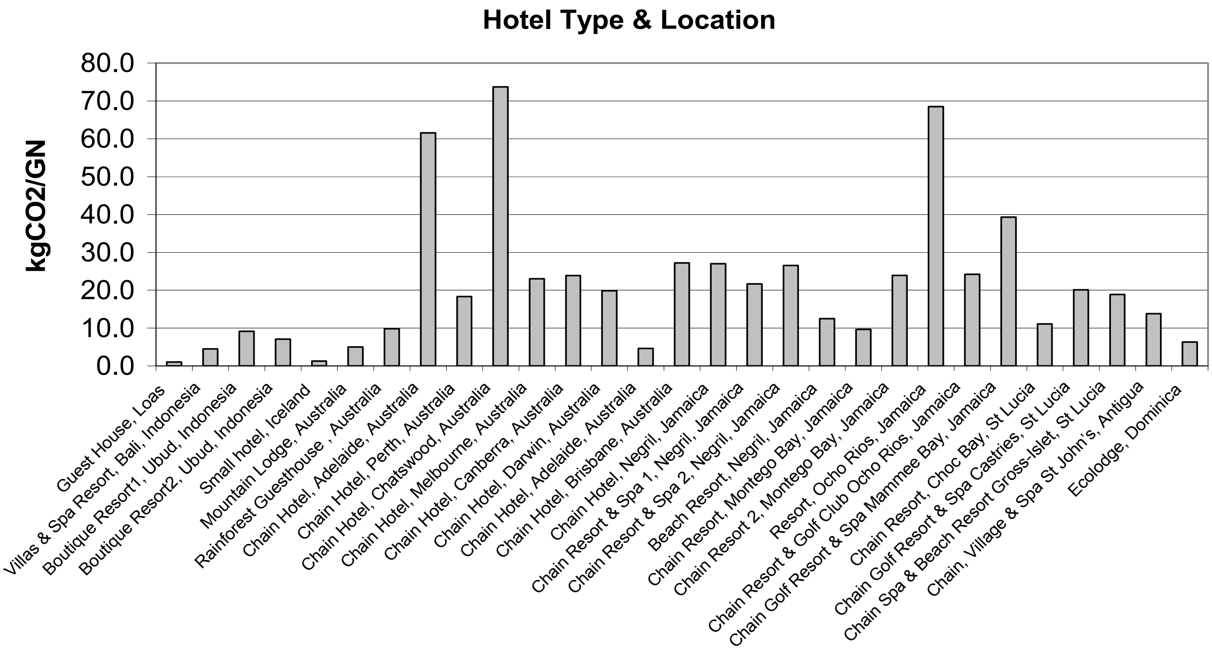


Figure 6 Range of reported CO_2 emissions within the same certification scheme with the same level

4. Conclusion and Further Work

The environmental performance of certified hotels, with respect to CO_2 emissions, was investigated to study the effectiveness of certification in reducing global CO_2 emissions in the hotel sector. Preliminary results from the analysis of the primary raw data collected from the selected hotels have shown no direct reduction in CO_2 emissions attributable to certification alone.

Several fundamental weaknesses were identified:

- No benchmarking of CO_2 emissions in schemes (*except one*)
- Incorrect accounting for CO_2
- Adding different types of energy together *i.e delivered electricity and fuels.*
- Weighting of categories in the awarding of credits for certification.
- Numerical errors in calculations
- Confusing proliferation of certification schemes with varying criteria and benchmarks.
- Lack of transparency
    - in the publication of benchmarks in the public domain which allows a wide range of emissions to occur within the same scheme.
    - in the declaration of the criteria used by the certifying bodies to judge the data from the hotels. For example, they may be using out of date benchmarks and there may be some occasions where they are using average rather than good / best practice for comparison.
    - in the way the data is collected and sent to the certifying body and the accounting of numbers of people *i.e. night, day, resident staff* and areas included.[1]
    - in identifying different parts of the hotel that may have different performance and identifying the difference between where an improvement is made and claims are made for that improvement (if there is no sub-metering.)
    - in the identification of final energy use *i.e is it representative of the whole building, a conference hall or a only a bedroom*
    - as to what building type is being used to establish the benchmarks against which the subject hotel is being judged *i.e. LEED*
    - in what benchmarks have been used in the award of certification.
    - Lack of disclosure to the public that the certification has been awarded for design intent or for operational performance *i.e. LEED, BREEAM is for design and simulated data whereas Green Globe, Nordic Swan is based on operational data.*

Certification is commendable for addressing a wide range of impacts but it does not account for CO_2 emissions in audits. Certification must make the calculation of CO_2 emissions a mandatory category which has to be properly computed. The weighting of this and other categories must be rigorous and reflect the level of impact on global CO_2 emissions.

A simple, accurate method of CO_2 emissions calculation needs to be developed which can be adopted universally. The calculation method needs to be transparent and standardized. This should be made a compulsory requirement of any performance analysis. The calculation of CO_2 emissions per guest night, would enable comparisons between different size hotels. The setting of benchmarks should follow the reference function constituting part of the hotel[2] rather than a single benchmark or the concept of a reference hotel.

Compulsory sub-metering, to monitor consumption in energy intensive facilities such as kitchens, laundries or swimming pools, would be a pre-requisite to ensure accurate data collection and feedback and to identify exceptional or unusual patterns of energy consumption.

An independent assessor or dedicated in-house team would decide the monitoring points and specify or install the sub-meters on site to ensure accurate data collection and feedback.

Three levels of assessment could be made; 1) Calculation of global CO_2 emissions based on fuel bills; 2) Separation of *architectural e.g.* space heating/cooling and lighting, and *domestic* energy use e.g . hot water, laundry etc. and identification of associated fuel use for each separated function. 3) *Sub-division* within architectural and domestic energy categories i.e. is the laundry outsourced or in-house; use of electric or gas driven tumble dryer with timer and humidity control. Compulsory sub-metering would identify exceptional or unusual patterns of energy consumption, help diagnose the cause enabling recommendations to be made to rectify the problem thus reducing the environmental impact of the hotel.

1 In some cases there is some confusion between the equivalence of a day and overnight guests. However, Green Globe certification accounts for this and allows one day guest equivalent to 1/3 guest night and Nordic Swan allows one day guest equivalent to ½ guest night.

2 Bohdanowicz (2006) originally proposed to disaggregate hotels into modules with individual energy indicators rather than a single indicator for whole hotel as currently the case.

This method is the first step of the diagnostic process leading to a solution to rectify the problem thus reducing the environmental impact of the hotel. However, tourism-induced CO_2 emissions are unlikely to be reduced only through voluntary, "soft" instruments such as our proposed method of CO_2 emissions calculation but need to be coupled with indispensable "hard" instruments such as the removal of tax exemptions on aviation fuel or the introduction of a mandatory carbon tax. This would start hotels focussing attention on their CO_2 emissions.

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THREE STUDIES ON THE PROMOTION OF ASSESSMENT TOOLS AND MARKET TRANSFORMATION: THE CASE OF CASBEE

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Keywords: Assessment tool, Market transformation, CASBEE, Productivity, Human sensitivity

Summary

Lively debate is continuing internationally regarding sustainable building assessment tools and market transformation. The improvement of assessment tools from the viewpoint of market transformation, the rating of buildings using assessment tools, and the provision of a framework to bring about market transformation are important. Also, strengthening the relationship between assessment tools and carbon neutrality, the continuation of dialog with the various stakeholders, and measurement of energy performance, etc., have been raised as important tasks.

For CASBEE also, the promotion of voluntary market transformation has been adopted as an important task. As the author's personal opinion, the following three points for the promotion have been identified and discussed. (1) The pursuit of ease of understanding and explanation of the benefits, (2) Investigation of the introduction of productivity into assessment tools, (3) Investigation of indices taking into consideration human sensitivity.

1. The pursuit of ease of understanding and explanation of the benefits

1.1 The achievement of ease of understanding in CASBEE for New Construction

First, to clearly demonstrate the CO_2 emission performance and the evaluation of global warming measures. Then to explain in an easy to understand manner the economic benefit, the productivity benefit, the direct effects for buildings of each use, the effect of a building of rank S, etc. Promotion of ease of understanding, ease of visualization, such as 5-star rating, etc., with emphasis on certification rather than ranking.

The results display sheet for the Japanese assessment tool CASBEE for New Construction (2008 version) was designed. This has been revised with the main purpose of clarifying global warming measures, and the three items "Consideration of global warming," "Consideration for local environment," and "Consideration for surrounding environment" have been re-formulated as evaluation items for the off-site environment (LR-3). Also, the tool has been revised to reflect simplified calculation of life cycle CO_2, and the evaluation of "Consideration of global warming" by the ratio of emissions compared with a reference building. Further, the ranks S, A, B^+, B^-, and C have been linked with a 5-star rating, for ease of visual understanding.

Figure 1 shows the distribution of CASBEE assessment results for Building Contractors Society 2006 design and built projects (23 companies, 591 projects). Each year the number of CASBEE evaluations by general contractors has been increasing steadily. Also, the trend towards designing for higher ranks (B^+ ~ A ~ S) than the standard level is increasing. In this way, from the rank of a building design and confirmation of the plot position, the use of the tool to promote better environmental performance is promoted.

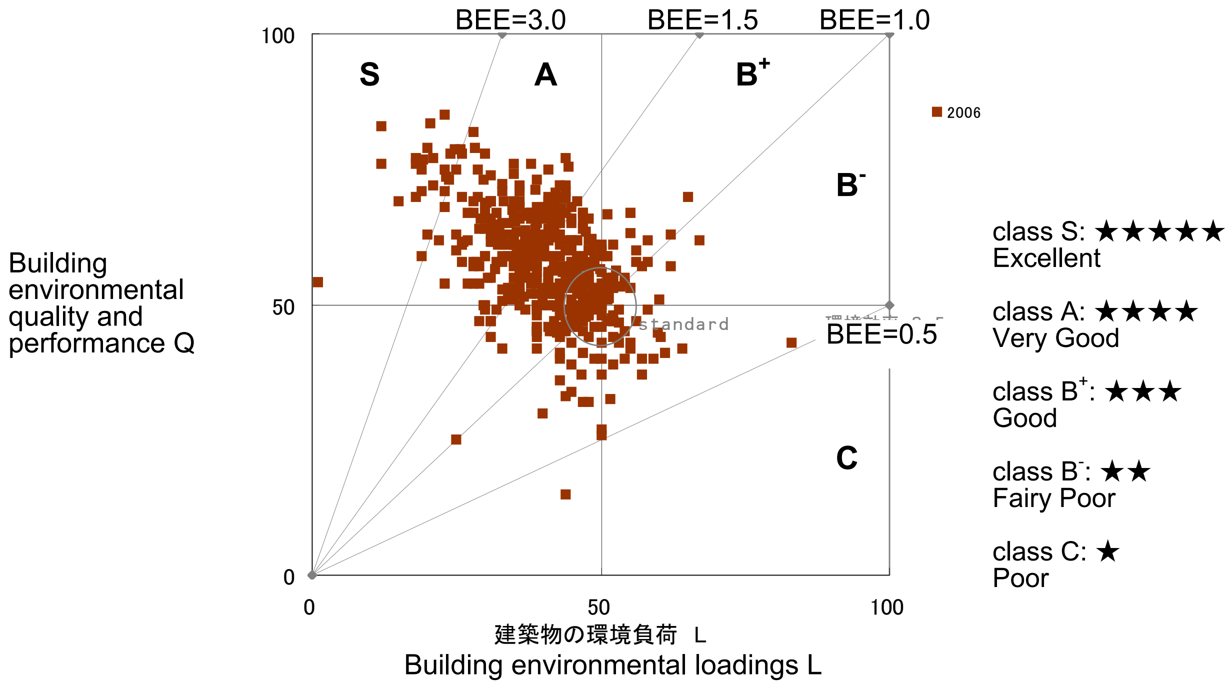

Figure 1. Distribution of CASBEE assessment results for Building Contractors Society 2006 design and built projects (23 companies, 591 projects)

1.2 Revision of CASBEE for Existing Building and investigation of widening use

Following CASBEE for New Construction, CASBEE for Existing Building is being revised. Examples of assessment by CASBEE for Existing Building are still very few, so it is important to increase the number of assessment examples. The items for revision are mainly as follows.

<Clarification of energy performance results and global warming measures>

· As for the new construction version, assessment to clarify measures for global warming is being introduced, and the items in off-site environment (LR3) are being changed to global warming, local environment, and surrounding environment.

· Conversion of energy performance results to CO_2, and calculations of $LCCO_2$ is carried out, and evaluated by comparison with a reference building

<Intellectual productivity>

· Discussed later (see item 3)

<Expansion in the number of assessment examples>

· Encouragement of the transition from new construction certification to existing building certification

· The use of CASBEE for Existing Building for the assessment of renovation in renovation projects such as housing and building, “Model low CO_2 subsidy projects by MLIT," etc.

<Improvement in ease of use and reduction in evaluation load>

· Investigation of a simplified version of existing building assessment

· For large scale refurbishment projects, investigation of mechanisms of submitting CASBEE for Existing Building/Renovation, together with an energy saving plan (however, this would be in accordance with the decisions of each local government).

<Linking with real estate appraisal and valuation>

Real estate appraisal and valuation is almost always concerned with existing buildings. Currently in the real estate appraisal and valuation field, there is momentum towards investigating methods of appraisal and valuation that take into consideration the environment. Here, if each of the items of CASBEE for existing building is recognized in the market, and also if its use in real estate appraisal and valuation spreads, there is the possibility that use of CASBEE spread greatly. Rather than doing nothing until the market becomes aware, it is necessary to raise the awareness of each of the items, by showing the market the results of this kind of research. Table 1 shows a list of the evaluation items of CASBEE for Existing Building. Items related to increase of income are shown in orange, and items related to cost reduction are shown in green. An outline summary is as follows.

(1) “Indoor environment” is a factor that constitutes the building’s grade, it is recognized by the market, and it has potential of quantitative evaluation. In addition to this, if an item for evaluation of improvement in intellectual productivity is added, a quantitative value (increase in income) is obtained.

(2) The item of functionality (spaciousness, refreshment space, décor) of “Quality of service” is a factor that constitutes the building’s grade, it is recognized by the market, and it has potential of quantitative evaluation. The criterion for smooth access for the disabled can be qualitatively evaluated as the improvement in heartful building image.

(3) Durability and reliability, and flexibility and adaptability of “Quality of service” can be quantitatively evaluated (reduction in depreciation load) provided understandable evidence is provided, or qualitatively evaluated (improvement in image, avoidance of risk). (For Existing Building and Renovation, as in New Construction, it is necessary to carry out an study to determine the number of years of service life of the building structural materials.)

(4) It is necessary to raise the awareness of the market for outdoor environment on-site, and in the future it will be possible to qualitatively evaluate it (improvement of image).

(5) Quantitatively, energy reduction is cost reduction, and also has qualitative value (image improvement, risk avoidance). It is necessary to clarify the quantitative effects and analyze the qualitative effects of natural energy, etc. Regarding operational conditions, as the operational time becomes longer and density (people, heat generated by people, etc.) increases, the CO_2 emissions and energy cost increases. Without an energy efficient building, CO_2 emissions and energy cost increases. It is necessary to separate the two in real estate appraisal and valuation.

(6) It is necessary to raise the market awareness of resources and materials, and it is necessary to analyze the qualitative effects (image improvement, risk avoidance).

(7) Under off-site environment, it is necessary to reorganize the items into consideration of global warming, consideration for local environment, and consideration for surrounding environment, and add $LCCO_2$ evaluation, as in New Construction. Consideration of global warming (including evaluation of life cycle CO_2) has value from both the quantitative effect (cost reduction) and the qualitative effect (image improvement, risk avoidance). It is necessary to raise the awareness of the market for consideration for local environment, and consideration for surrounding environment, and it is necessary to analyze the qualitative effects (image improvement, risk avoidance).

Looking at the items separately, from the point of view of resulting in quantitative value, it is considered that the items can be divided into those items that are easy to understand and that can be adopted by the market and those engaged in real estate appraisal and valuation, and those items that for the time being should be analyzed for their qualitative value. It is considered that where possible, the items should be introduced into assessment tool of existing building and renovation.

Table 1. Items for which has potential of quantitative evaluation in real estate appraisal in CASBEE for Existing Building

Q Building Environmental Quality & Performance				
Q-1	Indoor Environment			
	1 Noise & Acoustics			
		1.1 Noise		
			1	Background noise
			2	Equipment noise
		1.2 Sound Insulation		
			1	Sound Insulation of Openings
			2	Sound Insulation of Partition Walls
			3	Sound Insulation of Floor Slabs (light impact)
			4	Sound Insulation of Floor Slabs (heavy impact)
		1.3 Sound Absorption		
	2 Thermal Comfort			
		2.1 Room Temperature Control		
			1	Room Temperature Setting
			2	Variable Loads & Following-up Control
			3	Perimeter Performance
			4	Zoned Control
			5	Temperature & Humidity Control
			6	Individual Control
			7	Allowance for After-hours Air Conditioning
			8	Monitoring Systems
		2.2 Humidity Control		
		2.3 Type of Air Conditioning System		
			1	High and low temperature difference
			2	Average air velocity
	3 Lighting & Illumination			
		3.1 Daylighting		
			1	Daylight Factor
			2	Openings by Orientation
			3	Daylight Devices
		3.2 Anti-glare Measures		
			1	Glare from light fixtures
			2	Daylight control
		3.3 Illuminance Level		
			1	Illuminance
			2	Uniformity Ratio of Illuminance
		3.4 Lighting Controllability		
	4 Air Quality			
		4.1 Source Control		
			1	Chemical Pollutants
			2	Mineral Fiber
			3	Mites, Mold etc.
			4	Legionella
		4.2 Ventilation		
			1	Ventilation Rate
			2	Natural Ventilation Performance
			3	Consideration for Outside Air Intake
			4	Air Supply Planning
		4.3 Operation Plan		
			1	CO_2 Monitoring
			2	Control of Smoking

Q-2	Quality of Service			
	1 Service Ability			
		1.1 Functionality & Usability		
			1	Provision of Space & Storage
			2	Adaptation of Building & Services to IT Innovation
			3	Barrier-free Planning
		1.2 Amenity		
			1	Perceived Spaciousness & Access to View
			2	Space for Refreshment
			3	Décor Planning
		1.3 Maintenance		
			1	Total program for maintenance
			2	Cleaning management
			3	Sanitary management
	2 Durability & Reliability			
		2.1 Earthquake Resistance		
			1	Earthquake-resistance
			2	Seismic Isolation & Vibration Damping Systems
		2.2 Service Life of Components		
			1	Service life of structural materials
			2	Necessary Refurbishment Interval for Exterior Finishes
			3	Necessary Renewal Interval for Main Interior Finishes
			4	Necessary Renewal Interval for Plumbing & Wiring Materials
			5	Necessary Renewal Interval for Major Equipment & Services
		2.3 Suitable replacement		
			1	Replacement of penthouse (roof) and exterior finish
			2	Replacement of piping and wiring
			3	Replacement of main equipment
		2.4 Reliability		
			1	HVAC System
			2	Water Supply & Drainage
			3	Electrical Equipment
			4	Support Method of Machines & Ducts
			5	Communications & IT equipment
	3 Flexibility & Adaptability			
		3.1 Spatial Margin		
			1	Allowance for Story Height
			2	Adaptability of Floor Layout
		3.2 Floor Load Margin		
		3.3 Adaptability of Facilities		
			1	Ease of Air Conditioning Duct Renewal
			2	Ease of Water Supply & Drain Pipe Renewal
			3	Ease of Electrical Wiring Renewal
			4	Ease of Communications Cable Renewal
			5	Ease of Equipment Renewal
			6	Provision of Backup Space
Q-3	Outdoor Environment on Site			
	1 Preservation & Creation of Biotope			
	2 Townscape & Landscape			
	3 Local Characteristics & Outdoor Amenity			
		3.1 Attention to Local Character & Improvement of Comfort		
		3.2 Improvement of the Thermal Environment on Site		

LR Reduction of Building Environmental Loadings				
LR-1	Energy			
	1 Building Thermal Load			
	2 Natural Energy Utilization			
	3 Efficiency in Building Service System			
	4 Efficient Operation			
		4.1 Monitoring		
		4.2 Operational Management System		
LR-2	Resources & Materials			
	1 Water Resources			
		1.1 Water Saving		
		1.2 Rainwater & Gray Water		
			1	Rainwater Use Systems
			2	Gray Water Reuse System
	2 Reduction of use of non-recyclable resources			
		2.1 Reduction of material volume		
		2.2 Reuse of Existing Building Skeleton etc.		
		2.3 Reuse Efficiency of Materials Used in Structure		
		2.4 Reuse Efficiency of Non-structural Materials		
		2.5 Timber from Sustainable Forestry		
		2.6 Reusability of Components & Materials		
	3 Avoid use of contaminants			
		3.1 Use materials that do not contain hazadous materials		
		3.2 Use of CFCs & Halons		
			1	Fire Retardant
			2	Insulation Materials
			3	Refrigerants
LR-3	Off-site Environment			
	1 Consideration to global warming environment			
	2 Consideration to global environment			
		2.1 Air Pollution		
		2.2 Heat island effect		
		2.3 Load on Local Infrastructure		
			1	Rainwater treatment load reduction
			2	Waste water treatment load reduction
			3	Traffic load reduction
			4	Waste treatment load control
	3 Consideration to surrounding			
		3.1 Noise, vibration, odor, and contamination by chemical substanc		
			1	Noise
			2	Vibration
			3	Odors
			4	Contamination by chemical substance
		3.2 Wind Damage & Sunlight Obstruction		
			1	Wind Damage
			2	Sunlight Obstruction
		3.3 Light Pollution		
			1	Measures for lights leaking to the outside
			2	Measures for sunlight reflection on building exterior wall

Increase of Income | Cost Reduction

2. Study of the introduction of productivity into assessment tools

2.1 Study of the introduction of intellectual productivity in offices and others

By reducing the sick building syndrome and improving the thermal and light environment, work efficiency can be improved, and as a result the level of health and productivity is improved. It is clear that the annual benefit brought about by this exceeds by far the associated construction cost.

Currently, the productivity research committee, which is supported by the Ministry of Land, Infrastructure, Transport and Tourism, is carrying out academic research on the improvement in productivity from the architectural viewpoint, and is studying the establishment of methods for planning of architectural spaces, environmental and equipment planning, and their evaluation and rating. In the sub-committee on evaluation and rating, there are various studies being carried out to incorporate intellectual productivity into CASBEE. In the future, equations for the relationship between score and productivity index (productivity value, conversion to a monetary value, etc.) for evaluation items that are associated with intellectual productivity, such as Q1: indoor environment, Q2: part of quality of service, Q3: part of outdoor environment, LR1: part of energy, etc., will be defined for both individuals and organizations as a whole, and the addition of a quantitative index chart for productivity will be studied.

2.2 The concept of the three layer model for productivity in offices and others

At present studies are being carried out on planning of architectural spaces, and environmental and equipment planning, and their evaluation and rating, considering a layered model for productivity from the architectural viewpoint. It is considered that every day people pass through these layers, while carrying out their activities.

The first layer is the “information processing” layer in which standard processing of knowledge and information and work processing is carried out. Under the current paradigm, a work environment and health environment are sought in order to maintain the environment. Evaluation is attempted by measuring absentee rates, health management costs, etc. The yardstick is coarse but measurement is simple, and this has been partially incorporated into assessment tools, etc.

The second layer is the “knowledge processing” layer in which knowledge and information are sought and processed. Under the current paradigm, efforts are made to improve the mental, physiological, and physical comfort environment, the health environment, and the quality of space, with the objective of improving the quality of space and environment. Evaluation is carried out by quantitatively evaluating the work efficiency and the mental and physiological effects, and the target is to carry out economic evaluation. The methods of measurement are rather complex, but research on these methods is proceeding at present.

The third layer is the “knowledge creation” layer, in which value creation and innovation are carried out. Space and environment that can stimulate knowledge creation is sought. For example, a space or environment having the characteristics that it is possible to concentrate, communicate, and relax can stimulate a person to create knowledge. A person’s actions in response to a space or environment are various, such as deep thought, friendly chat, exchange of opinions, etc., but it it is hypothetized that the result is invigoration of the place, leading to knowledge creation. No method of measuring this type of intellectual value creation has yet been established, so it is considered that its evaluation is a task for the future.

However, this is not to say that there are absolutely no indications regarding what constitutes excellent space for productivity. It is possible to imagine offices with lively communication and intellectual stimulation, or serene contemplative space such as shrines and temples, and other spaces. Also, new architectural experiments that aim for improved productivity have intensified in recent years, so there are many architectural spaces that can give us hints.

It is considered that if it is possible to accumulate many examples where there has been a good physiological and mental effect on individuals, resulting in invigoration of the place as an organization, or resulting in knowledge creation by individuals or organizations, then it will open the road to development of architectural design methods for excellent productivity and its evaluation.

2.3 Study of productivity from the viewpoint of users or businesses

The spaces and physical environments created by architecture, such as offices, schools, hospitals, and other facilities, are provided in accordance with the users of each facility. For example, a hospital is a space with comfortable sickrooms and advanced medical treatment equipment, an office is a comfortable workplace, environment and communication space.

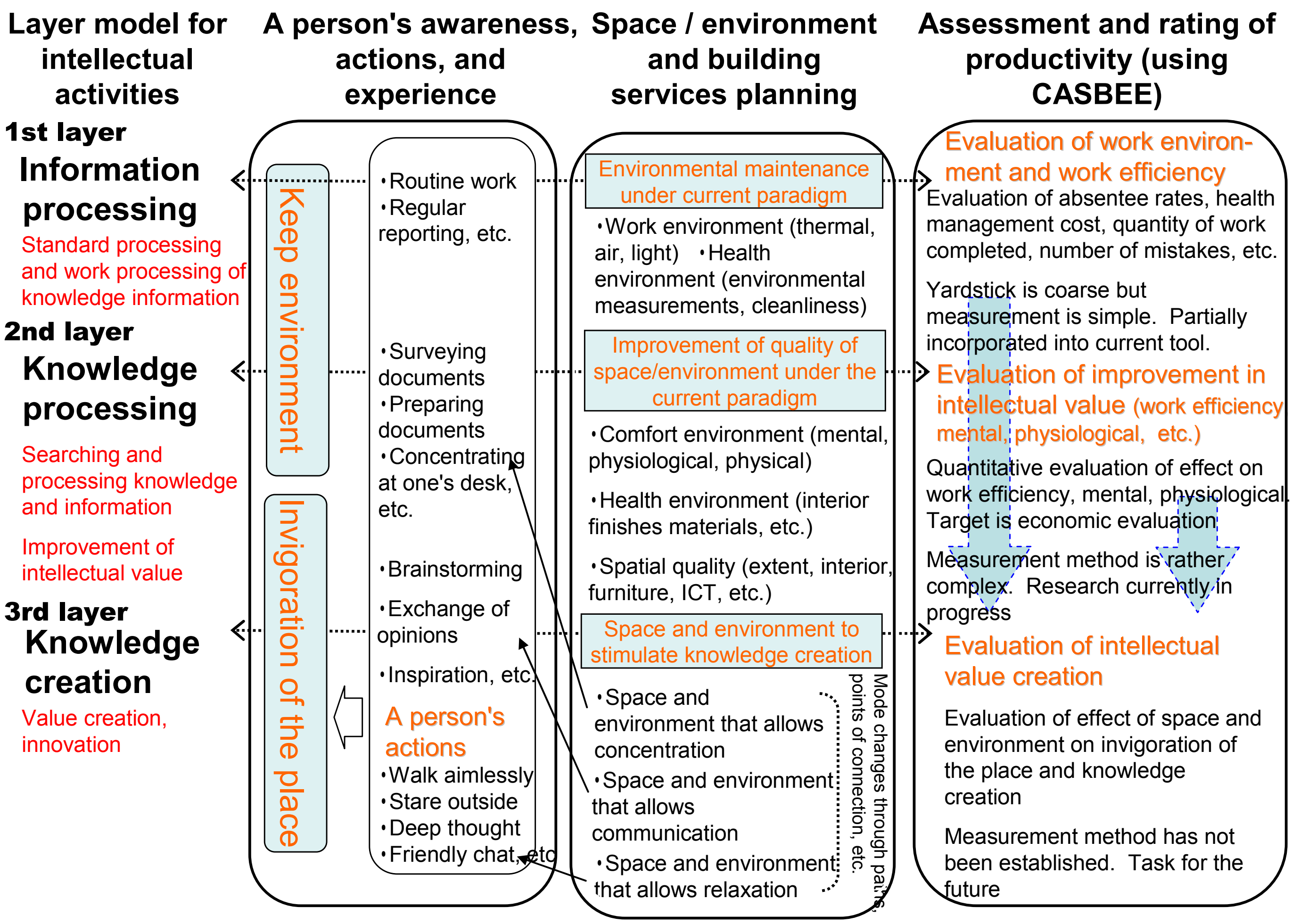

Figure 3 Layer model for Architectural spaces and Intellectual activities

Before these things, a more environmental positive value is created. An improvement in productivity is aimed for, for example, an improvement in test results in a school, and an increase in business in an office. In this way, it is possible to consider how productivity can be improved in buildings of each use, using a table such as Table 2.

Further, by specifically considering, from the viewpoint of a tenant moving into that building, what is attractive, what is the totally expected effect of the building, and so on, it is possible to study the meaning of the effect of improving productivity from the viewpoint of users or businesses, and how to measure it.

The above was just an indication of a part of the methodology under study, but it is necessary that this kind of study and survey continues.

Table 2 Study of productivity from the viewpoint of users or businesses

		Office	School	Hospital	Commercial	Research facility	Factory
Architectural space and environment		Comfortable work space Space for communication with outside Attractive environment to be in	Comfortable classrooms and outdoor space Environment that is attractive for both students and teachers	Comfortable sickrooms Comfortable condition of medical treatment Sufficient medical equipment	Space to encourage buying and satisfaction Space and environment that encourages people to stay in for a long time	Inspiring space and environment Communication space Attractive environment to be in	Physical environment for producing products Space and environment that is comfortable for the workers
Positive value of environment	Increase in productivity	New proposals or increased business	Improved test results Improved rate of success in proceeding to higher education	High treatment rate Early discharge	Increase in sales per unit area	Increase in the frequency of inventions or discoveries	Improvement in productivity per unit time or per unit area
	Stronger attraction for tenants	New ideas forthcoming Possibility of collaboration Always comfortable	Excellent students Excellent teachers	Excellent doctors	Many buyers Buyers spend well	Excellent researchers gather	-
	Expected effect	Reduction in move-out rates and vacancy rates	The maximum numbers of students can always be obtained Possible to select the best students	Higher admissions so that there are no vacant rooms for the wealthier patients	Attract tenants that can attract customers Increase in customers	Creation of new research results	Improvement in productivity per unit investment

3. Study of indices taking into consideration human sensitivity

As stated previously regarding productivity, a built space with thermal, light, sound, air, and ICT environment that places importance on the human sensitivity, is considered to be important for knowledge creation. Also, a rich life in harmony with nature and landscape is important, and these are considered to be communication tools for gaining the understanding of the occupants and residents.

As a specific method for this purpose, indices for universal design evaluation taking human sensitivity into account are being studied. Table 3 shows the essential features of these indices. The evaluation items derived from the five senses are hearing (natural sound, sensible sound, echoes), touch (disposition, sense of walking, sense of touch), seeing (texture of materials, light and shade, spaciousness), smell (natural, materials, smell of a location), and so on. Comprehensive evaluation items include stimulation from the surrounding environment, stimulation due to natural change, comfort, etc. These are weighted to obtain an overall evaluation.

Figure 4 shows an example of an evaluation that was attempted with evaluation by an evaluation index scheme that takes human sensitivity into account and CASBEE assessment on the two axes. It is considered that both good “environmental assessment by CASBEE” and good “index evaluation taking into consideration human sensitivity” is desirable. On the other hand, it is expected that the required rank or grade will vary depending on the building type, the charactor of the building, and the requirements of the owner. Also, it is considered that in the future the creation of buildings with still higher evaluation for both indices will become the target.

Table 3 Main items for evaluation indices taking human sensitivity into consideration (proposed)

Base of sense	Stimulation from the surrounding environment
	Stimulation from natural change
	Trigger from acts of movement
	Take into consideration Comfort
Sense of hearing	Natural sound
	Sound sensible to a person
	Sound of space
Sense of touch	Skin touch
	Sense of walking
	Sensing with hands and feet
Sense of sight	Texture feeling of materials
	Light and shade of space
	Extent of space
Sense of smell	Natural smells
	Smell of materials
	Smell of place

4. Conclusions

(1) For assessment tools, the pursuit of ease of understanding and explanation of the benefits are important. It is required to clearly demonstrate the CO_2 emission performance and the evaluation of global warming measures. Then to explain in an easy to understand manner the economic benefit, the productivity benefit, the direct effects for buildings of each type.

(2) It is necessary to introduce productivity for assessment tools. Especially, space and environment to stimulate knowledge creation is required and measurement method is the task for the future.

(3) Indices for universal design evaluation taking human sensitivity into account should be studied at present and in the future.

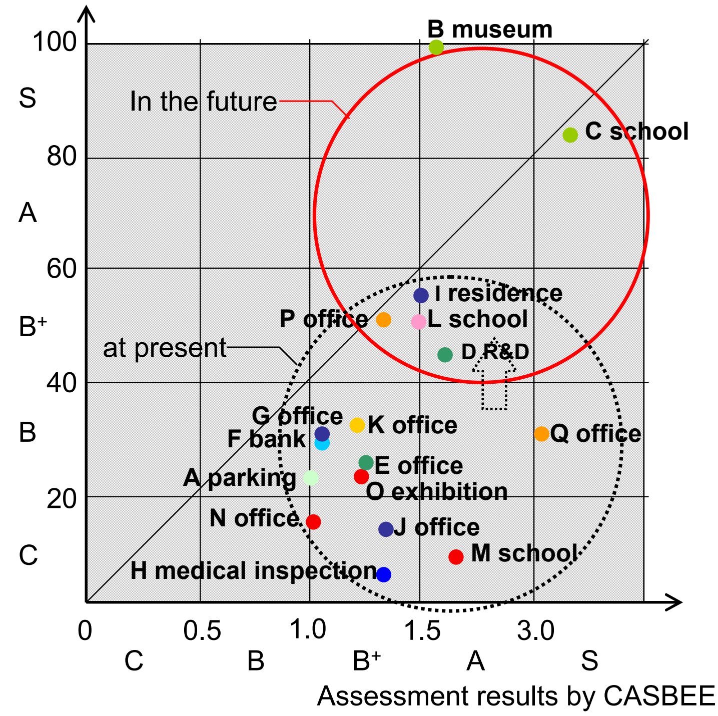

Figure 4 Case studies by indices taking into consideration human sensitivity and CASBEE

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CONSTRUCTION AND ECO-EFFICIENCY EVALUATION OF LIVEABLE COMMUNITIES IN CHINESE TOWNS

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Keywords: liveable community, construction, eco-efficiency, evaluation, town

Summary

This paper analyzes the community environment and its characteristics in Chinese towns, discusses main targets, basic principles and environmental considerations associated with liveable community construction in towns. It sets up the life cycle process of liveable community construction which includes four stages: planning and design, buildings construction, operation and management, and building dismantlement. A construction technology system composed of four sub-systems is also established: 1) technologies of ecological environment planning; 2) technologies of environmental protection; 3) technologies of water and energy-saving, waste reduction and reuse; 4) technologies of recyclable materials.

Based on two previous national key R&D programs of our research team funded by Ministry of Science and Technology, P.R.C, the paper introduces four typical construction demonstrations for liveable communities in towns in different areas, and formulates the application of community construction technology system and eco-efficiency evaluation in Yanhe eco-village as a case study.

The paper formulates the concept of eco-efficiency of liveable community construction, suggesting that eco-efficiency can be evaluated by the ecological capacity control indicator (ECCI) and the ecological footprint method. ECCI is established to indicate the integrated ability and ecological capacity of each control factor of ecological capacity of liveable communities, and the evaluation framework of ECCI - composed of a three-level indicator system - is set up. Applying this evaluation indicator system to case studies, we compared the liveability of communities between Mulan town and Huazhuang town, and performed the integrated evaluation of eco-efficiency for community construction.

It is concluded that the construction development of communities in Chinese towns should be liveability-oriented, that this should be prioritized over the entire building life cycle, the eco-efficiency evaluation method should be applied during the process, and the key issues and targets should be clarified in the development of the eco-efficiency evaluation method.

1. Community Environment in Chinese Towns

1.1 Development in Chinese towns

In China, town refers to all settlements with a larger area than a village and usually smaller than a city. According to China's current standards for administrative towns formulated in 1986, a town can be recognized if it includes a county government and has a non-agricultural population of more than 2,000.

In China's urbanization process, towns have been developing rapidly and continuously. From 1978 to 2006, the number of towns increased from 2173 to 19369; the total population in cities and towns soared from 170 million to 577 million; the urbanization rate grew from 17.9% to 43.9%. In 2006, non-agricultural population in towns exceeded 200 million, and the development of sustainable communities in towns became the focus in the process of China’s urbanization. Meanwhile, the communities in towns have formed a unique community construction environment which is different from that in big cities and rural areas.

1.2 Characteristics of community environment in towns

Compared with big cities, community environment in towns has the following four characteristics:

(1) Most residents in towns are rural population. Agricultural population accounts for about 65.3% of the total population in towns.

(2) The density of population in towns is comparatively small. Apart from economically developed areas, farming land takes up a large proportion of the town's total land. In China, the per-capita area in towns is nearly 5.5 times that of big cities.

(3) Community environment in towns has distinctive characteristics. China is a multi-nationality nation with a vast area where the diversity in the natural resources supply, geography and climate, customs, economic and social development levels lead to community environments of different characteristics.

(4) Ecological environment of communities in towns is very fragile. Community environment is easily influenced by pesticide pollution, excessive land development, industrial pollution from factories development, and biodiversity reduction due to the damage to the original ecological environment, etc. Compared to large cities, the ecological environment of towns is more vulnerable due to inadequate environmental protection measures.

2 Construction Technology System for Liveable Community in Towns

2.1 Liveable community in towns

The Ministry of Housing and Urban-Rural Development of China (MOHURD) announced the Scientific Evaluation Criteria for Liveable City (CSUS, 2007), which defines liveable city as "the settlements with good living and space environment, good humanity and social environment, good ecological and natural environment, and clean and efficient production environment". Liveable city has the following six characteristics in China: social civilization, economic prosperity, beautiful environment, resource capacity, convenient life and public safety. Leadership in Energy and Environmental Design for Neighborhood Development (USGBC, 2002) gives quantitative evaluation criteria for green building within communities, in terms of sustainable sites, water efficiency, energy and atmosphere, etc.

Currently, basic liveability factors of community in towns in China should include physical, spiritual and environmental factors (Hua, 2006), which are reflected in civilized community, excellent environment, abundant life, energy-saving and environmental friendliness, safety and comfort.

2.2 Construction technology system and eco-efficiency evaluation of liveable community

Sustainable resource utilization, sustainable economic growth, sustainable environmental improvement and sustainable social justice should be adopted as the basic principles for liveable community construction in towns. Resource and energy-saving, environmental protection, human-orientation, and resource integration should be promoted in community construction and operation so as to form a high-efficiency and low-energy construction model with low pollution, ecological balance and comfortable living.

Construction of liveable communities in towns would be prioritized over the whole building life cycle process. It can be divided into four stages: planning and design, building construction, operation and management and building dismantlement. The related construction technology system and eco-efficiency evaluation includes: 1) technologies of ecological environment planning; 2) technologies of environmental protection; 3) technologies of water and energy-saving, waste reduction and reuse; 4) technologies of recyclable materials.

The Construction Technology System and Eco-efficiency Evaluation of Liveable Communities in Towns (CTSEELCT) is shown in Figure 1.

2.3 Construction and demonstrations of liveable communities in different areas in China

China is a vast nation with different economic and social development levels and different natural resources. According to the geological positions and economic development levels, communities in towns of China are divided into several classes in this paper: economically developed communities in eastern and southern coastal areas, ecological communities in central areas, folk-style communities in western areas and communities in cold northern areas. Four typical construction demonstrations for liveable communities in towns in different areas are shown in Figure 2.

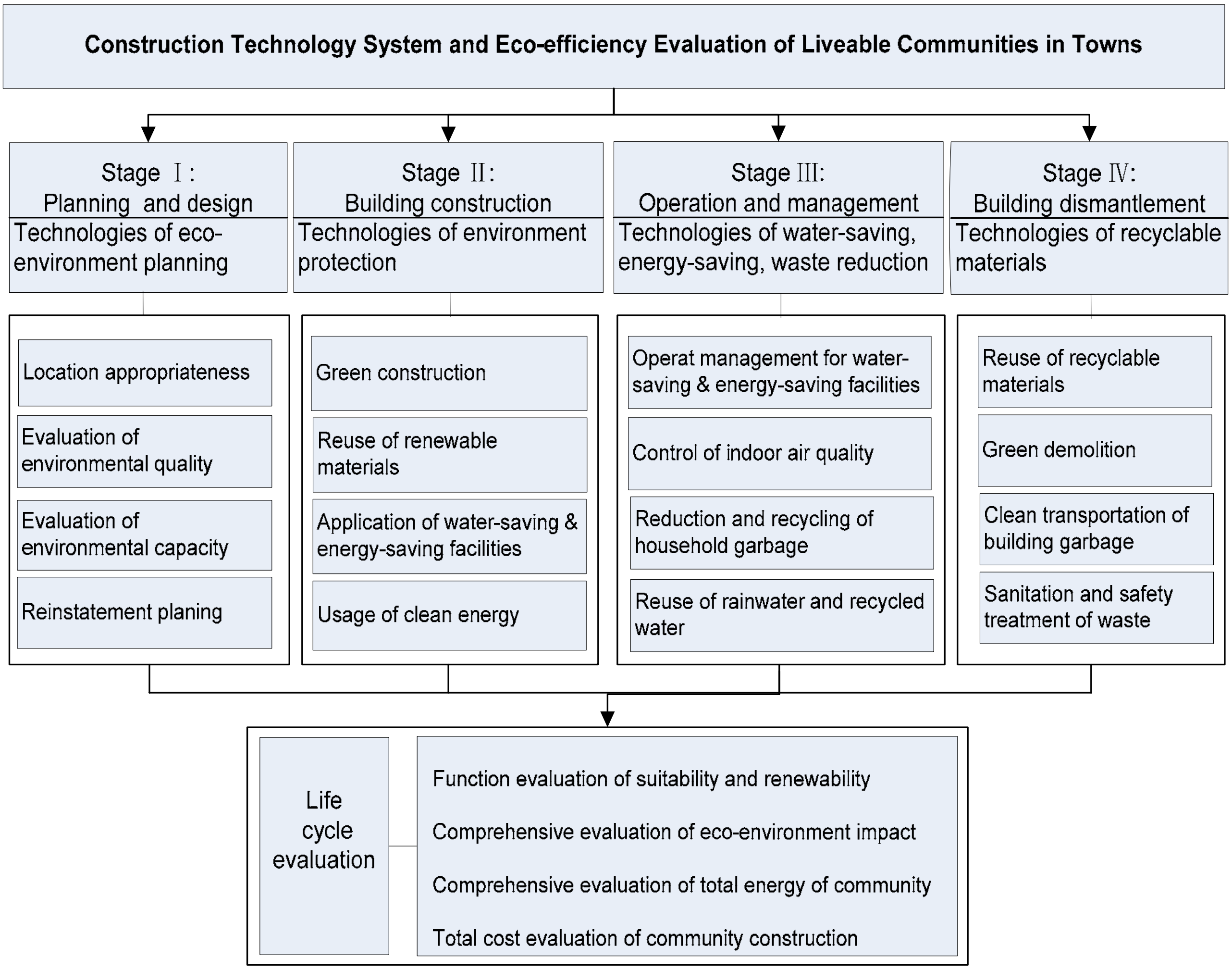

Figure 1 Construction technology system and eco-efficiency evaluation of liveable communities in towns

Developed community Huazhuang town in Jiangsu | Eco-community Yanhe village in Hubei | Folk-style community Tunpu town in Guizhou | Straw-bale community Hongtuya town in Jilin

Figure 2 Construction demonstrations for liveable communities in towns in different areas in China

From 2005 to 2006, our research team at Huazhong University of Science and Technology (HUST) undertook two key R&D programs funded by Ministry of Science and Technology, P.R.C (MOST): “Study and Demonstration on Construction Techniques of Eco-building”, and “Study and Demonstration on Key Construction Techniques for Ecological and Energy-saving Community in Towns". Several demonstration communities have been constructed in Huazhuang town (Jiangsu province), Zhuanghu village in Huairou district (Beijing), Weihushan scenic spot in Hailin city (Heilongjiang province), Hongtuya town in Baishan city (Jilin province), Mulan town in Wuhan city (Hubei province) and Yanhe eco-village in Wushan town (Hubei province). We have successfully applied the above technology system and eco-efficiency evaluation in these construction demonstrations.

An application of CTSEELCT in Yanhe eco-village construction is shown in Figure 3.

Figure 3 Application of CTSEELCT in Yanhe eco-village construction

3 Eco-efficiency Evaluation of Liveable Community in Towns

This paper evaluates the eco-efficiency of liveable community in towns by ecological capacity control indicator (ECCI) and ecological footprint through the demonstration projects. ECCI indicates the controlling level of environmental capacity of liveable community construction in towns, whereas ecological footprint evaluation reveals the eco-share ratio of towns. The eco-efficiency can be deduced from comparison of the results, which can also indicate the measures necessary to improve the condition of liveable community construction.

3.1 Eco-efficiency of liveable community construction

The concept of eco-efficiency is to promote the minimization of environmental impact of production processes. The World Business Council for Sustainable Development states that "Eco-efficiency is reached by the delivery of competitively priced goods and services that satisfy human needs and bring life quality, while progressively reducing the impacts to environment and resource intensity throughout the life cycle to a level at least in line with the earth's estimated carrying capacity." (NRTEE, 2001).

Eco-efficiency of liveable community construction means that all the activities in the life cycle process, including planning and design, building construction, operation and management and building dismantlement, should have minimized ecological impact.

The eco-efficiency of liveable community construction can be evaluated by ECCI and ecological footprint method.

3.2 Ecological capacity evaluation of liveable community construction

The paper analyzes and evaluates the ecological capacity of two types of communities in towns by eco-efficiency evaluation. One is an ecological community beside mountains and rivers in central area in Mulan town of Wuhan city, the main income source of which is eco-tourism; the other is a community in an economically developed area of southeast in Huazhong town, relying on industry for income.

3.2.1 Evaluation of ecological capacity control indicator

According to the CTSEELCT, the paper establishes the ecological capacity control indicator (ECCI) so as to indicate the integrated ability and ecological capacity of each control factor of ecological capacity of liveable communities.

The evaluation framework of ECCI can be classified into a three level indicator system.

The first level is ECCI. The greater the value of ECCI, the better the control ability of ecological capacity, and the better the corresponding comments. The classification and comments of ECCI are shown in Table 1.

Table 1 Level I: ECCI - Classification and Comments

Classification	ECCI	Comments
1	> 0.75	Very Good
2	0.50 ～ 0.75	Good
3	0.35 ～ 0.50	Middle
4	0.25 ～ 0.35	Low
5	< 0.25	Worse

Formula of ECCI is as follows:

$$\mathrm{ECCI} = \sum_{i=1}^{n} V_i W_i \quad (1)$$

Where:

V_i denotes the second level indicator value; W_i denotes its weight calculated by Analytic Hierarchy Process (AHP); n denotes items of second level indicator (Ministry of Environmental Protection of China, 2002).

The second level is ecological capacity control and evaluation indicator, including four sublevels: population capacity, land capacity, resources capacity and waste treatment capacity.

The third level is detailed evaluation indicator for ecological capacity which including 21 sub-indicators.

Evaluation indicator system of ecological capacity in towns is shown in Table 2.

Table 2 Evaluation Indicator System of Ecological Capacity in Towns

Level II	Level III	Level II	Level III
Population capacity B_1	C_1 Natural population growth rate	Resources capacity B_3	C_{11} Energy efficiency
	C_2 Population density		C_{12} Comprehensive grain production capability
	C_3 Proportion of non-agricultural population		C_{13} Per capita fresh water
	C_4 Employment rate		C_{14} Energy consumption of per million yuan of output
	C_5 per capita GDP		C_{15} Energy-saving efficiency
Land capacity B_2	C_6 Per capita arable land		C_{16} Renewable energy utilization rate
	C_7 Water area	Waste treatment capacity B_4	C_{17} Wastewater treatment rate
	C_8 Per capita built-up area		C_{18} Domestic refuse treatment rate
	C_9 Forest coverage rate		C_{19} Percentage of environmental protection input in GDP
	C_{10} Development available wasteland		C_{20} Per capita green area in built-up areas
			C_{21} Comprehensive utilization rate of straw

Using the above evaluation indicator system, we were able to compare the case studies of Mulan town and Huazhuang town.

The comparison of ECCI in Mulan town and Huazhuang town with the Affordable Standard of Towns in China (ASTC) is shown in Figure 4.

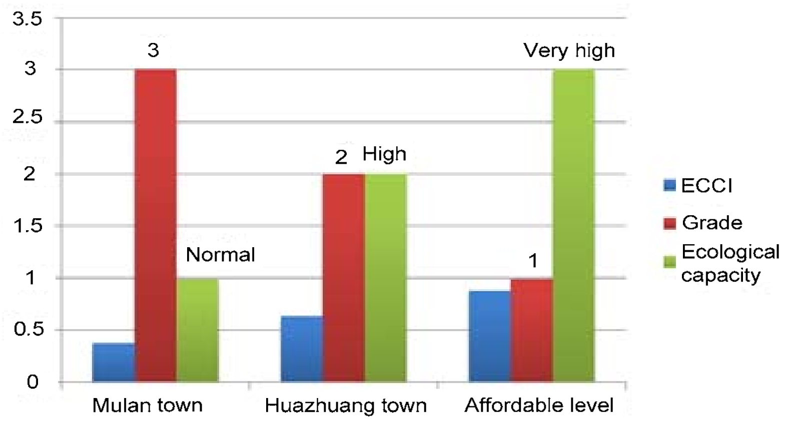

Figure 4 Comparison of ECCI in Mulan town and Huazhuang town with ASTC

The comparison of ecological capacity control factors of Mulan town and Huazhuang town with ASTC are shown in Figure 5.

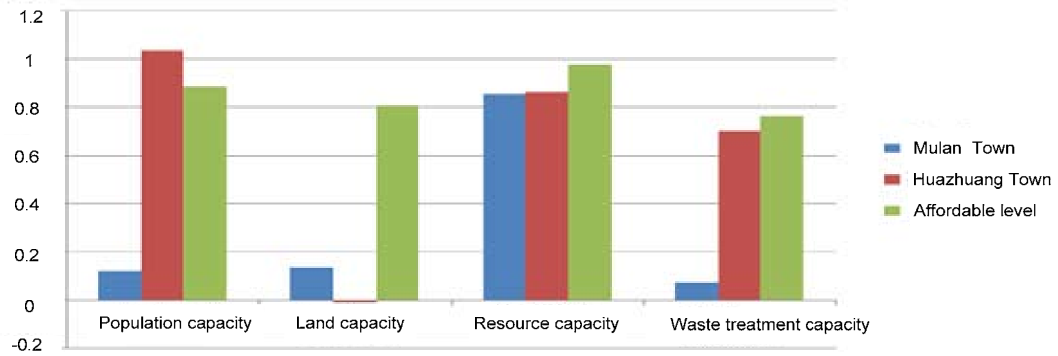

Figure 5 Comparison of ecological capacity control factors in Mulan town and Huazhuang town with ASTC

According to the above analysis, we can find:

1) Most of the ecological capacities of Mulan and Huazhuang are lower than ASTC，but the population capacity in Huazhuang is higher than Mulan and ASTC. This is because Huazhuang, as an economically developed town, can offer more employment and the people there are richer.

2) The land capacities in Mulan and Huazhuang are somewhat lower than ASTC, which indicates that both towns lack land resources.

3) The resource capacities of Mulan and Huazhuang are close to ASTC, because resources supply in both towns is from the outside. Therefore, it is very important to improve the efficiency of energy usage and promote the use of renewable energy for sustainable development of two towns.

4) The waste treatment capacities of the two towns are different. Huazhuang, the developed town, pays more attention to environmental protection, as the indicators of green ratio, air condition, noise, cleaning rates of waste gas and water, rate of multipurpose utilization of solid waste all approach the ASTC benchmark. In Mulan, a town of abundant ecological environmental resources, the indicators of cleaning rate of waste water and solid waste are much lower than ASTC. Therefore, measures to improve planning and construction for liveable communities have been taken in Mulan.

3.2.2 Ecological capacity evaluation of community

Taking the eco-footprint method, the eco-share ratio, the per capita ecological footprint and the per capita ecological capacity of Mulan town and Huazhuang town were evaluated.

1) Evaluation of eco-share ratio. Eco-share ratio was 80.00% in Mulan and 226.1% in Huazhuang in 2005.

2) Evaluation of per capita ecological footprint and per capita ecological capacity. The comparison of per capita ecological footprint between Mulan and Huzhuang in 2005 is shown in Figure 6, and the comparison of per capita ecological capacity between Mulan and Huzhuang in 2005 in Figure 7.

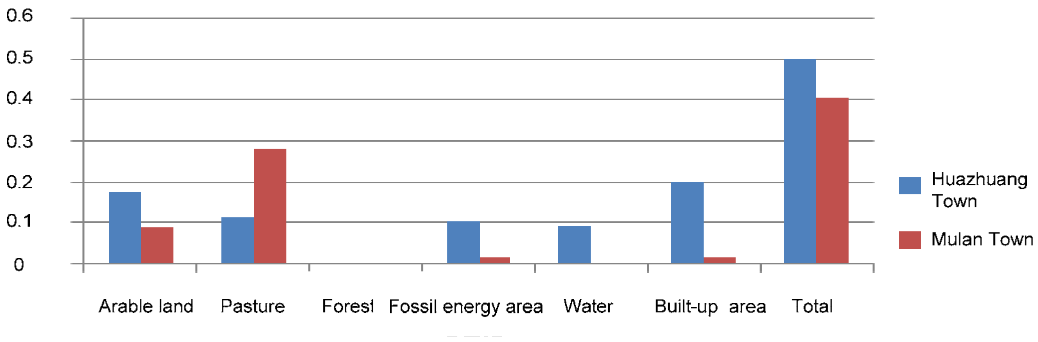

Figure 6 Comparison of per capita ecological footprint between Mulan and Huazhuang in 2005

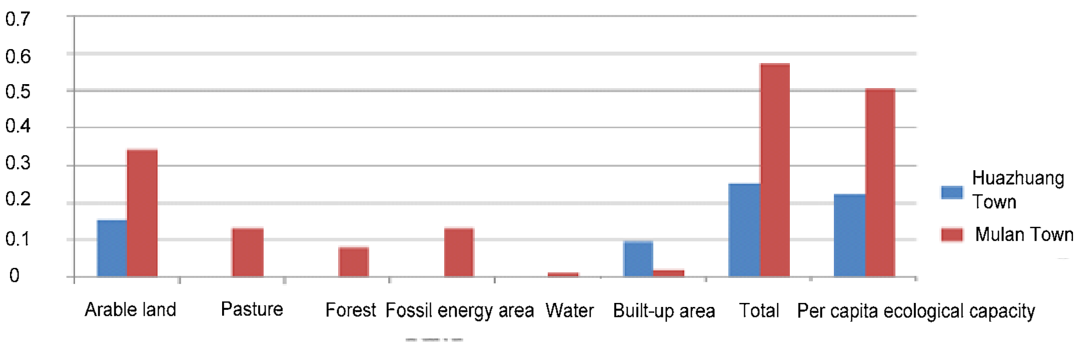

Figure 7 Comparison of per capita ecological capacity between Mulan and Huazhuang in 2005

3.2.3 Integrated evaluation of eco-efficiency for community construction

(1) The integrated evaluation outcome

If the eco-share ratio of community is lower (or eco-capacity is higher), but the control ability of environmental capacity (ECCI) of community is higher, then the eco-efficiency of community is higher, and the liveability in this kind of community is better. But when the results of these two data are conflicting, the eco-efficiency should be deduced from ECCI.

(2) Comparison of eco-efficiency

1) Eco-share ratio: The eco-share ratio in Mulan town is 0.8000 while that in Huazhong town is 2.2610.

2) ECCI: ECCI in Mulan town is 0.4049 while that in Huazhong town is 0.6325, but both are lower than ASTC. The eco-efficiency of Huazhong is higher than that in Mulan, i.e. the community of Huazhong is more liveable than that of Mulan.

3) Control ability of eco-capacity: Huazhong is a developed town with higher employment rate and GDP than that of Mulan, so the population capacity of Huazhong is higher than that of Mulan. Therefore, the control ability of eco-capacity of Huazhong is higher than that of Mulan.

4) Economic development factor: Economic development is a very important factor to improve environment for liveable community in towns.

4 Conclusions

(1) The construction development of communities in towns of China should be liveability-oriented. The five developing principles should be followed: civilized community, excellent environment, abundant life, energy-saving and environmental friendliness, safety and comfort.

(2) The liveable community construction should be prioritized over the whole life cycle process. The four stages of the process are planning and design, building construction, operation and management, and building dismantlement. The related construction technology system should be developed and promoted in this process.

(3) The liveable community construction should apply the eco-efficiency evaluation method. There are many different and unique characteristics of community construction in towns of China. Therefore, to establish the eco-efficiency evaluation method is beneficial for guiding and promoting the liveable community construction.

(4) The key issues and targets should be clarified in development of eco-efficiency evaluation method. The key to develop eco-efficiency evaluation technology of liveable community in towns is to improve the

eco-capacity evaluation system. The aim of eco-efficiency evaluation is to lead the liveable community construction in towns of China in a more sustainable way.

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DEFINING SUSTAINABILITY FOR AUSTRALIAN ROAD INFRASTRUCTURE PROJECTS

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Keywords: Sustainable development, road infrastructure, construction management, project delivery, performance enhancement.

Abstract

Australia is currently riding on a resource boom, thanks to the economic development of its northern neighbors. This demand and the country's own growing economy and population, has resulted in an unprecedented scale of infrastructure upgrade and new development in many states across Australia. Road and highway construction often leads other infrastructure development. Under the public awareness on sustainability and due to their impact on the environment, road infrastructure projects put pressure on all stakeholders, including local, state and federal governments, to look for economically feasible, socially viable and environmentally responsible project outcomes. This calls for the adoption of sustainability principles through project delivery. Literature study and consultation with some professions of the industry found that there is an absence of common understanding on what constitutes sustainability in the infrastructure context. Its priorities are often interpreted differently among stakeholders. As a result, policies on sustainability remain largely ideological and are often not realized to the full potential through actual project delivery.

A research is being conducted to identify the common perceptions and expectations by different stakeholders towards achieving sustainability in road and highway infrastructure projects. Face to face interviews on selected representatives of these stakeholders were carried out in order to select and categorize, confirm and prioritize a list of sustainability performance targets identified through literature and past research. This effort is being followed by a Delphi study with the assistance of industry professionals and academic experts, which will further consider the interrelationship and influence of the sustainability indicators. By identifying and integrating different perceptions and priority needs of the stakeholders, coupled with the identification of key sustainability indicators and solutions for critical issues in subsequent development stages, a set of decision-making guidelines can be developed to help promote and drive tangible sustainability agenda in road and highway infrastructure projects.

1. Introduction

Australia is currently in the grip of buoyant national economy. A few catalysts have contributed to this growth, surge in resources export, substantial foreign investments and increased population, to name a few. These development patterns have coupled with improved living standards and growing societal expectations, which in turn caused an unprecedented demand for infrastructure development.

Road and highway construction often leads other types of infrastructure development. Substantial and comprehensive transport networks are critical to the booming mining, mineral processing and export industries. The fact that the majority of the population lives outside the greater metropolitan areas of Australian capital cities and growing regional communities adds further pressure to the already bottle-neck situations on roads and highways.

Having recognized the potential as well as impending hindrance to the economy if the problems of inadequate roads infrastructure worsens, the Australian government is committed to build, improve and upgrade. With increasing public concern over the environment, it is also natural to expect that any infrastructure development is integrated with the concept of sustainable principles, as it will not only bring about economic gains, but also social and environment benefits for which large infrastructure developments are held accountable.

Although in an ideal sense the principles of sustainability should drive road infrastructure development, many stakeholders can be involved in the process and this has seemed to complicate the matter. Different disciplines are unwilling or unable to consider the views represented by others because there is no common language place (Lombardi and Brandon, 1997). Different individuals and organizations have expressed different perceptions and definitions of sustainability (Shelbourne, et al., 2006). The fragmented and diverse business nature of the industry accounts for such scenarios, which are exacerbated by the adversarial cultures within the industry (Chan et al., 2005). As a result, policies on sustainability often remain largely ideological and are often not reflected in the actual project delivery. Without common understanding among these stakeholders, achieving sustainability outcomes in road infrastructure projects remains a formidable task.

2. Overview of Australian Infrastructure Industry

Integral to the Australian building and construction industry, infrastructure development is an engine of growth driving its national economy. The infrastructure industry has direct impact on Australian's well-being and progress by providing roads and highways, water and electrical supply and communication essential for daily living and business operations. The industry has a significant influence on the effectiveness and efficiency of other industries to compete locally and in global market and provides for a myriad of support businesses (CRC for Construction Innovation, 2006). Infrastructure development is both critical and inevitable.

The demand on Australian infrastructure development is constantly on the rise. This is being fuelled by strong economic position with substantial foreign investment in the country and increased global demand for resources and energy particularly from neighboring countries, general prosperity with improved living standard, population growth and major migration which calls for greater infrastructure needs. Moreover, Australians have become used to high standards of infrastructure and their expectations will continue. This is becoming a major concern as new capital works still predominate in the public mind and the renewal of existing infrastructure is often taking for granted by the general public (Burns et al., 1999).

An analysis conducted by the Commonwealth of Australia (1999) on Australian building and construction industries revealed that the engineering construction market segment is employing 35,600 people (4.8% of the total industry's employment) with approximately 3100 firms. Given the booming economy, it is expected to rise. The engineering construction market segment is mainly engaged in engineering or infrastructure projects such as railways, dams, roads and bridges, major pipelines and eletricity and other utilities infrastructure.

The resources-led boom, particularly in Western Australia and Queensland, has resulted in high pressure on infrastructure. In Queensland, it is reported that the state government will invest over AUD$ 82 billion in the next 20 years under an ambitious infrastructure program, to cover four main types of infrastructure demands. (Table 1). Large projects which is over AUD$ 1 billion in value each will take up almost AUD$20 billion in that AUD$82 billion as a whole (Queensland Government, 2007). Road, rail and public transport infrastructure that top the list account for over 60% of the total investment.

Table 1: Infrastructure Spending for Queensland for 2007-2026.

TYPE OF INFRASTRUCTURE	INVESTMENT VALUE (AUD$'billion)
1. Road, Rail and Public Transport	50.78
2. Energy Networks	16.00
3. Social and Community	8.00
4. Water Infrastructure	7.50
Total	82.28

The geographical widespread of Australia and its necessary decentralized economic and social development means substantial transport network is required for its own mobility and for movement of a vast range of goods and services, and their providers, to meet its needs. From employees accessing their workplaces, students traveling to and from schools, and families going for weekend leisure outings, our society places enormous demand on road infrastructure to move people about in a safe, timely, efficient and environmentally friendly manner.

As these infrastructure systems experience unprecedented demand for both new built and regeneration, disturbances to human life and the ecosystem can be resulted. Therefore, enhancement of sustainability in infrastructure development is crucial in order to ensure minimal impacts to the environment, social and cultural aspects of a community and at the same time, achieve economic outcomes. To do so, integrating sustainable principles in infrastructure development by respective stakeholders is the only way forward.

3. Stakeholders in Road Infrastructure Projects

Road infrastructure development is complex. This is due to the large scale and use of huge resources that characterizes the nature of its development. Necessarily, it involves multiple parties to undertake the multi-faceted development as 'stakeholders'. In general, stakeholders are individuals or organizations that are either affected by or affect the development of the project; and therefore, capturing their input is a crucial component of the project development process (El-Gohany et al, 2006).

Infrastructure stakeholders span a wide spectrum of people and organizations, bringing together a vast a array of skills as well as disciplinary capabilities necessary for the implementation of infrastructure projects. El-Gohany et al. (2006) categorized infrastructure stakeholders into three types:

- *Responsible Stakeholder* refers to an organization or individual who has some degree of responsibility or liability with regard to the development process;
- *An Impacted Stakeholder* refers to an organization or individual who is directly or indirectly affected by the development process; and
- *An Interested Stakeholder* refers to an organization or individual who is not directly impacted by the project, but who would like to participate and provide his opinion in the infrastructure development process.

Adapting from the above, for this research, the definition on stakeholders is expanded to identify the various stakeholders in road infrastructure projects development, as below:

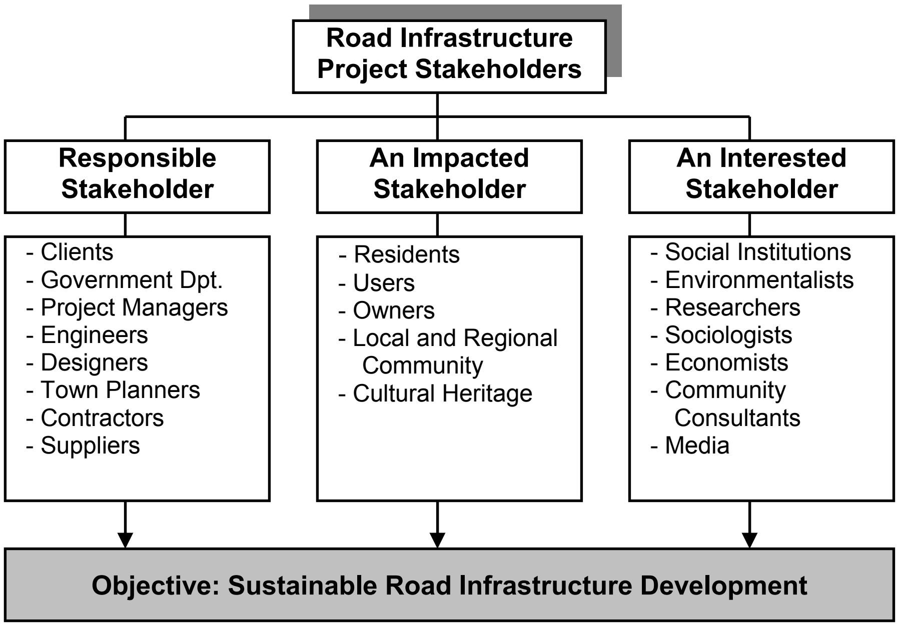

Figure 1: Road Infrastructure Project Stakeholders

Depending on their professional requirements and business nature, they enter the competitive infrastructure market with specific drive. Different stakeholders have different levels and types of investment and interest in construction project (Newcombe, 2003). It is important for the project's objectives to mesh with its stakeholders', and that they continue to fit with stakeholders' strategic interests as the project evolves, conditions vary and the interdependencies of key systems, stakeholders and their objectives change (Morris, 1994). Failing to realize this would potentially jeopardize the project objectives and its smooth implementation. Successful completion of construction projects is therefore dependent on meeting the expectation of stakeholders (Cleland, 1995).

Each stakeholder is motivated by their own interests. As a result, their perceptions on what constitutes sustainable road infrastructure development vary accordingly. Often, they perceive from their own point of benefits and priorities. Therefore to achieve infrastructure sustainability, understanding their varying perceptions and needs and integrating them into the design and delivery of road projects becomes crucial.

4. Defining Sustainable Road Infrastructure Projects

A research project is being done in Queensland to develop integrated decision-making guidelines for the improvement of sustainability outcomes in infrastructure projects. The on-going project employs a combination of face-to-face interviews with industry professionals, a Delphi study among experienced practitioners and academics, and case study techniques to collect expert opinions as well as real-life project information.

The project began by interviewing 20 targeted senior representatives within the collaborating infrastructure stakeholders in Queensland, Australia. Many have the experience of working with all professions represented in this group and even with each other (businesses) as partners of major consortiums for large projects in Queensland, interstate and in some cases, overseas. They comprise of government departments, financier/banks, environmentalists, community consultants, contractor/builders, designers, engineers, project managers, town planners and cultural heritage experts. Collectively, these high-ranking professionals possess a wealth of experience in a diverse range of infrastructure projects such as roads and highways, rails, seaports, airports and dams. However, the interview was specific on roads infrastructure development.

Literature studies have helped the compilation of over 16 categories and 300 sustainability sub-indicators overall. This long list reduced to 10 categories and around 200 sub-indicators through the interview as the most appropriate and applicable under local conditions. The triangulation of interview results provided an overall picture of sustainability in relation to roads infrastructure development in Australia. Table 2 summarizes the findings on sustainability priorities and indicators:

Table 2 Sustainable Roads Infrastructure Indicators

NO.	SUSTAINABILITY PRIORITIES	INDICATORS	SUB-INDICATORS
1.	INSTITUTIONAL	**Appropriate Development Control**	Guidelines control, National sustainable development strategies, Environmental Impact Assessment, Program of integrated environmental and economic accounting.
		Legislative Requirements	Policy/ strategy match, Match design standard with project function, Compliance with contract document & project specifications, Compliance with environmental legislation.
2.	ENVIRONMENT	**Land Use**	Extent of loss of habitat and feeding grounds, Extent of erosion and sediment, Maintain good agricultural land.
		Soils/Topography/Geology	Soil types and erosion risk, Reuse of topsoil, Minimize soil disturbance.
		Water Quality	Maintain water quality in water bodies, Polluted run-off control in construction site, (eg. spills, heavy metals, hydrocarbon etc.), Impact on downstream environments & groundwater resources, Sensitivity of surrounding water bodies and receiving environments, Water consumption.
		Hydrology/Hydraulics	Maintain catchment integrity, Preserve drainage pattern, Retain flood ameliorating areas (eg. wetlands).
		Air Quality	Reducing greenhouse emissions, Dust from construction site
		Noise and Vibration	Potential increase in noise in future, Acceptable level of noise on site.
		Ecology	Habitat protection, Reprovision of habitat, Maintain canopy connectivity, Minimize fragmentation of species populations (eg. habitat loss and isolation), Maintain under-storey habitat connectivity, Plant recovery, stored for later introduction to the site.
		Visual Impact	Visually prominent areas, Areas of natural and cultural significance, Contributing factors to scenic quality.

		Waste Management	Reducing and avoiding generation of wastes, Resource recovery (eg. reusing and recycling wastes), Conservation of highly valued resources, Site clean up, Waste disposal at approved disposal site.
		Vegetation Management	Vegetation protection and conservation, Preserve existing riparian vegetation at creek, Impact to significant flora species, Re-vegetation treatment and maintenance, Regeneration of native flora.
		Fauna Management	Impact to fauna populations & species, Impact on fish (eg. fish habitat, fish passage), Presence of forested habitat areas, wetlands and water bodies, Creation of fauna habitat, Fauna fencing and underpasses, Provide dispersal routes/wildlife corridors/crossing points, Provide compensatory habitat, Weed invasions, Connectivity of wildlife corridors, Connectivity of fauna corridors (eg. canopy bridge).
		Erosion Management and Sediment Control	Permanent control, Temporary control.
		Temporary Site Management	Site camps away from natural areas, Site camp hygiene and cleanliness, Energy consumption.
3.	**ECONOMIC**	**Direct Cost**	Life cycle cost (eg. Initial Cost, Capital cost, Operation cost, Maintenance cost)
		Indirect Cost	Resettling cost of people, Rehabilitating cost of ecosystem/ environmental cost, Adverse impact on tourism values.
		Revenues	User fees, Reserve funds, Private sector investment (eg. PPP).
4.	**SOCIAL & CULTURAL**	**Cultural Heritage**	Indigenous heritage, Shared and natural heritage, Artifacts/archaeological site, Documentary records and works of art.
		Public Access	Reduce commuter times, Distance from public access, Pedestrian/cycle/vehicle access, Suitability in ease of access, Provision of scenic routes, Provision of recreational facilities (eg. lookouts, picnic areas etc), Travel mode choice.
5.	**RESOURCE UTILIZATION & MANAGEMENT**	**Site Access**	Routes for construction traffic, Controlled site access to legitimated traffic, Vehicles wash down before & after leaving the site.
		Material Availability	Use of local materials, Availability of construction material.
		Type	Prefabricated material, Innovative material.
		Constructability	Early contractors' involvement
		Reusability	Re-cyclability of materials, Reusability of moulds and formworks etc.
		Quality Assurance	Ease of quality control
6.	**HEALTH & SAFETY**	**Occupational**	Short-term health (eg. spread of disease, cleanliness of site etc), Long-term health (eg. respiratory duct disease, permanent deafness etc), Accidents, injuries and fatalities etc., Management system (eg. policy, program etc), Construction working time.
		Public	Road safety, Hazardous goods.
7.	**PROJECT MANAGEMENT**	**Contract**	Type of contract, Inclusion of sustainability clauses, Project duration, Incentives for meeting sustainability performance, Penalties for non-compliant operations, Project Risk, Auditing.
		Procurement Method	Approach/criterion towards contractor, Choice of delivery system (eg. Alliance, design-build etc), Experience in environmentally sensitive works as prequalification requirement, Documented and implemented environmental due diligence system.
		Training and Education	Pre-start training courses as part of condition of contract,

			Training program for new, replacement and temporary staff.
8.	**RELATIONSHIP MANAGEMENT**	**Responsible Stakeholders**	Clients, Government Departments, Project Managers, Engineers, Designers, Town Planners, Contractors, Suppliers
		Impacted Stakeholders	Residents, Users, Owners, Local and Regional Community, Cultural Heritage.
		Interested Stakeholders	Social Institutions, Environmentalists, Researchers, Sociologists, Economists, Community Consultants, Media.
9.	**PUBLIC GOVERNANCE &COMMUNITY ENGAGEMENT**	**Public Governance**	Public viability & impact, Early community/public consultation, Social Impact Assessment, Open assessment, Appropriate links for communities, industry and other infrastructure amenities.
		Community Involvement	Local communities' involvement, Support existing social campaigns, Community awareness in environment, Community acceptance, Responsibility.
10.	**ENGINEERING**	**Performance**	Carrying capacity, Durability, Reliability, Resiliency, Robustness, Adaptability.

Ten sustainability priorities for roads infrastructure projects were identified. While four were the so-called traditional sustainability components (institutional, environment, economic, and social and cultural), six were road infrastructure project specific components (resource utilization and management, health and safety, project management, relationship management, public governance and community engagement, and engineering issues). To obtain measurable outcomes, each component was categorically broken into related indicators and sub-indicators. Each sub-indicator represents issue to be addressed in order to achieve sustainability deliverables in roads infrastructure projects.

The interviews have also yielded stakeholder responses towards the driving factors for them and their businesses to engage in sustainability issues in infrastructure (Table 3). It is interesting to note that contrary to previous belief that the construction sector are mainly 'forced' to accept responsibilities towards sustainability due to external pressure, there have been considerable elements of internal volition, which motivates the individuals and businesses to take on the challenge. How to use this improving self-esteem to uplift the general take-up rate on sustainability measures at all fronts will prove to be an interesting and important aspect of new research.

Table 3 Drivers and motivation of stakeholders towards infrastructure sustainability

SOURCE	CATEGORY	ELEMENTS
External Pressure	***Global pressure***	Concerns on climate change, global warming and other environment disasters; call by UN and world organizations
	Government requirements	Complying to government legislations, contract documents and project specifications
	Business survival	Sustainability is currently being seen as a new cutting-edge business commodity; Keeping up with latest market trends
Internal Volition	***Human survival***	Ensure long-term survival of human beings; Concepts of "the earth, our home" "our common humanity", and "our common future"
	Community expectation	Community as the major stakeholder; Used to high quality of infrastructure due to improved standard of living
	Individual volition	Proud be to good citizen; Education and training, and up-bringing has direct impact on individuals taking up sustainability initiatives voluntarily

Based on the initial list of sustainability indicators as presented above, a Delphi study is being conducted to further identify key sustainability indicators in terms of strengths, along with identifying the critical issues that impede on infrastructure sustainability initiatives and the possible relationships among them. The list of key sustainability indicators and critical issues identified through the Delphi study will reflect the consensual opinions of a group of highly experienced and regarded industry professionals and academic experts on both the theory and practice aspects of infrastructure sustainability in road projects. While not meant to be exhaustive, the list will serve as a basis for finding solutions for the critical issues identified in a defined context.

By integrating the different perceptions and priority needs of the stakeholders, identifying and applying key sustainability indicators and solutions for critical issues, a set of integrated decision-making guidelines for enhancing sustainable deliverables can be expected for the promotion and implementation of sustainability strategies in projects delivery processes.

5. Conclusion

Australia is currently experiencing unprecedented infrastructure demands especially on roads and highways construction to sustain its buoyant economy and general prosperity. The incorporation of sustainability principles in the infrastructure development is a crucial element to ensure economically feasible, socially viable and environmentally responsible project outcomes. Thorough understanding on different perceptions and priority needs of various stakeholders and ways of working with and integration these differences should be an imperative step leading to sustainability engagement for mutual benefits of stakeholders. It will also be vitally important, as proved in this research, to establish key sustainability indicators and identify critical issues that may guide sustainability initiatives through project delivery. The list of key sustainability indicators under ten sustainability priorities specific to roads infrastructure development will serve as a starting point for finding solutions of dealing with sustainability in this particular type of projects. A framework of integrated approaches to decision-making will be necessary for the practical implementation of sustainability strategies in road infrastructure projects.

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AMOUNT OF BODY ENERGY VERSUS EXTERNAL ENERGY – A DECISIVE RATIO FOR SUSTAINABLE STRUCTURES

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Keywords: mobility, settlement structures, human behavior, energy amount, body energy, attractiveness

Summary

Sustainable development may only be reached by taking into account the characteristics of human beings. In particular this implies to include - beside of the needs of humans - the abilities of perception and assessment by the human species.

One of the main problems lies in the human's self circumvention by orientation on current aspects of quality of life. Problems likely will return in the course of feedback loops.

A great part of the steering forces of humans are unconscious. We have to realize that we are genetically intended to measure e.g. distances (and time) by the use of our own body-energy. Humans spend a certain percentage of the average daily available body energy for mobility. Therefore time (stability of travel time budgets) is only an indicator for a cause lying behind this, namely the constancy of the expended body energy.

Both the perception of time and body energy as well as of causalities is subject of the sensory perception. According to Weber- Fechners law the resulted feeling goes down with every additional (stimulus) unit. In the traffic sphere the named law occurs in a negative overvaluation of longer activities using body energy eg. by exponential negative acceptance of long way distances or excessively increasing negative assessment of waiting times.

Since, we have no sensorium and experience for using external energy we loose any control if we try to substitute in most cases small reductions of body energy by use of non renewable energy. In principle, the diminution from body energy expenditure (as is striven for in car oriented structures with car parks in a short distance) is an immanent from the entropy´s derivable target in all living beings. The indicator "body energy" therefore is an essential indicator of the control of the settlement structure used as an indicator describing body energy amount assessing accessibility of means of transport in a comprehensive way.

1. Current state of discussion, introduction

The connections represented by Newman, Kenworthy 1989 between energy consumptions of different towns in proportion to the (settlement) densities in the continental comparison are essential to create a fundamental sensibility for the problems. However, the use of average densities is already problematic due to the different town structures. By the way span widths of about 1000 inhabitants per km^2 (e.g. Houston) and more than 9000 inhabitants per km^2 (e.g. New York) in American towns are given too.

In principle, such an intercontinental comparison in the current situation always leads to high correlation qualities (see Figure 1). The density parameters disguise however planningly essential influence factors of the various aspects of the accessibility. However accessibilities like access distances and with that transgressions of boundaries of means of transportation like riding a bike or mobility forms like to go afoot to count physical aspects, as well as also financial aspects of the accessibility like prices of petrol (in proportion to the spending power) or also accessibilities and acceptance of public transport (modal-split) or the fall apart of functions have to be considered.

It is largely undisputed that the „driving forces" of the increasing extension of spatial settlement structures development come from increasing speeds in the transport system. The use of external energy sources allows to overcome borders of specific means of transport using only body energy.

The bases of the constancy of travel time budgets (about 60-70 minutes of mobility time per day) are to be found in evolutionary mechanisms (ratio of the effort to obtain food in comparison to the benefit of body energy). Life time needs life energy. The human being must expend body energy constantly to get his existence and to keep the proportion of food supply and food consumption. By that humans spend a certain percentage of the average available body energy per day for the mobility. Therefore time (time constancy) is only an indicator for a cause lying behind this, namely the constant budget of expendable body energy.

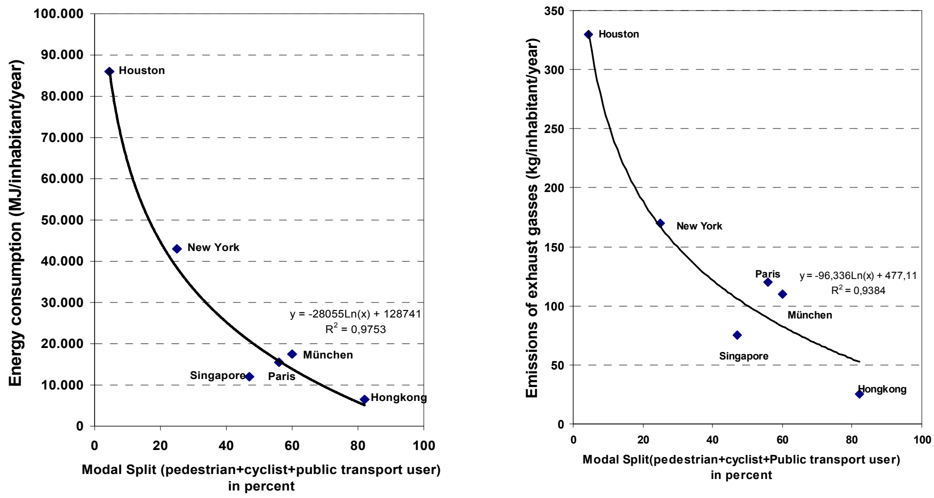


Figure 1: Comparison between parts of mobility based on body energy (pedestrian, cyclist, public transport user) and energy consumption respectively emission of exhaust gasses, source: World Statistic Yearbook

The figures show that a number of different essential traffic-orientated parameters actually show significant connections in the intercontinental comparison. These connections, however, can if needed be for example set the direction in the continental context or also in the municipal area.

There are considerable effects of settlement densities on access distances as well as on application boundaries however they do not offer feedback possibilities to the bases of the mobility.

2. Speed, travel time and structures

2.1 Correlations between speed and settlement structures

Settlement structures orientate themselves towards the dominating traffic system of the respective epoch. Older settlement structures (up to the 19th century) had to orientate themselves at biological borders (man, horse). Outer limits like town embankments arrived.

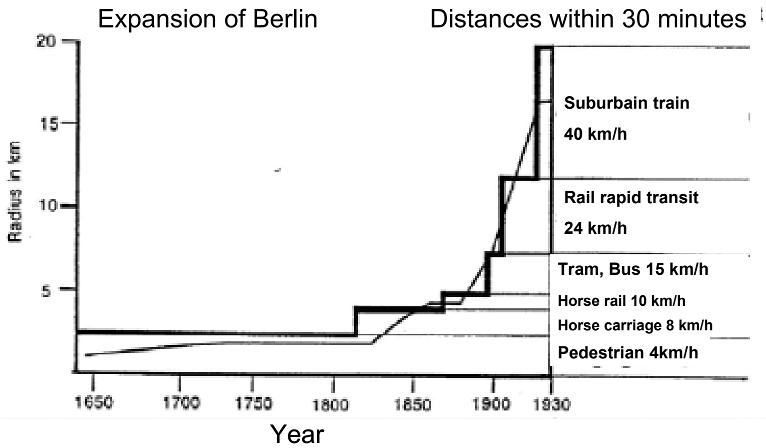


Figure 2: Settlement extension as a result of the dominating means of transportation of the respective epoch

The biological boundaries of human beings lie in average at about 60 to 70 minutes per day (mobility time budget as a constant). The limitation of the extension of the settlement structures known in the Anglo-American sphere under "Marchetti´s constant" can be derived directly from biological constants. Every rise of the speeds therefore runs by the supply of external energy (in comparison with the internal body energy) for an extension of the settlement structures automatically.

The connections between speed of transportation means and the extension of the settlement structure are already known and named in numerous works (see Knoflacher 1996, Macoun 2005 and others).

2.2 Times and distances

The cumulative frequencies (see Figure 3) show that way distances put back with body energy lie to about 80% within 2 kilometres. These mobility forms hold the settlement structures together. On the other hand, there are about 80% of the ways by means of car or public transport over 2 kilometres, about 20% even over about 20 kilometres.

While more than 70% of the ways covered by individual modes of mobility amount to less than 30 minutes, the users of public transport lose this opposite increasingly time, caused by considerable access distances to the stops of the public traffic partly.

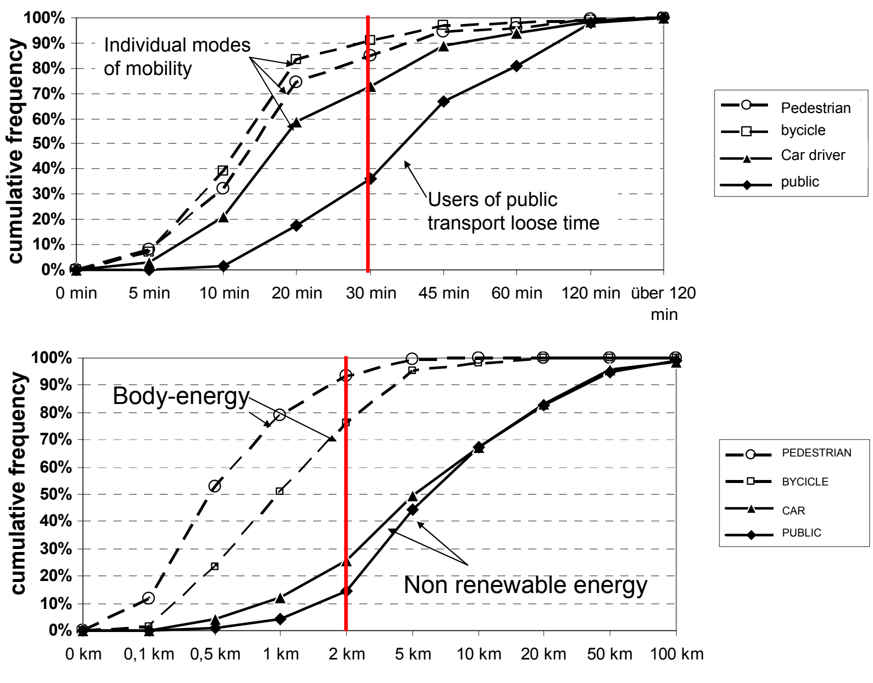


Figure 3: Cumulative frequencies of trips with different modes of transport in Austria, depending on trip length respectively travel time, source: Herry, Sammer 1996

3 System point of view versus individual perception

3.1 Body energy constancy and mobility time constancy

Based on the evaluation of empirical data on driving times provided by the UK´s National Travel Surveys Kölbl R., Helbing D., 2003 concluded in their study that the empirical data as given statistically rather assure a concept of constant daily journey energy (with energy in the mobility phase the body energy is meant here) than a concept of constant mobility time.

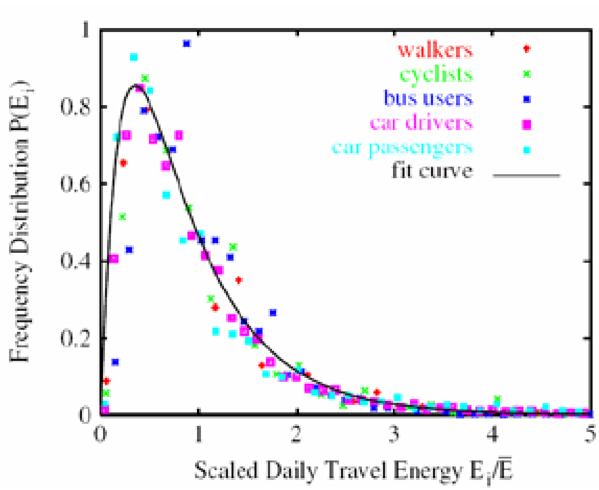


Figure 4: Scaled, time-averaged travel-time distributions for different modes of transport in linear representation, source: Kölbl R., Helbing D., 2003

Within the statistical variation (and rounding errors for small frequencies, which were magnified in a semilogarithmic plot) the mode-specific data could all be fitted by a universal curve, the travel-energy distribution. In contrast to utility functions of classical decision models which were typically based on preferences, this approach contains only physical variables such as journey times and energies, which are better measurable.

The far-reaching constancy of the body energy consumption in the daily mobility time budget is the result of an assessment mechanism of benefits for the energy to be expended in proportion to the effort.

3.2 Perception problem

The acceptance of the effort of body energy in the daily mobility phase is subject to a permanent assessment according to costs and benefits. The acceptance of footpath distances (and with that the effort of body energy) follows a negative exponential function which can be referred to laws of nature (entropy - main clause of the thermodynamics). Derived connections are known in biology as the “Weber-Fechner law”, in the economy as the “law of the diminishing marginal utility”.

The charging mechanisms of the assessment of the body energy consumptions are carried out on an unconscious cellular one to instincts level (Riedl 1981). It is fundamental to acknowledge that human beings are subject to difficulties at the perception of our environment. The individual intuitions are therefore different from the system view particularly (with respect to time, space and causalities)

Table 1: Comparison of system point of view with (objective und subjective) point of view of the individual represented for the problems of knowledge time, space and energy/causality (following Kantsche Apriori); source: Riedl 1981, Macoun 2000

	System point of view	Individual point of view	
		objective	**subjective**
Time	Constancy of time	(physical) Time	Assessment of time
Space	Depends on speed	Habitat	Space of experience
Energy (Causality)	Total energy amount (non renewable)	Body energy	Weighted body energy (e.g. Pulse, Stress)

Obviously the subjective individual perception of time advantages in the traffic and settlement system is compensated for by system effects. Streets for example built for the improvement in accessibilities and higher speeds are used for the attainment of remote (and cheaper) locations. Therefore putative time advantages are converted due to the mobility time constancy to larger distances. Obviously time advantages are weighted less compared with other influence factors and advantages (for example cost advantages).

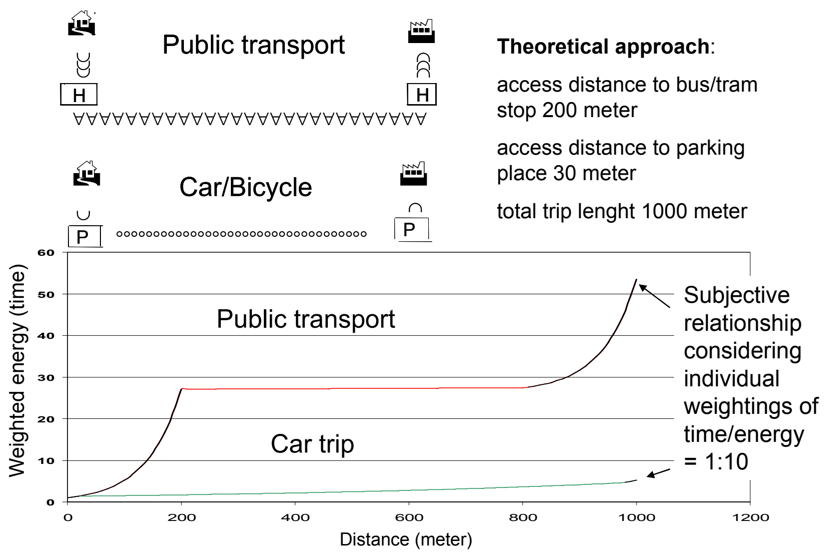


Figure 5: Schematic representation of the weighted (individual assessed) body energy consumption in case of journeys with public transport or with the passenger car. (door-to-door trip length of 1 kilometer, resistance function after Walther, 1997).

Time, body energy but also causalities as basically all sensory perceptions will be (Knoflacher 1996, Walter 1997) assessed in the transport sphere in accordance with Weber-Fechner´s law, this means that e.g. longer waiting times or footpath distances are judged excessively negative and show an acceptance falling exponentially in the consequence.

However, just like with every sensory perception, the Weber-Fechner law must be applied. The Weber-Fechner law attempts to describe the relationship between the physical magnitudes of stimuli and the perceived intensity of stimuli. Fundamentally the Weber-Fechner law as well as the acceptance of footpath distances or the acceptance of waiting times is finally based on the first main clause of the thermodynamic (entropy, Boltzmann equation)

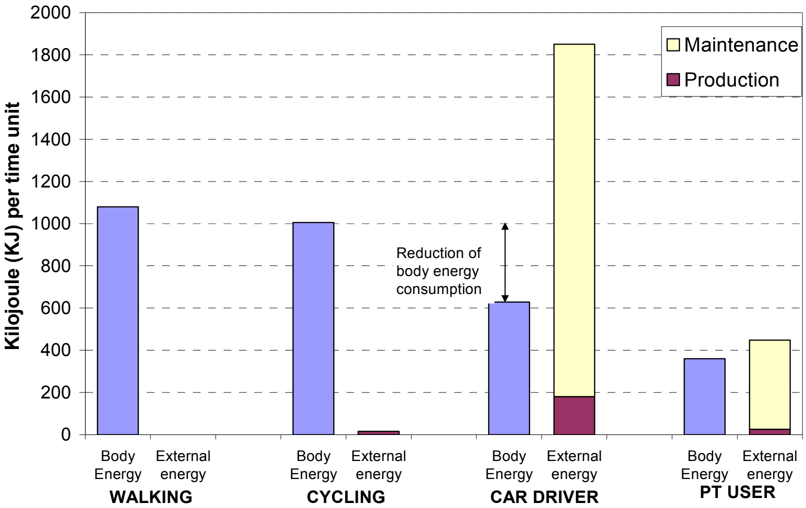
The assessment substantial of the time (advantages) and body energy consumption for the behaviour therefore show weightings (see a schematic representation Figure 5).

To this one the excessive weighting of the foot way distances shows the problems of differently access distances to means of transportation (e.g. bus stop 200 m, parking place 30 meters). The body expenditure of energy to reach the systems is therefore an essential term of the control of the traffic behavior. It is here major in the general comparison to achieve equal opportunities. We have to bear in mind that additional amounts of body energy also will be caused by bad weather conditions (cold, heat), information procurement necessities, waiting times and so on. All of these are calculable.

4. Body energy versus external energy

This obviously given assessment mechanism of the diminution and minimization of the body energy consumption immanent in human beings (something what is sensed as something to strive for and logically) led for the time being to a preferential treatment of private motorized transport means (with short distances to the vehicle) due to the charging mechanism to the saving of body energy and in the consequence to the road construction and due to the mobility time constancy for the extension of the settlement structures.

The minimization of the body energy by the use of external energy (over centuries by the use of the horse) at present is particularly reached by exceeding use of not lasting energy sources.



Walking (4 km/h), Cycling (10 km/h), Car (mean town/rural trip), Public transport (Sitting in means of transport, without Access)

Figure 6: Confrontation of energy charges for body energy and external energy in kJ at different mobility forms; Body stocking Energy: KJ/hour, External Energy: KJ/minute.

Body energy expenditures are highly dependent on the situation however they represent a function of the speed primarily. The usage of external energy overcomes natural biological (application-) limits and makes higher speeds possible. Figure 6 shows that rather small body energy savings (about 200 kJ/h) are substituted by consumptions of external energy of more than 100.000 kJ/h. (please note that Figure 6 displays external energy for production and maintenance in KJ/ minute).

A consistent putting into action of body energy saving approaches like in car oriented settlement parts or in an extreme form in some American and Australian towns leads apparently and inevitably to the preferential treatment of the car and by this to a car oriented settlement structure. As a consequence application boundaries of body energy oriented mobility forms are exceeded.

In the consequence due to larger access distances in disperse settlement structures public transport is not a traffic type identical in chance due to the body energy assessment at the access to the stop either.

5. Conclusion

In principle, the representation of the positive effects of higher densities makes sense for several reasons of e.g. needs to reduce the waste of space, ecological footprint and so on. Settlement structure planning however needs basic indicators to get orientation. Settlement density as an indicator conceals indicators like accessibilities, acceptance of public traffic, function mixture, inhabitant/ workplace conditions, falling apart of functions like shopping centres and localisation in the area. Older towns this one show also clear differences between settlement parts (see Macoun 2005).

However higher densities strengthen energy saving transport modes.

Future city and regional planning has to bear in mind that human beings are planning out of their specific demands, which seem to change with the dominating system of the respective epoch. Nevertheless there are constants which are lying in nature of human beings.

Indicators shall provide guidelines and make control options possible. Indicators of sustainability have to be system spanning and/or distance-to-target indicators (if target definition is possible) as an essential prerequisite. A reliable indicator of sustainability describing settlement structures also has to take into account the necessities of minimising energy (body energy and external energy).

The body energy of the transport system users is an essential indicator for the city and regional planning. Since body energy minimization is a target of all living beings (in comparison with the benefit) a minimization only then can be target of the settlement structure planning if the indicator is used system spanning for instance as a comparison of body energy consumption at the attainment of the different motorized transport means or in the complete way chain. The control will be carried out via the body energy requirement at the accesses to the transport systems (Car, PT).

The reaction of the settlement structures to the new mobility forms therefore follows the laws of nature, it seems therefore possible to carry out a future sustainable planning on a high extent based on physical (and biological) indicators claiming that the settlement structure planning takes into account these laws and principles.

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SUSTAINABLE INDUSTRIAL AND BUSINESS PARKS: DECISION MAKING METHOD FOR DIAGNOSIS AND PROJECT SPECIFICATION BRIEF

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Summary

Assessment methods, management guidelines or environmental charters for Industrial and Business Parks (IBP) have grown since the end of 1990's in response to their increasing development, including in a variable extent environment and sustainable development related concerns. Creation of IBP can bring several benefits to local authorities, notably with regard to economical and social issues. Existing tools have mainly contributed to design and running phases. Nevertheless, upstream phases concerning, for example, the adequate choice of the localization of IBP and the definition of project features, constitute key moments to achieve sustainability.

The OASIS method, (Outil d'Analyse et Système d'Indicateurs pour les Sites d'accueil) Analysis Tool and Indicators System for the hosting Sites of Industrial and Business Parks, presented in this paper, aims at facilitating integration of sustainable development principles from the earliest studies of an IBP project. By taking into account multiple themes, scales and actors, OASIS fosters the development of dialogue between project stakeholders. OASIS is a decision making tool intended for contracting authorities and park manager teams.

After explaining the national and international context of the OASIS development and the approach used, the sustainability criteria on which the method is based are presented. The paper focuses on the upstream phase of an IBP project by presenting the unit processes at the diagnosis phase, the rating system of the sustainability criteria and the form, content and benefits of OASIS outputs. Finally, first results of test of the method and prospects for evolution are discussed.

1. Stakes for Industrial Business Parks

The economic observatories noticed the multiplication of IBP development projects. Local authorities are interested into theses projects because of their:

- Economical impact through companies' settlements, and the economic dynamics which result.
- Social impact through jobs creation. These jobs rise living standards and promote the development of population,
- Financial impact through various tax incomes,
- Political impact by enhancing the status of the community on a regional or on a national scene.

Given these significant impacts, an IBP project must be a worthwhile investment, considered on the long term. It must be attractive to encourage settlements and provide a sustainable management system. It must be also healthy and respectful of its urban and natural environment.

To achieve this goal, our research group set up a decision making tool for working out project specification brief, design and monitoring of IBP project. At this stage of the research, the tool is meant to be used particularly in the French context and is operational at the diagnosis phase.

By 'project specification brief' we refer in this paper to a structured document which records contracting authority's objectives, needs and requirements about the features of the project in terms of functional, architectural, technical and notably of sustainability aspects, taking into account the specific urban, environmental, economical…context. The project specification brief represents the starting point of the design team work.

2. Context of the Work and Chosen Approach

2.1 French Context: Methods and Tools

Several methods and tools have been developed and tested today in France. We have particularly analysed and taken into account these methods because they deal with main relevant issues for the French context.

Different kinds of methods and tools are available for IBP contracting authorities with different objectives:

- Methods to set up environmental charters. These charters should be the result of debates and consensus. In the framework of our study we analyse the charter's models supplied by ARENE Ile-de-France1 and by PALME2 association.
- Methods to set up and implement management systems and to follow up sustainable development issues. They are often based on a framework (tables, indicators). They can provide situational awareness of the site. They help to define the project and its priorities. These include methods of Orée[3] and of APDD[4] associations.

These methods and tools aim at involving different stakeholders by consulting or inviting them to take part in various debates. Thus, charters in particular represent a consensus and a common commitment tool. The use of this tool is widespread in French IBP projects claiming environmental approach. Mobility, water, energy and waste management, as well as environmental quality of building, are the main issues of the charters.

The analysis of existing methods and tools has highlighted relevant and most common sustainable development issues. These issues are closer to the environmental concerns than sustainable ones. For example, environmental topics such as waste management are well taken into account. The IBP integration in the territory is a key element as well but relatively less common in methods and approaches.

Existing tools and methods seem not to take into account all the necessary issues to make decision, i.e. the choice of IBP site.

2.2 European and International Context: Experimentations and Approaches

Environmental quality and sustainability of Industrial and Business Parks is a relatively new concept at the international scale. Voluntary experimentations, initiatives and approaches aiming at minimising environmental impacts have been set up since the 90s in the United States, Asia and Europe. The United Nations Environment Programme (UNEP), Division of Technology, Industry, and Economics worked out and published at the end of the 90s guidelines[5] for environmental management focused on providing environmental services for companies, on encouraging companies' environmental initiatives, on monitoring environmental quality, on developing and implementing environmental action plans, etc. UNEP also carried out a survey on IBP projects in Canada, China, Thailand, Indonesia, India, UK and Denmark[6]. As far as Europe is concerned, a French consultant, e-parc, has benchmarked European environmental IBP located notably in North of Europe. Some European countries, such as Italy, have introduced environmental requirements for IBP in a national law entrusting to each Region the working out of detailed list and methods. Thus, many ecological IBP have risen putting into practice principles on mobility, water, waste, landscape, energy, noise, equipments and services. Environment Park in Torino is one of the most famous and broke the new ground. Despite of all of these interesting dynamics, there is no consensus at the international or European level how best to tackle IBP sustainability issues.

The analysis of these different surveys and initiatives shows that the concept of IBP's sustainability is tackled firstly from an environmental and from a management point of view. Social and economic issues are considered as goals or results of the environmental quality (i.e. providing an attractive field for companies, opening the way to specific funding) and are not directly involved in assessment or actions' implementation. Industrial ecology and environmental management such as ISO14001 or EMAS represent the most common ways to introduce environmental principles in IBP. The choice of activities to be hosted, the setting up of common services and of an authority to manage them seem to have priority over location choice, upstream environmental performances identification, and sustainable design. Nevertheless many environmental and socio economic (i.e. mobility, noise, landscape, energy supply…) impacts are influenced by location choice and can be minimized by a sustainable design of buildings and outdoor spaces.

Thus, we have decided to focus our method on upstream phase and on all sustainable issues and to support decision making on location and activities. In this sense, our method can supply a complementary approach to management during the running phase and to industrial ecology.

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[1] Public Agency of environment and new energies, for Paris area
[2] National association for environmental quality and sustainable development of IBP
[3] Association for the environmental management and sustainable development
[4] Association of best practices for sustainable development. Known today as the international centre of resources and innovation for the sustainable development
[5] http://www.uneptie.org/pc/ind-estates/guidelines/aboutTR39.htm
[6] http://www.uneptie.org/pc/ind-estates/casestudies/casestudies-index.htm

3. Description of the OASIS Features, Analysis Framework and Method

3.1 Presentation of OASIS main features

OASIS (*Outil d'Analyse et Système d'Indicateurs pour les Sites d'accueil*), Analysis Tool and Indicators System for the hosting Sites of Industrial and Business Parks, is a decision making tool targeted at the contracting authority team (at the upstream and design phases), carrying out a diagnosis of the IBP project regarding the constraints and opportunities of the site, and making recommendations in order to elaborate the project specification brief. OASIS integrates the three dimensions of sustainability – environmental, social and economic – in a transversal and operative way from the earliest feasibility studies. It is based on an analysis framework, structuring and detailing sustainability issues adapted to IBP.

Nowadays it supplies:

- The setting up of project first requirements
- A diagnosis for the creation of an IBP
- Recommendations for the project specification brief
- A management assistance

From the earliest stages OASIS allows to draw up a first general survey of the site and its exchange basin[7] characteristics regarding sustainable development. The OASIS method is implemented by an operator who can be a consultant, a member of the contracting authority team, etc. OASIS permits to establish a sustainability diagnosis specific to the considered project. Thus it reinforces or introduces questions about choices concerning location of the IBP or activities to be hosted.

OASIS provides clarity on the sustainable objectives to be integrated in the project and notably in the project specification brief. This method identifies sustainability potential (strengths and weaknesses) related to the considered site and/or to the considered project. Some themes are identified by the contracting authority team to take priority for the considered project. They are called "Priority Themes".

Once diagnosis is performed and expectations, stakes and performances are identified with regard to the sustainability themes (list of themes supplied by the method), the OASIS tool can be used to follow-up the integration of sustainability during the design phase (ex-ante assessment of the project).

OASIS is designed to foster dialogue between the different stakeholders regarding the choices for the location of the IBP, the contents and the sustainable requirements of the project.

3.2 A Criteria Tree Structure for the Analysis Framework

The OASIS analysis framework is made of a criteria tree structure containing the relevant sustainability items, in order to give a synthetic view of the hosting site and territory features. The tree structure includes Objectives, Themes, Analysis Elements, Basic Questions and Indicators.

The main issues to be studied when dealing with a sustainable project of Industrial and Business Park are represented by six Objectives, linked to one or more of the three dimensions of sustainability, as shown in table 1.

Table 1 The six Objectives of the framework

Objective	Sustainability dimension		
	Environment	Economy	Society
Quality of the local environment	✓		✓
Natural resources and heritage preservation	✓	✓	
Planet preservation	✓		
Integration of the park into the territory		✓	✓
Internal cohesion of the park		✓	✓
Actors' commitment for sustainability	✓	✓	✓

At the second level, the Themes specify the issues of concern included in each Objective. Then the Analysis Elements detail in a concrete way the different facets of each Theme.

The following table shows, under the six Objectives, all the Themes and Analysis Elements of the OASIS tree structure.

[7] The exchange basin describes all the territories which have a relationship with IBP (relation with the surroundings in terms of ecological or economical impacts, but also relation with further territories which have economical relationship such as other cities of the region).

Table 2 OASIS tree structure

Quality of the local environment	
Landscape and visual aspects	Natural and rural landscapes
	Urban landscapes
Acoustic comfort	Site sensitivity
	Activities - Traffic
Outdoor air quality and olfactory comfort	Local air quality
	Activities
	Traffic
Sewerage	Water collection network - Sewerage
	Pollution and rejected water quality
Waste	Collection
	Management and treatment
Electromagnetic fields	Fittings
	Electromagnetic field levels
Risks	Natural risks
	Rainwater infiltration – Permeability
	Technological risks
Hygiene and repair	Cleaning
	Citizenship
Security and safety	Thefts and offences
	Accidents on public road

Natural resources and heritage preservation	
Energy	Local resources
	Consumption (operation phase)
Water	Source – Feeding network
	Consumption and management
Land	Pollution
	Management
	Land value
Materials	Construction materials
	Recycling and valorisation
Natural and built heritage	Natural heritage
	Built heritage

Planet preservation	
Climate change	Greenhouse gases
Ozone layer	Ozone-depleting substances

Integration of the park into the territory	
Close equipment and services	Services to enterprises
	Services to users
Mobility, transport and telecom networks	Major transport axis
	Access to the zone
	Vehicle parking
	Telecom networks
Employment and territory economy	Employing territory
	Skill poles and major economy poles
Training, influence and dynamism	Training
	Influence and dynamism
Urban diversity	Usage distribution
	Urban sectors in recession
Population	Social features
	Project acceptability by population
Social integration through employment	Unemployment
	Social insertion through employment
Functional changes	(to be used at running phase)

Internal cohesion of the park	
Welcome and accompanying	(To be used at running phase)
Management and follow-up of the park	
Synergy inter-enterprises	

Actors' commitment for sustainability
Citizenship
Local authority's commitment
Developer's commitment
Enterprises' commitment

Basic Questions correspond to detailed questions enabling to go more deeply in the Analysis Elements. Two types of Basic Questions have been defined: "state" and "response" oriented ones. "State" questions relate to an existing situation, most of time local, whereas "response" ones deal with actions implemented by local public or private actors in order to improve a situation or reduce an impact. Example of a "response" question linked to "local energy resources" element: "Is the local authority leading a political strategy in order to diversify the energy sources by promoting local ones?"

Indicators are diversified. They may be quantitative (where possible) or qualitative. OASIS indicators system is composed by a mix of indicators found in scientific or technical literature and of other ones specifically developed for OASIS. They focus on the most important points of each Analysis Element. They form the concrete information on which the rating system will be based.

As OASIS wants to be flexible and adaptable, Basic Questions and Indicators, or possibly Analysis Elements can be added to reflect the specificities of the project and improve the relevance of the diagnosis.

3.3 OASIS Unit Processes for the Diagnosis Phase

Concerning the carrying out of the diagnosis, four unit processes can be distinguished. These processes are not steps which are clearly separated with a start and an end, but they are following each other and they are often overlapping each other.

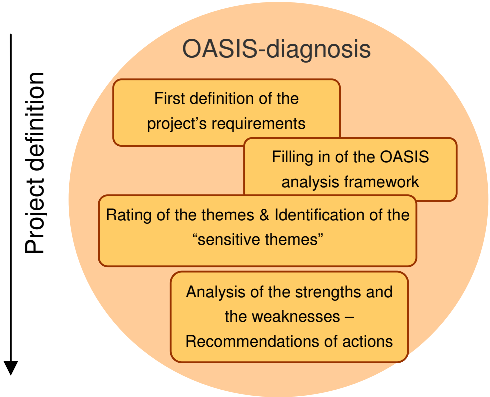


Figure 1 OASIS unit processes for diagnosis

The first unit process is the starting point of all the OASIS procedure. At this point the dialogue process with the contracting authority team starts. This process allows a strong involvement of the contracting authority team in the diagnosis. The first project's requirements and priority themes are identified here. The "Priority themes" require a special attention. Thus special warning thresholds are pointed out for the measure of the associated indicators (see below the OASIS rating system paragraph). The success of this unit process represents a key point and influences the following of the OASIS diagnosis.

The second unit process corresponds to the filling in of the OASIS analysis framework. In order to fill in the diagnosis, the OASIS operator answers to a string of questions and fill in indicators linked with each analysis element of each theme. This phase enables the operator to gather all the information connected with the hosting site and its exchange basin necessary for the diagnosis.

The third unit process consists in rating the themes which have been completed. In order to rate a theme each indicator is marked out by the OASIS operator. One interesting output of this unit process is the identification of the "sensitive themes" on which a particular attention must be paid.

The fourth and last unit process permits to analyse the gathered data in terms of strengths and weaknesses, and to make recommendations on the basis of the diagnosis. These recommendations will be integrated into the project specification brief.

3.4 OASIS Rating System

The OASIS rating system enables to rate indicators supplied by the analysis framework. As indicators express issues belonging to themes, rating indicators and gathering the results enable to assess the sustainable themes. The rating is made by the OASIS operator. The rating is given from the point of view lead by the trinomial: site (or exchange basin) / sustainability issues / project's requirements.

The assessment of themes highlights the strengths and the weaknesses of the site and of its exchange basin beside sustainability issues and project's requirements. Those rates serve as starting points for the identification of the sustainability potential, for the analysis and thus for the working out of recommendations for the project specification brief.

Indicators are rated by values included in the interval [-1; +1]. The negative limit (-1) corresponds to the maximum of weaknesses. Reciprocally the positive limit (+1) corresponds to the maximum of strengths.

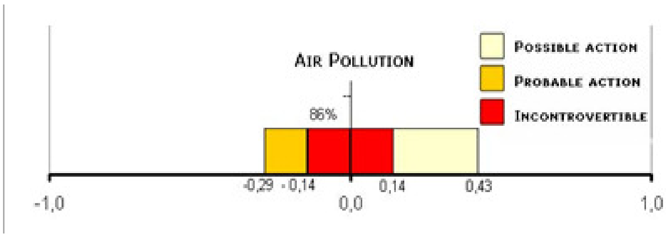
OASIS rating system enables the contracting authority team to point out the sensitive themes regarding sustainability and project's requirements. In order to point out the sensitive themes, two warning thresholds are defined for each theme: one high threshold for the strengths and one low threshold for the weaknesses. The exceeding of these warning thresholds should draw the attention and require a specific treatment. Thus these warning thresholds represent some interest filters. The exceeding of these thresholds for a theme makes declare it as sensitive beside sustainability (it can be a positive sensitivity or an unfavourable sensitivity). It is important to note that the warning thresholds are chosen and validated by the contracting authority team.

The values located between the low and the high warning thresholds describe a situation that doesn't have priority for the project.

OASIS rating system is based on the following principles:

- Total traceability of the data and the rates. It is possible for each theme to visualise all the rates of the indicators linked to the theme and to visualise the warning thresholds.
- No compensation of the weaknesses (negative note) by the strengths (positive note). The rates given for the weaknesses and the rates given for the strengths are counted separately in order that a weakness cannot be balanced by one or several strengths. Graphically, the right side of the rating segment shows the strengths while the left side shows the weaknesses (see figure 2 below).

- Differentiated visualisation of the common data (ordinary data which correspond neither to strength nor to a weakness) and of the remarkable data. Graphically a common data corresponds to a value located in the central interval.
- Visualisation of the non available data. The lack of data is a useful piece of information in order to assess the relevance of the results (relative uncertainty). The diagnosis is not frozen because of this lack of data but the reliability of the result is incomplete and needs to be pointed out. Graphically an indicator which is totally filled in will be represented by a segment with a thickness of 1. On the contrary an indicator which is only filled in at a rate of 70% will be represented by a segment with a thickness of 0.7.
- Opportunity to design and to visualize some useful families of data for the project (e.g.: scale at which actions should be performed, priority of action, reliability of the data)
- Opportunity to modify the warning thresholds of the themes (it corresponds to a change of the frame of reference so as to match to more demanding requests notably in order to take into account themes having priority for the project).



Visualisation of the available data: thickness: 0.86 (86%)

No compensation: a rating for the strengths and a rating for the weaknesses: 43% of strength and 29% of weaknesses

- **Visualization of the common data:** warning thresholds that define a limit between common values and the need of a specific action. The 2 sticks (negative and positive) are less than 0.5 (default value) and do not need special actions
- **Design of useful families:** In this example the family concerns priority of action (translated into colour categories)

Figure 2 Example of the rating system concerning the « Air Pollution » theme

3.5 OASIS Outputs

Once the indicators and the sustainability themes are assessed, these results are organised into summarized and operative forms in order to enable further use and to be communicated to the different project stakeholders, these requiring different levels of information. Thus, OASIS outputs are presented through Analysis Sheets (detailed information) and/or Profiles (synthetic information).

3.5.1. Analysis Sheets

As far as the Analysis Sheets are concerned, a template is provided to the user. They are organised according to the sustainability themes and contain three parts that sum up:

- The main results of the inventory (answers to the Basic Questions see § 3.1) and of the rating of indicators. This information is given for each analysis element belonging to the theme;
- The main results of the analysis with focus on strengths and weaknesses regarding to IBP location, choice of activities to be hosted, sustainability issues and project requirements;
- The recommendations for the project specification brief. This part, based on the analysis results, highlights the strengths to be enhanced and the weaknesses to be reduced. The need to carry out complementary and detailed surveys may be pointed out at this step. In this part, the OASIS operator may also warn the contracting authority on the appropriateness (possibly bad) of the chosen IBP location to implement the project (in terms of activities and of sustainability objectives). In order to address recommendations in an operative way and to make easier the link between the project specification brief and later the design phase, they are formulated according to physical objects (like roads, green spaces, building…) or organizational elements of the future IBP. A matrix connecting sustainability themes to a list of operational elements is supplied to the OASIS operator.

3.5.2. Sustainability Profiles

In order to give visual and synthetic view of the diagnosis results according to the work scale of each stakeholder, OASIS generates three profiles according to the three main scales of an IBP project, more explicitly:

1- Building and building surroundings – reflecting companies' concerns and duties,

2- IBP site – reflecting IBP developer's or manager's ones,

3- Territory – reflecting local government's ones.

The profiles are represented by diagrams showing the assessment of sustainability themes (according to the rating system). In order to be relevant for the setting of the project goals, each profile takes into account only indicators the actors of the project can influence. In this sense this kind of outputs represents effective means to point out responsibilities, to raise awareness and to organize actions improving project sustainability at different scales.

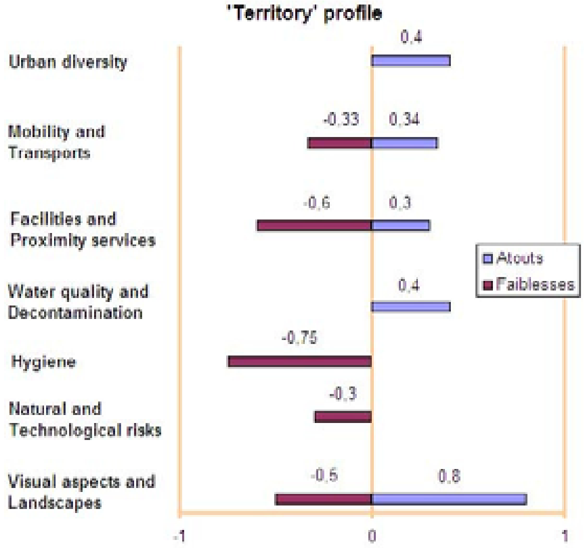


Figure 3 Example of "territory" profile showing strengths and weaknesses of each theme

A fourth profile focused on chosen activities may be useful for IBP development. This profile shows the assessment of sustainability themes according to a specific filter: the chosen (or to be chosen) activities to be hosted by the IBP. As the other three profiles described above, this profile does not visualize assessment of the whole indicators. Those taken into account here are the indicators that can be negatively or positively affected by chosen activities. Thus, this 'activities profile' allows validating choices and highlighting, from a sustainability point of view, need to change activities. In case of this change cannot be done, this profile helps pointing out specific requirements to be introduced in the project specification brief.

All these profiles represent a good communication tool on the basis of which dialogue among stakeholders can be set up.

4. First Results of the Grenoble Experimentation

A test of the method has been carried out on the site of a new IBP in Grenoble (France). The contracting authority has just started the project process and clearly announces the willing to build an exemplary IBP in terms of sustainability focusing notably on the Factor 4 concept.

This test perfectly showed the need of a tool allowing the starting and the first definition of clear project requirements. Used from the earliest stage of the project, OASIS has helped contracting authority specifying expected project features regarding sustainability and to better address his communication actions towards stakeholders. Compared to a standard environmental analysis, OASIS has taken into account a large panel of issues also related to economy and social aspects that made the contracting authority team think about "unusual" topics such as social insertion through employment. The sustainability profiles have been particularly appreciated by the contracting authority for their overall and comprehensive view on the site features.

Table 3 Strengths and weaknesses of the Grenoble site

Sustainability Objectives	*Strengths*	*Weaknesses*
Quality of the local environment	Landscape	Hygiene and repair
Natural resources and heritage preservation	Energy	
	Land	
	Natural heritage	
Integration of the park into the territory	Employment and territory economy	Close equipment and services
	Training, influence and dynamism	Access to the site
Actors' commitment for sustainability	Local authority's commitment	
	Enterprises' commitment	

5. Discussion

5.1 OASIS Benefits

Today OASIS is an operational method and gives an undoubtedly support to the contracting authority team in working out the project specifications brief (upstream phase). Complementary with more urban oriented analysis, OASIS provides an overall picture (because of the joint use of questions and indicators) but relatively exhaustive diagnosis on main sustainability issues concerning IBP. It is an undoubted help focused on two points. On the one hand OASIS allows defining the first project's requirements in agreement with the project stakeholders. On the other hand OASIS provides an analysis and some recommendations based on strengths and weaknesses of the site and of the project beside sustainability issues.

5.2 Prospects for OASIS Evolution

CSTB intends to continue to make OASIS more operational for practitioners, by developing a software tool and some guidelines.

In order to guarantee the creation of sustainable Industrial and Business Parks, the approach enhanced in the developed method must not stop at the diagnosis and definition of project specifications phases. It is necessary to help also the next phases of a project: the design and the running phases. The analysis framework will need to be adapted in order to address all the relevant topics, with adapted indicators, especially for the operation phase. This has to be studied from an assessment point of view, promoting a continuous improvement approach, and developed in close co-operation with practitioners.

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NEIGHBOURHOODS, LOCAL AUTHORITIES AND COMMUNITY DEVELOPMENT: OPPORTUNITIES FOR IMPROVED SUSTAINABILITY

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Summary

Over the last four years Beacon Pathway Ltd has been developing a Neighbourhood Sustainability Framework through which the sustainability of neighbourhoods can be assessed. In the development phase prototypes of the framework and tools have been tested. This has involved working with developers and local authorities. In doing so, opportunities to retrofit neighbourhoods for greater sustainability through active local partnerships have emerged. This paper reviews the way in which the prototype Neighbourhood Sustainability Framework and tools combined with some house level research into housing conditions opened up and assisted with opportunities for community development as well as improved environmental outcomes in a lower to middle income suburb in West Auckland at both the neighbourhood and house levels.

1. Introduction

Beacon Pathway Ltd (Beacon) is a research consortium that seeks to radically change the design, construction and renovation of New Zealand's homes and neighbourhoods. Beacon aims to bring about a significant improvement in the sustainability of the residential built environment in New Zealand through science-based New Zealand research.

To improve the sustainability of neighbourhoods both existing and new in New Zealand, Beacon has been developing a Neighbourhood Sustainability Framework which includes two tools to assess neighbourhoods and identify opportunities for improved sustainability. This reflects on the process, findings and outcomes of Beacon's participation in the West Harbour Project through which Waitakere City Council and Housing New Zealand Corporation are now actively considering options for the rejuvenation and retrofitting of West Harbour, an area in Waitakere City, part of the Auckland regional conurbation. Beacon's participation in the West Harbour Project has involved two key activities. Firstly, the application of the Neighbourhood Sustainability Framework and its prototype neighbourhood assessment tools. Secondly, an analysis of the condition of the housing stock to establish the nature and extent of house-based retrofit opportunities. These two components together highlighted, perhaps in a very unique way, the profound connections between dwelling sustainability and neighbourhood sustainability.

2. Beacon's Role in West Harbour

The West Harbour Neighbourhood Sustainability Project (now coined Tatou West Harbour) is part of the wider ***Massey Matters Project.*** Massey Matters was initiated by Council in 2006. This project has seen Waitakere City Council working alongside the local community and other partners to develop a programme for long term, community driven, sustainable neighbourhood renewal and development in the Massey area designed to deliver:

A Sustainable Urban Massey

- *Building community activity, networks, connectivity and sense of pride and identity.*
- *Improving current urban form and infrastructure (e.g. services, facilities, connectivity, natural environment)*

Four key principles continue to guide the development of Massey Matters:

- Working with the Massey community
- Sustainable suburban development
- Collaboration and partnership
- Concurrent planning and action.

The initial conversations between Beacon, Waitakere City Council and Housing New Zealand Corporation identified West Harbour as a site for neighbourhoods retrofit. There were opportunities for Beacon to test its Neighbourhood Sustainability Framework and to use that research as a key contributor to the development phase of Tatou West Harbour and a way of flagging local issues around sustainability and the identification of options to make the neighbourhood work better. The research has practically acted as a catalyst for ongoing discussion with local communities, Waitakere City Council and other stakeholders in the West Harbour area about the options and sequencing of retrofit work.

Beacon's involvement in the West Harbour Project was prompted by Beacon's recognition that its retrofitting packages at the house level and its Neighbourhood Sustainability Framework and associated tools must work for practitioners, investors and decision-makers. Beacon's role was to provide the Tatou West Harbour stakeholders with: robust assessment of the sustainability of a neighbourhood in West Harbour; robust data on the house condition of the West Harbour housing stock; and a set of neighbourhood retrofit options for further consideration designed to optimise the sustainability of the neighbourhood as a whole and the dwellings within it.

3. The Neighbourhood Sustainability Framework

Beacon Pathway Ltd. (Beacon) has developed a Neighbourhood Sustainability Framework (NSF) and prototype tools to assess New Zealand neighbourhoods. That framework is developed around six critical domains and a specified neighbourhood goal (Figure 1).

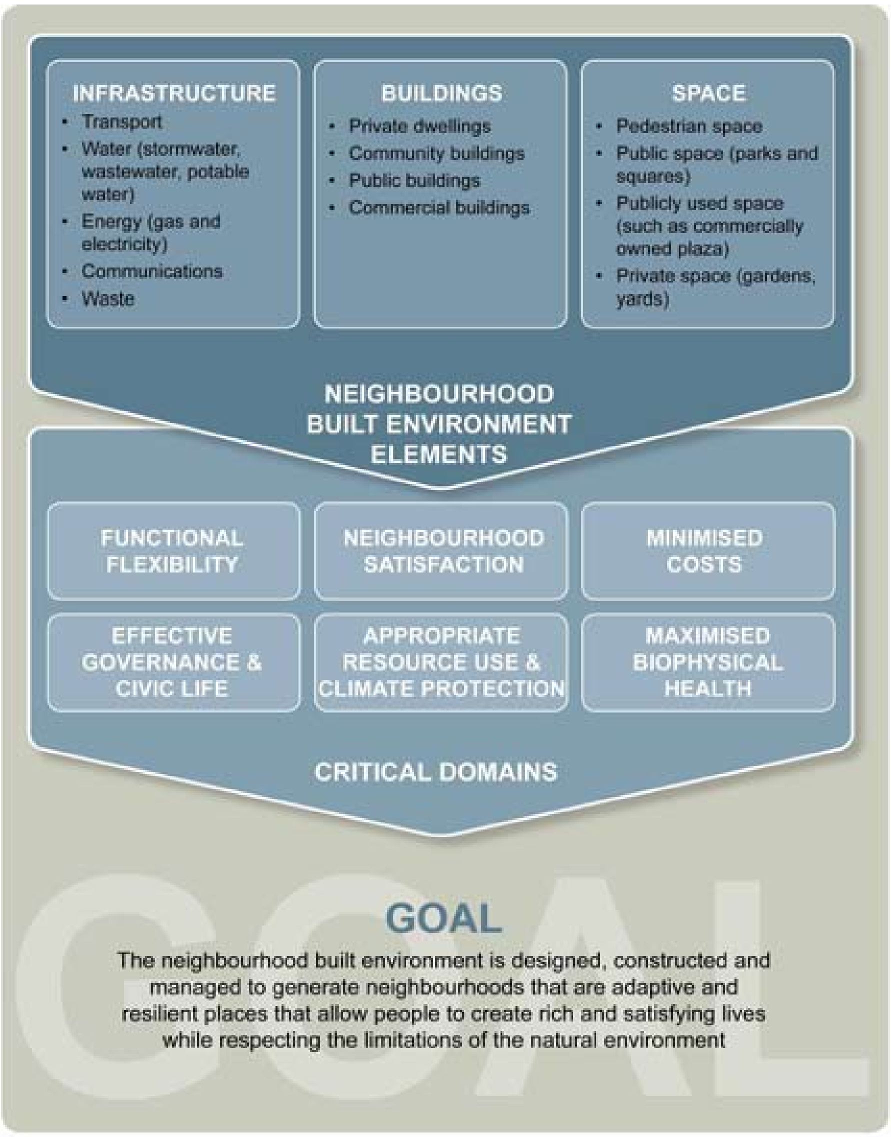

Figure 1: The Neighbourhood Sustainability Framework

The tools that support the Neighbourhood Sustainability Framework are the:

- Built Environment Observational Assessment Tool[1] which involves a structured, expert assessment of the built environment; and
- Resident Self-report Tool which involves collecting and analysing resident's behaviour and perception in relationship to the critical domains of the NSF.

The Observational Assessment Tool consists of a mixture of measurement and professional judgement structured through a set of well-defined requirements and guidelines. The Resident Self-report Tool is applied as a resident questionnaire that is delivered to householders. The results are reported as relative values to a baseline database of neighbourhood behaviours and perceptions. The aim of the tools is to pinpoint neighbourhood strength and weaknesses and assist in identifying the critical priorities for the management and retrofit of neighbourhoods.

Both tools are described in detail in the report *NH103a The Beacon Neighbourhood Tools* (Lietz et al, 2007). Broadly, however, they measure a series of critical sustainability issues that a substantial body of international research indicates affects, and is affected by, the built environment. Those are:

- *The use of motor vehicles, particularly private motor vehicles*. Greenhouse gas emissions, storm water pollution and air pollution are associated with vehicle emissions. Travelling time in motor vehicles has significant social and economic costs and presents the second highest direct costs to households. Those unable or unwilling to drive are at risk of social exclusion and marginalisation. Walking is associated with neighbourhood interaction and increased informal surveillance. Neighbourhood form impacts on both motor vehicle use and walking.

- *The provision and accessibility of quality and nature of public space*. Public space can generate interaction, provide local natural habitats. They also can be used to manage storm water. Well designed public space can increase walking and provide for creative and physical activities.

- *Neighbourhood built environments work when they are flexibility and adaptable*. Robust neighbourhoods stand the test of time. Key action pathways to ensure flexibility and adaptability include a mixture in building typology and dwelling size, mixed use, local facilities and the availability of public transport.

- *Higher density can reduce resource use and generate economies of scale*. Density intensification can reduce sprawl, reduce the amount of land that is taken out of natural ecosystems, generate population critical mass, affect travel and neighbourhood behaviours. Higher density therefore improves the viability of town centres and public transport and directly affects travel behaviour. Higher land prices inevitably encourage the market to reduce lot sizes. Intensification, whether through pricing or through regulation, is occurring in many neighbourhoods and presents challenges to current neighbourhood built environment design and the construction of the buildings in them.

Both the Observational Assessment Tool and the Resident Self-Report Tool are directed to measuring the extent to which neighbourhood plans and existing neighbourhoods respond positively to those challenges. Initially, a draft version of the United States Green Building Council's LEED-ND was tested as the observational assessment tool for the NSF. This was found to be unsuitable for New Zealand conditions, was very labour intensive, was directed at scoring designs rather than facilitating decision-making, was less useful in relation to existing neighbourhoods, and generated some quite contradictory outcomes. For instance, a number of existing New Zealand neighbourhoods on which the draft LEED-ND was applied had good surveillance although no had the features that would generate a good score in relation to surveillance. Consequently, an alternative Observational Assessment Tool was developed that measures:

- Access to basic every day facilities within walking distance
  - Schools
  - Reserves
  - Local shops
- Access to and adequacy of public transport within walking distance
- Quality of space
  - Streetscape, including but not limited to walkability
  - Public open space
- Efficient use of space and viability of local centres
  - Residential density
  - Previous use of the site
- Diversity
  - Mixed use

[1] Referred to as the 'Observational Assessment Tool'.

  - Public space
  - Housing Diversity (cost, size and typology)
- Protection and enhancement of the natural environment
  - Stormwater management
  - Protection and creation of habitat
  - Riparian, coastal and wetland management.

The Resident Self-Report Tool collects data related to:
- intention to move because of housing
- use of foot/bicycle/public transport for work/ study
- intention to move because of neighbourhood
- condition of house
- condition of garden
- perceptions of safety
- noise disturbance
- knowing neighbours
- perceptions of the neighbours
- identification with the neighbourhood and belonging
- car use
- composting
- provision for wildlife
- gardens and pools
- organic gardening
- participation in local groups
- use of public spaces
- dwelling energy efficiency
- dwelling water efficiency
- neighbourhood food expenditure.

Scores are currently banded as follows:
- Outstanding sustainability over 60 points
- High sustainability 46-60 points
- Medium sustainability 30-45 points
- Low sustainability under 30 points

For Tatou West Harbour, the Observational Assessment Tool was applied in the same manner as it has been for all previous case studies. The questionnaire used for the Resident Self-Report questionnaire, however, was accompanied by an additional set of questions to assist the Tatou West Harbour Project in collecting some additional data of interest without over-burdening residents with repeated social surveying. The questionnaire was distributed to the neighbourhood households through direct delivery. A 36 percent response rate was achieved. This is somewhat less than in previous case studies. The number of returns (149 responses), however, are adequate to drive the assessment calculator.

4. The House Condition Survey

The House Condition Survey undertaken in West Harbour involved surveying 100 houses to establish the physical condition of the dwellings in the area. The sample was stratified to ensure a selection of 75 privately owned houses (either in private rental or owner occupier) and 25 houses owned by Housing New Zealand Corporation. Houses were selected randomly and field surveyors were provided with a strict set of replacement rules and protocols to ensure that field surveyors did not undertake a biased sampling pattern. The surveying was undertaken using a slightly modified version of the BRANZ House Condition Survey which has been used for community-based condition surveying in low income communities. It provides data comparable to the data reported by BRANZ for the New Zealand House Condition Survey. Surveying was undertaken by Eco-Matters Environment Trust, a Waitakere-based organisation with considerable experience in dwelling energy and water retrofitting.

5. Results of the Neighbourhood Assessment

West Harbour achieved a medium sustainability rating using the Observational Assessment Tool, which can be seen as a positive result for a suburban neighbourhood, such as West Harbour. The Resident Self-report Tool however generated a low sustainability ranking. Table 1 puts West Harbour's results in context with the results from some of Beacon's earlier case study neighbourhoods. The different results generated by the two tools suggest that priority should be given to interventions that will improve resident experiences. Table 2 summarises the strengths and weaknesses of West Harbour.

Table 1: West Harbour Beacon Neighbourhood Assessment Results

Sustainability Rating	Observational Assessment	Resident Self-Report Assessment
	46-60	15 +
High	▪ Blake St – Ponsonby ▪ Petone	▪ Petone ▪ Blake St – Ponsonby
	30-45	10-14.9
Medium	▪ Aranui ▪ ***West Harbour*** ▪ Harbourview ▪ ChCh East Inner City	▪ Harbourview ▪ ChCh East Inner City
	<30	<10
Low	▪ Waimanu Bay ▪ Dannemora	▪ ***West Harbour*** ▪ Aranui

Table 2: West Harbour Key Strength and Weaknesses

Key Strengths	Key Weaknesses
• Good walking access to local services and facilities (shops, school, early childhood centres, community facilities and parks). • Food shopping is highly localised. • Good quality of space (parks and streetscape). • Good passive surveillance of streets and quite good surveillance of parks and walkways. • Protection of riparian area along the Manutewhau Stream. • Proximity to Westgate. • Affordable Housing. • Smaller homes available (2 bedroom). • Convenient bus stops and access to five bus routes.	• Serious concerns around safety when walking at night. • Noise considered to be a problem by many. • More than average number of people looking at moving because their house no longer suits them. • More than average people looking to move because of the neighbourhood. • Lower than average levels of neighbourhood interaction. • Low Public Transport usage. • No bus service after 7pm. • Low levels of walking and cycling. • Lack of stormwater treatment. • Disconnected street network.

6. Results of the House Condition Assessment

The results of the House Condition Survey can be summarised as follows:

- The condition of the West Harbour stock is slightly poorer than the national stock: The National stock, on average, is in the Very Good category while the West Harbour stock is, on average, in the Good category.
- Average costs of outstanding maintenance was 42 percent higher in the West Harbour stock than the cost of repair for stock nationally.
- West Harbour dwellings appear to be particularly vulnerable to issues associated with water damage, cold and damp. Indicators of those problems include:
  - 53.3 percent of West Harbour dwellings have Poor or Moderate ceiling insulation
  - 15.2 percent of West Harbour houses having mould to Serious or Poor levels compared to only 2.7 percent of dwellings in the BRANZ's 2005 New Zealand House Condition Survey.
  - 20 percent of West Harbour houses with rising damp compared to 8 percent of dwellings in the BRANZ's 2005 New Zealand House Condition Survey.
  - 7 percent of West Harbour houses with water ponding compared to 2 percent of dwellings in the BRANZ's 2005 New Zealand House Condition Survey.
  - 6 percent of West Harbour houses with timber decay compared to 1 percent of dwellings in the BRANZ's 2005 New Zealand House Condition Survey.
  - 4 percent of West Harbour houses with subsidence compared to 0 percent of dwellings in the BRANZ's 2005 New Zealand House Condition Survey.
  - 4 percent of West Harbour houses with cupped floor boards compared to 1 percent of dwellings in the BRANZ's 2005 New Zealand House Condition Survey.
  - 13 percent of West Harbour houses with fungi on the wall claddings compared to 6 percent of dwellings in the BRANZ's 2005 New Zealand House Condition Survey.
  - 3 percent of West Harbour houses with leaks at the joints of wall claddings compared to 1 percent of dwellings in the BRANZ's 2005 New Zealand House Condition Survey.

- 33 percent of West Harbour houses with moss growth on the roof cladding compared to 24 percent of dwellings in the BRANZ's 2005 New Zealand House Condition Survey.
- 11 percent of West Harbour houses with cracked roof tiles compared to 3 percent of dwellings in the BRANZ's 2005 New Zealand House Condition Survey.
- 7 percent of West Harbour houses with rust in gutters compared to 1 percent of dwellings in the BRANZ's 2005 New Zealand House Condition Survey.
- 15 percent of West Harbour houses with shower lining decay compared to 7 percent of dwellings in the BRANZ's 2005 New Zealand House Condition Survey.
- 8 percent of West Harbour houses with leaking kitchen outlets compared to 1 percent of dwellings in the BRANZ's 2005 New Zealand House Condition Survey.

7. Some Options for a West Harbour

Three key findings had emerged from the Neighbourhood Sustainability Framework application. Those were that:

- There were some critical built environment issues that inhibited neighbourhood satisfaction and interaction including:
  - concerns about safety associated with:
    - anxieties around walking at night
    - noise
    - dissatisfaction with and a desire to move because of the type of housing.
    - poor connectivity and some areas in which amenity values could be better optimised.
- The physical condition of the neighbourhood appeared to be affected by very wet ground conditions, with surface flows over footpath and properties in places.
- There was a strong foundation of attachment to the community with potential to promote this further through on-going improvement of the built environment and amenities.

The House Condition Survey found that the area did have a higher than average level of unmet house maintenance. It also found that many of the problems with houses appeared to be associated with higher than usual levels of damp. Those findings were consistent with and supported the findings of the Observational Assessment Tool and the Resident Self-Report Tool. That data and Waitakere City Council's and Housing New Zealand Corporation's own experience in West Harbour suggested that neighbourhood built environment projects should focus on providing opportunities for people to interact, on improving safety and on creating community pride and engagement. Community development and management initiatives were identified as an important investment in this neighbourhood. Built environment projects can be used catalyst for the community to come together around a practical and achievable initiative.

The findings emerging from the application of the Neighbourhood Sustainability Framework were the basis for the Beacon Neighbourhood Team's identification of retrofit priorities and options for West Harbour. Those findings alone were not sufficient to develop a set of retrofit options. The following data was also compiled to contextualise and inform the development of retrofit options:

- A summary of information about the houses in the neighbourhood contained in the Quotable Values New Zealand database held by Waitakere City Council;
- A summary of relevant 2006 census data for the closest matching mesh blocks;
- The locations of Housing New Zealand Corporation properties;
- Water use statistics from WCC; and,
- Observations from a night walking audit undertaken to pinpoint safety issues while walking at night.

Following discussions with the stakeholders the retrofit options set out in Table 3 were recommended for further investigation.

Table 3: Retrofit Options for West Harbour

Project	Contributes to
Intersection of Moire Rd and West Harbour Drive as a neighbourhood focal point This could include HNZC neighbourhood office, WCC community broker, etc. Could have affordable accommodation above. This could be the beginning of a community/commercial hub.	• Local focus point • Catalyst for other development • Neighbourhood management • Provision of local facilities
Raintank retrofit Retrofit houses with rain/detention tanks and connect overflows to stormwater system.	• Stormwater management • Water efficiency • Reducing dampness problems in homes and gardens. • More useable outside space for homeowners
Stormwater retrofit of roads Possibly concentrating on Moire Road	• Stormwater management • Quality of Space
Household sustainability retrofit Retrofit homes with • energy and water saving measures • replace unsafe/unhealthy heating • ventilation measures • Compost bins • Smoke alarms • Washing lines	• Energy efficiency • Water efficiency • Occupant health • Waste minimisation • Fire safety • Increased pride in individual houses and the neighbourhood
Reclaiming the road reserve Provide planting, seating, art, play opportunities.	• Community interaction • Sense of place
Lighting Improvements Improve street lighting by better maintenance, etc	• Safety while walking at night
Manutewhau Stream clean up Clean up stream and improve walkway	• Access to Moire Park • Recreation
Develop walkway from 19a West Harbour Drive to Manutewhau Stream Formalise this walkway	• Access to Moire Park • Recreation
Disused Reserve at 19a West Harbour Drive Develop into community managed neighbourhood reserve that could include a community building or hub	• Community engagement • Visibility of Tatou West Harbour • local community workers

8. Houses, Neighbourhoods and Pathways to Sustainability – Some Reflections

From Beacon's point of view, this project was designed to:

- Test the nature and limits of the contribution that the Neighbourhood Sustainability Framework and its tools could make to stakeholders concerned with the rejuvenation and retrofitting of neighbourhoods.
- Establish the extent of retrofit need at the house-level in an ordinary, 1970s, entry-level subdivision and options to address those needs.

The Neighbourhood Sustainability Framework has demonstrated its utility in planning and management of existing neighbourhoods to improve neighbourhood performance. In this, the Neighbourhood Sustainability Framework differs from other neighbourhood or community directed planning tools such as the LEED-neighbourhood tool promoted by the United States Green Building Council and the Greenprint developed by BRE (BRE Sustainable Communities Team). The latter has been developed to "assist design teams in delivering masterplans that maximise the potential for sustainable communities."

With regard to the latter, the House Condition Survey is a well-tested tool and it provided a strong indication of the major patterns of condition problems and repair/maintenance needs in the area. That data was critical to identifying the types of retrofit options that were most likely to generate the greatest performance benefit while minimising costs. Given that the two key stakeholders, Waitakere City Council and Housing New Zealand Corporation, are involved in existing energy retrofit programmes, this provided the ability to assess likely demand for and adequacy of programme coverage.

Perhaps more importantly, however, this project demonstrated an unexpected synergy between the results of applying the Neighbourhood Sustainability Framework's tools and the results of the House Condition Survey. Both indicated issues around housing. The Neighbourhood Observational Assessment indicated issues around storm water management. The Resident Self-Report Tool identified issues around a desire to move because of housing dissatisfaction. The House Condition Survey indicated house-level problems, particularly associated with damp and poor managed water in and around dwellings. The resolution of storm water issues at the neighbourhood level became indicated as both a pathway to improved neighbourhood performance and improved dwelling performance.

This connection between neighbourhood and housing sustainability has, in recent years in New Zealand, at least, has been largely forgotten. It is also largely absent from the discussion about the continuum of sustainability that reaches from individuals to households to neighbourhoods to settlements to regions and, eventually, to nations. The latter continuum is often conceived of as simply a matter of aggregation. That is, neighbourhoods, cities and regions are seen as not being sustainable if individuals are not, collectively, living sustainably. Similarly, there is acceptance that households can not act sustainably if the form of settlements and if city system infrastructure such as transport fail to support low-resource styles of living. This is a sort of 'nesting' conception of sustainability in which individuals are seen as needing to be 'nested' in sustainable houses, and sustainable houses 'nested' in sustainable neighbourhoods and so forth. This research, however, demonstrates the iterative impacts on house-level and neighbourhood sustainability of the quality of sub-divisions and the quality of the housing placed on those sub-divisions.

The results of applying the Neighbourhood Sustainability Framework also prompted some very real and practical responses. Waitakere City Council secured a Low Impact Design grant from the Auckland Regional Council to investigate retrofit options aimed at improvements in storm water quality. This work is currently being completed. It is hoped that this will result in some demonstration rain gardens to improve local storm water quality. . In addition, the concerns about neighbourhood safety prompted some immediate Council responses such as tree trimming, fixing broken street lighting and graffiti removal. Research results also continue to feed into ongoing discussions at street level and within Council, with the need for long term 'master' type plan for the area now acknowledged ***Tatou West Harbour*** is fast becoming a successful demonstration of community based action aimed at positive changes to make the West Harbour a better place to live for both current and future generations.

Community development practitioners that have been working in ***Massey Matters*** and in ***Tatou West Harbour*** see the NSF as having limited usefulness in the neighbourhood retrofit context unless it is integrated and applied within the context of community development processes. This is absolutely consistent with both international best practice and the NSF itself. The NSF is designed to assist practitioners. It is a tool to assist with planning, reflection and decision-making. It does not replace practitioners or processes. Just as 'green building' tools such as the LEED-ND in the United States or Beacon's NOW Home® or New Zealand's recently released Lifetime Design guidelines do not replace the designer or architect, nor does the NSF and its tools replace the myriad of practitioners that make neighbourhood rejuvenation and retrofit a pathway to liveability and sustainability. The NSF tools do not replace the processes of stakeholder and community engagement. The application of the NSF will not bring change nor the resources needed to generate change. What the NSF does do is identify a variety of built environment adjustment options. Indeed, in some circumstances, it can indicate whether the critical focus should be on built environment change or on community engagement. For instance, West Harbour, like Aranui, another of our case studies, shows a 'split' pattern in which the observational assessment of the built environment generated a higher sustainability score than the resident self-report. It is relatively early in the application of the NSF, so it the precise conditions that generate this split pattern are unclear. But it appears to emerge where residents feel somewhat marginalised. Community engagement is critical in those communities, even when, perhaps especially, when the focus of action is on the built environment.

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BEACON NOW HOMES® AND NOW HOME® RENOVATIONS: TRANSFORMING NEW ZEALAND'S HOUSING STOCK

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Summary

New Zealand's housing stock is well known for being cold, damp and resource inefficient. Beacon Pathway Limited aims to drive change in the New Zealand housing sector to see a significant improvement in the sustainability of our housing stock. In particular Beacon's focus is on "ordinary" homes and occupants – rather than the top 5% niche normally the subject of eco home and high sustainability aspiration.

In order to achieve this Beacon has developed two NOW Homes® and nine NOW Home® Renovations – houses built and renovated for an average budget for ordinary families which perform significantly better than the vast majority of New Zealand houses. These homes have been monitored in terms of their resource use, quality of the indoor environment and overall sustainability against key performance indicators and benchmarks set by Beacon. The homes have now demonstrated that development and retrofitting of these homes with current technology and for prices within the reach of ordinary households, significantly higher quality and healthier and more resource efficient housing is able to be developed. These results have been achieved without any specific training or behaviour modification of the occupants.

1. Introduction

The sustainability of the residential built environment is an important issue for New Zealand, as a significant proportion of the energy and water consumed (Statistics New Zealand, 2006) and waste produced (Kazor and Koppel, 2007) in the country occurs in people's homes. Similarly the health of the indoor environment within homes has a significant impact on the overall health of the community, particularly as relates to respiratory conditions.

Beacon Pathway is the vehicle chosen by a number of like-minded organisations that seek to radically change the design, construction and renovation of New Zealand's homes and neighbourhoods. Our goal is to significantly improve housing sustainability through scientific research, communication, information sharing, and advocacy, opinion forming and networking.

The Foundation for Research, Science and Technology matches funding from Beacon's shareholding partners, a unique mix of industry, local government and research organisations: Building Research, Scion, New Zealand Steel, Waitakere City Council and Fletcher Building.

Established in 2004, with a focus on new technology for new homes, it became quickly apparent the principal opportunity for Beacon to impact lies not with the 25,000 new homes we build each year, but in transforming our existing 1.6 million homes. A large proportion of these homes are poorly insulated, damp, and consume relatively high quantities of energy and water (Storey, Page, van Wyk, Collins and Kreil 2004).

As part of its applied research approach Beacon has built two resource efficient NOW Homes® in Waitakere and Rotorua and retrofitted nine "average" existing homes in Porirua in the Wellington Region These homes have been monitored against benchmarks that Beacon has set around what defines a High Standard of Sustainability™ for homes. The homes are all occupied by ordinary families with no special training in sustainability behaviour.

1.1 Beacon's High Standard of Sustainability™

In order to provide a framework for Beacon to measure the influence it is having on the sustainability of houses at a national level, and to provide a useful benchmark against which individual households can evaluate their home's performance, Beacon has developed benchmarks for a High Standard of Sustainability™ (HSS) in homes (Easton, 2006). These benchmarks have focused on five key aspects of dwelling sustainability:

- Energy Use
- Water Use
- Indoor Environment Quality
- Waste
- Materials

Underpinning these five technical aspects of dwelling sustainability are the issues of affordability and future flexibility. When considering the individual household benchmarks at which the HSS performance indicators should be set, affordability was a significant consideration (Easton, 2006). The benchmarks have therefore been set at levels where many of the features used to bring about their achievement are:

- low cost (eg simple measures such as fitting of draught stoppers and use of low-flow shower heads)
- have a payback period of less than the expected life of the product
- In the case of new development, can be undertaken at no or minimal extra cost (eg passive solar design).

The benchmarks developed represent a preliminary "line in the sand" for Beacon and are expected to be updated and refined over time, and as the research into the state of New Zealand's home performance continues. While detailed comparative work is still being undertaken, new homes built to achieve the Beacon HSS appear to be roughly comparable with a "good" rating (56-69 points) under the BRANZ Green Homes Scheme (New Zealand's only current sustainable home rating scheme), or a Level 4 compliance with the UK Code for Sustainable Homes. This compares with, for example, the average new New Zealand home, which would score around 10-15 points under the BRANZ Green Homes Scheme and not achieve a rating on the UK Code for Sustainable Homes. In other words while the Beacon HSS benchmarks are significantly higher than the minimum requirements of the NZ Building Code, but are set to be within what is a considered to be able to be a reasonable target for all new homes to achieve by 2012.

2. Beacon's NOW Homes®

Beacon has developed two NOW Homes® – in Waitakere and Rotorua. The Waitakere NOW Home® was completed in August 2005 and the Rotorua NOW Home® in September 2006. Both homes were designed and built to budgets and constraints typical of "ordinary" New Zealand housing rather than aimed at the top 5% of the market more typical of other "ecohomes". The Rotorua NOW Home® was developed in conjunction with Housing New Zealand Corporation and was designed and built for a budget at the affordable end of the market.

Passive solar design, resource efficiency, minimisation of hazardous materials and future flexibility were all key considerations in designing and building the homes. As a result less than 2.5 tonnes of construction waste was produced in each home's construction. This compares with a Tauranga study of construction waste produced in the development of new 3 bedroom homes that found that each home produced 6 tonnes of construction waste (Kazor and Keppel, 2007).

2.1 Waitakere NOW Home®

The Waitakere NOW Home® uses timber weatherboards, fixed to a timber frame on a heavily-insulated concrete slab. The roof is concrete tile, and the ceilings and walls are heavily insulated. The entire building is double glazed.

The building is sited to maximise the benefits of passive solar heating, using the highly insulated envelope to trap and retain the sun's warmth – mainly via the polished (no carpets) concrete slab. Passive ventilation is incorporated in the design to facilitate air changes without creating draughts – important for a healthy indoor environment.

A solar water heater is installed on the roof, and a water tank collects rainwater from the roof. The tank water is used for many non-potable water needs within the house. Where possible light fittings are high-efficiency compact fluorescent types.

The majority of the appliances belong to the tenants, however the range, fridge, dishwasher and washing machine are new efficient items supplied as chattels.

The Waitakere NOW Home® was been occupied over the period September 2005 – March 2008 by a family of four (two adults, two children). At the start of the tenancy the two children were of pre school age.

2.2 Performance of the Waitakere NOW Home®

Monitoring of the Waitakere NOW Home® includes the collection of end use information for both the electricity and water use. Temperature and humidity are measured in each room as well as CO_2 in the living room. The water temperatures, solar radiation and water flows for the solar water heater were also measured (French et al, 2006).

Post occupancy evaluation surveys were also undertaken to capture the occupants' experiences compared with the previous house they lived in, to gain an understanding of the occupants' behavior and influence on the house performance as well as the influence of the house on the occupants.

2.2.1 Energy use within the Waitakere NOW Home®

In its first year of occupancy the Waitakere NOW Home® used 7400 kwh/year of electricity, with supplementary heating required on only two days. When compared to the occupants' previous dwelling, this was 45% less electricity than they used in their previous home (French et al, 2006). Figure 2 compares the electricity use between the occupants' previous dwelling and the first year of occupancy of the Waitakere NOW Home®. While there is a substantial difference, it can be seen that the gap was gradually closing over time. This trend continued into the second year of occupancy – with the occupants using 8500 kwh/year. A matched pair analysis of the electricity use was undertaken against the HEEP dataset[1], this showed that in the second year of monitoring the home used 25% less energy than comparable households, a reduction from the 33% less energy than comparable households used in the matched pair analysis undertaken in the first year (Pollard, French, Heinrich, Jaques, and Zhao, 2008).

Analysis of the both the monitoring data and post occupancy survey information reveals that the main cause of this significant rebound effect has been in the form of additional hot water use (longer and more frequent showers) and additional appliances being introduced into the home.

In addition the electricity use was supplemented by the electricity load (850 kwh/year) of the principal income earner in the family setting up a home office in the house, a core component of which was a computer server.

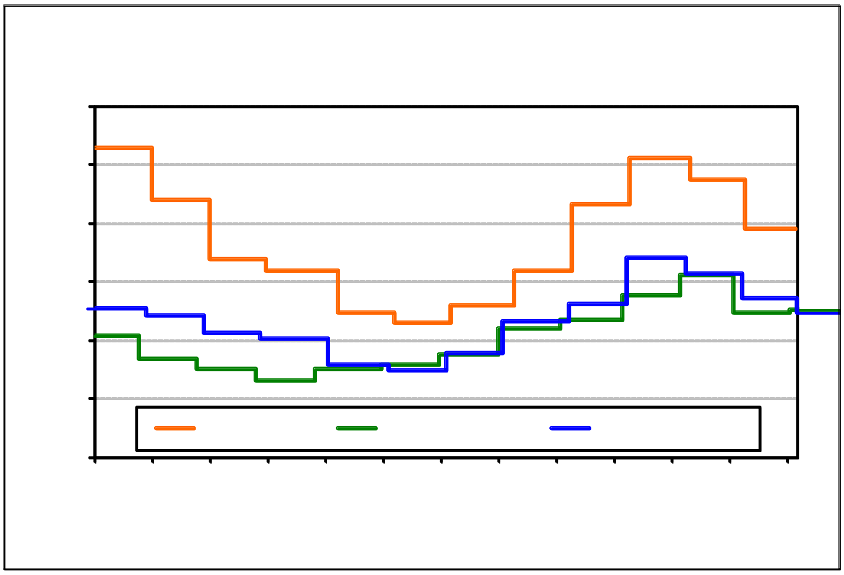

Figure 1 Comparison of electricity use by the occupants of the Waitakere NOW Home® compared to their previous home (after Pollard et al, 2008)

2.2.2 Water use within the Waitakere NOW Home®

Water use in the Waitakere NOW Home® was similar over the two years of occupancy, with a reduction in both total and reticulated water use in the second year (Pollard et al, 2008). Little good data exists on average water use in New Zealand (one of the reasons why NOW Home® data is significant), however comparisons with the surrounding households can be made due to the existence of metering. In their first year of occupancy the household used an average of 100 litres per person per day of reticulated water, with 189 litres per person per day of total water - the difference being supplied by the rainwater tank (French et al, 2006). In the second year of occupancy the household water use dropped to 85 litres per person per day of reticulated water and 172 litres per person per day of total water (Pollard et al, 2008).

[1] HEEP – Household Energy End Use Project – a BRANZ Limited project where the energy end uses of 400 households across New Zealand were monitored and analysed in detail.

2.2.3 Indoor Environment Quality within the Waitakere NOW Home®

Temperature and humidity data collected across the first year of occupancy identified that the temperatures within the home were maintained within healthy and comfortable parameters for the vast majority of the time occupied (Pollard et al, 2008). In terms of user behavior, a portable heater was only required to be used by the tenants twice during what was a colder than average winter. Humidity levels however in the home were sometimes higher than considered desirable, particularly in winter and in the main bedroom next to the ensuite (French et al, 2006). Installation of a mechanical venting system in both bathrooms occurred prior to the second winter of monitoring, as it was suspected that this was a contributing cause to the humidity problems.

2.2.4 Experience of the occupants of the Waitakere NOW Home®

Interviews with the tenants and post occupancy evaluation identified that they considered the Waitakere NOW Home® to be "their best home ever". When compared with previous dwellings the family had occupied, in particular they valued the following features of the home:

- comfort (thermal, fresh air, lighting, sound insulation),
- physical attributes (concrete floor),
- utility (spaciousness, interior layout and flow), and
- service provision (electricity bills and hot water heating, recycling, security[2], clothes line)

In terms of the features that were repeatedly discussed as being exemplary, the three that stood out were:

- the layout of the rooms and good use of space
- the thermal performance of the house, in terms of temperature stability and (almost) negating the necessity for winter-time space heating
- the concrete floor – in terms of its ability to keep clean.

The tenants thought that the overwhelmingly positive features of the house and its surroundings made a significant positive contribution to their inter-family relationships (Pollard et al, 2008).

2.3 Rotorua NOW Home®

The Rotorua NOW Home® has been built on the same principles of design and material selection as the Waitakere house, with the benefit of subsequently available knowledge, as well as meeting Housing New Zealand Corporation requirements for social housing. The house is owned by Housing New Zealand Corporation (HNZC), the main social housing provided in New Zealand, and forms part of their rental housing portfolio.

The Rotorua NOW Home® uses preprimed timber plywood and prepainted steel for cladding, fixed to a timber frame on a heavily-insulated concrete slab. The roof is prepainted steel, and the ceilings and walls are heavily insulated. The entire building is double glazed.

A solar water heater is installed on the roof, and a 5000 litre underground water tank collects rainwater from the roof. The tank water is used for toilet flushing and to supply the washing machine within the house. All light fittings are high-efficiency compact fluorescent types. Unlike the Waitakere Home, appliances were not supplied with the home, with the exception of the stove as HNZC policy is to not include whiteware.

Due to Rotorua's colder climate, the space heating requirement was four times that of the Waitakere NOW Home® and a low emission pellet burner was installed to provide supplementary heating.

The house was designed to provide for wheelchair access, and a second bathroom included was specifically designed for accessibility.

The home has been tenanted since September 2006 by ordinary HNZC tenants.

2.3.1 Preliminary Monitoring Results from the Rotorua NOW Home®

Monitoring results for the first year of occupancy have been analysed. Due to gaps in the data set because of issues with continuous data collection, the findings are considered to preliminary only. Analysis of the results (Jaques, Mathews and Pollard, 2007) indicates that reticulated energy use is lower than for the Waitakere NOW Home®, with 6800 kwh used in the first year of occupancy. In particular the proportion of energy used for appliances is significantly lower than that in the Waitakere NOW Home®.

[2] This rating is somewhat artificial, as their views were based on a private security firm checking the area at regular periods – which would not happen in more standard situations.

Despite the presence of a pellet burner as a heating source, temperatures in the home occasionally fall below the benchmarks set in the Beacon High Standard of Sustainability – and World Health Organisation recommended minimums. Investigations into the cause of this are still underway, but indications are that this is as a result of a combination of factors:

- The tenant has covered the concrete floor thermal mass with carpet, preventing it from functioning as intended
- Tenant operation of the pellet burner does not appear to optimize its performance
- Difficulty in heat circulation to the bedrooms

Total water use is 199 litres per day, however at this stage the reticulated water use is not known, as analysis is still being undertaken.

3. Beacon's NOW Home® Renovations

In order to research how to improve the sustainability of existing homes, over February to June 2007 nine homes in Papakowhai, Wellington have been retrofitted with different packages of interventions. The houses were selected to provide case studies of "ordinary homes" in a middle income suburb. Middle income households were chosen because an evaluation of existing retrofit programmes (McChesney and Amitrano, 2006) found that low income households were the major beneficiaries of current government and community sponsored retrofit programmes, and often where the householders suffer from respiratory health problems. While laudable programmes, the performance data collected from the retrofitted homes is not considered to be representative of the wider performance of New Zealand's housing stock as the homes are generally chronically under heated. In addition, research has found (McChesney and Amitrano, 2006) that because of the very low level of energy retrofits undertaken as part of the programmes, temperatures in the homes remain well below World Health Organisation suggested standards (and the Beacon HSS benchmarks) and, unsurprisingly, significant rebound effect occurs in any energy savings.

Accordingly, the project is testing a range of retrofit options aimed at determining what are the best (lowest cost, easiest to implement and most effective) packages of retrofit options which will substantially improve the resource use of a home and improve the indoor environment to meet Beacon HSS benchmarks. These retrofit packages address a number of core components which Beacon considers need to be included in a retrofit which will substantially improve the sustainability of a home. Different combinations of the following key features have been included in the packages:

- Significant increases in insulation (ceiling, underfloor and walls)
- Double glazing
- Solar hot water systems
- Fixed heat sources (heat pump, pellet burner and low emission wood burner)
- Water efficiency measures such as low flow fittings
- Mechanical ventilation of kitchen (rangehoods) and venting of driers
- Showerdomes (a device fitted over the top of the shower to prevent steam creation or release of moisture to air)
- Compost or worm bin
- Basic energy efficiency measures (draught stopping, compact fluorescent lightbulbs etc)

The pre-retrofit energy and water use, temperature and humidity of the homes was been monitored by BRANZ Ltd, and a pre-retrofit waste audit was also undertaken. While the post retrofit monitoring will continue to the end of winter 2008, some preliminary analysis of the pre-retrofit monitoring data has been undertaken. This analysis indicates that winter time temperatures in all but one of the homes were below desired benchmark levels of 16°C in bedrooms and 18°C in living spaces. Average winter air temperatures in the living room ranged from 16.1°C to 22.2°C during the evening and 11.6°C to 16.7°C during the night in the main bedroom (Buckett, French, Zhao, Burgess and Hancock, 2007).

Detailed analysis of the pre-retrofit energy and water use has not yet been undertaken, but preliminary analysis indicates a wide range of energy use patterns influenced by a range of factors. The highest energy use occurred in a home with all electric heating, cooking and hot water (Buckett et al, 2007).

4.0 Discussion

The findings NOW Home® and NOW Home® Renovation projects to date raise a number of interesting discussion points about the interaction between homes and their occupants, and the effect on occupant behavior of living in a more resource efficient home than their previous experiences. Further research is being undertaken to better understand this interaction, but there are some key points which arise from the data to date.

4.1 Rebound Effects in the Waitakere NOW Home®

The Waitakere NOW Home® was occupied by an "average" income household, who, by comparison with the HEEP matched pairs for energy use and surrounding households for water use (French et al, 2006) were relatively high resource users. In the first year of occupancy, the energy and water use of the household appeared to be substantially mitigated by the features of the Waitakere NOW Home®. This was experienced by the occupants in the form of reduced energy and water bills, with substantial financial savings. Towards the end of the first year, and into the second year, substantial rebound effects occurred (Pollard et al, 2008). This was largely in the form of increased hot water and appliance use, with new appliances introduced into the dwelling. In addition occupancy of the dwelling, in the form of its use as a home office appeared to increase over time – perhaps in response to the level of comfort provided by the dwelling. While not all of the resource efficiency gains have been taken back by the occupants (which still remains, compared to their previous home, 25% more energy efficient), there has been a substantial increase in energy use in particular. The increase in water use through showering has been more than mitigated by a decrease in outdoor garden water use – perhaps reflecting the initial garden establishment process being complete.

Informal discussions with the occupants of the home indicated that they were surprised when their power bills began to increase, and when combined with rising electricity costs, in the second winter became comparable with those from their previous home. It may be that there is a threshold above which the occupants would not increase their resource usage because of affordability limits and that this, combined with the amount of physical space in the home to accommodate more appliances, may result in a tailing off of the rebound effect in subsequent years.

While monitoring data for the second year of occupancy of the Rotorua NOW Home® is not yet available, it will be interesting to compare what, if any, rebound effect occurs for this low income household with little discretionary income. Already appliance use (and therefore electricity) costs, is substantially lower than in the Waitakere NOW Home®, and overall electricity use is lower. It may be that, given the fixed income of the household, that takeback in the form of increased use of the pellet burner to gain additional comfort, ahead of appliance use, may occur. In this respect a carbon neutral heating appliance such as a pellet burner (which burns pellets made from wood waste generated in the plantation timber industry) is an ideal heating source for a low income household. Pellets are purchased in bags and the household is able to manage their heating costs on a weekly basis though how many bags they purchase.

4.2 Passive Solar Design and Thermal Mass in the Rotorua NOW Home®

The response of the Rotorua NOW Home® occupant to the concrete thermal mass floor in the home was unexpected, given that the Waitakere NOW Home® occupants valued this feature very highly. In the case of the Rotorua NOW Home®, the occupants quickly covered the floor with several rugs, adversely affecting its function. This is likely to be a contributor to colder than ideal temperatures being experienced in the home, as the thermal mass function was included in the design phase modeling the expected thermal performance of the home.

The reasons why the floor has been covered raise issues which need to be addressed if this approach is used more widely in this type of housing.

The occupants moved into the home immediately on it's completion in September 2006 – which in Rotorua is still cold and a core part of the heating season. The concrete slab had had little time to dry out, a process which could be expected to occur over the next year or so. To the new occupants it felt cold and they complained of this. In addition, one of the occupants was an elderly lady in her 90s, and the occupants expressed concern that a fall onto the floor may result in her suffering significant harm, or even broken bones. Whether or not such an occurrence is likely was immaterial to the occupants, as the perception issues drove their behavior.

Tenancy agreements do not generally include requirements around use of temporary floor coverings. If thermal mass is to be used in social housing, then it may be that other methods of incorporating high thermal mass, where occupant operation would have less influence may be preferable.

5.0 Conclusions

When considering how to move New Zealand homes towards a higher degree of sustainability, engagement of dwelling owners is a primary consideration. While the NOW Home® projects are showing the ability of features within a home to substantially mitigate against high resource using behaviours, these can easily be taken back by occupants in the form of increased services (eg hot water, heating) or through the addition of appliances.

A fundamental difference between more sustainable, and conventional housing however, is the ability of the home to be operated in an efficient and comfortable manner. Much conventional housing has no ability to be operated efficiently, without significant impacts on the comfort and health of the home. Homes such as the Beacon NOW Homes® are able to be operated with relatively low resource use, while still maintaining healthy and comfortable conditions inside.

The vast majority of homes which will be in use over the next 50 years have already been built (Amitrano, Kirk and Page 2006). Yet, the BRANZ House Condition Survey indicates that New Zealanders already under-maintain their homes (Clark et al 2005). When renovation data is considered, it is clear that much of the renovation undertaken is cosmetic in nature (Amitrano et al, 2006) and does not address the sustainability of New Zealanders' homes.

New Zealander's homes are the single largest investment that many people will make in their lifetime. They are also the place where many people spend most of their time. Yet when compared to a motor car, existing New Zealand homes have very few regulatory requirements placed upon them. A car requires a six monthly warrant of fitness and an annual registration, yet once they have achieved Code Compliance our homes do not require any kind of check, even at change of ownership or tenancy, to determine whether they are healthy, efficient or suitable for the household type who is proposing to live in them.

The Beacon NOW Home® and NOW Home® Renovation Projects aim to provide robust evidence around ways to improve the sustainability of New Zealand homes. While primarily research projects, there has been strong interest in the demonstration value of the homes – how ordinary New Zealanders can live ordinary lives but with a lesser impact on the environment, and in greater health and comfort than is currently the norm.

Acknowledgements

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ENERGY EFFICIENCY IN COMMERCIAL BUILDINGS EXPERIENCES AND RESULTS FROM THE GERMAN FUNDING PROGRAM ENERGY OPTIMIZED BUILDING, ENOB

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Summary

In order to gain access to the energy use in office buildings, the German Federal Ministry for Economy launched an intensive research and demonstration program in 1995. In advance of the 2002 EU EBPD (Energy Performance Directive) a limited Primary Energy Coefficient of 100 kWh/m² a has been postulated as a goal for the complete building services technology (HVAC + lighting) for all demonstration buildings to be supported. Another specification was to avoid active cooling measures within main parts of the buildings. Techniques like natural or mechanical night ventilation or heat removal by slab cooling with vertical ground poles were applied as well as earth-to-air heat exchangers in the ventilation system. An accompanying research was established to keep track of the results and lessons learned from 24 demonstration buildings realized and monitored until end of 2008.

As one outcome this paper summarizes the energy performance of a selection of characteristic buildings together with an overview on the summer thermal comfort situations achieved. This work will proceed during the next five years. Another result is that a higher quality of energy and comfort building performance will not necessarily cause extra building cost when the project has been planned carefully by an integrated design process. Future results and building data can be downloaded from: www.enob.info.

1. Introduction and Background

1.1 Energy Use in Office Buildings

Numerous office buildings of the eighties were designed to isolate the internal conditions from the outdoor climate as completely as possible, at the cost of high energy consumption. Thermal and visual comfort as well as the air quality is guaranteed by extensive technical building services for heating, ventilation, air-conditioning and lighting (HVACL). High investment and operating costs are accepted to ensure that it can control even extreme indoor conditions caused by generously or even totally glazed building envelopes. In combination with the space demand of wiring for communications technology - double floors, suspended ceilings - it is quite common to occupy 20 to 30 % of the building volume for technical services solely. The main share of the electricity consumption is due to the HVACL facilities and not to the office equipment.

Despite the heat generation associated with electricity consumption within the building (internal heat gains), the space heating demand in Mid and North European Climates is still dominating the overall energy figure due to the high proportion of glazing and the high air exchange rates. Fig. 1a gives a qualitative impression of a typical energy consumption profile as a function of the outdoor temperature, the so called ET- diagram. In addition to a base energy load which is independent of the weather, there is a contribution for heating and humidifying below the balance temperature, and for cooling and dehumidifying above it. The balance temperature is defined by the outdoor temperature at which thermal losses are balanced by the internal and solar gains. The base load is mainly caused by office equipment and the idling consumption of building services technology. The waste heat associated with the base load affects the position of the balance temperature. The higher the base load, the lower is the balance temperature. Due to the decoupling of the room air from the building mass - suspended ceilings, double floors, lightweight walls - and the maintenance of constant indoor conditions throughout the whole year, there are hardly any days when there is neither active heating nor cooling demand.

1.2 Thermal Comfort and Health

The diverse technical approaches to achieve a good indoor climate were often accompanied by complaints from office workers about many types of discomfort and dissatisfaction, which are summarised as the "Sick Building Syndrome". One German investigation of this phenomenon, the so-called "ProClima-Project" (Bischoff, 2003), reaches the conclusion that although buildings with air conditioning maintain an objectively good indoor climate, they are subjectively rated lower than naturally ventilated working conditions by the majority of persons questioned. The rating is significantly affected by

- the magnitude which an individual person can determine the prevailing conditions at his workplace and

- the degree of maintenance of the technical service systems

Today an increasing fraction of office buildings are being constructed or retrofitted which allow individuals to control their own indoor climate to a large extent, and which replace almost complete isolation from the weather outdoors by moderate interaction. Daylit workplaces and the option for natural ventilation are typical characteristics. However, a combination of integrated measures to achieve so-called "passive cooling" is a pre-requisite if summer comfort is to be ensured without actively cooling or dehumidifying the inlet air. This type of concept became known as "lean building", due to the smaller volume of the service equipment required. The task is to design buildings in such a way that even if outdoor weather conditions vary greatly, the indoor conditions remain within a well-defined comfort zone, which fit the occupant's needs, Fig. 1b. The comfort zone is exceeded only for periods of extreme outdoor temperatures. The maximum acceptable number of working hours with temperatures above the comfort zone has to be discussed based on simulation results in the early design phase of a building and checked against legal standards.

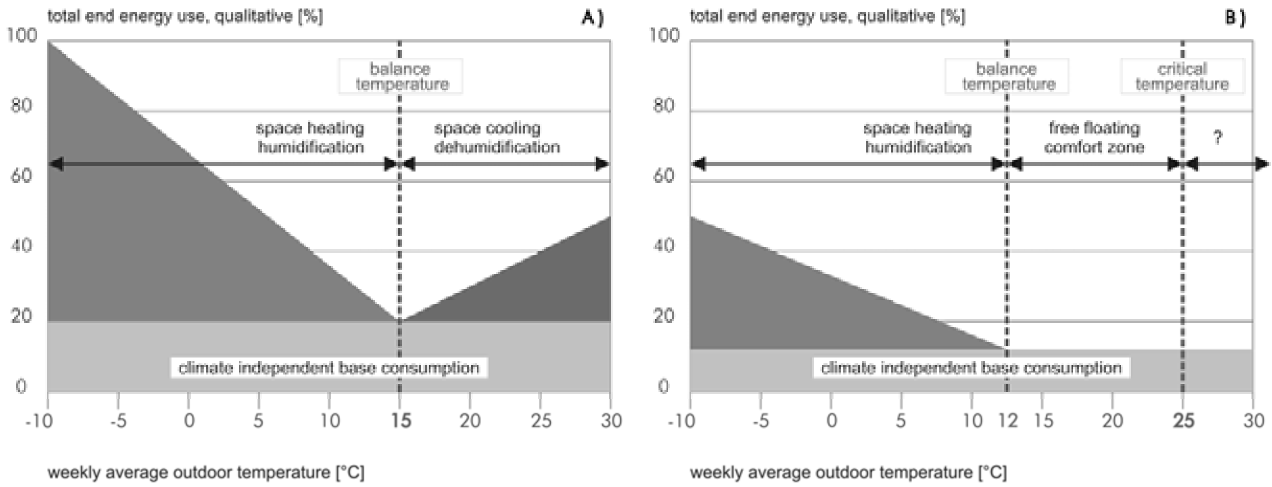


Figure 1 Qualitative profile of the energy consumption of a "conventional building" (A) compared to a "lean building" (B), the so-called ET-diagram.

2. Results and Experiences

2.1 Energy Monitoring

Table 2 gives an overview of the monitored projects and the applied passive cooling concepts. Detailed information together with a comprehensive overview on results and experiences are presented in (Voss et al., 2005). Additional information is available via internet (www.enob.info).

Data are presented for end and primary energy use respectively, taking into account the energy conversion factors for the specific conditions of Germany as given with a national standard (DIN 4701-10, 2001). Using the primary energy factor concept allows the comparison of the building's energy consumption and to rate the energy supply in terms CO_2 emissions.

Figure 2 summarises the monitoring results from buildings for which data from at least one year is available. We have chosen to present the information as a graph rather than numerically, as the boundary from HVACL to user-specific electricity consumption (PC, printers etc.) was difficult to define in some cases. This could cause quantitative but not qualitative changes to the results. Particularly for separating the electricity use for the type of energy service (e.g. electricity for lighting and for computer operation) requires a very detailed and expensive metering concept. It is not common to allocate the electric circuits within a building according to the equipment connected to them. In many cases, detailed analysis of the electricity consumption helped to identify weaknesses in system operation and aid their correction.

In order to separate the effects of reduced energy use and energy efficient energy supply, in case of CHP and photovoltaic to the primary energy balance were shown separately.

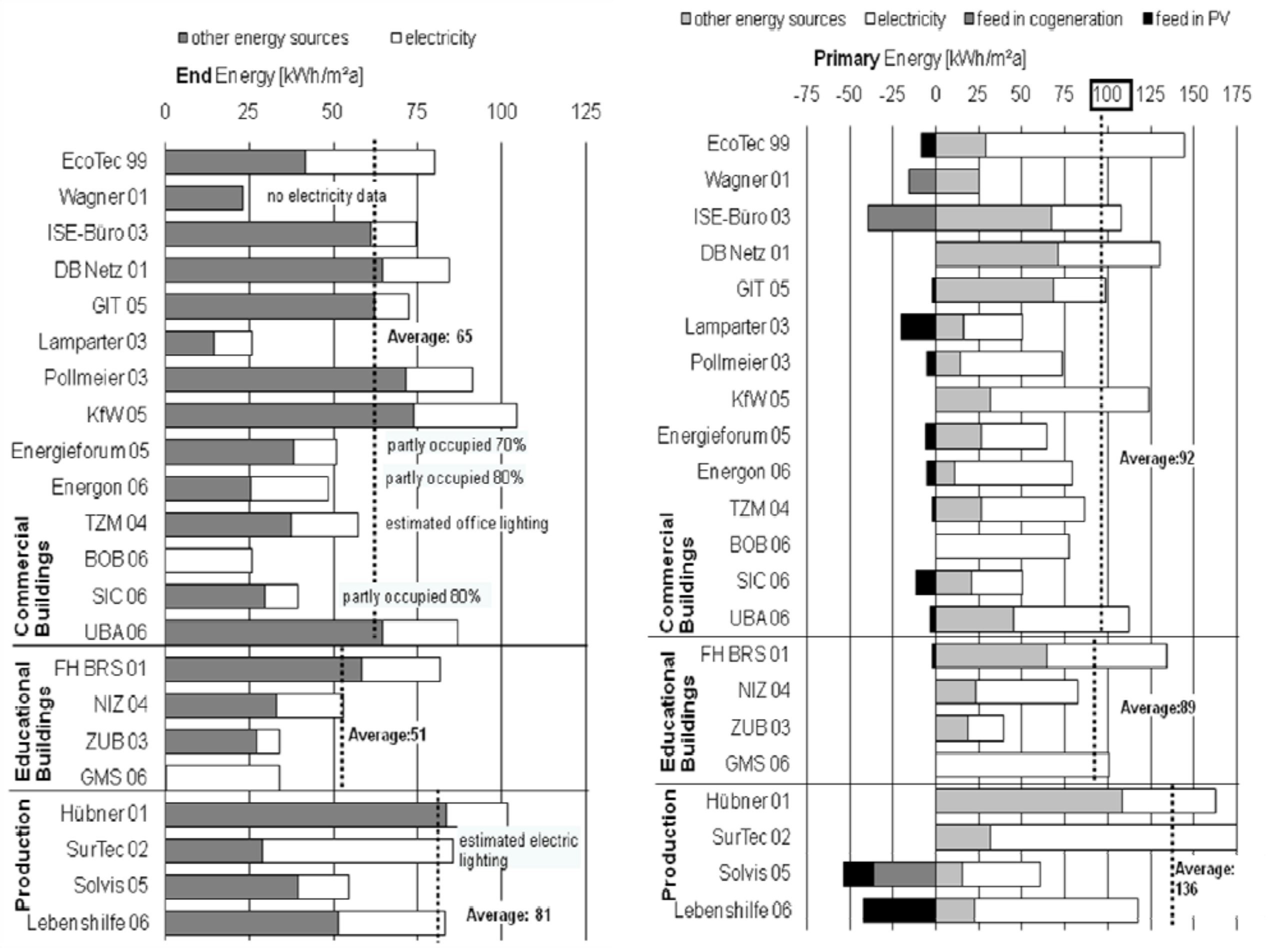
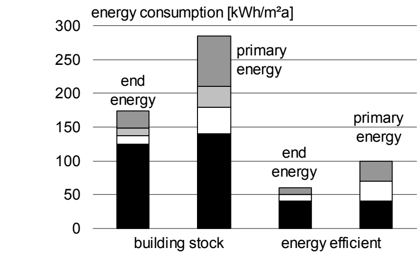


Figure 2 *Measured end energy (left diagram) and primary energy coefficients derived from them (right diagram). All data refer to the heated net floor area. Data are collected from the monitoring institutions according to tab. 1. The primary energy factors and electricity credits are based on German DIN 4701 (DIN 4710, 2001): Electricity 3, fossil fuels 1.1, biomass 0.2. To simplify the balancing procedure, photovoltaic electricity (PV) was evaluated with the same electricity credit as for combined heat and power plants (CHP). The consumption values refer to HVACL. The numbers following the project titles indicate the year for the measurements. The data source in each case was the university which was responsible for the measurement program. In the case of the "ISE-Büro" building, a zone of 525 m² consisting purely of offices plus the adjoining access areas was selected from the Institute building with a total area of 14,000 m². Aside from the Hübner building the so called production buildings have a mixed use of office and workshop or pharmaceutical production.*

Nine out of the 14 office and educational buildings show primary energy consumption below or close to the required limit of 100 kWh/m²a, five buildings range above this limit. As the end energy use for HVACL in production buildings (workshops, factories) strongly depends on the requirements regarding indoor air quality and internal loads strongly depend on the production process, a fixed primary energy target of 100 was achieved by two of the four evaluated production buildings. It is satisfying to see that the consumption of each building is much lower than the comparative values for the building stock according to Fig.3.

Individual design and target values are only available for some of the buildings, as no common methodology for calculation of the energy demand for cooling, ventilation and lighting was used. Heating energy demand was calculated based on the national standard (DIN 4108-6, 1994). Building simulations were performed for most of the buildings. Therefore comparisons with target values are valid only for the same building.

The limit for primary energy use was exceeded in some cases caused by unexpected high heating demands (DB, GIT), high electricity consumption for lighting (FH BRS, Hübner), etc. Some of the causes are due to the building concepts; others could have been avoided by an improved energy management. The Pollmeier building avoided high consumption values for primary energy, despite unexpectedly high heating energy consumption by burning wood off-cuts from its own sawmill, representing a largely CO_2-neutral source. Combined heat and power plants result in a primary energy credit (Wagner, ISE, Solvis), as the measured gas consumption also contributes to electricity generation and thus to substitution of grid electricity. Drawing heat from a district heating network with CHP also proved to be favourable (ECOTEC, ZUB).



	building stock		energy efficient	
lighting	25	75	10	30
cooling	11	30	0	0
ventilation	13	40	10	30
heating	125	140	40	40

Figure 3 Target values for energy efficient office buildings according to the program compared to end energy use values for office buildings from the existing stock in Mid European climate according to (Weber 2002). The net heated floor area is used as the reference area. End energy was transferred to primary energy by a factor of 3 in the case of electricity and about 1 for all other forms of end energy in order to compare it with typical German situation.

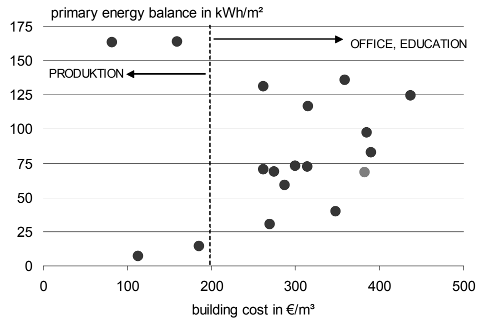


Figure 4 Primary energy use versus building cost. The primary energy use is more or less independent from the cost for construction and HVAC equipment.

Aside from energy saving and thermal use of renewable energy, some of the buildings apply measures such as combined heat and power plants (co-generation) or photovoltaics to produce electricity to feed into the public grid. This energy subsidies grid electricity to be generated on national average conditions with a mixture of power plants. In case of so called "zero energy buildings" primary energy credits for the subsidies grid electricity balance the buildings primary energy consumption on a yearly cycle. Three projects (Wagner, Lamparter and Solvis) enter the range of a "zero energy building" by the combined approach of minimized consumption and more or less equivalent credits (Fig. 5).

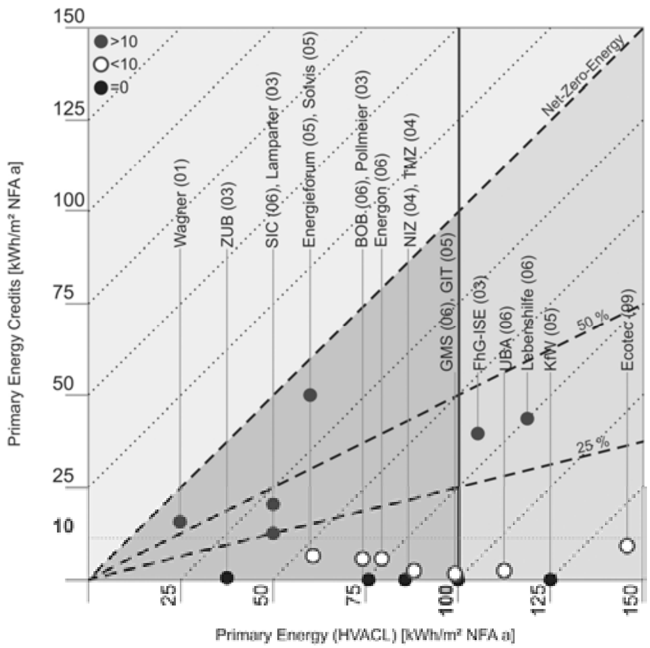


Figure 5 Primary energy consumption versus primary energy credits (from PV or CHP). Dotted lines show buildings of the same primary energy balance. Note: The primary energy consumption of Wagner building does not include electricity for HVACL.

2.2 Technologies Used by the Demonstration Buildings

The combinations of technologies to achieve energy efficiency depend on individual energy goals, specifications of local conditions and building type, use and location. The four tops used in the projects include Heat Recovery, Passive Cooling, Building Automation and Daylighting as illustrated in Fig. 6.

	Ecotec	Wagner	Hübner	FhG-ISE	DB-Netz	FH-BRS	GIT	Lamparter	NIZ	SurTec	ZUB	Pollmeier	Solvis	KfW	Energieforum	Energon	TMZ	BOB	GMS	Lebenshilfe	UBA	SIC	Ritter	DVZ Barnim	Regionshaus
Passive house concept	○	●	○	○	○	○	○	●	○	●	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○
Passive Cooling	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○
Optimization of daylight	○	●	○	●	●	●	●	●	●	○	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●
Automation of artificial light	●	○	○	●	●	●	○	○	●	○	○	○	○	○	○	○	○	○	●	○	●	○	●	●	○
Atrium	○	○	○	●	●	●	○	○	●	●	●	●	○	●	●	●	○	○	●	●	●	○	○	●	○
Solar thermal	●	●	●	●	○	○	○	●	○	○	○	○	●	●	○	○	●	○	○	○	●	●	●	○	○
Solar power	●	○	○	●	○	●	●	●	○	○	○	●	●	○	●	●	●	○	○	●	●	●	●	●	○
Heat recovery	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Activation of thermal mass	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	●	○	●	●	●	○	○	●	●	●
Ground coupled heat exchanger	○	●	●	●	●	●	●	●	○	●	●	○	○	○	○	○	○	○	○	○	●	○	○	○	○
Geothermal piles	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	●	●	●	○
Geothermal probes	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●	○	●	○	○	○	○	○	○	●
Combined heat and power (CHP)	○	●	○	●	○	●	○	○	○	○	○	○	●	○	○	○	○	○	○	○	●	○	○	○	○
Trigeneration system	○	○	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Heat Pump	●	○	○	○	○	○	●	○	○	○	○	●	●	○	●	○	●	●	●	●	○	○	●	●	○
Building Automation	●	●	○	●	●	●	●	●	●	○	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●
Use of Biomass	○	○	○	○	○	○	○	○	○	○	○	●	●	●	○	○	○	○	●	●	○	○	○	○	○
Rainwater concept	○	●	●	○	○	●	○	●	○	○	○	○	○	○	○	●	●	●	●	●	●	●	●	○	○
Ecologic Building materials	○	○	●	○	○	●	○	○	○	○	●	○	●	○	○	●	○	○	○	●	●	○	○	●	○

Figure 6 Overview of 19 strategies and technologies used in the demonstration buildings of EnOB.

2.3 Passive Cooling and Summer Comfort

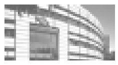
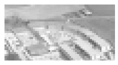
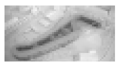
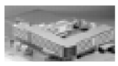
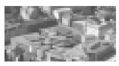
In order to improve indoor conditions in summer, so-called "passive cooling" concepts were an integrated part of each building design in different ways and to a varying extent. Passive cooling means the interaction of all measures which act to reduce the heat gains on the one hand, and on the other, which make natural heat sinks such as night air and ground accessible. So in this paper "passive cooling" includes techniques, which are not using a thermodynamic cycle process. The remaining heat loads are transferred to the surroundings with a certain time delay. Heat storage in the building construction, both during the course of a day and over longer hot periods, is substantial.

In view of the limited cooling capacity and the long time constants, the main design priority is to restrict the amplitude and dynamics of external heat gains. Thus, none of the buildings provides an entirely glazed façade. The average ratio of glazing to opaque area was 43 % or 27 % related to floor area. Almost all of the buildings use external adjustable solar shading except buildings with slab cooling systems (enhanced cooling capacity). Experiences show that the total solar energy transmittance (g_{tot}-value) for glazing and sun-shading should not exceed 10-15% (Zimmermann 1999). This can be achieved for internal blinds or blinds in the gap between the glass panes only in combination with solar control glazing (g_{glass}<40%), or by external blinds and standard heat protection glazing. A detailed analysis regarding manual blind use in two buildings (ISE, Lamparter) shows a strong correlation between solar penetration depth and blind occlusion (Reinhart 2002, Herkel 2005). External loads in these cases range in the order of internal loads (Pfafferott 2005). The average daily total internal heat gains observed range between 100 and 200 Wh/m². The range refers to the density of occupation, the operation mode of the computer systems and the lighting concepts, Tab. 1.

Table 1 Internal heat gains detected in selected projects.
Numbers refer to Wh per m² office floor area and day. Data source: Monitoring team

Project	Total	Persons	Equipment	Lighting
Wagner	100	24	66	10
DB Netz	141	30	79	32
Lamparter	100	40	-	-
FhG ISE	188	53	125	10
Pollmeier	92	21	50	21

Table 2 Demonstration Buildings with a comparison of the applied passive cooling concepts

Building	Monitoring Team	Net heated area $[m^2]$	Umean $[W/m^2K]$	Aperture area / net heated area	Night ventilation	Earth-to-air heat exch.	Slab cooling	Ground pillars	
ECOTEC	University of Bremen	2,941	0.54	0.13	X				
Wagner	University of Marburg	1,948	0.21	0.25	X	X			
Hübner	University of Hannover	2,122	0.32	0.18	X	X			
FhG-ISE	Applied University of Biberach, FhG-ISE	13,150	0.43	0.21	X	X			
DB Netz	Technical University of Karlsruhe	5,974	0.57	0.24	X	X			
FH BRS	University of Dortmund	26,987	0.42	0.34	X	X			
GIT	University of Siegen	3,243	0.36	0.27	X	X			
Lamparter	Applied University of Stuttgart	1,000	0.30	0.28	X	X			
Surtec	University of Darmstadt, Passive House Institute	4,423	0.27	0.34	X	X			
ZUB	University of Kassel	1,732	0.32	0.21		X	X		
Pollmeier	ZUB, Kassel	3,510	0.29	0.33	X				
Solvis	Applied University of Braunschweig	8,215	0.61	0.17	X				
KfW	Technical University of Karlsruhe	8,585	0.54	0.15	X				
Energieforum	Technical University of Braunschweig	20,693	0.69	0.17	X			X	
Energon	Applied University of Ulm	6,911	-	0.23			X	X	
BOB	Applied University of Cologne	2,072	0.48	0.25			X	X	
GMS	Applied University of Biberach	10,650	0.43	0.24			X		
Lebenshilfe	Technical University of Munich	4,623	0.38	0.24	X		X		
UBA	Technical University of Cottbus	32,384	-		X	X			
SIC	Applied University of Offenburg	13,833	0.74	0.23	X			X	
Ritter	Technical University of Karlsruhe	3,232	0.49	0.54				X	
DVZ Barnim	Technical University of Cottbus	19,399	0.43	0.3	X			X	
Regionshaus	Institut für Gebäude- und Solartechnik, TUBS	7,222	-	0.30				X	

Most of the projects realized in an early period of the funding program applied night ventilation combined with earth-to-air heat exchangers to remove excess heat in summer; several of the recent projects applied slab cooling in concert with vertical ground ducts or ground pillars due to the increased cooling capacity. For mechanical and hybrid night ventilation COPs between 4.5 and 14 have been monitored which are higher than those of conventional cooling but also show the need for quality assurance during the design phase and in building commissioning. The evaluated earth-to-air heat exchangers achieved COPs between 20 and 280.

Within the framework of EnBau:MONITOR the passive cooling concepts were evaluated regarding to the achieved thermal comfort. Thus, standardized graphs had been provided as part of the accompanying research in order to allow the comparison of results on summer indoor conditions between different projects. Figure 7 illustrates the results using annual cumulative frequency distributions for the indoor air temperature. If the upper limit of 25°C according to DIN 1946-2, old edition, is taken as a reference, the buildings demonstrate that the frequency of higher temperatures can be kept below 10% of the usual working hours with suitable passive cooling measures of building design strategies.

Nevertheless this consideration does not indicate whether an acceptable thermal comfort was achieved in the buildings or not. The main disadvantage of a cumulative frequency distribution analysis for thermal comfort is the information loss on the correlation between indoor and real time outdoor temperatures monitored. Four different comfort criteria, ISO 7730 according to Fanger, the proposal for the European standard prEN15251, the former DIN 1946 and the new Dutch NPR-CR 1752 have been used to analyze comparative building comfort performances. For detailed discussion on these criteria see (Pfafferott 2006).

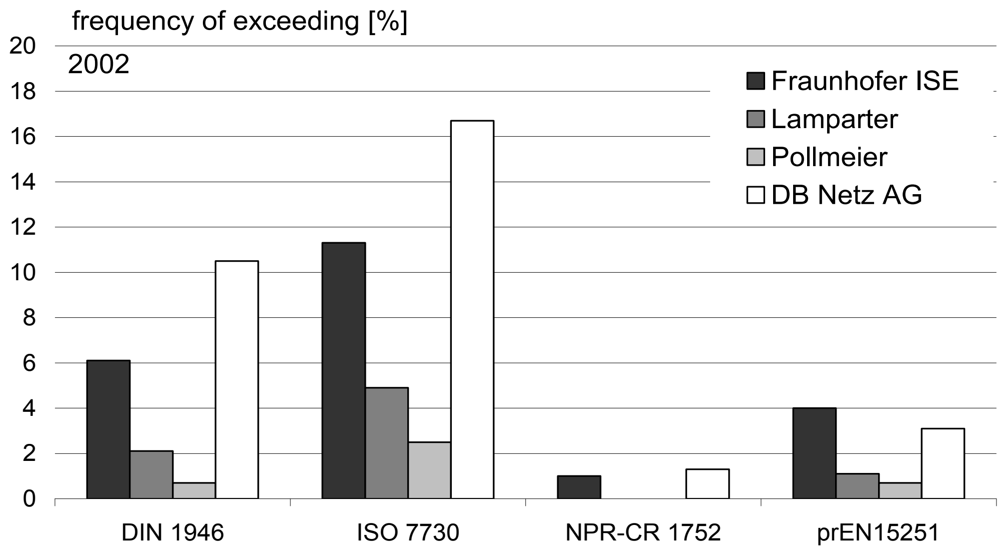


Fig. 7 *Comfort analysis on four buildings in 2002. Each building is not only performing differently for the four used comfort criteria: It is a basic assumption, that the criteria should qualitatively yield the same conclusion: If a building is better than another in criterion A, it is also better in criteria B, C and D. Nevertheless, the comfort criteria can give different quantitative numbers for comfort, since the criteria are based on different studies, databases and assumptions: Criterion A can be exceeded by 5% while criterion B is only exceeded by 2% of all working hours.*

3. Discussion and Conclusions

The results of the monitored buildings show, that the energy consumption of new office buildings can be reduced by 50% compared to the building stock without enhancing building construction costs compared to the average. The limitation of a primary energy consumption of 100 kWh/m²a and even lower is possible.

Future building concepts will focus on the goal of achieving zero energy demand on an annual base, first buildings within the program EnOB already showed the possibility of such concepts combining a low energy demand with a renewable energy supply.

The results of the passively cooled low-energy office buildings provide a high thermal comfort even without mechanical cooling or air-conditioning, when the heat dissipation in summer is enhanced by e.g. thermally activated building components or night ventilation. The evaluation of passively cooled office buildings demonstrates that during a commonly hot summer such as 2003 prevalent criteria for thermal comfort in naturally ventilated buildings (i.e. prEN 15251) are exceeded for less than 5% of the building operation time – considering realistic user behavior.

4. Acknowledgements

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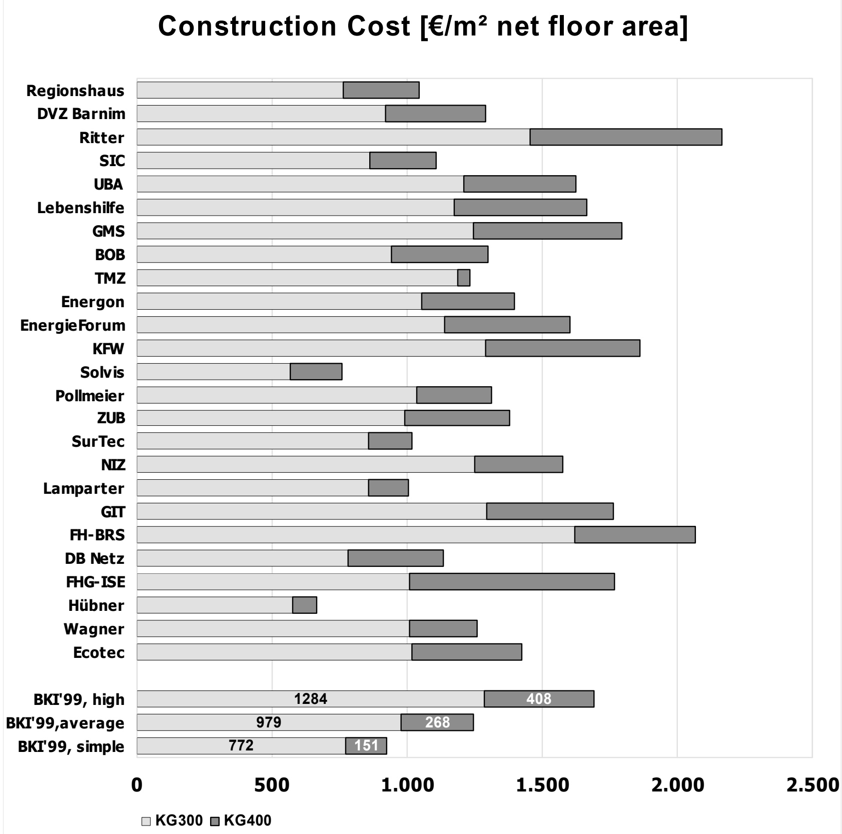
Fig. 8

Consideration of Construction Cost. The demonstration projects have lined up with the purpose to achieve long term energy-savings and cost-effectiveness during building operation. They also show that high performance buildings can be realized to normal market conditions. Finally it is important that there is a balance between architectural quality and comfort, the "right" cost-consciousness of builder-owners and a certain flexibility in dealing with the costs during building design phase and construction (cost shifting).



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TITLE: INTERNATIONAL SUSTAINABLE DESIGN – APPLYING GLOBAL THINKING AND LOCAL KNOWLEDGE

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Keywords: Global thinking, Local knowledge, Globalization, Localization, Sustainable Development, Technology transfer

Summary

This paper postulates that design practitioners have much to gain from learning to apply *global thinking* on sustainability, and from bringing the benefits of cultural exchange and *local knowledge*, to international projects. Global thinking and local knowledge can be seen as unifying elements which have the potential to reconcile the two, often incongruous, processes of globalization and localization. Co-optimizing these two approaches can be challenging however; the limited interactions, cultural differences and financial pressures of modern international design projects stretch the ability of design teams to capture these opportunities. This paper proposes a series of strategies for international designers who aim to transcend these barriers. These strategies are illustrated through the contextualization of international projects within broader economic and social movements, through a summary of the benefits and barriers to the application of progressive approaches, and through a series of case studies that highlight the challenges and opportunities of seeking to unify global thinking and local knowledge.

1. Missed opportunities in international design projects

International architectural and design projects have been common for hundreds of years, but never at the scale, speed and frequency of today. There is a clear trend in the development of an international marketplace, whereby architects and engineers, often based in leading economies, or working for multinational corporations, apply their expertise on projects in countries and regions at different stages of development.

The plethora of international collaboration, and the accompanying confluence of worldviews, result in clear benefits for the application of international construction standards and the transfer of technologies, but often miss a host of opportunities. This paper concentrates on two key ‘missed opportunities’: firstly, the chance to put new technological and conceptual tools into use by applying progressive *global thinking* on sustainable development; and secondly, the essential value of *local knowledge* on architecture, climate and culture, for application in both project-specific and broader international contexts.

1.1 Global thinking and local knowledge: a reconciliation of globalization and localization?

The range of different architectural styles used in international projects is a testament to the globalization of the marketplace. Beneath this diversity often lies a tension between cultural forces where global trends clash with local identity and environmental protection is undervalued. Where *local* or *other* knowledge is not considered complementary by incoming international designers, the result has often been the devaluation and engulfment of local knowledge by dominant, sometimes unsustainable, global trends (Satler, 1999).

It is also evident that some international projects have been successful in integrating different cultures and global trends to create both new regional cultures and projects which are coherent with their physical environment (Liangyong, 2000). The processes of globalization and localization in international design projects should be understood as interlinked and inseparable, even if they sometime seem at odds; denying the existence of one in the design process can only have negative effects on the project in question (Liangyong, 2000; Mahgoub, 2003).

Sustainable development - the direction of progressive global thinking - has to be linked to, and guided by, ecological and human social systems, hitherto inherently local in nature. The sustainability challenge tackled in this paper is then the integration and harnessing of global thinking and local knowledge, and the development of an alternative understanding of what international design can be; as seen by Satler (1999) (through the eyes of Frank Lloyd Wright), “one that understands the essential need to preserve and respect diversity, as well as house seemingly disparate philosophies of space, people, and their interactions within the built form”.

1.2 The value of local knowledge

Investors and governments in growing economies, working on projects of national political significance, often look to established international design firms for their status and reputation. These multinational companies can offer unparalleled depth and breadth of expertise, and have access to the nucleus of scientific and technological knowledge. However, these companies may not have specific contextual experience in the countries or local areas in question, and critically may not recognize the value of engaging with local knowledge.

Knowledge of local and traditional construction practices is a pre-requisite in designing architecturally, environmentally and culturally appropriate buildings. Vernacular architecture can inform sustainability thinking in the careful consideration of a building's relationship with its inhabitants, and in providing integrated solutions of climatic problems that optimize physical and social functionality (Liangyong, 2000; Oliver, 2003). These lessons may be applicable both in the project in question, and in other contexts: regions with similar climates and natural resource availabilities, areas where traditional approaches have been lost with time, or projects where a radical conceptual rethink is required. More fundamentally, local knowledge can prevent critical design flaws and help ensure that solutions will be owned and managed successfully by project stakeholders.

1.4 Barriers to the integration of global thinking and local knowledge

Applying the principles and philosophies of local cultures, alongside the values, attitudes, and techniques familiar to the international designer, is a significant challenge for the individual; efforts to take on this challenge are also often stymied by economic factors and client priorities that leave no space or time for 'ancillary' considerations. A key factor in high-profile projects, which tend to attract international collaboration, is that clients often aspire to modes of construction considered to represent modernity, whose performance may be environmentally poor e.g. the 'glass box'. The analysis of the appropriateness of the solution is lost underneath the desire to implement what is seen to signify 'development' (Du Plessis, 2001). 'Symbols of modernity' - SUVs, skyscrapers and sprawling suburbia - become the only perceived routes to modernization (Abel, 1994; Liangyong, 2000).

The needs and priorities of incoming designers, local architects and project stakeholders are often not well-aligned, even when a common commitment to 'sustainability' exists. Indeed, there is often a starkly different emphasis within sustainable development approaches between countries; Guthrie (2006) distinguishes between a 'developed world' agenda where the primary focus is on the *sustainable* and a 'developing world' agenda where the primary focus is on the *development*. It follows that stakeholder engagement and public participation in scheme development is essential to identify contextual factors and local preferences that should influence project design and guide technology transfer (WCED, 1987).

Where local knowledge is concerned, incoming designers have historically taken extreme positions on its importance in project development: alternately as a scapegoat for underdevelopment in opposition to modern knowledge, and as a panacea for sustainability (Nydrgren, 1999). It is neither; while engagement and empowerment of local knowledge should, at its best, result in entirely new architectural, ecological or even psychological perspectives for incoming designers, these will necessarily be contextualized by the designer's own life, culture and training, and by the ongoing process of globalization.

A summary of benefits related to the application of global thinking and local knowledge, and barriers to their successful incorporation, are summarized in Table 1.

Table 1 Benefits of the application of global thinking and local knowledge and barriers to achieving them

Opportunity	Benefit	Barriers
Application of progressive **global thinking**	• Displacement of unsustainable development models • Transfer of new environmental technologies and approaches • Education and long-term technology transfer • Appropriate buildings through integration of local knowledge	• Vision of modernity often based on unsustainable practice (SUV, glass towers) • Proposed sustainability model not aligned with local needs and priorities • Economic structure not conducive to long term commitment inherent to sustainability • Lack of capacity in developing world to assimilate technologies/concepts • Lack of focus on long-term operability and maintenance of projects • 'We know best' attitude of incoming consultants

Application and export of **local knowledge**	• Transfer of relevant low-tech climate control features • District and on-site solutions as alternatives to 'end of pipe' technological fixes • Re-invigoration of traditional materials and construction techniques • Introduction of a holistic approach to materials and resources	• Lack of awareness/interest of consultants or clients as to value of local knowledge • Inability of incoming designers to step out of their frame of reference • Collecting/accessing/distinguishing local knowledge • Pace of modern architectural design schedule not conducive to local studies • Lack of common graphic or technical language to allow for inter-disciplinary studies • Ability of traditional techniques to demonstrate/satisfy stringent international comfort or structural standards

1.3 The role of technology transfer

The environment is one of the major areas where technological transfer and global thinking can make a significant difference to the development path of emerging economies. Concurrently, interest in the wider dissemination of traditional and situated knowledge, in areas such as passive climate control or earthen construction, continues to grow.

There is a tendency to present technology transfer in a unidirectional manner, but the real interaction between technology exchange and situated knowledge is far more complex. For example, various forms of composting technologies for human sanitation have been used successfully in many regions across millennia. Recent analysis of the transfer of 'eco-sanitation' technologies has tracked these ancient ideas from Vietnam, to Sweden and the U.S., and back again to Vietnam, with incremental benefits at each stage (Esry et al, 1998).

Applying global knowledge and local thinking means identifying technologies from a wide spectrum that provide responses to local conditions; technology transfers that meet local needs and priorities are far more likely to be successful (Metz, 2000). We know that the imposition of technologies, concepts and scientific knowledge without the engagement and support of a broad range of local stakeholders will result in failed projects (Clark and Murdoch, 1997). For example, the introduction of high-rise buildings in urban areas of India, without proper attention to the cultural shift this represents, and without due regard to incorporation of unfamiliar maintenance regimes, has resulted in buildings falling rapidly into disrepair (Joshi, 2008). Sustainability thinking, which considers the broader appropriateness of solutions, is a good framework to ensure that the right technologies and concepts from global thinking respond to project–specific requirements.

2.0 Strategies for applying global thinking and local knowledge

It is straightforward to highlight the barriers to the application of global thinking and local knowledge; the next step is to try to develop strategies to overcome them. Understanding which motivations and worldviews are prevalent in projects, and how they are shaping developments, allows us to think about behavioral changes that would make this possible. This section outlines and develops some potential strategies for achieving this.

2.1 Specific barriers, targeted strategies

The strategies summarized in Table 3 represent potential approaches for overcoming the types of barriers introduced in Section 1.3. Strategies highlighted in bold are explored further in Section 2.2.

Table 3 Potential strategies for incoming designers

Opportunity	Barriers	Potential Strategies for Incoming Designers
Application of progressive **global thinking** on sustainability	Vision of modernity based on unsustainable practice	• Showcase high-profile LEED subscribers to clients/investors • **Showcase culturally consistent, world-class buildings to clients/investors (2.2.1)**
	'Sustainability' considered ulterior to local needs and priorities	• Stakeholder engagement and participation in design process • **Development of clear, widely agreed, definitions of sustainability and a means of measurement (2.2.2)**

	Lack of local capacity to assimilate technologies/concepts	• Build-in educational components to collaborative design teams • Run public information sessions • **Find a direct application/or a design metaphor (2.2.3)**
	High cost of environmental technologies	• Investigate international subsidies/trading schemes • Wider assessment of benefits • Focus on low cost, low tech design solutions
	Lack of focus on long-term operability and maintenance	• Build maintenance and operability training and post-occupancy evaluation into scope
	Clients don't recognize value of incorporating local knowledge	• Highlight marketing/community/political value in local stakeholder engagement
Application of **local knowledge**	Lack of awareness/open-mindedness of incoming designers	• Request (or require) multi-week study period in local area in scope and fee proposal
	Lack of time in the design process	• Demonstrate economic value of low-energy designs
	Lack of access to demonstrable technologies and concepts	• **Hire a local architectural historian/professor/anthropologist (2.2.4)**
	Ability of traditional techniques to satisfy stringent comfort or structural demands	• Use of pilot projects before scaling-up

2.2 Further Exploration of Potential Strategies

Four of the key strategies highlighted in Table 3 are elaborated upon as follows:

2.2.1 A new vision of world-class: Showcase green, culturally consistent, world-class buildings to clients/investors

Some projects may be diverted from developing environmentally and socially sustainable solutions by client fixation on a certain type of development. If designers wish to facilitate environmentally sustainable projects, they have a role to play in promoting more sustainable solutions by convincing clients of their financial viability and wider value. Increasingly, high-profile mainstream buildings have looked to improve and promote their environmental performance through the introduction of 'green building' techniques and assessment methodologies such as LEED. It is part of the role of the designer to capitalize on momentum towards greener construction to support a new paradigm of modernity: desirable, 'green' buildings.

2.2.2 Integrating Sustainability: Development of clear, widely agreed, definitions and a means of measurement

If the 'sustainability vision', as understood by the incoming designer, is not shared by others - the client, investors, local consultants or directly affected stakeholders - it will be very difficult to implement sustainability objectives. Bartlett and Guthrie (2005) state that: "for sustainability to be successfully taken into account in building projects there must be an appropriate culture, clear definitions, means of measurement and the use of tools". Creating an appropriate culture is challenging and time-consuming, but progress can be made if commitment to a shared sustainability vision is established from the start. A transparent and open process of engagement with all parties will facilitate an appreciation of local needs and priorities, and pave the way for defining context-specific objectives, that are understood and valued across the board. If definitions and priorities are widely accepted, then targets and indicators can be attached to objectives to provide a means of measurement.

4.2.3 Communicating New Concepts: direct applications, design metaphors

Designers may need to adapt their communication techniques when working on international projects. Technology or knowledge transfer, without effective dialogue, can become an imposition, and hence a potential failure. While enthusiasm for the proven benefits of technologies and concepts on one side can force ideas through, this does not necessarily mean that they will be well understood or received by others. It is the responsibility of the team members introducing new ideas to communicate these benefits to those whose understanding and acceptance is crucial to the success of the project. If ideas represent a departure from the conventional approach, a first step would be to look for historical precedents in the area that might provide context and visualization.

4.2.4 Accessing Local Knowledge: spend time in places, spend time with people

Local knowledge can be important in both realizing immediate project success, and in capturing ideas that have exportable relevance. Design teams that recognize the importance of local knowledge could request and justify in their scope a significant study period in the local area. The value of local knowledge increases when understanding goes beyond local building techniques, to an appreciation of current and traditional modes of interaction with buildings. Culturally specific ideas of functionality may not be immediately apparent to incoming designers. Contributions from participants who are personally, rather than professionally, connected with the spaces and areas in question can be particularly valuable. Beyond professional interactions, simply spending time with local people who have an appreciation of social, political, commercial and anthropological factors can help foster a deep understanding of local conditions that can in turn inform design. One strategy could see the use of junior staff on study periods, or intense periods of engagement in the area in question, as conduits for incorporating that knowledge into the design process.

3.0 Case Studies – Successful application of global thinking and local knowledge?

In our work we often come across different combinations of the barriers and challenges outlined in this paper. In some instances we have been successful in overcoming these challenges, sometimes through strategy, sometimes through luck; in others, constraints of time and money have stymied our efforts. Four specific examples, detailed below, demonstrate aspects of the application of global thinking and local knowledge; each example elaborates on previously highlighted opportunities, barriers and strategies.

3.1. Lutsch Redevelopment, Moscow – Creating a new vision of world-class

Opportunity: Transfer of new environmental approaches
Barrier: Clients vision of modernity not linked to sustainable practice
Strategy: Showcase of high-profile LEED-accredited projects and associated business value

Project Background

The Lutsch project consisted of the redevelopment of a former light bulb factory in Moscow into an office complex with associated retail, parking and external landscape space. The developer was a sizeable Russian company, looking at the time to break into the international market. The developer put together an international design team on which Buro Happold was a key member supplying MEP, Structures and Sustainability services. Originally, there were no particular 'green' aspirations for the development and a marked lack of knowledge and interest in green building assessment on the part of the developer.

Technological/Conceptual Approach

Buro Happold recognized the potential to introduce LEED assessment as a means to drive improved environmental performance and to market the development. Knowledge of the value of LEED and other green building assessments was well established in BH at a senior level across the company. BH hence utilized senior managers to advocate LEED as a means to establish the developer as an international player and to provide a competitive edge over contenders in the international marketplace. Developments and developers who had adopted LEED were showcased and the types of tenants they were attracting highlighted. The developer was convinced by the business case supplied for the marketing opportunity represented by pursuing LEED accreditation.

Outcomes

LEED Core and Shell is currently being pursued and a marketing program was develed to make a statement about the progressive nature of the development. As a result the developer has subsequently changed construction practices in other parts of their business towards a greener performance.

The adoption of LEED represents in this case the successful meshing of client priorities with an international SD-directed assessment approach. The challenge was to understand the developers concerns, values and objectives and interpret them in a sustainability framework. The experience reinforced the understanding that sustainability in its broadest sense can often make for a good business case even when the client is focused only on a single bottom line. It was also a reminder of the influence that personnel with understanding and appreciation of sustainability issues can have on project partners.

3.2 Infrastructure Improvements, Tedrum, Tibet – Building on local practices and precedents

Opportunity: Appropriate development through integration of local knowledge
Barrier: Local suitability of imported design solutions
Strategy: Engagement with community knowledge and local construction experts

Project Background

In August of 2003, a collaboration of design professionals from the San Francisco Bay Area was hired by a Non Governmental Organization to consider planning and design for a 4,000 acre parcel of land in the Tedrum Valley of Tibet. The program sought to upgrade infrastructure while easing the way for eco-tourism in one of the twelve most sacred sites in Tibet. The identification of environmental technologies that responded and resonated with local practices with the added benefits of modern innovations was prioritized.

Technological/Conceptual Approach

Solutions were required to “tread lightly” in order to maintain the pristine natural environment, making decentralized waste recycling a preferred solution. Proposals for human waste-recycling systems in areas where there is no precedent for this type of sanitation system often encounter serious issues (Esry et al, 1998). Engagement with community members, local experts and ‘barefoot’ engineers was key to identifying this opportunity identified local precedents for these types of systems. Systems that were proposed utilized traditional concepts (such as human waste recycling) but with modern technological innovations to improve system efficiencies.

Outcomes

The passive systems that were proposed were widely accepted by the community and its leaders. Success of the project was determined by the group’s prior identification of the importance of integrating local practices and their willingness and ability to spend time engaging with and incorporating these practices into design outcomes.

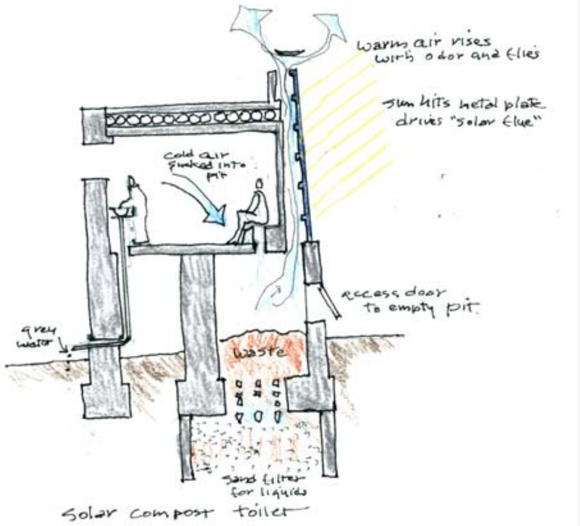

Figure 3 *Drawing for Proposed Solar Composting Toilet Systems Source: The Mountain Institute Peak Enterprise Program*

3.3 Passive Cooling Stacks in Las Vegas – Low-tech technology transfer

Opportunity: Transfer of low-tech passive cooling systems
Barrier: Quantifying/comparing performance of low-tech designs
Strategy: Demonstration of the economic and aesthetic value of low-energy designs through additional study

Project Background

BH have been involved in inputting sustainability concepts into proposals for a new hotel and casino complex in Las Vegas. BH were able to draw on their significant experience on projects in the Middle East to propose passive cooling stacks as functional and aesthetic elements of the architectural design. Natural draft cooling towers were proposed for the Las Vegas project, to provide localized comfort for cafes and park areas, although for architectural reasons were ultimately not included in the final design.

Technological/Conceptual Approach

Passive Ventilation Stacks have been observed through experience on BH projects in the Middle East; climate analysis for Las Vegas showed suitable conditions for the application of similar technologies. Research and case studies were completed to demonstrate the economic and aesthetic value of low-energy designs.

Outcomes

Despite not being integrated into the design the experience of proposing these systems highlighted another key barrier of comparing low-tech designs with other methods of thermal comfort like trees or other shading techniques. The project underlined the importance of quantifiable comparability when applying 'traditional' technologies in other innovative contexts.

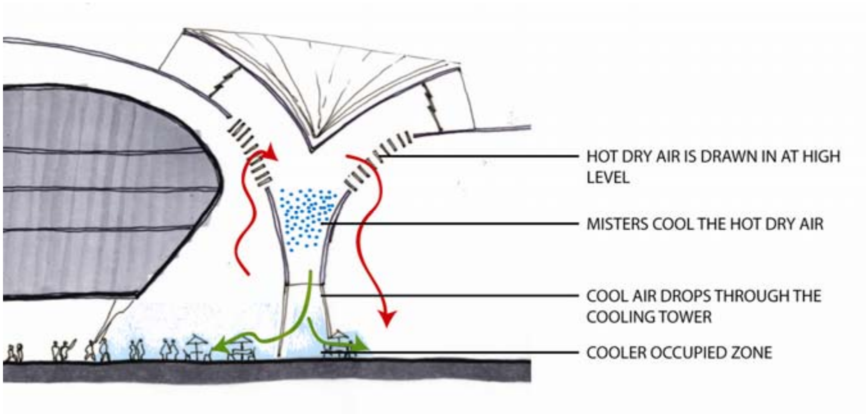

Figure 5 Passive ventilation system proposed for Vegas project. Source: Buro Happold

3.4 Decentralized Wastewater Treatment, Hyderabad, India – Closed loop systems

Opportunity: District and on-site solutions as alternatives to 'end of pipe' systems
Barrier: Access to local technical knowledge of design of biological wastewater treatment systems.
Strategy: Multi-week study period looking at decentralized technologies in the area

Project Background

BH have invested personnel time in visiting projects in India to better understand local approaches with a view to development of future projects in the area. This led to recognition of the need to develop expertise in the application of Decentralized Wastewater Systems (DEWATs), particularly constructed wetlands. After investing time in development this strategic capability, BH was then able to propose and design a DEWAT system at a masterplanning level on a mixed-use development project in Hyderabad.

Technological/Conceptual Approach

Decentralized or on-site systems are individual, multiple-household or small community systems that collect and treat wastewater at or near the point of generation. Decentralized systems can represent better value than conventional systems in situations where infrastructure is created from scratch, reducing both costs of infrastructure and environmental impacts. In India, they are becoming more widely used and understood. In proposing these systems in Hyderabad, these economic and environmental sustainability benefits were highlighted by BH.

Outcomes

BH have subsequently proposed DEWAT systems in a number of projects in India and further afield. Development of knowledge in this area was due to the investment of time into exploring local and innovative approaches. BH has subsequently formally recognized the added-value of local engagement by building time for cultural exchange into new projects, and the importance of looking beyond conventional 'end-of-pipe' infrastructure solutions.

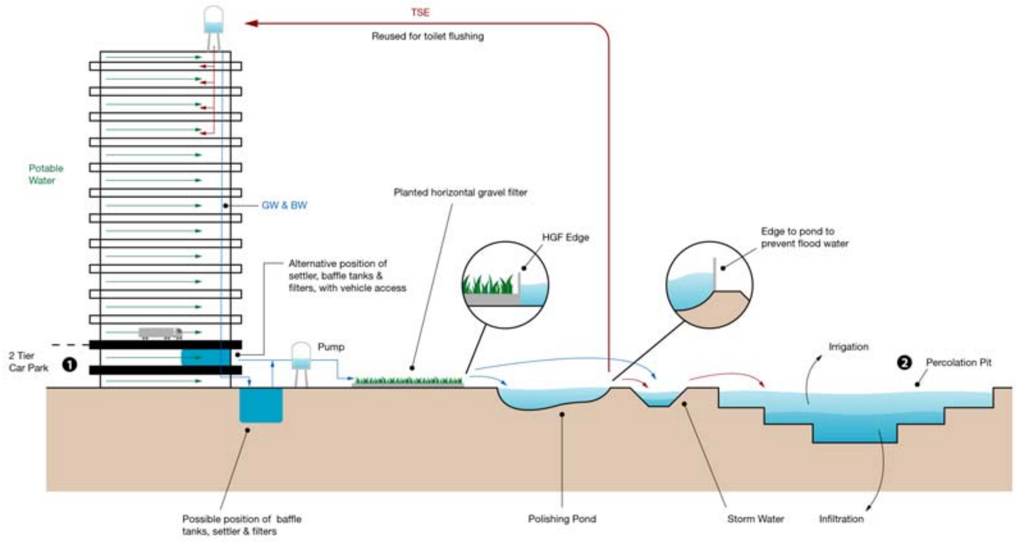

Figure 5 System Diagram for Hyderabad project. Source: Buro Happold

5.0 CONCLUDING REMARKS

A clear message from the case studies introduced in this paper is that assimilating the two areas of global and local expertise can contribute to sustainable development and should be an axiom of international design projects. Applying the concepts of global thinking and local knowledge outlined in this paper is very challenging giving the temporal, financial and communication constraints prevalent in modern international design projects. The approaches and strategies proposed in this paper are designed to inspire and enable architects and engineers who appreciate the untapped potential in international design projects and who want to find ways to add further value. A key lesson is that thinking along distinct developed-developing, modern-traditional, global-local lines, may not always be an appropriate conceptual approach when trying to co-optimize many variables. Optimizing benefits for all parties entails: understanding the motivations and worldviews that shape projects; correctly accessing and assessing local conditions; and subsequently selecting and developing tools and strategies to modify trajectories towards more sustainable development.

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URBAN-WIDE POTENTIAL OF SUSTAINABLE OFFICE REFURBISHMENT
[REVISED 24TH JULY 2008]

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Keywords: renovation, office, sustainable, LEED, energy, Canada, replicable, carbon

Summary

This paper assesses the urban-wide potential of a range of sustainable office refurbishment measures that have been implemented and evaluated in a case study exercise.

The office refurbishment project analyzed in this paper is Canada's first LEED Canada-CI (commercial interiors) project and has achieved Platinum certification as a result of the many sustainable design features included: Enermodal Engineering Ltd.'s Calgary office, completed in 2007. The range of measures implemented and evaluated in this paper include

- enhanced lighting design,
- recycling facilities,
- efficient office equipment and appliances,
- low-emitting fixtures and fittings,
- sustainable transport incentives,
- low embodied energy materials,
- occupant comfort control,
- water efficient fixtures and fittings,
- layout for daylight and views, and
- energy management and monitoring.

This paper evaluates the effectiveness of each of the measures that were implemented, and appraises the potential for replication across a large urban area (the municipality of Calgary population approx 1 million). It concludes that there is a great potential for carbon and water savings, increased occupant health and well-being, and for a small incremental cost. It also comments on the potential overall contribution to sustainability of each of the measures, evaluated against a range of sustainability metrics including potential energy/carbon and water savings, capital costs, materials and waste reduction, and social and health impacts, ease of implementation and replicability. It was found that the measures having the highest contribution to sustainability in the case study analyzed were: enhanced lighting design, use of recycling facilities, efficient equipment and appliances, low-emitting fixtures and fittings, and sustainable transport incentives.

1. Introduction

1.1 Office Refurbishment Case Study

This case study is based on the renovation of a 100 m^2 office space carried out by Enermodal Engineering Ltd. in downtown Calgary. Enermodal Engineering Ltd. is a consulting firm committed to improving the sustainability (especially energy and resource efficiency) of buildings and building products. With a staff of 60 in Kitchener (Head Office), Denver, and Phoenix, Enermodal's fourth office in Calgary was designed to showcase the company's longstanding expertise in environmental design and construction, provide staff with a green office to work in, and serve as a replicable demonstration and promotional project for sustainable office practices to Enermodal's clients and office visitors.

The office is located on the 6th floor of an 11 storey building in the historic Mission District of downtown Calgary. The space was formerly used as a dentist's office, with finishes dating to the 1980's, therefore the majority of finishes were not in suitable condition for re-use and could not be retained. The scope of the project included removal of the original internals and the installation of a washroom, a small kitchen area, a boardroom and general office area. The scope of the work included new interior partitions, ceiling tiles, millwork (in the kitchen area), flooring, and furniture. As this project is the renovation of a leased space, two major areas of interest, the HVAC systems and the building envelope. It was not possible to consider either of these were important aspects of building performance as they are both controlled by the landlord.

1.2 LEED Canada for Commercial Interiors

The office refurbishment was designed and constructed following the principles of LEED Canada-CI (Leadership in Energy and Environmental Design Canada for Commercial Interiors), which is implemented by the Canadian Green Building Council (www.cagbc.org) in Canada. LEED-CI is a point-based rating system and a green building benchmark. It is tailored for the tenant improvement market, i.e those projects that do not usually have control over whole building operations but only a renovation of part of an existing building. LEED is currently the most widely used Green Building system in North America (97 certified and 760 registered buildings to date in Canada)[1].

The project was started at the same time as the official launch of the LEED-CI program by the CaGBC, in late 2006. The Enermodal Engineering Ltd. Calgary Office went on to become not only the first project to be certified by the CaGBC under the LEED Canada-CI rating system, but it also achieved a *Platinum* rating, the highest level of achievement and distinction offered. See Appendix A for a LEED Canada-CI Scorecard.

Figure 1 Enermodal Engineering Ltd. Calgary office kitchenette featuring low embodied energy and low emitting materials.

2. Urban Context

The City of Calgary is a city of over 1 million people in Alberta, Western Canada. The city is in a time of economic boom, largely due to oil and gas exploration, and is home to the second largest concentration of corporate head offices in the country[2], which has led to an increased demand for office space. Calgary has over 31 million square feet of office space and has experienced vacancy rates between 0.5% and 3.5% in the past two years[3]. This high demand for office space has meant higher than average levels of churn as: corporations take on new space for additional employees; and other corporations are forced out of the downtown core and into less expensive spaces as rent costs in Calgary have soared to be the 28th highest in the world, amongst the top ten in the world for growth[4]. Therefore this paper is timely as it examines the potential of a range of sustainable office refurbishment practices across the city.

3. Performance Analysis of Sustainable Refurbishment Measures

3.1 Methodology

The measures implemented in the Enermodal Engineering Ltd. Calgary Office were evaluated using the following criteria:

3.1.1 Ease of Implementation

Measures were graded based on how easy they were to implement into the design and construction of the office, relative to standard practice. The acceptability of the practice/technology in the market place was also considered (i.e. level of expertise required for design and installation). The main factors that were taken into account were feedback from the General Contractor (who had 15 years of experience but none in green construction), the requirement for specialist design inputs or the need to use specialist equipment i.e. how much harder was this measure to include compared to the standard alternative?

3.1.2 Cost of Implementation

Measures were graded based on their incremental capital cost relative to standard practice. Although many major manufacturers and suppliers are now offering more sustainable products, there is still a cost associated with many sustainable office measures.

3.1.3 Social/Health and Productivity

Measures were reviewed on their level of contribution to providing a healthy working environment for its occupants. As many office workers spent as much as 90% of their time indoors, avoidance of products that may cause ill health and promotion of measures that enhance well-being take on much significance. Each measure was assessed for their ability to improve occupant health, comfort and well-being.

3.1.4 Carbon Reduction

Reduction in carbon emissions as a result of efficient use of energy in buildings is one of the most pressing issues given current concerns over climate change. Measures were assessed for their contribution, if any, to energy/carbon reduction.

3.1.5 Materials and Waste Reduction

Measures were assessed for their contribution to natural resource consumption and waste reduction. Materials/measures were evaluated over for their impacts over their life cycle. Products and practices' embodied energy, minimal waste production/consumption, and minimal end-of-use environmental impacts were considered.

3.1.6 Replicability

Measures were evaluated for their ability to be replicated on an urban-wide level. The impacts associated with supply and demand of materials and products, varied geographic applicability, and appropriateness for a wide variety of space use types were considered.

3.2 Analysis

Please see Appendix B, which shows a matrix analyzing the performance of the various measures implemented. The measures are described and discussed below:

3.2.1 Enhanced Lighting Design

A combination of low-mercury High-Output T5, T8, and compact fluorescent fixtures were installed throughout. All fixtures are controlled with occupancy sensors, and perimeter lighting is further controlled with daylight sensors (dimming ballasts) and manual on-off override switches. White ceiling tiles were also used to increase reflectance and further reduce the installed lighting power. These measures combine to achieve a 38% reduction in lighting power density below ASHRAE Standard 90.1-2004.

Electrical design for reduced light power density required no specialist expertise. Although fewer light fixture choices are available at the highest efficiencies used, all are available from many well known manufacturers. However, installation and set up of the daylight and occupancy sensors did require a small amount of additional time and adjustment. The resulting lighting levels and controls have provided a comfortable, energy efficient working environment and the principles could be easily applied with good results to most typical office refurbishment projects.

3.2.2 Recycling facilities

The refurbishment included the installation of a recycling storage centre in the kitchenette. Separate storage containers for compostable materials, glass/metal, plastic, cardboard/paper are provided. Paper and cardboard are first collected in “blue boxes” located within each office prior to storage in the kitchenette. The storage area is 0.6 m^3, which is collected by a specialist recycling contractor and delivered to recycling facilities every two weeks.

The recyclable materials storage facilities can be easily and discretely incorporated into almost any office refurbishment project but the ongoing success of the scheme is highly dependent on the quality of the service provided by the local collection service. There were some concerns over odors from the compostable waste at the outset but these have been easily manageable with regular collections and housekeeping. Installing similar recyclable materials storage in other office refurbishments should be easily achievable but the ongoing success of such schemes would rest on user education and the local collection service.

3.2.3 Efficient Equipment and Appliances

All office equipment and appliances are ENERGY STAR rated (where eligible), including: notebook computers, monitors, dishwasher, refrigerator, and printer/copier/fax machine. ENERGY STAR is a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy. It provides an energy performance rating system which recognizes energy efficient products and practices[5].

ENERGY STAR appliances are widely available with little or no cost premium and there are no significant barriers to the uptake of this measure. Efficient appliances and equipment were easily specified and can be implemented on any scale of office refurbishment.

3.2.4 Low emitting fixtures and fittings

Construction adhesives, sealants, plus paints and coatings were all selected to be low-emitting. The office achieved over 85% reduction in volatile organic compounds compared to LEED performance limits. The office also installed Green Label Plus[6] certified carpet tile, urea-formaldehyde free composite wood and agrifibre products, and the reused and GREENGUARD[7] Certification Program certified furniture. Green Label Plus and GREENGUARD are the most recognized low emissions certification programs in North America for carpet systems and furniture, respectively.

Selecting low-emitting adhesives, sealants, paints, and coatings required additional research prior to specifying and purchasing products. Experience with this project was that, whilst most contractors required assistance, guidance, and education on low-emitting product selection, most were receptive of the measure. These products had no additional costs associated with their use or application.

The majority of carpet manufacturers now offer low-emitting products, and a selection of Green Label Plus carpet was neither difficult nor significantly more expensive than standard carpets. Similarly, GREENGUARD furniture was found to be readily available from local furniture dealers although this requirement did limit the number of stores and suppliers. GREENGUARD furniture was primarily in the upper range of quality; these products tended to be expensive, but were similarly priced relative to products of comparable quality.

Urea formaldehyde-free wood and agrifibre products were the most time consuming to source due to a lack of readily available product alternatives and difficulty in obtaining product specifications and information from suppliers.

3.2.5 Sustainable Transport Incentives

A bicycle storage system was designed specifically to address the space constraints of this project. A shower stall was also installed in the washroom to encourage employees to cycle, walk, or jog to and from work. The number of parking spaces provided by Enermodal was limited to meet but not exceed the local zoning bylaw. A carpool program was established to provide incentives to employees who carpool regularly to and fro the office.

Additional work was required to survey employees and produce a transportation management plan. The incentives and alternative transportation opportunities presented to occupants was well received and easily managed once implemented. Little cost was required to provide infrastructure to support the alternative transportation options.

3.2.6 Low embodied energy materials

A wide variety of environmentally friendly products were sourced. Products with regionally manufactured and extracted materials were selected wherever available. 45% of furniture and furnishings (by cost) were purchased reused. Products with the highest possible recycled content were selected, including the reflective white ceiling tiles, gypsum board, ceramic and carpet tile, composite wood, insulation, new furniture, and steel studs. The interior doors and sidelight frames were made from FSC-certified cherry. FSC-certified wood has been harvested from forests in an environmentally and socially responsible manner (certification is provided by the Forest Stewardship Council[8]). The highlight of the office materials is the high rapidly renewable content used (over 12%), which includes bamboo flooring, Woodstalk® wheat board casing, and Kirei® board cabinets (made of sorghum). The kitchenette countertop is made from Paperstone®, a surface constructed of 100% post-consumer recycled and FSC-certified paper.

Additional work was required to research and procure alternative materials. In general the costs of low-embodied energy materials was negligible; although some innovative products carried a premium and no similar products were available, other products used such as used furniture provided cost savings. As with using low-emitting materials, some education and monitoring was required to ensure that contractors were aware of the desired product requirements and purchased appropriate products.

3.2.7 Occupant comfort control

Temperature is controlled via four wall-mounted thermostats, and airflow can be controlled manually within each room using operable diffuser grilles.

Design for occupant comfort control does not require any additional level of expertise; however it does require more thought to ensure all work areas have been appropriately addressed. Implementing additional control devices had a negligible impact on capital cost, and provided no difficulties during construction. Post-occupancy feedback showed that the increased level of comfort control was widely utilized, providing a high level of satisfaction and comfort.

3.2.8 Water efficient fixtures and fittings

The washroom was remodeled to include an ultra low-flow shower (3.8 litres per minute), a dual-flush toilet (6 and 3 litre per flush options), and a self-mixing 1.9 litre per minute lavatory faucet controlled with an infra-red sensor. These features, along with a low-flow kitchen faucet (3.8 litres per minute) save over 50% of water consumption compared to the LEED-CI baseline.

There was a small capital cost increase to purchase infra-red sensors and low-flow fixtures. It was found that lavatory faucets were easily sourced, however low-flow showerheads were more difficult to purchase due to a lack of product options and suppliers. Dual-flush toilets are now produced by most major manufacturers and are becoming increasingly easy to specify. The selection of toilets was greatly increased when residential-style fixtures were included in addition to commercial fixtures. It was found that the acceptability of low-flow fixtures varied widely with each individual and company that was dealt with, but are becoming increasingly accepted in Canada.

3.2.9 Layout for daylight and views

The office layout places all regularly occupied rooms along the perimeter, providing a view to the outdoors and naturally lighting all of these spaces.

Space layouts to optimize daylight and views does not require any special expertise, however is not always considered during design, nor might it be possible with deep plan office renovation projects. Regularly occupied spaces such as offices and meeting rooms were strategically placed along the exterior of the floor plate adjacent to windows. Occasionally used spaces such as the foyer, the kitchenette and the hallway were placed adjacent to the exterior spaces, and connected with the outdoors indirectly by using interior sidelights. Storage spaces and the washroom were placed on the interior where daylight and views had the lowest benefit and priority.

3.2.10 Energy management and monitoring

Temperature, relative humidity, and carbon dioxide sensors continuously monitor the indoor comfort conditions, and this data is also available “live” on the educational kiosk display.

Electrical wiring had to be considered during design, and was set up such that all lighting fixtures and plug loads were fed to a circuit breaker located within the office space. Additional cost was required to purchase an electronic meter and set up a management program to record the data collected. The continuous monitoring of electricity consumption has provided a public display feature (it is part of the educational cost) that is very popular with occupants and visitors. It has allowed the energy department of Enermodal Engineering the ability to frequently re-evaluate energy loads within the office and assists them explore opportunities to maximize efficiency. The office has been able to reduce the lighting and plug load electrical consumption to less than 70 kWh/m^2 in the first year of operation.

4. Conclusions

The preceding analysis indicates that there is a great potential for implementing several sustainable building measures for office refurbishment projects in Calgary. Furthermore, the analysis showed that many of the measures can be implemented at relatively little incremental capital cost, but would provide savings of carbon, natural resources, and water, while increasing occupant comfort and well-being.

Although all measures analyzed offer some form of benefit, the following measures were found to provide the most benefit overall, based on the criteria considered:

- enhanced and efficient lighting design,
- recycling storage facilities,
- energy efficient office equipment and kitchen appliances,
- low VOC emitting fixtures and fittings, and
- sustainable transport incentives.

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Appendix A. LEED Canada-CI Scorecard for Enermodal Engineering Ltd. Calgary Office

LEED® Canada - CI 1.0

GREEN BUILDING RATING SYSTEM

Building with purpose

Enermodal Engineering Ltd. - Calgary Office

CaGBC Project # 10526

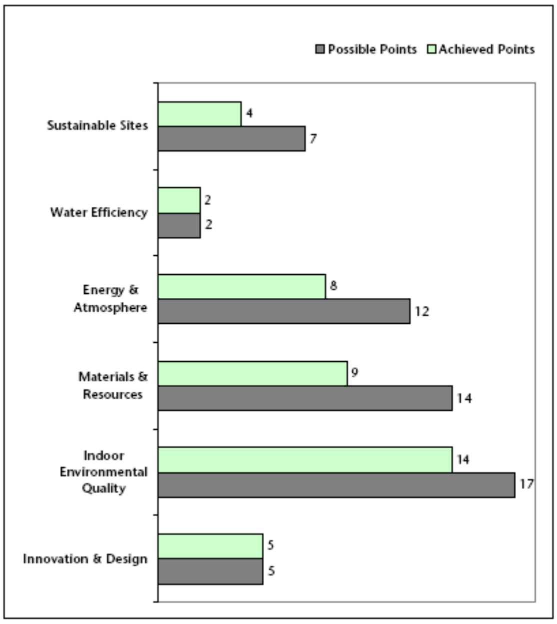
5 October 2007

42 Points Achieved — *Gold Rating Achieved* — **Possible Points: 57**

Certified 21-26 points Silver 27-31 points Gold 32-41 points Platinum 42-57 points

4	Sustainable Sites		Possible Points 7
	Credit 1	Select a LEED Certified Building OR Options A - L (Maximum 3 Points)	3
	Credit 1	Option A. Brownfield Redevelopment	0.5
	Credit 1	Option B. Stormwater Management, Rate and Quantity	0.5
	Credit 1	Option C. Stormwater Management, Treatment	0.5
0.5	Credit 1	Option D. Heat Island Reduction, Non-Roof	0.5
	Credit 1	Option E. Heat Island Reduction, Roof	0.5
	Credit 1	Option F. Light Pollution Reduction	0.5
	Credit 1	Option G. Water Efficient Irrigation, Reduced Potable Water Consumption	0.5
	Credit 1	Option H. Water Efficient Irrigation, No Potable Water Use or No Irrigation	0.5
	Credit 1	Option I. Innovative Wastewater Technologies	0.5
	Credit 1	Option J. Water Use Reduction, 20% or 30% Reduction	1
	Credit 1	Option K. Onsite Renewable Energy	1
0.5	Credit 1	Option L. Other Quantifiable Environmental Performance	3
1	Credit 2	Development Density and Community Connectivity	1
1	Credit 3.1	Alternative Transportation, Public Transportation Access	1
1	Credit 3.2	Alternative Transportation, Bicycle Storage & Changing Rooms	1
	Credit 3.3	Alternative Transportation, Parking Availability	1

2	Water Efficiency		Possible Points 2
1	Credit 1.1	Water Use Reduction, 20% Reduction	1
1	Credit 1.2	Water Use Reduction, 30% Reduction	1



8	Energy & Atmosphere		Possible Points 12
Y	Prereq 1	Fundamental Commissioning	Required
Y	Prereq 2	Minimum Energy Performance	Required
Y	Prereq 3	CFC Reduction in HVAC&R Equipment	Required
3	Credit 1.1	Optimize Energy Performance, Lighting Power	3
1	Credit 1.2	Optimize Energy Performance, Lighting Controls	1
	Credit 1.3	Optimize Energy Performance, HVAC	2
2	Credit 1.4	Optimize Energy Performance, Equipment & Appliances	2
	Credit 2	Enhanced Commissioning	1
1	Credit 3	Energy Use, Measurement & Payment Accountability	2
1	Credit 4	Green Power	1

9	Materials & Resources		Possible Points 14
Y	Prereq 1	Storage & Collection of Recyclables	Required
	Credit 1.1	Tenant Space, Long-Term Commitment	1
	Credit 1.2	Building Reuse, Maintain 40% of Interior Non-Structural Components	1
	Credit 1.3	Building Reuse, Maintain 60% of Interior Non-Structural Components	1
1	Credit 2.1	Construction Waste Management, Divert 50% from Landfill	1
1	Credit 2.2	Construction Waste Management, Divert 75% from Landfill	1
	Credit 3.1	Resource Reuse, 5%	1
	Credit 3.2	Resource Reuse, 10%	1
1	Credit 3.3	Resource Reuse, 30% Furniture and Furnishings	1
1	Credit 4.1	Recycled Content, 10% (post-consumer + ½ pre-consumer)	1
1	Credit 4.2	Recycled Content, 20% (post-consumer + ½ pre-consumer)	1
1	Credit 5.1	Regional Materials, 20% Manufactured Regionally	1
1	Credit 5.2	Regional Materials, 10% Extracted and Manufactured Regionally	1
1	Credit 6	Rapidly Renewable Materials	1
1	Credit 7	Certified Wood	1

14	Indoor Environmental Quality		Possible Points 17
Y	Prereq 1	Minimum IAQ Performance	Required
Y	Prereq 2	Environmental Tobacco Smoke (ETS) Control	Required
1	Credit 1	Outdoor Air Delivery Monitoring	1
	Credit 2	Increased Ventilation	1
1	Credit 3.1	Construction IAQ Management Plan, During Construction	1
	Credit 3.2	Construction IAQ Management Plan, Before Occupancy	1
1	Credit 4.1	Low-Emitting Materials, Adhesives & Sealants	1
1	Credit 4.2	Low-Emitting Materials, Paints and Coating	1
1	Credit 4.3	Low-Emitting Materials, Carpet Systems	1
1	Credit 4.4	Low-Emitting Materials, Composite Wood and Laminate Adhesives	1
1	Credit 4.5	Low-Emitting Materials, Systems Furniture and Seating	1
	Credit 5	Indoor Chemical and Pollutant Source Control	1
1	Credit 6.1	Controllability of Systems, Lighting	1
1	Credit 6.2	Controllability of Systems, Temperature and Ventilation	1
1	Credit 7.1	Thermal Comfort, Compliance	1
1	Credit 7.2	Thermal Comfort, Monitoring	1
1	Credit 8.1	Daylight & Views, Daylight 75% of Spaces	1
1	Credit 8.2	Daylight & Views, Daylight 90% of Spaces	1
1	Credit 8.3	Daylight & Views, Views for 90% of Seated Spaces	1

5	Innovation & Design Process		Possible Points 5
1	Credit 1.1	Innovation in Design: Exceptional Performance - Water Use Reduction at 50%	1
1	Credit 1.2	Innovation in Design: Exceptional Performance - Rapidly Renewable Materials	1
1	Credit 1.3	Innovation in Design: Composting Program	1
1	Credit 1.4	Innovation in Design: Education Outreach Program	1
1	Credit 2	LEED® Accredited Professional	1

Figure A1 LEED Canada-CI Scorecard for Enermodal Engineering Ltd. Calgary Office.

Measures	Ease of Implementation	Cost of Implementation	Social/Health and Productivity	Carbon Reduction	Materials and Waste Reduction	Replicability	Total
	Minimal workability, high acceptability = 3	None, minimal = 3	Significant benefits = 3	Significant = 3	Large reductions = 3	Easily transferable = 3	
	Moderate workability & acceptability = 2	Low to medium = 2	Some benefits = 2	Medium = 2	Medium reductions = 2	Medium level of opportunity = 2	
* Not applicable = 0 for all categories	Significant work, low acceptability = 1	High = 1	Little or no benefits = 1	Low = 1	Low reductions = 1	Low level of opportunity = 1	
Enhanced Lighting Design	2	2	3	3	0	3	13
Recycling Facilities	3	2	1	1	3	3	13
Efficient Equipment and Appliances	3	3	0	3	0	3	12
Low-Emitting Fixtures and Fittings	3	2	3	0	1	3	12
Sustainable Transport Incentives	1	2	3	3	0	3	12
Low Embodied Energy Materials	1	2	2	2	3	1	11
Occupant Comfort Control	2	2	3	2	0	2	11
Water Efficient Fixtures and Fittings	3	2	1	1	0	3	10
Layout for Daylight and Views	1	2	3	2	0	1	9
Energy Management and Monitoring	1	2	1	2	0	2	8

Figure B1 Assessment tool used to evaluate performance of sustainability measures implemented.

CLINICAL OUTCOMES AND SUBJECTIVE VALUATIONS FOR REMODELLED GREEN HEALTH CARE FACILITIES

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Key Words: Sustainability, facility remodelling, evidence based, acuity-adaptability, whole life cycle costing, uncertainty analysis

Summary:

The aim of this conference paper is to discuss a new approach to redevelopment appraisal for green health-care facilities. Research shows the need to combine various models or approaches to achieve this objective due to uncertainties from clinical outcomes and subjective valuations of decision makers. This study attempts to combine three major approaches/models to green healthcare facility redevelopment: clinical evidence based assessment, whole of life cycle costing (WLCC) and uncertainty analysis.

The design concept behind acuity-adaptability (AA) rooms is patient rooms be designed to accommodate all levels of care and patients to remain in that room throughout hospitalization (Hendrich; Fay and Sorrells 2004). Flexible healthcare services accommodate changes in patients' acuities. The main advantages are reductions in patient movements, improved health care and safety and shorter average length of stay (Ulrich et al 2004). Secondary advantages are reduced staff workloads, maximized bed utilization, increased patient satisfaction and lower costs.

Current health and building related research efforts on green health-care facilities focus on energy savings and indoor environmental quality (IEQ) impacts. However, additional research into systematic assessments of other aspects of sustainability, such as facility flexibility and AA patient room should be considered.

Recent studies indicated that AA patient rooms reduce infection rates, increase the expected occupant health and improved staff/patient satisfaction outcomes in a cost-effective (CE) manner. However, there is still knowledge gaps in the evidence base whether financial investment for this type of facility produces adequate return on investment (ROI).

In this discussion, three public healthcare hospitals in Singapore are to be study samples. They have remodelled and added AA rooms to existing facilities and assessed the building for sustainability. These facilities have now been in service for at least two years and served end users such as patients, clinical and non-clinical workforce, visitors and the local community.

This proposed study program consists of four stages. The first stage is a literature review on how health environment adapts to meet the needs of society in 21st Century in terms of sustainability.

1. INTRODUCTION

Hospitals are some of the most expensive facilities to build due to complex infrastructure, medical technology and government regulations and building codes. Investing in healthcare facility and deciding what components to incorporate into remodelled or new facility requires clear comprehension of intended outcomes (Levin et al 2006).

The largest challenge facing the health sector is the necessity to maintain or improve clinical outcomes, operational effectiveness, revenue and patient/staff satisfaction while reducing capital, operational and support costs (Hosking and Jarvis 2003). At same time, health management must attain unprecedented levels of equipment, staff retention and sustainable adaptability (Mirrielees 2006). Effective management of physical and staff assets play an increasingly important role in optimising CE concerns (Wauters 2005). Health management are increasingly required to demonstrate potential benefits other than costs from a sustainable perspective (Kaatz et al 2006).

This research aims to improve current set of appraisal tools to meet uncertainties resulting from multiple objectives from decision-makers and stakeholders in health sector. The secondary aim is to identify broad goals and sub goals of interested parties to formulate and identify a set of relevant indicators supporting sustainability in health facilities. The literature review (LR) has identified the means to compare investment options with respect to non-commensurable criteria and to quantify uncertainties in a consistent and transparent manner as knowledge gap. This study proposes a holistic whole of life cycle costing (WLCC) model for appraising green healthcare facility investments by aligning and integrating relevant elements of decision-making, uncertainty analysis, project management, logistics, system engineering, maintenance and life cycle costing (LCC) and delivery of care (DC). (Boussabaine and Kirkham 2006)

Objectives of this study are: First, to assess investment appraisal and uncertainties based on a modified LCC methodology (Boussabaine and Kirkham 2006). Second, to evaluate the impact of indoor environment (IE) on staff and clinical outcomes in context of AA rooms within green and conventional facilities (Martini; Discoli and Rosenfeld 2007). Third, to establish design effectiveness on staff collaboration efforts and retention rate (Seppänen and Fisk 2005). Fourth, to discuss issues related to implementing evidence based design with focus on sustainability to link benefits of systematic post occupancy assessment with practice-based research (Hamilton 2003). Fifth, to document the impact of sustainability issues such as single versus multi bed rooms, IEQ, supportive workplace and improved layout; improved physical settings that contribute to safer, effective healing outcomes and better workplaces in remodelled facilities (Bordass and Leaman 2005).

2. LITERATURE REVIEW

There are several reasons for using formal clinical research data and results to guide green facility appraisal in health sector (Okoroh et al 2001). Unlike other building types, where poorly designed IE cause annoyances and minor health problems (Hirota 2005), fatalities could result from similar IE conditions in hospitals.

Just as medicine moves towards ‘evidence-based medicine' where clinical choices are informed by research; ‘evidence-based design’, guided by rigorous research, provide directions to sustainable healthcare facility design and decision-making processes (Ulrich et al 2004). The primary reason is that evidence-based sustainable design; results in demonstrated improvements in clinical outcomes, economic performance, staff productivity and patient satisfaction (Becker and Parsons 2007).

The following research questions are guiding this literature review:

a. What are the differences in construction, operation and management costs, infection control and decision-making between AA rooms and multi-occupancy rooms in green and conventional hospitals?
b. What are the therapeutic impacts (social interaction, patient privacy) of AA rooms versus multi-occupancy rooms in green and conventional hospitals?

2.1 Economic Benefits

Throughout the 1980s and 1990s, demands for greater convenience and new technologies and the resultant cost pressures led to major shifts in provision of healthcare (McDermott; Parsons and Cornia 1994). Focus shifted from a primary in-patient activity to more of an outpatient approach. The LR indicated a profound effect on in-patient activity due to facility remodelling. Data from these studies indicate significant variations in admissions by these facilities. Overall, these studies indicate that most remodelled facilities experience significant growth in in-patient admission activity (Hosking and Jarvis 2003). The increases attributed to demographics and use rates are insufficient to explain the magnitude of increase.

Pursuing a green facility remodelling strategy has tremendous implications for the healthcare sector and its constituents (Holtz 2006). While the potential benefit is significant, such an approach requires capital resources, placing enormous stakes on success or failure of execution (Pelleier and Weil 2003). Good redevelopment appraisal depends not only on quality of data for analysis and evaluation it depends on objectives of both decision-makers and stakeholders (Omura 2004). It is important to identify broad goals and sub-goals of the interested parties to formulate and identify a set of relevant indicators supporting the redevelopment appraisal process (World Health Organisation 2002).

Further investigations into this area of research, including meticulous collection and verification of longitudinal data, would assist in future planning of facilities (Turpin-Brooks and Viccars 2006). Given the magnitude of investments associated with remodelled facilities, it is important to analyse the impact of decision making based on profitability attributes (Chow-Chua and Goh 2002).

2.2 Green Remodelled Healthcare Facility

Green remodelled facilities improve hospital environments in four key ways (Ulrich et al 2004):

a. Enhancing patient safety by reducing the risk of infections, injuries and medication errors
b. Eliminating IE stressors, such as noise, that affects healing outcomes and staff performance
c. Reducing stress and promote healing by providing more pleasant and comfortable environment and support for patients
d. improving staff performance and retention rates

The LR suggests that facility redevelopment or remodelling has significant impact on financial and operational performance (Hui; Wong and Wan 2008) as well as on patient and staff welfare. The costs and risks involved are substantial (Lutzendorf ;Lorenz &Truck 2006). If current trend remains or accelerates, sustainable remodelled facilities would be more prevalent due to competition within the health sector (Simms and Rogers 2006). Studies revealed that site selection; together with operational planning and sustainable facility design; provide efficient staffing and optimal level of health outcome for patients (Kantrowitz et al 1993). Future decision-making needs to be strategic due to a shortage of caregivers and resources. There are significant advantages to organizational innovations and changes for both patients and caregivers by incorporating sustainability concerns into investment and remodelling decisions (Hosking and Jarvis 2003).

2.3 Acuity-Adaptable Rooms

In conventional hospitals, patients are moved to different types of nursing ward to receive the required level of care that match their patterns of acuity during their hospital stay. This leads to problems such as missed treatments, medication errors, infection rates, injuries due to transfer activities and transfer costs (Okoroh; Ilozor and Gombera 2006). Number of patients requiring progressive care has increased sharply and led to demand for special rooms that can adapt to changing medical technology and services (Bodenhelmer 2005).

In AA room, rather than organizing care around levels of patient acuity, rooms or wards are designed to accommodate all levels of care while still organized by specialty (Levin et al 2006). They make it possible to reduce the number of Intensive care units or other specialized units. Patients are assigned to any AA room and remain until discharged (McDermott C. and Stock 2007). Another advantage is that nursing stations can become decentralized throughout the ward or floor facilitated by monitoring technology (Chaudhury; Mahmood and Valente 2005).The results are reduced health and safety related problems as well as increasing retention rate for healthcare givers and their productivity levels. (Fisk 2002)

LR indicated that the satisfaction of staff and patients was higher when patients remained in a single room throughout their entire stay compared to those moved during stay. In addition, the length of stay (LOS), staff workload and mortality/infection rate decreased and fewer transfers resulted in cost savings (McDermott C. and Stock 2007). Findings demonstrated that remote and flexible monitoring decrease the LOS and reduced costs. (Calkins and Cassella 2007)

2.4 Methods

Investments in facilities are assessed with respect to LCC as well as economic lifespan (Shohet 2003). Outcome of redevelopment appraisal with respect to these economic criteria is generally non-deterministic. To evaluate different investment options require probabilistic modelling to account for uncertainties (Suthummanon and Omachonu 2008).

WLCC methodology considers a multitude of different quantitative and qualitative criteria characterising facility redevelopment (Lavelle 2003). Delays due to re-work; reputation of vendors; builder expertise, expected system reliability and performance have direct impacts on outcome of redevelopment decisions related to facility remodelling or refurbishment of healthcare facilities (Lennerts et al 2005).

2.5 Metrics

Typical investment analyses indicate economic feasibility or CE of investment options by calculating WLCC metrics such as Return on Investment (ROI), Net Present Value (NPV) and Payback Period (PB) (Boussabaine and Kirkham 2004). The role of UA is vague in these models (Pelletier and Weil 2003; Pelzeter 2007). For the purpose of this study, a WLCC model based on Temporal Utility Model whereby redevelopment investments are seen as a decision making process focused on achieving a reservation value or utility of possible investment options as precondition. After meeting this precondition, the next step is to determine the maximum value or utility of a set of admissible investment options (Lavelle 2003). However, investments in healthcare facility are unique, as sources of uncertainty stem from variability of clinical outcomes (Mainz 2003; Sohet and Lavy 2004), and subjective valuations of many decision makers given new data as evens unfold (Fleming 2005). Methods that address these uncertainties by supporting subjective judgements include Markov Chain Monte Carlo methods developed for Bayesian probabilistic modelling and statistical inference that support uncertainty analysis (Zhang and Vidakovic 2005; Cooper et al 2006).

2.6 Key findings from Literature

Recent review of the literature (Ulrich et al 2004) on sustainable design demonstrated that patient-centred and acute care environments facilitate positive patient outcomes such as increased patient privacy, better opportunity to recovery and shorter LOS. The few articles' dealing with overall cost issues in hospitals, did not focus on AA room types, and associated costs. Studies on patient/caregivers' perception of the advantages and disadvantages of AA rooms versus multi-occupancy rooms are just as limited (van de Glind; de Roode and Goossensen 2007).

The major issues in the literature synthesized into four main categories and subdivided into empirical and non-empirical studies:

a. Cost and decision making related issues
b. Infection control
c. Healthcare facility management/patient care
d. Therapeutic impacts

Articles on cost and management issues are mainly non-empirical and prescriptive in nature (Sohet and Lavy 2004). A limited number of empirical clinical studies based on therapeutic benefits of AA rooms and infection control have been carried out (van de Glind; de Roode and Goossensen 2007). The authors identified a gap in research supporting cost reductions based on linking AA rooms to other healing environment design principles (Ulrich 1991).

The key drawbacks are higher construction costs required to redevelop entire healthcare facilities into AA rooms (Bodenhelmer 2005). By design, AA rooms require larger rooms and flexible medical infrastructure; means either longer travelling distance or fewer rooms per floor and less revenue per room (Nelson; West and Goodman 2005). Other major obstacles include impacts on existing staff levels. While technology and staff can facilitate different levels of treatment within a unit, it is unrealistic to expect all staff to maintain expertise in all areas (Chaudhury; Mahmood and Valente 2006).

As mentioned earlier, AA rooms and sustainable design are poised to be the leading trend in healthcare facility planning and design (Hamilton 2001; Levin 2006; Becker and Parsons 2007). Both empirical and non-empirical literature demonstrates advantages of AA rooms for improvements in patient care and greater flexibility in operation. However, the LR highlights a limited interpretation of the benefits of AA rooms within the context of care-related issues, environmental concerns and management practices to bring about desired and sustainable outcomes in remodelled hospitals (Liyanage and Egbu 2005; Hirota 2007).

3. APPROACH

The modified WLCC model for evaluating LCC and the question of assessment adequacy, as mentioned by Pelzeter, are investigated in this study. The primary goal of evaluation is to aid health management in structuring and quantifying investment related issues characterised by multiple criteria decision analyses and uncertainty methodology mentioned by Pelletier and Weil. Assessment process are evaluated using Bayesian probabilistic modelling based on Markov Chain Monte Carlo methods and statistical inference in the form of degree-of-belief probabilities methodology proposed by Zhang and Vidakovic. The scope of WLCC assessment determined by the strategic nature of facility remodelling appraisal is considered.

WLCC metrics may be used to compare several investment options. Comparing the ROI, NPV and PB of each solution provides the means to evaluate cost implications over the economic life of a facility. Existing WLCC models fail to provide a method for systematic data collection for a decision making process as mentioned by Sohet and Lavy. As WLCC considers only economic cost of a facility, the methodology has limited impact post handover unless the proposed framework includes operational cost metrics for performance measurement.

For the purpose of this study, the proposed objectives incorporated three levels of detail:

a. Strategic (i.e. structure, envelope, services etc)
b. System (i.e. operations and management, utilities, staff turnover etc)
c. Detail (i.e. head panel, LOS, internet hook-ups, mortality rate etc)

This provides the modified WLCC model the ability to optimise multi-criteria decision-making during the design phase and conduct uncertainty analysis with greater precision.

4. PILOT STUDY

In this study, the basis for choosing a population of patients included consolidation needs, characteristics of bottlenecks, and needs for a population with a predictable clinical course as shown by the survey conducted by Hirota. After the selection of a patient population, the next phase is to focus on the following attributes of AA rooms/wards:

a. Resource wastage
b. Caregivers' work environment and satisfaction
c. Characteristics of care delivery model
d. Flexibility and adaptability of support for future DC and patient flow
e. Cost-benefit and CE within green healthcare facilities

To assess the impact of AA rooms in sustainable healthcare facilities, O'Sullivan et al mentioned various clinical and financial measures to be collected before and after the remodelling exercise. Two years of baseline data, similar to the data collection by Sharshar, to be collected from the two green hospitals and one conventional hospital in Singapore; demographics, admissions/discharge/transfers, LOS, staff and patients' satisfaction levels, bed efficiency, charge/costs, nursing work loads before and after the facility remodelling. A list of 20 survey questions is to be formulated, based on similar inquiry conducted by Hirota, into RA of green healthcare facilities. The proposed areas of inquiry are:

a. Did the patients have fewer complications (adjusted for severity) when compared to cohort of matched patients? Did mortality rate changed?
b. Did the sentinel event index (e.g. falls, medication errors, complaints etc) decreased?
c. Compared with baseline data, did job satisfaction increase amongst clinicians due to incorporation of key sustainability features into healthcare facilities? (Technology, green environment, care delivery model) What are the expected outcomes over time?
d. Will patients' satisfaction levels be higher compared to baseline data?
e. Will nursing recruitment and retention improve in AA rooms in remodelled green healthcare facility?
f. Are flexibility and adaptability features within green AA rooms able to match current medical technology to patient and staff needs?
g. What market impact can be measured or quantified with physician, patient, or patient's family? Will patients recommend AA rooms in green healthcare facility to others?
h. Compare with baseline data on costs of labour (direct, indirect and fixed) resulting from changes to environment, technology and care delivery model

Patient's levels of satisfaction and dissatisfaction in AA rooms in both green and conventional healthcare facilities are to be compared. This provides an indication of how closely patients' experiences match their expectations as well as patient's overall willingness to pay or recommend the healthcare facility to family and friends.

Results from this study would indicate whether AA room design in green healthcare facility provide a more cost effective advantage in reducing costs, staffing hours and improving delivery of care based on World Health Organisation methodology. In the short term, data from this study might indicate the likelihood of stretching additional capacity out of identical number of beds through provision of additional AA rooms. Another possibility is improving CE by the reduction of physical plant space requirements to AA rooms due to decision-making process as mentioned by Nelson, West and Goodman.

5. CONCLUSION

This discussion has examined the possibility of achieving improvements to remodelled healthcare facilities by targeting bed placements in AA rooms, communication and housecleaning in a more CE manner. Previous research, especially studies by Ulrich, has indicated that healthcare decision makers support green design features in new or remodelled facilities that promote the wellness of patients and retain staff. The objective of this study is to provide health administrators with means to reach decisions on redevelopment strategies

The impacts and benefits of a green remodelled facility strategy is to be evaluated by analysing pre-, post-utilisation performance, and benchmarking against conventional facilities under similar conditions based on a proposed WLCC model.

The analysis will focus on data from pre- and post-remodelled in-patient admission and outpatient visits to AA rooms/wards of sample facilities. Primary and secondary data is to derive from three sources for this on-going study: Alexandra Hospital (Singapore), Singapore General Hospital (Singapore) and Changi Hospital (Singapore).

A second stage of the study is intend to track remodelled green facility activity through a combination of interviews with architectural firms, their staff's experience as well as that of facility management, staff and patients. There are seven public hospitals in Singapore including three green healthcare facilities. Two green remodelled and one conventional public healthcare facility would be participating in this study.

External factors such as geographical locations, private versus public, socio-economic status of community and physician practice patterns could have profound effect on green remodelled healthcare facility in terms of operational and financial effectiveness and performance. Other factors that could complicate research include age and type of healthcare facilities investigated as indicated in study by Hosking and Jarvis.

By identifying and making allowances for these limitations, mentioned by Ohkusa and Sugawara, during analysis stage, the appraisal can measure both qualitative and quantitative improvements for health facility over current WLCC model. Once the study is completed, the results will be presented.

6. ACKNOWLEDGEMENTS

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The authors regret that the only remaining green public hospital, Tan Tock Seng Hospital (Singapore), is unable to participate in this study as they are still in process of remodelling their existing facilities.

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IN SEARCH OF NET ZERO – CALGARY INTERNATIONAL AIRPORT EXPANSION

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Keywords: sustainable, energy, modeling, life-cycle, building, airport, NPV, ROI

Summary

In 2007, Calgary International Airport surpassed the 12 million passenger mark, continuing the greater than forecast growth seen over the previous four years. The Calgary Airport Authority is reviewing options to accommodate these increases. The existing Calgary International Airport has three concourses. One option under review to address the increased passenger traffic is an expansion to the International/Trans-border facilities. This would take the form of a new 72,000 m^2 concourse. In addition to increased processing capacity, expanded retail and duty free shopping facilities will contribute to the airports overall revenue stream. During planning meetings, the Authority has stressed that their stated environmental goals were a key factor in any solution proposed. A theme that emerged during these initial planning meetings was: could the expansion be accomplished without increasing the net energy consumption and greenhouse gas (GHG) production of the existing campus – the "Net Zero" solution? Through modeling and life cycle analyses, a solution that meets the Calgary Airport Authorities economic and operating criteria was identified that also presents a "Net Zero" option for the expansion with an annualized return on investment of 6.1%.

1. Background

In 2007, Calgary International Airport surpassed the 12 million passenger mark continuing the greater than forecast growth seen over the previous four years as illustrated in Table 1. The existing terminal, with upgrades between 1998 and 2004, is designed to handle 11 million passengers. The Calgary Airport Authority is reviewing options to deal with these increases. One option under review is an expansion of its terminal and airside facilities. The expansion will be designed to accommodate passenger growth for the next two decades.

Table 1 – Calgary International Airport Historical Passenger Traffic

Year	2001	2002	2003	2004	2005	2006	2007
No. of PAX	7,794,519	7,884,194	8,576,541	9,174,039	10,148,718	11,279,080	12,257,865
% Change	-3.66%	1.15%	8.78%	6.97%	10.62%	11.14%	8.68%

As part of the 2004 Calgary International Airport Master Plan, the Authority introduced the following statement:

"... in addition to minimizing the environmental impact of fostering aviation development and economic growth, the Airport Authority will strive to exemplify strong environmental stewardship to local, national and international communities through innovation, leadership and new partnerships."

During planning meetings, the Authority stressed that their stated environmental goals were a key factor in any solution proposed. A theme that emerged during initial planning meetings was: could the expansion be accomplished without increasing the net energy consumption and greenhouse gas (GHG) production of the existing campus – the "Net Zero" solution? As a result, the Authority authorized a Mechanical and Electrical Master Plan, one facet of which would review the feasibility.

This paper presents a synopsis of the analyses that were performed and the recommendations presented to the Authority for its consideration when finalizing its decision on what measures to implement in an expansion scenario. All currency quoted are in 2008 Canadian dollars.

2. Existing Terminal Baseline (Utility and GHG Production)

Calgary International Airport's terminal has three concourses (refer to Figure 1), which have been opened, expanded or upgraded over a ten year period, 1998 to 2004. Pier B/C handles international and trans-border (US/Canada) flights; the passenger segment that has experienced the most growth. The current expansion targets this area. The planned 72,000 m^2 expansion will also increase the processing capacity of Canada Border Services Agency and US Customs and Border Protection pre-clearance operations.

The current terminal covers 141,648 m^2 of roofed area, consisting of Concourse A through D, Main Terminal and Courtyard Infill.

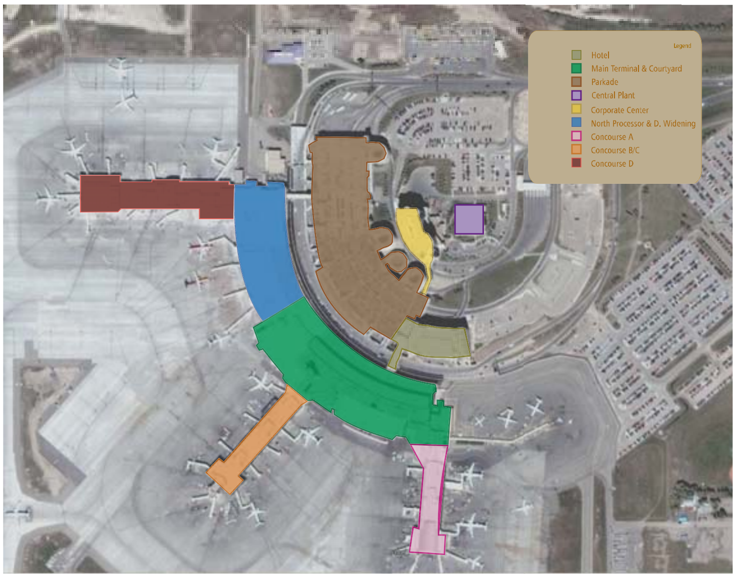

Figure 1 – Existing Calgary International Terminal

The Authority has kept historical data on utility consumption, providing a good basis for baseline development. Figures 2 though 4 represent the historical annual unit (*utility*/m^2) consumptions for each utility of the existing terminal.

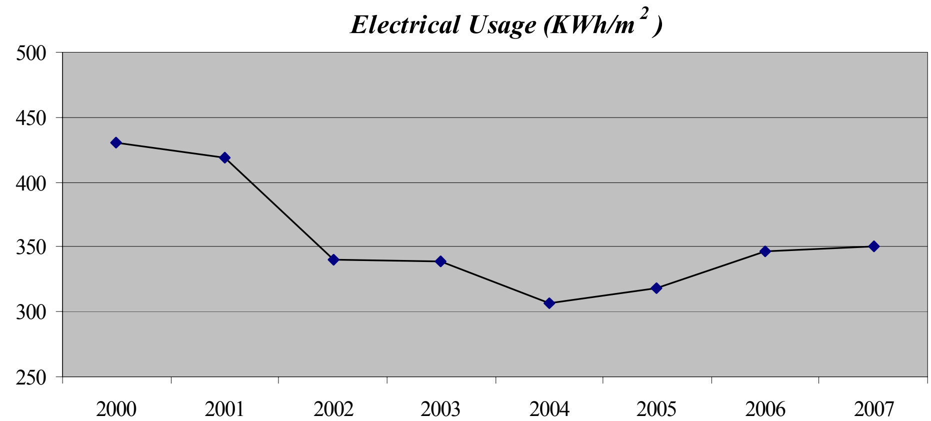

Figure 2 – Historical Annual Electricity Consumption

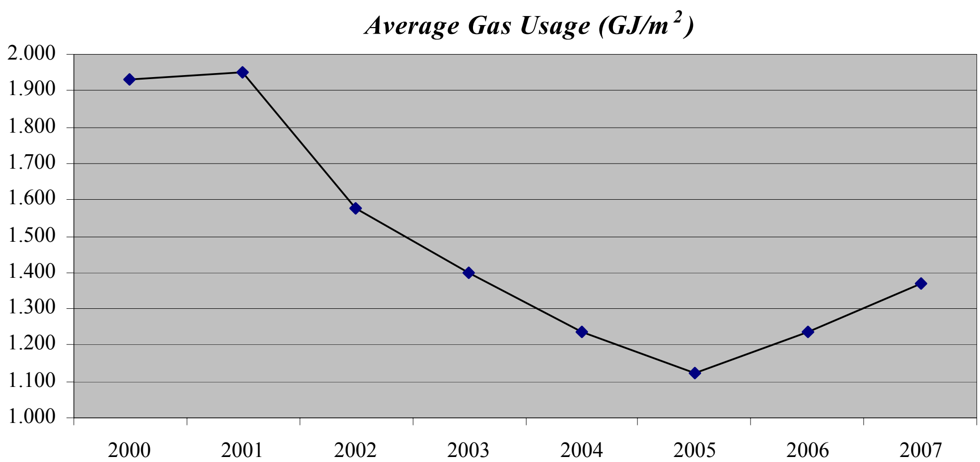

Figure 3 – Historical Annual Natural Gas Consumption

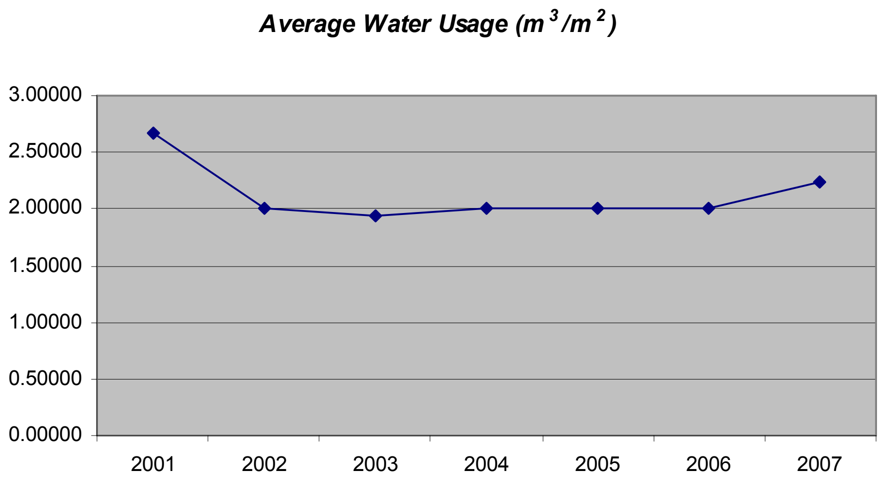

Figure 4 – Historical Annual Water Consumption

The historical utility consumptions were converted to equivalent tons of CO2 equivalents (tCO2e) using the conversion parameters in Table 5:

Table 2 – Tons of CO_2 Equivalent Conversions

Utility	Electricity Consumption (MWh)	Natural Gas Consumption (GJ)	Water Consumption (m^3)
$tCO_2e/unit*m^2$	915/MWh	0.08/GJ	$0/m^3$*

* - treatment, distribution, sewerage energy were discounted as these figures were unavailable

The resulting historical tons of CO_2 equivalents are shown in Figure 5:

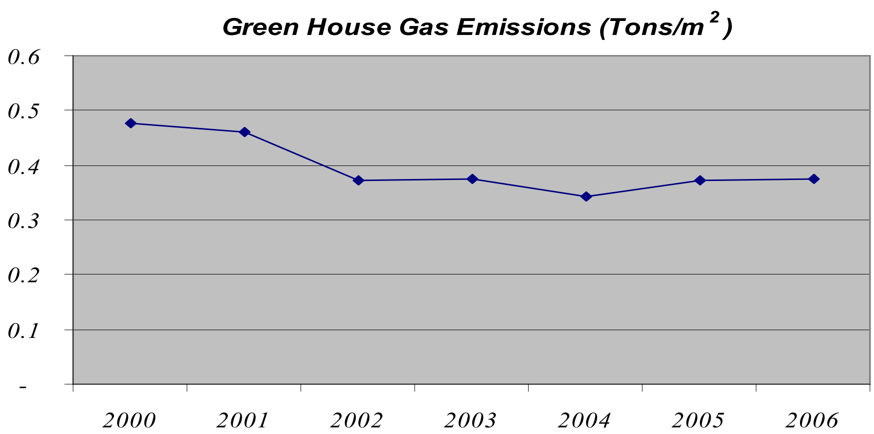

Figure 5 – Historical Tons CO_2 Equivalents

The baseline was chosen as the most stringent value over the prior five years (2002 – 2007). The resulting baseline for the Airport was set as shown in Table 3:

Table 3 – Baseline Figures for Net Zero Comparisons

Utility	Electricity Consumption (kWh/m^2)	Natural Gas Consumption (GJ/m^2)	Water Consumption (m^3/m^2)	CO2e Generation (tCO_2e/m^2)
Baseline	306	1.12	1.93	0.34

A benchmarking study of airports within the Canadian context was simultaneously undertaken at the following airports – Edmonton, Montreal, Ottawa, Toronto, and Vancouver. The results of this study were not available at the time of writing of this paper.

3. Energy/Utility Consumption Models

Several techniques were used to generate energy and utility consumption models. Energy and electrical consumption models were developed using the TRNSYS 16.1 simulation package, and water consumption models were developed using the Canadian Green Building Council (CaGBC) simulation calculations.

The expansion scenario includes a new three level Concourse E, shown in Figure 6. With three levels, this addition will add approximately 72,000 m^2 to the terminal area, thus bringing the total terminal area to 213,648 m^2. This will be an increase of 51 % from the gross area in 2007.

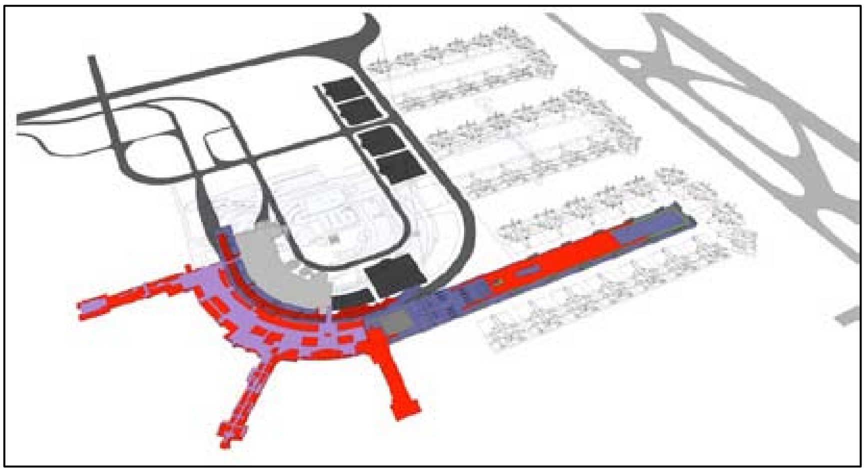

Figure 6 – Expanded Calgary International Airport

An initial 'calibration' consumption model of the existing terminal was developed to identify the deviation between the models used for determining the operating parameters compared to 2006 actual readings. The results of the calibration model, presented in Table 4, revealed an overall deviation of plus 28% for energy and minus 15% for water consumption.

Table 4 – Calibration Model Results

Utility	Power Consumption (MWh/year)	Heating Energy Consumption (MWh/year)	Cooling Energy Consumption (MWh/year)	Water Consumption (m^3/year)
Model	53,801	38,730	2,850	245,953
2006 Actual*	32,022	38,913	3,723	288,872

* - Normalized for Area

Subsequently, six models were developed, labeled V0 through V5. The following is a brief description and intent of each model.

Model V0 – This model represents the most basic form of development of the terminal and its concourses. No emphasis is placed on bettering the existing performance parameters of the facility. Existing envelope, mechanical and electrical systems are matched on the new Concourse E and only maintenance and repair/replacement of these systems are carried out during redevelopment of the existing terminal and concourses. The central plant and services remain in service and are expanded as required to meet the new loads.

Model V1 – This model adds sensible heat recovery to model V0 including the existing terminal. No water consumption reduction measures are taken. The central plant and services remain in service and are expanded as required to meet the new loads.

Model V2 – This model reflects significant upgrades to improve energy performance and water consumption. In this model, total (enthalpy) heat recovery is added to Model V0; moderate water conservation is undertaken by converting all fixtures to low flow water saving fixtures; the envelope of the entire facility, including the existing terminal, is upgraded to a high performance envelope through new construction and redevelopment; and day lighting controls are introduced. The central plant and services remain in service but are not expanded as there is no net increase in load.

Model V3 – Aggressive measures are introduced in this model. The fundamental HVAC systems are replaced with high performance, low energy systems (radiant slabs and displacement ventilation, hybrid ventilation), earth tube pre-conditioning on all new construction, enthalpy heat recovery is fully deployed, the envelope is upgraded, aggressive day lighting strategies employed and water consuming fixtures are converted to ultra-low flow and/or waterless technologies. Energy sources and services are decentralized to reduce distribution losses and to take advantage of 'point of use' efficiencies.

Model V4 – This model optimizes the energy sources and supply systems for Model V3. This involves tri-generation, rain water harvesting and grey water recycling.

Model V5 – This model introduces alternative energy sources, specifically photovoltaic power generation and the purchase of wind generated power to minimize GHG production.

A significant consumer of electrical power was the lighting allowance made for retail operations. The Authority had identified a vibrant retail component as being essential to the revenue generation opportunities for the airport. Building parameters applied to each model are listed in Table 5:

Table 5 – Model Building Parameters

	Model V0	Model V1	Model V2	Model V3	Model V4	Model V5
Lighting (Standard)	14 W/m^2	14 W/m^2	14 W/m^2	14 W/m^2	14 W/m^2	14 W/m^2
Lighting (Retail)	60 W/m^2	60 W/m^2	60 W/m^2	60 W/m^2	60 W/m^2	60 W/m^2
Auxiliary Power	10 W/m^2	10 W/m^2	10 W/m^2	10 W/m^2	10 W/m^2	10 W/m^2
Glazing Light Transmittance	50%	50%	70%	70%	70%	70%
Solar Heat Gain Coefficient	0.45	0.45	0.5	0.5	0.5	0.5
U Value	1.7 W/m^{2}K	1.7 W/m^{2}K	0.7 W/m^{2}K	0.7 W/m^{2}K	0.7 W/m^{2}K	0.7 W/m^{2}K
Shading	Internal	Internal	Reflective, Out of Space	Reflective, Out of Space	Reflective, Out of Space	Reflective, Out of Space
FC	0.95	0.95	0.25	0.25	0.25	0.25
Total SHGC (glass + shades)	0.43	0.43	0.12	0.12	0.12	0.12
Skylights	None	None	8% of Roof Area, Triple Glazed	8% of Roof Area, Triple Glazed	8% of Roof Area, Triple Glazed	8% of Roof Area, Triple Glazed
Roof U Value	0.45 W/m^{2}K	0.45 W/m^{2}K	0.26 W/m^{2}K	0.26 W/m^{2}K	0.26 W/m^{2}K	0.26 W/m^{2}K
Floor U Value	0.45 W/m^{2}K	0.45 W/m^{2}K	0.26 W/m^{2}K	0.26 W/m^{2}K	0.26 W/m^{2}K	0.26 W/m^{2}K
Opaque Façade U Value	0.7 W/m^{2}K	0.7 W/m^{2}K	0.37 W/m^{2}K	0.37 W/m^{2}K	0.37 W/m^{2}K	0.37 W/m^{2}K
Plumbing Fixture Type	Normal	Normal	Low Flow	Ultra Low Flow/Waterless	Rain Water Harvesting, Grey Water Recycling	Rain Water Harvesting, Grey Water Recycling

The results of the modeling exercise, by model, are shown in Table 6:

Table 6 – Model Annual Utility and Water Consumption Performance

	Model V0	Model V1	Model V2	Model V3	Model V4	Model V5
Heating	389 kWh/m^2	240 kWh/m^2	211 kWh/m^2	108 kWh/m^2	206 kWh/m^2	206 kWh/m^2
Cooling	51 kW/m^2	50 kWh/m^2	24 kWh/m^2	28 kWh/m^2	70 kWh/m^2	70 kWh/m^2
Electricity	349 kWh/m^2	349 kWh/m^2	251 kWh/m^2	208 kWh/m^2	-7 kWh/m^2	-61 kWh/m^2
Potable Water Consumption	1.246 m^3/m^2	1.246 m^3/m^2	0.817 m^3/m^2	0.600 m^3/m^2	0.472 m^3/m^2	0.472 m^3/m^2
GHG Production	0.46 Tons CO_{2e}/m^2	0.41 Tons CO_{2e}/m^2	0.31 Tons CO_{2e}/m^2	0.23 Tons CO_{2e}/m^2	0.08 Tons CO_{2e}/m^2	0.0 Tons CO_{2e}/m^2

Referring to Table 3 – Baseline, it can be seen that Models V2, V3, V4 and V5 present "Net Zero" solutions, referenced to current energy and water consumption, for the expansion and redevelopment.

4. Economic/Life Cycle Analyses

The true value of an investment is often not measured only in the capital cost, but in the long term benefits of systems impacted by the measures. The simulation models developed had Life Cycle Cost (LCC) analyses performed on each in order to gain insight into the long term costs associated with each proposal. These costs can then be used to compare the complete investment and annualized rate of return in terms of capital cost required vs. Net Present Value (NPV) of the running costs (cash flows).

Two tools were used to develop the LCC analyses: PACES and RETScreen. The PACES (Parametric Cost Engineering System) software is based on patented cost estimating techniques and is used to create cost estimates and LCC analyses early in the programming and design phase of a project. PACES uses pre-engineered model parameters and construction criteria to accurately predict construction costs using limited design information. PACES was used for the LCC analyses for models V0 through V3. RETScreen, developed by Natural Resources Canada, is a unique decision support tool developed with the contribution of numerous experts from government, industry, and academia. The software can be used worldwide to evaluate the energy production and savings, life-cycle costs, emission reductions, financial viability and risk for various types of energy efficient and Renewable Energy Technologies (RET's). RETScreen, in combination with PACES was used for the LCC analyses for models V4 and V5. Items that were not factored in the analyses include retail operations revenue, GHG credit values and productivity gains from employees. For the economic analyses, common parameters used for all models are summarized in Table 7:

Table 7 – Economic Parameters for Life Cycle Analyses

Item	Value
Year Existing Terminal Constructed	1976
Year Concourse E Constructed	2013
Year Existing Terminal/Concourses Redeveloped	2016
Year LCC Analyses Start	2008
Year LCC Analyses End	2025
Major Existing Terminal Upgrades	2002
LCC Analyses Centered on	Mid-Point of Timeline (2016)
Existing Terminal Area	126,348 m^2
Concourse E Area	72,000 m^2
Central Plant Area	6,040 m^2
Escalation Rate (Average for 2008 – 2025)	3%
Discount Rate/Capital Interest Rate (2008 – 2025)	3%
Blended Electricity Rate (2008 – 2025)	$0.095/kWh (based on lg. term Enmax Rates)
Blended Natural Gas Rate (2008 – 2025)	$8.63/GJ
Escalation on Utility Rates	0.01% (fixed rates for span of analysis)
Central Plant Labour Costs	$9.79/$m^2$ (no expansion to existing)
Central Plant Labour Costs	$14.63/$m^2$ (expanded to First Class Plant)

Figure 7 and Table 8 summarize the results of the analyses graphically and in tabular form.

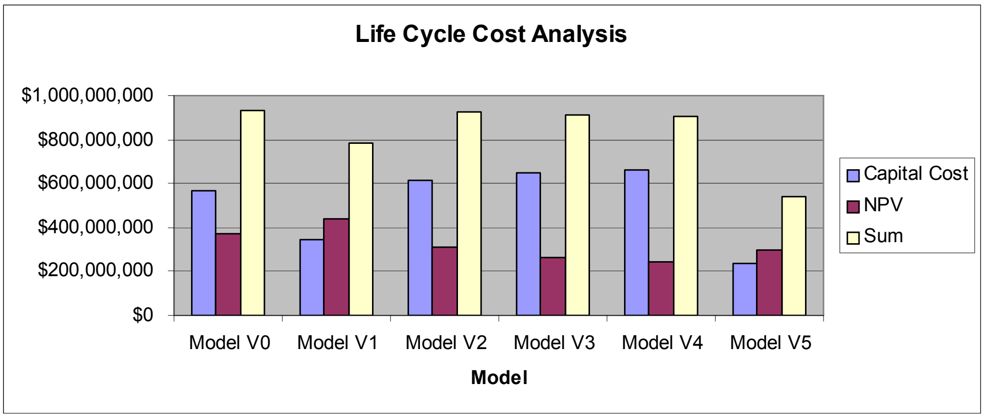

Figure 7 – Capital Cost vs. Net Present Value (NPV)

Table 8 – Annualized Return on Investment

	Model V0	Model V1	Model V2	Model V3	Model V4	Model V5
Capital Cost (2008 $'s)	$566,493,731	$574,840,356	$615,747,749	$647,100,873	$659,737,286	$704,748,571
NPV	$368,426,650	$347,775,157	$308,081,195	$261,985,439	$244,724,643	$238,741,626
Return	---	11.4%	5.6%	6.1%	6.1%	4.3%

From these results, several scenarios emerge. Model V1 shows the best annualized return on investment but does not meet the "Net Zero" criteria. Models V3 and V4 show identical annualized rates of return, and both meet the "Net Zero" criteria. Model V5 has the lowest annualized rate of return. Model V5 is the scenario where renewable energy sources are incorporated and the lower return is an indicator of the relative cost of this type of energy source compared to conventional sources in North America.

5. Ranking

In order to facilitate developing the ideal parameters for the Calgary Airport Authority for future development and redevelopment, a priority system was developed in consultation with the Airport Authority that weighed the importance of the overall parameters identified as critical to the decision making process.

Based on the Airport Authority's view of the level of importance each of these parameters has towards future expansions and/or renovations, the following priority system was established:

3 – High Level of Importance

2 – Moderate Level of Importance

1 – Low Level of Importance

Table 9 lists the parameters and their priorities as developed by the Calgary Airport Authority:

Table 9 – Ranking Parameters and Their Importance

Description	Priority
Capital Costs	3
Operating Costs	3
Redundancy	1
Ease of Implementation	2
Life Cycle Cost/Net Present Value	2
Industry Leadership	2
Environmental Stewardship	3
Reliability	2
Mechanical System Flexibility	1
Electrical Systems Flexibility	2
Airport Operations/Passenger Convenience	2
Ease of Plant Operation	1
Land Use Implications	1
Simplicity	1
Centralized Plant vs. Decentralized Plant	1

Once the parameters had been identified by the Airport Authority, a five point ranking system was developed to evaluate the effect that each model has on the parameters listed above. The five point ranking system was a sliding scale with a 5 meaning the model best met the requirements of the parameter and a 0 least met the requirements of the parameter. Each model rank was then weighted by the parameter priority value. The results of this ranking system are summarized in Table 10:

Table 10 – Ranked Models Based on Calgary Airport Authority Priorities

Parameter	V0	V1	V2	V3	V4	V5
Capital Costs	15	12	9	6	3	0
Operating Costs	0	3	6	9	12	15
Redundancy	0	1	2	5	3	4
Ease of Implementation	10	8	6	0	2	4
Life Cycle Cost/Net Present Value	2	6	4	10	8	0
Industry Leadership	0	6	4	6	8	10
Environmental Stewardship	0	3	6	9	12	15
Reliability	0	2	4	6	8	10
Mechanical System Flexibility	0	1	2	5	3	4
Electrical Systems Flexibility	0	2	4	6	8	10
Airport Operations/Pass. Convenience	0	2	4	10	8	6
Ease of Plant Operation	5	3	2	4	1	0
Land Use Implications	0	4	5	3	2	1
Simplicity	2	1	0	5	4	3
Centralized Pland vs. Decentralized Plant	0	1	2	5	4	3
Total Weighted Points	34	51	60	89	86	85

Based on the total sums Table 10, it can be seen that models V3, V4 & V5 resulted in a very close ranking score, where as models V0, V1 & V2 were collectively ranked significantly lower. This indicates that, based on the parameters outlined by the Calgary Airport Authority, the V3, V4 and V5 model options provide very similar benefits. From Table 10, model V3 has the highest ranking of the proposed modeling options. This proposed design option best addresses the factors outlined by the Calgary Airport Authority.

6. Conclusion

The comparative energy/utility consumption model results for annual primary energy consumption are presented in Figure 8. As can be seen, Models V4 and V5 achieve a 'net zero' status even at the primary energy level. Model V5 has the highest likely capital cost (and the highest degree of difficulty for implementation). Conversely, Model V0 has the highest consumption in all areas and the lowest capital cost and degree of difficulty for implementation.

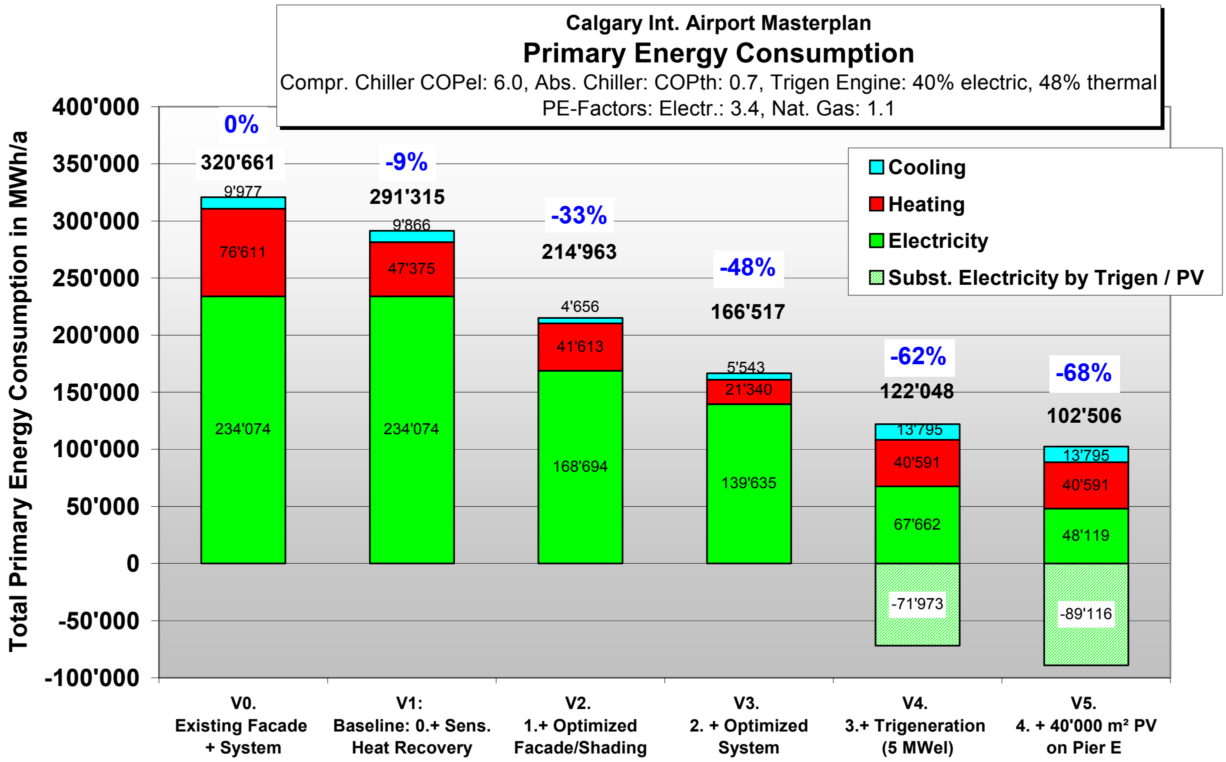

Figure 8 – Total Primary Energy Consumption for All Models

From a Net Present Value (NPV) point of view, Model V4 provides the best balance between capital and operating costs over the life of the model scenario. From the ranking criteria established with the Calgary Airport Authority, Model V3 met the most criteria; however Models V4 and V5 were very close. The annualized rates of return for Models V3 and V4 were identical. The preliminary recommendation to the Calgary Airport Authority was Model V4; achieving a "Net Zero" expansion and redevelopment (both in terms of site energy consumption and primary energy consumption) relative to the energy consumption of the existing campus; and an annualized rate of return on the additional capital cost that provides long term financial benefit. The Calgary Airport Authority has not yet adopted any recommendation.

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ENERGY SAVINGS: THE CLIENT AS CHANGE AGENT

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Keywords: client, users, innovation, network, energy, public policy

Summary

This study will show that clients ***can*** act as change agents in order to reduce the energy consumption in buildings, but not all strategies are equally successful and appropriate. In recent years, the construction client has been called upon by policy makers, the architectural, engineering and construction industry (AEC) and the clients themselves to become a change agent that can stimulate the required reduction of CO_2 emissions. Despite these calls for action, little is known about ***how*** clients can make a difference as change agents. Consequently, this study will critically assess the impact and success of the various strategies deployed by a group of Swedish clients and building owners forming a strategic innovation network in order to become change agents in construction and real estate. Based on documentary analysis and interviews, the analysis will draw on a combination of innovation theories dealing with the role of users, various constructivist approaches on the co-construction of technologies and users along with studies on procurement and the role of clients in changing the construction and real estate cluster.

1. Background

In Europe, 40 % of the total energy consumption is related to buildings. A number of public policies have been implemented in the European countries to reduce the total energy consumption (AID-EE EU project 2006b & 2006c). Despite the impact of these public policies, it has also become clear that further actions from the construction industry itself are necessary to achieve the desired goal of reducing CO_2 emissions. However, it is widely recognized that the construction industry suffers from a low level of innovation. Thus, in recent years the client has been called upon by policy makers, the AEC (Architectural, Engineering and Construction) industry and the clients themselves to become change agents that can stimulate the required reduction of CO_2 emissions.

These calls are now manifesting themselves in various forms like the governmental building policy for public clients in e.g. Denmark and the Netherlands, the revaluing construction initiative of CIB and the establishment of the International Construction Clients Forum (ICCF) as well as a similar network for public real estate owners (PURE-net). Despite these calls for action, little is known about ***how*** clients in practice can make a difference as change agents.

This study will analyze how a group of Swedish clients and building owners have attempted to become a collective change agent by forming a strategic innovation network named BELOK in order to reduce energy consumption in commercial facilities. Further, the study will critically assess the impact and success of the various strategies deployed and the tools developed by the strategic innovation network of clients.

2. Research design

The research design of this study includes data from two main sources. First, this study is based on an analysis of a range of documentary sources: Public policy documents, strategic policy documents of the organization, minutes from steering committee meetings 2001-2007, the internal and the external part of the website of the organization as well as reports, articles and tools from various research and development projects initiated by BELOK.

Second, this study is based on five evaluation meetings held from August to October 2007 with 2-10 participants and representing 3 BELOK members, 4 from the BELOK administration (chairman, coordinator, Swedish Energy Agency and the Swedish Construction Clients Association), 5 other members in the BELOK Committee and 4 participants in BELOK projects. The evaluation meetings were supplemented with informal correspondence by email with the secretariat of BELOK as well as the coordinator and the chairman of BELOK. Last, the pre-conclusion was presented at the BELOK steering committee meeting 12 October 2007 and at the BELOK meeting no. 29 on 14 November 2007, both in Stockholm.

3. Theoretical framework

If we scrutinize the slogan of 'the client as change agent' closer, the three keywords of the slogan will point at key issues and research questions dealt with in different strains of theoretical and empirical studies:

- The keyword 'client' may translate in to the field of 'construction procurement' dealing with issues related to e.g. procurement systems, contractual arrangements, trust and conflict resolution.
- The keyword 'change' may translate in to the field of 'innovation' dealing with issues related to the nature of innovations, drivers of innovation, innovation process and innovation systems.
- The keyword 'agent' may translate in to the field of 'agency' dealing with the dualism of actors and structures in relation to the role as users, clients and stakeholders.

Consequently, the analysis will draw on a combination of insights from these three specialized fields of inquiry. More specifically, the study will draw on a combination of innovation theories dealing with the role of users most notably the concept of lead users, various constructivist approaches on the co-construction of users and technologies, and the role of clients in changing the construction industry as dealt with by the CIB Task Group 58 and the literature on construction procurement.

3.1 Construction procurement: the role of the client

For the past 20 years or so, the Working Commission WO92 on Procurement Systems within the International Council for Research and Innovation in Building and Construction (CIB) has discussed the issue of construction procurement. The focus of WO92 has largely been on the proper design of procurement systems so as to ensure the best performance of the building.

In 1999, the present coordinators of WO92 (Rowlinson & McDermott eds. 1999) edited a thorough overview of procurement systems. First, the collection describes the background of WO92 and introduces the key issues, which have emerged through time like procurement strategies and systems, contractual arrangements, forms of contract and the nature of the construction process. The second part deals with organizational issues in procurement systems with a focus on e.g. the client organization, strategic briefing, value management, organizational design and project success factors and organizational learning. In the third section, emergent issues in procurement systems are approached like the importance of culture, sustainability and the use of new web-based technologies. Finally, the anthology deals with procurement systems in practice in relation to partnering as well as methods and criteria for evaluating and selecting contractors.

While WO92 has largely focused on the proper design of procurement systems so as to ensure the best performance of the building, attention has increasingly been turned towards using procurement to stimulate innovation for example as an element in a public demand-oriented innovation policy (see e.g. Edler & Georghiou 2007). Manseau & Seaden (eds. 2001) sampled an international collection of papers and studies from CIB Task Group 35 focusing on how public policies can stimulate and support innovation in construction.

Most notable internationally is the establishment of the CIB Task Group 58 on client and construction innovation and the 'clients driving construction innovation' conferences in Australia (see e.g. Brown et al. 2005 & 2006).Despite the quality of the individual papers, most of the contributions tends to focus on the subject matter e.g. information and communication technologies, sustainability or performance assessment rather than discussing the concept of the client and how clients act as change agents.

In Sweden, the Swedish Association of Construction Clients has been highly engaged in developing projects and programs to gain experiences with the client as a change agent. In 1997, the Swedish Academy of Engineering Science in collaboration with leading building owners and clients published a highly influential study on organizational competences for clients. The report (IVA 1997) suggests that the client must maintain a broad spectrum of competences in order to manage planning, execution and operation of a building. The report (IVA 1997) goes on to identify the competences needed by a client in order to handle the relationship with the owner, the customer, society and the building sector.

3.2 Innovation management: the client as user

According to Dodgson, Gann & Salter (2002), the literature on innovation management has dealt with four questions. First, researchers have analyzed the nature of innovation activities by asking questions on whether innovations are radical/incremental, continuous/discontinuous, has transilience in its effects on existing ways of doing things, changes over life-cycles, are modular/architectural (systemic), results in dominant designs, or is sustaining/disruptive. Second, other approaches consider the sources of innovation which can broadly be grouped in the science-push model, the demand-pull model, and the coupling model. Third, approaches related to analysis of the innovation process include the chain-linked model, the innovation journey, and various innovation management approaches focusing on organizational integration, technology strategies and knowledge management. Fourth, approaches concerned with innovation systems has focused on systems of innovation on a national, regional, sector and technological level, analyses of networks to which firms belong, and the integration of complex product systems.

Within the demand-pull model, von Hippel (1986) has been highly influential in showing the importance of users in the development of new technologies. Von Hippel (1986: 791) has in particular introduced the concept of lead users:

"Lead users are users whose present strong needs will become general in a marketplace months or years in the future. Since lead users are familiar with conditions which lie in the future for most others, they can serve as a need-forecasting laboratory for marketing research. Moreover, since lead users often attempt to fill the need they experience, they can provide new product concept and design data as well."

Another important concept introduced by von Hippel & Katz (2002) is toolkits for user-centred innovation. Von Hippel & Katz (2002) stress that traditional product development, where manufacturers first uncover users' needs and then develop responsive products, is insufficient, because the users needs change rapidly. By using toolkits the manufacturers have given up the idea, that they can understand the users need in detail. To illustrate the toolkits they use the pizza as an example, where many aspects of the design such as the dough and the sauce have been made standard, and the user choice has been restricted to the single task of designing the topping. Von Hippel & Katz (2002) found that toolkits for user innovation are applicable to essentially all types of products and services with many different user demands. Von Hippel & Katz (2002) stress some conditions that influence the use of the toolkit: It is important that the toolkit is designed in a way that leaves room for “learning by doing via trial and error”, there has to be an appropriate "solution space", the toolkit shall be "user-friendly", there may be module libraries, and lastly there may be a problem in translating user designs into production specifications, because of difference in language, context, elements etc. so the toolkits have to be convertible between user and production.

3.3 Agency and structure: mutual shaping of clients/users and technologies

Since the 1980s it has been argued within science and technology studies (STS), that technology is socially shaped and designed. The point of departure in STS is that technical objects and social relations are bound together and that actors and technology are co-constructed. The distinction between the social and the technical is not given beforehand, but is the result of a mutual shaping process (Bijker et al. 1987; Bijker & Law eds. 1992). Various sociologists and historians of technology have put the image of a modern society created and built by experts, scientist and engineers under pressure. By emphasizing the developments in daily life and the use of new products, the users have been made visible as co-constructers of the modern technology society. In the following some of the different perspectives of the role of the users are described.

Pinch & Bijker (1984) were some of the first to include the users in technology development by introducing the concepts of interpretative flexibility and relevant social groups. In the now classical study of the birth of the bicycle, Pinch & Bijker (1984) illustrate how other perspectives and groups than engineers, designers and scientists enter into the design process by defining problems and develop solutions interpreted through respective technological frames of the groups. The technological frames guide thinking and interaction within and between the different relevant social groups.

Based on a collection of papers from various theoretical starting points, Oudshoorn & Pinch (eds. 2003) attempt to bridge various approaches to the co-construction of users and technology. First, the collection of papers addresses the active role of users as well as resistance and non-use in shaping socio-technical change. Second, focus is on the multiple collectives like advocacy groups and experts who attempt to speak on behalf of the users and the ways in which they represent the diversity of users. Third, focus is turned towards the multiple locations where the configuring of users in the development of technology is taking place. These locations include the design phase of a new technology, testing by clinical trials of drugs and the mediation process between production and consumption, in which mutual articulation and alignment of product characteristics and user requirements is taking place. In sum, although the collection of papers show the creative agency of users in shaping socio-technical change, the studies also show how agency is constrained by government regulations, gender relations etc.

In a previous paper on industrialized single-family house building, Haugbølle & Forman (2006) has shown just how relevant this perspective is for a renewed understanding of the role of the client/user/owner/facility manager etc. as multi-centred. That is, users of single-family houses hold multiple perspectives or focal points which are time-dependent in two ways since they are coupled to the life-cycle of the building as well as the life-cycle of the actor. Further, the different positions will interfere with each other.

4. The case of BELOK: A strategic innovation network

In the following, we will address BELOK as a strategic innovation network dealing with the organization of the network, the development activities being carried out, how the results are being disseminated and the effects of the activities of the network.

4.1 Organization of BELOK

The Swedish government has a national vision of reducing the energy consumption by 20 % from 1995 to 2020 and 50 % from 1995 to 2050. To fulfill this vision, the Swedish Energy Agency has among other means applied a technique procurement strategy (Swedish Energy Agency 2007) as well as cooperation with selected groups of innovative purchasers like BELOK to develop and disseminate energy efficient techniques and methods. Hence, BELOK was established in 2001 on the initiative of the Swedish Energy Agency in collaboration with leading clients and building owners of commercial facilities. The vision, mission and objectives of BELOK are (www.belok.se):

– BELOK is a group of leading building owners carrying out projects on real estate for commercial purposes, which leads the way for reducing energy consumption combined with improved functionality and comfort in the building.

– BELOK supports promising and energy efficient products, systems and methods and create the necessary conditions for implementation and fast introduction to the market.

– BELOK energy solutions must be cost effective, so that the long-term cost balances the energy profit.

– BELOK projects are followed up by evaluation and monitoring the realized energy improvements and their influence on the functionality of the building.

In 2007, 13 commercial real estate owners are members of BELOK, and eight of them have been members since the establishment of BELOK. Five companies are private, two companies are owned by regions and six companies are owned by the government. No members are from municipalities in Sweden. BELOK has got five new members the last five years, and one company has withdrawn its membership in the same period. Although the number of members is fairly small, the 13 BELOK members own 17 % of the total segment of 155 million m^2 heated area of commercial facilities. Further, the 13 BELOK members own buildings at a total market value of 263 billion SEK, and in 2006 the yearly investment by the 13 BELOK members reached 19 billion SEK or 32 % of the total investment in commercial facilities. Thus, the BELOK members represent a significant share of the market for commercial facilities.

The driving force in BELOK is a group of enthusiastic and committed representatives for owners of commercial facilities supported by a chairman and a secretary, all with high technical, research and commercial competences. Since 2005, BELOK has been hosted by the Swedish Construction Clients Association, which is an organization of about 120 professional private and public owners and landlords in Sweden. The board, called the BELOK Committee, has 8 members including one from the Swedish Energy Agency and one from the Swedish Construction Clients Association.

Since 2005, the BELOK Committee has been responsible for drafting two-year development programs and selecting relevant development projects to be initiated. The latest program covers the period 2007-8 with a total budget of 25 million SEK of which 9 million SEK is granted from the Swedish Energy Agency and the remaining 64 % is financed by BELOK members. Although the two-year programs are formally approved by the Swedish Energy Agency, autonomy is de facto granted to the BELOK Committee to make the decisions regarding new projects etc.

The regular appropriation of new development programs by the Swedish Energy Agency for BELOK and the delegation of professional decision-making to the BELOK Committee have been essential for the success of BELOK. All interviewees highly praise the Swedish Energy Agency for the way they support BELOK and the strategy of using the innovative real estate owners as brokers for implementing new and improved energy technology and methods in the construction and real estate sectors.

Suppliers and participants in BELOK projects support this strongly and add, that BELOK is an excellent venue for meeting new suppliers and ideas, where they have the opportunity to get vital experience in front-running projects and to be accepted by a strong group of buyers. Under normal circumstances it would be impossible for them to penetrate the market so quickly.

4.2 Development activities

It is a characteristic of the innovation process that the majority of projects are primarily based on 'a good idea' developed by technicians, based on technically based research and in close collaboration between the main partners in the supply chain and the professional customer – the owner and member of BELOK. This practice, however, has a number of implications.

First, the development projects initiated by BELOK can be divided into two main categories. Until today, BELOK has launched 15 technical product-oriented projects and 8 process-related development projects. Technical projects like the development of HVAC installations and glass façade systems dominate the portfolio of development projects. Among others, the technical projects include:

– Office building with glass facades.

– Ventilation with variable air flow.

– Electro filter in ventilation.

- Chilled beam systems in cooling towers.
- Consumption of electricity.
- Control and monitoring systems.

Management and process-related projects play a smaller role in BELOK compared with technical product projects. Among others, the process-related projects include:

- BV^2-Arch - Energy design of building.
- Demands and specifications.
- Energy management and declaration.
- Tenancy contracts with incentives.

BELOK has put less effort into the process-related projects compared with the technical product-oriented projects, and the evaluation indicates that process projects are more complicated for BELOK to implement. Improved and more efficient processes are a supplement to product development and supporting the dissemination of new energy efficient technologies. It is therefore important for BELOK to improve the process developments in the future. Thus, a challenge for BELOK could be to improve the processes by putting more focus on the needs of the individual target groups and to fulfill specific objectives for development of communication, competence and energy efficient attitudes.

Second, the type of innovations addressed by BELOK tends to be incremental in nature, thereby reducing the associated risk for the involved actors. All development and demonstration projects are based on a solid technical research background, and they are only initiated if they appear to be ready for introduction on the market. More risky projects are seldom initiated, and at least once BELOK felt obliged to stop a project because it did not rest on solid technical ground and was not mature for market introduction.

Third, certain perspectives like the perspective of end-users are largely left out of sight due to the close collaboration with the main partners in the supply chain. All development and demonstration projects are based on a solid research background, and they are executed mainly by technicians and researchers. The documentation and information are aimed at the same group. It is noticeable that far less attention has been paid to the operational end-user in facilities management, how to improve the design and construction process, and how the results could be disseminated to other owners, internally in BELOK companies as well as to other consultants, contractors and suppliers. The result is that more simple and user-oriented information materials is lacking regarding state-of-the-art and actions to be taken for others than the front-runners and the technicians.

4.3 Dissemination

When looking at the dissemination activities of the BELOK network it is worth considering which groups are the target groups of dissemination and information activities. Six target groups may be identified:

- 1. Internally in BELOK companies.
- 2. Between BELOK members.
- 3. Other owners and projects.
- 4. Researchers, universities and schools.
- 5. Technical suppliers.
- 6. Consultants and contractors.

BELOK has carried out a number of dissemination activities, but the predominant method is through internal meetings aimed at the members of BELOK. The stability and commitment of participants in the work of BELOK is noticeable. Since the start of BELOK in 2001, 28 meetings have been held. Seven persons have participated in 75 % or more of these meetings, and they include the chairman, the secretary and the representative of the Swedish Energy Agency. The last four old member companies have participated in around 50 % of the meetings. Three of the new members have participated in 75 % or more of the meetings since becoming members of BELOK, and the last two new members have participated in around 50 % of the meetings. Eight member companies have been represented by only one person in the BELOK meetings, and the rest has been represented by two to four persons.

Frequent interaction is ensured by two-day meetings four times a year, where ideas are turned into action and development projects in an open and friendly atmosphere between professional colleagues. Especially the person to person discussions and exchange of experiences during breaks and in the evening are important. Several interviewees expressed the importance of the informal discussions between the members and the Swedish Energy Agency, and that the Swedish Energy Agency are faithful participants at both BELOK meetings and the BELOK Committee. It is also important that decisions are made on technical and professional grounds and linked directly to demonstration projects and developments on site. Some interviewees even considers the meetings and the professional contacts and discussions as their most important training venue as innovative owners.

Whereas commitment and frequent interaction marks the internal dissemination of results and lessons learned, the external dissemination to actors outside BELOK tends to be more random hitherto. Results and lessons learned from the development of techniques, products and processes are important to disseminate to the individual partners in the sector if the effect should be measurable not only in the development projects but in all commercial facilities in Sweden. Although BELOK recognize the importance of external dissemination to other actors in the construction and real estate cluster, there does not seem to be a clear strategy and operational plan for dissemination from the creative and innovative members in BELOK to other building owners, consultants, suppliers etc. The BELOK website is the main channel for disseminating information from BELOK, but also seminars and competitions on technique procurement are channels for dissemination. However, BELOK does not use e.g. newsletters or professional trade courses as means to communicate results and lessons learned.

First, the BELOK website gives information on all finished projects and projects in progress. Specific tools like BELOK life cycle costs calculation and early energy calculation for architects – BV^2-Arch – can be downloaded free of charge. Common demands and specifications on indoor climate, energy and control and monitoring systems can also be downloaded from the website free of charge. The website also contains a list of members and the description of the BELOK organization with contact addresses. On the front page latest news and cross-reference to the archives of news are given. Managing and updating the website regularly has turned out to be more challenging than anticipated. Thus, BELOK has now hired an external supplier to help improve the website with a monthly updating.

Second, the number of public seminars held by BELOK in 2006 and 2007 has been modest. On the website, information is given on two seminars held in September 2006 and in May/June 2007. The first seminar discussed results on daylight and sun shutters. The second seminar discussed energy consumption, indoor climate, daylight and life cycle cost in glass office buildings. No information is given on the website on new seminars, workshops or site visits to be held in 2007 or 2008.

The third dissemination channel for BELOK is the technique procurement and the announcement of a competition, the winner and the winning project. The competition is part of the technical procurement method that the Swedish Energy Agency uses to improve energy efficient methods and new techniques (Swedish Energy Agency 2007, Persson 2004), and it is followed up by installation, testing and evaluation. BELOK has completed two competitions: one competition on BV^2-Arch and one on control and monitoring systems. The competition on technique procurement proves to the market that BELOK is an important player in the development of commercial building and demonstrates in practice the vision for future techniques, product, tools and processes. At the same time the innovative owners demonstrate their willingness to make energy efficient decisions and buy new energy efficient techniques and processes. The interviewees gave the impression of a successful process that was completed and reported in a professional way but with a number of practical challenges for future improvement like readiness of technologies, sufficient number of competitors and the specifications and the evaluation methods must be documented in advance and fit for the owner and consultant in the decision process.

4.4 Effects

The previous chapters have dealt with the first three out of four bullet points regarding the vision, mission and objectives of BELOK. Now, the attention will be turned towards the last bullet point stating that BELOK projects are followed up by evaluation and monitoring the realized energy improvements and their influence on the functionality of the building.

BELOK is facing a serious challenge of measuring and documenting the overall effect of BELOK and the individual development projects. Scrutinizing the few reports from the finished projects, reveal a number of problems in assessing the results, fixing the reference points and calculating the specific and future cost and energy savings compared with traditional techniques and processes. A similar observation was reported in 2006 by Lars J. Nilsson (AID-EE EU project 2006a) in a European study on energy efficiency policies (AID-EE EU project 2006b & 2006c).

The observed and reported problems of measuring the effect of the finished projects stems from earlier phases of the project, when the development projects were formulated and selected. In the selection process, measurable targets for energy improvements, indoor climate and cost reductions ought to be set if consistent assessments are to be carried out at the end of a project. Further, it should be described how it could be tested in the process and the delivery of the product. However, some of the BELOK projects set vague targets for energy consumption, and only a few of them describe the investments and savings in costs in a measurable way.

Thus, there appears to be little overall reflection on the cost-effectiveness of the individual development project. Often key issues related to dilemmas of investment cost versus life cycle costs as well as reduction of energy consumption versus improved indoor climate are not sufficiently dealt with in the project proposals. Further, the development projects are not primarily initiated because they add substantially to the fulfillment of objectives set in the national vision for energy consumption. Instead 'the good idea' and the technical maturity are more important concerns. Consequently, the initiated development projects do not necessarily provide 'best value for money' when it comes to parameters like low investment costs, quick dissemination, large reduction in energy consumption and large market shares.

The current situation is quite understandable. If BELOK starts claiming measurable targets for improvement in the energy consumption and long-term cost compared with a traditional technique and process, the energy and cost targets together with other performance parameters must be evaluated and reported in a systematic way by the owner and supplier. However, such a system for consistent and systematic evaluations does not exist at present. Thus, an important challenge for BELOK could be to develop simple and cost effective methods for different types of evaluations.

5. Conclusion

This study has analyzed how a group of clients have formed a strategic innovation network in order to act as change agent in the construction and real estate industry cluster with respect to improving energy performance of commercial facilities. The study has shown that clients ***can*** act as a change agent in order to reduce energy consumption in buildings, but not all strategies and tools are equally successful and appropriate. A number of observations lead to four lessons learned regarding ***how*** the client acts as change agent.

First, the driving force in BELOK is a group of enthusiastic and committed representatives for owners of commercial facilities, which represent a significant share of the market. The delegation of professional decision-making power and the regular appropriation of new development programs from the Swedish Energy Agency to BELOK have been essential for the strategy of using the innovative real estate owners as brokers for energy efficient technologies in the construction and real estate cluster. Suppliers and other participants in BELOK projects add that BELOK is an excellent venue for acquiring new vital experience in front-running projects and to be accepted by a strong group of buyers. Thus:

> *Lesson no. 1: If a strategic innovation network based on strong personal commitment is linked together with regular appropriation of public funding and decision-making power, (some) clients can and will act as change agents in the construction and real estate cluster.*

Second, the study has shown that the innovation process is primarily based on 'a good idea' developed by technicians, based on technically based research and in close collaboration between the main partners in the supply chain and the professional client. Some of the implications of this practice are: less effort into the process-related development projects, risk reduction and largely leaving out of sight certain perspectives of e.g. end-users. Thus:

> *Lesson no. 2: Clients are likely to undertake technical product-oriented and incremental innovations rather than process-related and/or radical innovations.*

Third, the internal dissemination activities of BELOK are strongly supported by the small, stable and committed group of actors along with the frequent interaction of that group. The external dissemination activities are, however, more random in character. That raises an important strategic question of what role should BELOK play as change agent: Do clients as change agents pull the rest of clients and/or do they push the supply chain? And how will they do that – by outdoing other actors, by active involvement of other actors, or by informing other actors of results and showing alternative routes? Clients need to be very aware of the differences and how they e.g. communicate in the different settings. Thus:

> *Lesson no. 3: In the role as change agent, clients need to carefully observe the balance between the double ambition of pulling/pushing the supply chain and pushing/pulling other clients.*

Fourth, BELOK is at present faced with the challenge of measuring and documenting the overall effect of BELOK and the individual development projects. Targets and results are not sufficiently set and described in a systematic manner, and there appears to be little overall reflection on the cost-effectiveness of the individual development project. Instead 'the good idea' and the technical maturity are more important concerns. Consequently, the initiated development projects do not necessarily provide 'best value for money'. Thus:

> *Lesson no. 4: The engagement of 'the good idea' needs to be linked closely with strategic objectives and systematic assessment of effects.*

In conclusion, BELOK pull the innovation in the real estate market and in the construction sector supported by universities by formulating common demands and specifications for better products, processes and knowledge. They implement new and better products and processes, and by good examples they demonstrate the effect on improved energy efficiencies, indoor climate and the long-term economy for the owner and end-user. They are also playing a role in the dissemination from the best owners to the rest of the real estate market, and to the construction and building products markets through supporting the best and most innovative consultants, contractors and producers.

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www.belok.se

CLIENT-LED SUSTAINABLE CONSTRUCTION: DECISION SUPPORT FOR WHOLE-LIFE COSTS IMPLICATIONS

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Summary

The client's role in leading change in the construction industry has been widely perceived as crucial and, on the theme of sustainable construction, it is advocated that clients must play their role to lead in engaging industry stakeholders in managing sustainable performance of construction projects. In essence, it is the client that makes the initial decision to procure construction works and the way in which procurement takes place. This influences the degree of environmentally-friendly (or sustainable) practice that is implemented in a project. For most building owners and property developers, this decision is affected by cost. And, in view of the significance of cost, the on-going research aims to ascertain the main type of developments that have been awarded the Green Mark, as well as study their winning green features. A proposed rule-based system that contains decision-support rules pertaining to the assessment of (whole-life) cost implications for this type of building projects is described. The system is to be developed to meet the criteria of Singapore's Green Mark Scheme. The Scheme has been devised and implemented by the Building and Construction Authority since January 2005.

1. Introduction

The Green Mark Scheme is a green building rating system used to evaluate a building, new or completed, for its environmental impact and performance. In each case, the assessment is based on five key criteria looking at levels of energy efficiency, water efficiency, site or project development and management (for new buildings) or building management and operation (for existing buildings), good indoor environmental quality and environmental protection, and environmental innovation. A point scoring system is used to quantify and ascertain the extent of environmental friendliness of the new or existing building.

Since January 2005, a total of 60 building projects have been awarded the Green Mark and they ranged from public to private developments, including residential, institutional and commercial types. Broadly intended, the scheme was developed by the Building and Construction Authority (BCA) of Singapore to promote sustainable development by raising environmental awareness among all participants in the construction industry, particularly, property developers, designers and contractors.

2. Aim and Objectives

In this paper, the research aims to ascertain the main type of developments that have been awarded the Green Mark, as well as study their winning green features. A proposed rule-based system that contains decision-support rules pertaining to the assessment of (whole-life) cost implications for this type of building projects is described and to be developed to meet the criteria of Singapore's Green Mark Scheme. Specifically, the objectives are as set out below.

a. To classify projects that have been awarded the Green Mark by types of development and client;
b. To compare the actual classification of projects with the theoretical classification;
c. To ascertain the type of developments that has the largest number of projects which have been awarded the Green Mark;
d. To classify the green features of this type of developments based on projects which have been awarded the Green Mark by building element; and
e. To map the BCA's Green Mark Scheme onto applicable components of whole-life costs by building element to develop rules for the proposed decision-support system.

3. Types of Clients

Traditionally, clients of the construction industry have been classified by interest and motivation in order to better understand their needs in a proposed development. The motivating factors can range from profit to social and use (Ferry et al., 1999). Now, in the contexts of sustainable construction and whole-life costs, the client's responsibility is broadened to encompass environmental impact concerns. The logical argument is that it is the client who makes the initial decision to procure construction works and the way in which procurement takes place. This influences the degree of environmentally-friendly (or sustainable) practice that is implemented in a project. For most building owners and property developers, this decision is affected by cost. Hence, there becomes an increasing pressure for clients to consider whole-life costs in their projects so as to attain overall best value.

From a review of the relevant literature to draw logic on areas of types of clients, sustainable construction and whole-life costs (Bathurst and Butler, 1980; Seeley, 1981; Addis and Talbot, 2001), a mapping of the degree of importance of sustainable construction and whole-life costs onto the different types of clients can be done. Essentially, it is a mapping based on theoretical assumptions. And as verification of the assumptions, classification of the types of projects that have been awarded the Green Mark from 2005 to 2007 will be made to establish the actual practice of different types of clients in Singapore. Table 1 shows the result of this theoretical mapping.

Table 1 Theoretical Mapping of Interest in Sustainable Construction and Whole-life Costs onto Different Types of Clients

	Public-Sector Clients	Private Occupiers (eg. Private Individual)	Private Occupiers (eg. Private Companies)	Private Property Companies
Type(s) of Development	Institutional Residential Industrial Commercial	Residential	Industrial Commercial	Residential Industrial Commercial
Interest in Sustainable Construction/Best Value Concept	Yes	No → Little	Little → Yes	Residential – No Industrial & Commercial – Yes
Interest in Whole-Life Costs	Yes	No → Little	Little → Yes	Residential – No Industrial & Commercial – Yes

Source: Author

4. Classification of Projects Awarded the Green Mark

Projects that have been awarded the Green Mark can be found in the BCA's website. The lists for projects awarded in 2005, 2006 and 2007 are used for the purpose of generating the classification by type of developments as shown in Table 2. There are altogether 60 winning projects that have been classified.

Table 2 Classification of Green Mark Projects by Type of Developments

Year of Award	Institutional	Residential	Industrial	Commercial
2005	3	8	1	5
2006	5	8	1	3
2007	5	11	2	8
Total = 60	13	27	4	16

From the mapping of interest of clients as shown in Table 1, the winning projects are also classified by type of clients to check and verify the theoretical assumptions made. The generated classification is given in Table 3.

Table 3 Classification of Green Mark Projects by Type of Clients

Year of Award	Public-Sector Clients	Private Occupiers (eg. Private Individual)	Private Occupiers (eg. Private Companies)	Private Property Companies
2005	3	0	1	13
2006	5	0	1	11
2007	6	0	2	18
Total = 60	14	0	4	42

As the category 'Private Property Companies' has the largest number of projects (i.e. 42), a breakdown is provided in Table 4 to show the distribution of projects among four main types of use. It is evident that private residential projects have the highest count (i.e. 26).

Table 4 Breakdown of Projects by Type of Use for the Category 'Private Property Companies'

Year of Award	Office	Residential (eg. Private Condominium)	Hotel	Retail
2005	5	8	0	0
2006	2	8	1	0
2007	3	10	1	4
Total = 42	10	26	2	4

5. Adoption of Building Elements of Singapore Standard CP80:1999

The Singapore Standard CP80:1999 has been developed to serve the key purpose of allowing the exchange of data and information to enable communication of design, construction and contractual matters relating to cost via a uniform classification format. The development of the national standard in 1999 involved a review of international standards and an adaptation of a few international standards to suit local use. The main components of the national standard are:

a. an elemental classification,
b. a work-section classification,
c. a mapping dictionary for elements and work sections, and
d. a set of guidance notes.

The elemental classification is adopted for this research. It comprises three main divisions. They are the group element, element and sub element. An example of the classification of elements of the group element "Superstructure" is given in Table 5.

Table 5 Elemental Classification of the Group Element "Superstructure"

Group Element	Element	Sub Element
Superstructure	• Columns and structural walls	• Columns • Structural walls
	• Upper floors	• Slabs • Beams • Steps and ramps
	• Roof	• Roof structure • Roof coverings • Roof drainage • Roof lights
	• Staircases	• Staircase structure • Staircase finishes • Handrails and balustrades
	• External walls and cladding	• External walls • Cladding • Curtain walls • Windows
	• Internal walls and partitions	• Partitions • Acoustic walls
	• Doors	• Internal doors • External doors

The Building Cost Information Service of the Royal Institution of Chartered Surveyors defines an element as a component that fulfils a specific function or functions irrespective of its design, specification or construction. A classification based on elements achieves standardisation. Hence, it is applied as the framework for mapping the Green Mark Scheme onto applicable components of whole-life costs to develop rules for building the decision-support system.

6. Classification of Green Features of Private Residential Projects

From Table 4, it can be seen that a total of 26 Private Residential projects have been awarded the Green Mark since 2005 and it forms the largest group among the types compared. The research now focuses on this category of projects for a further analysis of their winning features in order to gain an appreciation of latest industry trends and practices on environmentally-friendly design and technology. The information is extracted from the BCA's website. The green features are classified according to the various group elements. The result is shown in Table 6.

Table 6 Elemental Classification of Green Features of Private Residential Projects

Group Element and Element	Examples of Key Winning Green Features
1. Site Preparation: Demolition Site clearance Earthworks Soil investigation	• Use of seawater for ground improvement works with substantial water savings.
2. Substructure: Piling Foundation Basement Ground Slab	• Construction using circular diaphragm wall utilises less manpower and strutting materials. • Extensive use of sunpipes to bring natural daylight to the 3 basement levels. • Basement carpark is designed with about 20% opening for natural light and ventilation. This eliminates the need to provide full mechanical ventilation and water sprinkler fire fighting system.
3. Superstructure: Columns and structural walls Upper floors Roof Staircases External walls and cladding Internal walls and partitions Doors	• Staircase shelter – utilizes less concrete and steel for construction and less materials for accessories. • 'Parabienta' Green wall system is used to vertically green part of the building façade on 2nd floor of the Development along footpath adjacent to Orchard Boulevard. The system is lightweight and provides consistent greening. • The use of environment friendly and recycled materials manufactured locally or overseas for doors and dry wall partitions. • Extensive green provided to some areas of the rooftop to help reduce heat gain to the topmost residential units.
4. Finishes: Wall finishes Floor finishes Ceiling finishes	• Thermal insulating paint to all external walls for entire development to reduce solar heat gain and energy consumption. • The use of environment friendly and recycled materials manufactured locally or overseas for rubber floorings.
5. Fittings, Fixtures and Furnishing: Sanitary wares and fittings Fixtures and furniture Artworks and sculptures Soft furnishing	• All units are provided with dual flushing system water closets. • The use of environment friendly and recycled materials manufactured locally or overseas for wardrobes.

6. Services Installations: ACMV Sanitary and plumbing Electrical installations Transportation Communications installations Security systems Fire protection systems Gas installations Maintenance equipment Pool and water feature installations Special installations	• Use of energy efficient equipments such as – energy efficient lightings in common areas, inverter air-conditioning system, motor-roomless lifts. • Use of twin-chute pneumatic waste system to encourage recycling. • All apartments are provided with inverter multi-split air-con systems. • All apartments are provided with dimmer controls for living/dining and master bedroom. • Solar powered system for heated pool and aircraft warning lights. • Gearless traction elevator. • Solar panels are provided at the rooftop to harvest solar energy and motion sensors are provided at strategic locations to help reduce energy consumption from the Grid.
7. External Works: Surface treatments Drainage External services Minor building works	• Solar-powered lamps for landscape and pool deck. • Transplanting of mature trees. • Use of recycled plastic in children's playground equipment. • Environmentally friendly lightweight plastic grid for turfing along fire engine access way. • Rainwater harvesting system for irrigation of landscape.

7. Mapping the Green Mark Scheme onto Components of Whole-life Costs

In order to develop rules for the proposed decision-support system, there is a need to map the requirements of the Green Mark Scheme onto applicable components of whole-life costs. These components include the initial capital costs, operating costs, maintenance costs, management costs, opportunity costs and disposal costs of the asset at the end of its life (Addis and Talbot, 2001). As there are many mandatory and elective requirements under the Scheme, it is only possible to illustrate the mapping for a few group elements. The result is shown in Table 7.

Table 7 Mapping of Green Mark Requirements onto Whole-life Costs Components and Implications

Group Element and Element	BCA Green Mark Version RB/3.0 Category and Points Allocation	Component of Whole-Life Costs and Its Implication
Superstructure: Columns and structural walls Upper floors Roof Staircases External walls and cladding Internal walls and partitions Doors	Mandatory Requirements: M1 Building Envelope – RETV: RETV shall not exceed 25 W/m^2. Mandatory Requirements: M2 Roof – U Value: Weight group: Light, under 50kg/m^2, 0.8 W/m^{2}K; Medium, 50 to 230kg/m^2, 1.1 W/m^{2}K; Heavy, Over 230kg/m^2, 1.5 W/m^{2}K. Mandatory Requirements: M4 Air Tightness and Leakage: All windows on the building envelope shall not exceed the air leakage rates as specified in SS 212.	For External Walls: Initial capital costs – High Operating costs - Low Maintenance costs – Low For Roof: Initial capital costs – Very High Operating costs - Low Maintenance costs - High

	Elective Part 1 – Energy Efficiency: 1-1 Building Envelope – RETV: Max permissible RETV=25 W/m^2; 3 points for every reduction of 1 W/m^2 in RETV from the baseline. 1-2 Dwelling Unit Indoor Comfort: (a)(ii) Design for natural ventilation (applicable to development where air-conditioners are not provided) (0.6 point for every 10% of units with window openings facing north and south directions; 0.6 point for every 10% of living rooms and bedrooms designed with true cross ventilation) Elective Part 3 – Environmental Protection: 3-1 Sustainable Construction: (a) More efficient concrete usage for building components (0.1 point for every % reduction in the prescribed Concrete Usage Index (CUI) limit for residential buildings). Elective Part 5 – Other Green Features: 5-1 Green Features and Innovations: Self cleaning façade system (2 points for high impact item; 1 point for medium impact item; 0.5 point for low impact item).	
Finishes: Wall finishes Floor finishes Ceiling finishes	Elective Part 1 – Energy Efficiency: 1-7 Energy Efficient Features: Cool paints (2 points for high impact item; 1 point for medium impact item; 0.5 point for low impact item). Elective Part 4 – Indoor Environmental Quality: 4-2 Indoor Air Pollutants: (a) Use of low volatile organic compounds (VOC) paints certified under the Singapore Green Labelling Scheme (at least 90% of the total internal wall areas - 2 points). (b) Use of adhesives certified under the Singapore Green Labelling Scheme for composite wood products (1 point).	Initial capital costs - High Maintenance costs - Medium
Fittings, Fixtures and Furnishing: Sanitary wares and fittings Fixtures and furniture	Elective Part 2 – Water Efficiency: 2-1 Water Efficient Fittings: (a) Basin taps and mixers (b) Flushing cistern (c) Showers	Initial capital costs - High Operating costs - Low Maintenance costs - Medium

Artworks and sculptures Soft furnishing	(d) Sink/Bib taps and mixers (e) All other water fittings (at least 90% of the fitting type used; 0.5 points for Good; 1 point for V Good; 2 points for Excellent). Elective Part 4 – Indoor Environmental Quality: 4-2 Indoor Air Pollutants: (b) Use of adhesives certified under the Singapore Green Labelling Scheme for composite wood products (1 point).

8. Rules Development

The rule-based system will be developed using the ILOG *JRules* software. This software is able to manage rules throughout their life cycle, that is, from creation through testing, deployment and retirement to allow for greater flexibility to rules developers and managers, especially in the rapidly changing business environment.

The generic if-then structure of a rule is illustrated for the building envelope design as shown below:

A Rule-Based Decision Target (as an example):
If building envelope design meets "RETV requirement of not exceeding 25 W/m^2",
Then set initial cost to "high" and add the message "the likelihood of high is very high"
And set operating costs to "low" and add the message "the likelihood of low is very high".

It involves applying a set of pre-established vocabulary (see the underlined words) to define the rule's conditions and actions, as well as present the rule in a readable language.

9. Testing the Developed Rules

The different sets of rules developed for the main elements of a building will be verified against the process or product used in those buildings that have been awarded the Green Mark. Essentially, such Green Mark projects would have adopted energy efficient features, water conservation measures, made substantial use of greenery in their projects and ensured a good indoor environmental quality for their users, setting them apart from other buildings. Therefore, the rules will be adjusted or modified according to the best practices adopted in the Green Mark projects.

10. Conclusion and Discussion

The paper has presented the methodological process of ascertaining the type of knowledge and acquiring it for developing a rule-based system that will contain decision-support rules pertaining to the assessment of (whole-life) cost implications for building projects that will meet the requirements of Singapore's Green Mark Scheme. Firstly, it has classified projects that have been awarded the Green Mark by types of developments and clients. It has been found that the largest group is residential projects developed by private property companies (see Tables 3 and 4). Based on Table 1's classification, this finding deviates from the theoretical assumption that this type of clients is the least interested in sustainable construction and whole-life costs since it is generally understood that they develop (the condominiums) for sale and not ownership or use. Evidently, this assumption has been found to be not true in the case of Singapore. Secondly, it has classified the winning green features of this type of developments based on projects which have been awarded the Green Mark by building element to provide an appreciation of latest industry trends and practices on environmentally-friendly design and technology (see Table 6). Thirdly, the BCA's Green Mark Scheme has been mapped onto applicable components of whole-life costs by building element to develop rules for the proposed decision-support system (see Table 7). In the next stage of systems development, efforts will be spent on developing the if-then rules using the ILOG *JRules* software and testing them on actual projects.

Acknowledgement

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ENERGY BENEFITS AND COMPARISION OF DEDICATED OUTSIDE AIR SYSTEMS

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Keywords: Dedicated Outdoor Air System (DOAS), Energy Recovery Ventilator (ERV), Heat Reclaim, Run around coil, Plate heat exchanger, Desiccant Wheel, Humidity Control Unit (HCU),

Abstract

The comparison of ventilation technologies is often analysed at peak design, as it is difficult to model all relevant climatic scenarios. The energy of ventilation is a substantial energy load and an informed decision of the designer and owner is needed to ensure a sustainable outcome.

The new ASHRAE standard 62.1-2007 (5.10.1) points toward humidity level of 65%rh to model comparisons. Relevance to each technology with the energy saving initiatives of US standard ASHRAE 90.1 is made. Doing this the comparison of a mixed return system, against Dedicated Out-side Air Systems (DOAS) can be made with air and water cooled chillers. These methods can then be ranked on suitability based on peak demand, operating cost, and ventilation cooling performance requirements of various cases. We look at the use of Binmaker® weather data, and compare the DOAS methods of energy recovery ventilators, run around loop, and humidity control unit direct expansion (DX) desiccant package. The options are compared with the capital cost to model financial expectations of buildings in Darwin (Tropical) Brisbane (humid) Sydney (Moderate) and Melbourne (Mild), quantifying the effect of increasing ventilation for improved IAQ.

1. Introduction

Energy simulation of the ventilation humidity control technologies is required to be made to judge the best solution for the site needs. Considerations for site energy cost peak penalty and site humidity needs. Special considerations for access to high efficiency chiller, waste heat, solar hot water and gas can modify selection further. The return on investment will be made to maximize the savings opportunity.

2. Energy Simulations

2.1 Simulation Model, The Munters Makeup Air Modeling Method. (MMAMM)

The following is a comparison for the conventional mixed fresh air system with various available DOAS technologies. This is reviewed under an Australian Building Code BCA2007 JV4 (10) model where a reference performance is made of the baseline technology. A JV3 model is not practical as ACADS BSG, Trace, and Camel lack the options to match all the technology options. The methodology of JV 3 can then be applied for other components separately.

Binmaker® data in g/kg with average enthalpy in kJ/kg are used and mixture calculations are made and technology credits, for each increment of g/kg. Data is also available in individual hours and results are typically in +/-5% of the compressed version. The compressed version is selected as all the results are readable, however a detailed analysis on sensible heat impact in a building would need the detailed data due to the temperature variance per increment of g/kg. A comparison of the available technologies is made on Table 2 for 23 °C and 65%rh, and Table 3 for 23 °C and 50%rh for prominent Australian cities. A direct system sample comparison of Sydney is made in Table 7 between mixed return air with chiller system coefficient of performance (COP) of 3 and Drycool HCU unit using chilled water as a DOAS configuration.

2.2 Site Model description:

Analysis of only latent considerations is made in this comparison. Each technology provides different supply air temperatures and flow (see section 5.1 Design issues) so sensible analysis need separate consideration.

Comparative technologies

- Chilled water from air cooled chiller or DX set COP of 3 mixed with 81% return air
- Chilled water from air cooled chiller or DX set COP of 3 to fresh air AHU
- Chilled water from water cooled chiller system COP of 5.3
- Energy recovery ventilators ERV combined with Chilled water AHU
- Drycool HCU, Desiccant with DX reactivation fresh air package with MOD and ERV option
- Run around coil energy reclaim
- Indirect Evaporative pre-conditioner OASIS®

2.3 Parameters

Process: 2,800 L/s (10,000 m^3/hr, 6000cfm) ventilation to be proportioned
Duty: Absolute humidity 13.4g/kg and 10.2g/kg equivalent to (23 °C 65% and 50%rh) less nominal latent load from 336 people (23.5kWlatent) capacity from system. (Ref: Figure 12).
Ambient weather data: Binmaker® from Linric (9) in groups of g/kg with coincidental enthalpy's and number of hours (temperature optional)
Performance: From manufactures literature Trane Chiller system COP of 3 and 5.3, Des Champs ERV 70% efficiency, Munters Drycool® HCU 3g/kg credit with Copeland scroll COP of 2.7, 60%, Des Camps Run around coil 60%, Hours of operation: 24hr, 7 days
Utility cost: $A0.10/kWh nominal, excluding peak load and penalty need further consideration.

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Fresh air latent: Variable dependant on ambient with fixed fresh air flow 2,800 l/s (10,000m^3/hr) Statistical weather data is used to conduct the energy analysis. The annual hours that correspond to certain humidity conditions are shown at increments of 1g/kg. (Refer Figure 12).

Internal latent: The latent load is also considered with respect to the personnel and infiltration. Estimation is made number of people that occupy the space and a value for the ventilation is given based on the m²/ occupant. These values can vary with population or how industrious the area is
e.g Retail varies in:-
Australia :- 1 person per 6.5m^2, 7.5 l/s (27m^3/hr) pp, 5 l/s (18m^3/hr) with approval in tropical climate.
Singapore: - 1 person per 5m
China: 20-30m^3/hr (Restaurant, Office)
USA: - 1 person per 8m is commonly use. US STD: 120 sq.ft. per person based on ASHRAE. Note; Some engineers, subtract the area where the fixtures are, some do not. 15cfm pp (25m^3/hr)

The calculated load for 336 people is 70W or 100g/h of water per occupant. Infiltration is modeled through a conservative estimate of 30 doors, 2 x 2 meters each, opening for a period of fifteen seconds every hour. Results from the calculations (Figure 12) show a value of 13 g/kg for the room's moisture content and 20 g/kg ambient humidity. The velocity of the vapor in still air equals 0.2 m/s and exposed air 2m/s. Therefore, the moisture load is represented by a relation between, mass flow, density and moisture difference giving a total value of 31.3 kWr. (46.48 kg/hr)

Supply air compensation.
The required supply air therefore must compensate for a latent load of 46.48 kg/hr. The required Δ ω is related to the space moisture content (ω) and the supply air ω.

Δ ω = Space ω – supply air ω
Since, 46,480 [g/hr]= 10,000 [m^3/h] x 1.2 [kg/m] x Δ ω [g/kg]
Δ ω = 3.8 g/kg
Baseline supply of 10.6 g/kg or 14.9Cdp for Baseline (see table 7)

Drycool HCU obtains the Free effect of the desiccant is 3 g/kg,
The off coil duty is 10.7/kg (16 °Cdp)
Drycool HCU actual Supply air = 10.7- 3g/kg= 7.7g/kg or 10.1 °Cdp

3 Technology descriptions:

3.1. Air cooled chiller or DX set COP =3 system

As an alternative to a mixed return system a dedicated ventilation system run on chilled water/DX is modeled. This eliminates the energy drain of diluting the moisture in the fresh air before it is treated by a much larger airflow.

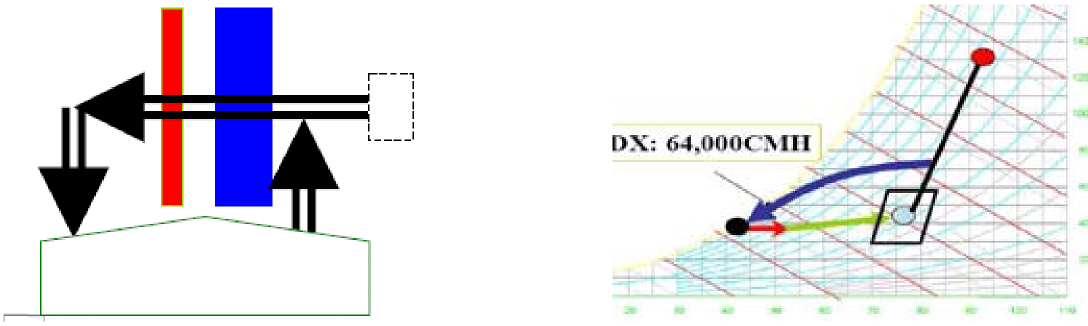

Figure 1 Air cooled chilled water system. Mixed Air supply 18,000L/s (64,000cmh)

3.2. Air cooled chiller or DX set COP =5.3 system for mixed return air
As per 3.1 but more efficiency when using high efficiency water cooled chillers (by cooling tower).

3.3 A water cooled chiller system has an operation assumed at COP=5.3, Legionella implications may not be acceptable to the client. A DOAS from a chilled water coil is treating the fresh air condition. Effectiveness on latent duty is dealt with and allows the central plant to run on cooling or heating only. This also provides better humidity control at part load and allows the central plant to control temperature. Advanced systems like SMAC® Shaw method (1) function this way however reverse cycle may not be possible from the chiller for heating when there is a dehumidification duty i.e. 18 ºC 100%rh.outside. (NOTE 10000CMH =2,800 L/s)

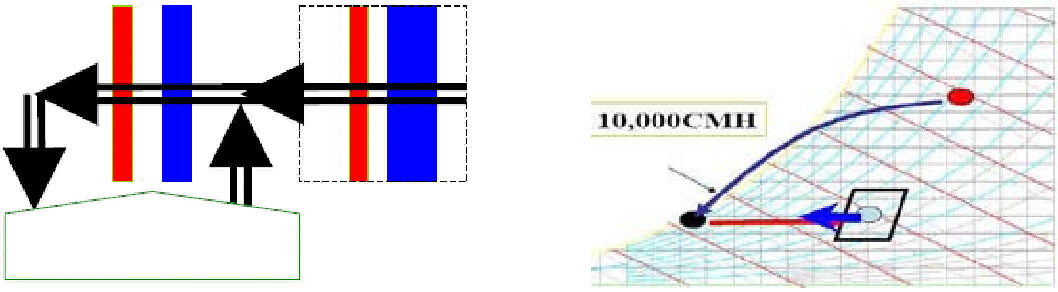

Figure 2 DOAS method, or fresh air chilled water DOAS. 2,800 l/s (10,000cmh)

3.4 Energy Recovery Ventilator (ERV) combines with above

Energy recovery ventilation requires the use of exhaust air from the space to precondition the outside air which is still required to satisfy the design requirement. Assumption of 75% applies to 100% exhaust use, and 50% efficiency applies to exhaust being 2/3 of ventilation.

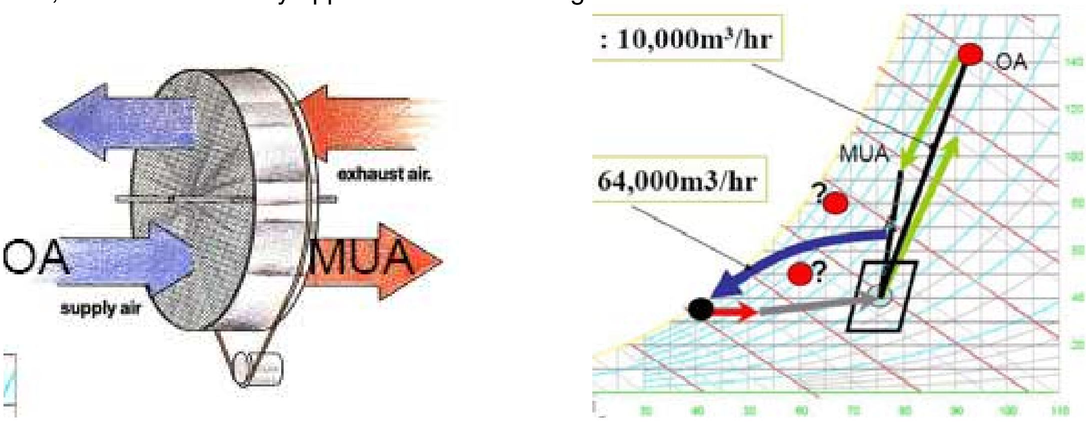

Figure 3 ERV-Chilled Water (NOTE: 10,000 / 64,000 cmh = 2,800 / 18,000L/s)

3.5 Humidity control unit, Desiccant with DX reactivation fresh air package

Full fresh air DX unit designed for ventilation latent load and reusing its own condenser heat for regeneration of the desiccant wheel. Munters Drycool® HCU compressors nominal COP of 2.7, and desiccant credit provides 3g/kg (15kj/kg), with equivalent reheat credit of 11 °C at all stages of compressor capacity. Note also reduces cooling duty for new installations (est. $A 400 per kWR)

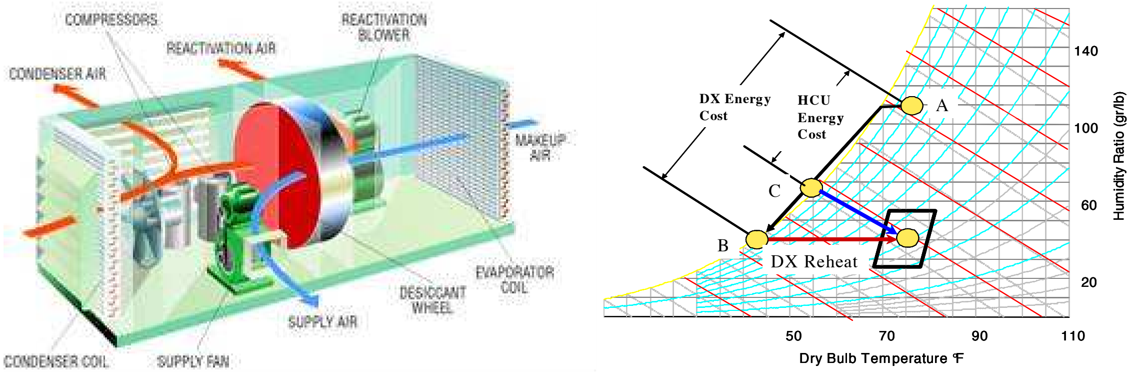

Figure 4 Munters Drycool (HCU) Humidity Control unit and Munters HCU psychrometric

3.6 Humidity control unit, Desiccant with Chilled water module (MOD) with DX fresh air package
Same as 3.5 with chilled water inlet coil from site services for improved efficiency and cost. HCU Copeland compressors nominal COP of 2.7 nominal ¼ cooling duty at 35kWr (10RT), and inlet chilled water module (MOD) coil duty a nominal ¾ of cooling duty 140kWr-0kWr variable

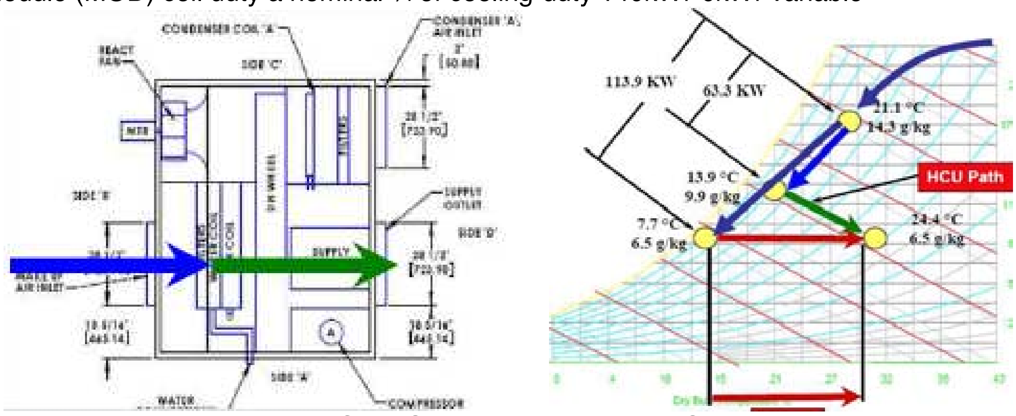

Figure 5: Munters Drycool HCU MOD Unit and Munters HCU psychrometric

3.7 Run around coil/plate sensible heat exchanger
Essentially provides an upstream energy credit equivalent to the 60% efficiency between ambient and the off coil condition. (Eg:- ambient 20 °C, off coil 10 °C, reheat 6K, supply 16 °C, inlet credit 6kJ/kg.)

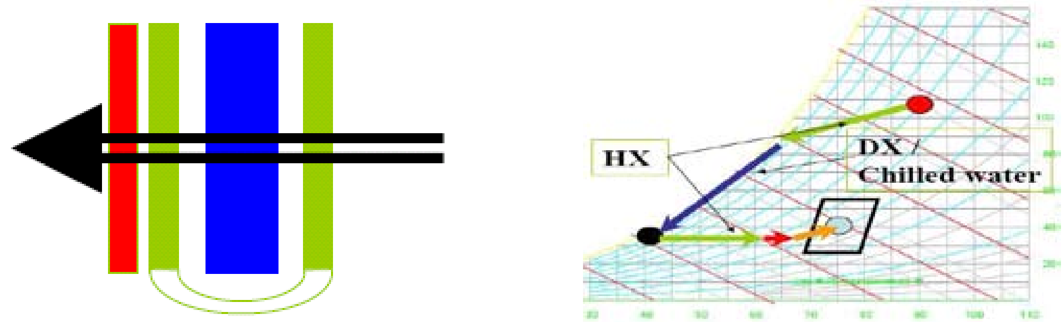

Figure 6 Heat reclaim and Psychrometric operation

3.8 Chilled water precooled Desiccant with gas reactivation fresh air package
Full fresh air chilled water COP of 5.3 preconditioning for a conventional desiccant dehumidifier which is powered by direct fired gas (cost est. 4c/kWh) with COP=1. The electric gas cost ratio of 2 allows the 25kJ/kg latent effect to be equivalent to an electric device with COP 1x2 = 2 for modeling purposes. CO_2 emissions would need recalculation. The supply air temperature would be 30 °C -40 °C and in need of closer sensible load scrutiny.

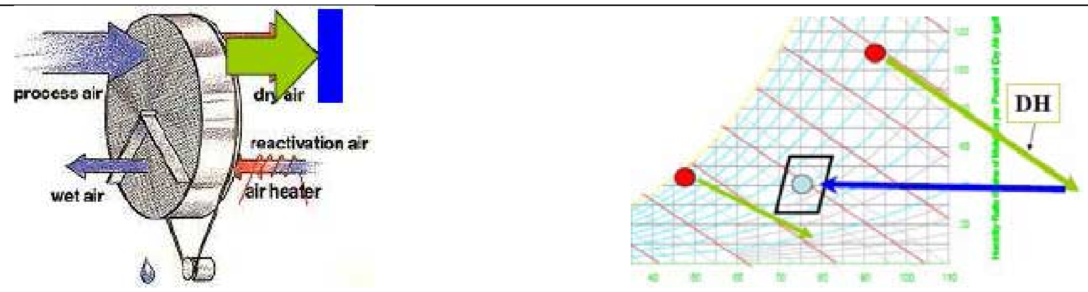

Figure 7: Gas Fired Desiccant dehumidifier and psychrometric chart

3.9 Indirect evaporative cooling on inlet

The system can use the low wet bulb of exhaust air and specially non media systems are able to use grey water. A 75% effect between outdoor air and exhaust wet bulb. Ambient wet bulb can be used to make us pressurization air. A post cooing coil is the calculated coil work, and evaporative cooling post cooling is a convenient option.

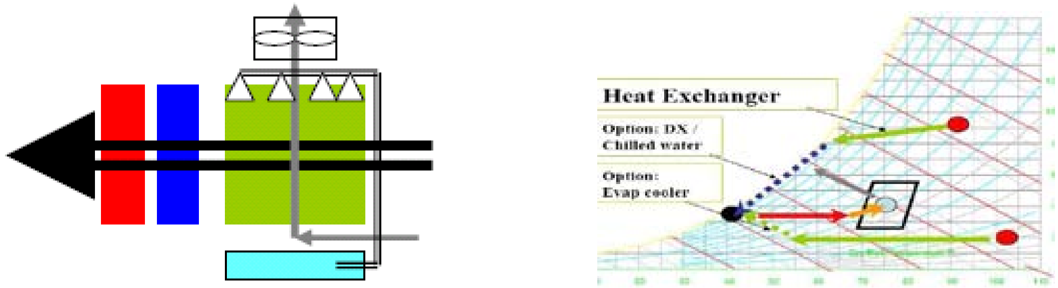

Figure 8: Indirect evaporative cooler and psychometric chart in humid and dry operation

4 COMPARISONS

4.1 Results summary: A review of the nominated technology against baseline follows.

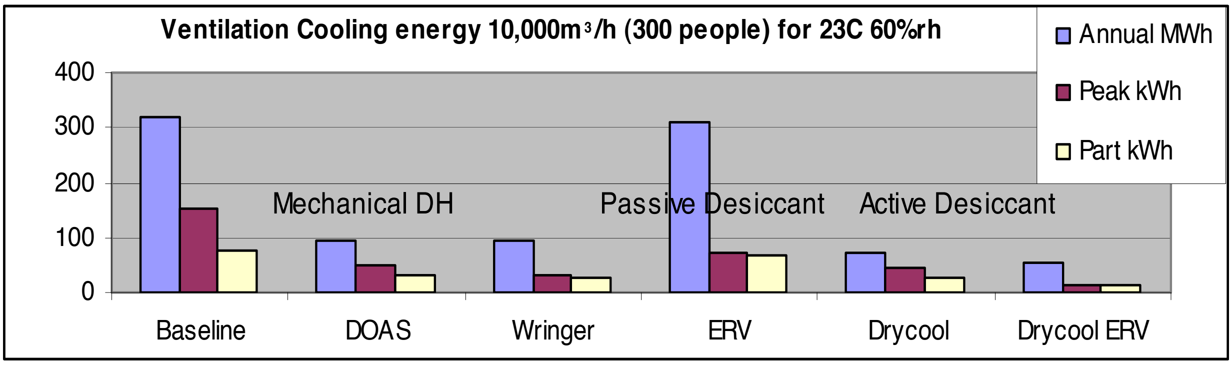

Table1 Sydney Results: Munters Makeup Air Modeling Method MMAMM (Annual, Peak and part load)

The most efficient mixed fresh air system is the COP = 5.3 chiller and comparison with the most efficient DOAS DrycoolHCU with chilled water follows in detail. (Also see Appendix Figure 12)

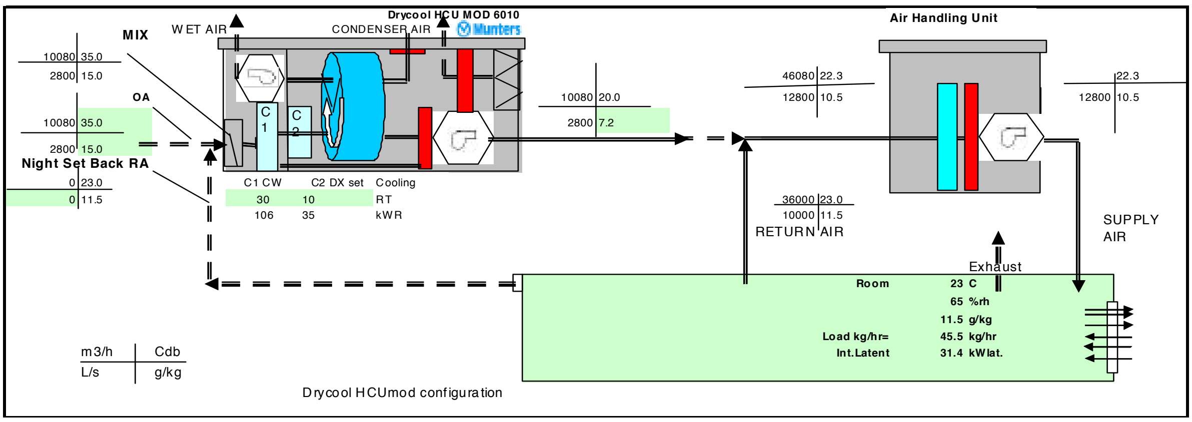

Figure 9 System schematic with Drycool HCU mod on fresh air

4.2 Detail on best mixed return Baseline option Vs best DOAS in Sydney @23C 65%rh

Baseline Water cooled chiller mixed return system COP=5.3		189,240 kWh	$18,924/year
Drycool HCU MOD		32,711 kWh	$ 3,271/year
Saving:	**147 TCO_2 –e**	**$15,323 /year**	**1.3 years Payback (3.3yr refit)**

4.3 Detail on best mixed return Baseline option Vs best DOAS in Sydney @23C 50%rh

Baseline Water cooled chiller mixed return system COP=5.3		373,160 kWh	$37,160/year
Drycool HCU MOD		82,181 kWh	$ 8,218/year
Saving:	**279 TCO_2 –e**	**$29,098 /year**	**0.7 years Payback (1.7yr refit)**

Munters

Comparison : Modular Outside Air Conditioning Systems MOACS and Baseline System
Site: Australian climate comparison
Date: 1/02/2008
Ref : S30354

Drycool HCU Module and Baseline (DX) System Comparison

Cities	Ventillation savings kWh	Ventilation savings $	Total savings	T.CO2 emission saved	Pay back* (years)	Pay back* (years)
Sydney	153,228	15,323	15,323	147	1.3	3.3
Melbourne	130,394	14,733	14,733	183	1.3	3.4
Brisbane	179,581	17,958	17,958	172	1.1	2.8

Basic Input Data

23	Room Cdb	0.10	Power cost /kWh
65	%RH Room	5.0	COP of Cooling plant
2800	Outside Air Flow (L/s)	10	HCU RT (HCU XXRT)
10000	Total Return Airflow (L/s)	60%	ERV effectiveness
12800	Supply airflow (L/s)	70%	Heat (Wringer) efficiency
10080	Outside Air Flow (m^3/hr)	27.6	C HUMIDEX aparent tempe
36000	Return Airflow (m^3/hr)		Capital cost
46080	Supply airflow (m^3/hr)		Installation

Figure 10 Latent kWh comparison 23 °C and 65%rh

Munters

Comparison : Modular Outside Air Conditioning Systems MOACS and Baseline System
Site: Australian climate comparison
Date: 1/02/2008
Ref : S30354

Drycool HCU Module and Baseline (DX) System Comparison

Cities	Ventillation savings kWh	Ventilation savings $	Total savings	T.CO2 emission saved	Pay back* (years)	Pay back* (years)
Sydney	290,979	29,098	29,098	279	0.7	1.7
Melbourne	282,728	28,273	28,273	396	0.7	1.8
Brisbane	315,322	31,532	31,532	303	0.6	1.6

Basic Input Data

23	Room Cdb	0.10	Power cost /kWh
50	%RH Room	5.0	COP of Cooling plant
2800	Outside Air Flow (L/s)	10	HCU RT (HCU XXRT)
10000	Total Return Airflow (L/s)	60%	ERV effectiveness
12800	Supply airflow (L/s)	70%	Heat (Wringer) efficiency
10080	Outside Air Flow (m^3/hr)	25.2	C HUMIDEX aparent tempe
36000	Return Airflow (m^3/hr)		Capital cost
46080	Supply airflow (m^3/hr)		Installation

Figure 11 Latent kWh comparison 23 °C 50%rh

5 Other Design issues

5.1 Equipment discussion

Further to Thirakomen's (1) overview, some operating characteristics need mention.

Chilled water from air cooled chiller or DX set COP 3 or 5.3 to fresh air AHU
May have reheat limitations under ASHRAE 90.1 regarding restriction of reheat for humidity control and Australian Building code (10) limiting reheat to 7.5°C i.e. 10 °C + 5 °C =15 °C, may have difficulty obtaining absolute humidity as it is working toward its operating point, lower chilled water temperature may be needed with worse COP. This method is the commercial norm with cheapest first cost.

Energy recovery ventilators (ERV)combine with above

Unable to achieve humidity set point at part load conditions i.e. 20°C 100%RH will enter untreated without chiller running. Comments for chilled water DX also applies. Needs exhaust air to be ducted to return and can get out of balance with dirty fresh air filters.

Humidity control unit, Desiccant with DX reactivation fresh air package

Qualify for LEED credits (ABGR Australia= 1 point) for maintaining duct RH below 80%rh and room below 60%rh. Able to provide dew point and lower at part load due to the desiccant removing moisture after the DX coil. Supply air typically 10 °C greater than dew point (i.e. 25 °C for 14.8 °C dp supply air in Figure 12). this suites lower average internal space load, post cooling can support peak design space heat loads such as chilled beams. Chiller efficiency is improved by needing 6 °C warmer water than other systems. Drawback is Drycool HCU is unable to operate in reverse cycle under 7 °C, post heater needed. Higher first cost due to the extra technology.

Run around coil

Same issues as Chilled water option although reheat at warmer temperatures is high (i.e. 35 °C ambient and 10 °C off coil, supply 25 °C, winter 15 °C and 10 °C off coil, supply 13 °C. Some adjustment for fan energy due to the extra exchange and the 180degree bend for plate HX is required. There is difficulty in efficiently obtaining 50%rh due to the internal load requiring a supply of 3.5Cdp.

Chilled water pre-cooled Desiccant with gas reactivation fresh air package

Full fresh air chilled water COP=5.3 preconditioning has a lower off coil duty and can therefore run more efficiently at higher temperature. The conventional desiccant dehumidifier which is powered by direct fired gas has a warm supply air temperature suitable for peak demand reduction and heating environments like swimming pools, or industrial process where design conditions below 50%rh.

5.2 Set point for comfort and building mould prevention

With the new summer controls for temperature the level of humidity needs close consideration. Due to this sample run of 65%rh can be compared with 50% rh using Humidex factor which is an operational health and safety indicator used by the Canadian Government. (7)
The conditions of 23 °C 65%rh is 27.2°C Humidex, (near peak of “no discomfort” scale) while 23 °C 50%rh is 25.2 °C is satisfactory, (26C and 65%rh can 32.6C discomfort level in Humidex)

Humidex = (air temperature) + h
h = (0.5555)*(e - 10.0)
e = 6.11 * exp (5417.7530 * ((1/273.16) - (1/dewpoint))) (Source: Environment Canada (7))
Scale Less than 29: No discomfort 30 to 39: Some discomfort, 40 to 45: Great discomfort;

Other RH set point issues are improved comfort, reduced mould and corrosion, dry ductwork and % RH on the building walls. Colder wall surface have a higher relative humidity than the room and should be kept below 60%rh to avoid mould propagation, current US methods employ 45F (7C) dew point buildings OA to evaporate water from construction leakage within a 2 days to avoid mould (6).

5.3 The potential price of Carbon (CO_2 emissions)

A nominal CO_2 emission credit has been included and recent figures of $50A per ton CO_2 has been nominated by Western Australian government.
The potential price of carbon:
“The IPCC summary outlines that the if the target for stabilisation of climate to between 450 and 550ppmv CO_2-eq (i.e. approx 2 degrees C), then the price for carbon should be set at up to US$100/t$CO_2$-eq. (paragraph 21)” (11)
This price would provide credit/reduced penalty of $US14,700 p.a. Vs Mixed chilled water.

6 Conclusions

A comparison of the most current ventilation systems were made and highlighted the benefit of DOAS compared to mixed return air system to control humidity. The energy model demonstrates that there are effective technologies in reducing power cost other than efficient chillers. A nominal guide for energy reduction can now be made to quickly identify viability of various technologies at peak and part load. The trade off of improved IAQ from increased ventilation can now be made against Peak energy cost and annual energy cost and CO_2 emissions.

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Appendix

Munters

Comparison : Modular Outside Air Conditioning Systems MOACS and Baseline System
Site: Sydney occupied space — Date: 1/02/2008
Location: Sydney — Ref : S30354

System:

23	Room °C db
65	Room Humidity %
2800	Outside Air (L/s)
10000	Return Air (L/s)
12800	Supply Air (L/s)
10080	O A (CMH)
0	R A (CMH)
0.10	Power cost $/kWh
5.0	COP of Cooling plant
10.0	HCU RT (Refrig. Ton)

Room
11.5 g/kg abs. hum.
52.2 kJ/kg enthalpy
16.1 °C dp dew point

Internal Latent analysis:

		kWR latent	kg/hr
373	People	26.13	37.89
50	15sec Door/h	5.23	7.58
	Other		0.00
	Total	31.36	45.48

SA Internal latent compensation Δg/kg
Baseline system 0.8 Δg/kg
MOACSsystem 3.8 Δg/kg
70% ERV effectiveness
60% Wringer Heat reclain
75% OASIS

Device duty

Required off coil duty
Baseline System
10.6 g/kg off Base Coil
14.9 °C dp off Base Coil
41.8 kJ/kg off Base Coil
MOACS system
7.7 g/kg off MOACS coil
10.1 °C dp MOACS off coil
29.5 kJ/kg off MOACS Coil
MOACS - HCU system
10.7 g/kg off HCU coil
15.0 °C dp HCU off coil
42.1 kJ/kg off HCU Coil

Ventilation Results :

Cooling coil duty	kWh	$ Saving	Peak kW	Payback yrs.
Baseline	185,940		76	
HCU	52,096	13,384	42	5.2
HCUmod	32,711	15,323	26	3.3
HCU-ERV	30,190	15,575	14	4.8
OASIS	141,085	4,485	27	8.9
Wringer	135,316	5,062	26	9.9
MOACS	148,635	3,730	31	14.7
ERV	173,044	1,290	36	11.6

HCU energy savings 153,228 kWh
TCO2 emission saved 147 at 0.96TCO2e/MWh

HCU Simple Payback
New construction 1.30 years
Retrofit 3.26 years

	Data insert, Binmaker			COIL WORK :Baseline system				Drycool HCU coil work			HCUmod	HCU-ERV	ERV	OASIS	MOACS	Wringer
HR (g/kg)	Totals>	8712		(entering coil)			185,940			52,096	32,711	30,190	177,481	141,085	148,635	135,316
.+/-0.5	hrs	°C db	h (kJ/kg)	kj/kg	Δh	kWr	kWh	Δh	kWr	kWh	kWh	kWh	kWh	kWh	kWh	kWh
Peak MC	1	26	76	57	34	518	104	34	114	42	26	14	36	27	31	26
Peak WB	1	35	75	57	33	502	100	33	111	40	25	14	36	22	30	22
19.5	6		76.8	58	16	238	286	35	117	256	161	86	218	188	188	188
18.5	45		73.9	57	15	229	2059	32	107	1755	1102	637	1607	1324	1324	1324
17.5	50		70.7	56	14	218	2184	29	96	1758	1104	695	1754	1368	1368	1368
16.5	105		66.5	55	13	204	4290	24	82	3144	1974	1424	3594	2576	2576	2576
15.5	245		63.4	55	13	194	9502	21	71	6394	4015	3260	8234	5502	5502	5502
14.5	491		59.7	54	12	182	17848	18	59	10602	6657	6389	16143	9832	9832	9832
13.5	469		56.8	53	11	172	16145	15	49	8454	5308	5308	15149	8488	8488	8488
12.5	538		53.1	52	11	160	17226	11	37	7300	4584	4584	16990	8442	8442	8442
11.5	752		49.8	52	10	149	22403	8	26	7103	4460	4460	23245	10126	10126	10126
10.5	880		46.6	51	9	138	24329	4	15	4818	3026	3026	24329	9963	9963	9963
9.5	745		42.7	50	8	125	18670	1	2	511	321	321	18670	6507	6507	6507
8.5	828		39.1	49	7	114	18796						18796	5279	5279	5279
7.5	786		35.4	49	7	101	15911						15911	3079	3079	3079
6.5	720		31.8	48	6	89	12841						12841	1086	1086	1086
5.5	1014		28.7	47												
4.5	942		24.2	46												
3.5	141		22.8	46												
2.5	3		18.7	45												

Munters

Comparison : Modular Outside Air Conditioning Systems MOACS and Baseline System
Site: Sydney occupied space — Date: 1/02/2008
Location: Sydney — Ref : S30354

System:

23	Room °C db
50	Room Humidity %
2800	Outside Air (L/s)
10000	Return Air (L/s)
12800	Supply Air (L/s)
10080	O A (CMH)
0	R A (CMH)
0.10	Power cost $/kWh
5.0	COP of Cooling plant
10.0	HCU RT (Refrig. Ton)

Room
8.8 g/kg abs. hum.
45.4 kJ/kg enthalpy
12.0 °C dp dewpoint

Internal Latent analysis:

		kWR latent	kg/hr
373	People	26.13	37.89
50	15sec Door/h	6.56	9.52
	Other		0.00
	Total	32.70	47.41

SA Internal latent compensation Δg/kg
Baseline system 0.9 Δg/kg
MOACSsystem 3.9 Δg/kg
70% ERV effectiveness
60% Wringer Heat reclain
75% OASIS

Device duty

Required off coil duty
Baseline System
7.9 g/kg off Base Coil
10.5 °C dp off Base Coil
30.5 kJ/kg off Base Coil
MOACS system
4.9 g/kg off MOACS coil
~~3.5~~ °C dp MOACS off coil
15.6 kJ/kg off MOACS Coil
MOACS - HCU system
7.9 g/kg off HCU coil
10.4 °C dp HCU off coil
30.2 kJ/kg off HCU Coil

Ventilation Results :

Cooling coil duty	kWh	$ Saving	Peak kW	Payback yrs.
Baseline	373,160		76	
HCU	130,881	24,228	56	2.9
HCUmod	82,181	29,098	35	1.7
HCU-ERV	77,411	29,575	21	2.5
OASIS	328,959	4,420	133	9.0
Wringer	272,115	10,104	34	4.9
MOACS	299,227	7,393	40	7.4
ERV	361,123	1,204	51	12.5

HCU energy savings 290,979 kWh
TCO2 emission saved 279 at 0.96TCO2e/MWh

HCU Simple Payback
New construction 0.68 years
Retrofit 1.72 years

	Data insert, Binmaker			COIL WORK :Baseline system				Drycool HCU coil work			HCUmod	HCU-ERV	ERV	OASIS	MOACS	Wringer
HR (g/kg)	Totals>	8712		(entering coil)			373,160			130,881	82,181	77,411	370,382	328,959	299,227	272,115
.+/-0.5	hrs	°C db	h (kJ/kg)	kj/kg	Δh	kWr	kWh	Δh	kWr	kWh	kWh	kWh	kWh	kWh	kWh	kWh
Peak MC	1	26	76	52	46	690	138	46	154	56	35	21	51	133	40	34
Peak WB	1	35	75	52	45	675	135	45	151	55	35	21	51	130	39	30
19.5	6		76.8	52	22	330	396	47	157	343	216	127	309	366	243	243
18.5	45		73.9	52	21	321	2885	44	147	2414	1516	943	2290	2659	1739	1739
17.5	50		70.7	51	20	310	3102	41	136	2490	1563	1035	2514	2850	1828	1828
16.5	105		66.5	50	20	296	6219	36	122	4681	2939	2138	5190	5690	3543	3543
15.5	245		63.4	49	19	286	14001	33	111	9979	6266	4927	11957	12767	7758	7758
14.5	491		59.7	49	18	274	26865	30	99	17786	11168	9728	23605	24390	14352	14352
13.5	469		56.8	48	17	264	24758	27	89	15316	9617	9617	22276	22394	12806	12806
12.5	538		53.1	47	17	252	27106	23	77	15173	9527	9527	25165	24394	13395	13395
11.5	752		49.8	46	16	241	36213	20	66	18107	11369	11369	34673	32423	17049	17049
10.5	880		46.6	46	15	230	40490	16	55	17695	11111	11111	40490	36055	18064	18064
9.5	745		42.7	45	14	217	32352	12	42	11412	7165	7165	32352	28597	13366	13366
8.5	828		39.1	44	14	205	34002	9	30	9065	5692	5692	34002	29829	12901	12901
7.5	786		35.4	43	13	193	30345	5	18	5027	3157	3157	30345	26384	10314	10314
6.5	720		31.8	42	12	181	26063	2	5	1394	875	875	26063	22434	7714	7714
5.5	1014		28.7	42	11	171	34654						34654	29544	8813	8813
4.5	942		24.2	41	10	156	29359						38632	24611	5353	5353
3.5	141		22.8	40	10	151	4266						5744	3556	673	673
2.5	3		18.7	40	9	138	83						120	68	6	6

Figure 12 Sample runs of ideal solution based compared with base line in Sydney
Selection at 23 °C 65 and 50% RH for Sydney, note off coil condition unobtainable at 3.6 °C.

CHANGES IN ENERGY CONSUMPTION SINCE 1990: RESULTS FROM A LONGITUDINAL STUDY OF LOW ENERGY DWELLINGS IN THE UK

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Keywords: Buildings, Domestic, Energy, Longitudinal

Summary

A follow-up study in 2007-2008 has been undertaken of 24 'low-energy' dwellings in Milton Keynes, UK, that were originally monitored for hourly energy consumption from 1989-1991. Results were compared under standardised daily external conditions of 5°C. No statistically significant evidence of change over 17 years was found in overall gas consumption at 63kWh/day (95%CI:50,77) and overall electricity usage at 14.6kWh/day (CI:10.6,18.7). Since the distribution of energy usage was skewed, dwellings were classified into three groups according to low, middle, and high energy usage in 1990. At follow-up, the high group accounted for most increases in energy use, consuming more energy than the other two groups combined; their gas usage was 98kWh/day (CI:78,117), and electricity usage almost doubled to 25kWh/day (CI:18-33). The high group comprised dwellings that were on average larger originally and had larger additions by 2007 than other groups. Their energy use was greater than the other two groups combined. The findings suggest that research for development of energy policy, including the effectiveness of building regulations in reducing carbon emissions, should focus both on households where the most energy is used and where future increases in electricity usage are most are likely to occur.

1. Introduction

As one of its stated objectives to deal with the challenge of climate change, the UK government aims to achieve a 60% reduction in carbon emissions by 2050 (Department of Trade and Industry 2007). Since 1990, total CO_2 emissions from the UK have reduced by nearly 6% to 153Mt of carbon in 2005. The domestic sector is estimated as contributing 27% (41.2 Mt) of total emissions, about 2% lower than in 1990. This decline includes the substantial impact of the shift from coal to gas generation, and hence an almost 30% decline in the carbon content of electricity generation over the period (Dept. of Trade and Industry 2007). More to the point, annual energy consumption in the domestic sector has risen since 1990 by 20% (565TWh/yr). While other energy sources, such as solid fuels declined over the same period, even on a per household basis by 2004 gas consumption had risen by 17% (to 15.5MWh/yr) and electricity by nearly 10% (to 4.5MWh/yr) (Dept. of Trade and Industry 2006).

These figures illustrate a central issue in accurately ascribing trends in energy usage in the domestic stock to specific factors and thereby in forming effective carbon emissions policy. Namely, these trends arise from dynamic and diverse environmental, physical, and social influences on the building stock and its occupants over the same period. In addition to warmer winters, including greater prevalence of gas central heating, higher levels of insulation, building fabric deterioration and renovation, house extensions and conservatories, and changes to building regulations. This has been accompanied by the impact of various sociodemographic trends, such as an aging population, fewer people per household, and relative changes in disposable income.

The current study is part of the Carbon Reduction in Buildings (CaRB) project that intends to use empirical data from longitudinal studies of temperature and energy usage to detect trends and assist with the development of socio-technical models for the domestic sector. Rather than rely on initiating a longitudinal study from scratch, where inevitable delays would be incurred before significant trends could emerge, the CaRB project has also sought suitable prior studies with accessible temperature, energy, and social data to serve as a baseline survey.

1.1 Milton Keynes Energy Park Study

In 2005 data was retrieved from a project that had been conducted from 1989-91 and that, in spite of some incompleteness in the range of information available, could act as a baseline. In an area then known as Milton Keynes Energy Park (Milton Keynes is a low density city located about 75km North-West of London), the original study had monitored more than 100 dwellings for hourly electricity and gas consumption. The dwellings essentially follow conventional UK housing design, but were built in 1987 to higher standards for energy performance than were required by the building regulations at that time (Edwards, 1990). They incorporated energy efficiency features, such as increased floor, wall, and loft insulation, double-glazing, and in some cases condensing boilers, so that they broadly corresponded to UK building standards of almost a decade later.

Based on results from the pilot study (Summerfield et al. 2007), the following hypotheses were advanced with respect to changes that would be observed in a follow-up study:

- Energy usage in both baseline and follow-up would have a highly skewed distribution across the sample
- Gas consumption would have risen, but this would be consistent with increases in floor area
- Electricity usage will have increased in line with increased ownership of appliances that either were uncommon or did not exist in 1990

2. Methodology

2.1 Baseline and Follow-up Studies

The original study monitored hourly gas and electricity consumption on more than 120 dwellings over a period of 18 months, from 6 January 1989 to 30 September 1990. Data was retrieved for 62 gas centrally heated dwellings. Unfortunately it was not possible to recover related social data, such as the number of occupants in each household. From late 2006, a follow-up survey was initiated by CaRB with recruitment of 28 households living in dwellings from the original study. None of the households were the original occupants in the dwellings during the baseline study, though some were aware that it had taken place due to remnants of metering equipment still visible by the entrance. Apart from those who were unable to be contacted, the reasons given by occupants for non-participation in the study were ‘lack of availability due to work commitments’, ‘being away during the start of the study period’, ‘moving to another home’, and ‘illness’. Building and interview surveys were conducted for each household, with gas and electricity meter readings taken on an approximately monthly basis. Three households dropped out during the monitoring phase of the follow-up study.

2.2 Statistical Analysis

The final sample with sufficient data at both time points comprised 24 gas centrally heated dwellings. To enable a comparison under standardised winter conditions (and without needing annual data), simple linear regression models were fitted for each dwelling, with weekly mean external temperature (T_{ex}) as a predictor of gas and electricity usage. As illustrated in figure 1, the regression model was restricted to T_{ex} < 15°C for gas usage, with estimate values obtained for both gas and electricity usage under the standardised conditions of T_{ex} = 5°C (Figure 1), a figure close to average heating season temperature in the UK. A similar process was carried out for the follow-up study, except using mean T_{ex} over intervals corresponding to the meter readings.

Since the distribution of energy consumption was found to be skewed, dwellings were then grouped into thirds based on their total energy consumption in the 1990 study, and referred to as the low (n=8), mid (n=8), and high (n=8), energy groups. Once a dwelling had been classified according to its energy consumption in 1990, it remained in the same group throughout the subsequent analysis to simplify interpretation of the results. Thus any change detected in a group has occurred to the same group of dwellings from baseline to follow-up studies. This classification process could have been done separately by gas and electricity, however it was found that essentially the same groups were formed in all cases (in other words high gas usage was likely to be accompanied by high electricity consumption). From the results obtain previously using regression models, average energy consumption of each group for both time points were calculated under the same standard conditions of daily T_{ex} = 5°C. All statistical analyses were carried out using SAS version 9.1.

2. Results

Just over half the sample are detached houses (n=13) and a more than a third are semi-detached (n=9), compared with 22% and 32% respectively across the UK (Shorrock & Utley 2003). The heated floor area of dwellings (that is, excluding unheated extensions, such as conservatories) has increased by 10% from 85m^2 to 93m^2. There are 2.5 (±0.2) people per household at follow-up, which based on the pilot study and national statistics is likely to represent a decline since 1990, especially with respect to the number of children in the housholds (Summerfield et al. 2007).

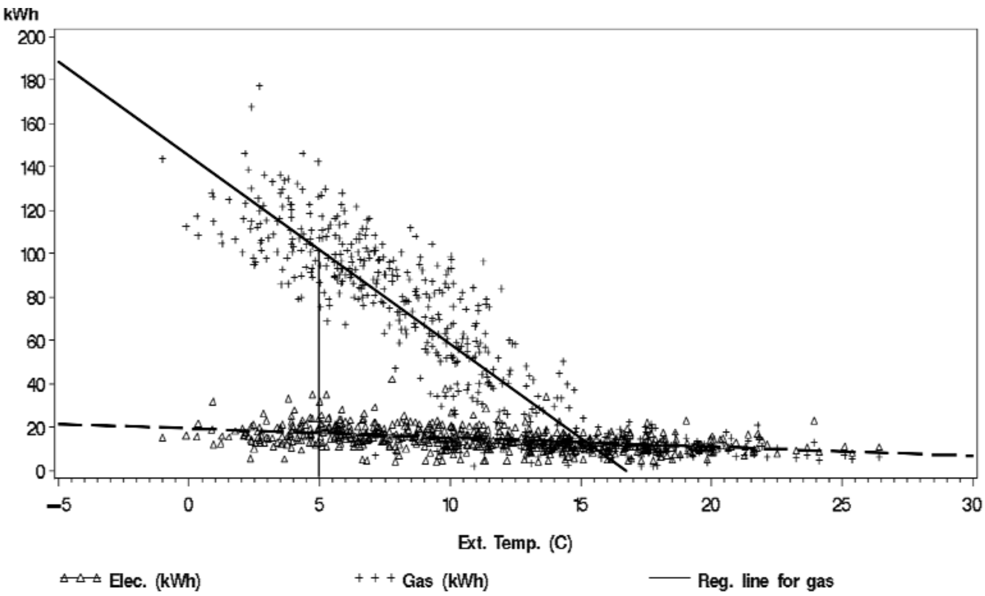

Figure 1 Daily gas (+) and electricity (Δ) use vs. external temperature for an example dwelling in 1990.

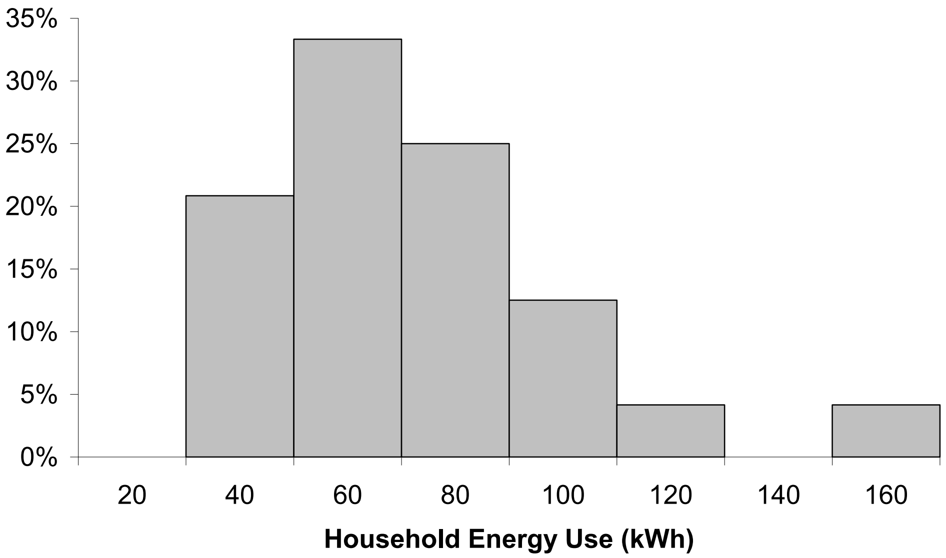

Figure 2 Histogram of energy usage for the 24 households in 1990 at external T=5°C.

Table 1 Daily household energy usage (CI:95%) at external T=5°C.

(kWh) (kWh/m^2)	1990	2007
Energy	74 (63,86)	78 (61,95)
Energy/A	0.87 (0.74,1.0)	0.84 (0.66,1.01)
Gas	64 (54,74)	63 (50,77)
Gas/A	0.75 (0.63,0.87)	0.68 (0.54,0.82)
Elec.	10 (8.7,11.3)	14.6 (10.6,18.7)
Elec./A	0.12 (0.1,0.13)	0.16 (0.11,0.2)
Floor Area (m^2)	85	93

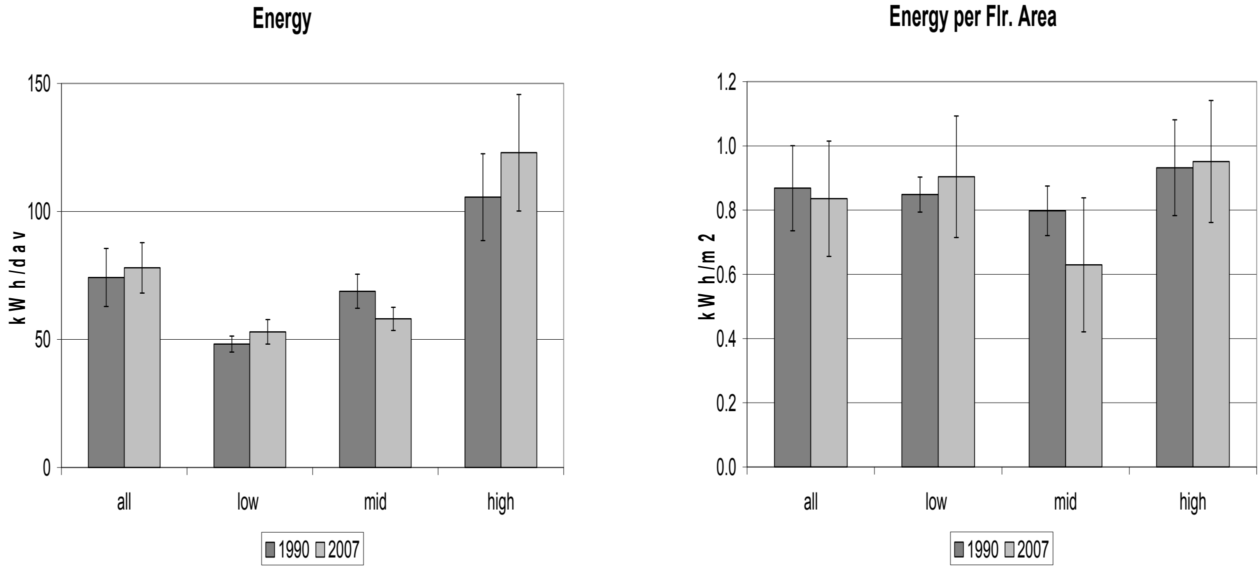

Figure 3. Daily household energy usage (95%CI) and normalised for floor area (right) for 1990 and 2005 by energy group (at external T=5°C).

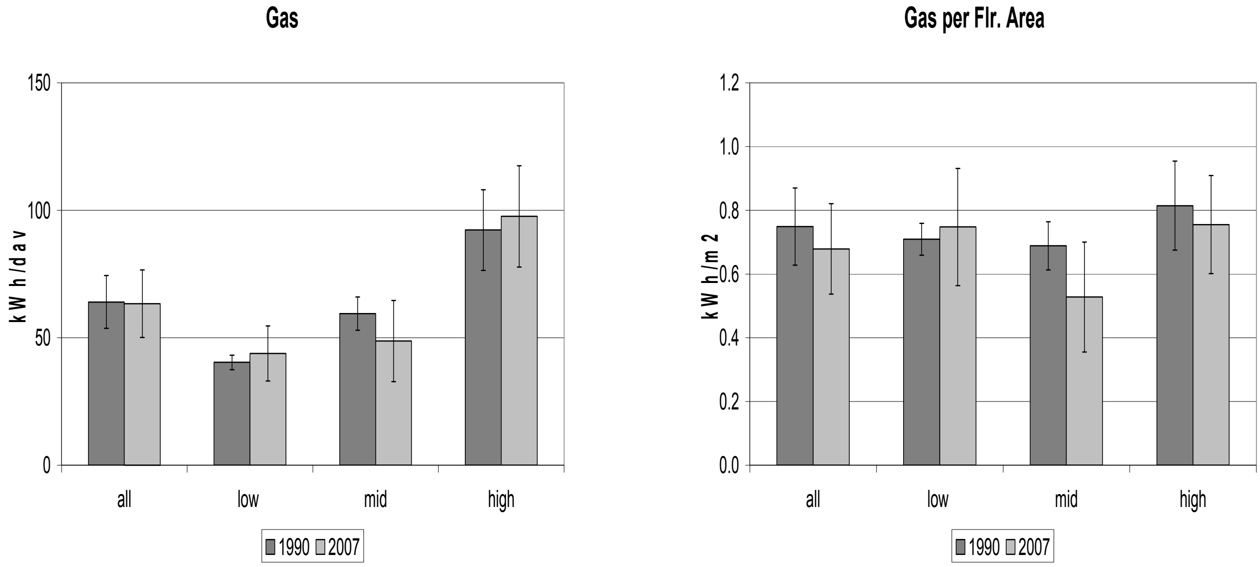

Figure 4. Daily household gas usage (95%CI) and normalised for floor area (right) for 1990 and 2005 by energy group (at external T=5°C).

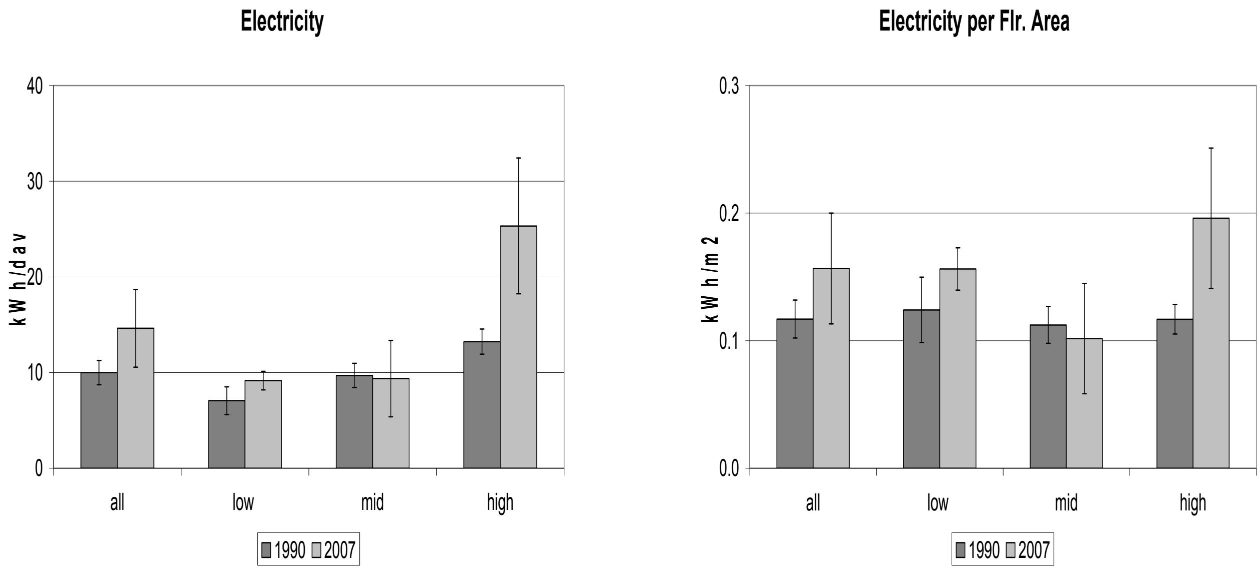

Figure 5. Daily household electricity usage (95%CI) and normalised for floor area (right) for 1990 and 2005 by energy group (at external T=5°C).

Table 1 gives overall results across the two studies, with energy usage at 78kWh (CI:61,95) in 2007 compared with 74kWh (CI:63,86) at baseline under standard winter conditions of external T=5°C. Although no statistically significant change ($P<0.05$) was observed for any of these results, the overall pattern of change hints at some increase in consumption for electricity. Figure 2 indicates that the sample is highly skewed so that it is not surprising that changes in the overall mean values are difficult to detect.

When the results were analysed by group according to low mid and high energy usage in 1990 (Table 2 and Figures 3 to 5), there is no evidence of significant change in the low and mid group. For the high group there was a clear pattern of increases over 1990 levels, that in terms of gas consumption was accounted for by a larger increase in floor area than in the other groups (up by 14% to 129m^2). Electricity consumption for the high group has almost doubled to 25kWh (CI:18,32) over 17 years and this results remains significant ($P<0.05$) even after normalising for floor area.

Table 2 Daily household energy usage (CI:95%) by group at external T=5°C.

kWh	Low Group.		Mid. Group.		High Group	
kWh/m^2	1990	2007	1990	2007	1990	2007
Energy	48(45,51)	53 (42,64)	69(62,76)	58 (39,77)	106(89,122)	123 (98,148)
Eng./A	0.85(0.78,0.93)	0.9 (0.71,1.09)	0.9(0.66,1.13)	0.63 (0.42,0.84)	0.93(0.8,1.06)	0.95 (0.76,1.14)
Gas	40(37,43)	44 (33,55)	59(53,66)	49 (33,65)	92(76,108)	98 (78,117)
Gas/A	0.72(0.65,0.78)	0.75 (0.56,0.93)	0.78(0.56,0.99)	0.53 (0.36,0.7)	0.81(0.7,0.93)	0.76 (0.6,0.91)
Elec.	7.1(5.6,8.5)	9.2 (8.2,10.1)	9.7(8.4,11)	9.4 (5.4,13.4)	**13.2(11.9,14.5)**	**25.3 (18.2,32.4)**
Elec./A	0.12(0.10,0.15)	0.16 (0.14,0.17)	0.12(0.10,0.15)	0.1 (0.06,0.14)	**0.12(0.10,0.13)**	**0.20 (0.14,0.25)**
Flr.A(m^2)	57	59	86	92	113	129

3. Discussion

The data collected in 1990 has provided an invaluable opportunity to undertake a longitudinal study of 24 low-energy dwellings in the UK and investigate changes in energy usage from baseline (1990) to follow-up (2007) under standard winter conditions of 5°. Gas consumption has essentially remained constant over the 17 years at 63kWh (95%CI: 50 to 77). Even though electricity consumption appeared to rise by 40% to 14kWh (95%CI: 10 to 18), the high degree in variance in the underlying data at follow-up often due monitoring spells where dwellings were possibly unoccupied, meant that changes observed in the overall results were not statistically significant.

However, when the results were analysed with dwellings classified into three groups, of low, mid, and high energy users according to the estimated consumption from the baseline data, a consistent pattern emerged whereby high energy users accounted for almost all of the increases only weakly apparent in the overall statistics. Unsurprisingly this tends to correspond with larger homes. There was weak evidence that energy use by the high energy group rose by 16% to 123kWh/day (95%CI: 98 to 148). Gas consumption may also be higher, but was (statistically) unchanged at ~0.8kWh/m2 when normalised for floor area. The houses in the high group have had additions that have resulted in an increase in heated floor area, and this occurred to a greater degree than in the other groups. Most notably, electricity usage has almost doubled in the high group to 25.3kWh/day (95%CI: 18 to 32). Rather than a change in the energy performance of dwellings, there has been a shift from gas to electricity in the high group, possibly reflecting an increase in appliance ownership and secondary electric heating in house extensions.

The main strength of this study lies in the detailed energy and building data collected in 1990 that forms the baseline survey. Although caution should be applied in terms of any implications at the national scale, since the sample was not a representative selection of the population of building stock, with an over-representation of detached dwellings. Nevertheless the occupants are likely to have undergone broadly similar social and demographic changes, such as owning more appliances. Moreover the results here appear to be consistent with the skewed energy consumption distribution that is evident in national figures, whereby the top 30% of households by income spend (and, by implication, use) more than all other households combined (Shorrock & Utley 2003). The results are also largely consistent with findings from the pilot study with respect to change observed mainly in the high usage group (Summerfield et al. 2007).

There is great value in following up this specific group of dwellings which represented best practice in the UK for the symbolically important year – in Kyoto Protocol terms – of 1990 and which were roughly a decade ahead of their time with respect to building regulation standards. Hence they also provide an indication of what might be expected a decade from now, from dwellings of an equivalent standard. The study has shown that some dwellings have remained essentially at 1990 energy usage or below and that there was no evidence of a decline in the energy performance of the building. Yet this was not necessarily the case for a group of dwellings that accounted for all the observed change. In summary, the high energy group not only increased, accounting for half (50%) of the energy used in 2007, it is almost three times more than the low group and nearly double that of the middle group. It appears that these dwellings increased in floor area more than was the case in other groups, and this may have been accompanied by increased appliance ownership and secondary electric heating. These findings highlight issues regarding the importance of effective targeting of energy conservation measures both to where consumption is greatest and where it is increasing most rapidly.

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ENVIRONMENTALLY SUSTAINABLE DESIGN ATLAS OF AUSTRALIA

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SUMMARY

The present paper introduces an atlas of air conditioning loads for a standard building form used throughout Australia. These loads were derived from the ACDB, and provide a case-study of the single building design simulated at various locations specified around Australia. Results from two software packages are compared: the Carrier air conditioning method to estimate loads (CAMEL) and DesignBuilder - with the US DOE EnergyPlus engine. We generated NEW CAMEL files derived from ACDB data 1967-1973 and 1995-2001. Then we compare the resulting cooling loads of ORIGINAL CAMEL data from 1970's data. With DesignBuilder we consider the cooling loads from DESIGN and TYPICAL weeks of data of the Reference Metrological Year (RMY) derived from the Australian Climate Data Bank (ACDB), and also the clear sky DESIGN DAY based on ASHRAE 94.6% drybulb and mean coincident wetbulb.

1. INTRODUCTION

The Australian Climate Data Bank (ACDB) consists of 35 years continuous hourly dry-bulb and wet-bulb temperatures, solar radiation, and wind data for each of the 69 locations around Australia [1]. For each location an 8860 hour Reference Meteorological Year (RMY) was developed by others with funding from the Australian Government [2]. The primary data observations were 1967 to 2002. The ACDB is used to provide weather files to building simulation programs such as Accurate (by CSIRO) and EnergyPlus (by US DOE) for use in building simulations. At each location the RMY uses dry bulb temperature only to selects a single one year pseudo dataset from the greater ACDB, by progressively eliminating full years with extreme temperature values, hot or cold, until only one year is left [2].

The ACDB is an hourly weather database – a necessary input to all modern building simulation programs. Prior to the ACDB there were air conditioning design datasets from mid 1970's through 1986 [5], based on 3-hourly measurements taken by meteorological observers that may exclude early morning first six hours. The air conditioning design method (CAMEL from AIRAH's Design Aid 9 algorithms [5]) was previous industry practice in Australia. CAMEL method is based on the extreme dry and wet-bulb temperatures. Design Aid 9 Appendix 1B [5] assumes "monthly one day in two years design conditions". So we calculated the 94% extreme dry bulb and wet bulb temperatures for the same locations as the ACDB localities to produce NEW CAMEL datafiles derived from the ACDB. Be aware that design assumption taken by CAMEL applies the extreme dry bulb and the extreme wet bulb each occurring concurrently, and with a clear sky. CRITICAL CAMEL datafiles were taken from the 100% extreme dry- and wet-bulb concurrently.

Ground truthed solar radiation data exists at a few state capitals with perhaps three years of measurement. The ACDB project extended these time series by remote sensing methods (satellite imagery), and expands the number of climate zones to produce an RMY composite of 12 months with a suit of meteorological data at each of 69 locations. RMY files could be improved by weighting for solar energy in a protocol of the American Society for Heating, Refrigeration and Airconditioning Engineers (ASHRAE) [2].

These given ACDB RMY files are used by simulation programs such as DesignBuilder(EnergyPlus) and FirstRate5(Accurate), but for air conditioning design programs such as CAMEL evaluate the response of the building to extreme value statistics, and so we compared the first 7 years (1967-1973) and last of the 7 years (1995-2001) of the Australian Climate Data Bank (ACDB) to produce two new sets of CAMEL design files: "NEW 1" and "NEW 2". This was done so we could compare with results from the ORIGINAL CAMEL data files (derived from 1970's data). By creating the 1995-2001 files, we analysed cooling loads and searched for any substantial or significant climate change effects since 1967-1973.

The seven-year ACDB weather data time-series 1967-1973 and also 1995-2001 was analysed at each location and results were converted into .txt format so that CAMEL can read the files as the 'new data' files. The procedure of generating data files and running CAMEL is shown in the flow chart below in Figure 1.

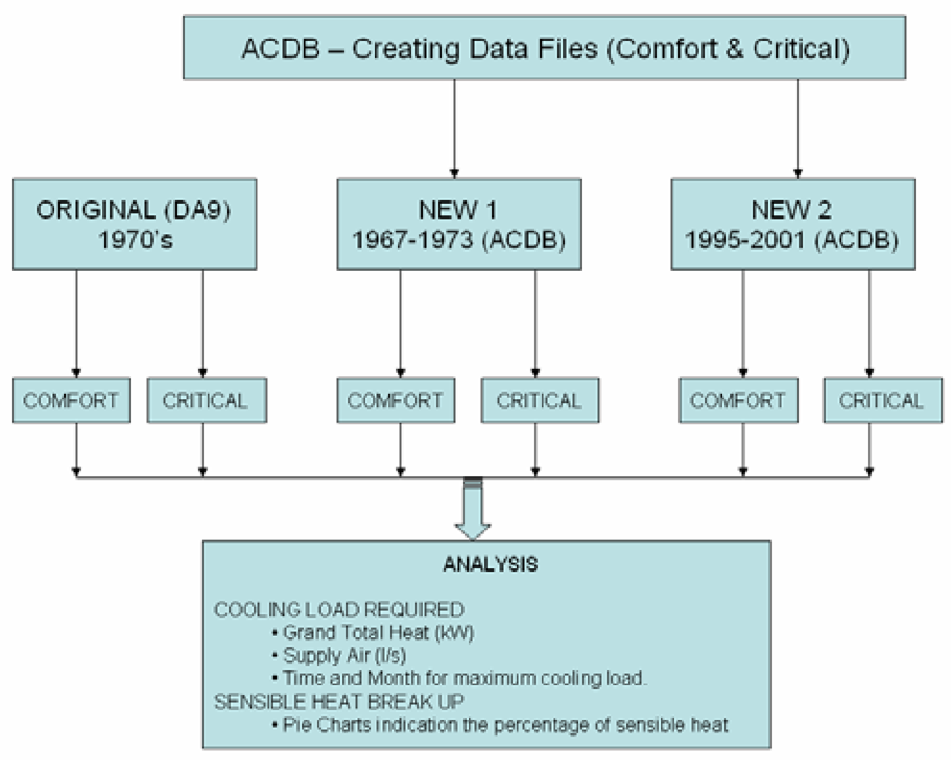

Figure 1: The flow chart indicates the procedure for CAMEL in order to receive an output result.

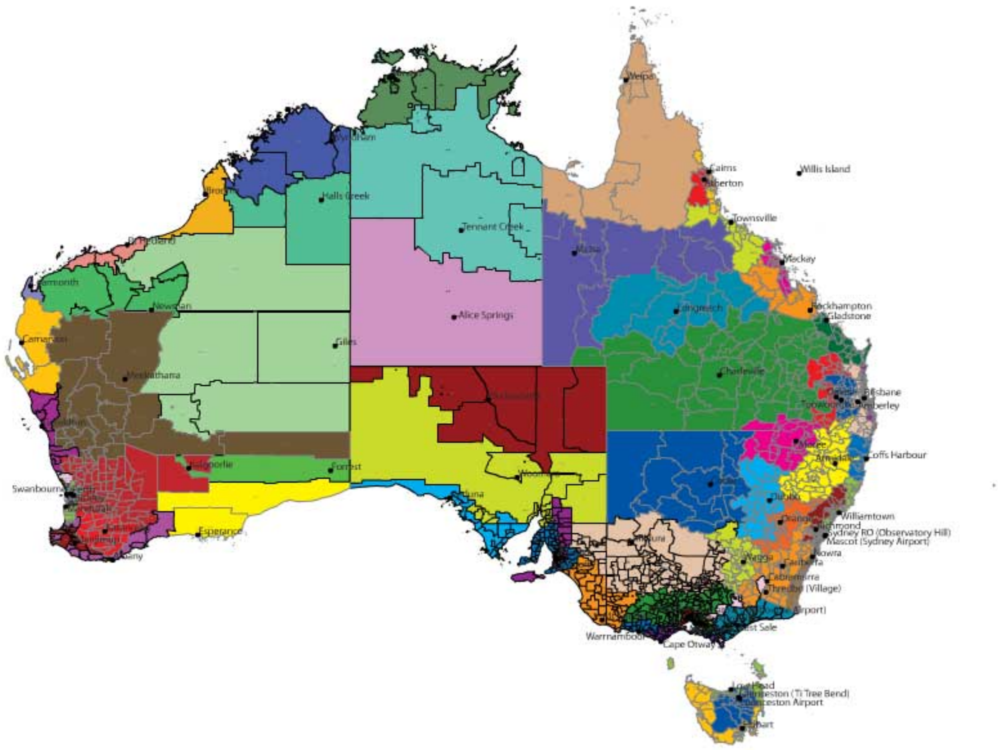

Figure 2 Australian climate databank zone (from www.nathers.gov.au [3]).

2. RESULTS

In various locations contributing factors generally are similar to the percentages illustrated in Figure 3 Albany WA. The break-down of sensible cooling loads from DesignBuilder and CAMEL were generally proportional to each other, but there are differences. CAMEL does not account for thermal storage effects of building mass as explicitly as EnergyPlus (the engine behind DesignBuilder). These pie charts concur that transmission gains through windows are the largest percentage of the overall sensible heat load, but this factor was greater in the CAMEL results. This may be attributed to DesignBuilder's assumption of an active use of shading devices by room occupants to reduce air conditioning loads. These pie charts indicate the amount of heat flows entering a model enhance future designs to use less mechanical ventilation, therefore predicting lower cooling loads. When there are lower cooling loads predicted by a software program, this reduces the cost of capital investment of equipment, and also increases the on-going efficiency of operation.

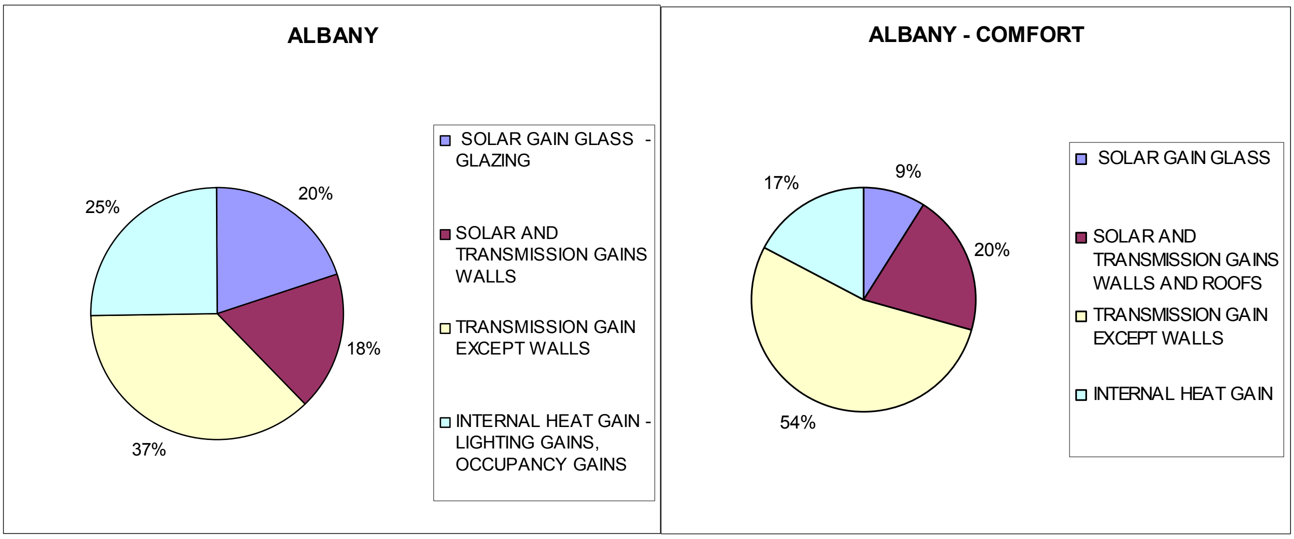

Figure 3 Example sensible heat breakup at Albany (WA) DesignBuilder (left); CAMEL (right).

The results of cooling load estimates obtained with DesignBuilder using the RMY files were compared with six sets of data files that were developed for CAMEL at each location. The CAMEL files are listed below:

- OLD COMFORT pre-1986 comfort condition
- NEW 1 COMFORT 1967-1973 comfort condition
- NEW 2 COMFORT 1995-2001 comfort condition
- OLD CRITICAL pre-1986 critical condition
- NEW 1 CRITICAL 1967-1973 critical condition
- NEW 2 CRITICAL 1995-2001 critical condition

These CAMEL output results are tabulated in tables 1, 2, 3, 4, 5, 6, 7 for Western Australian, Victoria, New South Wales, Tasmania, South Australia, Northern Territory and Queensland, respectively. These compare cooling load estimates obtained with DesignBuilder (EnergyPlus) using the RMY files "Summer Typical Week", "Summer Design Week", and the "cooling Design" from the 99.6% ASHRAE maximum design dry bulb temperature with clear sky solar radiation assumed on 15th January.

Table 1 Western Australia

WESTERN AUSTRALIA		DESIGN BUILDER			CAMEL comfort			CAMEL critical		
		SENSIBLE COOLING (kW)			SENSIBLE COOLING (kW)			SENSIBLE COOLING (kW)		
LOCATION	Latitude (S)	Summer Typical Week (ACDB RMY)	Summer Design Week (ACDB RMY)	Cooling Design (ASHRAE)	OLD CAMEL ?1970's (DA9)	NEW CAMEL 1967-73 (ACDB)	NEW CAMEL 1995-01 (ACDB)	OLD CAMEL ?1970's (DA9)	NEW CAMEL 1967-73 (ACDB)	NEW CAMEL 1995-01 (ACDB)
WYNDHAM	15.5	7.00	7.10	10.53	17.40	16.90	17.00	19.00	19.60	18.80
BROOME	18.0	5.60	6.30	9.33	14.30	14.00	17.80	15.80	17.50	17.80
HALLS CREEK	18.2	-	-	-	16.40	16.30	17.60	17.20	18.50	17.60
PT HEDLAND	20.3	-	-	10.32	13.00	15.20	19.90	15.60	19.00	19.90
LEARMONTH	22.2	6.40	7.20	10.29	16.80	10.20	19.80	18.20	10.20	19.80
NEWMAN	23.4	-	-	-	16.50	20.90	16.90	18.10	21.60	19.90
CARNARVON	24.9	5.10	6.60	8.96	12.10	11.90	17.40	14.10	17.60	17.40
GILES	25.0	6.90	7.30	9.87	15.40	13.40	19.10	16.80	13.50	19.10
MEEKATHARRA	26.6	7.30	7.70	10.21	9.71	16.90	19.50	14.30	18.90	19.50
GERALDTON	28.8	5.20	4.90	9.25	14.10	13.40	18.80	17.10	18.90	18.80
KALGOORLIE	30.8	6.10	6.70	9.54	14.80	15.30	19.00	17.30	18.90	19.00
FORREST	30.9	7.20	6.10	9.72	14.90	15.70	21.50	18.70	21.00	21.50
PERTH	31.9	4.60	6.70	8.76	16.40	13.70	17.60	18.10	18.70	17.60
BICKLEY	32.0	-	-	-	-	2.92	12.40	-	3.00	16.20
SWANBOURNE	32.0	-	-	-	-	7.92	16.20	-	8.02	16.20
MANDURAH	32.5	4.90	5.80	8.46	11.90	9.34	16.50	15.70	9.35	16.50
KATANNING	33.7	5.40	6.10	8.29	11.20	13.40	17.50	14.90	17.90	17.50
ESPERANCE	33.8	5.10	7.30	8.20	12.20	6.34	17.90	15.10	17.00	17.90
ALBANY	35.0	2.90	3.60	6.38	8.37	6.67	14.70	10.60	15.40	14.70

The Western Australia results for NEW 1 CAMEL proved fairly consistent with the ORIGINAL (DA9) input in both comfort and critical conditions. However, the NEW 2 data sets for "comfort conditions" are slightly greater, ranging with an increase of 0.10 kW to 6 kW, suggesting a climate change. But the "critical conditions" loads are similar in all cases (ORIGINAL DA9, NEW 1, and NEW 2). When comparing the CAMEL comfort and critical loads, the comfort conditions these appear to have changed in recent time. The critical loads have not changed with time, but have been met by the comfort load from the period of 1995-2001. This supports the practice of using old "critical conditions" to ensure comfortable air conditioning in the face of climate change. DesignBuilder predicts a smaller sensible cooling load than those from CAMEL. In some instances such as Wyndham, DesignBuilder predicted 6kW lower load, even in the heavier "cooling load" mode.

Table 2 Victoria

VICTORIA		DESIGN BUILDER			CAMEL comfort			CAMEL critical		
		SENSIBLE COOLING (kW)			SENSIBLE COOLING (kW)			SENSIBLE COOLING (kW)		
LOCATION	Latitude (S)	Summer Typical Week (ACDB RMY)	Summer Design Week (ACDB RMY)	Cooling Design (ASHRAE)	OLD CAMEL ?1970's (DA9)	NEW CAMEL 1967-73 (ACDB)	NEW CAMEL 1995-01 (ACDB)	OLD CAMEL ?1970's (DA9)	NEW CAMEL 1967-73 (ACDB)	NEW CAMEL 1995-01 (ACDB)
MILDURA	34.2	-	-	9.30	15.00	15.10	15.80	17.50	20.00	21.10
BALLARAT	37.5	-	-	6.70	8.52	10.40	10.80	11.40	15.50	15.10
TULLAMARINE	37.7	4.40	3.80	7.90	11.30	11.80	12.20	14.70	16.40	16.50
MELBOURNE	37.8	5.20	4.50	8.30	11.30	11.60	12.60	14.80	16.70	17.30
MOORABIN	38.0	3.50	3.80	7.90	N\A	7.31	12.00	N\A	16.00	16.70
EAST SALE	38.1	3.90	3.90	7.00	9.89	9.86	10.30	14.20	15.90	16.20
WARRNAMBOOL	38.4	2.90	5.20	7.20	10.10	4.07	10.70	14.70	4.11	16.70
CAPE OTWAY	38.9	-	-	-	7.60	5.12	6.58	12.60	15.10	15.20

The Victorian results from NEW 1 CAMEL proved marginally higher than OLD CAMEL. NEW 2 results were greater than NEW1 results in both comfort and critical conditions. However, both of the NEW data cooling loads were on average 1 to 3 kW higher for comfort and critical cases. These results identify that the cooling loads from OLD CAMEL data have been under-sized. The Victorian DesignBuilder loads are smaller than those from CAMEL. For example in the coastal location Warrnambool, the load from DesignBuilder ASHRAE is 1/3 below NEW 2 CAMEL comfort load.

Table 3 New South Wales

NSW		DESIGN BUILDER			CAMEL comfort			CAMEL critical		
		SENSIBLE COOLING (kW)			SENSIBLE COOLING (kW)			SENSIBLE COOLING (kW)		
LOCATION	Latitude (S)	Summer Typical Week (ACDB RMY)	Summer Design Week (ACDB RMY)	Cooling Design (ASHRAE)	OLD CAMEL ?1970's (DA9)	NEW CAMEL 1967-73 (ACDB)	NEW CAMEL 1995-01 (ACDB)	OLD CAMEL ?1970's (DA9)	NEW CAMEL 1967-73 (ACDB)	NEW CAMEL 1995-01 (ACDB)
MOREE	29.5	5.40	7.30	8.70	12.98	13.70	13.50	12.98	18.00	16.60
COFFS HARBOUR	30.3	3.90	3.40	6.50	7.42	6.42	6.65	8.41	6.42	13.60
COBAR	31.5	7.90	5.50	9.30	14.35	15.00	15.10	16.80	20.50	20.20
WILLIAMSTOWN	32.8	5.30	5.90	8.50	11.76	10.80	9.92	15.23	16.40	15.40
ORANGE	33.4	2.90	3.90	5.90	8.90	7.54	8.17	12.20	12.60	12.00
RICHMOND	33.6	6.80	6.90	10.10	13.36	12.90	11.70	16.33	16.90	18.10
SYDNEY	33.9	-	-	7.00	9.55	7.28	7.34	13.30	15.80	14.30
NOWRA	34.9	4.90	5.00	7.60	9.93	9.17	8.42	15.30	18.70	15.70
WAGGA	35.2	5.30	5.90	8.50	12.87	13.80	13.70	15.82	19.10	18.40
CANBERRA	35.3	3.00	5.60	7.20	10.80	10.80	10.50	13.00	16.40	14.60
ARMIDALE	-	-	-	-	8.82	7.90	7.57	10.50	12.00	11.00
CABRAMURRA	-	-	-	-	N\A	5.07	N\A	N\A	8.71	N\A
DUBBO	-	-	-	-	12.91	13.70	13.50	15.25	16.90	17.30
MASCOT	-	-	-	-	10.37	8.43	8.45	14.32	16.30	13.60
THREDBO	-	-	-	-	3.50	4.70	7.55	5.70	9.76	11.30

The New South Wales loads from NEW 2 CAMEL are less than ORIGINAL results for comfort conditions, although among the critical conditions NEW 2 CAMEL loads are generally increasing in recent years. The DesignBuilder cooling loads for NSW are smaller than CAMEL comfort loads. Summer typical week DesignBuilder load was about half of the CAMEL comfort load. DesignBuilder (ASHRAE) cooling design loads are closer to the CAMEL values. These ASHRAE-based results are generally about halfway between the RMY-based design week loads and the CAMEL comfort loads.

Table 4 Tasmania

TASMANIA		DESIGN BUILDER			CAMEL comfort			CAMEL critical		
		SENSIBLE COOLING (kW)			SENSIBLE COOLING (kW)			SENSIBLE COOLING (kW)		
LOCATION	Latitude (S)	Summer Typical Week (ACDB RMY)	Summer Design Week (ACDB RMY)	Cooling Design (ASHRAE)	OLD CAMEL ?1970's (DA9)	NEW CAMEL 1967-73 (ACDB)	NEW CAMEL 1995-01 (ACDB)	OLD CAMEL ?1970's (DA9)	NEW CAMEL 1967-73 (ACDB)	NEW CAMEL 1995-01 (ACDB)
LOW HEAD	41.1	-	-	-	4.60	4.10	2.50	5.20	11.60	5.10
LAUNCESTON (TI TREE BEND)	41.4	-	-	-	7.20	2.60	7.30	10.00	2.60	10.50
LAUNCESTON AIRPORT	41.5	2.80	3.30	5.10	-	6.70	6.40	-	11.90	10.00
HOBART	42.9	2.20	2.10	5.70	6.20	6.50	6.60	13.20	12.70	14.20

The Tasmanian results for CAMEL were fairly consistent among ORIGINAL and NEW data results. DesignBuilder cooling design loads were 1/3 less than the comfort loads from CAMEL.

Table 5 South Australia

SOUTH AUSTRALIA		DESIGN BUILDER			CAMEL comfort			CAMEL critical		
		SENSIBLE COOLING (kW)			SENSIBLE COOLING (kW)			SENSIBLE COOLING (kW)		
LOCATION	Latitude (S)	Summer Typical Week (ACDB RMY)	Summer Design Week (ACDB RMY)	Cooling Design (ASHRAE)	OLD CAMEL ?1970's (DA9)	NEW CAMEL 1967-73 (ACDB)	NEW CAMEL 1995-01 (ACDB)	OLD CAMEL ?1970's (DA9)	NEW CAMEL 1967-73 (ACDB)	NEW CAMEL 1995-01 (ACDB)
WOOMERA	31.2	7.14	8.39	11.12	14.98	14.82	15.78	18.49	17.58	18.39
CEDUNA	32.1	4.75	7.42	10.75	14.4	14.48	11.74	17.97	18.91	17.58
ADELAIDE	35	6.97	8.15	9.72	12.15	11.74	13.04	15.11	17.24	17.42
MT LOFTY	35	3.03	5.18	7.62	-	0.09	7.69	-	0.09	11.9
MT GAMBIER	37.8	5	5.27	8.7	10.74	10.22	11.24	15.05	15.82	16.07

South Australian results from CAMEL were much the same in the ORIGINAL and NEW cases -except Adelaide required more cooling, for both comfort and critical conditions, in the more recent CAMEL cases. The DesignBuilder design loads were generally a quarter lower than those required by CAMEL. In Ceduna, situated in a coastal area, DesignBuilder's load estimate was just 10% below the most recent NEW CAMEL.

Table 6 Northern Territory

NORTHERN TERRITORY		DESIGN BUILDER			CAMEL comfort			CAMEL critical		
		SENSIBLE COOLING (kW)			SENSIBLE COOLING (kW)			SENSIBLE COOLING (kW)		
LOCATION	Latitude (S)	Summer Typical Week (ACDB RMY)	Summer Design Week (ACDB RMY)	Cooling Design (ASHRAE)	OLD CAMEL ?1970's (DA9)	NEW CAMEL 1967-73 (ACDB)	NEW CAMEL 1995-01 (ACDB)	OLD CAMEL ?1970's (DA9)	NEW CAMEL 1967-73 (ACDB)	NEW CAMEL 1995-01 (ACDB)
DARWIN	12.4	6.36	7.22	9.22	11.15	10.81	10.89	11.82	12.4	12.4
TENNANT CREEK	19.7	7.68	7.99	11.15	15.51	15.19	14.66	16.65	17.52	16.26
ALICE SPRINGS	23.8	7.61	8.37	11	14.75	17.08	14.98	16.29	17.24	17.42

The Northern Territory results for CAMEL are fairly consistent among the ORIGINAL and NEW loads, with few variations. The DesignBuilder results were reduced about a quarter of what was required for CAMEL.

Table 7 Queensland

QUEENS LAND		DESIGN BUILDER SENSIBLE COOLING (kW)			CAMEL comfort SENSIBLE COOLING (kW)			CAMEL critical SENSIBLE COOLING (kW)		
LOCATION	Latitude (S)	Summer Typical Week (ACDB RMY)	Summer Design Week (ACDB RMY)	Cooling Design (ASHRAE)	OLD CAMEL ?1970's (DA9)	NEW CAMEL 1967-73 (ACDB)	NEW CAMEL 1995-01 (ACDB)	OLD CAMEL ?1970's (DA9)	NEW CAMEL 1967-73 (ACDB)	NEW CAMEL 1995-01 (ACDB)
WEIPA	12.7		7.06	9.44	12.12	11.99	12.7	13.06	13.52	13.85
WILLIS ISLAND	16.3		6.98	2.25		8.7	8.97	13.06	9.72	9.69
TOWNSVILLE	19.3		6.57	9.03	9.99	9.69	9.84	12.84	15.35	14.57
MT ISA	20.7	8.11	8.59	11.05	14.54	14.61	15.17	16.32	16.65	16.8
MACKAY	21.2	-	-	-	8.88	8.49	8.67	9.94	11.09	11.64
ROCKHAMPTON	23.4	6.14	7.53	9.61	11.46	11.53	12.48	14.21	16.46	15.33
LONGREACH	23.5	7.91	8.1	11.11	15.71	14.95	15.29	17.4	18.13	18.23
GLADSTONE	23.9	5.98	7.03	8.63	10.91	9.24	9.2	10.03	12.95	13.48
CHARLEVILLE	26.4	6.10	5.70	9.40	15.10	15.40	14.70	17.40	20.10	17.50
BRISBANE	27.4	3.30	5.30	7.10	8.80	8.80	8.30	12.00	13.50	11.70

The Queensland loads from CAMEL were similar in both OLD and NEW comfort loads. However, critical loads had increased in recent years in many locations. Gladstone requires 3.5 kW additional load than the OLD CAMEL had suggested. Typical of most of the other States and Territories of Australia, Queensland DesignBuilder cooling design loads were about a quarter less than NEW 2 CAMEL comfort loads.

3. DISCUSSION

DesignBuilder takes into consideration virtually any assembly of materials, and actively models the effects thermal storage mass, whereas CAMEL is not capable of modeling free-running dynamics. Some of the construction templates, and geographical locations listed in CAMEL were not necessarily listed in DesignBuilder menus, and therefore some guesswork was needed to choose comparable sets. Out of 69 locations in Australia, only 41 could be compared in the three input data modes of each software package. Generally southern coastal areas require less cooling than outback and northern regions – attributed to cool sea breezes. Generally we found that DesignBuilder cooling design loads (based on ASHRAE 99.4%) were about 75% of our most recent CAMEL comfort load estimates. In generating NEW 1 dataset 1967-1973 and NEW 2 dataset 1995-2001 we discovered many more instances of increasing cooling loads than the contrary. This might be attributed to global warming in general, and urban heat island developments.

4. CONCLUSION

DesignBuilder's cooling design loads are smaller than of those from CAMEL. The NEW CAMEL and DesignBuilder input files are derived from the same data source (ACDB), but they are derived by very different approaches. CAMEL weather files select the 94% extreme drybulb and 94% extreme wetbulb from seven years of records, resulting in a heavy factor-of-safety for plant sizing. DesignBuilder employs weather files that concatenated twelve disconnected "representative" months from at least 25 years of records into one pseudo year of data. Cooling simulation in DesignBuilder chooses the hottest week from the pseudo year of data, which includes cloud cover and other factors that mitigate the cooling load. Alternatively, the cooling load in DesignBuilder applies ASHRAE 99.6% drybulb and mean coincident wetbulb with a clear sky radiation model on 15th January.

Loads estimated by NEW 2 CAMEL for comfort conditions are understandably higher than the "cooling design" from DesignBuilder because CAMEL is heavy handed in adopting the 94% extreme value of wet- and also the dry- bulb temperature for each combination of hour-of-the-day and month-of-the-year with a return period of 2 years. DesignBuilder has adopted the ASHRAE design dry-bulb temperature as the 99.4% extreme value of temperature, and then taken the mean coincident wet-bulb and the mean coincident daily range of dry bulb, and applied an assumption of clear sky radiation on 15th January (high summer). Given that recent data is available to reflect climate change, it is not justified that CAMEL critical loads be considered in normal applications, nor should extreme wet bulbs be taken together with extreme dry bulbs.

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A SUSTAINABLE APPROACH OF ENERGY CONSERVATION IN IMPROVING THE ENVELOPE OF EXISTING BUILDINGS IN TAIWAN

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Keywords: energy conservation, existing buildings, envelope of buildings

Summary
Owing to diminishing global resources and the pressure of population growth, energy conservation has become the most critical issue about sustainability in the world. In Taiwan, the hot and humid climate results in a huge consumption of air conditioning system determined by the design of building envelope. Effective shading and heat insulation of the building envelope takes the important part in energy conservation. Hence, the Architecture and Building Research Institute of Taiwan has proposed a series of subsidization plans of the envelope energy efficiency improvement in existing buildings, which provide a linkage to the energy conservation indicator of Taiwan Green Building Evaluation System as well. This paper introduces the operation of improvement process and the performance of energy conservation after implementing the subsidization plan. By measuring and analyzing the performance of these cases, it showed a significant decrease in the consumption of electricity used in air conditioning systems and improved the indoor thermal environment with installing shading devices and roof heat insulation.

1. Introduction
Taiwan, which is located in tropical and subtropical regions, has a hot and humid climate. Air conditioning systems are indispensable equipments in daily life and they account for the majority of electricity consumption in the summer. However, due to improperly designed building envelopes and window ratios, air conditioning systems become inefficient. The research reveals that a building envelope, which has a depth of 5 m in the peripheral area, contributes 37.5% of the total energy consumption of air conditioning systems. Previous architectural designs in Taiwan, which incorporated more window shading and smaller openings in facades, conformed to a specific climatic pattern. Currently, architectural design criteria are being ignored by the designers. Hence, the Architecture and Building Research Institute (ABRI), Ministry of the Interior, has selected existing buildings that have potential for improvement in order to demonstrate and popularize energy-conservation concepts as part of its green building policy. By using window shadings and roof heat insulations, we can realize a comfortable and energy-conserving environment in government and residential buildings. This research will introduce the concepts of energy conservation in building envelopes, and its achievements and benefits will be discussed in the following sections.

2. Concepts of energy conservation in building envelopes
The four facades and roofs of buildings constitute a building envelope, as shown in figure 1. The consumption of energy by building envelopes is defined as the energy consumed by areas influenced by external climatic factors, thereby causing internal energy loss. Since Taiwan is located in tropical and subtropical regions, people rely on air conditioning systems, which maintain the indoor temperature and create a comfortable environment. This leads to a total energy consumption of more than 70% during summer. Therefore, the goal of realizing energy-saving technologies for building envelopes is equivalent to achieving a balance in the indoor temperature by reducing the loading of air conditioning systems due to the hot external environment.

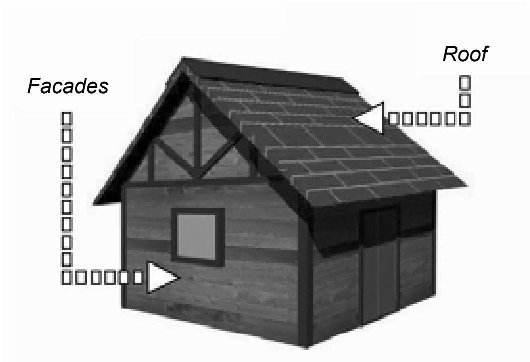

Figure 1 The four facades and roof of a building envelope.

Figure 2 shows the heat flow between the internal and the external environment of buildings. The factors that influence the heat flow are the temperature difference between the internal and external environments, the amount of solar radiation, the ratio of façade opening, and the characteristics of envelope materials. There are two major factors that cause the energy consumptions by building envelopes: the temperature difference between the internal and external environments and heat radiation. Consequently, the energy-saving technologies deal with this temperature difference by employing heat insulation, and they deal with the solar radiation by using window shadings.

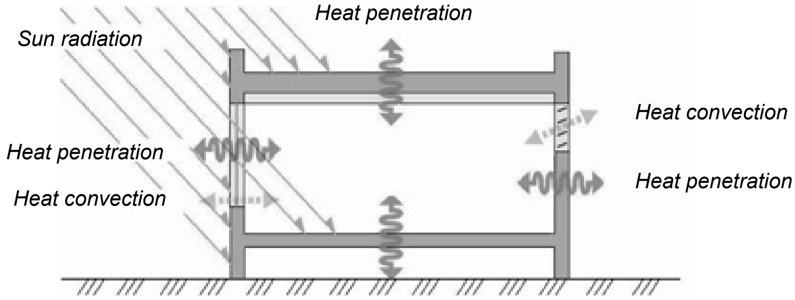

Figure 2 Heat flows between indoor and outdoor of buildings.

2.1 Heat insulation

Heat insulation can be achieved by adopting materials with a lower heat-conduction coefficient for the construction of building envelopes in order to withstand the temperature rise. Materials with a lower heat-conduction coefficient contribute to optimum horizontal roof heat insulation. The purposes of using these materials are given as follows.

1. Roof garden: The heat is reduced by spreading soil and planting various plants on building roofs. Not only the plants but the soil also reduces the heat by assisting water evaporation.

2. Air layer: The circulating air layer dissipates the heat, and thereby reduces the temperature.

3. Light-colored surface: A light-colored surface maintains a lower rate of heat absorption than a dark-colored one, thereby reflecting more heat radiation.

4. Cooling by evaporation: Sprinkling water on roofs helps to absorb heat and reduce temperature.

2.2 Window Shading

Window shading implies the installation of sunshades on any openings that a building might have (for example, windows) in order to prevent solar radiation from entering the room. In particular, external window shadings give the optimum results.

Different angles and directions of the sun's radiation must be considered when designing the outside window shadings. In general, horizontal shadings are suitable for the windows facing the south, while vertical shadings are suitable for the windows facing the east and west. An integration of horizontal and vertical shadings is suitable for the windows facing the southeast and southwest. Figure 3 suggests the type and direction required for the external window shading. The ratios of the solar radiation from different directions are shown in table 1; it appears that the most urgent requirement is window shadings for the windows facing the east and west.

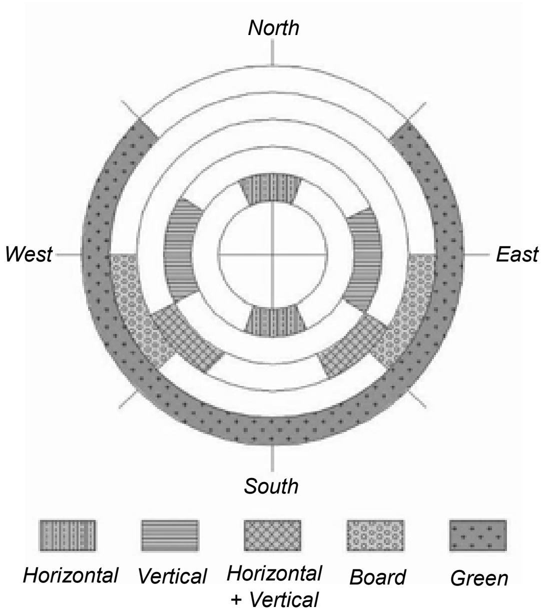

Figure 3 Suggestion for types and directions of window shadings.

Table 1 The ratio of sun radiation from different direction in Taiwan

Direction	South	East	West	North
Ration	1.0	1.24	1.24	0.81

The optimum shading not only blocks the unnecessary heat and light but also provides ample sunlight and a comfortable and warm internal environment. Furthermore, window shading offers sun shading, allows ample sunlight, provides ventilation, prevents rain from entering the room, and provides a beautiful view.

The benefit of sunshades was calculated by using the window shading cover coefficient, *Ki*, which is the ratio of the amount of solar radiation entering indoors by the amount throughout the year. For instance, *Ki* = 0.3 signifies that the window shading can block 70% of the solar radiation. A desirable value of *Ki* is between 0.3 and 0.5. If the coefficient is much lower, the interiors would require auxiliary lighting with artificial lights, which leads to energy dissipation in another form.

3. Subsidized projects applying energy-conservation techniques to improve existing buildings

After noticing that the existing building envelopes consumed large amounts of energy, the ABRI selected some potential buildings that could be used to promote “energy-saving" concepts formulated in the green building policy. The introduction of energy-saving designs in government and residential buildings, such as window shadings and roof heat insulation, which could improve the working and living environment, was subsidized. From 2002 to 2007, there were 116 cases of window shading and 220 cases of roof heat insulation.

3.1 Overall benefits of improvement

After government assistance and subsidies were given for this project, the expected energy-conservation benefits were obtained and the required regulation of building envelopes of green buildings was also achieved. The *Ki* requires a value lower than 0.5 and the roof heat insulation coefficient *Ui* must be lower than 1.2 W/m^2°C.

3.1.1 Benefits of window shading improvement

Taipei Veterans General Hospital (TVG), which represents the most effective case of subsidy in 2007, had changed the window shading coefficient *Ki* from 0.98 to 0.30; the improved benefit is up to 69.39%. Originally, the west facade was influenced by the strong solar radiation although the air conditioner system was operating simultaneously. By setting up the facility of window shading on the west façade, the problems caused to the staffs were solved. For other cases, the benefit ranges between 31.50% and 67.74%, and the average is 53.05%.

3.1.2 Benefit of roof heat insulation improvement

Ching-Hai Hospital in Taichung County, the most effective case of subsidy in 2007, had changed the roof heat insulation coefficient *Ui* from 2.95 to 0.98. *Ui* can be reduced from 2.95 to less than 1.2 in all cases by using the PS board heat insulating tile or rubber heat insulation tile for environmental protection. In other cases, the benefit obtained is between 52.56% and 64.41%, and the average is 59.18%. Roof heat insulation has certain benefits in that it improves the hot environment on the top of the floor.

3.2 Benefit of electrical energy saving

Improvements have been observed in 336 cases and 195 million NT dollars has been given as subsidy since 2002 to 2007; among them, in 116 cases, window shading has been set up over an area of 9445 m^2 and in 220 cases, roof heat insulation has been set up over an area of 58790 m^2. Through calculations, it has been found that 1 million and 933 thousand degrees of electricity can be saved every year. In other words, 4 million and 833 thousand NT dollars can be saved every year (calculate with 2.5 NT dollars for each degree of electricity).

For the window shading facility, energy consumption is reduced by 15% for air conditioners in a building envelope; further, 15 to 20 years are required to retrieve the subsidy. For the roof heat insulation facility, energy consumption can be reduced by 11% for air conditioners at the top floor of the building, and it takes about 4 to 5 years to retrieve the subsidy. Moreover, the southern part of Taiwan, which has a considerably higher temperature, is the most effective region for energy conservation and subsidies retrieval.

4. Improvements in building envelope measurement

In order to recognize the differences in the performance before and after energy-conservation techniques were applied for the building envelope, a few cases were estimated by using equipments. The testing samples were divided into two areas—before and after improvements—in order to check for conformation to the same outdoor climatic environment on the day of the experiment. The experiment was conducted by considering the effect of heat on a building and its residents.

4.1 Experimental equipment and measurement project

The experimental equipment includes a heat flow meter, thermocouple, thermometer, humidity meter, hot wire anemometer, pyrheliometer, and automatic data logger. The data logger can automatically collect the signal for voltages at intervals of 10 s; the parameters include temperature, humidity, air flow, thermal current, and solar radiation. After each 10 min, the data averages the sum recorded. The experimental equipments and field measurements are shown in figure 4.

Figure 4 The experimental equipment and field measurement.

4.2 Human body comfort index

The project adopts the *PMV* (predicted mean vote) and *PPD* (predicted percentage dissatisfied) indices as the criterion for the human body comfort index. This index is based on the body temperature flow, which includes wind temperature, wind speed, air humidity, the average of radiation temperature, body activity level, and clothing. In the indoor thermal environment index of ISO7730, the range for regulating *PMV* is from +3 to 3 (+3 < PMV < –3). When the *PMV* value approaches zero, the comfort quality is better. Table 2 shows the PMV assessment criterion. The *PPD* index is defined as the percentage of unsatisfied prediction, i.e., the range between 0 and 100%. When the *PPD* value is close to zero, it means that the quality of thermal comfort is better.

Table 2 PMV assessment criterion

PMV	Psychology
+3	Hot
+2	Warn
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

This research uses the ASHRAE Thermal Comfort Program Ver1.0 to calculate the *PMV* and *PPD* indices; this program was developed by U.C. Berkeley. According to the ASHRAE regulation, the parameters are set to Met = 1, clo = 0.5, and 101.325 kPa. The interface of the program is shown in figure 5.

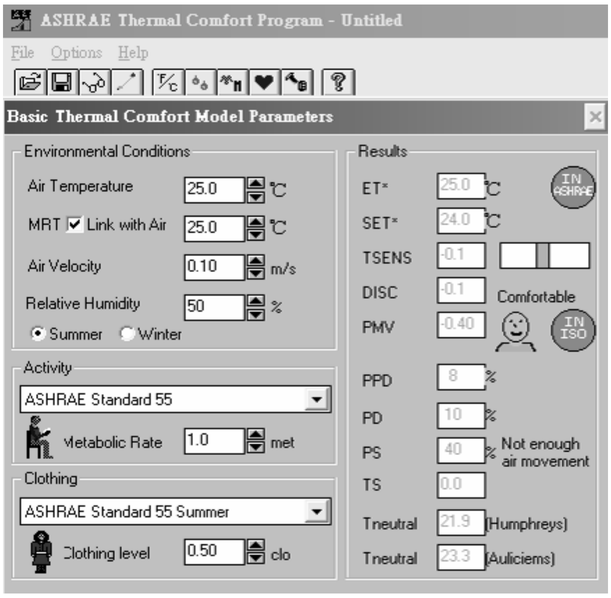

Figure 5 The interface of PMV-PPD evaluation.

4.3 Measurement results

4.3.1 Case of roof heat insulation—Chao-zhou simply court in Taiwan Ping-tung District Court

A. Heat-conduction coefficient *Ui*

The heat-conduction coefficient *Ui* is initially from 2.49 to 1.05 when using a PS board heat insulating tile on the roof. The benefit of improvement is up to 57.83% (2.49–1.05/2.49).

B. Indoor temperature

The indoor temperature that was estimated from the experiment had decreased from 2 to 3°C due to roof heat insulation. Figure 6 reveals that the roof heat insulation contributes to the energy saving of air conditioners and leads to overall thermal comfort.

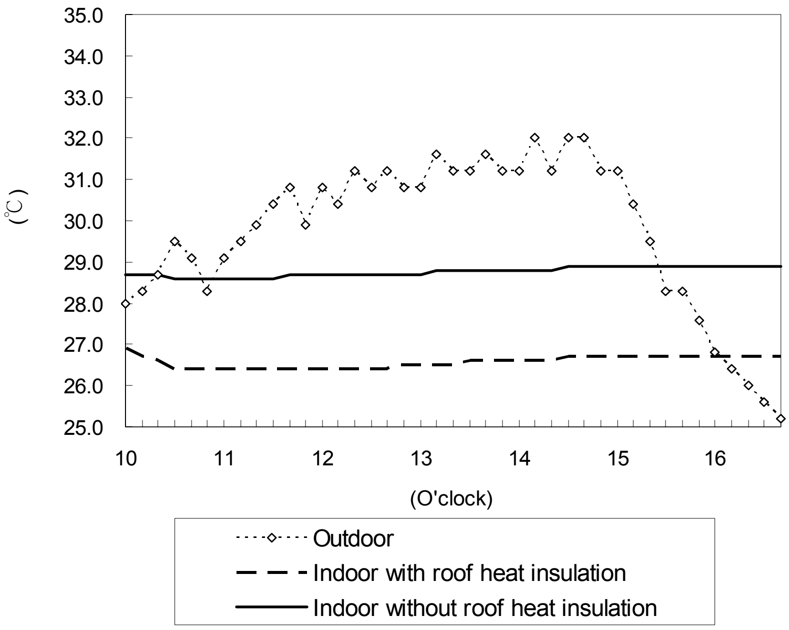

Figure 6 Comparison on temperature of roof heat insulation improvement.

C. Thermal comfort

The *PMV* maintains a value of 0.19 to 0.39 after the roof heat insulation, i.e., the psychological scale between slightly warm and neutral. The *PPD* value can be maintained between 5.9% and 8.1%. Both these values lead to improved thermal comfort.

4.3.2 Case of window shading—Ping-tung Branch, Administrative Executor's Office, MOJ

A. Window shading cover coefficient *Ki*

Ki is initially from 0.91 to 0.35 when the horizontal and vertical window shadings on the south-east side are used. The benefit of improvement is up to 61.54% (0.91–0.35/0.91). The comparison of solar radiation is shown in figure 7.

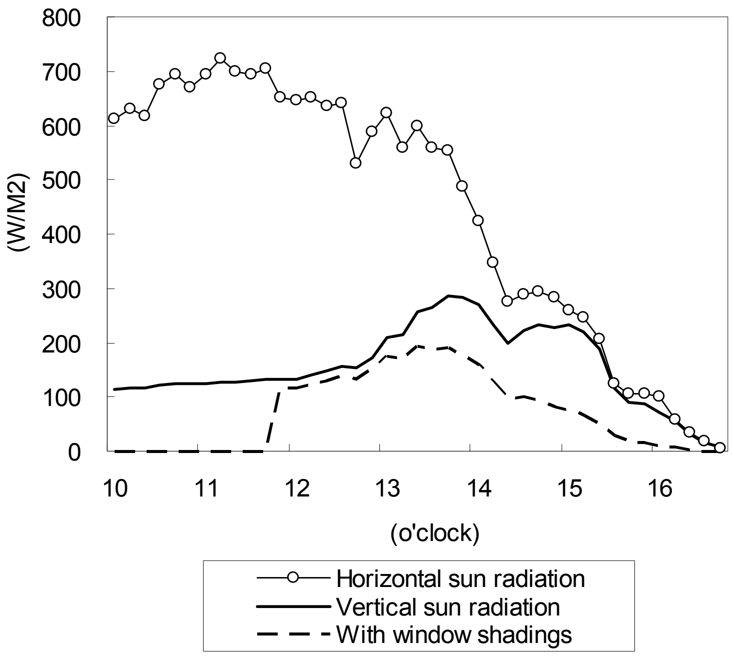

Figure 7 The comparison of sun radiation.

B. Indoor temperature

The indoor temperature that was estimated from the experiment decreased from 2 to 3°C due to the roof heat insulation. Figure 8 reveals that the roof heat insulation contributes to the energy saving of air conditioner and improves thermal comfort.

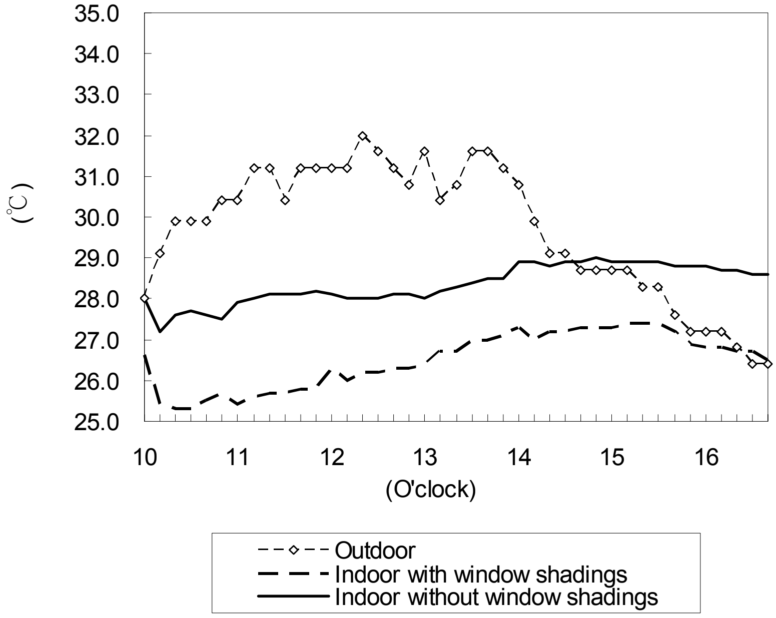

Figure 8 Comparison on temperature of window shadings improvement.

C. Thermal comfort

The *PMV* value is maintained between –0.18 and 0.57 after window shading; the psychological scale ranges as slightly cool, slightly warm, and neutral. The *PPD* value is maintained between 5.0% and 11.8%. Both these values represent a high degree of thermal comfort.

4.4 Discussion

The energy-saving techniques, roof heat insulation, and window shading can efficiently improve the energy consumption of a building envelope and yet maintain a high degree of thermal comfort. Since the measurements were carried out in October, the solar radiation is lower than that in summer. Otherwise, the improvements would have been greater obviously.

5. Brochure of energy-conservation design for buildings

Among the methods used to promote energy-saving, an effective one was using a brochure that will introduce energy-saving results into a citizen's daily life. This brochure introduces a clear description in order to illustrate the improved cases, references, and experiences. It is divided into four parts. The first part describes the general concept of energy conservation that provides a clear concept to the user by explaining the building envelope theory and regulation. The second and third parts provide the roof heat insulation and window shading improvement operations by describing the tactics, design criteria, the procedure of design, the different types, and precautions. The fourth part gives the various cases that showed improvement and the benefit of improvements. This can provide a prototype for designers who will adjust the design in accordance with the requirement and condition. Consequently, the brochure provides a simple explanation, graphic illustration, benefits, and the actual picture for people to examine the building on their own. People can follow the instructions suggested in the brochure to improve their house. In this manner, the idea of energy saving can be popularized universally.

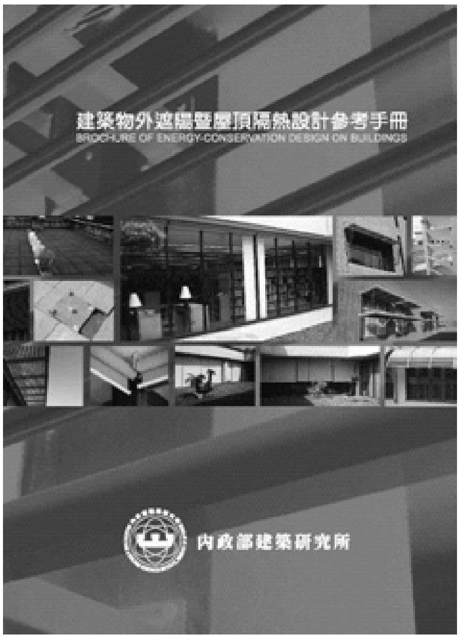

Figure 9 The brochure of energy-conservation design on buildings.

6. Conclusion

Window shading and roof heat insulation could effectively improve the energy consumption of building envelopes. They not only create a healthy indoor environment but also maintain a global ecology. The objective of this research is to attempt to reward and subsidize existing buildings to reduce the use of air conditioners and accomplish the purpose of energy conservation. The final goal of the green policy is to reduce the ozone depletion and balance the ecosystem. The ultimate aim is to promote global awareness for energy conservation. This will make Taiwan a green community and an eco-friendly city.

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EAWAG FORUM CHRIESBACH - A STEP TOWARDS THE 2000-WATT SOCIETY

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Keywords: 2000-watt society, energy efficient construction, heating, solar energy, sustainability.

Summary

Eawag, the Swiss Federal Institute of Aquatic Science and Technology in Dübendorf is the internationally active aquatic research institute of the ETH domain. It is committed to the ecological, economical, and socially responsible management of water. In the spirit of scientific advancement, the competition brief for Eawag's new head office, Forum Chriesbach, called for the exemplary and progressive management of all resources and a visionary concept regarding ecological sustainability. The building was constructed in the years 2004 to 2006 and has been in use since June 2006. It meets the requirements of the 2000-watt society, a vision put forward by scientists of the ETH domain, which calls for freezing the worldwide energy consumption at the present level of about 2000 Watts/capita. With its approximately 340 MJ/m^{2}a or 600 Watts/capita, Forum Chriesbach proves not only that the vision is practicable for office buildings but also that this can be achieved by using conventional materials and existing technologies. The building meets high standards of functionality, aesthetics and comfort. Creating such a building, however, is possible only with a team of highly qualified architects, planners, specialists and, of course, dedicated clients. In order to achieve sustainability before fossil energy resources are depleted entirely and climate change effects become too disastrous, more such teams must become active: immediately and forcefully.

1. The Idea of a 2000-Watt Society

World primary energy consumption in the year 2005 amounted to about 123,557,142 GWh, supplied namely by coal (27.8%), oil (36.3%), gas (23.6%), nuclear energy (5.9%) and hydropower (6.3%) (BP 2007). With a world population of 6,514,751,000 people (UN 2006), this annual energy consumption is equivalent to a continuous power per capita of 2,165 Watts. The worldwide consumption of energy is still increasing by about 2-3% annually (Fig. 1). Given the fact that fossil energy resources are limited and their usage environmentally disastrous, scientists from the ETH domain have formulated the vision to stabilize energy consumption at the average level of 2,000 Watts per capita (= 17,520 kWh per year). While the USA uses more than 10,000 Watts per capita, developing and emerging market countries like Pakistan or China still consume less than 2,000 Watts per capita with, however, the trend tending upwards. Switzerland crossed the 2,000 Watt line in the 50s and at present every Swiss consumes more than 5,000 Watts (Fig. 2). The vision stipulates that the transformation should be possible without a loss in the standard of living.

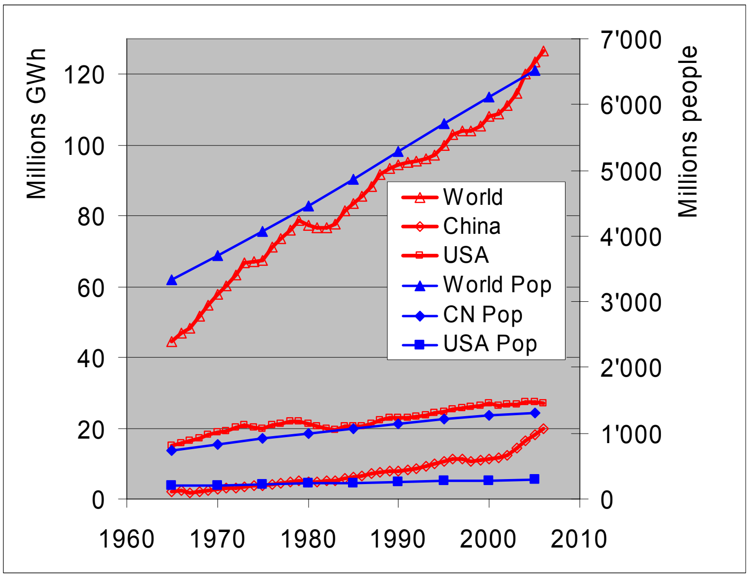

Figure 1 Development of primary energy production (BP 2006) and of population (United Nations 2006) within the past 40 years. The USA and China, with a population of about 25% of the world, consume 37% of the energy.

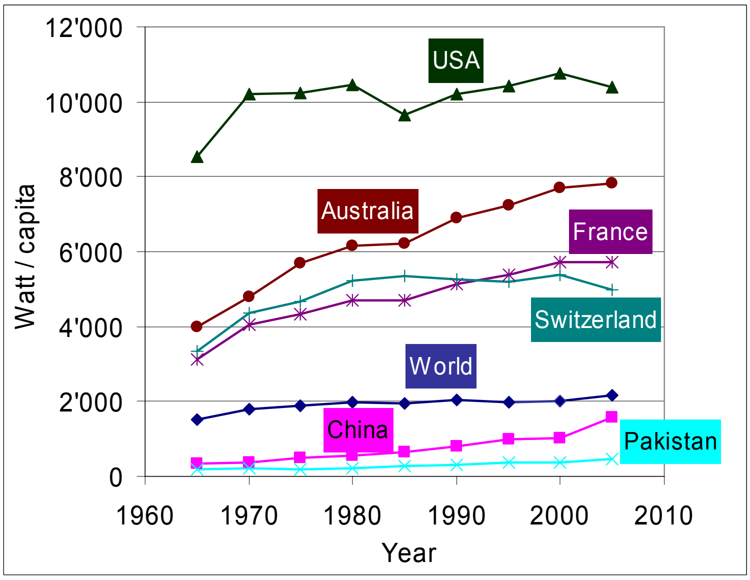

Figure 2 Development of primary energy consumption per capita. From 1980 until 2000 the world average power demand remained relatively constant at a level of about 2000 Watts/capita, but has started rising again since then. While China has developed towards the 2000 Watt line, the USA and other industrialized countries have managed to slightly decrease their consumption. Data sources: BP 2006 and United Nations 2006.

One fourth of the 323,897 GWh of primary energy used in Switzerland in the year 2006 is 'lost' during conversion to final energy (mainly nuclear energy to electricity) and the rest is used as shown in Table 1. We assume that about $^1/_3$ of primary energy, i.e. 600-700 Watts/capita can be used for work space. Koschenz and Pfeiffer (2005) estimate that in Switzerland about half of the total primary energy goes into construction and building operations and thereof 780 Watts/capita is used in office work space and 320 Watts/capita in industry. The grey energy imported with products is not taken into account in this data. Thus, if an office or industry building consumes less than about 700 Watts/capita, it can be considered as compatible with the 2000 Watt-society.

Table 1 Final energy usage in Switzerland 2006 (Population 7,557,000)

	GWh/a	%
Households	72,186	29.3
Industry	49,264	20.0
Services	40,217	16.3
Traffic	81,119	32.9
Agriculture	3,972	1.6
Total	246,758	100.0

2. The Forum Chriesbach Building

2.1 Eawag's Competition Brief for the Building

Eawag, the Swiss Federal Institute of Aquatic Science and Technology, is committed to the sustainable use of water. With its more than 400 employees it does research, teaching and consulting to further this aim both in Switzerland and globally, thereby bridging the gap between basic science and practice. It is located on a campus in Dübendorf together with its sister institute, Empa[1], which is concerned with materials and construction research. The new building is Eawag's head quarters, comprising office space for 150 employees, a lecture hall for 140 people as well as seminar and conference rooms for about 160 people. The room program also includes the new joint library of Eawag and Empa, a staff canteen, and a foyer for exhibitions and conferences.

Eawag and Empa, together with BaFA - their construction agent, insisted that their commitment to sustainability had to be realized in an exemplary and progressive form. The structural and technical measures had to be innovative and, indeed, exceed current technological standards. All resources had to be handled frugally - energy, materials, land and funds. At least $^1/_3$ of the electricity requirements must be covered by the building's own photovoltaic system. Room temperatures must not drop below 19°C and not exceed 26°C. Rainwater had to be used for toilet flushing and urine had to be collected separately for research purposes.

2.2 The Project Winner

In January 2003 the project 'Vision' of Bob Gysin + Partner BGP had been selected by the jury out of 6 projects, and in December 2003 the Swiss Parliament granted 32.72 million Swiss Francs to construct the building. In July 2004 construction started and in June 2006 the keys were handed over to Eawag.

Table 2 Technical data of Forum Chriesbach.

Building volume	38,615	m^3
Floor area	8,533	m^2
Energy reference area (weighted)	11,170	m^2
Roof area (building footprint)	1,886	m^2
Photovoltaic panel area (77 kWp)	459	m^2
Evacuated heat pipe solar collectors	50	m^2
Construction costs	30	Mio CHF

[1] The domain of the Swiss Federal institutes of Technology (ETH domain) consists of the two national technical Universities, ETH Zürich and EPF Lausanne, and the four research institutes Eawag, Empa, PSI, and WSL.

Figure 3 Eawag Forum Chriesbach: Characteristic facade with blue louvers, solar energy equipment on roof and air inlet of thermal register (behind tree on the NE - side of the building. Photo, A. Bryner Eawag 2. March 2007).

Figure 4 Eawag Forum Chriesbach: The impressive atrium with conference rooms jutting out into the void and the model of a water molecule for projections with two beamers inside it (Photo H. Güttinger, 30. January 2007).

The building has no active heating or cooling system except for a few radiators in the ground floor and cooling ceilings in the conference and seminar rooms. The energy concept relies on conserving the heat generated inside in winter and on preventing solar radiation energy from penetrating in summer. The minimized surface area of the compact building and its extremely tight insulation keep the heat 'losses' of people (~70 Watts), personal computers (~100 Watts) and light (~100 Watts) inside. These internal energy sources together with heat recovery from used air, waste heat from kitchen appliances and computer servers provide enough heat to keep the building at comfortable temperatures most of the time. The import of energy from the district network is therefore minimal and amounts to only some 31 MWh/a primary energy (~3,000 liters of oil), a quantity that is normally used for a conventional one-family house. Fig. 5 illustrates the potential of heat and cooling energy reductions in Forum Chriesbach as compared to conventional buildings and the 'Minergie' standards. There are clear limits to the reduction of electricity and grey energy demands; these must be produced with renewable energies to attain sustainability. However, grey energy can be at least partly controlled by clever materials choices and by maximizing the lifespan of constructions.

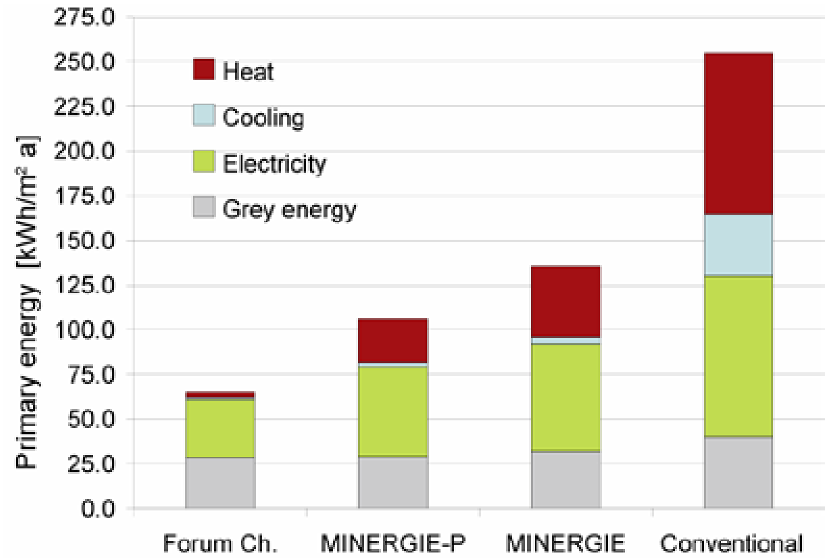

Figure 5 *Energy demand in Forum Chriesbach as compared to a similar building designed and constructed without concern for sustainability (conventional) or according to the Swiss standards Minergie or Minergie-P. Heat and cooling demands can be reduced relatively easily to almost null while electricity and grey energy for construction and materials remain significant.*

Another special feature of Forum Chriesbach is its thermal register, a collection of 78 pipes 20 m long and buried in the soil in the northeast of the building (see Fig. 3). Fresh air enters the building through this register and is thus cooled in summer and warmed up in winter by advective heat exchange with the soil, which has temperatures fluctuating at around 10°C. All the computer servers for the whole of Eawag are installed in the Forum Chriesbach and are cooled mainly by air. During winter this warmed up air is also used to heat the fresh incoming air, which is then distributed into the comfort zone, i.e. into the office, conference and seminar rooms, the library and the restaurant.

The most striking feature of the building is its 1,232 blue glass louvers. They are fixed on the fire egress scaffolding around the building. Their main function is shadowing and to that aim they rotate in 5° movements about their axis, following the daily track of the sun, all panes of each facade in synchrony. However, when outside temperatures rise above 30°C, shadowing by the louvers and cooling in the thermal register are not sufficient to keep room temperature below 26°C as required. Compounding this problem, internal heat sources from men and computers also emit their extra heat in summer. To overcome these difficulties a night cooling system has been installed: when outside temperatures drop below inside temperatures during the night, the hopper windows in each room and in the atrium roof automatically open, allowing convection driven air circulation. The intruding fresh air then cools the concrete mass of the building and thus the inside temperatures can be kept at comfortable levels of 24-26°C the whole day long, even when it is very hot outside.

2.3 Two Years' Experience in Forum Chriesbach

In June 2006 Eawag employees began to occupy their new space in Forum Chriesbach and the theoretical concepts had to prove their everyday fitness. A two-year optimization phase was started to fix everything that has not been properly designed, constructed or installed, and to adjust the control system in accordance with the real behavior of the building and its inhabitants.

To the great relief of the architects and planners, of the directorate of Eawag, and of those working in the building, things have gone well: summer temperatures have remained at perfect levels between 24°C and 26°C in hot July and August. Spring and autumn temperatures were too low but could be adjusted, and winter temperatures did not drop below 19°C - normally. It has turned out that not all of the office spaces are occupied full time and by as many people as planned. Scientists spend part of their time in the laboratory, doing field work, attending conferences, or are lecturing at other institutes, and many of the administrative employees work part time. Additionally, some exposed rooms in the corners of the building have greater losses through the walls and less passive solar gains than projected. Also, many Eawag workers use laptops and flat screens instead of less energy-efficient desk top models. Therefore, more heat energy had to be drawn from the district area network than planned. But, even if this extra heat remained about twice as much as projected, in absolute terms it still is very little energy. And, most importantly, there is optimization potential left because some systems still do not perform properly. One of these is the shading system in the glass roof of the atrium, whose blinds too often shut in winter, not allowing passive solar gains. Another is the heat storage tank, which does not get all the available solar energy but too quickly recharges from the district network; its control system has yet to be adjusted. We are confident, however, that once the remaining problems have been ironed out the building will perform better and the number of Eawag people working in it who are content ,even in cold winters, will increase. In summer everyone is happy with the building's performance.

Table 3 Energy consumption details in Forum Chriesbach. The relative values have been calculated using the height weighted energy reference area of 11,170 m² and the average number of people working in the Forum Chriesbach, some 200 people in total. (150 office workplaces and 50 people using library, restaurant and seminar rooms). The estimations of elevated energy usage (last column) are based on extrapolations from measurements in the months July to December 2007.

	Final energy (plan)		**Primary energy (plan)**		**final energy (real)**
	MWh/a	kWh/m2 a	MWh/a	W/cap	MWh/a (Estimations)
Electricity without servers	181	16.2	543	309.9	190 - 210
Electricity servers (15.5 kW)	136	12.2	408	232.5	130 - 140
Heat from network	24	2.1	31	17.7	30 - 50
Heat export to network	-6	-0.5	-8	-4.3	-10 - 0
Cooling from network	22	1.9	24	13.5	20 - 45
PV-system (77 kWp)	60	5.4	180	102.7	60 - 65
Solar collectors	24	2.2	31	17.9	15 - 30
Grey energy			319	182.2	(37.6 years life span)

Electricity demand has been above projections as well. Luckily enough, the performance of the solar panels has also been above expectations. Several causes have been identified for the elevated electricity consumption: about twice as many people as projected take their meals in the staff canteen and office lights have to be turned on longer because of the shading by the louvers, which have not yet been optimally adjusted. The most extraordinary revelation was that the hopper windows' motors were turned on permanently and consumed an extra 20 MWh/a - about $^1/_3$ of solar production! These have been fixed meanwhile.

In Eawag Forum Chriesbach an extensive monitoring system with several thousand data points has been installed, but not every sensor and energy meter has worked well from the beginning. We still do not have reliable energy usage data for a whole year but we believe that most of the problems observed can be solved and that the real energy consumption will be at levels very close to those projected.

3. Conclusions

The two years of working in Forum Chriesbach illustrate that the main promises concerning its sustainability have been fulfilled. The buildings performance meets the requirements of a 2000-watt society, namely the 600-700 Watts/capita energy demand. With a demand of 340 MJ/m2a it also meets the 2000-watt society requirements for office buildings, which have been stipulated to be 480 MJ/m2a (including 140 MJ/m2a for mobility, SIA 2006). Fig. 6 shows how much energy per person is used in Forum Chriesbach for construction, cooling, heating, electricity and computer servers. With heating and cooling minimized, it is particularly electrical energy that remains to be produced sustainably and used efficiently. The optimization of usage and performance of computer servers is of particular importance and must be given high priority. Grey energy can be controlled, at least partially, by careful choices of materials and by taking into account the life spans of buildings. With 572 CHF/m3 the construction costs of Forum Chriesbach has not been significantly different to those of comparable buildings. Intelligently designed buildings are not only affordable and can be energy efficient, they can also provide more comfort than conventional buildings, as summer working conditions in Forum Chriesbach demonstrate.

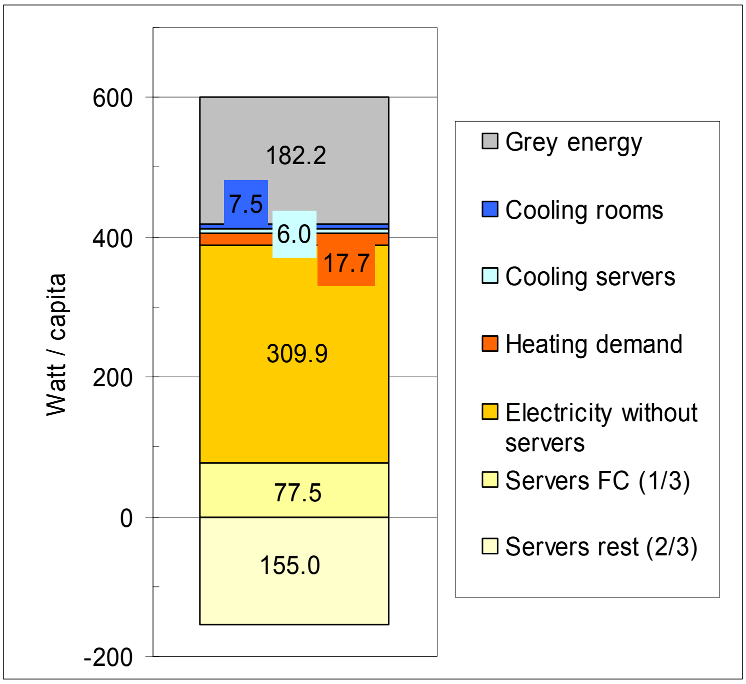

Figure 6 Per capita primary energy consumption of Forum Chriesbach for the different usages (see Table 3 for absolute values).The calculations have been performed assuming that 200 people work in the building. Because the computer servers installed are for the whole of Eawag, only $^1/_3$ of their total electricity demand has been allocated to those employees in Forum Chriesbach. Thus the energy demand per capita amounts to about 600 Watts.

There are some prerequisites to the realization of such a building. Daniel Wentz (2007) has put these down in his beautifully written book about Forum Chriesbach:

It is not the central architectural concept that is new (super-insulated passive solar buildings have existed for decades). The significant distinction here is how the people behind the project worked together with a shared sense of responsibility, commitment, and purpose. Showing social, environmental, and scientific engagement, the client prescribed standards for the design that go far beyond the norm, beyond any building code, and expressly sought to test the limits of what is possible. The design team shares the client's philosophy, and delivered the necessary background and know-how, working together with the client, users, and contractors throughout the five-year duration of the project. ... The lessons of Forum Chriesbach have global ramifications. The building proves that by using conventional materials and known transferable technologies, a high level of performance is not only possible, but affordable and practicable. This level is vital to a sustainable future. This building makes sense in every respect - economically, socially, ecologically, functionally, and aesthetically. In a world in which sustainability is in question, in which better ways of shaping and managing our environment must urgently be adopted, Forum Chriesbach stands as a model of how to build for the future.

The goal to stabilize energy consumption at a level of 2000 Watt/capita means that industrialized countries have to reduce their energy demand drastically while developing countries might still increase theirs. It also means that fossil fuels have to be substituted for within the next 80 years2 at the latest because they will then be exhausted. Therefore, 1.25 % of fossil fuels have to be compensated for annually and an additional 2-3% for the growth in demand. These challenges require all our creativity and effort and must be tackled as soon and as quickly as possible. Avoiding the additional negative effects of climate change, of course, would demand an even faster substitution of fossil fuel energy.

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[2] Reserves/production for oil is 40 years, for gas 63 years, and for coal 147 years, but production is still increasing by more than 2% annually (BP 2007).

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ENERGY AND MOISTURE RELATED USER BEHAVIOUR MEASUREMENTS IN RESIDENTIAL BUILDINGS – STUDY APPROACH

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Summary

Increasing demands on lower energy use in buildings have resulted in a demand for better energy calculations and better input data regarding the building user's energy related behaviour. Parameters that are important for these issues are occupancy levels, household electricity use, facility electricity use, domestic hot water use, heat use, indoor temperature and indoor relative humidity. For residential buildings, there is a lack of these data, which also needs to be resolved over time, in a way so that both short term and long term variations can be described. If all these data are measured at the same time for the same case, it would be possible to search for relationships between the different parameters. This would help to perform energy calculations in the design phase as well as energy investigations in existing buildings. An intended study will measure the mentioned parameters in approximately 20 Swedish residential buildings spread throughout the country, from an intended latitude of N56° to N67°. The measurements will be performed hourly during one year. All parameters will be measured at the building level, providing average values including many apartments. This paper describes the study approach and gives preliminary results from a pre test case.

1. Introduction

In the building industry, it is necessary to perform calculations regarding energy use and moisture levels in different parts of the construction to ensure that a building will be sustainable and healthy. To make accurate predictions on energy use and moisture levels, input data are needed in order to simulate energy use and indoor climate and verify results from simulation programs. As a part of a new study, several indoor related parameters will be measured in several Swedish residential multi family apartment buildings during at least one year with hourly readings. Since several parameters are measured, there will be an opportunity to correlate different parameters. Since the outdoor is also monitored, occupancy levels will be calculated as well as moisture supply and production.

Tso and Yau (2003) studied the daily use patterns of household electricity in about 1500 households in Hong Kong. The use was about the same during the whole day except for a large peak in the evening. Riddell and Manson (1995) studied power usage patterns of domestic consumers in New Zealand. It was found that the different patterns for mid morning and early evening peaks could be observed in both studies. Capasso et al (1994) monitored the electricity use during 22 working days in 95 households in Milan. The daily average load profile showed a smaller peak at eight o'clock in the morning and a bigger peak at eight o'clock in the evening. Paatero and Lund (2006) monitored use of household electricity in 702 households in Finland. The use was least around 5 o'clock in the morning. After the morning peak the use stayed at a higher level compared to the use during the night. The variations during the day have a large peak around eight o'clock in the evening during both weekdays and weekends. The use increased during the morning but there was no peak. Between mornings and evenings, the use was higher during weekends compared to weekdays.

Papakostas et al (1995) monitored domestic hot water heating in four apartment buildings in a Solar Village in Greece. Average domestic hot water use patterns by day of the week were analysed. During weekdays, the patterns showed equal characteristics. The highest peak in use was between 20:00 and 22:00 and the second highest peak around 13:00. During weekends the peaks appeared earlier and the use was more uniform. Vine et al (1987) monitored domestic hot water use in four low income apartment buildings in San

Francisco. During a typical day, there was a peak in use during the morning and another peak in the evening. These peaks were related to bathing practice and cooking and dishwashing. Different usage patterns were observed for weekdays and weekends.

Lee et al (2001) measured CO_2 concentration in living rooms and kitchens in six homes in Hong Kong. The average concentration varied between 500 and 1000 ppm. High CO_2 concentration was generally found in small kitchens with insufficient ventilation. Parent et al (1998) studied difference in CO_2 concentration between rooms in buildings that used different types of ventilation systems. The CO_2 concentration differed a lot between rooms in buildings that used natural ventilation while the difference was minor betweens rooms in buildings that used mechanical ventilation. Lawrence and Braun (2007) developed and tested a methodology for estimating schedules for CO_2 generation rates using short-term field testing. Lech et al. (1996) measured the amount of time spent indoors and Johansson (2005) measured occupancy in offices but there is a lack of reliable data on residential buildings related to the apartment.

Papakostas and Sotiropoulos (1997) studied occupational and energy patterns for 158 families living in the outskirts of Athens, using questionnaires. Attendance rate patterns during the day are described for different family members and typical families, and activity patterns for different electrical appliances are presented.

There seems to be a lack of data, showing annual variations, particularly for many parameters that can be correlated, including many apartments. The objective of the study is to measure a number of parameters in residential buildings in order to give the opportunity to correlate these different parameters with each other. This paper presents the study approach and a test case which has been used to provide insight into potential problems, both methodologically and practically, so they can be solved before the measurements are started in full scale.

2. Methods

By measuring different parameters in the exhaust air of residential buildings, a large number of apartments can be included in the study at a reasonable cost, compared to measuring in individual apartments. On the other hand, it will not be possible to find distributions between apartments inside a certain residential building or distributions between different rooms in an apartment. In the future, verifications are planed to be carried out in the test case or in more cases by use of questionnaires or apartment loggers regarding some of the parameters.

2.1 Measured parameters

The parameters to be measured are carbon dioxide levels in both the central exhaust unit and outdoors, ventilation airflow rate, temperatures in the central exhaust unit and outdoors, relative humidity in the central exhaust unit and outdoors, household electricity use, overall electricity use, use of space heating and domestic hot water heating. Using these parameters, occupancy levels, moisture supply, moisture production, indoor temperatures and parts of the power balance needed for energy calculations of buildings can be calculated. Measurements will be performed hourly to make it possible to obtain daily and weekly time variations. The purpose is to measure for at least a year to obtain annual time distribution and be able to evaluate the methods during different outdoor conditions. The residential buildings are not yet determined.

2.2 Errors

The study will not give detailed information about levels in each room of each apartment but will instead give airflow rate weighted averages of the apartment levels for a large number of apartments, which is the aim of the study. By that, it will be difficult to know if a measured value is the airflow weighted point value at the exhaust devices or if it is the airflow weighted average value of the entire apartments. In fact, it will be a combination of both.

A major methodological error in this study is to determine the airflow rate that changes the air in the building. Buildings are exposed to leakage due to wind and buoyancy that changes the air in the apartments as well as the mechanical ventilation system does. The actual air change rate can be measured with tracer gas methods but it would be expensive to do it annually so it is not realistic if many buildings are included. On the other hand, this error can be minimized with the use of buildings with mechanical exhaust air only. That leads to a depressurisation of the building which reduces the exfiltration and by that the air change per hour from leakage. Typically, it is decreased by a factor of 5 compared to a building with balanced ventilation (Johansson, 2005). If a building has mechanical exhaust and an air tightness of 0.8 $l/(s \cdot m^2$ surrounding walls) at 50 Pa testing pressure, a constant airflow rate of $1\% \cdot 0.8$ $l/(s \cdot m^2)$ can be assumed in normal conditions (Johansson, 2005). If it is assumed 1.4 m^2 surrounding area per 1 m^2 floor area, 0.011 $l/(s \cdot m^2$ floor) is added to the mechanical ventilation. This can be corrected for in the analysis but is small compared to the former Swedish Building regulation (Boverket, 2002) that demands a ventilation airflow rate of 0.35 $l/(s \cdot m^2$ floor). Therefore, exhaust ventilated buildings that take the kitchen stove air through the same ducts as the rest of the exhaust air will be used in this study. Exhaust air is taken from bathrooms, kitchens and laundry rooms. Outdoor air inlets are located in bedrooms and living rooms in almost all Swedish residential buildings.

If people in the buildings open windows, the air change per hour increases dramatically (Nordquist, 2002). That could mean that during the summer period, the measured values regarding moisture and carbon dioxide are not applicable for supply and production calculations. Still, they give point level information at the exhaust devices. The window airing may be checked in the test case at some points by visual checks from outside or by a questionnaire.

Even if carbon dioxide production indoors can be obtained, it can be influenced by, for example, pets, burning candles and plants. The carbon dioxide production from the human being also varies a lot depending on, for example, activity and body mass. The measurements will not specify where the carbon dioxide comes from and the occupancy calculations have to rely on typical figures of production rates for human beings. On the other hand, the intended measurements will tell how a demand controlled ventilation system will react since such a system is usually controlled by carbon dioxide. Verification in the test case on occupancy and other carbon dioxide producers or reducers can help.

The temperature indoors can have errors such as if it is measured in the central exhaust unit, if the ducts are not insulted and located in cold or warm spaces. These things might be visible in the buildings. There can also be leakage in the exhaust duct system that means that cold air is drawn into the system and the airflow rate measurement becomes wrong.

2.3 Theories and analysis

The measurements and calculations of temperatures, relative humidity, moisture supply and moisture production are discussed by Bagge and Johansson (2008). The production of carbon dioxide can be described by Equation 1 where C_p is the carbon dioxide production in l/s, C_{in} is the carbon dioxide volume concentration in the exhaust air and C_{out} is the carbon dioxide volume concentration in the outdoor air and q is the ventilation airflow rate of the building in l/s. It is assumed that there is no buffering. The effect of buffering and time lags will be analyzed in the study.

$$C_p = \left(C_{in} - C_{out}\right) \cdot q \qquad (1)$$

If a person produces c_p l/s carbon dioxide that enters the building indoor, Equation 2 gives the equivalent number of persons, N, that need to be in the building. Here, C_p can be corrected for other producing or reducing species in the building.

$$N = \frac{C_p}{c_p} \qquad (2)$$

Since the activity level varies in residential buildings, it is difficult to determine an average c_p. For typical office work, c_p is given to 19 l/h for adults but for other activity levels it can vary between 10 l/h and 170 l/h (Nilsson, 2003; Ashrae, 2001; European Conserted Action, 1992). In residential buildings, people are suspected to be sleeping a large part of the time they occupy their homes and that certainly gives lower c_p. The verification will give some results on correlations between occupancy and total carbon dioxide production.

The variations of parameters during the day were studied. A difference can be calculated between each hourly value and a corresponding daily average value. The variations are presented as averages of these differences for all weekdays and weekends respectively.

2.4 Measuring equipment

The measurement sensors will be placed close to the exhaust fan in the main duct of the exhaust ventilation system for measuring the indoor temperature and relative humidity. Outdoors, the placement is shielded from too much wind and preferably from rain. Temperature, humidity and carbon dioxide concentration will be measured and wind and solar radiation will be bought from SMHI (2005) if possible. Since the loggers will measure for a year at each location, the set up must be robust and may not disturb the daily work or living.

The carbon dioxide sensors have a typical error of ±20 ppm. Since levels should vary between 400 ppm and approximately 800 ppm of carbon dioxide, the error of the difference can reach 10% of the scale if the exhaust air logger shows +20 ppm and the outdoor logger -20 ppm.

Temperatures are measured with loggers with a specified error of ±0.35°C. Generally, the experience from these devices is that it is seldom more than ±0.2°C. The relative humidity is measured with the same loggers that also have voltage input for pressure drop measurements for obtaining airflow rates and carbon dioxide concentrations. The relative humidity error is given to 2.5% absolutely. The voltage error is small compared to the error of the pressure drop sensor. The flow can be believed to have an error of ±7% of the reading including pressure sensor and variations in the fan pressure drop outlets.

The loggers will be calibrated regarding temperature and relative humidity to decrease the possible combined errors due to the fact that the error of the difference can be much higher.

Electricity and energy use should be measured by existing meters used for billing. The accuracy of these meters should be good enough but has to be checked in each case.

2.5 Number of studied cases and their location

The idea with the study is to receive useful data that is time resolved over average values. Since the method does not give apartment distributions, the only location distribution will be from the averages of the different buildings. If 15 buildings are measured and there are 20 apartments in each building, the entire study will give an average value of 300 apartments. The 15 buildings can also provide some distribution data between the buildings, or at least information on geographical distributions if they are located in different cities. Preferably, five buildings close to each other will be found in three different cities from south to north Sweden to represent different outdoor climates. Each group of five buildings will make it cheaper to measure outdoors and make it possible to look at differences between buildings. The setup and number will be discussed with statisticians.

2.6 Test case

The test case is a five-story multi-family building located in Malmö, Sweden. It was built during 2000 and 2001. The building consists of 16 apartments. The ventilation system is mechanical exhaust air. An exhaust air heat pump supports space heating. Additional space heating and domestic hot water heating is supported by district heating.

3. Results from the test case

Details regarding relative humidity, moisture supply and moisture production is presented in Bagge and Johansson (2008). Figure 1 presents measured indoor and outdoor temperatures. The average outdoor temperature during the measurement period was 4.8°C and varied between 0.7°C and 8.2°C. The average indoor temperature was 20.3°C and varied between 19.8°C and 21.0°C.

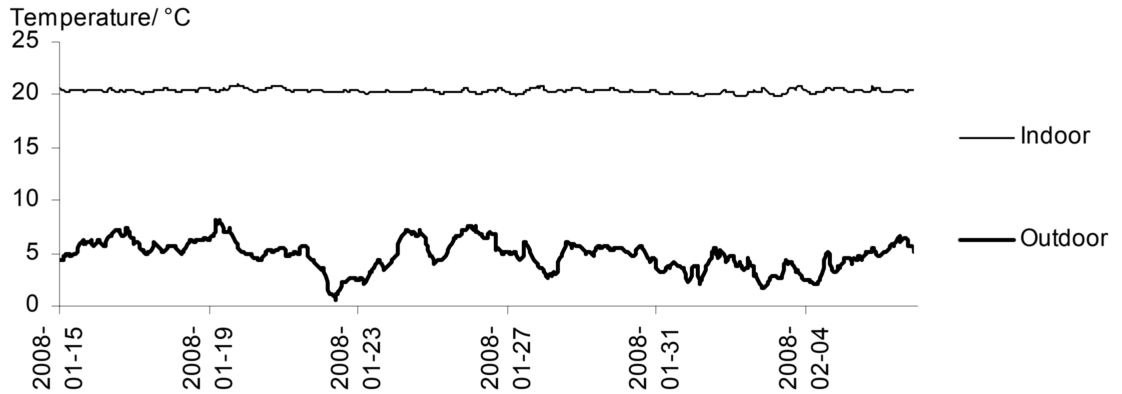

Figure 1 Indoor and outdoor temperatures during the measurement period.

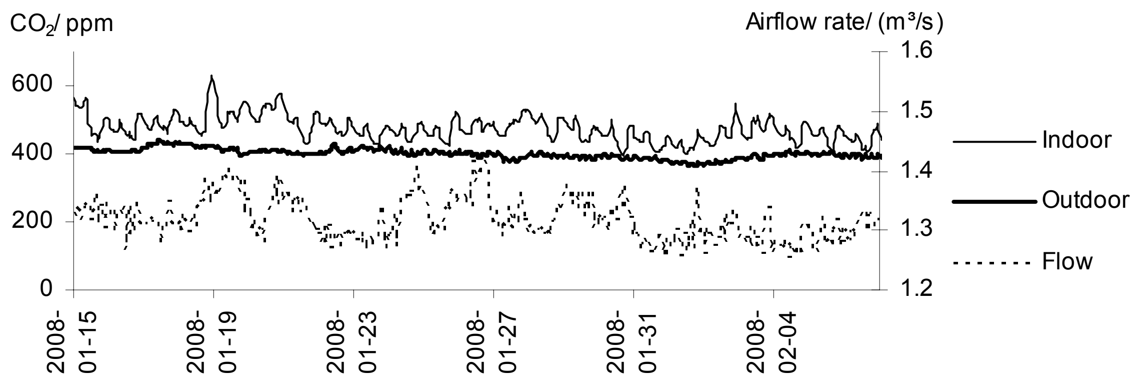

Figure 2 Indoor and outdoor CO_2-levels and airflow rates during the measurement period.

Figure 2 presents the carbon dioxide levels indoors and outdoors and the airflow rate. The average airflow rate was 1.32 m³/s and varied between 1.25 m³/s and 1.42 m³/s.

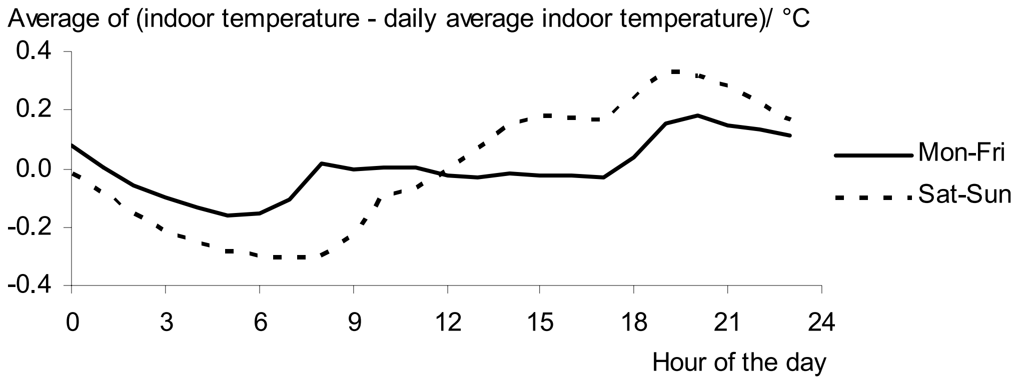

Figure 3 Variations in Indoor temperature during the day, presented for weekdays and weekends respectively.

Figure 3 gives the daily variations in indoor temperature for weekdays and weekends respectively. The average indoor temperature during weekdays was 20.35°C and during weekends 20.38°C. During weekdays the temperature decreased during the night, increased during the morning where after it decreased slightly during the day, increased during the evening and reached a maximum at 20:00. During weekends the temperature decreased during the night, increased during the morning and the afternoon and reached a maximum at 19:00. During weekends, the increase in temperature during mornings occurred later compared to weekdays.

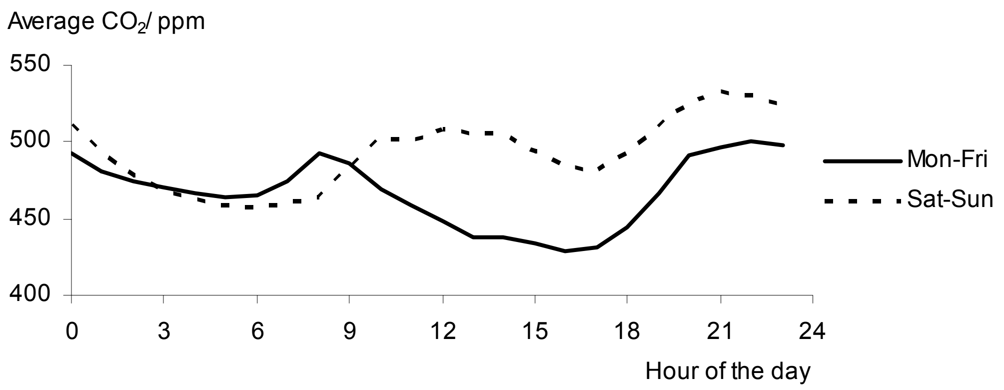

Figure 4 Variations in CO_2-concentration indoors during the day, presented for weekdays and weekends respectively.

Figure 4 presents the variations during the day of the CO_2 concentration indoors. The average CO_2 concentration during weekdays was 467 ppm and during weekends 493 ppm. During weekdays the CO_2 concentration decreased slightly during the night, had a peak at 08:00 where after it decreased during the morning and stayed on a low level during the afternoon where after it increased during the evening. During weekends the relative humidity decreased slightly during the night, increased during the morning and stayed on a high level during the day where after it decreased slightly during late afternoon followed by an increase during the evening. During weekends, the increase during mornings occurred later compared to weekdays.

Figure 5 presents the CO_2-production during the day. The average CO_2 production during weekdays was 0.085 l/s and during weekends 0.13 l/s. The CO_2 production, given by Equation 1, follows the CO_2 concentration since the airflow rate and the outdoor CO_2 concentration is rather constant. Increased airflow rate can only be caused by stove ventilation that the user higher during cooking.

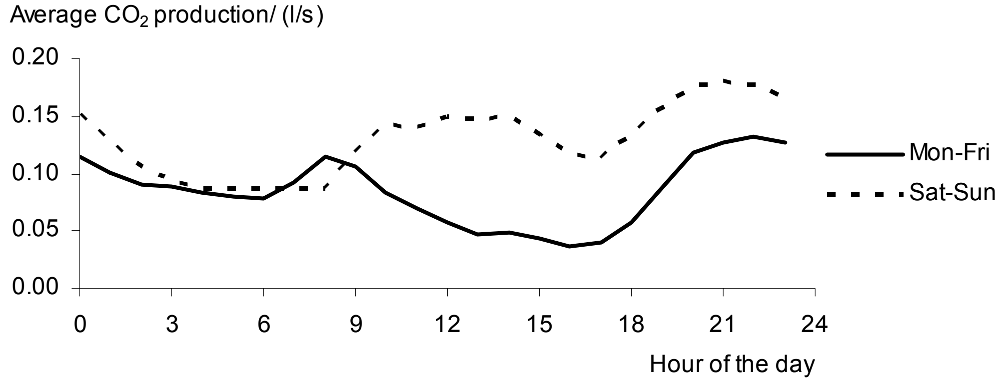

Figure 5 CO_2-production and estimated occupancy during the day, presented for weekdays and weekends respectively.

3.1 Use of electricity and domestic hot water

The energy use at the property was studied earlier by Bagge (2007). Use of electricity was measured hourly during 2005. The use includes both household electricity and common electricity. Figure 6 presents the daily variations in use of electricity during weekdays and weekends respectively.

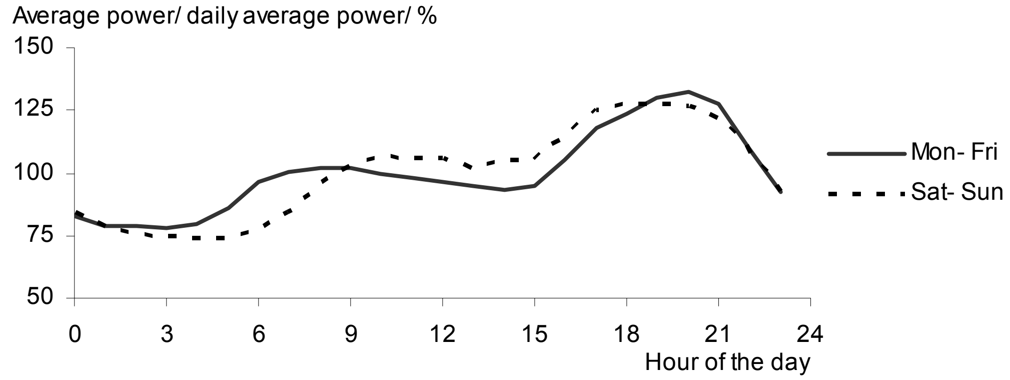

Figure 6 The variation in use of electricity, including household electricity and common electricity, during the day, presented for weekdays and weekends respectively.

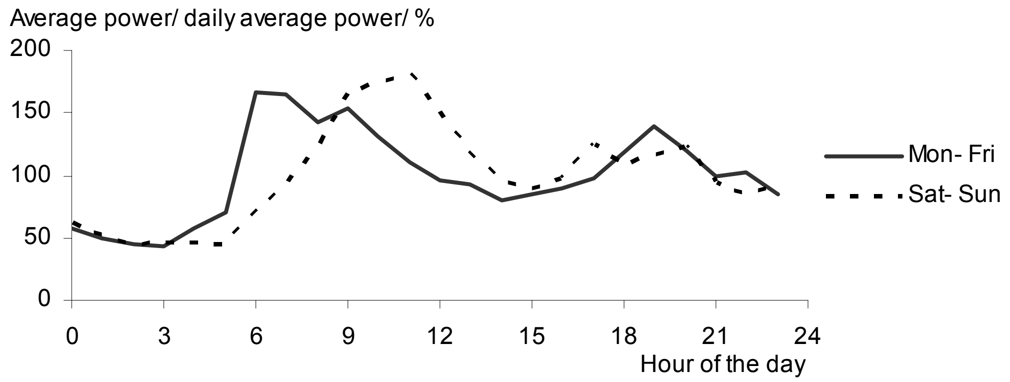

Figure 7 The variation in use of domestic hot water heating during the day, presented for weekdays and weekends respectively.

The use of domestic hot water was not measured separately, neither the volume used nor the energy used for domestic hot water heating. However, during the summer there should not be any need for space heating and thus the use of district heating should be used solely for heating the domestic hot water. During 2005 use of district heating during July and August was measured hourly. Since the measurements are from the summer months when people typically have vacation, the usage patterns during the day might be different from the rest of the year. Figure 7 presents the daily variations in use of domestic hot water heating during weekdays and weekends respectively.

The daily variations in use of household electricity and domestic hot water have equal characteristics. There are peaks at the same times during mornings and evenings. However, the peak during morning is larger for domestic hot water and the peak during evening is larger for household electricity.

Figure 8 presents weekday variations during the day in the indoor temperature, use of energy for domestic hot water, total electricity, moisture supply and CO_2 production. All these parameters have equal characteristics with one peak during morning and one during evening. The peaks for the different parameters had different phase displacement which can be caused by buffering and time lags between different physical phenomena.

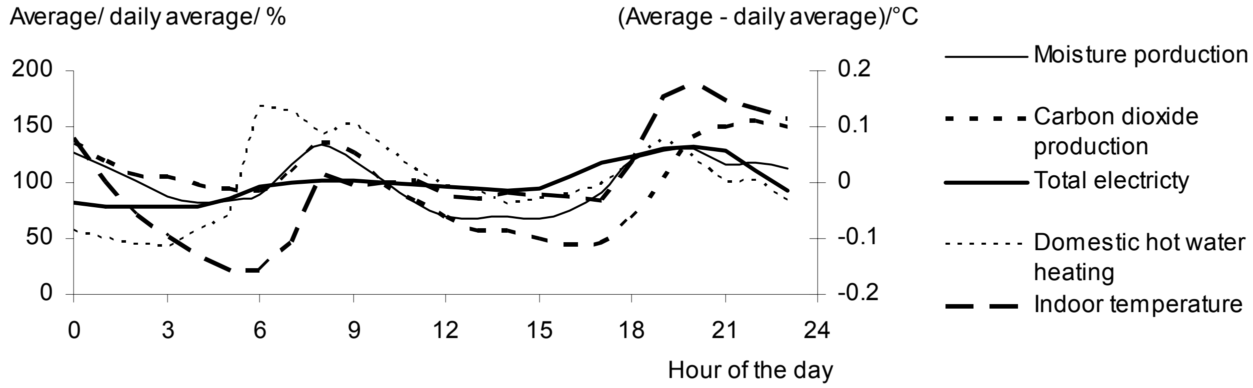

Figure 8 Weekday variations during the day in the use of energy for domestic hot water, total electricity, moisture supply, CO_2 production on the left axis, and temperature on the right axis.

4. Discussion and conclusions

In the study, a number of uncertain, user related parameters are going to be measured in several residential buildings. The idea to measure many parameters in many apartments for a reasonable amount of money forces a number of assumptions into the study that increase the errors and make some analyses impossible. Examples are window airing and leakage that influences both moisture measurements and occupancy measurements or distributions between apartments in a certain building or between single rooms inside an apartment. Despite the weaknesses, a lot of useful information can be provided by the data that will be obtained if they are representative.

With the amount of needed equipment, there is a need for cost effective sensors and measuring equipment. It seems that the equipment that was tested will be appropriate but calibration is needed according to the error analysis. The carbon dioxide sensors seem to show large errors due to their automatic calibration used in the test case. This auto calibration will be switched off and the sensors will be calibrated manually before measurements and checked again after. Measured data will be linearly corrected for the drift over the measured period.

The average CO_2 production during weekends was 53% higher compared to weekdays which might indicate higher occupancy level during weekends. For all measured parameters the peak during weekends occurs later compared to weekdays, which is believed to be due to earlier mornings for the residents during the weekdays.

Several of the measured parameters have equal characteristics as shown in Figure 8. This indicates a relationship between different parameters and that it could be possible to correlate them in such a way that one parameter can be estimated from another. Hopefully, this study and presented test case will give data on averages, distributions between houses, daily variations, annual variation and correlation levels between several parameters to help to improve simulations of indoor climate and energy use in residential buildings.

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IR THERMOGRAPHY FOR THE PERFORMANCE ASSESSMENT OF A BIPV INSTALLATION ON A PUBLIC BUILDING IN GREECE

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Keywords: building façade, materials defects, manufacturing faults, module malfunction

Summary

Photovoltaic (PV) cells, integrated within a building façade are an application of growing interest, in Europe and Greece. In order to assess their performance after their installation new tools and methods of investigation are needed. In this work a non destructive technique, infrared thermography was used as a diagnostic tool for the performance assessment of a photovoltaic array integrated on the southern façade of public building, NTUA's Chemical Engineering Building. This grid-connected 50 kWp solar photovoltaic array, installed under an EC Thermie Project (SE-142-97-GR-ES), operates in a standard and hybrid PV-Thermal configuration, meant to save conventional energy. The thermographic system used for the analysis covers the wavelength region 8-12 μm. The thermal images obtained showed that there are notable temperature differences on number PV panels, which may be attributed to material defects, manufacturing faults, module malfunction, and external abuse.

1. Introduction

Photovoltaic (PV) cells, when integrated within a building façade, offer the possibility of generating electric power and heat for local use or export. At the present time there is significant R&D activity through Europe, which attempting to improve operational efficiency of photovoltaic cells, ensure their attractiveness to designers for use as a façade element and develop know-how in relation to façade integration. The expectation is that such facades, especially at public buildings will enhance the thermal performance of the envelope and provide and economic delivery of electric power (Clarke et al. 1996).

In this work a BIPV system, installed on the southern facade of a public building in Greece, Chemical Engineering School Building of the National Technical University of Athens (NTUA), was investigated with the aid of infrared thermography.

The use of infrared thermography in the analysis of a building's envelope is really developing in recent years. The use of IR data for the calculation of heat transfer coefficients is reviewed in Astarita et al. 2000, while Grinzato et al. (1998) analyse quantitative infrared thermography in buildings. Avdelidis & Moropoulou (2004) discuss the use of IR thermography in buildings of historic interest and Bazilian et al. (2002) use thermographic analysis of a building integrated photovoltaic (BIPV) system. This analysis allows for the interpretation of the surface emissivities and operating temperatures, as well as qualitative graphic analysis of temperature gradients. The use of an infrared camera is invaluable in the study of the thermal performance and the relevant parameters in a BIPV system, especially as a diagnostic tool for potential problems, since it involves a relatively quick procedure, which can be accomplished without the need for interrupting system operations.

2. BIPV project study

2.1 BIPV project description

In this work was performed thermographic analysis on the PV arrays of the southern façade of the NTUA's Chemical Engineering building complex (Figure 1). The photovoltaic project was realized under a Thermie Program (SE-142-97-GR-ES), which involved integrating 50 kWp grid-connected solar photovoltaic arrays on the facade and the roof, operating in a standard and hybrid PV-Thermal configuration, meant to save conventional energy (thus limiting pollution normally associated with the latter) and, at the same time, to improve the thermal comfort in the adjacent large laboratory space. The project was inaugurated at October 2002.

Figure 1 Building façade with the first six PV arrays

The concept of the hybrid operation (Figure 2) is simple enough : in the winter, the working area air is heated up by rising via free convection in the narrow space between PV's and external wall, and is returned to the interior, thus utilizing the rejected heat due to the low electrical conversion of the PV modules.

In the hot season, on the other hand, the same kind of draft behind the arrays can lead cooler air from the northern side of the laboratory into the laboratory, before venting it into the atmosphere.

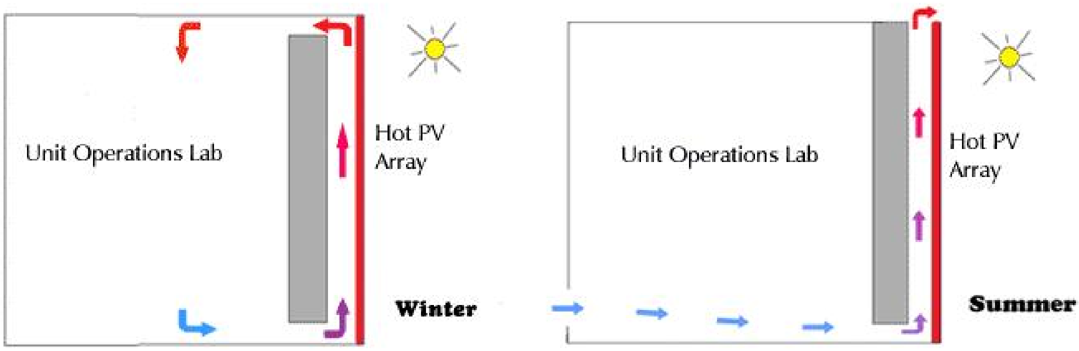

Figure 2 Schematic of the thermal operation of the hybrid system

The installed arrays, which have a direct-south orientation, use a total of 752 polycrystalline Si modules (Eurosolare PL810), each having a 67 Wp rating, and 8 Fronius IG60 inverters that supply the grid with a maximum power of about 33-34 W.

Such integration demonstrates the potential of solar retrofitting, using appropriate photovoltaic systems and basic heat transfer techniques. As shown above, the technology applied in the hybrid arrays exploits the synergy between the need for cooling the PV cells and the existence of a heating load in the adjacent working space.

The vertical facade arrays are located outside the southern walls of the large corridors and the Computer Centre, as well as on the southern side of the Unit Operations Lab. The tilted roof-top arrays, on the other hand, are situated above the laboratory, on the southern side of its protruding central dome. The conversion of DC into AC current is effected in the inverters' room, on the laboratory's mezzanine, and is finally led to the power distribution cabinet in the basement (Figure 3).

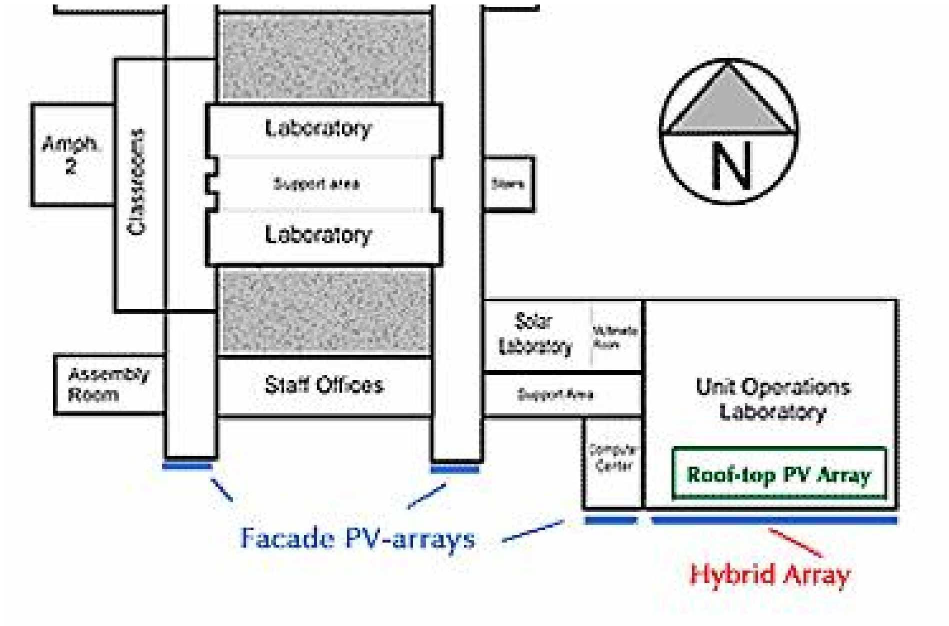

Figure 3 Ground plan of Chemical Engineering Building where PV arrays are placed

The conversion of DC into AC current is effected in the inverters' room, on the laboratory's mezzanine, and is finally led to the power distribution cabinet in the basement.

2.2 Experimental Procedure

Infrared thermography is the technology of converting incoming IR radiation into visible light that can be converted to an electronic form for representation. The use of IR thermography has grown considerably in the last decade. Hand-held IR cameras allow consultants and engineers to do on-site work in the built environment. The cameras, though expensive, are relatively robust. The IR detector is a transducer that reads the incoming radiative energy and transforms it into a voltage or a current so it can be digitally rendered (Astarita et al. 2000).

Thermographic analysis is both non-destructive and non-evasive, which contribute to its benefits in investigating operating electric (PV) systems already installed as a roofing product (Titman, 2001). This allows the analysis of a power system without having to interrupt its operation. In many cases the evaluative process can take place without ever having to enter a facility or structure. This is valuable in terms of time and safety.

In this work it was used an infrared camera was used, which operates in the 8-12 μm range of the spectrum (TVS-2000 MKIILW Nippon Avionics).The thermographs were taken in September and October of 2006, between the hours 10am to 5pm.

The thermographs were continuously recorded using a pal video, but also at selected time intervals. The ambient conditions were also recorded (air temperature, relative humidity, velocity). Better quality had the images at sunny, windless days with low ambient moisture content.

3. Results

In the series of images which follows, the left column presents the surface under investigation, while the right column shows the corresponding thermograph. As expected, the best IR thermographic testing images resulted during sunny windless days with low relative humidity.

In the thermograph of Figure 4 hot spots were detected corresponding to areas where the panels have been severely damaged as a result of vandalism, i.e. by stone and bottle throwing.

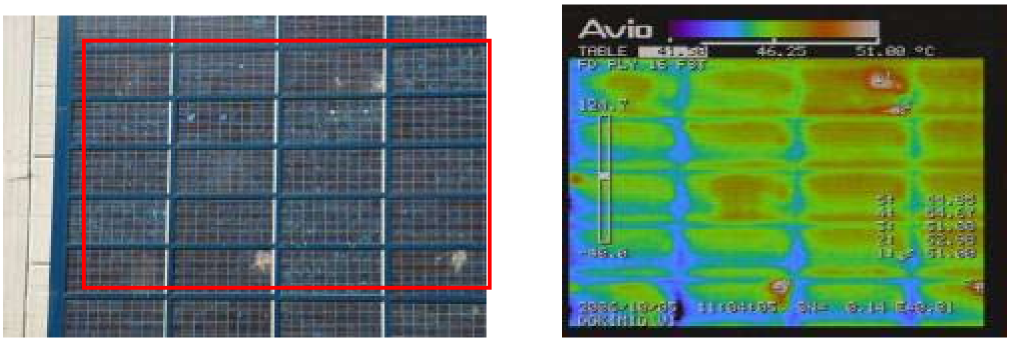

Figure 4 Hot spot detection in a vandalized array

In Figure 5 hot spots were detected in an array without visible external damage on its surface. Thus, the problem must be attributed to internal causes, such as corrosion, or shadow effects, e.g. from the mounting system's aluminium joint covering ribbons. Such hot spots appear in the same areas of the array modules.

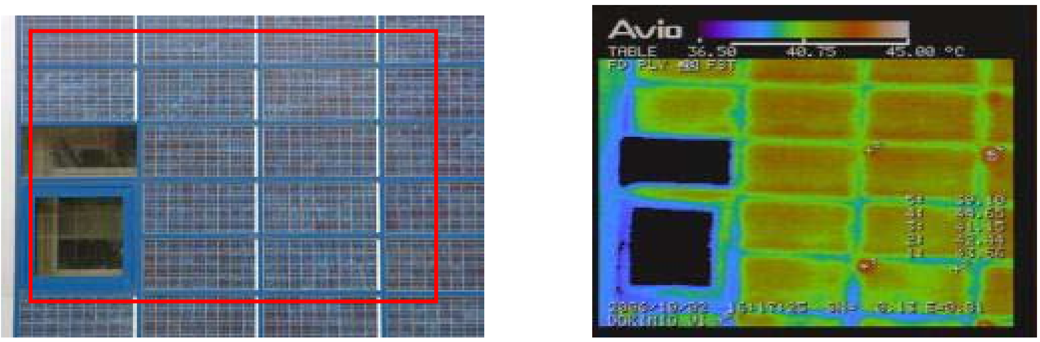

Figure 5 Hot spot detection in an externally undamaged array

Areas around windows exhibiting lower temperatures are shown in Figure 6. Thermal alternation is steep, while the difference between maximum and minimum temperature is substantial. On the upper thermograph two hot spots were also detected, just below the window.

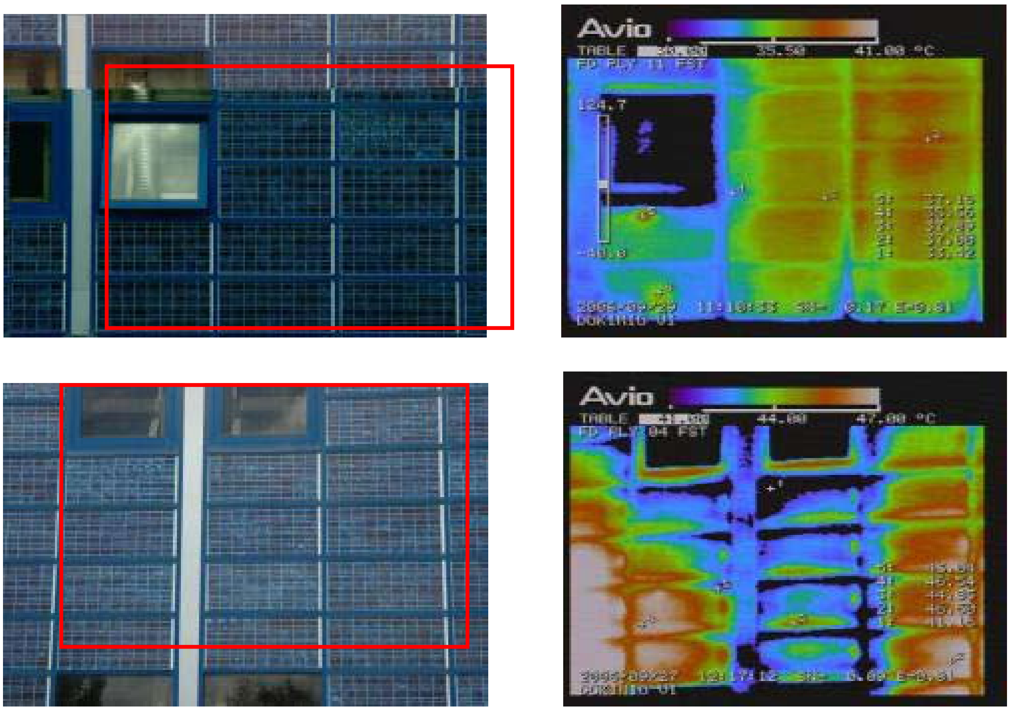

Figure 6   Areas around windows exhibiting lower temperatures

Elongated horizontal hot spots are shown in Figure 7, producing almost vertical temperature gradients in the modules. Main cause of this temperature differentiation is the shadow effect from the horizontal aluminum profiles of the mounting system, under certain angles of solar incidence.

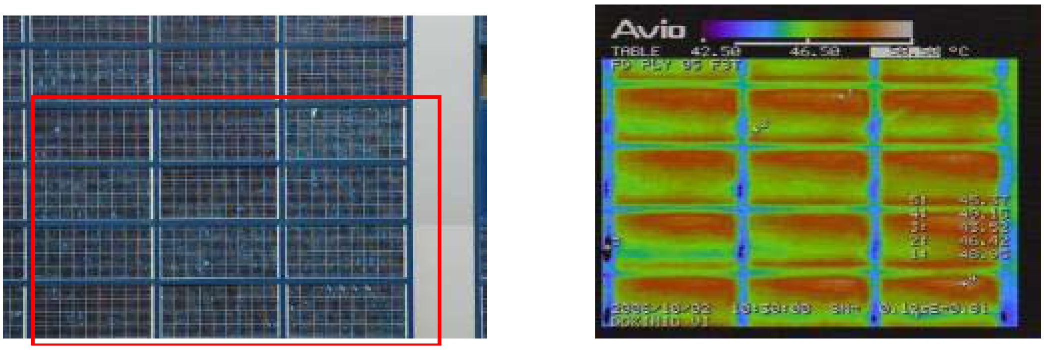

Figure 7   Elongated hot spots in the modules.

The identification of a shadow effect caused by elements of the mounting system was probably the most interesting finding of this thermographic investigation, and convincing proof of the effectiveness of the IR camera as a fault diagnosing tool. The mounting frame turned out to be slightly problematic, because the horizontal metal profiles which cover the joints between modules in the array, under certain solar incidence angles create a thin shadow on the PV material along their upper side. Besides lowering the power output, such shadows cause local overheating and, in the long term, accelerated aging of the modules involved.

The damages which resulted from vandalisms (Figure 4) caused a substantial decrease in the power output of the particular array, estimated at 13.5 %. Moreover, there is no way of telling how fast the unavoidable corrosion – from water penetration through the cracks – will further degrade the array operation.

4. Conclusions

BIPV in the National Technical University of Athens is one of the first large scale PV building applications in Greece. Infrared thermography can be used as a diagnostic tool for photovoltaics during their operation. Malfunctions, semiconductor material and insulation defects, as well as external damages, can be detected easily and quickly, without complicated procedures. IR thermography can be applied both to large and small-scale systems, in order to help restore or even improve the operation of the array.

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WIRELESS HOUSE, SELF - SUFFICIENT AND SUSTAINABLE BUILDING SOLUTIONS

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Summary

After decades of development and marketing efforts, passive houses have finally reached the mass market, especially in (Central) Europe. Along with the drastically reduced energy demand for the operation of passive houses, energy autonomous and self-sufficient building solutions have become technically and economically feasible. Research projects carried out by the Center for Appropriate Technology (GrAT) focus not only on the lifecycle of passive houses and use of renewable materials, but also on the vision of “wireless” (energy self-sufficient) buildings.

Currently small-scale stand-alone energy supply solutions are in operation. Depending on their size and application they may include wind turbines, PV modules or power blocks, possibly combined with lead acid batteries. However, these systems are cost competitive only in areas without grid connection. GrAT does not aim at these niche market solutions, but develops strategies and technical solutions for the mass market within the scope of the “Wireless House” project. The research tasks include the development of highly cost-effective small scale Concentrated Solar Power (CSP) systems for self-sufficient solar housing, including medium temperature (MT) storage for electricity generation, cooling and cooking. The whole system is heat driven and therefore avoids conversion losses. Generated heat (~300°C) will be stored to be flexibly used for different user needs. If this concept proves its practical feasibility, it will be an important step in the development of affordable solar housing solutions succeeding the current passive house trend.

1 Introduction

As a result of energy efficient building design and passive house technology, heating and cooling demands can be drastically reduced. Based upon this significant achievement, new and more radical solutions for energy supply strategies have become more feasible than before, both economically and technically. The passive house technology is therefore an important pre-condition for the next step. It can be seen as an enabling technology for further innovations towards the “Wireless House”. In this paper, the applied research and development of the Wireless House is presented. ‘Wireless’ in this context describes the independence of the house, free from public energy infrastructure and grid connection. In other words, the wireless house is totally energy self-sufficient. Application of the concept is, however, not limited to a single house, but it can be expanded to groups of houses and residential areas, where these houses may be connected into a micro net sharing energy generation and/or storage facilities.

The entire development of the Wireless House will be progressed based upon previous research results and demonstration projects. For example, the *Factor 10* building “S-House” (www.s-house.at, Wimmer, et al. 2005; Wimmer, et al. 2006) which demonstrates the feasibility of extremely energy efficient constructions will be taken as the prerequisite for the next innovation steps. By using natural materials such as straw, clay and wood, the consumption of resources during the construction of a building could be minimized by Factor 10.

The development for the Wireless House started from an analysis of actual needs of inhabitants rather than the current level of energy consumption in a modern household. This approach is typical for the philosophy of Appropriate Technology, which focuses on human needs and natural boundaries. This perspective often leads to radical system innovation instead of incremental improvements. Appropriate technology has two major goals: to improve the quality of life, and to reduce the environmental load and resource consumption. These goals are not in contradiction, but often can be achieved at the same time.

2 Background

Because of the progress in building design and solar architecture during the last fifteen years, room heating and cooling in passive houses no longer holds the major share of energy consumption. The average annual heating demand in passive houses can be reduced even below the required standard of 15kWh/m2a. The significance of household appliances and electrical/electronic devices for the energy demand in households is steadily increasing (Austrian Association of Electricity Companies- VÖE, 2007). The share of electricity in total energy consumption worldwide is projected to rise from 16% in 2004 to 21% in 2030. The annual growth rate varies from 2% in Europe up to almost 8% in China. The demand for electricity grows most rapidly in households, due to increasing use of electric and electronic appliances (Priddel, 2006). Supply and demand management for electric energy on a national level shows the drastic problem of secure supply of electricity. Electricity capacity margins are necessary to guarantee a secure energy supply. As energy demand is growing the capacity has to be increased and also the margins are augmented. The margins in different countries, like the US, the UK and Austria are between 15% and 25% (EIA, 2007, Grimston, 2005, Boltz, 2007). High costs for new power plants and high voltage grids as well as a growing opposition among the society against such projects demand for radical new solutions.

Availability and convenience are among the main factors why most of our household appliances run on electric energy. Consumers are used to a "plug and play" habit with regard to household equipment. Although an extensive study of Least Cost Planning in Austria showed an increased ecological and economical efficiency by systematically integrating the energy reduction potential of the demand side (Adensam, H. 1996) producers still do not see energy efficiency as an important development goal (Paula, et al. 2007). This behaviour results in the constantly rising consumption of electric energy.

However, is it really electricity what is actually needed? We want a hot meal, a cool storage for food and beverages, a hot shower and light for reading. In other words, what we need is not electricity but ‘energy services’. A closer look at the actual needs unveils what types of energy services are required in our everyday life. Table 1 shows the current average energy consumption used for appliances providing various energy services.

For comparison, three different consumption scenarios have been defined: Scenario one represents a conventional house, characterized by high energy demand for room heating (or cooling) due to poor energy efficiency of the building. For this scenario, it is assumed that the house is equipped with standard household appliances. This model fits the current consumption patterns in Western Europe. Scenario two is referred to as “modern house”. The energy standard of the building meets the latest legal regulations and it is equipped with A-rated household appliances. Compared to the “average house”, energy for heating is saved up to 50%, and the electric energy demand drops to one third of that of an average traditional household. Scenario three represents the best practice. In particular, heating and cooling demands are reduced to a minimum level due to passive house design and technology. The energy demand of household appliances is the same as in scenario two, but thermal energy is provided directly without conversion losses.

Table 1 Comparison of energy demand for different scenarios

Energy applications	Energy demand of an average house(hold) (kWh/a)		Energy demand of a modern house(hold) (kWh/a)		Energy demand of the Wireless House concept (kWh/a)	
	total	electric	total	electric	total	electric
Kitchen stove	1000	1000	500	500	500	*low*
Oven	78	78	39	39	39	*low*
Washing machine	378	378	189	189	189	15
Cloth dryer	528	528	264	264	264	*low*
Dish washer	456	456	228	228	228	110
Refrigerator	333	333	167	167	167	*low*
Freezer	356	356	178	178	178	*low*
Small devices	170	170	170	170	170	170
TV - / Hi-Fi – System	250	250	250	250	250	250
PC	70	70	70	70	70	70
Light	500	500	100	100	50	50
Hot water	2373	2373	2373	0	2373	0
Heating	14000	0	6000	0	600	0
Total	20491	6491	10527	2154	5077	665

According to Table 1, quantitative ranking of the appliances providing energy services in an average household[1] is as follows:

1. Hot water representing almost 1/3 of the total energy demand
2. Electric kitchen stove, due to its high load
3. Washing machine dryer and other appliances
4. Freezer and refrigerator
5. Light, computer, TV

Other than light and computer equipment which can only be run on electricity, other energy services actually require either heat or coldness, and transform electricity into thermal energy. Appliances that convert electricity into thermal energy of high or low temperature consume most of the energy in an “average household”.

Taking into consideration the conversion losses, however, the use of electric energy is a very inefficient way of providing thermal energy services. Instead, solar radiation can be used directly to produce heat, especially in regions where plenty of sunshine is available. High temperature is required for cooking, and therefore, the solar energy needs to be concentrated and stored. The temperature obtained from water-based flat panel systems reaches up to 100 degrees centigrade. For higher temperature levels thermal oil can be used instead of water.

Research and development efforts focusing on electric power generation from renewable sources including solar radiation often aim at making components more efficient and production more economical. Nevertheless, a huge portion of the generated energy is lost during the conversion. Additionally there is substantial potential for energy conservation regarding the optimization of the demand side, which is currently not utilized

3 The Wireless House Concept

Buildings that produce equal or even more energy than they consume are in existence. The available concepts can be categorised into *grid connected* and *stand alone* solutions. The idea of grid connected systems is to compensate the energy demand in periods of energy shortage with an energy surplus inducted into the grid at another time. These so called “plus energy” houses, generate a surplus of electricity based on an annual balance. In other words, a shortage in winter is compensated or even overcompensated by a surplus in summer. The grid connection ensures a continuous energy supply for the house over the whole year. It absorbs the surplus of energy and delivers energy in case of shortage.

Stand alone energy systems however have different requirements. As they are independent from infrastructure they have to provide *enough* energy at any time. This requires capacity margin as well as a storage system that is able to buffer the difference between supply and demand over the annual cycle. Nevertheless, most of the stand-alone systems only focus on the supply side. The major concern is “how to generate and store as much energy as necessary, given the current demand level?” These systems, depending on their size, including wind turbines, PV modules or power blocks, are often combined with lead acid batteries. They are regarded as expensive and only suitable for very remote areas without any grid, like mountains or undeveloped rural regions.

The Wireless House concept is not just another stand alone system but it aims to develop a new strategy for a house or a living unit which is not connected to an energy infrastructure, by actively taking the real demands into consideration. As explained earlier, most of current electric energy demands are related to heating and cooling rather than direct use of electricity. Therefore, the most intuitive solution will be to use the thermal energy from the sun instead of redundantly converting solar radiation to electricity and then to heat again.

Just like other stand-alone systems, the new solution has to provide the required amount of energy with sufficient margin to be used at any time even in periods of poor supply conditions (e.g. night time, cloudy days). However the developed concept focuses on both, the supply and the demand side, and it aims to make use of thermal energy as efficiently as possible. Figure 1 shows, that a house powered by solar energy can be realized only by drastically reducing the energy demand. Whereas the total energy consumption of modern house (holds) exceeds the produced solar energy during six months of the year, the Wireless House can be served by solar energy all year round. Only for less than two months yearly, additional energy from other energy sources (such as a biomass back-up system) may be necessary in order to assure sufficient energy supply.

[1] room heating is excluded

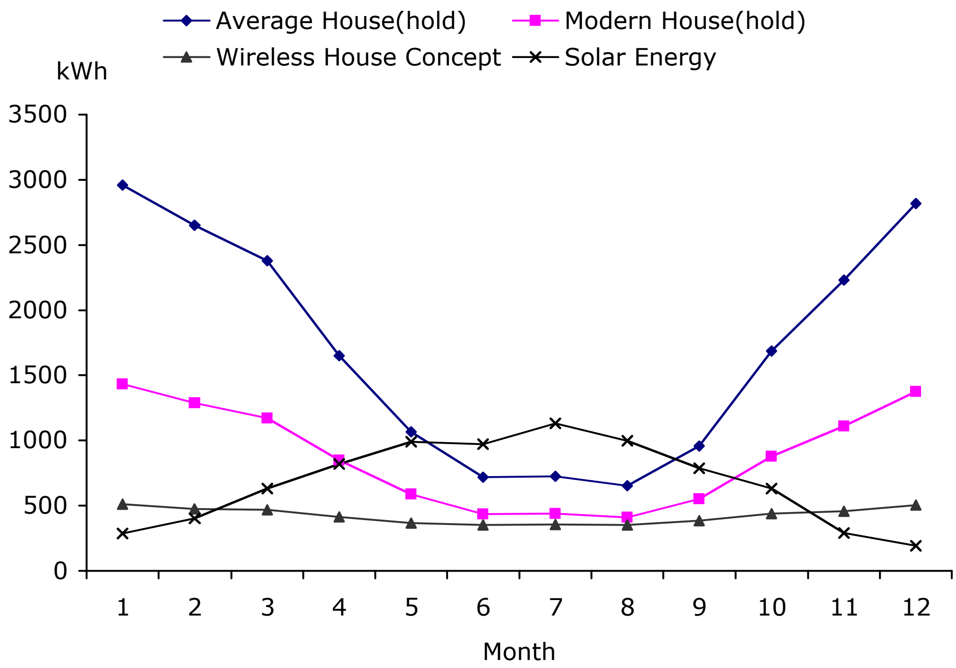

Figure 1: Total energy demand of different house(hold) types and available solar energy over the annual cycle

The concept is based on a number of assumptions, which are described as follows:

• Assumption 1: Heating and cooling demand is reduced to a minimum by passive solar architecture.

Compared to conventional existing buildings passive houses reduce energy demands for heating and cooling by a factor 10 to 20 (Wimmer, et al. 2005). Whereas the focus in cold regions is put on the reduction of heating energy, in warmer regions the reduction of demand for cooling energy is a bigger concern. The house design consequently varies according to local situation and user needs.

• Assumption 2: Thermal energy on mid temperature level is generated from concentrated solar energy and biomass.

The required temperature levels are defined by the need areas in modern households (e.g. baking, cooking, washing, and cooling). Kitchen stoves and baking ovens have to provide a temperature of up to 300°C, which is the highest temperature level. Therefore, about 300°C is the threshold for generating devices as well as for storage. Parabolic trough or dish concentrators can easily provide this level of temperature in any climate regions as far as there is sufficient direct solar radiation. A back up system running on biomass can cover the periods of poor solar gain. The new system operates with high margins over the hot period of the year (see Figure 1). During the cold period the necessary margin will be guaranteed by the proper dimensioning of the biomass system.

• Assumption 3: Thermal energy services are provided directly from collected heat, therefore minimising conversion losses.

Conventional household appliances are operated by electricity, which is afflicted with conversion and transport losses. For the Wireless House these losses can be considerably reduced. Thermal energy produced mainly by solar energy will directly supply household appliances like kitchen stoves and ovens. The heat is transported from the point of generation to the storage and to the household appliances by the help of thermal oil as a heat transfer medium, which works at ambient pressure up to 355°C (Fragol Schmierstoff). The concept allows for cascade use of the produced heat from 300°C down to 60°C. The highest temperature level of up to 300°C is necessary for baking. Cooling and freezing can be operated by applying absorption cooling machines requiring temperatures between 90°C and 150°C. Further household appliances like washing machine, dryer, and dish washer will be provided with temperatures below 100°C. Space heating and warm water needs even lower temperatures of approximately 60°C.

• Assumption 4: Electric energy demand will be minimized due to highly efficient components for lighting, computing and media operation.

Household appliances, which need electricity like TV set, Hi-Fi stereo, computer, electric motors and lighting, already have a relatively low energy demand. Furthermore in the new Wireless House the electricity demand will be further reduced by the use of latest energy efficient equipment (e.g. LED lights instead of light bulbs or energy saving lamps). However the trend of growing numbers of electric and electronic devices in the household, and bigger screens for TV, computer monitors, and the constantly rising energy consumption for stand-by mode (Paula, et al. 2007), requires an intelligent management system as well.

• Assumption 5: The remaining rest electricity demand can be generated from thermal sources.

The supply of electricity is realised with the help of technologies, which convert thermal energy at the given temperature level of approximately 300°C into electricity. Among the different energy technologies (steam power, thermo-electric generator, ORC) examined, the Stirling engine proved to be most appropriate for a household installation. Its successful integration into the Wireless House concept needs the adaptation of a low-temperature Stirling engine.

Based on these five assumptions the Wireless House has been developed as a new demand-and-supply matching system. This includes multiple sources of input with planned capacity margin (the buffer between supply and consumption) to secure stabilised supply of energy.

3.1 System layout: Multi-source and multi-use system

The input side of the system is realised by the combination of solar concentrators, solar panels and a biomass back-up system. The system is designed to run mostly on solar energy at a mid-temperature level of 300°C, and a biomass system is used as a back-up. The input- and output-components for different temperature levels are shown in the following figure.

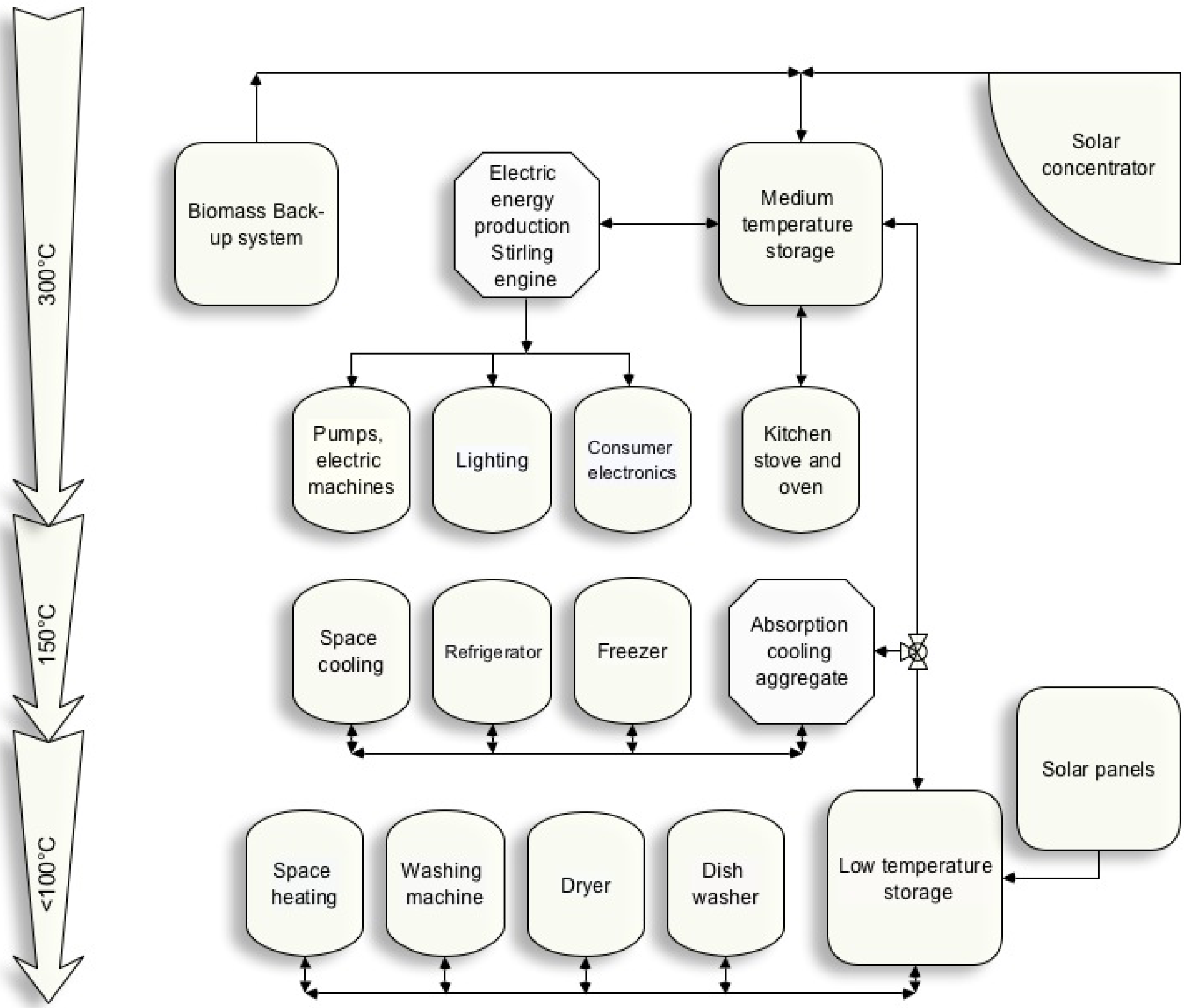

Figure 2: The Wireless House concept, input and output components and temperature levels

3.2 Technology and components

One of the main innovations of the system is the consequent chain of utilization of thermal energy. The generated energy at mid-temperature level is stored for a cascade use to operate heat-driven household appliances from 300°C down to 60°C and to produce the small amount of electric energy, which is still needed in the Wireless House.

3.2.1 Concentrating solar energy

A low cost parabolic dish concentrator has been developed. The main innovations are the receiver and the newly developed tracking system aiming at minimization of investment costs. The receiver contains the heat transfer medium, thermal oil, which is heated up to 300°C. Compared to dish Stirling engines, for example, the temperature is not maximized but kept at a mid-temperature level and subsequently transported to the thermal storage.

3.2.2 Mid temperature thermal storage

The storage of heat at mid-temperature level without losses over a certain period of time is the challenge as well as one of the key components of the Wireless House system. Although heat storage systems are used in industrial processes, the development of this mid-temperature storage for the use in buildings is rather new. The storage is responsible for the supply of heat-driven household appliances and for the production of electricity. There are different technologies available for the storage of thermal energy. The combination of solid stone storage with thermal oil storage was examined. The result was the storage volume of around $10m^3$ that could supply 380kWh, enough for a period of two weeks without solar gain. As the reduction of thermal losses at the temperature level of 300°C is extensive, the use of other technologies like chemical storage systems (e.g. magnesium hydride MgH_2) was also considered. These chemical-based systems have advantages of loss-free storage and a drastically reduced storage volume by a Factor 10, compared to the state-of-the-art latent-heat stone storage system (Kleinwächter, 2003).

3.2.3 Low temperature Stirling engine

The chosen technical solution for the conversion of thermal energy at 300°C into electricity is a low temperature Stirling engine. As it is designed to constantly generate electricity, it can be kept at a rather small power capacity (less than 1kW). Furthermore the battery back-up is calculated only for the peak loads. Latest developments in the field of Stirling engines demonstrate first prototypes of low temperature Stirling engines with between 1kW and 10kW power capacity. The energy efficiency of the developed engine has reached more than 12% (Takeuchi, 2007a, b). Based on these results, the Stirling engine will be adapted for the specific application in the Wireless House.

3.2.4 Heat-driven household appliances

As explained above, in the Wireless House, appliances can be categorised by the energy form they require (i.e. some can be powered by thermal energy, and some are operated with electricity only). Presuming that all the heat-driven household equipment is powered by thermal energy, it is necessary to redesign and reengineer current appliances that run on electricity. As mentioned earlier, this alteration can result in the drastic reduction of electric energy demand, and create a higher and relatively constant demand of thermal energy, over the whole year. The household appliances can be categorised according to the temperature level they need for operation. This leads to four classes of appliances. Those which need the highest temperature up to 300°C are kitchen stoves and ovens. The second temperature class up to 150°C contains the cooling devices, refrigerators, freezers and air conditioners. The first two classes need thermal oil as a heat transfer medium. The third group, with temperatures below 90°C, contains devices for washing, drying and cleaning dishes and clothes. The lowest heat, 60°C and lower, is used for the production of hot water and for space heating.

A number of technical solutions based on existing components like absorption cooling devices and thermal oil ovens used in the food processing industry, have been adapted to the scale of households. First low cost prototypes were already tested to be positive. The results show that the chosen technologies are suitable to reach the aims of the Wireless House and meet the needs of the users.

3.3 Application possibilities

If a society is still based on agriculture, and not yet fully facilitated by infrastructure, there is no need for enormous investment for the establishment of infrastructure. Instead, individual energy self-sufficient units can, if it is required, establish an autonomous network. This approach is regarded to be promising not only in developing countries where the status of infrastructure is generally poor, but also in industrialized countries such as EU member states, especially in rural areas.

It is highly important to follow up the research results through practical applications. Therefore a series of pilot and demonstration projects are under development. In Austria, Italy, and Switzerland, a number of houses, and even small villages, are planned to be constructed.

4 Conclusions

The constantly rising energy consumption as well as increasing energy costs asks for radical instruments for reduction of energy consumption and for sustainable solutions. The Wireless House concept aims to create solutions for completely independent and energy self-sufficient housing. It rather focuses on the whole system of housing, integrating the demand side as well as the production side, than solely developing singular technical solutions. This approach will have far-reaching consequences in residential areas, both in industrialised and developing countries.

The concept is especially useful for remote areas or scattered geography. For these regions, the Wireless House can be a good solution for getting access to communication (e.g. media, mobile communication) and gaining comfort. Currently prototypes are under development to be tested and to be demonstrated in the first Wireless Houses. The concept will be further developed, expanded and put into practice in a number of Zero Carbon Village projects.

5 Acknowledgement

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TOOLS FOR ENVIRONMENT-BASED DECISION MAKING

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Summary

Existing assessment tools for the built environment have been designed for use in a reactive evaluation process rather than in a proactive decision process. Whereas current assessment tools generally catalog past decisions, the proposed decision-assistance [DA] tools focus on (1) guiding decisions when they are made and (2) directing relevant and timely information to specific decision makers. These proposed tools may better support the implementation of environmental strategies in the building industry.

The authors advocate:

A. The identification of topics within existing assessment tools for use in applicable decision categories.
B. The development of new DA tools tailored to specific decision makers.
C. An overarching framework to coordinate DA tools, track past decisions, and collect public contributions.

1. Current Use of Assessment Tools

Existing assessment tools for the built environment have been designed for use in a reactive evaluation process rather than in a proactive decision process. Although professionals in the building industry have accepted the use of building rating systems during project development, the existing assessment tools are not well designed to function as design aids. The proposed DA tools would guide decisions as they are made rather than document the decisions after they are made. The current assessment tools do not fit this intended purpose for the following reasons:

1.1 Current assessment tools present achievements categorized by physical components or environmental aspects, missing the opportunity to highlight a process of decision-making over time. Commonly, tools relate to a particular building typology and then group individual assessment topics by project components or environmental resources or impacts. By presenting the individual assessment topics all at once, the current assessment tools deemphasize decisions made at various stages of a project in terms of its timeline.

1.2 Current assessment tools stress the integrated approach of sustainable initiatives, inviting several disciplines to provide input in a holistic process. The emphasis on integration denies the assessment tools the opportunity to present clear directives for each decision maker. Because they include information that is applicable to so many participating entities, the assessment tools become diluted overall, failing as specific and thorough guides.

1.3 Current assessment tools tend to be ignored in the earliest stages of project development and do not address changes in the building throughout its lifetime. Often the owner commences the assessment services during the design phase; thus the assessment tools are applied to a project only after the site has been selected and the building program has been established - decisions that may have been guided, if at all, by only a vague understanding of the assessment criteria. Also, many of the earliest decisions will have been made by entities other than the owner, such as local, state, and federal governments, or international commissions. Current assessment tools are closely linked to the design and construction phases of a project, and building operations and renovations are addressed in subsequent, non-integrated rating systems, if at all. As a result, the produced ratings tend to become quickly outdated since they fail to reflect building modifications or fluctuations in life-cycle operations and maintenance.

1.4 Current assessment tools do not provide for clear interaction between project team members. Preferences by one team member may not be apparent to another unless expressed outside of the system.

1.5 Current assessment tools, in general, focus on one project at a time and cannot demonstrate associations between several buildings in a complex or portfolio. Thus they do not educate users about the cumulative effect of several buildings that rate well in the certification process. Nor can the current assessment tools aid the design team in developing a sense of greater environmental responsibility, such as for a region or the planet, outside of their desire to reach a higher rating level when their scope is limited to singular projects.

1.6 Current assessment tools also do not provide accumulated data from one project to another, or between rating systems. Because they fail to track and update information from the decision makers, assessment tools consider each project in isolation, and cannot be used to guide decisions in subsequent developments.

1.7 Current assessment tools can only indirectly affect the building industry. Through the advertising potential of positive ratings, these tools claim to affect the market by economically incentivizing environmentally responsible decision-making in the building industry. However, this market-driven approach appears somewhat circuitous and less effective than a direct method to affect change. Some of the current assessment tools do act as incentive programs, promising an award for a positive rating. A certification or plaque thus represents an opportunity to achieve broad market exposure, but requires very long feedback cycles to begin affecting the building industry's production methods. Furthermore, relying on entities like building product manufacturers, outside of the direct reach of building rating systems, to affect the market significantly weakens the argument that assessment tools assert pressure towards market-wide sustainability.

2. Proposed Objectives for Decision-Assistance (DA) Tools

Based on the above shortfalls in the current assessment tools, the authors propose the following objectives for DA tools:

2.1 Allow for a decision-making process over time

2.2 Provide clear guidance to each decision maker

2.3 Support the entire life-cycle of a building

2.4 Show input from project team members

2.5 Demonstrate the impact of decisions beyond a singular building

2.6 Track decisions in a public database

2.7 Affect direct change on the market

The proposed tools would each be directed at a particular decision maker, whether a developer, international commission, mechanical engineer or building operations vendor, and would be tailored to that entity's relationship to the project throughout its lifetime. These tools would help guide the decision makers through their range of choices in the built environment, and would be called decision-assistance (DA) tools.

3. Proposed Framework for DA Tools

In order to establish DA tools with thorough access to relevant and timely information, an open-source framework based on wiki technology is hereby proposed. Such a framework will ensure that the DA tools are available for use as design guides and that they contain publicly shared knowledge on topics relevant to each decision maker. In detail, the DA tool framework will:

3.1 Allow for a decision-making process over time: The framework will be made up of a number of DA tools. Each of the DA tools will focus on how to positively affect decisions when they are made rather than record decisions after they are already in place, allowing decision makers to actively take environmental impact into account. Rather than a single assessment tool that catalogs decisions made by different entities at various points in the lifetime of a project, one can imagine a set of several DA tools that each focus on a single responsible team member. The DA tools may be linked to form a greater system, a framework, or they may stand as individual options to be used as needed.

3.2 Provide clear guidance to each decision maker: Because each DA tool will focus on a single decision maker, the information provided will be tailored to that entity's specialized knowledge-base. Introducing sustainable options directly to the relevant decision maker will allow issues to be addressed very early in a development's progress, facilitating integration of sustainable policies from a project's initial stages.

3.3 Support the entire life-cycle of a building: The DA tools, each directed at one decision maker, will give guidance to the decision maker throughout their relationship with the project. From international commissions to architects to facility managers and demolition contractors, the combined DA tools will reach out to everyone throughout the entire life-cycle of a project. A framework of DA tools will therefore resemble an overlapping group of timelines, each timeline representative of a particular entity's involvement in a development, in contrast to the approach of current assessment tools in which all the decision makers are required to participate in the assessment during one brief period in the project development.

3.4 Show input from project team members: Although each DA tool will emphasize the needs of a particular decision maker, it will also allow the other decision makers or project team members in supplementary roles to offer advice or information regarding their preferences. For example, within an owner's DA tool, the architect may stress the aesthetic desirability and environmental benefit of underground parking, although the owner will ultimately make the choice.

3.5 Demonstrate the impact of decisions beyond a singular building: Each of the DA tools will identify and describe the greater impacts of any potentially applied development strategy, on a region or the planet for example, based on past facts and future projections - including differing opinions and the surrounding debates between politicians, scientists, special interest groups and others. The open-source capability of the DA tools will keep information current and abundant as it facilitates a democratic dissemination of knowledge to the decision makers from all sides of the debates, and the participation of the public will keep the maintenance of DA tools manageable.

3.6 Track decisions in a public database: Each DA tool will inherently include more data capture and tracking than is common with current assessment tools. A historical record of environmental choices could become a powerful political instrument and prove useful to public interest groups or consumer advocates that value transparency in government. Such a database will also provide researchers the ability to track common disincentives towards certain environmentally responsible decisions and may lead to the development of economic incentives.

3.7 Affect direct change on the market: By being specific to decision makers, DA tools will have an immediate opportunity to affect market change. Within the knowledge base associated with each tool, readily accessible information on incentives, such as financial benefits or marketing exposure, may directly influence decisions.

4. Content of DA Tools, as derived from Current Assessment Tools

The authors suggest thirteen DA tools, based on proposed major decision categories as shown in Table 1, where each category relates to decisions in the entire project development that can be assigned to a single type of decision maker. Current assessment tools were reviewed in order to determine what existing individual assessment criteria, "credits," may easily transfer into the proposed DA tools.

Table 1 Decision Categories

1. International Policies
2. National Policies
3. National Land Planning
4. Community Plan
5. Community Operations
6. Investment (ownership, location)
7. Building Property Design
8. Building Structure Design
9. Building Interior Design
10. Building Product Manufacturing & Distribution
11. Construction
12. Portfolio or Building Operations
13. Building Operations Vending

In order to identify which individual credits could become part of a DA tool based on an intended decision maker, the following current assessment tools were reviewed: LEED-NC 2.2, Green Star NZ - Office Design v1.2, CASBEE-NC, 2006 NABERS Office, SBTool version SBT07, and BREAAM: Offices 2006.

Because these reviewed assessment tools sort their individual credits into groupings based on the building systems affected or resources used, commonly including groups for water use, air quality and building materials, no entire grouping from these assessment tools may be easily transferred into a single DA tool. For example, the current assessment tools typically include credits for general location and context;

however, these credits may be mixed in with sustainable site design items and landscape design issues, requiring several decision makers to participate in the “Site” grouping of an assessment tool.

The focus of the research was on the most commonly used assessment tools; those not reviewed include rating systems specifically designed for building operations and community design. For example, the U.S. Green Building Council’s Leadership in Energy and Environmental Design program includes a rating system called LEED for Existing Buildings: Operations & Maintenance, whose assessment topics could be extracted for use in decision categories like “Portfolio or Building Operations” or “Building Operations Vending.” LEED for Neighborhood Development could also be useful for the DA tool, “Community Plan.”

The following analysis of each proposed DA tool describes the intended decision maker involved and gives examples of relevant topics from some of the reviewed assessment tools.

4.1 International Policies

International Policies related to buildings are addressed by ongoing international forums, potentially leading to the ratification of internationally accepted protocols. Environmental issues like climate change affect the entire planet; thus the evolution of international policies in regard to the building industry is critically important. Decisions regarding these policies are implicitly addressed in several building rating tools, such as:

The use of alternate refrigerants that are less depleting to the ozone layer and that create lower amounts of greenhouse gases, as addressed in LEED-NC 2.2 EA Credit 3, Enhanced Refrigerant Management.

The practice of sustainable forestry, protecting against the destruction of forests including rainforests and old-growth forests, and the encouragement of reforestation for carbon sequestering, as touched on by LEED-NC 2.2 MR Credit 7, Certified Wood.

The Green Star Credit Ene-2: CO_2 Emissions encourages the reduction of carbon dioxide, a contributor to climate change, by requesting descriptions and comparisons of a building’s energy sources in terms of predicted carbon dioxide emissions.

Recognizing the importance of reductions in harmful emissions from building energy use, BREEAM Credit P11 advocates the completion of a feasibility study in the use of local renewable energy. The credit further encourages the implementation of energy plans that incorporate a high percentage of the researched strategies.

4.2 National Policies

National policies related to the development of buildings are typically directed by national technical departments under the authority of a country’s political leaders. These technical departments look into curbing pollution; the discharge of waste into water, land and air; limiting energy use per capita; and developing principles for the protection of ecosystems and wildlife throughout the country. Strategies researched by the departments may translate into laws and regulations, or they may provide the basis for environmental tax incentives. Examples for how these policies are addressed in building rating systems include:

The prevention of soil erosion and stream pollution, addressed in LEED-NC 2.2 SS Prerequisite 1, Erosion & Sedimentation Control, for temporary measures during construction, and in SS Credit 6.1, Stormwater Design: Quantity Control and SS Credit 6.2, Stormwater Design: Quality Control, for permanent measures during building operations.

Air pollution and energy use are affected by transportation to and from buildings by its occupants. LEED-NC 2.2 SS Credit 4.3, Alternative Transportation: Low-Emitting & Fuel Efficient Vehicles incentivizes the use of hybrid and alternative-fuel vehicles.

Green Star Credit Tra-2: Small Parking Spaces recognizes the tendency for smaller cars to be more energy efficient, and rewards the incorporation of parking spaces for very compact vehicles in the general parking plan.

4.3 Land Planning

Land planning is also conducted by national and regional departments subordinate to political leadership. This large-scale planning frequently deals with land to be set aside for highway and train transportation or for the protection of natural or historic treasures; but it may also safeguard bodies of water or agricultural land. Government property may be allocated through these programs for military purposes and regional public transportation systems. Current assessment tools may likely address some of these planning criteria:

Sites should be selected to avoid prime land that may better serve other purposes and should be avoided as building sites. Previously developed land or brownfields may be more suitable for building sites. For example, LEED-NC 2.2 addresses some of these issues in SS Credit 1, Site Selection and SS Credit 2, Brownfield Redevelopment.

BREEAM Credit P11 requires that a project team hire an ecology professional to oversee the development and implementation of an ecological management plan, as well as to educate the relevant workforce on how to protect local biodiversity during the construction work.

The net improvement of a building site's local ecology over its previous condition is addressed in Green Star Credit Eco-4.

Recognizing the often negative environmental impact of removing soil or adding fill to development sites, Green Star Credit Eco-5 encourages the balancing of cut and fill on the site.

4.4 Community Operations

On a local level, community departments, sometimes in close relationship with private vendors, address operational services to the general public on a daily basis. These services include the routing and maintenance of public transportation and the management of landfill and/or recycling waste. Examples of how these operational policies are addressed by current assessment tools include:

LEED-NC 2.2 SS Credit 4.3, Alternative Transportation: Public Transportation Access encourages development within ½ mile from a commuter train station or within 1/4 mile of two stops for more than one roundtrip bus line.

BREEAM Credit T08 encourages the investigation of transportation issues at an early stage in the project. This credit addresses the development of a travel plan tailored to the specific needs of the building occupants and incorporating public transportation options where possible.

4.5 Community Planning

Community planning departments, frequently with public input, devise ordinances for the physical layout of both new and existing developments. The resulting zoning ordinances regulate lot coverage, building height, historic preservation, solar access, the protection and planting of trees, and the avoidance of exterior light trespass, for example. Individual credits that could become part of a Community Plan decision-assistance tool include:

Dense developments and mixed-use communities maximize opportunities for pedestrian circulation. For example, LEED-NC 2.2, SS Credit 2, Development Density & Community Connectivity provides some criteria for higher density and mixed-use areas.

An exterior light ordinance may regulate that no exterior light can fall on a neighbor's property. Such a requirement is addressed in LEED-NC 2.2 SS Credit 8, Light Pollution Reduction.

Achieving local continuity in desirable neighborhood character is addressed in Green Star Credit Mat-2: Re-use of Facades, in which building facades are preserved and reused.

4.6 Investment

A building venture is typically undertaken by a building owner or developer. The owner may be any combination of private (for profit or non-profit) and/or public entities, and may include a group of investors not directly linked to the design and building decisions. Thus, a bank, real estate investment trust, or several private investors may be linked to a project. Many decisions at the time of investment chart the course for the project, such as identifying the type of building, its intended use, its targeted tenants, tentative building area, and a general target location. Decisions at this level lock the project development into some crucial design parameters.

Decisions reflecting site selection are for example addressed in the earlier discussed LEED-NC 2.2 credits SS Credit 1, Site Selection; SS Credit 2, Development Density & Community Connectivity; and SS Credit 3, Brownfield Redevelopment.

LEED-NC 2.2 MR Credit 1, Building Reuse addresses the choice between renovation and the tearing down of an existing structure.

4.7 Building Property

Site plans are designed by the architect and/or civil engineer with direction from the owner or developer, who often aim to maximize the building area on the site. Within the permissible ranges of zoning requirements and other regulations, the site plans address how much of the property is covered by structures and what areas are designated as open space. Environmental goals at the property level include the minimization of the building footprint and of hardscape, the use of light-colored/ shaded surfaces, the reduction and treatment of stormwater runoff, and the preservation, restoration or establishment of vegetated, wetland, and wildlife areas. Existing individual credits relating to these issues are addressed in several tools.

LEED-NC 2.2 SS Credit 5.1, Site Development: Protect or Restore Habitat and SS Credit 5.2, Site Development: Maximize Open Space reward the incorporation of designated open space on a development's site and the restoration of that open space to native vegetation.

Recognizing the participation of low-albedo materials on local temperature increases, LEED-NC 2.2 SS Credit 7.1, Heat Island Effect: Non-Roof suggests alternative hardscape colors and materials to lessen the development's impact on local microclimates.

4.8 Building Structure

The design of the building structure is often the first phase in which an architect and a green building assessment consultant are involved. Many of the design issues at the structural stage are driven by the owner, who may draw on the recommendations of the architect and green building assessment consultant. A structural engineer also has an important role in the selection of materials and dimensions of the structural building elements. The design issues considered by all the players at this stage include: anticipated length of use and desired durability of the structure, available structural materials, building orientation, shape, configuration and height, floor-to-floor height, major vertical circulation elements, desirable views and solar access, floor plate size and depth, building envelope materials for the roof and walls, glazing, insulation, and air-tightness. In this phase, decisions as to the building area and volume per occupant are solidified and the energy use per occupant will largely be determined.

LEED-NC 2.2, SS Credit 7.2, Heat Island Effect: Roof considers the incorporation of vegetated roofs or high-albedo coatings to reduce local heat gain and reduce building cooling loads.

LEED-NC 2.2 EA Credit 1, Optimize Energy Performance incorporates the building's shape, materiality, orientation, and operational systems to determine the building's net energy savings over a baseline building.

Natural daylighting strategies contribute to energy efficiency as well as to the well-being of occupants, as addressed in LEED-NC 2.2 EQ Credit 8.1, Daylight & Views: Daylight 75% of Spaces, and EQ Credit 8.2, Daylight & Views: Views 90% of Spaces. These individual credits use the building envelope configuration and materials to reward access to daylight and views for a high percentage of occupants.

BREEAM Credit HW02 encourages shallow floor plates in order to locate desks in an office setting within a reasonable distance from exterior windows.

SBT07 Credit A2.9 encourages a building orientation that suits local climates and aids in energy efficiency through the potential for passive solar systems.

4.9 Building Interior

Following or concurrently with the structural decisions, the architect and/or interior designer prepares documents for the building's interior environment, including the mechanical, electrical, and plumbing systems designed by engineers. Design issues related to the building's interior systems and materials contribute to energy efficiency, water conservation, indoor air quality, and controllability of the systems. Decisions could be more guided if specific disciplines were addressed; they could be more integrated if considered by a small team and along with the building structure. Interior layouts and material selections may address the life-cycle of the building elements and contribute to the healthfulness of the interiors, a major environmental consideration for this decision phase.

Controllability of system is addressed in LEED NC 2.2 EQ Credit 6.1 for Lighting and in EQ Credit 6.2 for Thermal Comfort.

Healthfulness of materials is addressed in LEED NC 2.2 EQ Credit 4: Low-Emitting Materials, which caps the VOC content of paints, composite wood products, and adhesives.

Interior noise pollution can negatively impact the well-being of occupants, and its avoidance is recognized in both BREEAM Credit HW17 and Green Star Credit IEQ-12: Internal Noise Levels.

4.10 Building Product Manufacturing & Distribution

Independently from the building development and design process, the building industry, with its manufacturers, distributors, transportation providers, show rooms, sales representatives, and sales centers, makes many decisions contributing to the ratings reflected in green building assessment systems.

The decisions address recycled content, recyclability, and the sourcing of products. Renewable sources, regional availability/manufacturing, harvesting, ecosystems endangerment through harvesting/extraction, and earthcrust exploitation may be considered, but may also be previously be addressed by governmental policies and regulations. For example, sustainable forest practices are addressed in LEED-NC 2.2 MR c7, Certified Wood.

4.11 Construction

The contractor or construction manager in charge of constructing a building project makes many building purchasing decisions and construction site management decisions, within the parameters defined by the owner and the design team's documents and in cooperation with the subcontractors. Issues include the indoor air quality management of the building under construction, the management of construction waste, and the sourcing and delivery of purchased products. In the construction DA tool, the owner and designers could make their preferences visible regarding construction management.

Regionally manufactured and regionally extracted materials may be given preference, for example. In LEED-NC 2.2, this is addressed in MR C5 Regional Materials.

Construction site management issues as to waste and indoor air quality are addressed in several rating systems, for example in LEED-NC 2.2 MR Credit 2, Construction Waste Management, or EQ Credit 3, Construction IAQ Management.

4.12 Portfolio & Building Operations

Once the building is constructed, the facility managers will make many decisions for the building operations throughout its lifetime. Decisions are made for a single building or for a portfolio of several buildings, and may include the use of vendors for cleaning, landscape maintenance, pest management, consumer waste removal / recycling, and building consumables. Building operations may address the maintenance of systems affecting indoor air quality, energy efficiency, and water use, and the measurement and verification of utility costs through submetering. This monitoring of energy uses and costs may inform the facility managers of what improvements make sense for the continued energy efficiency of the project, providing data regarding energy use per occupant or per unit area of the building.

These decisions are somewhat addressed in assessment tools for new design and construction, but usually in more detail in tools specifically geared toward the operations of existing buildings.

LEED-NC 2.2 EA Credit 5, Measurement & Verification establishes parameters for periodic measurement and verification programs.

Recognizing the varying limits of human comfort, LEED EQ Credit 7.2, Thermal Comfort: Verification addresses input from the building occupants regarding their satisfaction with the building's thermal characteristics.

4.13 Building Operations Vending

Each vendor for building operations makes decisions that affect the environment. If the DA tools for these entities described the preferred operations and maintenance methods of the facility managers, vendors could tailor their services accordingly. The maintenance vendors may offer more environmentally sound cleaning, landscape management, pest control, consumer waste removal, and building consumables purchasing. Providers of utility services like electricity, gas, water, or communications, could also use the DA tools to track decisions related to the building operations and could suggest how different decisions may positively affect energy efficiency and what incentives may be available.

Many of these issues are addressed in assessment systems more geared toward the operations of buildings, such as LEED for Existing Buildings: Operation & Maintenance.

NABERS, a building rating system developed in Australia, deals primarily with post-occupancy environmental performance. This assessment tool addresses the relationship between a property owner and the utility companies that serve the project.

5. Summary and Recommendations

No easy correlation between current assessment systems and the proposed DA Tools was found. Existing assessment systems do not provide clear decision making paths toward more environmentally conscious built environments. If the need for new decision tools should become recognized and widely acknowledged, a large undertaking would be necessary to rework the existing assessment tools into DA tools. While the individual credits from current assessment tools used in the examples above may be suitable for some DA tools, they would require extensive modification to become user-friendly in such a new application. Also, the existing credits do not have the capability to forecast the greater environmental impacts of applied building strategies in an interactive format, or to track decisions. For now, existing assessment tools are primarily framed to document the results for singular projects, results of decisions that have already been made. The authors recommend:

5.1 To those developing current assessment tools: Relate assessment topics to decision categories. Existing credits may be suitable for integration in future DA tools specific to particular decision makers, and although credits would need further development to be user-friendly in such an application, identifying their decision categories now will ease a future transition. More specialized assessment systems, such as those for neighborhood planning or those for building operations, appear to be a better basis for DA tools; thus entire systems or parts of systems could be converted to decision categories.

5.2 To those developing DA tools: Consider specific uses and tailor the tools to a specific type of decision maker identified by a major decision category. Tools should be available to decision makers over the length of their relationships with a project, and should be capable of maintaining user accounts for a long time period.

5.3 To those developing all tools: Add a framework that coordinates assessment methods and supports both data tracking and a searchable public-knowledge database. Current assessment tools rate project characteristics with differing methods, and there appears to be little dialogue between systems. Coordination would more easily allow for the development of DA tools by providing quick access to the topics in existing assessment tools. Synchronize decision topics related to a global scale across systems, and add data, opinions, and other public information that support decision making. Consider adding the capability to track decisions and maintain a database of such recorded information.

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TITLE: GREEN BUILDINGS INITIATE, PROMOTE AND ENHANCE ENVIRONMENTAL STEWARDSHIP AND SUSTAINABILITY AMONG OCCUPANTS

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Keywords: LEED® Certified, green building, occupant, behavior, sustainability, environmental stewardship

Abstract

This study has examined occupants' perspectives on adopting environmental behaviors as a result of their occupying or not occupying a green building. It has also determined that this influences their behavior at home, work or elsewhere. Additionally, it assessed that when occupants are given the opportunity and the necessary tools to act "environmentally sustainable" within green buildings, they eventually adopt environmental behavior, outside the location of employment. An interview survey was conducted at two buildings in the City of Ottawa, Canada: a LEED® Certified building and a non-certified building.

As a result, the occupants employed in the LEED® Certified building have become more environmentally sustainable than occupants employed at the non-certified building. A majority of occupants (82%) have experienced increased awareness and interest levels in sustainability issues such as green buildings and also have also accumulated more knowledge on living sustainable. Occupants also experienced a positive change in their environmental behaviors concerning transportation, energy consumption and household activities. Furthermore, occupants of the LEED® Certified building have become promoters and stewards of green buildings in addition to environmental issues such as sustainability.

1. Introduction

The greater outcome of this study will find out if green buildings can be marketed to influence social change. The goal of the interview survey used in the study, was to discover occupants' perspectives on adopting environmental behaviors as a result of either occupying or not occupying a LEED® Certified building and attempt to discern whether these behaviors have also changed at home, work or elsewhere. This study also assesses that if occupants are given the opportunity and the necessary tools to act "environmentally sustainable" within green buildings, will they eventually adopt environmental behavior, outside their location of employment. Additionally, the interview survey was reviewed by, and received ethics clearance in 2005 through the Office of Research Ethics at the University of Waterloo, in Ontario, Canada.

1.1 Methodology

The survey was administered to two groups of people that were employed and occupied two separate buildings. Two different locations were chosen in order to find differentiation in the employees responses by either occupying or not occupying a LEED® Certified building.

Participants first surveyed on January 28th 2005, were employed within the LEED® Certified building, Mountain Equipment Co-op (MEC), (hereto referred as the "LEED® building"), located at 366 Richmond Road, in Ottawa, Canada. This building was chosen for the survey because during the time of the study, it was the only building in Ottawa certified by the LEED® (Leadership in Energy and Environmental Design) Canada Green Building Rating System. Participants in the second group were surveyed on January 25th 2005 and were employed at Bushtukah, (hereafter referred to as the "non-certified building"), situated at 203 Richmond Road, in Ottawa, Canada. The two retail stores were chosen for the study because they have a similar "culture", in which they sell the same genre of products such as outdoor sporting equipment and apparel, and therefore will have comparable staff in which to assess differences from the study. Additionally, both buildings are located near one another, within the neighborhood of Westboro Village in Ottawa.

1.1.1 Sampling

The interview survey was administered to fifteen employees at the LEED® building and eleven employees at non-certified building during non-working hours. All participants were approached at random selection or by choice of the store manager. Participants were given the same standardized recruitment letter and consent form prior to administering the survey, explaining that participation in the interview survey was voluntary and should take less than ten minutes of time. All information provided was kept confidential and grouped with responses from other participants and later destroyed. Participants were also informed that they were permitted to decline answering any questions or withdraw from the study at any time.

The sample of participants interviewed was 22% of the total number of employees from each building. This high percentage minimized the sampling error as well as the difference between the sample and population size. The sampling error was also minimized due to the vast range of respondents working in different areas of both stores (Palys, 1997).

1.1.2 Interview Survey

The interview survey was chosen because of the opportunity for high response rates. There was also a form of social contact created between the researcher and respondent; any ambiguities or misunderstandings, were clarified immediately. The choice of survey was selected because the end result of the study was to discover change in behavior when dealing with sustainability. The level vocabulary was appropriate due to the requirement of an adult for the survey (Palys, 1997).

In the study, both qualitative and quantitative questions were used to discover behavioral changes in occupants. The qualitative questions administered in the interview survey were open and general ("In your most descriptive words, what makes a building green, environmentally sustainable or significant?") and were based on the ethnographic approach, derived from the theme of anthropology, which emphasizes examining a culture (Trochim, 2002; Palys, 1997). Three of the questions were of open-ended structure, which provided many opportunities for response.

The analysis of the qualitative data from the interview survey was based on the U.S. National Science Foundation's qualitative modes of data analysis. Qualitative data can be studied from many angles in a variety of approaches because there is no standardization when describing environmental behavior. (Sharp et al., 1997).

2. Results

2.1 Level of Interested in Green Buildings

When occupants at the non-certified building were asked if they were informed or interested about environmentally sustainable issues such as "green buildings", 27% were neutral on the topic, 54% were somewhat interested, and 18% were very interested. At the LEED® building, 6% of the employees were neutral on the subject, 50% of the participants were somewhat interested and 44% of participants were very interested in environmentally sustainable issues such as green buildings. In summary, within the LEED® building, there is a significantly higher percentage (94%) of occupants who are very interested and somewhat interested in green buildings than occupants in the non-certified building.

2.2 Ranking General Issues

When employees were asked to rank three general issues (health care, economy and environment), from one (1) to three (3); where one is the most important and three is the least important, 27% of the non-certified building occupants chose the environment first, 54% selected the environment as second and 18% preferred the environment as third importance. Of the total respondents at the LEED® building, 50% placed the environment first, 44% ranked the environment as second, and 6% ranked it last.

In general, most occupants of the LEED® building chose the economy as their least important issue. In contrast, at the non-certified building most employees selected either the economy or healthcare as the most important issue. When associating the two questions, those occupants at the non-certified building that were either somewhat interested or very interested in green buildings, ranked the environment as the most important issue. Additionally, non-certified building occupants that had a neutral level of interest in green buildings ranked the environment as their second or third choice.

2.3 Defining a Green Building

Occupants were asked to define a "green" or "sustainable building" in their own words. The LEED® building group provided a substantial array of words that described sustainable building structures, components, materials, building functions and occupant well-being. They also referred to construction techniques and environmental philosophies. No two answers in this group were significantly comparable.

At the non-certified building, 63% of occupants defined an environmentally sustainable green building by expressing "energy efficiency". Other common definitions included "minimal use" or "low impact". Further definitions expressed were more sporadic and described building operations. One employee did not know how to describe a green building.

While comparing the two groups it is clear that those occupying the LEED® building have been enhanced with green building awareness. By examining the definitions provided, there were more detailed and specific responses. This is also apparent because they also targeted aspects of a green building that would be noticed by an occupant, such as: human health, indoor air quality, level of low Volatile Organic Compounds (VOC), amount of natural light and tenant satisfaction.

2.4 Environmental Behaviors Outside Employment

Employees were prompted to write down the environmental behaviors and actions they carry out outside their location of employment. The majority of the LEED® building occupants responded that they make use of sustainable transportation such as walking, biking, busing and carpooling. Nearly all of the occupants claimed they apply energy efficiency techniques and use sustainable energy at home in order to save money.

When the non-certified building employees were prompted to provide the environmental behaviors they carry out outside their location of employment, 63% mentioned that they recycle, 81% revealed that they use alternative transport when possible, 46% attempt to consume less water or energy, and 18% said they participate or are involved in environmental awareness programs or activities. The responses provided by the non-certified building were comparable to average environmental behaviors as defined by the frequency categories in the *Pennsylvania Environmental Readiness for the 21st Century Report* (PCER, 2005). These average environmental behaviors included behaviors such as transportation choice, learning about current issues, participation in environmental initiatives and recycling (PCER, 2005).

In comparison, the LEED® building group alluded to more detailed environmental activities that were not mentioned by the non-certified occupants. These behaviors are: composting, purchasing products with no packaging or their life cycle analysis and location, and the type of food (i.e. organic, vegetarian, or locally grown). Additionally LEED® building occupants showed a higher level of stewardship in regards to their lifestyle, in terms of: living space (size, location, number of roommates) and household practices (non air-conditioned, lower temperatures, minimal lighting).

2.5 Change to Environmental Behaviors

Occupants were asked if their environmental behaviors have changed since being employed at their particular building. Most (90%) of non-certified building occupants believed that there has little or no change in their environmental behaviors outside the work environment. In contrast, 69% of the LEED® building occupants felt that their environmental behaviors have changed since being employed in the green building.

There is an array of responses from LEED® building occupants pertaining to environmental behaviors that have changed since being employed at the particular building. Most respondents stated that they have become more aware about their habits at home because of their work environment. Several respondents confirmed that they have become environmentally responsible and have developed into being promoters of reducing impact on the environment. In particular, one respondent mentioned that their behavior has changed by being around environmentally aware people. Furthermore, employees in the LEED® building have become more aware of environmental issues and more knowledgeable on aspects of environmental sustainability and many respondents said they have initiated new life style choices.

2.6 Location of Employment Initiating, Promoting or Enhancing Awareness

LEED® building occupants were asked if their place of work has promoted initiated or enhanced their awareness towards environmental issues such as sustainability. Eighty-two percent (82%) responded in detail that their place of employment in the green building has enhanced their awareness. Many felt that by frequently working in a green building, people have become more eager and interested to learn about the building and other environmental issues. Other occupants felt that due to the ongoing initiatives with their employer, Mountain Equipment Co-op (MEC), they have changed their environmental responsibility perspectives. Other respondents mentioned that since their employer, MEC, currently has high standards and is an environmentally ethical place, occupants have become more aware of their daily activities at work and outside work. Additionally, some employees believe that working in a green building has caused them to promote environmental awareness by educating friends and family on impacts and benefits.

Nearly 18% of the occupants of the non-certified building felt that their location of employment has initiated, promoted or enhanced their awareness or interest towards environmentally sustainable issues. Of those that responded that their place of employment has changed their awareness, one mentioned that they have become more aware of the outdoors for recreation.

3. Discussion

The next section discusses a few theories that complement and support the analysis that green or LEED® Certified buildings promote environmental sustainability among its occupants.

3.1 Influencing Environmental behaviors

Barr (2002) has examined the concept of what makes individuals act sustainable. He argues that there is a moderately strong relationship between stated intent and behavior. There are several motives that manipulate these two concepts. Public communication towards environmental action may be manipulated or persuaded by different previous circumstances to that of actual behavior. Additionally, there is some difference in environmental action with what is expressed and what is reality. These differences are symbolized by the attitudes of the public and their environmental actions. In recent years, the most publicized issue has become environmental degradation. Since sustainability is now institutionalized in every facet of the government, it is ironic that there are many movements to attain environmental awareness, and there is much publicity on the consequences of bad environmental stewardship. (Barr, 2002).

Another variable that influences green stewardship are situational characteristics. A study completed by Daneshvary et al. (1998) found that individuals involved in a household paper-recycling program were more expected to also be willing to participate in a clothing-recycling program (Danshvary et al, 1998). This study complements the idea that individuals who are involved one environmental action are more likely to be involved in other actions (Barr, 2002). This theory is demonstrated by the LEED® building occupants. Since they are actively participating in sustainable activities at work, they are more likely to participate at home. Moreover, knowledge will influence social norms and affect acceptance of the standard (Barr, 2002).

Schahn & Holzer (1990) conducted another study focusing on factors that influence recycling behavior. This analysis established that having access to services or technologies will cause usage due to its convenience and ease (Schahn & Holzer, 1990). It is demonstrated in this study that green buildings provide more comfort and ease to learn and participate in overall sustainability. Technologies within green buildings require little or no effort by occupants and establish how painless it is to participate.

Scott (2004), expresses that in order to achieve sustainability, interest and keenness concerning change must occur. Change has to be appealing to the individual and including incentives on an occasional basis will render it more attractive. However, if the resources or the means are taken away, than a behavior change cannot exist (Scott, 2004). It is apparent that several employees in the LEED® building have indicated interested in learning more about green buildings, and as a result have become advocates.

3.2 The Tipping Point in Environmentalism

Gladwell (2002) and his theories that make up the concept of the "Tipping Point", illustrate that in this study, green buildings can be tipped into a new way of living and working. The "law of the few", demonstrates that individuals in a green building can act as persuaders, connectors or mavens and promote green behavior. Green buildings can become like an adhesive. They "stick" to occupants by promoting sustainable behaviors, by proving the ease of sustainability and by creating a trend to occupants. Green buildings provide a context for occupants, and they create a sustainable environment to which become social norms. (Gladwell, 2002).

3.3 Fostering Sustainable Behavior

Mackenzie-Mohr (1999), explores fostering behavior change in order to conduct social based marketing. He argues that initiatives that will promote behavior change are the most forceful when they are undertaken at the community stage and encompass contact with people. Prompts like technologies with in a green building can cause a person to remember to act sustainable elsewhere. (Mackenzie-Mohr, 1999). At the LEED® building, occupants have had positive changes to their awareness and interest levels in areas of sustainability.

As a result of occupying a LEED® building, the standards and social norms are created by the knowledge that has accumulated by occupants. Some individuals felt that the environment has now become an interest and they are inspired to learn more and consequently are more aware. In relation to this concept, green buildings break the barrier between thought and environmental action, and provide the link to rhetoric and reality (Mackenzie-Mohr, 1999). It is apparent in the LEED® building, occupants have brought this sustainable vision to other parts of their lives.

4. Conclusion

Green buildings provide a context within which sustainable norms and values are created due to experience, awareness accumulation and environmental stewardship activities. Since being employed in the green building, 82% and 69% of LEED® building occupants felt that their environmental awareness has increased and their environmental behaviors have changed, respectively. The difference between the responses from the two buildings describes that occupants will adopt environmental behaviors outside their location of employment as a result of occupying a LEED® building. Green buildings will break conventional lifestyles and establish the creation of societal environmental change.

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STUDY ON RESIDENT BEHAVIOR DURING CONSTRUCTION OF ENERGY-SAVING AND POLLUTION-REDUCTION COMMUNITY IN CHINA

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Keywords: energy-saving and pollution-reduction community (EPC); resident behavior; behavior value; eco-efficient; survey questionnaire; complex adaptive system

Summary

Chinese government has taken many measures to promote the resources-saving and environment-friendly society since 2004, which is regarded as national strategy. For both urban and rural communities are basic living places, construction of energy-saving and pollution-reduction community is the foundation and crucial field for the national strategy. Residents are the primary systemic agent of energy-saving and pollution-reduction community and it's necessary to study resident behavior for better participation guidance in energy-saving and pollution-reduction way.

Firstly, this paper divides the cognition evolvement of energy-saving and pollution-reduction community in China into three stages and puts forward challenges that will face. Secondly, the paper takes resident behavior as the object during one project's life cycle among a series of construction projects for energy-saving and pollution-reduction community, and sets up the system of resident behavior, which is composed of time sub-system, space sub-system, available resource sub-system and behavior planning. Thirdly, the paper establishes the decision-making model of resident behavior though the following three steps: the equations of behavior value and behavior eco-efficient are the first step based on Value Engineering Theory and Complex Adaptive System Theory, followed by the design of the survey questionnaire, and finally comes the decision-making process. At last, the paper introduces the result of questionnaire of Yanhe village demonstration, which could help make resident participative policies and accomplish construction projects of energy-saving and pollution-reduction community in developing countries.

1. Energy-saving and Pollution-reduction Community (EPC)

Energy-saving and pollution-reduction community (EPC) is a new residential district model with high resource efficiency, low environmental impact and comfortable eco-health. Compared with traditional community, EPC focuses on energy-saving and environment-friendly factors during its whole life cycle and emphasizes resident participation in order to reduce emission and domestic waste, raise resource value, decrease operation and management cost with the principles of sustainability and human-orientedness, which is a new development trend of human settlement at the beginning of the 21st century.

1.1 Cognition Evolvement of Energy-saving and Pollution-reduction Community

In western counties the research and demonstration of sustainable buildings and green communities have been advancing from 80s of the 20th century. The latest development of relative theories and technologies in green community field is beneficial to China. With rapid economic growth and urbanization in past decades in China, it's urgent to find a new development way to harmonize environment with economy. Under these circumstances, the cognition evolvement of EPC construction could be divided into three stages in China:

Stage one (1976-1999): increase living space per capita; improve building environment quality; raise performance-price ratio of housing. Although the construction criterions of energy-saving building were enacted in the regions not only with hot summer and cold winter but also with hot summer and warm winter, there were few feasible indicators and assessment methods. Housing construction is focused on quantity rather than quality. Problems between environments and buildings attracted extensive attention.

Stage two (2000-2005): build the society of resources-saving and environment-friendly; issue energy conservation law and relative provisions, technical criteria and standards; demonstrate pilot projects in the fields of green building, eco-building and sustainable building. During this period, there are 1 billion M^2 newly-built housing p.a., and newly-built housing and existing residential building keep the ratio of about 1 to 44 according to the statistics provided by Ministry of Housing and Urban-Rural Construction, the People's Republic of China. Only 3% of existing residential building and 5% newly-built housing are in accordance with the national energy-saving standard. Housing construction was focused on buildings rather than communities.

Stage three (2006-present): promote public energy-saving and pollution-reduction activities for building the society of resources-saving and environment-friendly after a series of severe environment pollution events of Taihu lake in Jiangsu province, Cao lake in Anhui province and Songhua river in northeast China; put forward quantitative indicators and quantitative environment management procedures after the compulsory targets of reducing energy consumption per unit GDP by 20% and total emission of major pollutions by 10% compared with that of 2005 are set in the outline of 11^{th} Five-year Plan for National Economic & Social Development of the People's Republic of China. Housing construction in the way of energy-saving and pollution- reduction is focused on both governance and public participation.
At present, EPC is the major long-term foundational task for building the resources-saving and environment-friendly society. Unlike the old mechanism that the government acts as the only leading agent, a new mechanism is formed for the cooperation among social power including government, enterprise, NGO and residents. EPC construction is actualized by bottom-to-up and up-to-bottom management.

1.2 Challenge for Constructing Energy-saving and Pollution-reduction Community

Up to 2020, there will be 68.6 billion M^2 building in Chinese cities, towns and villages (26.1 billion M^2 in cities and towns; 42.5 billion M^2 in villages) and housing will exceed half of the amount of these buildings. The construction of EPC will face the following challenges:

Challenge 1: contradiction between the rigid demand of increasing living space per capita and the resource consumption and pollution of developing construction industry.

The demand of increasing living space per capita is rigid with population explosion in China. Now our construction industry have many problems in waste on construction material, low efficiency of reclaiming refuse, high consumption and poor utilization of construction energy, short life cycle of existing housing, durative pollution of chemical, physical emission and greenhouse gas, and inefficient investment.

Challenge 2: contradiction between the limited affordable cost of constructing EPC with the background of developing economy level and the accessible multi-function of improving human settlements

With deteriorating environment quality, the public pays more and more attention to man-made environment for better living conditions. Building and infrastructure is physical base of community as the man-made environment in order to supply the space of residential, recreational and working function. The energy-saving products and material, or equipments with new energy are usually expensive without the support of mature relative industry system. It's crucial to find the satisfactory multi-function of EPC for residents considering their economic level.

Challenge 3: contradiction between the participation willing of residents in EPC and the lack of leading mechanism.

Faced with more severe environment pollution, the ignoring attitude is abandoned. The voluntary environment management and preventing treatments are carried into execution. People realize their interactive effects in EPC. For example, the total energy consumption of household electric appliances, such as heating, lighting, refrigeration, cooker and so on has been rising year after year, which is determined by residents. However, there are few approaches and legal rights for residents to participate in final environment decision-making.

2. Resident Behavior System in EPC

Residents play an important role in the construction process of EPC. For example, residents' needs could guide the choice of materials and products, their behaviors could determine the eco-efficiency, and their knowledge could influence the operation and management. The resident behavior system in EPC discusses what residents could do for the construction of EPC. This system is composed of time subsystem, space subsystem and available resource subsystem.

2.1 Time Subsystem

The time subsystem refers to the life cycle of construction projects in EPC, see figure 1. EPC construction is composed of a series of energy-saving and pollution-reduction projects. Residents should participate in these projects and their behavior should help projects construction in adaptive and accessible way. Referring to LCA, a project's life cycle is composed of four stages: planning and design (T_1), civil engineering construction and decorating (T_2), operation and improvement (T_3), demolish or renewal (T_4). Resident behavior should be suitable for the characteristics of different stages during life cycle of project in EPC (Peter 2004).

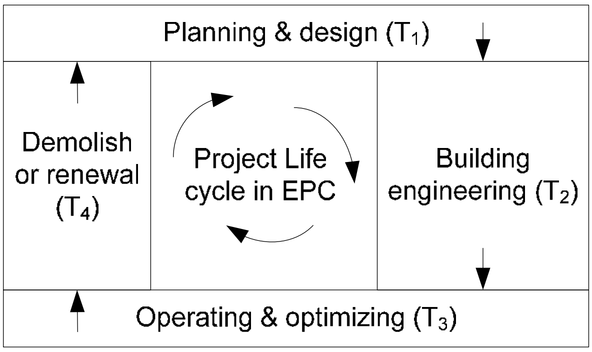

Figure 1 Life cycle of construction projects in energy-saving and pollution-reduction community (EPC)

2.2 Space Subsystem

The styles of building in China are mostly multistoried and high-rise, and residents have ownership and membership according to the Property Law and the land public-owned system of socialism of the P.R.China. Generally, the space of EPC could be classified into three types with the distinguished ownership of building:

Space 1 (S_1): private space of residents. Residents have integrated ownership of S_1 which is private space enclosed by wall, ceiling and floor.

Space 2 (S_2): common space of residents. All residents in EPC share S_2 with other members. S_2 consists of stairway, alley, corridor, common facilities and their chamber etc.

Space 3 (S_3): public space of residents. Residents in EPC and others outside EPC share the public ownership of S_3. Examples of S_3 are land, water, forest, mine, energy, biology, and climate.

2.3 Available Resource Subsystem

For residents in EPC, there are two kinds of available resources, natural resource and other resources from man-made factors including social, economic, environmental fields by labor. Available resource system is composed of natural resource, social resource, economic resource, and environmental resource. The major task of resident behavior during EPC construction is to enhance the function of environment resource with natural resource, economic resource and social resource. See figure 2.

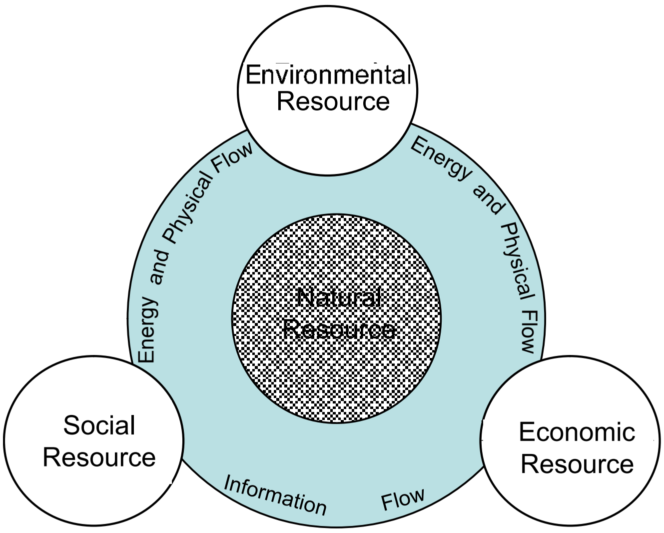

Figure 2 Four sub-subsystem of available resource subsystem for residents in energy-saving and pollution-reduction community (EPC)

Environmental resource sub-subsystem will reduce the quality and utility of living and result in uneconomical outputs if the eco-balance is destroyed. For residents in EPC, it should include outdoor and indoor water environment; air environment; noise, light and heat environment; green environment and sanitary environment.

Natural Resource sub-subsystem is the core and foundation of this subsystem. Residents in EPC should know the information about their resource occupation per capita and distribution, quantity, quality of natural resource.

Economic resource sub-subsystem takes natural resource transform with industry in order to form products and services that realize value by exchange. For residents in EPC, the stability and sustainable increase of their income should influence the utilization mode of natural resource, their understanding on cyclic economy and clean production should form information flow according to local natural resource and environment.

Social resource sub-subsystem affects human being in a nonmaterial way. This is the necessary support to ensure the transform from natural resource to economic resource. Natural resource is only pure natural substance and has no meaning for human being without social resources. For residents in EPC, it should include legal rights, cultural and customs, education and training, social welfare, and social equality.

2.4 Behavior Planning

The participative behavior, as shown in table 1, should be planned with resident's available resource responding to the time and space (F Yang et al. 2006).

Table 1 Behaviour Planning of Residents in EPC

Behaviors	S_1	S_2	S_3
T_1	Evaluate obtaining cost Analyze spatial form Belong to stratum	Make resource planning Enjoy open space Identify key environment factor	Assess resource occupation per capita Participate benefit distribution Harmonize whole social and environmental system
T_2	Develop new energy Choose recycled material Fix energy-saving facilities	Consume energy Survey infrastructure Implement green construction	Increase resource value Preserve culture and custom Operate living environment
T_3	Utilize Water, electricity, gas, heat and so on Clean pollution origin Make living water	Collect classified garbage Cooperate water recycle Integrate social organization	Appeal public service Maintain environment quality Educate and publicize Form social net and alliance
T_4	Recycle material Protect natural resource Endow legal rights	Assess environment risk Prevent pollution Keep health and safety	Keep social stability Claim protection and renewal Increase economic value

3 The Decision-Making Model of Resident Behavior

3.1 The Behavior Value of Resident

The behavior value of resident could use the following equation of function and cost referring to value engineering theory.

$$V = \sum_{i=1}^{n} V_i / n = \sum_{i=1}^{n} \frac{\sum_{j=1}^{4} \beta_j F_{ij}}{\sum_{j=1}^{4} C_{ij}} / n = \sum_{i=1}^{n} (\beta_1 V_{i1} + \beta_2 V_{i2} + \beta_3 V_{i3} + \beta_4 V_{i4}) / n \qquad (1)$$

Where:

V denotes average level of residents' behavior value in EPC including behavior value for environmental resource (V_{i1}), behavior value for natural resource (V_{i2}), behavior value for economic resource (V_{i3}), and behavior value for social resource (V_{i4})

n denotes the quantity of residents in a EPC, $i = 1, 2, \cdots\cdots, n$

β_j denotes the coefficient for corresponding function, and $\beta_1 + \beta_2 + \beta_3 + \beta_4 = 1$

F_{ij} denotes the function of one resident's behavior for one of four resource sub-subsystem, $j = 1, 2, 3, 4$

C_{ij} denotes the cost of one resident's behavior for corresponding resource sub-subsystem.

According to this equation, the behavior strategy of resident could be divided into three types, as is shown in table 2.

Table 2 Three Behavior Strategy of Resident in EPC

Behavior value	Behavior function	Behavior cost	Behavior strategy
V>0.6	increase	maintain or decrease	cooperation and participation
	maintain	decrease	
	decrease	substantial decrease	
	substantial increase	increase	
V: 0.4-0.6	decrease	decrease in same scale	In energy-saving and pollution-reduction way
	increase	increase in same scale	
	maintain	maintain	
V<0.4	decrease	Maintain or increase	nonparticipation
	maintain	increase	
	substantial decrease	decrease	
	increase	substantial increase	

Referring to the outputs of the National Key Technologies R&D Program of Tenth Five-Year Plan (2005BA807B08), which is named "Study and demonstration for construction techniques of eco-building in different areas of China", the following survey questionnaire for residents is used to assess their behavior value.

The survey questionnaire is composed of four parts with 45 items.

Part 1: satisfaction of environment renewal.

This factor consists of 26 items that focus on behaviors of indoor and outdoor environment renewal, which also displays that residents should participate in these emphases of EPC construction. There are 14 items for residents to assess their behavior value of indoor environment resource renewal as follows: building design, engineering quality, room arrangement, heat preservation, heat insulation, water supply, waste treatment, ventilation, window lighting, winter sunlight, energy for living, noise, new energy, and facilities. In addition, there are 12 items for residents to assess their behavior value of outdoor environment resource renewal including: community planning, transport arrangement, building characteristic, information construction, air quality, green place, pollution origin, sanitation, infrastructure, garbage collecting, new energy, and equipments.

Part 2: achievement of preserving natural resource.

This part has 7 items describing achievement of preserving natural resource by resident behavior including: land, water, forest, mine, energy, biology, and climate. Residents should understand the signification of natural resource first. Their attention determines the sustainable development of public space. The site testing data also help them acknowledge the problems and the progress before accomplishing these items.

Part 3: influence of improving economic resource.

There are 6 items in this factor that examine the influence of improving resident's economic resource after EPC construction including: employment, business, individual income, family income, family expenditures, and private investment. We should construct win-win EPC to replace the traditional community that wins economy and loses environment.

Part 4: ability of management and service.

In this part, there are 6 items including community management, service level, communication space, safety management, intercourse, and sense of place. There will be stronger links among EPC. This factor could guide resident behavior to partnering. Residents should share the information during the whole life cycle and join relative organization.

Every item is rated on a scale from 0.2, 0.4, 0.6, 0.8 to 1 as the representation of inefficacy, unobviousness, usefulness, obviousness and upgrade. Residents assess according to proposed indicators and give specific values. The preference of 4 factors is confirmed by resident willingness.

3.2 The Eco-Efficiency of Resident Behavior

According to environmental sociology, it's necessary to discuss the relation of resident and environment. We have looked at how to assess the behavior's value and the environmental impact together. As agents of EPC, residents' adaptive abilities to surroundings affect EPC sustainable development as complex system from bottom to top based on Complex Adaptive System (Stephen et al. 2002), see figure 3.

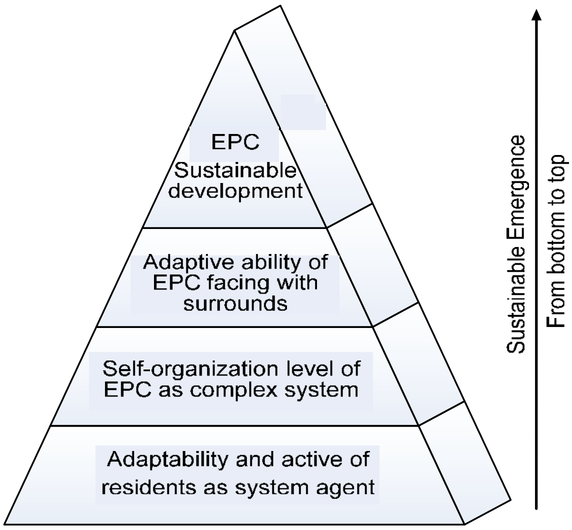

Figure 3 The sustainable emergence of EPC from bottom to top based on Complex Adaptive Theory

So far, BEE proposed "Eco-efficiency of Behavior = Environmental Impact / Behavior Value" for the basis of assess the eco-efficiency of resident behavior. This can be explained in the following equation:

Suppose $V \geq 0.4$, then

$$\text{BEE}=\sum_{i=1}^{n}\beta_1 V_{i1} / \sum_{i=1}^{n} V_i = \sum_{i=1}^{n}\frac{\beta_1 F_{i1}}{C_{i1}} / \sum_{i=1}^{n} V_i \quad (2)$$

The value of BEE is higher, and the contribution of resident behavior for their environmental resource renewal is more outstanding. The levels and comments of BEE are shown in table 3.

Table 3 Levels and Comments of BEE

Classification	BEE	Comments
1	>0.5	Alert level and residents must find new economic development way to sustain current environment
2	0.25～0.5	Good level and residents should pay enough attention on eco-education and information gain
3	<0.25	Worse level and residents ignore environmental resource value

3.3 The Decision-Making Process of Resident behavior

Benefit-oriented principle of resident behavior is the basic power to push EPC construction. The essential model of resident behavior is if something could do good to individual sustainable development, then residents enter project partnering system (Chan and Tam 1996). This principle and model show that the goal of resident behavior is to become adaptive agent facing with environment changed at every moment. In detail, the goals include: pursuing reasonable economic return, social return and environmental return. Residents could update the surrounding information and adjust behavior regular with accumulated and learnable information during the continual decision-making process.

For residents, the first phase is to learn and know the surroundings after gathering sufficient information by site exploring, questionnaire, interview, meeting etc., to analyze problems of EPC with arranging and comparing information; the second phase is to make behavior planning if problems are identified and observed. If residents ignore the problems considered by experts, residents wouldn't participate; the third phase is to renew environment by implementing behavior planning; the fourth phase is to assess their behavior value, their obtained function and their corresponding cost; the fifth phase is to enter project partnering system with owned resource if the ratio of function to cost is more than 0.4 (Eddie et al. 2002; Cheung et al. 2000); the sixth phase is to assess eco-efficiency of EPC and analyze new problems of next process if the previous process takes effect for upgrading eco-efficiency. However, residents will give up participation in EPC construction if there has no effect or downgrade eco-efficiency of previous process. See figure 4.

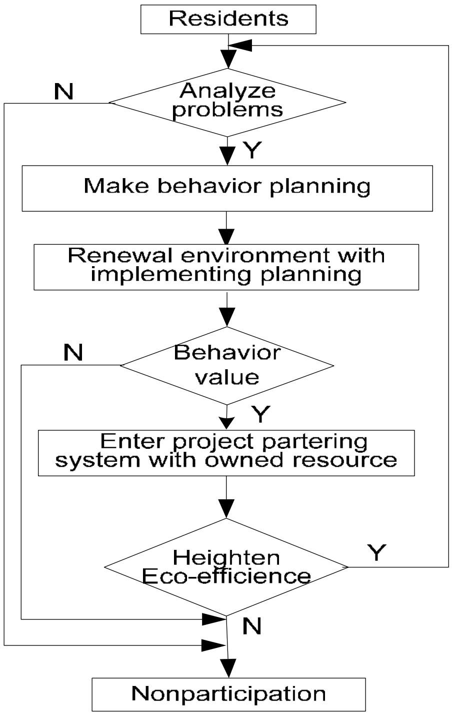

Figure 4 The decision-making process of resident behavior

4. Demonstration of EPC construction in China

4.1 Introduction of Demonstration Place, Yanhe Village

Yanhe village is located in mountainous area in Xiangfan city of Hubei province, China. It has 12 million M^2 land including 7.33 million M^2 forest, 0.64 million M^2 basic farmland, 0.66 million M^2 tea garden, 0.07 million M^2 construction land 0.01 million M^2 water area and other land. There are 242 families with 867 farmers. The main industry is agriculture, tea industry and eco-tourism. Yanhe village has developing economic level with a GDP of 10 million RMB.

Figure 6 Views of resident resource in Yanhe village (2008)

4.2 Making Behavior Planning

Combined with the result of site observation, interview and questionnaire, the behavior planning of residents is advanced with time subsystem and space subsystem, which is shown in table 4.

Table 4 Behavior Planning of Residents in EPC

Behaviors	S_1	S_2	S_3
T_1	Evaluate obtaining cost	Identify key environment factor	Harmonize whole social and environmental system
T_2	Develop new energy Fix energy-saving facilities	Consume energy	Increase resource value
T_3	Clean pollution origin	Integrate social organization	Maintain environment quality Educate and publicize
T_4	Protect natural resource Endow legal rights	Assess environment risk	Increase economic value

4.3 Assessment of Behavior Value and Eco-efficient with Questionnaire

In Yanhe, 50 questionnaires are delivered and 36 effective questionnaires are received. Then the numerical datum should be gained by above method, for example, n=36; the result of waste treatment item is 23.1% of 0.2 value, 7.7% of 0.4 value, 26.2% of 0.6 and 43.0% of 0.8. the value of this item is 0.826; what' more, 44% residents select environment resource as preference and then β_1 =0.44; in the same way, β_2 =0.13, β_3 =0.37 β_4 =0.06; then this paper accounts all 45 items of 36 residents with same way, behavior value is 0.572 and behavior eco-efficiency is 0.541. The results point out that Yanhe village is in energy-saving and pollution-reduction way and should find new economic growth power to sustain current environment in next behavior planning.

5. Conclusion

Residents' behavior should be conducted and enabled for long-term operation of EPC. This paper discusses the process, decision-making and eco-efficiency of resident behavior during EPC construction to find key factors, which help to make resident participative policies and accomplish construction projects. Resident's participation in EPC construction is significant both in developed countries and developing countries. Next, the following measures should be instituted: standard indicator of assessing behavior value has to be established by government or industry associations; the active participation of the community organization is encouraged; more education and training should be given to residents.

This paper is based on outputs of Chinese national key program "Study and Demonstration on Construction Techniques of Eco-building in Different Areas", and supported by Chinese national key program (2006-2010) on hand in Yanhe village, China.

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LAND PROPERTY DISTRIBUTIONS AS A MEANS FOR ENHANCING SUSTAINABLE BUILDING.
THE LUNDBY COMPETITION IN GOTHENBURG, SWEDEN, AS AN EXAMPLE

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Summary

This paper refers to an evaluation of a land property distribution competition arranged by the City of Gothenburg, Sweden. The competition aimed at combining high quality housing with energy efficiency, healthy indoor climate and cost efficiency proved in plans for management during ten years. About thirty-five firms showed interest in the competition and eight entries were delivered. The assessment was carried out in three steps. 1. An expert committee selected those entries that fulfilled the program goals. 2. The jury ranked these entries. 3. Following the order from the ranking, the jury assessed the financial and managerial capacity of the delivering firms. The outcome was that the two highest ranked proposals were delivered by serious developers. The results show that ambitious environmental qualities can be combined with economic goals. The dividing lines between the entries did mostly concern architectural qualities. Interviews have been carried out among a number of the competitors, the expert committee and the jury. The answers indicate that the competition process was well managed. A well-defined program and a transparent assessment are important instruments. Hence, the land property distribution instrument can be useful for municipalities for initiating sustainable building.

1. Introduction

The aim of this paper is to present a case in a larger research project about the impact of demonstration projects on the general practice concerning sustainable building (Edén et al. 2005). The case will be discussed in a governance perspective (Femenías 2008). Finally, the experience will be formulated in some advice for land property distribution competitions.

The background is that the building sector has been regarded as slow in the transition towards sustainable building. Some explanations are that the sector is heterogeneous and complex, consisting of a large variety of actors who work together in projects that are more or less unique. The built environment is one of the most long-lived artifacts in society and provides a most varying technical and cultural context. Hence, the uses of uniform legislative instruments have been found difficult to implement. However, the public sector can contribute to the development in many other ways. Authorities can act as large real estate owners, and managers of procurement. Municipalities can act through spatial planning but also as landowners. Land property distribution is a situation in which a city can negotiate with developers and, thus, by demanding certain qualities contribute to the implementation of new measures, for example measures about sustainable building (Stenberg 2006).

The city of Gothenburg made an open invitation for a land property distribution competition concerning sustainable building in the Lundby area in 2005. The result from this competition shows that the market has capacity to build good, cost-effective housing with much better energy efficiency and environmental qualities than what has been the general practice. This can be interpreted in one way that the sector is “slow”, but it also shows that the sector can act innovative in certain situations (Rubino 2007). Land property distribution processes can, therefore, be used as situations for better building practice, both on general level and is special, future oriented competitions.

2. Preparatory phase

2.1 A political initiative

The process started in 2003 with the submittance of a motion in the city council. The motion proposed that the city should complete an “urban eco-village” in order to set a learning example for the building sector. The motion was passed and the assignment was given to the property Management Office and the Town Planning Office. These offices invited Chalmers University of Technology for an open discussion about the project. The recommendation from the researchers was that the city should make an inventory of "ecological experiments in the city in order to get a platform for the ambitions in a new initiative.

2.2 A pre-study

The inventory showed that there were quite a few projects in Gothenburg and its close neighborhoods dealing with sustainability issues. However, all of them had not been evaluated, and the overall knowledge about them was poor.

The aim of the inventory was to spread information abut existing projects and to learn from them and use the learning as input in forthcoming projects. One important finding was that many projects were diffuse regarding the goal settings and evaluations. Some could be characterized as "green catalogues" with a lot of innovative devices but without any plan for evaluation of the experiments. Others were focused one, limited aspect, only energy or only materials for example, and also not very innovative. In order to find a platform for new, both "realistic" and "innovative" projects the author needed to formulate a framework, consisting of three "ambition levels" The levels were used both concerning technologies and processes. Among the projects some represented available technologies in experimental design processes while others represented innovate technologies in ordinary deign and procurement processes ((Thuvander 2004, Femenías 2004).

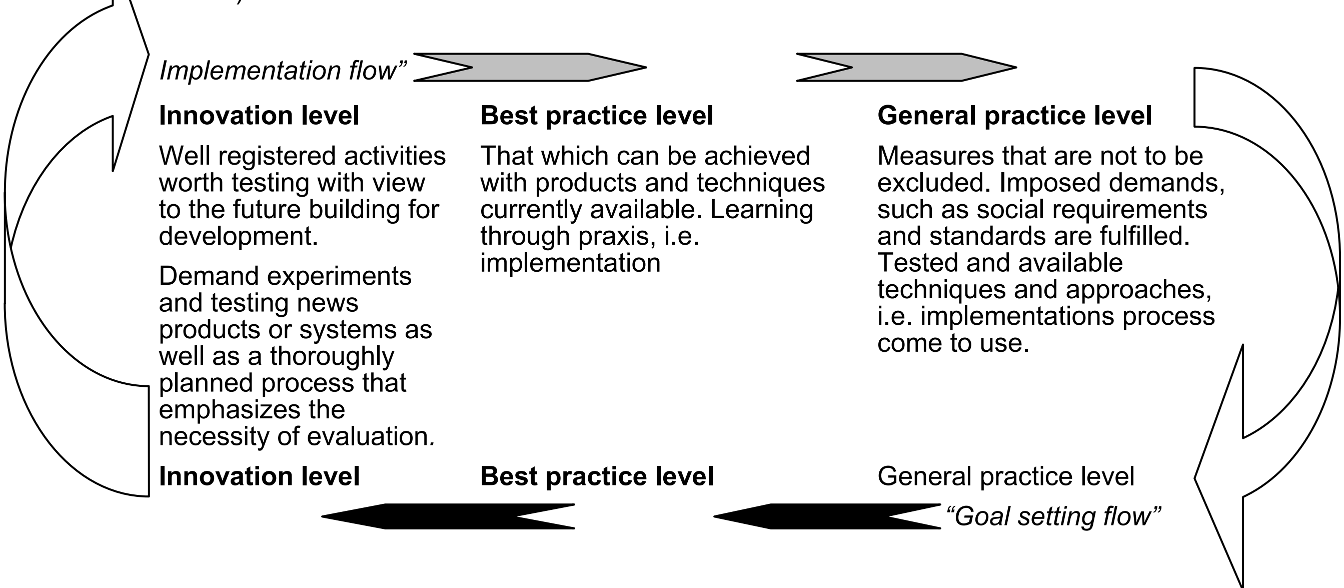

Figure 3 Ambition levels in a project There are two important "flows" from projects. The "implementation flow" (grey arrows) means that acquired knowledge from experiments will develop the sector, first in demonstration projects and when these are evaluated become general practice. The "goal setting flow" (black arrows) means that if the general practice is insufficient you need demonstration projects to begin with in order to develop better practice. If there is a lack of products or systems for necessary problems experiments need to be carried out. Both "flows "can be present simultaneously. The bows indicate that the boundaries between the "ambition levels" are changing over time. Hence, some of the projects in the report were innovative when they were accomplished, but represent "best practice" or even "general practice" today.

In figure 3 you can see that there is a general practice with more or less self evident qualities that should not be neglected. The best practice level contains measures that are available on the market, but in one way or another needs extra efforts to be accomplished. The innovation level consists of un-tested measures that have to be designed as parts of a regular experiment, with clear aims and a plan for evaluation. One important difference between "best practice" and "experiment" is that an experiment is allowed to fail, while a best practice project should have goals that can be reached and with the aim to demonstrate that what can be reached without the risk of failure. The conclusion of the pre-study was that if the city should launch a competition with the aim to set a learning example for practitioners the level should at least be "best practice" but also with elements of controlled experiments (Thuvander 2004).

2.3 Writing the competition program

When the report was published, City officials and a consultant started to formulate a competition program. The general aims of the competitions were said to be:

- Proposals for good dwellings with "reasonable" rental costs and a commitment from the proposer for a long term management.

- Proposals for healthy buildings with low environmental impact and contributing to sustainable development.
- Proposals that use experience gained in previous projects, mainly corresponding to the best practice level but allowing defined innovations adaptable to the chosen site. Some of the important features in the program are presented in tables 1-3. (Program 2005)

Table 1 DWELLINGS

Exploitation	No minimum or maximum levels of dwellings were formulated. The reason was that since the proposer should own and manage the area, the proposer had the overview of the total economy. The distribution of flats was, however, set to: 1 room dwellings – 20% 2 room dwellings – 40% 3 room dwellings – 20% 4-5 room dwellings – 20 %
Design	The design shall mirror the special prerequisites in the site and in the project aims
Functions,	The buildings codes shall be followed
Accessibility	The special codes shall be followed
Safety	The guidelines from the police in shall be followed
Use	The systems and the structures shall be robust and easy to maintain. Special attention shall be paid to community activities

Table 2 ENVIRONMENT

Health, indoor environment	The dwellings shall be certified according to the “P-mark” system. The P-mark is defined by SP, the Technical Research Institute of Sweden and comprises: Thermal comfort Air quality Emissions from materials Ventilation Moisture safety Air tightness Acoustics Light Water quality Management and control (P-mark 2008)
Materials – waste	Smallest possible impact
Energy	Not more than 90 kWh/m^2 year The proportion between heat and electricity shall be showed in “e-norm” calculations A plan for following the energy use during the management shall be presented
Water	The systems shall be deigned to ensure a resource efficient use of Drinking water Storm water Water for sewage

Table 3 ACCOMPLISHMENT

Commitment	The area shall be a part of the company’s normal housing stock for ten years. During this period the “P-mark” features shall be maintained
Costs/rental costs	The yearly costs shall be presented for year 1 and year 10 concerning Capital costs Energy costs Water costs Maintenance costs Other costs
Documentation – evaluation	The proposer shall formulate a program for following: The use of energy and water The usability Costs for management and maintenance

3. Competition phase

3.1 Interest

The competition gained interest from about 35 companies. Of these, 8 delivered entries

3.2 Jury

The jury consisted or the political board of the Property office. The jury appointed an expert committee for detailed analyses. The committee consisted of officials from the Town planning office assessing the dwellings; researchers assessing the energy calculations and indoor climate; consultants assessing the cost calculations and program for management. The committee also made a joint, holistic assessment of each entry. The authors of this paper were all members of the expert committee.

3.3 Assessment structure

The environmental, technical and economical assessments followed an elaborated matrix with about 50 different checkpoints. The architectural assessment used 18 aspects. The analyses were grouped into three main themes.

3.3.1 Area/dwellings

The area and its relation to the surrounding urban patterns
The buildings and efficient use of space and volumes
Standards and functionality of the flats
Standards and functionality of common spaces and outdoor functions
Design and function of the outdoor spaces
Accessibility, safety and usability

3.3.2 Environment

Health, indoor environment
Materials/ waste in relation to resource efficiency and ecocycles
Energy use in relation to resource efficiency and ecocycles
Water use in relation to resource efficiency and ecocycles
Adaptation to local conditions

3.3.3 Accomplishment and management

Rental levels and annual costs
Documentation and evaluation
Quality assurance and environmental work during the productions phase
Rental levels and annual costs
Quality assurance and environmental work during the use phase

3.3.4 Overarching aspects

The basic requirement is well designed dwellings and buildings with efficient use of plans and volumes. Proposals that are possible to accomplish will be selected, those that are assessed to contribute most to sustainable development will be ranked.

3.4 Two steps

The first step consisted of the selection a ranking of anonymous proposals. Before announcing the result the jury opened the envelopes following the ranking list in order to test the proposers' ability to fulfill the requirements for at least ten years of management. The procedure can be described as an architectural-technical competition in step 1, while step 2 is a test of the capacity of the owner.

3.5 Results from assessment step 1

In general, the entries were well worked out and comparable. Some characteristics are shown in table 4. Table 4 also shows some of the difficulties in the program. One was the varying exploitation, which still did not seem to have had too much impact on the final rental cost. All rental levels could be said to be “normal”. The second was that the tool for energy calculations could be interpreted in more than one way. The developer of entry H made the effort to demonstrate this for the jury.

Table 4 SUMMARY OF ENTRIES

Entry	Exploitation (flats)	Calculated Rent (SEK/m^2 year)	Energy (kWh/m^2 year)
A	70	1100	81
B	120	Not shown. Annual cost 1337	Not shown Ambition 105
C	72	1270	67/88
D	75	1160	67
E	59	1195	64
F	45	1150	Not shown
G	64	1095	Two calculations one with faults. Own system 83
H	101	1250	Two calculations 99/113 or 59/67

Very soon the entries could be divided into three main categories. A "top", consisting of two proposals, A and D, which fulfilled all qualities. A "middle", consisting of three proposals in with just one or two weaknesses that needed improvement, C, E and H. A "bottom" consisting of entries that did not fulfill goals or with severe weaknesses in the architectural approach, B, F and G. In this stage the discussion mostly touched architectural matters, since the technical and economical conditions were more or less solved or solvable in the proposals. The expert committee delivered their ranking as in table 5.

Table 4 RANKING OF THE ENTRIES

Category	Entry	Comments
Top	A	An experimental ventilation system, but since the developer accepts the P-mark, the system will be tested
	D	Prepared for PV:s and alternative sewage system.
Middle	C	Nice scale but a problematic high rise building, probably included in order to raise the exploitation
	E	A scale that was a little awkward on the site and lack of landscaping details
	H	The exploitation has lead to a parking garage and a density that gives unacceptable shade conditions in the outdoor areas.
Bottom	F	Almost a "middle grouper" with a nice scale and functional flats. However lacking important information about energy and details
	B	Weaknesses in the gardening design and in interior plans. Important calculations are missing. The energy ambition not sufficient.
	G	Lack of architectural qualities in both outdoor and interior deign. Calculations not credible

From tables 4 and 5 it becomes evident that there has been no contradiction between "soft" architectural - environmental qualities and "hard" technical – economical qualities. The pattern is evident, the top category consists of the entries that are in fulfill all qualities and where the final ranking depends on the differences in the architectural design. The middle category consists of entries that fulfill most of the important goals, and that can be adjusted concerning some weaknesses in he architectural design. The third category consists of entries that need to elaborated concerning both "soft" and "hard" aspects.

3.6 Final assessment

The jury accepted the categories delivered by the expert committee. In the final ranking the jury prioritized proposal A because the urban approach was judged to be the most appropriate according the urban qualities in relation to the surroundings. After the all envelopes were opened following the ranking order. Both entry A and D were found to be delivered by developers with sufficient managerial capacity. Entry A was, therefore, received the right to develop the site. The prize sum was after that given equally to all the delivered entries.

4. Evaluation phase

4.1 Interviews

After the competition most of the participators, also some of those who did not deliver a proposal have been interviewed (Skuflic' et al)

4.2 The report with prior projects

The report has been said to be both informative and inspiring. Some competitors interpreted it as a signal that the competition had its focus on environmental aspects.

4.3 The program

The main tendency is that the program was very clear. The goals were reasonable, although they were ambitious and required lots of work. Some participators meant that the mixture of sometimes fixed and sometimes open goals provided difficulties. Open aspects were the lack of goals for exploitation, the formulation "normal" rental costs and only "sustainable" material choices. Fixed aspects were the P-mark, energy balance, safety, accessibility etc. One pattern in the answers is that the architects appreciated the openness concerning the exploitation.

4.3.1 Energy

The target value of 90 kWh/m^2 year is by some regarded as too tough and by others too generous. As a comparison you can mention that the building code allows 110 kWh/m^2 year, while the best examples in the pre study had reached 50 – 80 kWh/m^2 year. Furthermore. the building code does not include energy for domestic electricity use, while the measured use in the examples include all use of energy. One participant would have liked division between use of heat and use of electricity. The calculation method were questioned by many, even if they understood that it is a common tool, which is fairly easy to use.

4.3.2 P-mark

Not all were familiar with the method. Those who are used to it means that it functions well and ensures quality. The P-mark harmonizes with the building code; the only difference is the demand for annual controls. For those who were unfamiliar the requirement meant efforts in learning. Some entries did not show how the P-mark was met, only made a statement that it should be reached if they got the opportunity to continue their project. One meant it that it was so self-evident that it did not need to be mentioned in the entry.

4.3.2 Rental costs

Some participators asked for more precise target values, but it has not seemed to be an important issue.

4.3.3 Management

The requirement that the company should own and manage the area for ten years was appreciated by most of the respondents. Some architects appreciated it very much, since the requirement calls for long term thinking and makes it easier to argue for the use of life cycle cost instruments. The requirement meant more work for both architects and developers, but many appreciate that documentation was required, because that had made the competition into learning project. It had, however been easier to deliver the documentation if some kinds of common guidelines had been introduced

4.4 Learning

The pre-knowledge among the competitors differs. Two architects belong to the pioneer generation in Sweden, and have completed several experiments and demonstration projects since the 1980-ies (entries C and D). Three managers have experience from energy efficient projects (entries D, E and H). Neither the manager nor the architect behind entry A had worked with sustainability issues before, but engaged a engineer with an overall environmental experience as a partner.

With the exception of small remarks all participators have shown confidence in the expert committee and the jury. The assessment and the ranking have been accepted. On the other hand, many wanted more feedback. The written assessment and the prize ceremony resembled an ordinary judgment in an architectural competition. The assessment document should have given more thematic comparisons. One respondent would have liked weights to difference aspects.

4.5 Economy

It costs to participate in a land property distribution competition. The respondents still claimed that the prize had no importance; the learning and the opportunity to market the company towards the city were the main reasons for participation. A prize gives legitimacy to a competition and in this case it gave at least some pay-back to the participators, roughly half of the costs. Also, the assessment procedure has been costly for the city, with about eight specialists working at least one month each in the assessment.

4.6 Those who not fulfilled

And what happened with the other 27? The reasons for not fulfilling the competition are mainly two, lack of time and, for consultants, difficulty to find a developer. Some answers indicate that an ambitious competition like this one is impossible for Small or Medium sized developers. Those people would have preferred a procedure with an architectural competition as a first phase. One of these SME:s put a lot of work into a proposal, but came to the conclusion that the program was too conventional and meant the experts in the committee represented conservative thinking.

5. Discussion and conclusions

Four questions will be discussed: First of all, a more general one, about the obstacles for implementing sustainable building. Secondly, competitions as means for learning. Thirdly, land property distribution competitions as governance. Fourthly, the relation between "hard" and "soft" measures.

5.1 Obstacles for sustainable building

From the Lundby competition you can draw the conclusions that "costs" or that "it costs" is not an obstacle for sustainable building. At least not as long as the investments are made by managers with a long term perspective. Lack of knowledge and experience is a more credible obstacle. Many of the participators, including the winner, had never before been asked to fulfill goals similar to the Lundby program, but had managed to fulfill the goals. There is a threshold in the sector, which is that many firms have to make a first time investment in learning. Any project can be the base for learning, as long as someone sets goals and the project team together work to reach the goals.

5.2 Land property distribution competitions as means for learning

The land property distribution process has many possibilities to initiate such investments in learning. If a city formulates conditions for the distribution that are proven to be achievable, also the inexperienced developer is willing to learn in order to stay on the market. The learning can, thus, be imposed on the consultants, but the efforts and costs can also be shared by a team. Land property distribution competitions represent a costly procedure for all participators. On the other hand, such a competition results in a "real" and "realizable" project and can, therefore, be used regularly in order to push the market a step further from ingrown routines. The "ordinary" land property distribution can, of course, also contribute to learning, if there is a policy or similar instruments that contain certain qualities that shall be reached.

5.3 Land property distribution competitions as governance

The "governance" perspective can be said to consist of three elements, governance, standardization and visibility (Femenías et.al. 2008, Gram-Hanssen 2008). The Lundby competition is interesting in all perspectives. 1) Governance: It represents a new kind of cooperation between public and private stakeholders. 2) Standardization: It contains new standards and tools for assessment, although on a local level. The process also legitimizes the concept of sustainable building as a "general" and not "special" practice. 3) Visibility: Finally it contributes to visibility, both in measuring performance data but also by building new examples of sustainable housing.

5.4 Competing on "hard" or "soft qualities?

An interesting feature in the Lundby competition was that the competitive ingredients mostly touched architectural matters. When it came to costs or energy the figures were fairly similar and if the calculations were correct there was not so much more to discuss. Some respondents were a little disappointed; they had expected a "competition in ecology". This question is of course crucial but has not given answer. Architecture always is an "open" matter and will always be a dividing line in competitions. But how do you compare a brilliant architectural entry with sufficient energy balance with a conventional architectural entry with an excitingly low energy balance? Can you put weights as one respondent asked for? No! Or – do not try to put weights that compare qualities from different worlds. A system for ranking energy balances and costs could be developed, and criteria for assessing architecture can be developed. But, since weights only can be attached to already familiar features, and since one of the aims with competitions is the birth of unexpected solutions, it seems meaningless to advertise weights in advance, or even use them at all.

5.5 Conclusions – how to use the land property distribution competition instrument

The technical contents can be said to be generic for all building, while the architectural qualities are bound to a local context. A program ought to be clear regarding the differences in these aspects. The Lundby program worked well, but the assessment criteria could have been advertised a little bit more in advance, especially that you cannot compensate lack of basic architectural qualities with low environmental impact, or vice versa. The goal is to unite the "hard", generic qualities with "soft", local ones into one integrated design concept.

The difference between a land property distribution competition and an "ordinary" architectural competition is the aim to create realizable projects without further development of an idea. It means that the goals ought to be possible to reach with available products and techniques; that is the "best practice" level. Demands for innovations and experiments passes a boundary in which research needs to be integrated in the project. The request that entries could contain elements of experiments did not fall out well in the Lundby competition. It might be that the authors were not skilled enough to make relevant suggestions, or it might just as well be an ambition that shall be saved for other types of competitions or assignments.

The conclusion is that the "normal" land property distribution can very well be used in raising the qualities in "general practice". In Gothenburg, the Property management committee has used the experience from the Lundby competition in a policy for all coming land property distribution processes.

The competition form should be used when there are good reasons to renew a policy or to set examples for new standards on the "best practice level." Currently, two years after the Lundby competition there is almost an explosion of passive house projects in Scandinavia, with an energy use down to 50 kWH/m^2 and year. These projects are so many that they very soon could represent a "general practice level". (Passivhus Norden 2008). So, from an energy point of view, there are motives enough for a new land property distribution competition, for example introducing passive standards or even "0-energy" housing. There are more reasons, such as the environmental impact from the material use, new systems for sewage and water treatment, just to mention a few aspects for which a new "best practice" level needs to be visualized and legitimized.

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LIFE CYCLE ASSESSMENT OF FOREST AND WOOD PRODUCTS IN AUSTRALIA

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Summary

Sustainability imperatives are starting to drive business decisions and government policies. As solutions are sought to growing environmental assessments, it is important to know how much energy, water or chemical has gone into manufacturing a product, and what greenhouse gas emissions or other emissions to the environment have been released in the process. The first national rigorous Life Cycle Inventory (LCI) of representative Australian forestry and wood products and processes was developed to allow the environmental impacts of the production of common engineered timber products and systems to be quantified and evaluated from cradle-to-gate. The Life Cycle Inventory database covers five categories of forestry and wood products: softwood plantation and hardwood native forests; softwood framing and hardwood timbers; veneer and plywood, and LVL; particleboard and MDF; and glulam and engineered I-beams. The coverage target was to obtain data on at least 50% of Australian production in the defined categories to create a Life Cycle Inventory for a wider range (over 60) of commercial forestry and wood products. This paper outlines the development of the Life Cycle Inventory of Australian forestry and wood products and provides some results and benefits.

1. Introduction

Over recent years there has been a growing recognition that consumption of manufactured products affects both resources and the environment (RMIT Centre for Design 1997) and that the production of a product impacts the environment, beginning with the extraction of raw materials, through processing, subsequent manufacturing, use and disposal, as well as all necessary transportation. Business decisions and government policies (Australian Government, Business Roundtable on Sustainable Development 2008) are starting to be driven by such sustainability imperatives. Governments are increasingly incorporating consideration of environmental impacts and sustainable development in policy decisions and are also increasingly holding product manufacturers accountable for their actions. Environmental assessments of products require details of how much energy, water or chemical has gone into manufacturing a product, and what greenhouse gas emissions or other emissions to the environment have been released in the process.

There is little verified life cycle information available on forestry and wood products; and Life Cycle Inventory (LCI) information for wood products is the least well defined in any current Australian Life Cycle Inventory database. Thus, wood products are at a distinct disadvantage compared to other products, such as steel and concrete, as there is no detailed database to provide strategic insight for use in pro-active environmental marketing, process improvement, comparison for product substitution, and, importantly, supply of information for building evaluation tools.

Organisations such as CORRIM in North America have worked with a variety of stakeholders over several years to produce an extensive publicly available Life Cycle Inventory of forestry and wood products in the United States (Wilson 2005). Of the available Life Cycle Inventory data for wood products used in Australia, few are based upon detailed analysis of the Australian forestry and wood products industry. The Life Cycle

Inventory database will ensure the content is compatible with international standards and with an Australian National Life Cycle Inventory Database whose specifications are currently being determined.

A thorough and detailed approach to a LCI for forestry and wood products was undertaken to provide a LCI database of representative wood products and processes used in Australia. Direct detailed input from forest managers, distributors and product manufacturers was obtained to confirm the processes and values used in creating a LCI database of forestry and wood products. This paper outlines the development of the Life Cycle Inventory of Australian forestry and wood products and provides some results and benefits.

2. Life cycle assessment

Life Cycle Assessment (LCA) is described as an objective process to evaluate the environmental burdens associated with a product or process over its life cycle by identifying and quantifying energy and materials used and wastes released to the environment, to assess the impact of those energy and materials uses and releases on the environment, and to evaluate and implement opportunities to effect environmental improvements (Consoli et al. 1993). "Life cycle" refers to all activities from acquisition of raw materials through to product manufacturing, and to the end use of these products and their eventual disposal or recycle, i.e. from "cradle-to-grave". Thus, Life Cycle Assessment quantifies the flow of materials and energy into and out of a system, as shown in Figure 1.

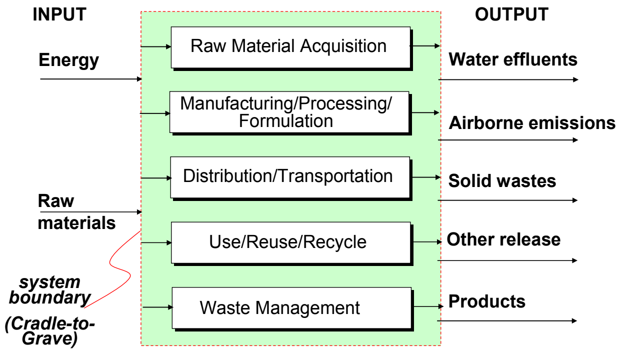

Figure 1 Life cycle assessment flow diagram showing indicative inputs and outputs

According to the ISO 14040 guidelines (ISO 14040 1998) to the Life Cycle Assessment methodological framework, a Life Cycle Assessment shall include four elements: goal and scope definition, inventory analysis, impact assessment, and interpretation of results. The key component is the inventory (known as a Life Cycle Inventory) which contains the values of all the inputs and outputs for relevant activities undertaken to produce a product. It is this information which provides a quantitative basis for comparison of the environmental impacts of building products.

The scope of a typical Life Cycle Inventory includes the inputs and outputs up to the factory gate, i.e. up to when a product is produced for a market as the consequent inputs and outputs depend on the application of that product. In addition, the development of a thorough forestry and wood products inventory results in the industry benefiting through a more advanced understanding of the life cycle of its products and processes.

It is most important to create a Life Cycle Inventory for wood products thoroughly for each type of product to ensure a quality database both for the forestry and wood products industry and for the industries which produce products which compete with wood products. There are established guidelines for creating a Life Cycle Inventory database in the form of the ISO 14040 series of standards (ISO 14040 1998). Currently there is work on setting standards for a wide-ranging Australian National Life Cycle Inventory database (AusLCI) (Tharumarajah, 2005) and all activities on a Life Cycle Inventory for wood products are compatible with this approach.

3. Life Cycle Inventories

Countries in Europe and North America have completed detailed analysis of forestry and wood products in close collaboration with industry and timber research organizations (e.g. Wilson 2005) as have Asian countries such as Japan (e.g. Tsuda et al 2006). Major international research studies conducted on the forest resource (*i.e*. production of logs) and major wood products relate principally to the timber framing of houses and wood building construction (e.g. Seppala et al. 1998 and Kakita et al. 2006)]. Many other counties have adopted their own national standards, as well have developing guidelines for specific industries, an example of which is the American Forest and Paper Association user's guide for the US forest industry (American Forest and Paper Association 1996).

In Australia, there have been a few Life Cycle Assessment studies undertaken for construction and packaging materials. Moreover, these studies did not so much include a full Life Cycle Assessment of wood or timber products but focused on embodied energy for timber products (e.g. Lawson 1996). Todd and Higham (1996) reviewed Life Cycle Assessments of forestry and wood products. Some researchers have tried to compare environmental impacts of wood products with other alternatives using a Life Cycle

Assessment method (e.g. Taylor and van Langenberg 2003). However, these Life Cycle Assessment and Life Cycle Inventories have had very limited work on the detail of forestry and wood products.

One of the key distinctions between Australian and international Life Cycle Inventory efforts has been the lack of coordination, the minimal representation of industry and the insubstantial detail of the final output in Australian databases, almost all of which are held in-house and not made public so that the data collection processes lack coordination and documentation is variable. In other countries, the process of effectively engaging industry has not only led to a comprehensive Life Cycle Inventory database, the process of data collection has also informed industry of the value and use of a Life Cycle Inventory database. As a result the Life Cycle Inventory database becomes a useable resource for industry.

4. Australian Life Cycle Inventory of forestry and wood products

The overall objective was to create the first national rigorous Life Cycle Inventory (LCI) of representative Australian forestry and wood products to enable evaluation and benchmarking of the environmental impacts of wood products for comparison with selected competing products.

4.1 Overview

A Life Cycle Inventory database for forestry and wood products aimed to be of high quality, contain a range of representative products, and be consistent, credible, and demonstrably independent. Practicalities such as focusing on a limited but representative range of wood products, availability of resources, and availability of data meant that many decisions were made on what would constitute a satisfactory Life Cycle Inventory database. The content was compatible with international standards and with an Australian National Life Cycle Inventory Database (AusLCI) whose specifications were being determined concurrently.

The underpinning principle was to obtain substantial industry input into a forestry and wood products life cycle inventory (LCI) database to confirm the processes and values used in creating a LCI database of timber products. The target was to obtain data from those producing between them at least 50% of Australian production in the defined categories. The range of data collected was, of necessity and lack of unlimited resources for its collection, restricted by what data industry had available or was willing to provide or what could be obtained from existing sources. The cooperation of the industry was excellent and resulted in good quality data and desired industry coverage but data collection was slower than anticipated.

The Australian Life Cycle Inventory database covers the following categories of forestry and wood products: softwood plantation and hardwood native forests; softwood framing and hardwood timbers; veneer and plywood, and LVL; particleboard and MDF; and glulam and engineered I-beams.

The data collection was up to the consumption phase for the wood products when sold to a consumer (known as a cradle-to-factory-gate study). This provides an accurate database of Australian wood products for various users to examine a wood product and consider its production history. Most importantly, it provides industry with a reference of production practices and the ability to benchmark and monitor performance over time. A cradle-to-gate study is a practical point to collect data for a Life Cycle Inventory database. For example, beyond this point, the useful life and maintenance requirements of wood products used in a building will depend upon a number of factors, including the exposure to various elements and the use and type of preservatives and paints, all highly variable and not within the responsibilities of producers and manufacturing plants.

While the original aim was to develop Life Cycle Inventories for generic wood products, the detailed data was sufficient to provide information on common categories of the generic products. Table 1 shows the original categories of products and the expanded (more specific) range of products developed for the Australian timber products Life Cycle Inventory database.

Table 1 Products in the Life Cycle Inventory database

Category	Products
Logs - Softwood	Peeler log, High quality saw log, Low quality saw log, Pulp log, Chips
Logs - Hardwood	Peeler log, Saw log, Pulp log
Sawn timber - Softwood and Hardwood	Rough sawn green timber, Rough sawn kiln dried timber, Planed kiln dried timber, Bark, Chips (as sawmill co product)
Plywood	Veneer, Interior Plywood, Exterior Plywood, Formply, T&G Flooring, Structural Plywood (each 3 thicknesses)
LVL	LVL (3 thicknesses)
Particleboard	Raw and Decorated (each 3 thicknesses)
MDF	Raw and Decorated (each 3 thicknesses)
Glulam	Pine, Hardwood
I-beams	OSB web and pine flanges, Plywood web and LVL flanges

4.2 Guidelines, documentation and quality assurance

It is most important to create a Life Cycle Inventory for wood products thoroughly for each type of product to ensure a quality database both for the forestry and wood products industry and for the industries who produce products which compete with wood products. There are established guidelines for creating a Life Cycle Inventory database in the form of the ISO 14040 series of standards (ISO 14040 1998), including ISO 14044 Life cycle assessment — Requirements and guidelines (ISO 14044 2006) and ISO/TS14048 Life cycle assessment — Data documentation format (ISO/TS 14048 2002).

CORRIM generally followed these guidelines in developing a Life Cycle Assessment methodological framework for their studies, but found it is essential to provide very detailed information on every aspect of data collection and process modelling to ensure consistency, compatibility and credibility in meeting the objectives of a Life Cycle Inventory database. Thus, the plan for developing a Life Cycle Inventory database included a preliminary step where standards are set and strict guidelines developed. The development of the Australian Life Cycle Inventory for forestry and wood products was no different.

ISO 14044:4.2.3.1 clearly states that the scope of a Life Cycle Inventory study shall specify the following items: product system to be studied; functions of the product system; functional unit; system boundary; allocation procedures; data requirements; assumptions; limitations; data quality requirements; type of critical review, if any; and type and format of the report required for the study. A quality assurance plan was put in place and data documentation spreadsheets developed in spreadsheet form with accompanying checklists to ensure documentation met ISO standards. Documents setting out the specific guidelines, quality assurance and documentation procedures and the Life Cycle Inventory database relating to the development of the Australian Life Cycle Inventory were prepared. An example of the detailed specifications is the system boundaries as shown in Figure 2.

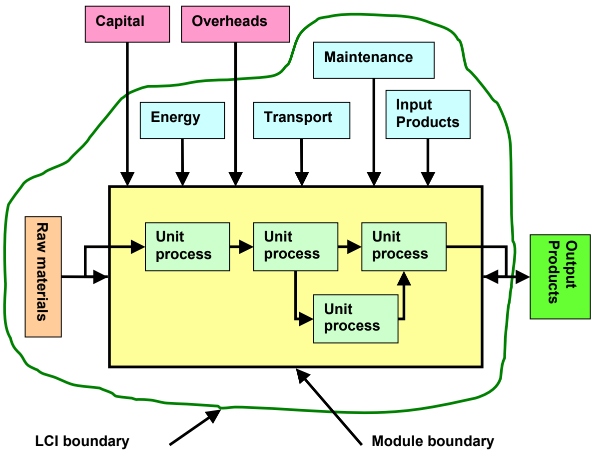

Figure 2 System boundaries for the LCI Timber project

The raw materials in Figure 2 are the materials obtained directly from the environment. The inputs between the Life Cycle Inventory boundary and the module boundary are common or pre-defined processes which can be called upon by any of the inventory product models. The common processes include logs from forests, glues, imported products and materials (glues and timber products such as oriented strand board), energy supplies (electricity, gas, etc), transport modes (ships, aeroplanes, rail, trucks, cars etc) and equipment. The output products include the main product, by-products and wastes.

4.3 Data collection

Survey forms identifying all required data were developed in collaboration with relevant industry input from each of the five areas: forests, sawmills, veneers and plywood, particleboard and MDF, glulam and engineered I-beams. From a comprehensive list of Australian forests, sawmills and wood product manufacturing plants, a list of the industry providers of forestry and wood products who would be sufficient to achieve a target of 50% of Australian production was drawn up and approached for participation in the surveys. Typical forests, mills and plants were visited for visual inspection, initial data collection and identification and understanding of processes.

Six case study regions – softwood plantations in the three States of Australia; and hardwood native regrowth forests also in three States of Australia became the representative sources of forest data. A seventh softwood plantation area was added later in a different State of Australia.

Because of the large number and hugely varying scale of sawmill operations, a sampling procedure was set up to capture data from as many as possible of the larger sawmills (approximately 22 softwood mills and 66 hardwood mills) using detailed data surveys. A simplified data form was sent randomly to a large number of the small sawmills to ensure that data from a full cross section of sawmills were included.

For the remaining plants manufacturing wood products in Australia, in any one category, there are less than ten producing almost all of the production in Australia so plants producing up to 80% of Australian production were approached. Where clear differences in processes among the competing plants could be identified, effort was made to include representatives of each identified type. The resulting coverage is shown in Table 2 for each category of forestry and wood product. Cooperation levels were generally very high and some very detailed data was made available thus ensuring a thorough understanding of the processes, their inputs and outputs and comprehensive maps of the processes.

Table 2 Coverage of Australian production

Category	Proportion of Australian production (approx %)
Forests - softwood plantation areas	60
Forests - hardwood regrowth forest areas	30
Sawmills - softwood	40
Sawmills - hardwood	30
Veneer and plywood manufacturing plants	90
LVL plants	50
Particleboard manufacturing plants	60
MDF plants	80
Glulam plants	53
I-beam plants	65

4.4 Environmental impact modelling

The data inputs and outputs per reference unit (e.g. usually m^3 or m^2 of a standard product) were then averaged for input into models developed in the SimaPro life cycle assessment software (PRé Consultants 2008) for all products except logs from forests where seven individual models were created.

From the visits to forests, mills and plants, comprehensive process maps were drawn up and then related individual processes were aggregated into a small number of processes which became the unit processes required of a life cycle inventory. The selection of unit processes was based on clearly defined steps in the process of producing the output products and influenced by the availability of data (or lack of being able to disaggregate available data). These unit processes were modelled in an integrated Simapro model to calculate the resulting inputs and outputs per reference unit (e.g. cubic metre of log or sawn timber or square metre of a plywood or particleboard) including all raw materials from growing forests and common processes such as Australian energy sources. The result is a Life Cycle Inventory of all inputs and outputs for the products listed in Table 1.

5. Some outcomes

5.1 Forestry

The Forestry process includes the establishment, growing and management of forests, harvesting of trees and transportation of logs to processing facilities.

Inputs considered in the forest production systems included: land, water, fuel/energy, chemicals and other materials (other resources, consumables and infrastructure). Averaged over the production cycle, land use efficiencies ranged from 0.05-0.08 ha m^{-3} for softwoods and 0.11 ha m^{-3} to 0.98 ha m^{-3} for hardwoods. Estimated water-use ranged from 0.3 to 0.7 Ml m^{-3} for softwoods compared with 1-10 Ml m^{-3} for native hardwoods. These differences were largely a result of the lower management and harvesting intensity of native forests compared with plantations.

Direct energy use varied from 198 MJ m^{-3} in softwood plantations to 464 MJ m^{-3} in hardwood native forests. Virtually all (>99%) energy use was associated with combustion of diesel in vehicles and machinery. The greater energy usage in hardwood native forests was largely due to greater fuel usage during harvesting. For softwood plantations, the largest contributor to energy inputs was haulage (51%), followed by harvesting (28%) and management (18%). For hardwoods, the highest contributor was harvesting (61%) followed by haulage (25%) and management (10%).

Assumed CO_2 sequestered by the forest and stored in wood products averaged 756 kg m^{-3} for softwood products and 1013 kg m^{-3} for hardwood products.

Direct emissions include both CO_2 and non-CO_2 emissions from operations under the control of the forest owner or contractor (e.g. this from fertiliser, burning or vehicle and machine use). Direct CO_2 emissions averaged 10 kg CO_2 m^{-3} for softwood plantations and 21 kg CO_2 m^{-3} for hardwood native forests. Major non-CO_2 emissions included CH_4, N_2O and NO_x. Using IPCC emission factors of 23 for CH_4 and 196 for N_2O, these non-CO_2 greenhouse gasses (GHGs) effectively contributed 7 kg CO_2-e m^{-3} from softwood plantations and 21 kg CO_2-e m^{-3} from hardwood native forests. Thus, total GHG emissions were 17 kg CO_2-e m^{-3} from softwood plantations and 42 kg CO_2-e m^{-3} from hardwood native forests.

SimaPro modeling was used to estimate total direct plus indirect (associated upstream processes such as fuel, energy and fertiliser production and transport) arising from wood production. Preliminary results for total GHG emissions associated with growing, harvesting and hauling an average log were 26 kg CO_2-e for plantation softwood compared with 60 kg CO_2-e for native hardwood logs. For softwood plantations 37% of total GHG emissions were due to burning and fertiliser application, 32% to log transport, 24% to timber harvesting, and 7% were due to forest management operations. For native hardwood forests 50% of total GHG emissions due to burning, 13% to log transport, 31% to timber harvesting, and 6% were due to forest management operations.

These emissions were allocated to wood products based on the total value of each product. For products from softwood plantations, total GHG emissions varied from 17 kg CO_2-e m^{-3} for pulplogs to 30 kg CO_2-e m^{-3} for large sawlogs. These represented between 2 and 4% of the total CO_2 sequestered in the logs. For hardwood logs, there was wider variation in allocation of CO_2-e emissions as a result of the greater variation in product value. Thus, CO_2-e emissions varied from 38 kg CO_2-e m^{-3} for low quality sawlogs and pulplogs or 3% of the total CO_2 sequestered to 146 kg CO_2-e m^{-3} for other logs (poles pile and girders) or 13% of the total CO_2 sequestered. Thus, the net amount of CO_2-e sequestered in plantation softwood products varied from 726 kg CO_2-e m^{-3} for large sawlogs to 740 kg CO_2-e m^{-3} for pulplogs and that for native hardwood products varied from 911 for other logs to 1017 kg CO_2-e m^{-3} for pulplogs.

It is thus critical that there is recognition given to the longer-term storage of carbon in forest products. If this occurs forestry will be reflected as a long-term sink for carbon in terms of net carbon storage in the logs harvested, otherwise forestry will be accounted as a small source of carbon emissions.

5.2 Softwood framing and hardwood timbers

The data collection provides a new benchmark for sawn timber building products in Australia. The results presented draw upon data collected from 24 sawmills from across Australia. In comparison, CORRIM collected data from eight sawmills for its data collection for sawmills. The data collection covers all Australian States and captures a significant proportion of total production.

The recovery rate reported for softwood primarily relates to dried and dressed radiata timber building products, with a particular focus on timber house framing, which is the dominant building product. The recovery rate of 45% for softwood building products fits in the middle of a wide range of rates previously reported, 45% (Pöyry 1999) and 47% (Ximenes) as well recovery rates reported by CORRIM of 42% (hemlock) and 58% (douglas fir) (Milota 2004).

The fuel mix in the softwood sample shows a very high reliance on wood residues for the kiln drying process. Approximately 80% of the heating energy in the study is from wood residues compared to approximately 58% in CORRIM (Milota, 2004) and this is reflected in the emissions profile reported.

Water use for the kilns was higher in Australia than in CORRIM. However, CORRIM reported high water usage in the log yards for sprinkling logs with water during storage. As a result the water usage in Australia for softwoods was much lower.

5.3 Veneer, plywood and LVL

Data for veneer, plywood and LVL has been collected from 80% of Australian plywood and LVL mills making this the most comprehensive analysis of these products undertaken, providing a new Australian benchmark. The plywood and LVL processes were compared and considered similar which enabled the use of plywood data in the LVL model. The results were generated by a single server version of the SimaPro software using the updated FWPA data libraries. The results are for average Australian veneer, plywood and LVL. The veneer process has four unit processes within the system boundary (Preparation, Conditioning, Green Veneer, Dry and Finish). The plywood and LVL processes both have three unit processes (Manufacture, Finish, and Packaging). There is also a separate boiler process and a glue-mixing unit process which have been detailed as separate unit processes, but secondary data created for LCI Timber was used.

The main inputs to manufacture 1m^3 of structural plywood include: 80 kg A-bond glue (which includes resins, flours, fillers, catalyst, etc.); 0.43 m^3 of hardwood veneer; 0.84 m^3 of softwood veneer; 0.0039 kg AACQ preservative (there are other inputs but in non-registering quantities). It takes 2.1 m^3 of logs to produce the veneer to make 1m^3 structural ply. The average results show that the yield of veneer from logs is approximately 40% compared to 50% estimated by CORRIM but varied between mills, with small labour intensive mills reporting higher recovery rates. The main source of energy is the boiler (3.6 GJ) which is mainly used in the veneer drying process. The electricity input is 165 kwh m^{-3}; LPG is 3.37 ltrs; and natural gas 0.351GJ. These energy sources are mainly used in the drying process (40% in drying). 640 ltrs of water is also consumed. Preliminary results for CO_2 emissions show that veneer drying accounts for the significant proportion. CO_2 emissions are broken down into 3 categories: CO_2 (1 tonne); CO_2 Biogenic (1 tonne); and CO_2 Fossil (67tonnes). This is a significant CO_2 release. 70% of CO_2 release is estimated to derive from the pressing process in plywood manufacture, and of this only 10% is down to the actual pressing process with over 30% originating from oil and gas production, and 30% from diesel production.

5.4 Glulam and engineered I-beams

Australian average glulam requires 501 MJ of energy to manufacture 1 m^3 of glulam. To manufacture 1 linear metre of I-beam, OSB web and pine flanges requires 9.3 MJ and 8.9 MJ for plywood web and LVL flanges, respectively. Table 3 shows an example of the timber and energy used in Australia in comparison to the CORRIM values for glulam. As seen in this table, to manufacture of 1 m^3 of glulam in Australia, 668 kg of sawn timber is required and 64.8 kg of shavings and trimmings and 63.4 kg of sawdust including wood waste are generated respectively. Wood recovery for glulam in terms of wood input as sawn timber and output as glulam was estimated at 81%, the rest being shavings and trimmings and sawdust (Table 3), which is similar to CORRIM's data (82% for PNW and SE).. Manufacture of Australian glulam consumes a little more electricity, requiring 364.6 MJ comparing to CORRIM's 304 MJ for PNW and 356 for SE, but the balance of other energy sources such as natural gas, or diesel are considerably much less for Australian glulam. The data collection for glulam and I-beam products provides a new benchmark for glulam and I-beam building products in Australia.

Table 3 Glulam product yields comparison

Wood Mass Balance (weighted average)	FWPA*	CORRIM (PNW)**	CORRIM (SE)***
Input (kg/m^3)	668	592	676
Output - Glulam (kg/m^3)	540	483	551
Output – shaving, trimming & sawdust (kg/m^3)	128+	89	119
Output - wood waste (kg/m^3)		20	6
Recovery of wood (%)	81%	82%	82%
Energy consumption (MJ)	501	893	1420

*Australian glulam weight averaged; **CORRIM (Pacific North West Area); ***CORRIM (South East Area)

6. Benefits

A major benefit of the Life Cycle Inventory of forestry and wood products for the industry is to have a credible quantitative basis for comparison of competing timber products and non-timber alternatives. Collection, enhancement and verification of data provide the industry with reliable environmental impact information to improve the environmental bottom line as well as providing data for assessing choice in building products on the basis of environmental impacts. The future potential in obtaining this information for the forestry and wood products industry means greater acceptance of wood as an environmental material choice, give wood products a greater prominence in evaluation tools, and greater understanding by the industry of future growth areas, such as recycling opportunities, service provision potential, and take back schemes, which would greatly add to the bottom-line in the future market place.

The project has produced the first national Life Cycle Inventory database on Australian forestry and wood products production with benefits including:

- The compilation of a common database for the wood industry,
- An objective and quantitative basis for comparison of competing wood products and non-wood alternatives,
- An objective and quantitative basis for comparing systems which incorporate wood products to those systems which use alternative materials, for example, complex composite products or whole houses,
- A method of comparing the environmental impacts of wood products from improved production processes,
- A database for use with Life Cycle Assessments of wood products and the buildings in which they are used,
- Provision of up-to-date credible industry based life cycle inventory information for life cycle assessment of wood products from Australian manufacturers,
- Support to manufacturers on environmental performance and impact assessment measures so environmental improvements can be addressed,
- Facilitating communication of environmental information to customers and other stakeholders,
- Setting a benchmark for carbon sequestration in wood products, and
- Setting an industry standard for handling of environmental data.

7. Conclusions

The development of a Life Cycle Inventory for Australian forestry and wood products is a major step forward in the provision of quality data on the environmental impacts of wood products used in building. The quality assurance procedures, in following the ISO Standards procedures and documentation, have set a high level for all following contributions to the developing Australian Life Cycle Inventory database (AusLCI). The wide forestry and wood industry coverage also makes the resulting Life Cycle Inventory very representative of Australian wood products and an excellent basis for assessing the environmental impacts of any application of wood products.

8. Acknowledgements

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HEAT LOSSES IN HOUSING DURING THE NIGHT STOPPED PERIOD OF THE HEATING SYSTEM

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Keywords: heat loss; overnight shut-off; lumped heat capacity; energy demand

Abstract

A new method is introduced for calculating heat loss in buildings while the heating system is off. Developed from the mass and physical properties of the materials as a starting point, it determines the temperature distribution under variable flow rate conditions in exterior walls in contact with the outdoor air or bounded by unheated premises, as well as in partition walls, furniture, household appliances and so on. The data on overnight temperature variations are then entered in the Lumped Heat Capacity model to obtain the temperature variation and heat loss in the solids inside the flats studied. Knowing the temperature distribution in outside walls, the heat loss across these walls can be calculated. Lastly, the heat loss resulting from the inflow of outdoor air is calculated as specified in legal standards. In the case study – three flats on a cold day 21-22 December 2006 – used as an example, heat lost was seen to constitute a significant fraction of each flat's daily demand and depend on its location in the building are discussed. The overnight loss generated in the top storey flat came to an additional 48.4% over and above daily demand; in the second and third storey flats the additional loss was 19.18% and 40.24%, respectively.

1. Introduction

Given the moderate climate prevailing on the Iberian peninsula, Spanish homes can be kept at a comfortable temperature with a maximum of 12 hours of heating daily, from around 11:00 a.m. to 11:00 p.m. As a rule then, the heating is off from 11:00 p.m. to 11:00 a.m. the next day. During this period buildings cool down, with heat transferred by convection across the enclosures in contact with the outdoor air or bounded by unheated premises. Air exchange and infiltration contribute to the decline in indoor temperatures. When the indoor air cools, the temperature of partition walls, furniture, household appliances and so on also drops. The following day, when the heating system begins to warm the building, partition walls, furniture and so on absorb heat from the surrounding air, raising their temperature to a comfortable level.

Scant literature can be found on this subject, for researchers and engineers have paid insufficient attention to this heat loss, which depends on building inertia and is replenished the next day. Standards in place in Spain, such as European standard EN 832:1998 and the more current international and European standard ISO-EN 12831, dating from 2003, can be used to evaluate this heat. The ISO-EN standard includes a simplified method for residential buildings based on the general assumption that indoor temperature declines by 3 ºC. Such assumption is imprecise, however, for the decline in indoor building temperatures depends on the outdoor temperature, wall composition and orientation, relative location, use and so on.

This paper introduces a method for determining heat loss in a three-storey building with an underground garage during the hours when the heating system is disconnected. Account is taken of the additional cooling caused by air exchange and infiltration. First, building heat loss is calculated on the basis of its heat capacity and air exchange rate to obtain the indoor temperature decline from 11:00 p.m., when the heating is turned off, until the next day. This information can then be used to determine the temperature decline in furniture, partition walls, household appliances and so forth. Knowing the variation in both the indoor and outdoor temperatures, the temperature distribution can be found for outside walls and walls bounded by unheated premises. Lastly, the total heat lost during the hours the heating system is off is calculated: this is the heat that needs to be replenished the next day. The results for three flats on a particularly cold day are discussed. While the method introduced is designed for general application, the wide variations in building conditions and flat use made it unfeasible to address all these factors in the present study. Consequently, the results obtained refer exclusively to the type of building analyzed.

2. Description of the building

Located in the city of Madrid, the building studied is an apartment complex consisting in three storeys and an underground garage with a total area of **584 m²**. Each storey has two flats with a built area of **70 m²** each. The floor plan for the standard flat studied, which is the same on all three storeys, is shown in Figure 1. The surrounding environment for each flat depends on the storey.

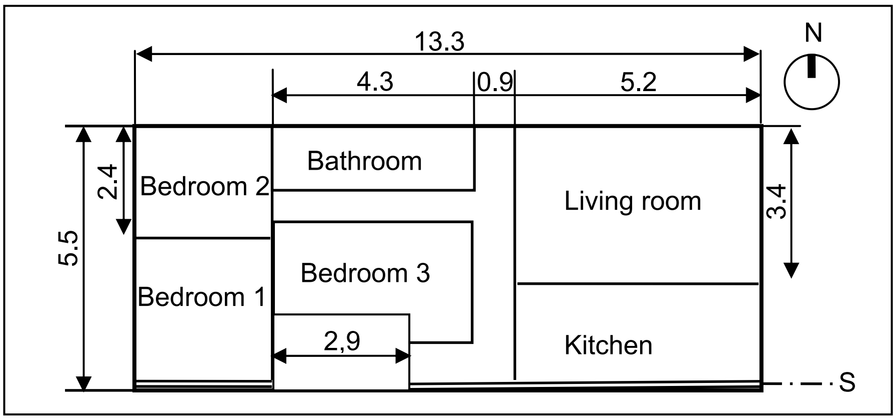


Figure 1. Flat A floor plan (dimensions in metres)

All the flats have outdoor walls facing east and west. The party wall on the north is bounded by unheated premises. The enclosures bounded by other heated housing are regarded to be adiabatic. The flat located on the third storey is exposed to the outdoors across the roof, while the first storey flat is exposed to the unheated garage, across the floor slab.

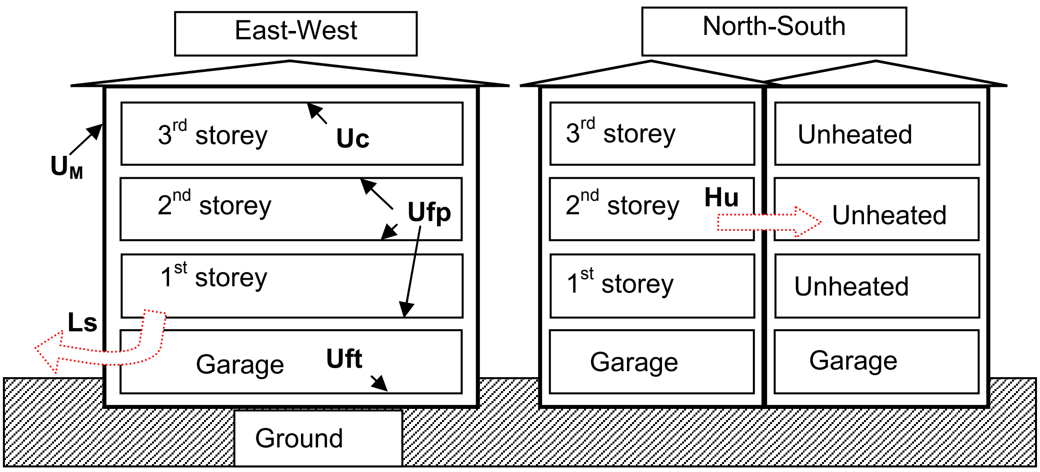


Figure 2. Cross-sections of the building

2.1. Enclosures in contact with the outdoor air

The enclosure characteristics shown in Table 1 were taken from the Technical Building Code (Spanish initials, CTE) while the physical properties, thermal transmission coefficients and so forth were taken from Spanish and European standard *UNE-EN 10456*.

Table 1. Heat transfer coefficients and specific heat capacity

	1st storey	**2nd storey**	**3rd storey**
C (KJ/kg°C)	34230	34230	34030
UA roof (W/°C)	---	---	33.49
UA wall (W/°C)	8.95	8.95	8.95
UA windows (W/°C)	27.85	27.85	27.85
Hu (W/°C)	9.4	8.8	9.6
Ls (W/°C)	---	---	21.12

2.2. Partition walls and furnishings

The flats are divided into rooms and premises by partition walls. The furniture is made of wood and the household appliances of a variety of materials. The partitions are *2.5 m* high and have a total length of *30 m*. They consist in 5-cm face brick plastered on both sides (1 cm each). For the intents and purposes of the present thermal calculations, this wall is replaced by another with equivalent density, specific heat and thermal conductivity (Table 2).

Table 2. Properties of wood and equivalent partitions.

	ρ (kg/m^3)	Cp (KJ/kgºC)	K_m (W/mºC)	V (m^3)
Wood	600	1.52	0.14	1.4
Equivalent partition	1.086	0.854	0.415	5.67

2.3. Enclosures bounded by unheated premises

2.3.1. Floor slab bounded by unheated garage

Further to European and international standard EN-ISO 13370, which contains the heat transmission coefficients for construction elements in or on the ground, the thermal coupling coefficient is **Ls=21.12 W/ºC.**

2.3.2. Party wall bounded by unheated premises

European and international standard EN-ISO 13789 explains how to determine the heat transmission coefficient across unheated premises, **Hu**. This coefficient takes account of the heat exchange between the unheated space and other indoor areas on the one hand and outdoors on the other. The air exchange rate in the unheated space is similar to the exchange rate inside the flats, namely 0.5 exchanges per hour. Table 1 gives the thermal transmission coefficients, **Hu**, for the three flats studied (layout as in Figure 1).

3. Variation in the indoor temperature in the flats

The study aimed to determined temperature variations inside the flats from the time the heating is turned off at 11:00 p.m., when the temperature was 21 ºC, until it is turned back on the next day at 11:00 a.m.

3.1. Equations used for the calculations

Heat losses in the flat are assumed to be due to heat transmission across enclosures and the entry of outdoor air as a result of air exchanges and infiltration, i.e., disregarding internal sources. Using an energy balance, the interior temperature **Tin** can be found with equation (1). The **UA(Tout-Tin)** member quantifies heat transmission across the enclosures, while the **ρCpV(Tout-Tin)** member assesses the cooling of indoor air due to the entry of cold exchange air and infiltration.

$$C \cdot \frac{dT_{\text{in}}}{dt} = UA \cdot (T_{out} - T_{\text{in}}) + \rho C_p V \cdot (T_{out} - T_{\text{in}}) \qquad (1)$$

In this equation, **ρCp=**0.34 Wh/ºC, **V** is the volume of exchanged air and **C** is the effective heat capacity of the heated volume. In other words, **C** corresponds to the variation in the amount of heat stored by the building structure when the indoor temperature variation is 1ºC during a given period. This parameter can be found with equation (2), defined in European standard EN 832:1998 as the sum of the effective heat capacities of all the indoor elements in the building in thermal contact with the indoor air.

$$C = \sum_j \sum_i \rho_{ij} c_{ij} d_{ij} A_j \qquad (2)$$

Where ρ_{ij} is the density of the layer i material in wall j, Cp_{ij} the specific heat of the layer i material in wall j, d_{ij} is the thickness of layer i on wall j, and A_j is the area of wall j located within the space studied. The temperature of the unheated premises is found from equation (3), in turn obtained from a heat balance resulting in thermal equilibrium.

$$T_u = \frac{\phi + T_{\text{in}} \cdot H_{iu} + T_{out} \cdot H_{uo}}{H_{iu} + H_{uo}} \qquad (3)$$

Φ is the heat flow generated in the unheated area (solar gain, internal sources and so on) and **H** is the heat transfer coefficient. Subscript **i** means indoor, **o** outdoor, and **u** refers to the unheated premises.

3.2. Calculating the indoor temperature in the flats

Adapting the calculations to the specific circumstances of flat type A yields a system of equations (4) from which the indoor air temperature can be determined in terms of the surrounding conditions, which in turn depend on construction components, weather conditions, the relative position in the building and so forth. The unheated premises considered are the premises bounded by the party wall, $\mathbf{T_{premises}}$ and the garage, $\mathbf{T_{garage}}$. Table 1 gives the effective heat capacity, **C**, of the flats and the heat transfer coefficients for the enclosures.

$$C\frac{dT_{in}}{dt} = UA(T_{out} - T_{in}) + \rho C_p V(T_{out} - T_{in}) + Hu(T_{premises} - T_{in}) + Ls(T_{garage} - T_{in})$$

$$T_{premises} = \frac{T_{in} \cdot Hiu + T_{out} \cdot Huo}{Hiu + Huo}$$

$$T_{garage} = \frac{T_{in} \cdot Hiu_g + T_{out} \cdot Huo_g}{Hiu_g + Huo_g} \qquad (4)$$

Figure 3 shows the temperature variation in third storey flat A from 11:00 p.m. on 21 December to 11:00 a.m. on 22 December.

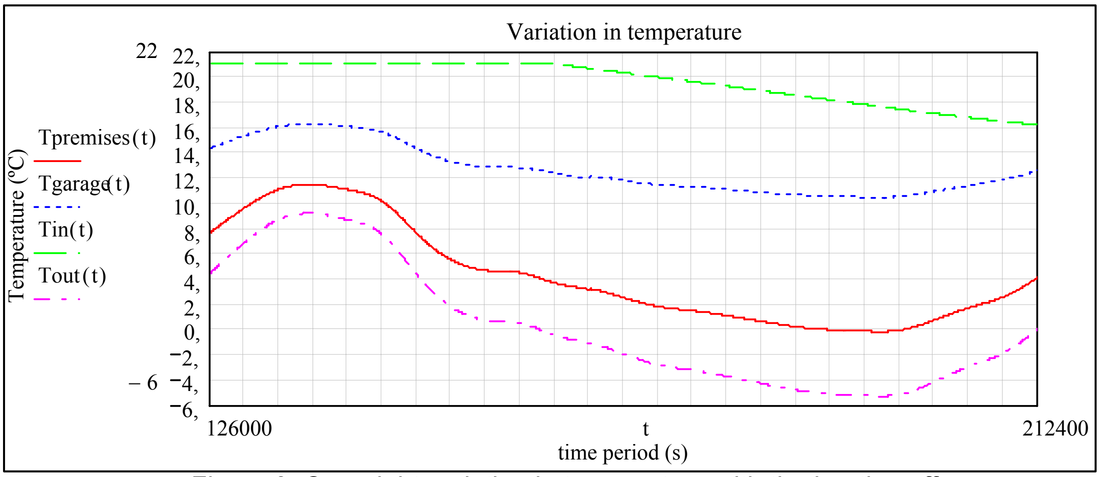


Figure 3. Overnight variation in temperature with the heating off

The indoor air temperature distribution during the hours the heating is off is obtained by repeating the calculations for the three vertically aligned flats and varying the number of air exchanges per hour from 0.5 to 1.5. Table 3 gives the final temperature at 11:00 a.m.

Table 3. Indoor temperature at the end of the period

	Final temperature (° C)		
	3rd storey	**2nd storey**	**1st storey**
n= 0.5	17.24	18.35	18.05
n=1	16.2	17.26	16.97
n=1.5	15.21	16.22	15.95

4. Heat loss in furnishings and partitions

The variation in the indoor temperature sets off convection heat transfer in the partition walls, furniture and appliances inside the flat. The temperature of these solids as the building cools is found with the Incropera and De Witt (1990) lumped heat capacity method. The dimensionless Biot number, equation (5), is first determined for wood and the equivalent wall to determine the applicability of the method,

$$Bi = \frac{h_i L_c}{K_m} \qquad (5)$$

where L_c is the characteristic length of the solids : the thickness of the equivalent wall or mean thickness of the wood; K_m is thermal conductivity; and h_i is the surface convection heat transfer coefficient. Since the Biot numbers found are less than one, as **Table 4** shows, the lumped heat capacity model can be used in both cases.

Table 4. Physical and geometric properties of the solids.

Material	h_i (W/m^{2}ºC)	L_c (m)	K_m(W/mºC)	Biot
Wood	2	0.025	0.21	0.238
Equivalent wall	2	0.07	0.415	0.337

4.1. Heat transfer equations

The heat transferred from the solids (wood, equivalent wall and so on) to the indoor air is found with equation (6).

$$q_{conv} = h_i A_s (T_{solid} - T_{in}) \qquad (6)$$

Where T_{solid} is the temperature of the solid, T_{in} the temperature of the indoor air and A_s the area of the solid exposed to heat exchange. The amount of conduction heat transferred inside the solid at a variable flow rate, which depends on time **t,** is the product of mass times the temperature variation, equation (7). Equation (8) is the energy balance.

$$q_{cond} = \rho V C_p \frac{dT_{solid}}{dt} \qquad (7)$$

$$-\rho V C_p \frac{dT_{solid}}{dt} = h_i A_s (T_{solid} - T_{in}) \qquad (8)$$

To facilitate the calculations involved in equation (8), a constant, β, is defined, and equation (10) is obtained:

$$\beta = \frac{h_i A_s}{\rho V C_p} \qquad (9)$$

$$\frac{dT_{solid}}{dt} = \beta (T_{in} - T_{solid}) \qquad (10)$$

The parameter defined in equation (9) for wood and the equivalent wall adopts the values of ***$1.7510^{-5}s^{-1}$ and $6.1610^{-5}s^{-1}$***, respectively. Equation (10) can be adapted for application to all the various materials. When the indoor temperature dips to 16.2 ºC, with **one** air exchange per hour, the equivalent wall cools to **17.58 ºC**, and the wood to **16.66 ºC**.

4.2. Heat transmitted from solids

The heat transferred from the solids to the indoor air between 11:00 p.m. and 11.00 a.m. the next day is found with equation (11).

$$Q_{tpp} = \sum \rho V C_P \Delta T_{mx} \quad (11)$$

Where Δt_{mx} is the difference between the peak temperatures of the solids during the period. Using equation (11) and assuming one air exchange per hour, the heat transmitted by the solids is as shown in Table 5. The thermal and geometric properties of the solids are given in Table 2.

Table 5. Heat transmitted by the solids

	Heat transmitted by the solids (kWh)		
	3rd storey	**2nd storey**	**1st storey**
Wood	1.348	1.049	1.128
Wall	4.765	3.697	3.981

5. Heat losses across enclosures

The building also loses heat across the enclosures in contact with the outdoor air or bounded by unheated buildings or flats. The heat transferred by an enclosure with an area of $\mathbf{A_{en}}$, once $\mathbf{T_{in}}$ its calculated from equation 1 and the outdoor temperature $\mathbf{T_{out}}$ has been measured, can be found with the following equation.

$$q_{ce} = U_{en} \cdot A_{en} \cdot (T_{\text{in}} - T_{out}) \quad (12)$$

The flow per unit of area:

$$\frac{q_{ce}}{A_{en}} = U_{en} \cdot (T_{\text{in}} - T_{out}) = U_i \cdot (T_{\text{in}} - T_i) \quad (13)$$

Equation (13), which gives the surface temperature for each component, **i**, in the wall,

$$T_{i+1} = T_i - R_i \cdot \frac{q_{ce}}{A_{en}} \quad (14)$$

may be re-written as follows:

$$\Delta T_i = R_i \cdot \frac{q_{ce}}{A_{en}} \quad (^{\circ}C) \quad (15)$$

5.1. Enclosures in contact with the outdoor air

Figure 4 shows the temperature distribution in the materials comprising the outside wall, obtained from equation (14), where **ti** is the initial temperature and **tf** the final temperature during the interval when the heating is off, obtained from the system of equations (4).

Given the indoor and outdoor temperatures, the difference for each material in the wall is obtained by applying equation (15). The heat lost across the wall is obtained by adding the heat lost by all its component materials, based on their known temperature differences and physical properties, equation (11). The heat loss for the third storey flat is **4.78 kWh**, while the values for the second and first storey flats are **3.67 kWh** and **3.97 kWh**, respectively.

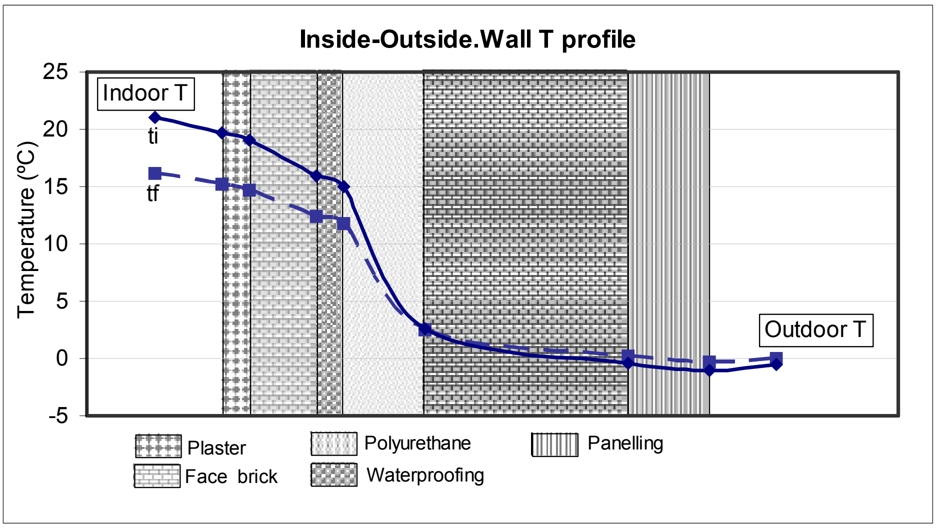


Figure 4. Inside-outside. Wall temperature profile.

5.2. Roof in contact with the outdoor air

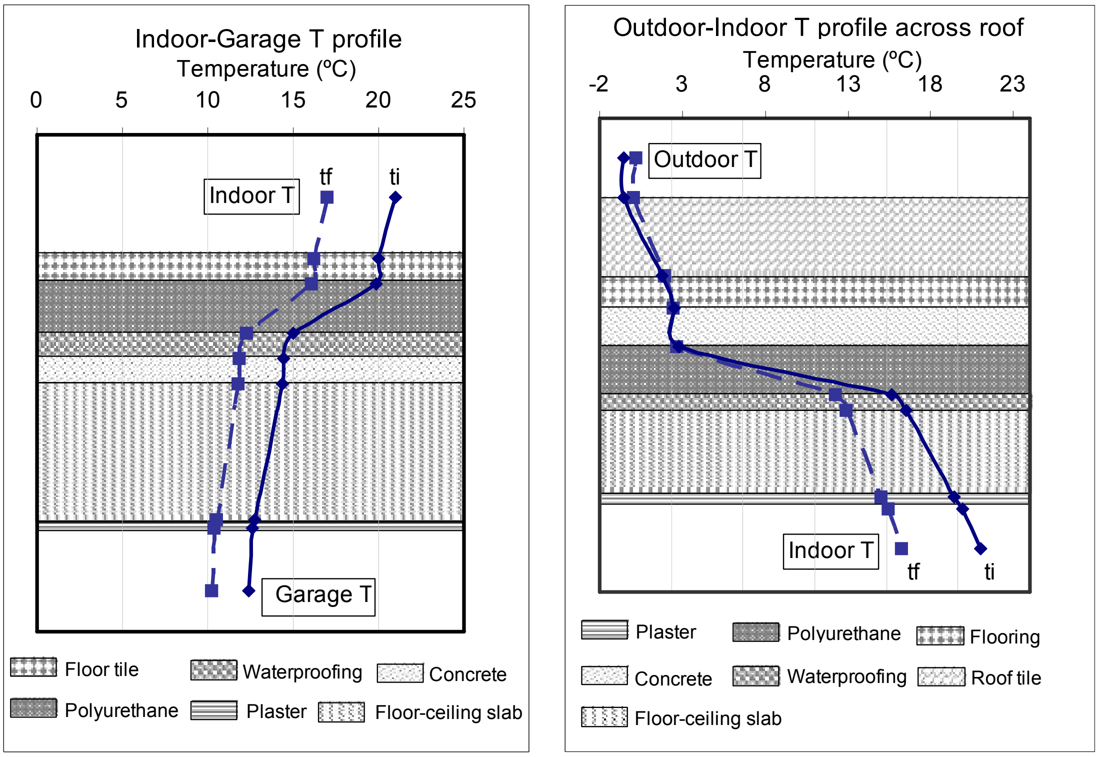
The method for calculating temperature variations in the roof is similar to the methods described in the preceding section for the outside wall. In this case, only the third storey is impacted, for its ceiling is in contact with the outdoor air across the roof slab. **Figure 5** shows the temperature in the roof materials. Using equation (11), the heat transmitted is found to be **21.9 kWh.**

5.3. Slab bounded by the garage

In this case only the first storey, whose floor is bounded by the unheated garage, is impacted. **Figure 6** shows the temperature in the slab materials. The value found when equation (13) is applied is **15.35 kWh.**

5.4. Party wall bounded by unheated premises

The heat required to raise the temperature of the materials in the party wall to the initial values is **9.97 kWh**, **8.2 kWh. y 8.41 kWh** for the third, second and first storeys, respectively.



Figures 5 and 6. Temperature profile for the slabs over the garage and third storey.

6. Total losses

Table 6 shows the total energy balance for the three flats. The heat demand for each flat, excluding the heat lost while the heating is off, is 75.7 kWh, 61.86 kWh and 68.91 kWh. The heat lost during the off period is 36.66 kWh, 11.86 kWh and 27.73 kWh, or an additional **40.24%** for the first storey, **19.18%** for the second storey and **48.4%** for the third storey flat.

Table 6. Energy balance for the three flats

	Heat transmitted (kWh)		
	3rd storey	2nd storey	1st storey
Wall	4.77	3.67	3.97
Party wall	9.97	8.19	8.41
Slab	**	**	15.35
Roof	21.90	**	**
TOTAL during the off period	**36.66**	**11.86**	**27.73**
Heating demand excluding losses	75.7	61.86	68.91
Total heating demand	**112.36**	**73.73**	**96.64**

7. Conclusions

The method introduced for calculating building heat loss when the heating is off constitutes an improvement over existing models. It consists in finding the temperature distribution in outside walls and walls bounded by unheated premises, as well as in partition walls, furniture, household appliances and so on.

The heat lost per flat between 11:00 p.m. on 21 December and 11:00 a.m. on 22 December 2006 was found to depend on the location of the flat in the building and to constitute a significant fraction of the daily demand. The additional loss generated in the top storey flat came to 48.4% over and above daily demand. The additional heat loss for the second storey flat was 19.18%, while the value for the first storey unit, bounded by the garage below, was 40.24%.

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DEVELOPMENT OF A DAMAGE-BASED SYSTEM FOR WEIGHTING ENVIRONMENTAL IMPACTS FROM BUILDINGS

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Summary

Weighting is applied to aggregating and communicate a large amount of information to stakeholders. Often the subjectivity involved in weighting leads to a diminished reliability and acceptability.

Different basis for weighting like monetarisation, damages, expert panels, questionnaires, etc have been applied in different assessment systems. However, after comparing different approaches, the use of the consequential implication of emissions and depletion of natural resources on human beings was considered to be the most relevant basis for a new system of weighting external impacts from buildings. A major simplification used is that damage to nature is transferred to endpoint problems on human beings. The principles of the Disability Adjusted Life Years system are adopted to qualify damage and annoyance to man. This was further complemented with a development of the European Quality of Life Scale system for facilitating setting new disability weights covering issues like loss of employment. Overall, the weighting system for each impact category includes different steps from defining endpoint problems to calculating a damage value, used to calculate the weights. Climate change is used as an illustration. Current lack of data poses a problem. The method is transparent and open for updating with improved data availability and quality.

1. Introduction

Almost all kinds of environmental assessments need to be interpreted for practical applicability. However there is still no consensus about how to perform this. The Standard for Life Cycle Impact Assessment (LCIA) stresses that normalisation; grouping and weighting are optional elements of an LCIA (ISO 2000). It further outlines that normalization employs baselines and/or reference information while grouping and weighting employ value-choices. Environmental assessment of buildings is no exception. In the area of environmental assessment of buildings, a large number of tools have been developed with no relation to any standardised methodology. Environmental indicators are chosen freely, quantitative and qualitative information is mixed and aggregated (weighted) into one or a few final scores.

Weighting is the heart of all assessment since it dominantly affects the overall performance score of the building being assessed (Lee et al 2002).

Contemporary weighting attempts are based on the rating of environmental performance of buildings by awarding credits and assigning performance points. The awarded points or credits are used in establishing scales for the different aspects or indicators being assessed.

Credit-scales bring the result to the same unit and enable the next step of weighting. However, so far there is no common basis for how the number of points which could be gained for individual indicators are set (Ding 2007). Working with whole point values for both qualitative and quantitative issues makes the system very crude and the result difficult to comprehend.

It is quite obvious that environmental assessment systems to a large extent are value based since indicators credit-scales and weighting are chosen in a subjective way. On the other hand, there are many common ingredients in these tools and a consensus will hopefully be reached in the future. The perspective of this contribution is the recognition of the importance of contributing to more similar and less subjective assessment tools regarding especially all these three factors. This paper presents an attempt of making weighting systems less value based. The context for this system was the EcoEffect method for environmental assessment of buildings developed by a group of researchers in Sweden. In this development work, weighting was recognized as a major problem and hence great efforts to develop a less subjective weighting process have been made.

2. Different basis for weighting

There are different starting points for establishing weights. Weights can, for instance, be calculated on the basis of quantitatively specified environmental goals or damages. The process of setting environmental goals renders them value-based but taken in a broader political context they have a legitimacy that can't be gained by a tool designer using votes from stakeholders as a basis for weights. Referring to national or international environmental targets for the weights the tool designer can claim that these weights are not subjectively set.

But the most common way to set and defend certain weights is to refer to votes from a group of “experts” or stakeholders. Such weights will reflect opinions in a certain area and time. Although looking objective at the time they may become obsolete from another perspective or at a different time.

Our point of view is that damage-based weights are the least subjective. The difficulty here is that the knowledge regarding future damages often is poor. On the other hand, this knowledge improves continuously and can be utilized without jeopardizing the method. It will instead strengthen it.

3. Damage-based weighting

With external environmental impact from a building is here meant impacts generated from building activities or use of buildings that contribute to environmental problems elsewhere, i.e. not affecting or targeting the building users specifically. It applies mostly to regional to global scale problems like climate change, acidification, toxicity etc.

The way to calculate contribution to external impacts is generally taken from the methodology of life cycle assessment (LCA), i.e. from inventory of emissions through out the life cycle of the product considered and knowledge about the potential contribution to each impact category from these emissions. Since one emission may have a larger impact per unit than another this is taken care of by factors representing these differences. The procedure ends up in an amount of equivalents that represents the potential impact. For instance, energy use in a building creates emissions corresponding to 1600 CO_2-equivalents/m^2, yr which is a way to measure contribution to climate change. If an overall judgment of the energy use in the building is asked, the significance of these equivalents compared to other equivalents for other kind of impacts has to be sorted out. The need for weighting thus arises. But to make aggregation possible first all equivalents have to be brought to the same unit to make weighting and addition possible. This is normally done by normalisation, i.e. dividing with a reference value with the same unit, for example the total amount of emitted equivalents of the same kind per capita in the country.

3.1 Defining and expressing damage

The motive of defining damage is uncovering the difference in significance between impact categories. From the damage point of view it could be defined as the difference in damage to people, ecosystems and resources caused by the different kinds of impacts. Since the external impacts are large scale problems, the difference in significance preferably should be compared on a global level. If impact category A is found to potentially create x times larger damage than impact B on the global scale, a unit contribution to A from a building should also be valued as x times worse than a unit contribution to B.

Damage to people can be measured in DALY (Disability Adjusted Life Years) developed by WHO (Murray and Lopez 1996). It is composed of two parts, one representing the inability to live a normal life when affected by a physical or physiological impairment, YLD (Years Lived Disabled), in this case caused by an environmental impact. The other part represents the theoretical suffering by an early death calculated as number of lost years compared to normal life length, YLL (Years Lost Life).

DALY [Years] = YLD+YLL

The YLD part has two components, one is a disability weight expressing the degree of disability the impairment causes and the other is the duration of the impairment.

YLD = dt * dw

dt: duration of impairment

dw: disability weight

Disability weights have been established by WHO for a large number of well-known diseases through a procedure of expert voting. These are both of physical and psychological type. For a population with groups of people with different kinds of impairments, DALYs can be calculated for each group and the sum indicates the magnitude of the total problem for the population. Once it is possible to find or establish disability weights for impairments caused by environmental impacts, one could determine the difference in significance through DALY calculations.

Each of the different impact categories includes a number of human problems. Although it might be impossible to tell all future potential human problems associated with different environmental impacts, there is broader awareness on a number of them. Tracking them down to individual human beings enables discussion at the level of endpoint problems for people. So the first step is to exhaustively identify as many endpoint problems related to each impact category as possible. An illustrative way of doing this is to draw cause-effect chains for each category, fig 1.

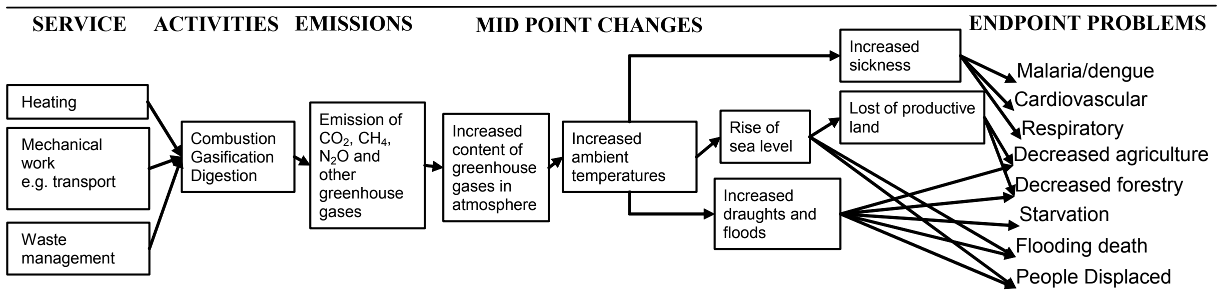

Figure 1 Example of a cause-effect chain for climate change

The endpoint problems identified for climate change are shown on the right side of the figure above. For malaria, dengue, cardiovascular and respiratory diseases, it is possible to find disability weights from WHO (Murray and Lopez 1996). The remaining endpoint problems are not particularly related to diseases and WHO gave no guidance on them. However, as they are problems affecting humans, it should be possible to express a disability weight to each of them in order to use the DALY system.

Glaumann et al (2005) presented a way to estimate disability weights for any human problem based on extension of the EuroQol system EQ 5D+system. This is a health classification system based on six aspects of quality of life; mobility, self care, usual activities, pain, anxiety and cognition. All kind of human problems can be associated to one or several of these aspects. Through a more elaborated problem definition and a clear score system, it is actually possible to set disability weights also on the remaining endpoint problems depicted above using this methodology.

Table 1 A procedure to arrive at disability weights

	Mobility	Self care	Usual activities	Pain/discomfort	Anxiety/depression	Cognition	**Mean value**	**Disability weight**
Malaria		Murray and Lopez (1996)						0,19
Starvation	0	0	2	2	3	2	1,50	0,38
Flooding		No disability weight						-
Drownings		No disability weight						-
Dengue		Murray and Lopez (1996)						0,19
Cardiovascula		Murray and Lopez (1996)						0,32
Respiratory		Murray and Lopez (1996)						0,10
People displaced	0	1	1	0	3	0	0,83	0,21
Decrease forestry - loss of job	0	0	0	0	3	0	0,50	0,13
Decrease agriculture - loss of job	0	0	0	0	3	0	0,50	0,13

0=no problem, 1=insignificant problems, 2=some problems, 3=large problems, 4=very large problems

4. Global damage per endpoint problem for each impact category

The bottom-line of this approach is estimation or calculation of the total number of DALYs associated with each endpoint problem through out the duration of endpoint problem caused by each impact category. Once disability weights have been established, there is also a need to estimate an average duration time per year for those who have been affected. At last the potential number of people that might be affected but will survive and those who die should also be estimated. The former number is used for calculating an average YLD value per year and the latter an YLL value per year. The sum of these multiplied by the total duration (years) for the impact under consideration finally gives the total damage for each endpoint problem. And the sum of all DALYs for the endpoint problems, i.e. future DALYs, within an impact category gives the basis for the category weight.

The calculation starts in estimating the number of affected today. Often figures are not available for the global situation but for a single country. Then this figure has to be extrapolated to the global situation. Some endpoint problems have been present long before the environmental impact occurred but have been accelerated due to the impact. In this case, the percentage of the existing problem that might have been caused by the impact should be established.

Since resource depletion and damage to ecosystems in the end will harm people as well we can try to reformulate those problems in terms of damage to people. For instance, acidification will harm people due to decreased incomes from forestry creating unemployment; acid lakes will decrease fishing harvest and maybe decreasing the value of the land next to the lake etc. Also it is possible to find disability weights and then calculate a damage value for such problems.

5. Calculating DALYs

To make this description more concrete the calculations for the climate change impact category is shown in the tables below.

Table 2 Estimation of number of people affected by environmental impact

Endpoint problem	Fatal cases/year	Non fatal cases/year	Reference/Remark
Malaria	52 500	30 000 000	Steen (1999)
	196 000		Goedkoop and Spriensma (2000)
Starvation	1 800 000	50 000 000	Steen (1999)
Flooding	15 000	150 000	Steen (1999)
Dengue	4 620	-	Goedkoop and Spriensma (2000)
Cardiovascular	350 000	-	Goedkoop and Spriensma (2000)
Respiratory	42 000	-	Goedkoop and Spriensma (2000)
People displaced	14 000	140 000	Goedkoop and Spriensma (2000)
Decrease forestry-LD	-	10 500 000	3% loss and 350 000 000 employed
Decrease agriculture-LD	-	60 000 000	5% loss and 1 200 000 000 employed

For each endpoint problem, different levels of data can be used to calculate the total DALY over the total duration of the impact.

At the detailed level where YLD values are missing, the following types of data are used:

Percentage of production loss or nuisance, A

This is where aspects such as decrease in agricultural production or forestry etc are accounted for.

The maximum number of potentially concerned per year locally today, B

Following the same example of agriculture or forestry, the total number of people working in the sector in a given geographic area can be used as a starting point.

Number of people affected directly at local level, C= A*B

Factor of conversion from local to global scale, f

This factor is meant to scale up from national and regional data to global data and it can be based on GDP or energy, population relationships etc.

Number of people affected at the global level, D=f*C

YLD per person and year, E

These values are either obtained from the literature or can be calculated as mentioned above.

Total YLD per year, F =D*E

The calculation of YLL is relatively shorter:

Number of deaths per year, G

Literature and expert estimations can be used in combination as a source of these figures.

YLL per person per year, H

There are literature sources providing YLL values for a number of diseases that constitute fatal endpoint problems.

Total YLL per year, I=G*H

Once the YLD and YLL, DALY for each

Total DALY per year, J=F+I

If and when the aforementioned calculations are based on a certain year which is different from the year of maximum effect or point of culmination, there is a need to introduce a factor of conversion and recalculate the DALY value:

Factor of conversion from current figure to the point of culmination, f_c

Total DALY per year cumulating point, $J_c= f_c*J$

More often the data on endpoint problems is available at aggregated level without discriminating what is related to environmental impacts and other causes. This aspect is taken care of by another parameter namely, *percentage of DALY caused by the environmental impact under consideration,* K.

In order to calculate the total DALY value for the endpoint problem, the duration of impact is required.

Duration of impact, d

For example, the duration of the climate change impact have been estimated to at least 500 years (Bernes, 2001). This means that after minimum 500 years has a new steady state climate been established on earth.

Total DALY over the duration of impact, $L= K*J_c*d/2$

Once the total DALY values are calculated for all endpoint problems associated with a given impact category such as climate change, their sum gives the total number of DALYs for that category.

The calculations and estimations outlined above can be seen as an extrapolation of the situation today, into one of the many possible scenarios. The same methodology opens up for the possibility of testing other scenarios and analyzing the associated consequences.

6. From DALYs to Weights

As can be seen in Table 3, the total number of DALYs calculated for climate change over the duration period is a very large number. The corresponding values for other impact categories are shown in same Table .

Table 3 DALYs calculated as basis for impact category weights.

Impact Categories	Total DALYs	In relation to climate change
Climate change	54 727 898 958	1,0000
Ozone depletion	23 713 561	0,0004
Photochemical ozone formation	2 315 091	0,0000
Acidification	156 899 640	0,0029
Nutrification	170 331 633	0,0031
Toxicity	37 188 697 118	0,6795
Ionising radiation	1 084 988 333	0,0198

As can be seen from the table above, there is large difference between values of the total number of DALYs for the different impact categories.

From a global human point of view, the climate change problem dominates all other categories except from toxicity emanating from synthetic chemicals and metals spread all over the world. From a local point of view, where fish harvest is affected, woods are dying etc the picture is another. While recognizing the significance of climate change, the more locally relevant problems have to be tackled at the same time. Local action may also be very efficient for solving local problems and often it would rather be irresponsible not to tackle them before putting all attention and resources on reducing contribution to climate change. It will always be important to combat local environmental problems in addition to the global ones.

A more balanced and reasonable picture from the point of view of a local or regional decision maker can be achieved through a discounting in time and scale.

In other words, the *Total DALY over the duration of the impact* (L) at the level of endpoint problems or at the impact category level is recalculated using a defined discounting function, f(di)

*Total DALY Discounted, M=L*f(di)*

Such a discounting function f(di) should be able to capture time frames from as short as a life time of man to the most long-lived impacts which are those associated with radioactive waste. Different exponential functions have been tested for the discounting purpose but in the end a natural logarithm seemed to fit the demands quite well. These values are shown in the end of the Table 4 below.

Table 4. Discounted DALYs and Relative weights

Impact Categories	Total DALYs	In relation to climate change	Discounted =ln	Relative weights
Climate change	54 727 898 958	1,0000	24,73	0,18
Ozone depletion	23 713 561	0,0004	16,98	0,12
Photochemical ozone formation	2 315 091	0,0000	14,65	0,11
Acidification	156 899 640	0,0029	18,87	0,14
Nutrification	170 331 633	0,0031	18,95	0,14
Toxicity	37 188 697 118	0,6795	24,34	0,17
Ionising radiation	1 084 988 333	0,0198	20,80	0,15

7. Conclusions

The method of estimating total DALYs for all endpoint problems is quite laborious. However, once it is done for the first time, there is only a need for updating. The weights can be used in different contexts as long as the principle is accepted. Apart from being an accepted the methodology, it is not value-based and it is easy to understand conceptually. If additional endpoint problems are identified they can easily be added to the existing ones.

Relatively the role of those who are involved in developing the method has nothing to do with what they think is relatively important as is often the case with most of other weighting approaches. On the contrary it is synthesis of existing knowledge and data that is processed and brought about the weights.

With regard to the data use, since estimations are also involved, critical reviews and improvements of the calculations are desired. Discussions around the size of different endpoint problems and alternative scenarios are certainly fruitful for legitimacy of methods like this. The number of estimations involved might look too much but the very large differences obtained between different endpoint problems shows that even large inaccuracies don't change the final result. Such inaccuracies do not change the ranking of the impact categories rendering the influence of uncertainties resulting from rough estimations invisible. Preliminary sensitivity analysis done internally on the weights showed that their relationship is fairly robust. Nevertheless, the specific data used to arrive at the weights needs improvement and scrutiny with increased knowledge and data availability. Certainly along with new data and knowledge, the calculations can and will be improved.

The future work in this area should focus both on using and testing such weighting methods. Besides, a parallel effort is required in terms of not only generating data but also enhancing access to what is available.

With regard to the limitation of the method, the linear model of the damage-based approach adopted here has the shortcoming of simplifying the cause-effect relations embedded in the environmental mechanisms that lead to the different endpoint problems. In reality the environmental mechanisms are non-linear and more complex than what can be captured using a linear model. The linear model dictates that the damage is proportional to the cause or "dose". This linearity at all doses implied implicitly in this weighting method deviates from what happens in natural systems where for a given environmental impact there is often a threshold, and no damage is caused until the threshold is overridden.

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PERFORMANCE INDICATORS FOR HEALTH, COMFORT AND SAFETY OF THE INDOOR ENVIRONMENT

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Summary

Under the ambitious acronym PERFECTION a new European coordination action has been launched. The project aims, via the development of an interoperable framework for performance indicators, at enabling the application of appropriate building design and technologies to improve the impact of the indoor built environment on health, comfort, feeling of safety, accessibility and positive stimulation.

A review of performance indicators currently used in design, construction and use will be undertaken. Areas where new indicators for health and safety (including accessibility and indoor environmental quality) should be developed will be defined. Recommendations for building design and technologies will be formulated in line with European directives on construction products and on energy building performance of buildings, the European environment & health action plan, the European green public procurement policies and the recently launched Lead Market Initiative on Sustainable Construction. A support tool should guide the use of correct indicators for a given context.

The project is carried out at an EU scale and the project results will reach every EU country. Next to 11 key partners, a great number of so called network partners representing industry from SMEs to LSEs, academia and research, will actively contribute to the common goal.

1. The PERFECTION Objectives

In the recent years, several approaches have been developed in the EU as regards the assessment of the indoor environment and building sustainability and the establishment of respective indicators. It is exactly because of the many activities and elaborations in the area of indoor environment and building sustainability that the potential of a co-ordinated activity is maximized. Learning from each other and setting a common agenda and a common roadmap constitute the obvious reasoning for this.

The aim of the PERFECTION coordination action is to help enable the application of new building design and technologies that improve the impact of the indoor built environment on health, comfort, feeling of safety and positive stimulation. In order to reach this objective, the project will deliver:

- a repository of good indoor performance indicators for health, comfort and safety
- a repository of state of the art environmental technologies that appear to have the potential for an important impact on the indoor performance and sustainability of the built domain
- an interoperable framework for performance indicators qualifying the indoor environment, allowing the successful life cycle management of sustainable buildings and stimulating the exploitation of appropriate technologies
- a decision support tool for different user groups applicable to different building types
- findings from selected pilot cases of the use of the indicators framework and the relevant indoor performance indicators
- recommendations on policies and the future research agenda: a roadmap including incentives and barriers for the application of building design and technologies to improve the quality of indoor environments

- knowledge and good practices on performance indicators for health, comfort and safety in the indoor environment.
- a wide dissemination of findings through an extensive expert network and the organisation of a series of events.

Figure 1 presents the PERFECTION framework, its mission statement and expected impacts and the main tasks to be executed in the 36 month project duration.

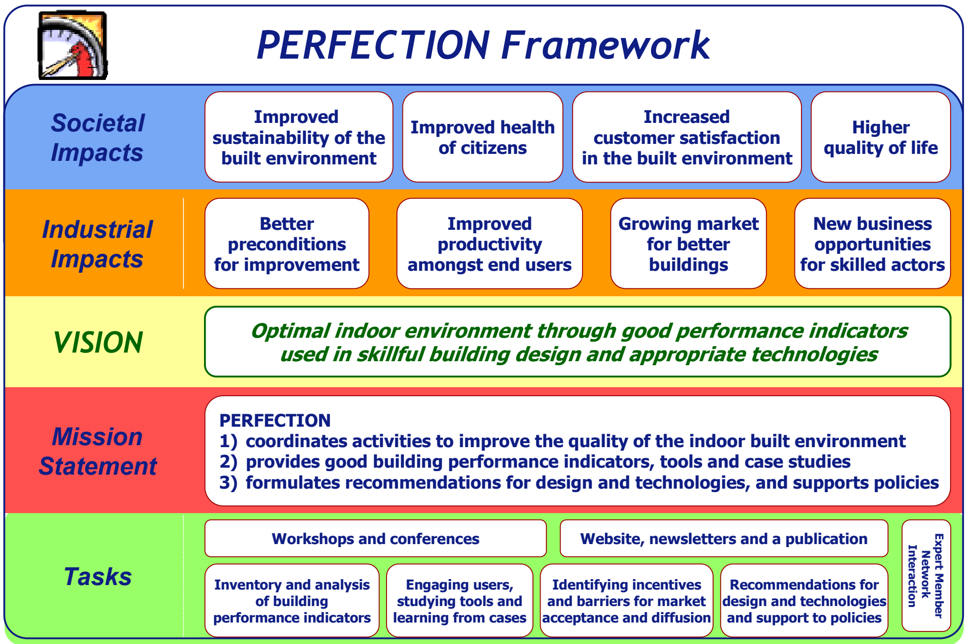

Figure 1: The PERFECTION Framework and its expected impacts

2. Towards a PERFECTION Building Performance Indicator Inventory and Framework

A number of the PERFECTION partners have been involved in the compilation of different performance and sustainability indicator systems in the immediate past (e.g. CRISP, ECOServe, Hope). However, the lack of a strong contextual element is what we see as one of the drawbacks in assessment methodologies, and related metrics and indicators. The indicator framework in PERFECTION will position not only health, comfort, safety and accessibility indicators, which in the LEnSE-project have been categorized in the Social Sustainability Theme. It should also include other important indoor performance indicators that touch on the sustainability aspects, such as adaptability or usability in a form that designers can communicate to clients. In this direction we will take into account the results of the LEnSE, ManuBuild, PeBBu and TISSUE projects to further detail or reformulate the core performance indicators and actively engage the end user considerations (Foliente et al. 2005; Huovila et al. 2004). The following figure 2 illustrates this approach.

Performance indicators for health, comfort and safety of the indoor built environment	
Indicators named in the ENV 3.1.5.2 Call	**Potential supplementary indoor performance indicators**
• Health • Comfort • Feeling of safety • Positive stimulation • Accessibility • Indoor environmental quality • Sustainable, low-energy built-environment	• adaptability / flexibility • service life • usability • life cycle costing • environmental pressure

Figure 2: Performance indicators covered by PERFECTION

CIB has produced an internationally accepted Compendium of Building Performance framework including the categories of safety, comfort, health & hygiene, service life, and usability and maintainability. CIB has also an active Working Commission W077 on Indoor climate and its recent large EC funded Performance Based Building Thematic Network (2001-2005) included a domain for Indoor Environment (ISO, 1984; Lützkendorf et al. 2005). An example of a practical tool containing a database of performance indicators for e.g. indoor conditions, comfort, safety and accessibility is shown below in figure 3.

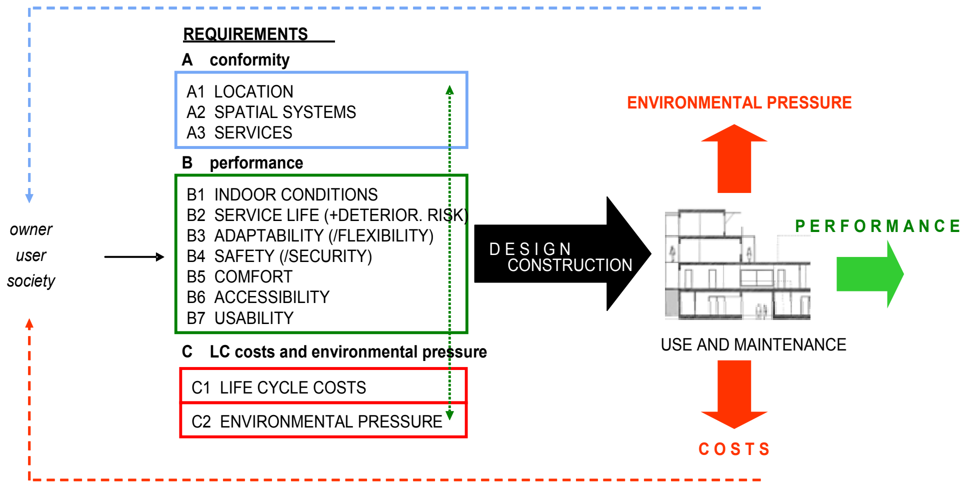

Figure 3: VTT's EcoProP tool[1] for design briefing and systematic requirements management.

2.1 Comfort related indicators

Review of comfort (and health, see the next paragraph) related indicators is based on existing publications, regulations and standards on the subject, e.g., EN 13779:2004, EN 15251:2007, NBN EN ISO 7730:2006, NBN EN 12464-1, FMA-LNE (2007), CEN TC 350 on sustainability of construction works and CEN TC351 on hazardous substances in construction products. Based upon earlier work a first subset of indicators has been established as the starting point.

- Hygrothermal comfort
  - Thermal conditions in winter and summer, as characterized by thermal comfort indices PMV-PPD[2], temperature and/or air velocity variations.
  - Local thermal discomfort, such as draught, radiant temperature asymmetry, vertical air temperature differences and floor surface temperatures.
  - Indoor air humidity
- Ventilation conditions
  - Ventilation rate/air flows
  - CO_2 concentration[3]
- Acoustic comfort
  - Acoustic insulation performance for airborne noise and structure-borne noise
  - Façade insulation performance
  - Background noise from indoor sources
  - Reverberation time and acoustical absorption

[1] http://cic.vtt.fi/eco/ecoprop/english/EcoProp_brochure.pdf
[2] The PMV-PPD index (EN ISO 7730) takes into account the influence of all 6 thermal parameters (clothing, activity, air and mean radiant temperature, air velocity and humidity).
[3] CO_2 concentration may be used to characterize air quality in buildings where people are the main pollution source (see EN 12251:2007).

- Lighting comfort (natural and artificial lighting)
    - Daylight factor
    - Maintained illuminance and uniformity
    - Distribution of luminances and reflection coefficients
    - Glare (as characterized by UGR (Unified Glare Rating))
    - Color Rendering Index and color temperature
- Vibrations
- Access
    - Access to adequate external space such as gardens, parks, squares, etc.
    - Access to indoor facilities related to the building
    - Access to parking/storage facilities

2.2 Health and Indoor Environment related indicators

The standardization work by e.g. ASHRAE, ASTM, CEN (TC156W1, TC264WG7, TC350, TC351), EC (CPD 89/106), EOTA (PT9), ISO (16000/TC146SC6, 16814/TC205) and WHO, without even mentioning all, gives extensive references on indoor health related indicators. Also legislation such as the Flemish Decree on indoor environmental quality, includes indoor environment and health related indicators. A first list of indicators has been defined and will be further elaborated:

- Indoor air quality
    - Quality of the Air Intake (especially relevant in urban and industrial areas)
    - Concentration of CO
    - Dust (Particulate Matter PM2,5 and PM10)
    - Total Volatile Organic Compounds (TVOC)
    - Formaldehyde, benzene, toluene, tetrachloroethylene, trichloroethylenen, ozone O_3, acetalaldehyde, other aldehydes
    - Asbestos
- Electro-magnetic Fields
- Biotic factors
    - Guanine
    - Cockroaches
    - Micro-organisms
    - Mites
    - Rats and mice
    - Mould
- Quality of drinking water
    - Microbial water contamination
    - Water pollutants

2.3 Accessibility and positive stimulation related indicators

Accessibility may be defined as a comfort-related issue, but is so specific that it probably should be dealt with in a specific category. The work of CIB Working Group 084 on building comfortable environments for all is particularly relevant with regard to indicators on accessibility and positive stimulation. Other interesting sources are amongst others UN Enable, the World Bank, Agenda 22, the European Concept for Accessibility, the European Institute for Design and Disability, ISO TC 59 SC16 "*Accessibility and Usability of* *the Built Environment*" and the recent EC funded RTD project POLIS - Decision support tools and policy initiatives in support of a universal design of buildings (2004-2006)[4].

Defining indicators which can be used to measure and/or monitor the accessibility or quality of the indoor environment is not an easy task. As most countries define detailed criteria in legislation, standards or guidelines, and work with consultants and checklists to guide and evaluate designs and buildings, the risk is high that the number of indicators will become too important to stay manageable. It will therefore be necessary to define broader categories, probably based upon the needs of the users, such as:

- Disabled Access. An important element here will be whether we categorize the users or not. As a matter of fact, the needs of wheelchair users, blind or deaf may be entirely different. However, as universal design starts from the point of view that the design should respect the needs of all users, the disabled users do often not like to be categorized. When defining indicators, it may be easier or even necessary to categorize.
- Children Access
- Pram Access
- …

Accessibility and positive stimulation are also closely linked. An accessible built environment is essential if one has the ambition to have an inclusive society where everyone is able to participate in normal daily activities, such as work, leisure, shopping, etc. On the other hand, the built environment and the buildings may be so that they stimulate people to move, to communicate, to look, to feel, to participate in society, etc. A target group which comes immediately to mind in this context is the ageing population, but also other groups, e.g., children, disabled, stressed and depressed, may profit from positive stimulation.

2.4 Safety and security related indicators

Safety and security have been dealt with in projects such as the EC-funded projects PRESCO (5FP European Network for Practical Recommendations for Sustainable Construction) and LEnSe (6FP STREP Methodology Development towards a Label for Environmental, Social and Economic Buildings). Also the work of CEN TC 325 on the Prevention of Crime by Urban Planning and Building Design is particularly interesting. This TC has in the recent year published a series of standards and specifications:

- NBN EN 14383-1:2006 – Prevention of crime - Urban planning and building design – Part 1: Definition of specific terms
- NBN ENV 14383-2:2004 – Prevention of crime - Urban planning and design - Part 2: Urban planning
- NBN CEN/TS 14383-3:2005 – Prevention of crime - Urban planning and building design - Part 3: Dwellings
- CEN/TS 14383-4:2006 – Prevention of crime - Urban planning and design - Part 4: Shops and offices.

However, safety includes also other indoor risks such as falling, electrical dangers, explosions, etc. In our views indicators should be defined for:

- Structural stability
- Flood risks
- Fire safety and alarms
- Fire fighting provisions
- Provision and Quality of Escape routes
- Lightning safety
- Prevention of crime – burglar proof provisions in the planning or design phase
- Static electricity
- Personal safety (slipperiness, risks of collisions, falling due to unexpected differences in height, etc.)

[4] http://www/polis-ubd.net

3. Other PERFECTION Objectives

3.1 Use of Technologies and Designs

Creating an indicator framework is merely the fist step of the PERFECTION coordination action. An important work package will focus on the use of indicators and the way they could stimulate the development and the uptake of new designs and technologies (Huovila 2007a; Huovila 2007b) In that regard a PERFECTION user decision support tool will be developed. It should comprise 2 modules:

- an evaluation module of specific technologies, services, etc. against metrics and benchmarks defined in the indicator framework.
- a promotional module where solutions that are related to the PERFECTION scope and achieve a building enhancement mark above a certain level will be publicised against a defined template

3.2 Policy Recommendations

PERFECTION has also policy related objectives. As a matter of fact, PERFECTION hopes to be able:

- To formulate a set of recommendations to the EC and the Member States with regard to incentives and barriers to new designs and technologies. As a matter of fact, the application of new and innovative designs and technologies allowing ameliorating the quality of the indoor environment is hindered by existing standards and regulations or by the conservatism in the sector. On the other hand, the uptake of such designs and technologies may be accelerated by incentives developed by the authorities such as green procurement or pilots at government associated buildings.
- To formulate a set of recommendations to the EC, the Member States and Industry with regard to the needs and priorities of the future. Reference is essentially made to the urgent technological needs in the short and medium term. As an example one could for instance name the need for sensors, technologies and designs to make sure the indoor CO_2 concentration is always below the threshold values, taking into account the human interaction.

PERFECTION CES NETWORK Main Input				Indoor Indicators						Indicator use				Policies				
				T1.1 Standards, regulations	T1.2 Research, policies	T1.3 Health & Comfort	T1.4 Accessibility & safety	T1.5 Indicator framework	T1.6 Indicator analysis	T2.1 User engagement	T2.2 Indicator tools	T2.3 Decision support tool	T2.4 Case studies	T3.1 Incentives and barriers	T3.2 Technological needs	T3.3 Policy support	T3.4 Indicator roadmaps	Main Interest and Knowledge Area
Industry frontrunners, good practices																		
1	Wienerberger NB	Ms. Inge Buyse	Belgium			X					X	X	X		X			Sustainable building & building materials
2	POLIS-21	Georges Alatzas	Cyprus				X					X	X			X		Decision support systems, accessibility
3	Architektibüroo Allan Strus OÜ	Allan Strus	Estonia			X	X						X			X		Architectural design, accessibility
4	JM Suomi Oy	Tuomas Leppänen	Finland			X					X		X					Indoor climate, moisture, health
5	Prode Architects and Consultants BNA	Freek den Dulk	Netherlands			X			X				X	X		X		Sustainable design, IAQ and consulting
6	Vista Utredning AS	Finn Aslaksen	Norway				X			X			X			X	X	Accessibility, universal design
7	Mostostal Warszawa S.A.	Pawel Poneta	Poland	X				X					X	X	X			Building performance, ECTP
8	ALIA	Miguel Mitre	Spain			X				X			X			X		Bioclimatic architecture, energy efficient design
9	Dragados	Carlos Bosch	Spain					X	X				X	X	X			Sustainable building, performance metrics, ECTP
10	Skanska	Kyösti Tuutti	Sweden					X			X		X	X	X			Building performance, indoor emissions
11	Planair SA	Pierre Renaud	Switzerland			X			X				X			X	X	Building physics, solar energy
Academic professionals, domain specific experts																		
12	University of Voralberg	Jens Schumacher	Austria								X	X	X	X	X		X	User-centred technologies, benchmarking
13	Technical University of Sofia	Petar Stankov	Bulgaria			X		X						X	X	X	X	Human comfort, energy and environment
14	University of Zagreb	Ljubomir Miščović	Croatia			X							X				X	Bioclimatic architecture, energy efficient architecture
15	Technical University of Denmark	Arsen Melikov	Denmark			X		X						X	X	X	X	Indoor performance
16	Karslruhe University	Thomas Lützkendorf	Germany	X				X	X								X	Performance metrods, indicator systems
16	Karslruhe University	Andreas Wagner	Germany			X	X						X				X	Energy efficiency and comfort
17	EMI	Károly Matolcsy	Hungary	X	X								X					Quality control and management, ENBRI
18	IBRI	Gudni Gudnason	Iceland								X	X						ICT tool development
18	IBRI	Bjorn Marteinsson	Iceland			X	X											Building design technologies, ENBRI, standardisation
19	UCD	Owen Lewis	Ireland			X								X	X		X	Architectural design, energy and indoor environment
20	CNR ITC	Mrs. Annalisa Morini	Italy				X					X	X			X		Accessibility, comfortable environments for all, ENBRI
21	Centre de Recherche Public Henri Tudor	Pierre Plumer	Luxembourg			X	X											Health aspects, accessibility
22	The University of Malta	Joseph Falzon	Malta			X	X										X	Energy, safety and performance of buildings
23	University of Minho	Luis Bragança	Portugal			X	X						X			X	X	Sustainable building, accessibility
24	Transylvania University of Brasov	Mrs.Venetta Sandu	Romania			X							X				X	Toxicity, indoor comfort indicators
25	Institute Mihailo Pupin	Mrs. Sanja Vranes	Serbia									X						IT and decision support systems
26	Slovak University of Technology	Dusan Petras	Slovakia			X							X					Building services, energy auditing
27	Gradbeni Institut ZRMK	Mrs. Marjana Sijanec Zavrl	Slovenia			X							X					Facility management, energy use, IAQ
28	European University of Madrid	Francisco Javier González	Spain			X							X					Sustainable architecture
29	Polytechnical University of Madrid	Ricardo Tendero	Spain			X							X					Sustainable building, indoor comfort
30	Lund University	Lars-Olof Nilsson	Sweden	X		X							X					Building performance, indoor emissions
31	Ankara University	Akin Kocak	Turkey									X		X	X	X	X	Policy, marketing and SME knowledge
32	Napier University	John Currie	UK			X						X	X					Energy and sustainability of buildings
33	CSIRO	Greg Foliente	Australia			X		X			X							Indoor health, building performance

Figure 4: The PERFECTION team covers various areas of expertise.

- To deliver a Policy Support Paper with regard to the CPD, EPBD, EEHAP, standards and regulations. This Paper will be based upon the work realised in WP1 and WP4, and will amongst others deal with the lack of knowledge and the lack of uniformity around Europe.
- To describe an Indoor Core Performance Indicator Roadmap that describes various development paths towards the desired future state taken cognisance of different time frames, technology maturity and relevant policy action plans (barriers and incentives). . The roadmap will be validated by an extensive network member group containing knowledge from different industrial and scientific domains.

3.3 PERFECTION Dissemination Activities

The project is carried out at an EU scale and the project results will reach every EU country as is illustrated in Figures 4 and 5. More than 40 experts from over 30 countries were carefully selected to the PERFECTION team to ensure the necessary depth and width. As figure 4 shows the network consists of experts from various domains focused within the ENV.3.1.5.2 call; such as indoor health issues, acoustics, universal design, performance metrics and tools, sustainable design and construction, etc. Clear project yardsticks are the following:

- Engaging in the project roll-out partners or subcontractors from all EU-27 countries and securing a networking effect, extending well beyond the project lifetime. Next to 11 key partners, a great number of so called network partners representing industry from SMEs to LSEs, academia and research, from all over the EU and the accession countries, are actively contributing to our common goal.
- Organizing five events all across Europe (North, East, South-East, South-West, Central), two with a policy focus, two with a research focus and one business focused. A sixth smaller-scale event will be organized for EC officers and will be focused on EC policies in the areas of environment, enterprise, transport and energy, employment, social affairs and equal opportunities.

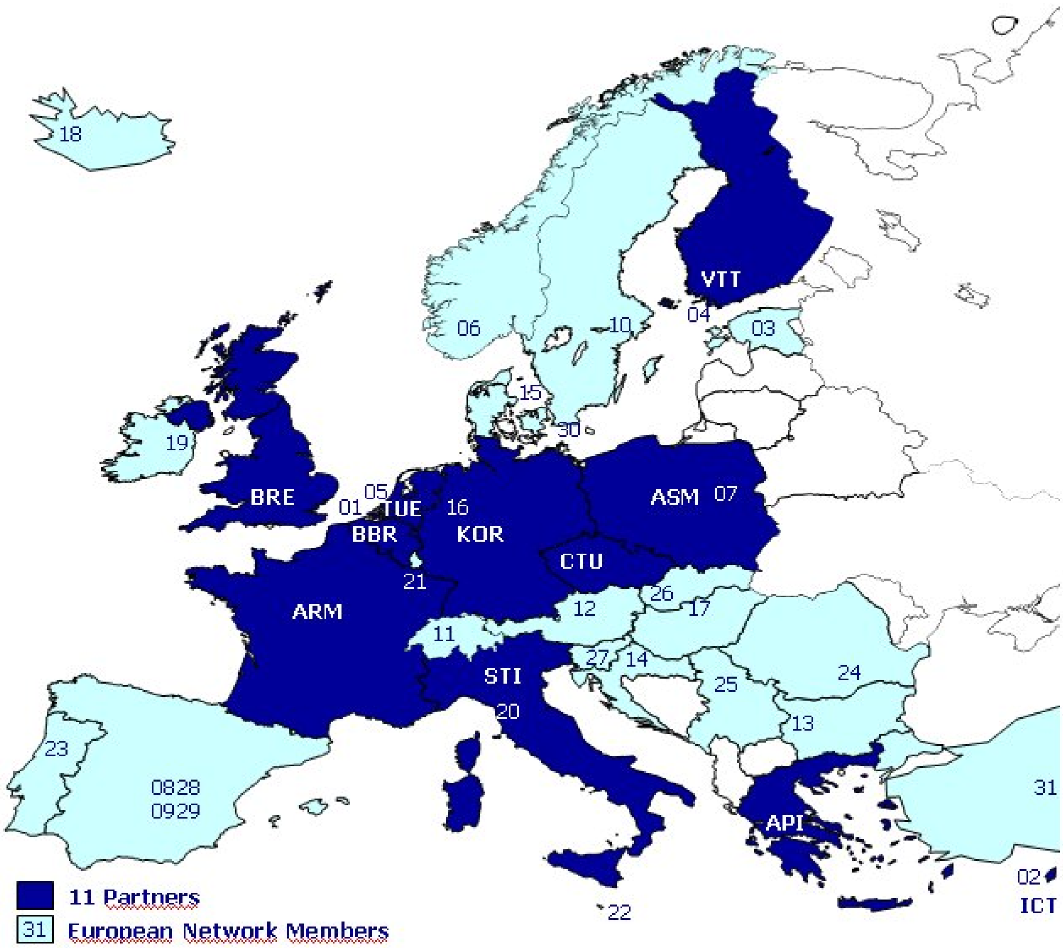

Figure 5: The PERFECTION Network encompasses well the European dimension.

- Producing a quality publication - showcase of a number of case studies across all EU-27 countries, whereby the impact of innovative and well defined technologies as well as policies on specific buildings will be presented in a user friendly way.

4. Conclusion

The PERFECTION coordination action just started in the middle of 2008 and runs over a period of 36 months. Contract negotiations were not yet finalised when submitting the paper. As such, not more than the project objectives and a first, premature subset of indicators could be presented in this paper. However, numerous initiatives will be taken in the coming months and years. This is an open invitation to participate and contribute whenever feasible. PERFECTION will inform you about progress.

5. Acknowledgement

PERFECTION is a coordination action that will be supported by the European Commission within the 7th Framework Programme Environment Calls as soon as contract negotiations are successfully terminated.

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DEVELOPING THE SUSTAINABLE BUILDING ASSESSMENT TOOL FOR STADIA

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Keywords: Sustainable Building Assessment Tool, SBAT, sustainability performance, FIFA 2010 World Cup, South Africa.

Summary

South Africa will, in 2010 host the continent's first FIFA World Cup, and in so doing attempt to continue the legacy of the Green Goal, developed for its predecessor, Germany, for the FIFA World Cup 2006. In preparation for the event, South Africa's Department of Environmental Affairs and Tourism (DEAT) aims to ensure that like the German stadia, South Africa stadia are environmentally sustainable, particularly in terms of water, energy and waste aspects.

A framework, specific to stadia, is required in order for the sustainability of each stadium to be rated. The Sustainable Building Assessment Tool (SBAT) has an existing structure; however its indicators are focused primarily on the assessment of commercial buildings.

The paper investigates a selection of indicators relevant for stadia and undertakes the development of an SBAT for Stadia for the environmental assessment of the 2010 World Cup stadia.

1 Introduction

South Africa will host the FIFA 2010 World Cup in three years' time and in keeping with the legacy left by the FIFA 2006 World Cup, the Department of Environmental Affairs and Tourism (DEAT) green status of the 2010 soccer stadiums is being reviewed.

1.1 Relevance

The review team proposed the use of the existing SBAT framework/methodology with adaptations to reflect the stadium building type. Table 1Table 1 outlines some differences between commercial buildings (for which the SBAT was originally intended) and stadium. This brief comparison shows that the two building types cannot be compared and therefore a tool targeting one building type (i.e. commercial building) cannot be used to measure the sustainability performance of the other (i.e. stadium) without being biased to the other (i.e. stadium).

Table 1 Comparison between a commercial building and a stadium

	BP Building, Cape Town	Green Point Stadium
Definition	A commercial building is a building type that is used for commercial use, including office buildings, warehouses, or retail (Wikipedia contributors, 2007).	A modern stadium is a predominantly outdoor place used for sports, concerts or other events. It consists of a field that is partly or completely surrounded by a structure designed to allow spectators to stand or sit and view the event (Wikipedia contributors, 2008).
Users	540 employees are accommodated in the building. At maximum capacity each employee has a space of 16,26m^2/occupant	50'000 spectators will seat on a structure that is open to most external element. Each spectator has a space of 1,97m^2
Occupancy	Approximately 260 days/year for a minimum of 12 hours/day	A minimum of 30 days/ year for a minimum of 4 hours/event
Area Analysis	More than 50% of the floor space is used for commercial purposes.	More than 50% of the floor space is used for spectator seating, VIP and media facilities.

Source: Sebake and Gibberd, 2008

1.2 Scope of Research

The research will present the development and use of the SBAT for Stadia assessment tool.

1.3 Research Aim and Questions

The aim of the research was to find an appropriate tool to assess the sustainability performance of the stadia for the 2010 FIFA World Cup.

The research question derived from this are:

- Can the SBAT be adapted to reflect the stadia building type?
- How will this new assessment tool be used?

1.4 Structure of the Paper

The paper is structured under the following headings; background, literature review, methodology, discussion and conclusions.

2 Background

2.1 South African Context

The Republic of South Africa is considered to be the most developed and modern country on the African continent. Since 1994, when the first democratic government was elected, South Africa has had positive economic growth (Knight, 2006). However, on the other side of these positive aspects, is a country which still has major social and economic problems, including poverty, inequality, unemployment, HIV/Aids and property and personal insecurity (Beall, et al, 2005).

It was in light of these socio-economic problems that South Africa's bid campaign for the 2010 Fédération Internationale de Football Association (FIFA) World Cup promised that it would ensure *"a lasting social legacy through the event and"* leverage "*the event to spread economic and social benefits beyond the borders of South Africa"* (DEAT, 2006). In May 2004, South Africa was awarded the rights to host the 2010 FIFA World Cup event. Ten stadiums will be constructed, upgraded or reconstructed for the event (FIFA, No date).

South Africa's hosting of the 2010 event presents an opportunity not only to run a successful event but also to achieve the political and social promises on which South Africa's bid campaign was based (Cornelissen, Swart 2006). In addition to fulfilling the promises made, South Africa will take on the challenge of upholding the standards set by Germany during the 2006 FIFA World Cup event, which was carried out in an environmentally accountable way.

South Africa's Department of Environmental Affairs and Tourism (DEAT) has addressed this challenge by setting up the Review of the Greening Status of the Stadia for the 2010 World Cup in South Africa project which is currently undertaken by Green by Design (GbD), Paul Carew Consulting (PjC) and the South African Council for Scientific and Industrial Research (CSIR). The project aims to review the sustainability initiatives that have been included in the host stadia, identify gaps and where appropriate provide recommendations.

2.2 SBAT framework

The SBAT framework includes criteria in all three sustainability aspects, namely, economic, environmental and social as outlined below (Gibberd, 2003):

- Economic: local economy; efficiency; adaptability and flexibility; ongoing costs; capital costs.
- Environmental: water; energy; waste; site; materials and components.
- Social: occupant comfort; inclusive environments; access to facilities; participation and control; education, health and safety.

Each of the 15 criteria has a set of five sub-criteria linked to indicators that are used to measure the sustainability performance of a proposed design or existing building (see Table 2).

Table 2 The Structure of the Sustainable Building Assessment Tool (SBAT)

Sustainability aspect	Criteria	Sub-Criteria	Indicator
EC ECONOMIC	EC1 Local Economy	EC1.1 Local Labour	Use of local (from within 50km of the site) labourers
		EC1.2 Local Materials	Building material sourced from within the country
		EC1.3 Local Materials and Components	Material and components sourced from within the country

		EC1.4 Local Furniture and Fittings	Furniture and fittings sourced from within the country
		EC1.5 Maintenance	Maintenance and repairs can be undertaken by local SMMEs (turnover of <R5m)
Total: 3 aspects	Total: 15 criteria	Total: 75 sub-criteria	Total: 75 indicators

Source: Sebake and Gibberd, 2008

3 Literature Review

3.1. Greening of sporting events

The concept of sustainable development has been defined by the World Commission on Environment and Development (WCED) in their Brundtland Report as meeting the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). This was recognized as a balance between the environmental protection, economic growth and social development dimensions in 1992 at the Rio Declaration by the United Nations NGO Committee on Sustainable Development (UN, No date a).

Table 3 Chronology of global commitments to Sustainable Development and the Incorporation of Sustainability principles in the Olympics and FIFA

Sustainable Development	Year	Incorporation of Sustainability in the Olympics and FIFA
Brundtland Commission defines "sustainable development"	1987	
BREEAM – the first environmental assessment tool id developed	1990	
	1994	The Green Olympics are hosted (Lillehammer) IOC / UNEP Cooperative Agreement signed - aims to raise awareness and educate people on environmental issues in sport
	1995	
	1996	Environmental Protection is added to the Olympic Charter
Establishment of the Global Reporting Initiative (GRI)	1997	
Formation of the World Green Building Council Release of the first draft of GRI's Sustainability Reporting Guidelines	1999	Agenda 21: Sport for Sustainable Development is adopted by IOC
	2000	Sidney develops the "Olympic and Paralympic Games Environmental Benchmarks"
Release of the second version of GRI's Sustainability Reporting Guidelines	2002	
Development of the Sustainable Building Assessment Tool (SBAT)	2003	
	2006	Torino 2006 Olympics – first sustainable Olympics FIFA 2006 Germany – Green Goal Initiative
Formation of the South African Green Building Council	2007	FIFA Technical Requirements adds 'Green Goal' chapter

Source: Sebake and Gibberd, 2008

Of the largest global sporting organizations, the International Olympic Committee (IOC) was the first to respond to the global concern on environmental concern. This was done by the Local Organising Committee (LOC) who incorporated environmental practices in the implementation of the Lillehammer 1994 Winter Games. Subsequent LOCs followed this example including the Nagano 1998, Sydney 2000, Salt lake City 2002, Athens 2004 and Torino 2006 (IOC, 2007). The most recent Olympics Games stand out because the Torino Organizing Committee (TOROC) pioneered the move to sustainability reporting based on the Global Reporting Initiative (GRI) guidelines (TOROC, 2005). This ensured that planning, implementation and monitoring incorporated the three sustainability dimensions recognized at the 1992 Rio Declaration which went beyond focusing on environmental issues.

It is evident from the preparation of the following three Olympic Games events, namely Beijing 2008, Vancouver 2010 and London 2012, that the respective LOCs have been influenced by the sustainability practices undertaken in the Torino 2006 Winter Games and will be addressing sustainability as a major concern (IOC, No date).

The 2006 FIFA World Cup LOC were inspired by the successes of Australia for the 2000 Summer Olympics in Sydney and submitted a chapter called Environmental Concept for the stadia as part of their bid campaign even before FIFA required any commitment to Environmental Protection or Sustainable Development.

The Green Goal initiative was developed by the 2006 LOC who worked with the Öko-Institut and the World Wildlife Fund (WWF) to develop guidelines and objectives for the event. Implementation of the initiative was difficult, mainly because construction of the stadia had already begun. The programme therefore only had a limited impact on the stadium planning (Öko-Institut, 2006).

Following Germany's successful hosting of the 2006 World Cup, FIFA (like the IOC following the Lillehammer Games in 1994) showed its support for environmental protection by adding a Green Goal chapter in its Football Stadiums: Technical Recommendations and Requirements (FIFA, 2007) manual and the incorporation of Environmental Protection in the host city agreement with the 2010 FIFA World Cup LOC and the host city (CoCT, 2006, pp 3). The host cities have been bound by this agreement to plan, implement and operate the 2010 stadia in an environmentally sustainable manner. South African legislation (which has been guided by global priorities encapsulated through documents like the Agenda 21, Millennium Development Goals and the Johannesburg Plan of Implementation (DEAT, 2006)) has provided additional guidance.

3.2 The use of Assessment tools for Sporting events

Table 4 Assessment tools used

	Tools used
Sydney 2000	Green Star
Torino 2006	SEA GRI guidelines
Vancouver 2010	LEED
London 2012	BREEAM Bespoke

4 Methodology

4.1 Background of the Review Project

The Review of the Greening of the Stadia for the FIFA 2010 World Cup project was initiated by the Department of Environmental Affairs and Tourism (DEAT) to review the sustainability initiatives that have been included in the host stadia, identify gaps and where appropriate provide recommendations. The project commenced in July 2007 and is undertaken by Green by Design (GbD), Paul Carew Consulting (PjC) and the South African Council for Scientific and Industrial Research (CSIR). To date two stadia (Moses Mabhida Stadium and Green Point Stadium and one training venue (Athlone Stadium) have been reviewed.

The original terms of reference (ToR) for the proposal received from DEAT included environmental assessment of water, energy, waste and transport issues as outlined in the Green Goal Report (iSeluleko Consulting 2007). The review team's successful proposal to DEAT responded to these issues and included the suggestion that the SBAT be used to address some of the broader social and economic issues rather than solely focusing on environmental issues.

The review project widened the scope from a purely environmental focus and acknowledged South African local concerns, by assessing the social and economic issues. The use of the SBAT, which has been found to be the most suitable tool for a developing country context (Kaatz, et al, 2002) was therefore appropriate for use for the review project.

4.2 The Development of the SBAT for Stadia

The existing Sustainable Building Assessment Tool (SBAT) was adapted to create the SBAT for Stadia through the development of a set of indicators and targets/benchmarks that would support the assessment of the sustainability performance of the 2010 FIFA World Cup stadia.

The development process of the SBAT for Stadia is reflected in Diagram 1 (Sebake and Gibberd, 2008). The process is described below:

- The first stage (A) requires the review of relevant literature subsequent to the completion of the first SBAT version in 2003.
- From the review, an assessment framework is developed (B). This will be used to assess the appropriateness of new indicators to global trends.
- In the third stage (C), a review of the SBAT and the relevant building type is undertaken. Indicators not relevant to the building type are removed.
- Building specific indicators are added to the amended list of indicators (D). This stage is best undertaken in conjunction with the development of related targets / benchmarks where they exist (E).
- The indicators are then prioritized using the assessment framework developed in B above to ensure that each criterion has five indicators (one per sub-criteria) (F).
- This prioritization and elimination of indicators results in the first draft SBAT for Stadia (G).
- The SBAT for Stadia should ideally be piloted before being published on the website for public use (H). The field testing was with the first stadium.
- The piloting of the first draft SBAT for Stadia assessment tools will require input from relevant professional experts (I), and may lead to indicator – target / benchmarks set (J).

- Using this feedback and field testing, revise the SBAT for Stadia accordingly (K).
- Publish the revised version of the SBAT for Building Type on the www.sustainablebuilding.co.za website (L) and request user feedback over a three month period.
- Use the feedback and comments received from the users (M) to revise the tool before publishing a third and final version SBAT for Stadia online (N).

4.3 Assessment Process using the SBAT for Stadia

To date two stadiums and one training venue have been appraised. For the purposes of this paper, the focus will remain on the stadia for the event, not on the training venues. The two stadia will be referred to as stadium A and stadium B in order of commencement.

The review of the stadium was undertaken in three stages. The three stages are described in the following sections, which also highlight how the SBAT was used.

4.3.1 Stage 1: The Initial Workshop

The objective of the first stage was to review the existing sustainability initiatives and undertake an appraisal of the possibilities and opportunities that had not been explored.

During this stage, a full day workshop with the stadium authority and individual professional team members was held. This provided the review the sustainability initiatives currently being implemented in the stadium design. These included energy, water, waste, transportation, urban design and material selection.

Following the workshop, additional information was requested from the professional team, including technical documentation (i.e. a site plan, plans of all the levels, sections along both axes of the stadium) and any available and appropriate reports.

The information gathered from the workshop and from the professional team following the workshop is used to develop the first SBAT appraisal and the first draft of the stadium review report. The report consists of two parts; namely the general information and the stadium review.

The general information presents the host city's activities regarding and provided a contextual introduction of the stadium. The stadium review shows the results of the first SBAT appraisal and describes how the stadium design performs in terms of the sustainability review criteria defined in the TOR (i.e. water, energy, waste, transport). Possibilities and opportunities At the end of this stage, gaps in information were highlighted, particularly with regard to the SBAT, which could not be finalised without the missing data. The report, including the incomplete SBAT appraisal, was sent to the stadium authority, who shared this with the professional team.

4.3.2 Stage 2: The Interim Workshop

The objective of the second stage was to assess the feasibility of each of the possibilities and opportunities identified in the first draft report. Both of the stadiums reviewed have reached this stage, however the stadium A has had an additional visit, because processes have been improved.

During this stage, a half day workshop with the stadium authority and selected professional team members was held. This provided the review team with an opportunity to present the first draft report. The first stadium visited provided valuable feedback; however too much time was spend discussing the SBAT rating defeating the objective of the workshop. Following the feedback session, the shades of green decision-making matrix, developed by GbD, was drawn up to assist in allocating resources for the possibilities and opportunities identified.

Following the workshop a SBAT questionnaire was designed to capture missing information. This specifically sought information that was not easily accessible from drawings or reports. The SBAT questionnaire was sent to the stadium authority who forwarded it to the professional team. The SBAT questionnaire was then completed as far as was possible by one or more professional team members. Where information was readily available in a report or other documents not already submitted, this was requested in order to assist the review team and lessen the work load on the professional team.

At the end of this stage, gaps in information were highlighted, particularly with regard to the SBAT, which could not be finalised without the missing data. The report, including the incomplete SBAT appraisal, was sent to the stadium authority.

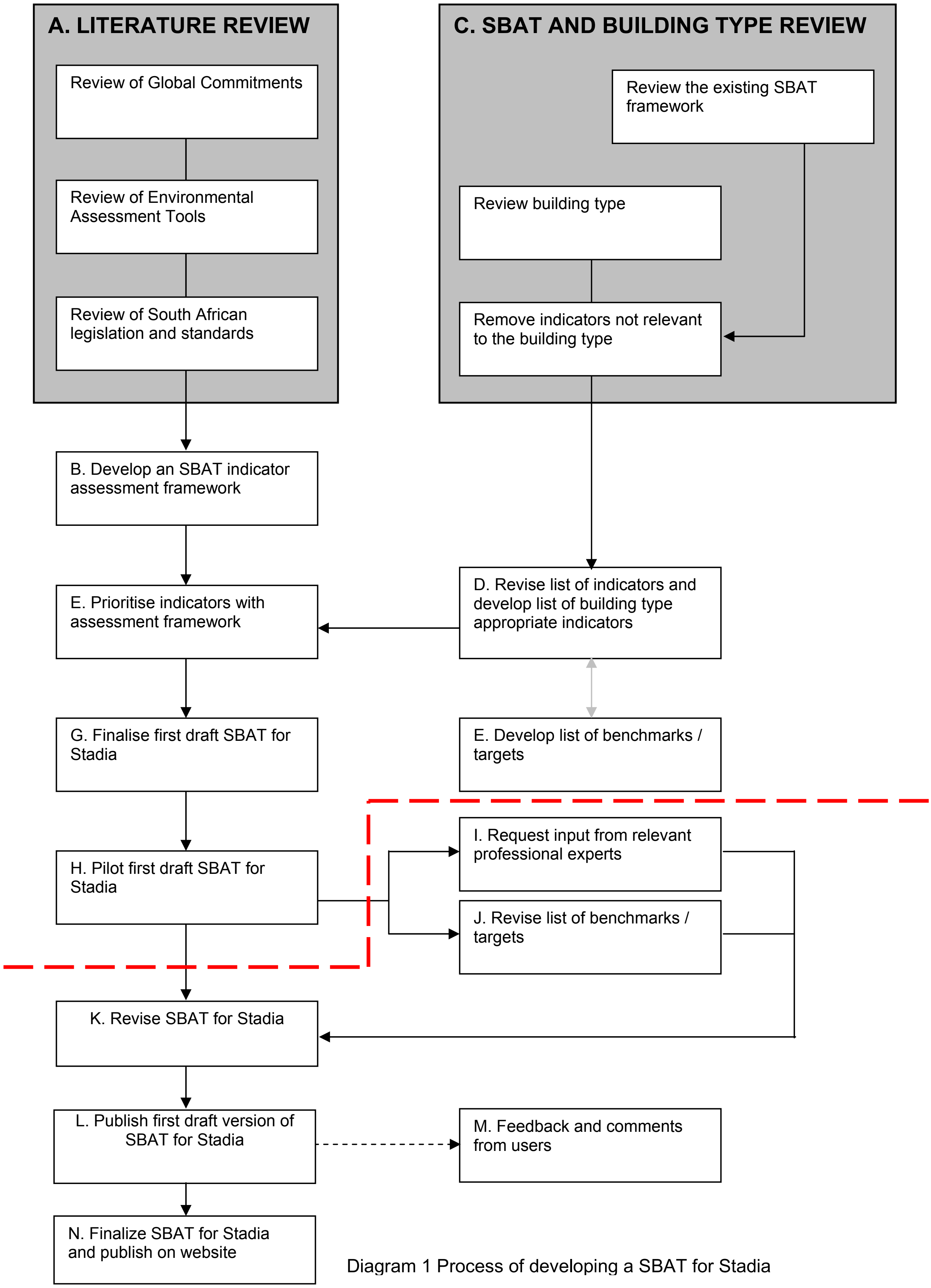

Diagram 1 Process of developing a SBAT for Stadia

4.3.3 Stage 3: The Final Workshop

The objective of the third and final stage is to finalize and present the final report to stadium authority and selected professional team members, and to submit the final report to DEAT. Only one of the two stadia currently under review has reached this stage, however the presentation still needs to take place.

During this stage, a half day workshop with the stadium authority and selected professional team members will be held. This provided the review team with an opportunity to present the final report with incorporating all the comments received from the stadium authority and professional team.

The final report consisted of a completed SBAT appraisal with information used from the SBAT questionnaire sent to the stadium authority. The SBAT diagram (see Figure 1) for the first and currently only stadium to reach this stage was incorporated in the report without the rating figures and final score.

4.4 An Overview of the SBAT Performance

The SBAT report above indicates that the overall sustainability performance of the stadium is good and fairly well balanced across the three different sustainability areas. Relatively poor performing areas include efficiency, water and site rated just under a score of 3 (Average). Areas that appear to perform well include the local economy, adaptability, materials & components, spectator comfort rated well over 3 (Very Good).

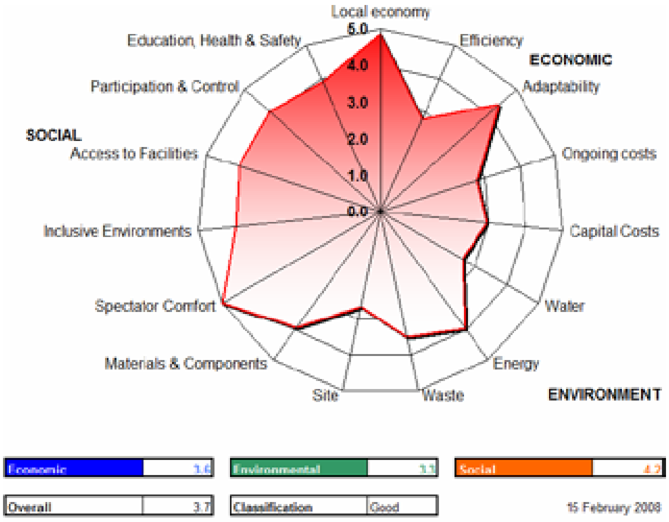

Figure 1 SBAT Radar Diagram Report

The overall rating is “Good” (score between 3.1 and 4) indicates that the approach taken is robust and may lead to a “Very Good” sustainability performance. The balanced performance (ratings vary from 3.6 to 4.2) within the three sustainability areas confirms that there has been an even and effective handling of the performance objectives and that one area (such as environmental issues) has not been allowed to eclipse the others. This balance is likely to have been achieved as a result of the experience of the professional team, the procurement policy and other policies being applied to the project.

5 Discussion

The 6th principle of the Rio Declaration on Environment and Development states that the *“special situation and needs of developing countries…shall be given special priority…”* (UN, No date). This suggests that as a developing country, South Africa needs to ensure that its social and economic issues are addressed before the environmental ones. Although this was aptly highlighted in the bid campaign the planning of the 2010 event has *“...unlike other World Cups … been burdened with near-extreme expectations about what it can in fact achieve with regard to social and … regional economic integration”* (Ndaba, 2007).

The review project widened the scope from a purely environmental focus and acknowledged South African local concerns, by assessing the social and economic issues. The use of the SBAT, which has been found to be the most suitable tool for a developing country context (Kaatz, et al, 2002) was therefore appropriate for use for the review project.

6 Conclusions

The development of the SBAT for Stadia has resulted in a set of indicators and targets which have not been previously available. The development of the tool will be useful for the construction of new and major refurbishment and possibly assist with the monitoring of existing stadia.

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UNDERSTANDING THE SOCIO-TECHNICAL SYSTEM AND TRANSITION OF BUILDING STOCK AND SUPPORTING INFRASTRUCTURE TO ACHIEVE SUSTAINABILITY

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Summary

In this paper, we address the changes needed to realize a substantial reduction of carbon dioxide emissions from the non-residential sector. We try to expand our consideration by focusing beyond technological change and looking instead into the socio-technical system, which refers to a system providing a societal function—a shelter for business and services in case of non-residential sector buildings, consisting of not only technologies but also a cluster of other elements, for example, the building industry, standards and regulations, energy utilities and infrastructure, and cultural and local contexts. The questions addressed in this paper are:

(1) Whether or not achieving a low carbon society requires a structural change in the building system (seen as a socio-technical system)? and
(2) If so, what kinds of change must be addressed in the building system to obtain a substantial reduction in carbon dioxide emissions?

In order to answer these questions, we first identified several carbon dioxide management concepts. We then conducted a case study in which we applied these concepts to the non-residential sector of the city of Osaka, Japan, as a case study to estimate the potential reduction in carbon dioxide emissions. The results show that achieving a substantial reduction requires a structural change in the building system. We finally derived some key challenges to identify possible pathways toward achieving a low carbon society.

1. Introduction

The transition of the building stock and infrastructure toward low carbon emissions is an emerging challenge. This is mainly due to the increasing pressure of global warming and the threat of depletion of fossil fuels. The Japanese residential and non-residential building sectors currently accounts for 32% of the national carbon dioxide emissions, and their emissions increased by 37% and 44% from 1990 to 2005, respectively. A clear gap exists between the current increasing trend in carbon dioxide emissions and the reduced emission level required to achieve a low carbon society. While it is true that a large number of “green” buildings have been constructed in Japan, they only occupy a small portion of the total building stock. The increase in the number of green buildings is offset, for example, by an increase in the total floor area of buildings and the level of services provided in buildings.

Recently, an increasing number of studies have been conducted on estimation of potential reduction in carbon dioxide emissions derived from the building sector with a long-term perspective. Previous research implied that a significant reduction of carbon dioxide emission is achievable in the building sector by a strategic implementation of carbon management concepts. Such studies are relevant not only for developing a shared vision of how the sector should function in our society, but also for searching for possible transition pathways that lead to the envisioned future. In such studies, however, little attention has been paid to the difficulties that must be overcome to realize the changes proposed in the study. Some changes might be of an incremental kind, for example, an improvement in the energy efficiency of appliances and an increase in the share of green buildings in the market. Some changes might be of a more radical kind, in tandem with a structural change in the system providing the societal function of housing and shelter for business and services. A system that provides a societal function such as transportation, health care, education, and energy supply is called a “socio-technical system” (Geels, 2005). The building system (i.e., the socio-technical system providing the societal function of housing and shelter for business and services) consists of a cluster of elements including land ownership and land owners, occupants/residents, appliances/equipment, building engineering systems (ventilation, air-conditioning, lighting, etc.), regulations and standard elements of the building industry such as the construction company and/or the maintenance and operation networks. The socio-technical system also includes all local contexts, energy utilities, and urban form and community.

Researchers studying innovations in the socio-technical system have pointed out that although substantial improvements in efficiency may still be possible with innovations of an incremental kind, larger jumps in efficiency will only be possible with radical innovations; these will require changes from, for example, one building system to another (Geels et al., 2004). If the results of this research are true, a transition of the building sector toward a low carbon society might require integral innovations leading to a structural change in the building system. They also pointed out that leading and managing a structural change in socio-technical systems is very difficult because the elements comprising a socio-technical system are interwoven with multiple societal processes and rooted in our societal structure (Rotmans et al., 2003).

The building system might share the nature of socio-technical systems. Indeed, the building system has evolved through more than a hundred years of history, and the elements of the system listed above are mutually interwoven. Any single factor of the system cannot achieve its purpose without using the resources of the others. There are shared explicit (e.g. regulations, standards, codes) and implicit rules (e.g. expectations, common practice) have been developed in the system throughout history. These rules stabilize the system. Sources of structural change tend to be pushed out from the system even though small changes and technological innovations occur in the system due to the rules.

How do we recognize whether an assumed change in a socio-technical system is of an incremental or a radical kind? The former fit the rules existing in the system, generally leading to an improvement in the system as well as strengthening its stability. On the other hand, a radical change means that a structural change occurs, and consequently, the elements of the system and the correlations among them are reconfigured. For example, in the case of the building system, technological advancement in the existing energy consuming appliances/equipment (e.g., heat source machine) can be said to be an incremental improvement. It is unlikely that such a technological improvement results in a structural change in the building system. On the other hand, dissemination of distributed generation technologies (e.g., micro turbines and fuel cells), for example, could possibly lead to a structural change for the following reasons: the electricity utility must adjust its generation capacity and tariff in accordance with a substantial change in the electricity demand. City gas utilities would increase their supply capacity and strengthen their distribution network. Design of heat source systems will therefore be different because utilization of waste heat generated by distributed generators results in energy and expenditure savings. Urban energy flow might vary considerably. Standards and codes would be developed to assure safety and quality of service provided by the system. These are examples of possible changes resulting from the dissemination of new technologies. The elements and correlations among the elements will be reconfigured through the transition process in this case. It is obvious that leading and managing such a structural change is difficult.

In this context, two questions arise:

(1) Does achieving a low carbon society require a structural change in the building sector?

(2) If so, what kinds of changes must be addressed in the building system to spearhead a substantial reduction in carbon dioxide emissions?

Japanese society tends to pursue a development model of a somewhat incremental kind that relies on developing individual technologies and pursuing partial improvement in the elements of a system. Thus, it is important to make sure that such an incremental development will really assure the sustainability of our building sector. The aim of this paper is to answer these questions as a preliminary study on the transition pathways of the Japanese residential and non-residential building sectors.

In this paper, we first try to understand the elements consisting of the building system (as a socio-technical system) and their connection to energy usage. Based on this understanding, we specify several concepts for managing carbon dioxide emissions applicable to the building system. We qualitatively evaluate if applying these concepts to a large extent must accompany a structural change in the building system. We then develop scenarios combining the carbon dioxide management concepts, and then estimate to what extent carbon dioxide emissions from the building stock of Osaka City in Japan can be reduced until 2050 by introducing the carbon dioxide management concepts addressed previously. We obtain the answer to question (1) based on the results of the case study. We also derive some key challenges as an answer to question (2).

2. Understanding the building system using spatial hierarchy

In this section, we identify key elements of the building system that provide the societal function of shelter for business and services, in order to specify the options available for managing carbon dioxide emissions. For classification purposes, we use a spatial hierarchy consisting of the nation/region, city, district/neighborhood, building and appliances/equipment. We then analyze the correlations that exist between the elements identified in each layer of the spatial hierarchy and energy usage in buildings. Finally, we qualitatively evaluate whether the implementation of each of the carbon dioxide management concepts identified in a particular layer of the spatial hierarchy is likely to accompany a structural change in the building system.

2.1 Spatial hierarchy and carbon dioxide management concepts

Figure 1 lists the elements involved in each layer of the hierarchy. We identified physical properties that represent the links between the elements listed for each layer and energy usage in non-residential sector buildings. Based upon the understanding of the structure, we identified the following five carbon dioxide management concepts applicable to each layer of the spatial hierarchy:

(1) Improvement in the efficiency of energy-consuming appliances/equipment

(2) Dissemination of energy-saving measures for buildings, such as improvement in the insulation performance of a building's envelope
(3) Local energy planning, i.e., optimization of the local energy generation and distribution systems, including the development of district heating and cooling systems, and the adoption of renewable technologies at a local level
(4) Management of land usage and urban form (Jaccard et al., 1997)
(5) Improvement in the carbon dioxide emission factor of the electricity grid by improving the generation efficiencies of power plants, switching fuel, adopting carbon dioxide sequestration and storage, and increasing the share of nuclear power and renewable energy sources.

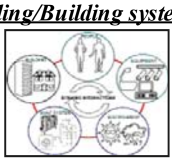
Spatial layer	Elements	Physical property	CO_2 management concept	Key actor
National/Regional 	Population, economic activity National and Regional Planning Utility (Electricity, City gas)	National/regional building stock Population CO_2 emission factor of the grid electricity	Improvement in the CO_2 emission factor of the electricity grid	National government, Energy utility
City 	Urban planning, Urban form, Land use	Distribution of building stock	Management of land use and urban form	Local authority
District/Neighborhood 	Local context (history, land ownership, area), Community-scale energy generation & distribution system (e.g., DHC)	Density, function (usage), gross floor area, distribution of size and configuration, total number of buildings	Optimization of the local energy generation & distribution	Local community Developer
Building/Building system 	Building structure, principal usage, insulation performance, building systems (air-conditioning, ventilation, lighting, etc.)	Number of energy saving measures adopted in buildings Share of heat source systems	Dissemination of energy saving measures	Building owner Building industry National/local government Residents/occupants
Appliance/Equipment 	Lighting, OA, pump, fan, heat source machine Alternative technologies (e.g. LED)	Energy efficiency	Improvement of energy efficiency (stepwise improvement, technological substitution)	Manufacturers National government Users

Figure 1 Elements comprising the building system and classification of carbon management concepts.

2.2 Linkages of the elements involved in each spatial layer with the energy usage in buildings

2.2.1 Appliances and equipment

Technological advancement in energy-consuming appliances and equipment that is currently used in buildings might directly contribute to reducing energy demand and carbon dioxide emission. The key players in this layer are the manufacturers of appliances/equipment. In Japan, manufacturing companies tend to deliver the most energy efficient products to the market, because energy efficiency is one of the most important buying factors for customers. National standards (e.g., energy efficiency standards) have been implemented to influence the pace and direction of technological advancement.

In this study, we survey information on lighting and heat source machines as examples of key technologies. Table 1 lists the energy efficiency of these appliances/equipment, extrapolated to the year 2050 based on a number of roadmaps and technical reports on the technologies, in addition to discussions with experts in this field. The column titled "Baseline" in the table lists the efficiencies of these appliances/equipment, which is assumed to be the average level of the stock. We will estimate potential reductions in carbon dioxide emission from the non-residential sector of the city of Osaka in Section 3 using the values listed in Table 1.

2.2.2 Building and building system

Buildings are constructed to serve a particular function or purpose. Building engineering systems (e.g., ventilation, air-conditioning, and lighting systems) are designed and operated to maintain an appropriate

Table 1 Efficiency arising from lighting and heat source machines.

Technologies		Baseline	Year 2050	Note
Lighting	Technology	Fluorescent	LED	
	Luminous efficiency	70 [lm/W]	150 [lm/W]	
Absorption chiller [high heat value]	Cooling COP*	1.00	1.65	
Compression chiller	Cooling COP	4.5	8.0	Inverter technology will be introduced to improve part-load operation
Air-source heat pump	Cooling COP	2.9	5.0	
	Heating COP	3.1	5.4	
Room air-conditioner for commercial buildings	Cooling COP	2.6	4.0	
	Heating COP	3.1	5.0	

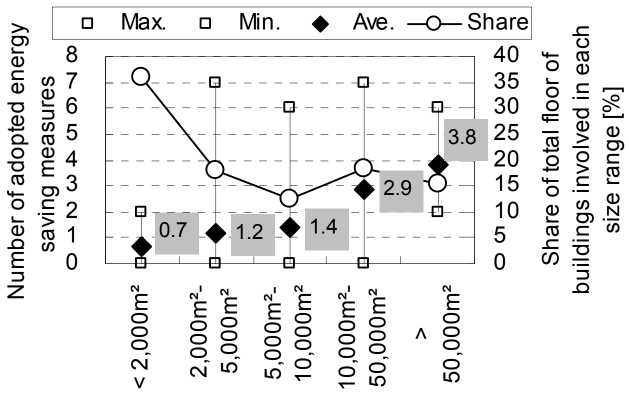
* COP (Coefficient of performance)

indoor environment and to fulfill a particular function. The key players in this layer are building owners and the building industry (e.g., construction and maintenance companies).

We identified a number of energy saving technologies adopted in buildings and the share of heat source systems as physical properties representing the link between elements involved in this layer and energy usage in buildings. We performed statistical analysis on these data and found that there is a trend indicating that larger buildings with more energy-intensive usage (e.g., hospitals) are equipped with a larger number of energy saving measures. Figure 2 shows the average number of energy saving measures in office buildings. For the analysis, we classified the building stock by size. As shown in the figure, larger buildings are equipped with a larger number of energy saving measures. A similar trend can be found in other principal usages—larger buildings with more energy intensive usage have higher energy efficiency. However, small buildings, which account for a large portion of the total building stock in Japan, have been equipped with only a small number of energy saving measures (see Figure 2).

Building regulations and standard (e.g., the Law Concerning the Rational Use of Energy, Japan) has been gradually enforced due to growing pressure for climate protection and higher energy prices. Subsidy programs and different policy initiatives have also been promoted to enhance new business and practices that promote energy saving, such as those of Energy Service Company (ESCO). However, the progress in the energy efficiency of buildings has so far been very slow.

Integrating a large number of energy saving measures makes building design, construction process, and maintenance activity more complex. One needs to fully take into account the local conditions of a specific site. Dissemination of energy saving measures means that conventional norms practiced daily will be no longer be applicable. Thus, although full dissemination of energy saving measures seems to be an extension of the currently slow progress, it also requires a structural change in the building system itself.



The bars show the maximum & minimum number observed in the sample. The number shows the average number of adopted measures.

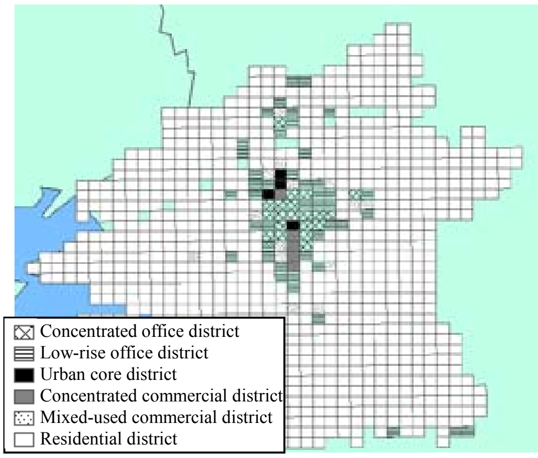


Figure 2 Average number of adopted energy saving measures. *Figure 3 Result of classification of grid cells.*

2.2.3 Neighborhood to district

The carbon dioxide emission management concept in this layer consists of local energy generation and distribution planning. In particular, we focus on the development of energy generation and distribution systems that fit local conditions. District heating and cooling systems in a district with high building density may be considered as examples. Another example is to promote renewable technologies in districts with low building density. There is no question that a radical change is necessary to introduce a energy generation and distribution systems appropriate every local conditions.

Regarding this layer, we would like to focus more on the correlations between energy usage in buildings and the elements of this layer, the local context, and the urban form. These correlations are often ignored in technological studies. However, these elements have a significant influence on energy usage, even in the building sector. This is because these elements predetermine size and configuration, as well as principal usage of buildings located in a given district or neighborhood[1]. A district or neighborhood has a certain function that is defined in the city plan or which has been established through history. This global function determines the amount of building stock accumulated in a district/neighborhood and the function of the individual buildings in the district. The accumulated building stock is realized in a specific local context, with its own history and within its piece of land. These local contexts, in addition to zoning codes and standards, will significantly influence the form and configuration of buildings. This, in turn, means that similar buildings are likely to be duplicated in a district or a neighborhood over the course of time because the local context and urban from do not vary much over a span of a few years.

This implies that a district/neighborhood has certain characteristic in energy demands. In order to quantitatively analyze the influence of local context and urban form on energy usage in buildings, we performed a simulation study. We first developed a grid cell dataset using 500 × 500-m grid cells for the elements that represent the properties of this layer, as listed in Figure 1. The grid cells were classified into six district categories, as shown in Figure 3. We then selected a representative district for each district category. All buildings in the representative districts were surveyed to perform an energy demand simulation. The district-level energy system simulation model developed in this research was applied to the representative districts in order to quantify the energy demand per unit floor area (Yamaguchi, 2007a). The space heating and cooling, hot water, and electricity demand profiles for each building were simulated on an hourly basis. The total end-use energy consumption in buildings was then simulated taking into account the specific configuration of the energy generation and distribution systems. The end-use energy consumption per unit floor area was then quantified by dividing the total end-use energy consumption of all the buildings by the total floor area. Figure 4 shows the procedure of the simulation.

Step 1
Clustering of districts (500 × 500-m grid cells) into several district categories according to the characteristics of building stock (resulting in 6 district categories)

Step 2
Selecting representative districts each representing a district category and developing a database on buildings in the district to perform energy demand simulation

Step 3
Performing district-level simulations to quantify energy consumption per unit floor area in each representative district (the result of this step are used in section 2.2.2)

Step 4
Aggregating the total end-use energy consumption by using the representative end-use energy consumption determined in Step 3 for each *district category* (the result of this step are used in section 3)

Figure 4 Procedure for quantifying the end-use energy consumption

Table 2 shows values of the parameters indicating the characteristics of each district category. Table 2 also shows the energy demand characteristics (measured as a proportion of the total end use of electricity and city gas of the consumption and peak demand for electricity), and the carbon dioxide emission per unit floor area of non-residential sector buildings. The values in the table encompass the influence of the distribution of size, configuration and usage of buildings, predetermined by the local context and urban from, as well as the reality in adoption of energy saving measures and heat source systems explained in 2.2.2. The table shows that each district category has different characteristics with regard to energy usage and carbon dioxide emission. This result clearly shows that local context and urban from have a strong influence on the energy usage in non-residential sector buildings.

Table 2 Characteristics of district categories and energy demand profile.

District category	Gross floor area	% in total floor area	Principal usage		% of buildings with total floor area		
			Office	Others (retail hotel, etc.)	< 5000 m^2	<10000 m^2	> 10000 m^2
Concentrated office	210%	19%	83%	17%	26%	15%	59%
Low-rise office	56%	14%	64%	29%	51%	16%	34%
Urban core	345%	14%	31%	69%	11%	5%	84%
Concentrated commercial			20%	79%	34%	6%	59%
Mixed-used commercial	146%	10%	58%	38%	38%	13%	49%
Residential	16%	43%	52%	31%	91%	9%	0%

District category	Share in secondary energy		Indicator	
	Electricity	City gas	CO_2 [kg-CO_2/m^2•y]	Peak electricity demand [W/m]
Concentrated office	71%	29%	62.2	60.3
Low-rise office	69%	31%	69.4	65.6
Urban core	61%	39%	83.8	61.9
Concentrated commercial	64%	36%	84.1	58.6
Mixed-used commercial	69%	31%	72.8	63.8
Residential	77%	23%	67.8	85.2

[1] Size, configuration, and principal usage mainly determine the characteristics of energy usage in the following manner:
- Size and configuration (shape, zoning adopted) of buildings, which affect the thermodynamic characteristics of buildings and efficiencies of heat distribution systems
- Usage of spaces in buildings, which determines the scale and pattern of heat gains and electricity loads from spaces and operation hours of HVAC systems
- Adopted energy saving measures and heat source systems, which generally depend on the size and usage of buildings, as mentioned above

2.2.4 City

The carbon management concept identified in this layer refers to the management of urban form. The physical property representing this layer is the distribution of building stock. Management of urban from is very important as we have already shown in Table 2. Jaccard et al. (1997) suggest a group of policy instruments as community energy management (CEM) to promote management of the urban form and adjustment of the local context. However, management of urban form is not easy to achieve because it means the demise of the structure explained in 2.2.3. It should be noted that opportunities must be created to implement management of urban form when a change in the social environment occurs, such as a change in demand for business and services potentially due to a decreasing and aging population. It is also important to adjust the spatial distribution of building stock so that carbon emissions derived from buildings are minimized on integration of all the carbon management concepts.

2.2.5 Other elements

It should be noted that the carbon intensity of the electricity grid and occupant behavior/lifestyle are important factors that might have a strong influence on energy usage in the building sector. This study does not adequately take these factors into account.

3. Potential reduction in carbon dioxide emissions by implementing carbon management concepts

In this section, we present a case study that investigates the technological potential for reduction in carbon dioxide emissions from the non-residential sector of Osaka City, Japan, which has a total floor area of 54 million m^2 in the non-residential sector. It annually emits approximately four million tons of carbon dioxide. In this study, we consider the year 2000 as the starting point and 2050 as the projected end point.

Five scenarios were designed to meet each management concept, as shown in Table 3. We qualitatively evaluated whether changes assumed in these scenarios require a structural change in the building system based on the analysis presented in Section 2.

Table 3 Description of CO_2 abatement scenarios.

Scenario	Management Concept	Description	Incremental or radical?
Scenario 1	Advancement in technology	Table 2 shows the efficiencies of the technologies considered for baseline estimation and those extrapolated for the year 2050. We assumed a 40% decrease in electricity consumption of office equipment in addition to the change listed in Table 2.	Incremental
Scenario 2	Dissemination of energy-saving measures	Energy saving measures available at the building level are fully incorporated into buildings. The available energy-saving measures are assumed to consist of improvements in insulation performance, advanced lighting control, outdoor air intake, and variable speed control in heat distribution systems.	Radical (being an extension of the current trajectory of incremental change)
Scenario 3	Optimization of heat source systems	The configuration of heat source systems in the buildings is replaced by new systems that minimize CO_2 emissions using available heat source machines. We assume the introduction of district heating and cooling systems in districts with a gross floor area of more than 100%. For districts with a gross floor area less than 100%, we assume that optimization leads to heat source systems being replaced with those using heat pumps (air-source heat pumps and room air-conditioner for the non-residential buildings listed in Table 2) operated using electricity.	Radical
Scenario 4	Management of the form of urban building stock	Implementation of spatial management methods, such as growth control and restrictive zoning codes, to manage the form of the building stock at the neighborhood level, such that the building stock will be accumulated in a form with a lower CO_2 emission per unit floor area. It was assumed that a scheme to replace small buildings with large buildings will be applied throughout the city. It was also assumed that district heating and cooling systems will be developed in districts with a relatively high density.	Radical
Scenario 5	Improvement in the CO_2 emission factor of the electricity grid	The CO_2 emission factor of the electricity grid is currently 238.4 kg-CO_2/MWh in Osaka City. For Scenarios 1 to 4, we have assumed it remains at the same level until 2050. In this scenario, it is assumed that the value is improved by 20% to 190.7 kg-CO_2/MWh. This would be realized by changing fuels, adopting CO_2 sequestration, and increasing the contribution of nuclear power generation and renewable energy sources.	-

3.1 Simulation model

In order to quantitatively evaluate the measures considered in this study, we developed a simulation model. Most of this procedure has already been presented in 2.2.3 (see Figure 5). The feature of this model is to deal with a district as a unit. We classified districts into several district categories. The clustering of districts aims to indicate connections between the spatial building stock pattern and a strategy to manage energy usage and carbon dioxide emission in the districts. We then selected a representative district for each district category and performed simulations to quantify the end energy consumption per unit floor area for each representative district. We finally quantified the total end-use energy consumption and carbon dioxide emission from the non-residential sector in Osaka City by multiplying the total floor area of the building stock in the districts by the end-use energy consumption per unit floor area; this was calculated for each representative district. We call this modeling approach "district clustering modeling approach"; a detailed explanation of this modeling method is given elsewhere (Yamaguchi et al., 2007b). The bottom-up structure of the model allows it to seamlessly take into account the performance of energy-consuming appliances/equipment, building systems, and local energy generation and distribution systems.

3.2 Results

Figure 5 shows the estimated potential reduction in carbon dioxide emissions. This was calculated based on the baseline emission (3650 thousand ton-CO_2/year), and a detailed decomposition of each scenario's carbon dioxide reduction. Scenario 1 assumes only the reduction in carbon dioxide emission due to the advancement of the technologies listed in Table 1. If the carbon dioxide emission factor of the electricity grid remains at the current level of 238.4 kg-CO_2/MWh for the city of Osaka until the year 2050, technological advancements in lighting, office equipment, and heat source machines alone would reduce the carbon dioxide emissions by 18%. Scenario 2 assumes that the energy saving measures at the available building level were fully incorporated into the buildings. A complete dissemination of the energy saving measures would contribute to a further reduction in the carbon dioxide emission of 19%.

Scenario 3 assumes that each building will replace their heat source systems with those that minimize carbon dioxide emissions using the available heat source technologies listed in Table 1. We also considered development of district heating and cooling systems in the minimization process for districts with a gross floor area of more than 100%. The replacement of heat source systems by those using compression chillers and heat pumps driven by electricity and the development of district heating and cooling systems in densely constructed districts would account for approximately 12% of the carbon dioxide emission reduction.

Scenario 4 assumes the implementation of spatial management methods, such as growth control and restrictive zoning codes, to manage spatial building stock patterns in such a way that the building stocks are accumulated in an urban form with lower carbon dioxide emission per unit floor area. Based on the simulation results of Scenario 3, changes in the urban from were designed as shown in Table 1. Management of the urban form examined in Scenario 4 would contribute to an increase in the carbon dioxide emission reduction potential by 6%. The increase in the carbon dioxide emission potential of Scenario 4 compared to Scenario 3 is relatively modest. However, this does not mean that management of urban form will be less effective in the reduction of carbon dioxide emissions. It is difficult to realize the situation assumed in Scenarios 2 and 3, in which all buildings, including small ones, would fully install available energy saving measures and highly efficient heat source systems. Management of urban form would contribute considerably to reducing the carbon dioxide emissions by assisting in the transition of the urban energy systems toward those assumed in Scenarios 2 and 3.

Scenario 5 assumes improvement in the carbon dioxide emission factor of the electricity grid by 20%, which would lead to a further reduction in carbon dioxide emissions by 8%.

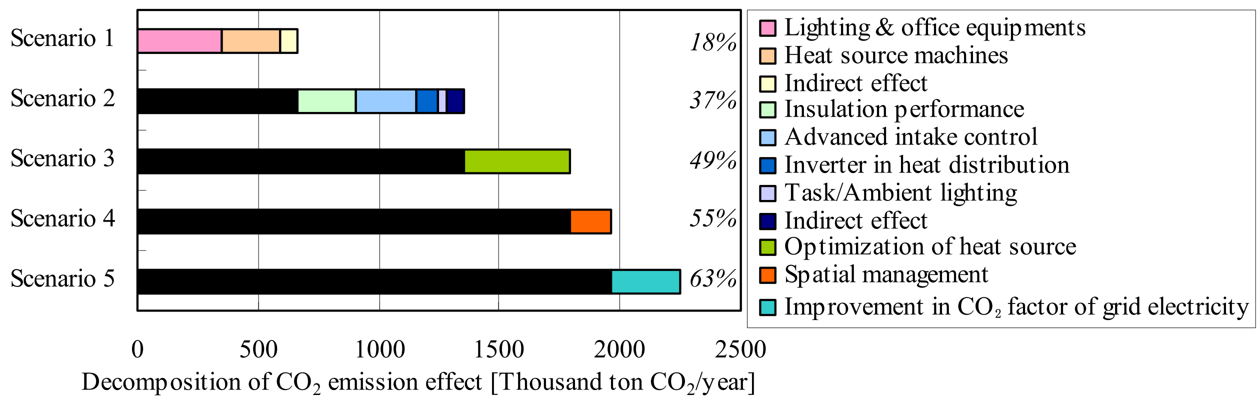


Figure 5 Carbon dioxide emission reduction under carbon dioxide abatement scenarios and its decomposition

4. Implications

(1) Does achieving a low carbon society require a structural change in the building sector?

Any single carbon dioxide management concept cannot achieve a substantial reduction in carbon dioxide emissions. This result implies that achieving a substantial reduction in carbon dioxide emission in the non-residential sector requires a structural change in the building system and providing the societal function of shelter for business and services.

(2) What kinds of change must be addressed in the building system to lead to a substantial reduction in carbon dioxide emissions?

Advancement in technologies and complete dissemination of energy saving measures into buildings are necessary challenges that should be addressed when considering a long-term scenario for the non-residential sector. Here, we only considered common technological options currently in practice, meaning that we assumed the changes were only an extension of the current practice. In order to lead to a substantial reduction in carbon dioxide emissions, more radical changes might be incorporated, for example, incorporation of a "zero emission" concept in the building design.

Implementation of the other carbon dioxide management concepts will require more radical changes in the building system. The implementation of local energy generation and distribution planning and management for the urban form are also relevant and should be addressed in the long-term scenario; this implementation is comparable to that due to an improvement in the carbon intensity of the electricity grid. Further reduction in carbon dioxide emission could be attained in several ways, although these pathways require a structural change in the building system. One possibility is the use of highly efficient, distributed generation technologies (e.g., solid oxide fuel cells) and renewable sources. An important challenge is to establish synergy among the actions in each layer of the spatial hierarchy. For example, management of urban form should be applied to maximize the benefit of implementing local energy generation and distribution planning.

5. Conclusion

This paper presented preliminary results on the transition of the Japanese non-residential sector toward a low carbon society. The questions addressed in this paper are as follows:
(1) Does achieving a low carbon society require a structural change in the building sector?
(2) If so, what kinds of change must be addressed in the building system to lead to a substantial reduction in carbon dioxide emissions?

In order to answer these questions, we identified several carbon dioxide management concepts based on our analysis of the elements that are relevant to energy usage in buildings. We tried to understand these elements and their correlations as a socio-technical system that provides the societal function of shelter for business and services. We then conducted a case study in which we quantified the potential reduction in carbon dioxide emission of the non-residential sector of Osaka City, Japan, due to the strategic implementation of the carbon dioxide management concepts identified above. The results of this case study showed that achieving a low carbon society requires radical changes that do not fit to the current dominant practice in the building system (e.g. complete dissemination of energy saving measures, appropriate implementation of local energy generation and distribution planning and management of urban form). In other words, the transition requires larger, more integral innovations in the socio-technical system consisting of a cluster of elements, including land ownership and land owners, occupants/residents, appliances/equipment, building systems (systems for ventilation, air-conditioning, lighting, etc.), buildings, regulations and standards, the building industry (e.g., construction companies and maintenance and operation networks), local infrastructure and energy utilities (electricity, gas, etc.), as well as urban form and local community.

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THE BURBS ARE ALRIGHT

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Summary

Connected. Viable. Livable. Sustainability is flowing into the mainstream. As part of this cultural awakening the suburbs will be reinvented on a massive scale. Their potential to model the triple bottom line at community scale has already begun to be realized.

In the late 19th century electricity held potential for global change. But it was the distribution of power and subsequent opportunities for connecting innumerable inventions that transformed this newly harnessed energy source into a cultural necessity. From the internal combustion engine to Model T, binary code to laptop, and radio wave to PDA innovation integrated through infrastructure continues to transform the mainstream.

Sustainable technologies will be introduced through innovative infrastructure to transform the viability and livability of the suburbs. This process will also realize the potential for giving back to the earth and reducing greenhouse gas emissions.

Over forty million homes make up suburbs in North America alone. Their design, delivery and servicing has remained unchanged for over fifty years. Buildings are designed independent of their sites and connected to centralized municipal services. Infrastructure replacement backlogs are escalating, funding is diminishing and warming weather trends are dramatically increasing the amount of storm related damage. Suburbs represent a huge liability environmentally, socially and economically.

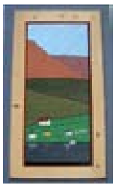
Five strategies are evolving to address these challenges:

- Integrated design process: consensus-based mixed use communities
- Conservation – greenbelt boundaries, retrofit rather than replace
- Reintegrating building + site systems: garden roofs, intensified native plantings, shading, absorptive pavements, high performance envelopes
- Renewable energy technologies combined with conventional building systems
- Decentralizing intelligent site servicing: plug-in energy + waste systems

Smart communities will replace centralized aging infrastructure with on-site modularized components managed with offsite wireless intelligence. The suburbs represent a huge opportunity for introducing these strategies to address climate change.

1. The Burbs Are Alright

Tofino, Vancouver Island. Western tip of Canada, in sight of Meares Island in Clayoquot Sound, a UNESCO World Heritage Site where two thousand year old red cedars stand and the Nuu-chah-nulth First Nation originated ten millennia ago. This is the home of Laura. She runs eco-tours along the northern Pacific Rim where fishing once flourished. People and dwellings are rooted in these irreplaceable islands.



Woody Point. Newfoundland. East across the continent to Gros Morne National Park, a World Heritage Site where the ochre rock of the earth's mantle towers above the landscape. Enduring proof of tectonic plate theory. Home of Charlie Payne, folk musician, artist and builder. His family fished the Grand Banks here for 300 years. But the cod are gone. Charlie now recycles buildings. His gallery is a former fishing gear shed moved inland to display local art celebrating the spirit of this place along with the traditional island jigs and reels he performs and records.

Laura and Charlie are worlds apart in the Canadian hinterlands. Yet they share the passion and urgency of experiencing parts of the planet that are fragile and unique. The sense of place in their communities endures through the connections they have crafted with the environment.

Cobourg. A town of 20,000 midway between these two worlds on the north shore of Ontario, one of the Great Lakes, the largest reserve of fresh water on the continent. Settlement is just over two hundred years old. Suburbia has sprawled beyond the historic core of the community in just over fifty. This is where the rest of Canada lives, in housing detached from the natural and historic sense of the place.

To the north is the Oak Ridges Moraine, a vast, rolling glacial deposit. Now protected as the primary source of fresh water for hundreds of inland communities, it serves as a natural boundary to suburban sprawl. Here in Northumberland County indigenous tall grass prairie is slowly being reintroduced and thousands of acres of forest have been reestablished after being stripped a century ago for the British fleet. Some old growth hemlock and pine have endured for over 350 years.

Community facilities in suburban Cobourg and similar towns are now being designed to connect with such local natural features and to optimize energy use and environmental performance. As learning centres, they are also serving as mentors for suburban dwellers and inspiring green transformations in local backyards. Sustainability is beginning to transform the Burbs.

The Suburbs include more than forty million homes in North America, over five million in Canada (1, 2). Design, delivery and servicing has remained unchanged for over fifty years. Generic buildings are installed and connected to centralized aging municipal infrastructure. Repair backlogs are escalating and funding diminishing. In Canada, average house sizes have doubled to 1900 square feet in the past 30 years (3). Development densities are in the order of six detached dwellings per acre (4).

From the first subdivisions of 750 square foot dwellings built to accommodate families following the Second World War, the Burbs have been informed by the automobile. In recent years the most frequent car trips have reduced to less than 2 miles and the numbers of vehicles per household have grown as younger generations stay longer at home. Home improvements account for nearly $40 billion CAD annually in local business (5). Yet energy conservation improvements have been a low priority in consumer spending. Air quality is diminishing, energy consumption continues to rise and neighbourhoods lack a sense of place. The Burbs must be connected to the environment on several levels to be engaged in efforts to address climate change.

The auto industry is being transformed by efforts such as Google's Automotive X PRIZE competition (6). It is engaging innovative minds in the development and delivery to market of a sustainable car at scale. The winning vehicle is required to attain 100 mpg, meet existing safety standards, and be deliverable through mass-production. Technologies now also exist to enable Burb houses to be made net energy producers, and properties redesigned to lighten their burden on municipal infrastructure and the environment.

Viable solutions for car and house are now shifting from unique, inspiring showcases to workable, reliable applications integrating locally serviceable, affordable technologies. Ford advanced the Model-T in this way by designing a flex-fuel engine that would allow farmers to produce and use their own ethanol (7).

Education, awareness and engagement are necessary for mainstream uptake of this shift. In the case of the Burbs, resident buy-in is essential. However, the suburbs have been disconnected from sustainable settlement principles and benefits since inception. Like the car in the driveway it is the model with which three generations have become increasingly comfortable. However, as Canadian folk singer Bruce Cockburn laments, "The trouble with normal is it always gets worse" (8).

What are beginning to take shape are a series of events engaging the Burb resident as part of local solutions that are making their communities more viable, livable and connected. The following strategies are emerging.

- Consensus and Mentor Buildings
- Conservation, Boundaries and Opportunities
- House and Park
- House as Platform
- House as Portal
- Both/And…Balanced Solutions

1.1 Consensus and the Mentor Buildings

Residents give sense of place to their communities through their recreation, work, purchases and votes. Yet while the urbanite and hinterland resident have generally been more engaged with the environment, those in the Burbs less so. A generation ago urban activists championed resource conservation, alternative energy initiatives and air quality restoration in light of industrial disasters laying waste to their back yards. Three Mile Island, a flaming Lake Erie and the Sydney Tar Ponds come to mind. With kindred urgency, those in the hinterland have rallied to prevent similar disasters such as the clear cutting of old growth forest at Meares Island. The suburban experience, buffered from these realities has helped to preserve the viability and profitability of these same industries. This consumer cohort with lawn, car and home has stoked the economy at the expense of the environment. However, a consensus on the need for action on climate change that also engages the Burbs appears to be building. Recent regional events in Ontario appear to have assisted in advancing this phenomenon.

The Ice Storm of 1998 destroyed thousands of trees and left hundreds of communities without heat and power, in some cases for weeks. Neighbours volunteered firewood, generators, food and water. Ad hoc disaster relief centres were set up. Municipalities were overwhelmed and advised residents to be prepared to wait for assistance for up to 72 hours. The need for local emergency preparedness plans became immediately apparent. Residents woke up to the need to be more self-reliant in their own back yards.

The Walkerton Water Crisis in 2000 resulted in several deaths as a result of inadequately treated water from the municipal system being distributed to local residents. Confidence in municipal infrastructure and provincial safety standards was shaken. Government inquiries and the overhauling of Ontario drinking water regulations followed.

In 2003 a massive power failure shut down distribution grids across the north eastern US and Canada. Summer cooling demands had exceeded infrastructure capacity. Again, hundreds of communities were without power for several days. A pending Ontario initiative to deregulate power supply was cancelled. It was now apparent to elected officials that aging infrastructure was increasingly becoming a liability. Residents were more frequently being put at risk and costs for repairs and ongoing insurance coverage were escalating. Officials became determined to renew confidence in their constituencies as places to live and invest.

Communities are now focusing infrastructure renewal projects on ways to increase the energy and environmental performance of their aging centralized plants. In the order of 40% of the operating costs shouldered by communities in Ontario is directly related to maintaining water and sewage treatment and distribution systems. Residential resource conservation programs are also being introduced. Low flow plumbing fixture installations, compact fluorescent lighting retrofits, waste and recycling programs are examples.

One of the most visible emerging strategies is Mentor Buildings. These sustainable design learning centres are situated in high profile locations in communities. Open to the public they provide hands-on education about green building and site technologies that can be introduced into residents' homes and back yards.

The Northumberland County headquarters completed in Cobourg in 2007 was designed to administer community programs and also serve as a post-disaster response command centre. The facility and site have been made sustainable through an integrated design process. This approach built on the consensus-based cross-departmental decision making culture that characterizes the County organization, a contrast to the more traditional "silo" approach to public administration.

The headquarters demonstrates the role public buildings can play in communities as mentors in sustainable design. Site features include local vernacular dry stone walls, native drought-resistant plantings and a planted south canopy. Sustainable technologies also include a geo-thermal system designed to use off-peak electrical power. It will also accommodate adjacent County facilities as their HVAC systems come due for replacement. The 40,000 square feet building is set into a hill so that the lower level is able to benefit from the moderating effect of the surrounding earth. The advanced envelope is designed to assist in reducing energy demand by an estimated 30% compared to the Canadian Model National Energy Code for Buildings. This results in a reduction of annual energy costs in the order of $15,000 AUD.

Millwork, wall and floor finishing include light colours to maximize light diffusion. Council chamber millwork also combines four local wood species – ash, cedar, birch and maple – acknowledgement of the reverence the local Ojibway First Nation has traditionally placed in these woods and their abundance along Lake Ontario's north shore. Today, this tradition continues with the Eastern Ontario Model Forest administering one of the largest tracts of sustainably managed forest on public and private lands in North America.

The above measures were conceived, developed and combined through an integrated design process to provide a community facility that is serving to educate and empower local residents to introduce similar measures into their homes.

They demonstrate the "soft path" approach to sustainable design pioneered by Amory Lovins – combining the efficient use of resources with renewable energy technologies (9). The initial public open house was attended by 300 residents.

The design for the Lake Simcoe Region Conservation Authority administration centre in Newmarket, Ontario completed by TSH in 2006 is the result of a similar process and performs a parallel function in the community. As a regulating agency reviewing new development applications, it was essential to the Conservation Authority that the design demonstrate their commitment to sustainable design, showing that they "walk the talk".

In 2008, TSH will complete for the Ganaraska Region Conservation Authority a new Forest Education Centre north of Cobourg on the Oak Ridges Moraine. It will build on the theme of the forest as classroom. Storm and grey water recycling, solar pv, in-floor radiant heating and planted roof technologies will be exposed for learning. In-line water and electrical meter read-outs will be positioned for visiting groups to measure conservation efforts through eco-challenges while in residence. The facility will be a sustainability classroom.

As with the Northumberland County Headquarters, each of the above projects is designed to engage, inspire, educate and motivate individuals and communities alike to action. Through consensus-built design solutions they are demonstrating viable, affordable commitments to the soft path, the route to healthy, financially sound resource efficient projects. With several local public models of investment in green technologies in their back yard as learning centres, residents are beginning to have the local means and confidence to integrate aspects of sustainable design into their homes.

1.2 Conservation, Boundaries and Opportunities

Perhaps the most successful Canadian example of linking sustainable community leadership with suburban development is Okotoks, Alberta (10). Here municipal leaders faced a dilemma with a local population boom on the horizon and the natural resources extraction and processing industries in full swing: unlimited growth and economic wealth or a more balanced, sustainable triple bottom line future. Consensus was reached on the latter and today Okotoks is growing based on the carrying capacity of the river running through it which is the sole source for potable water and sewage treatment. Current population is 18,000 and the sustainable growth cap has been set at 30,000. The community will be built out within twenty years.

Okotoks is unique in Canada geographically. It benefits from one of the highest solar intensities in the country. Working with the federal government the suburban development of Drakes Landing proposed within the community the design of homes heated, cooled and powered by solar thermal/photo-voltaic systems. Homes are fitted with collection equipment and a central energy sink stores and redistributes energy. The initial development sold out and subsequent phases are in progress. Managed growth based on the carrying capacity of local resources has resulted in a community being able to give back to the environment through the application of soft path principles. Home owners have already experienced healthy returns on investment. As a win-win for nature and human settlement, Okotoks is an excellent example of both/and thinking as a community realizes the benefits of the environment and economics working together.

North of Cobourg, Ontario the Oak Ridges Moraine is a similarly unique phenomenon formed at the end of the last ice age. Extending across the province this winding deposit of granular material serves as the purifier and repository for fresh water for hundreds of inland communities.

The province has enacted a Green Belt to conserve the moraine and provide a boundary to urban growth which is expected to double to six million people in the next twenty years. This regional conservation initiative is underpinning local efforts to introduce sustainable design initiatives.

(11- photo credit - H2OMES)

As an example, TSH alternative energy expert Michael Hubicki conceived and constructed *Unter den Birken* a model for sustainable residential design north of Cobourg (11). The project is recipient of provincial and federal awards for leadership in energy and environmental performance. The house features a two level configuration settled into a natural slope to take advantage of the moderating effect of the earth's temperature. A radiant in-floor heating system is fed by a solar thermal collector and biomass boiler. A tracking solar photo-voltaic array is coupled with a wind turbine, inverter and battery bank to provide electricity. Generated power is sold to the provincial energy utility to help offset the investment in alternative energy technologies. Electrical and water consumption readouts are located prominently in the house to keep resource use top-of-mind. The project champions *soft path* thinking, the inspired link between resource conservation and renewable energy technologies.

(12 – photo credit – Sentinel Power Systems)

Under the H2OMES program, *Unter den Birken* also serves as a green learning centre visited by individuals, community and school groups interested adopting aspects of the project in their homes and facilities. Most recently it served as a springboard for East Northumberland Secondary School students to put forward a proposal to erect a wind turbine and use the power to energize computers at the school in Brighton, Ontario. Working with Sentinel Power (12) the students are raising the funds for the project in partnership with local community groups.

TSH continues to evolve the concepts of *Unter den Birken* into larger community projects. These include the Lake Simcoe Region Conservation Authority administration centre, the Northumberland County headquarters and the Ganaraska Region Conservation Authority forest education centre profiled above.

As these projects come on stream each provide another learning centre, a portal, a wellspring for actual experience with sustainable design applications. Innovative technology solutions for buildings and sites are now working and available in the community backyard. Residents are motivated by the leadership such projects are providing and are gaining confidence that such working models have affordable applications for their homes.

1.3 House and Park

As with the solar intensity in Okotoks and the fresh water reserves of the Oak Ridges Moraine suburban developments hold their own latent environmental resources and infrastructure that can serve to transform consumer based realms into sources of production and renewal for energy and climate restoration. These transformations are beginning to occur as the result of growing awareness among suburban residents of the opportunities they have with their lands and buildings to address climate change by going green. 2007 has already been cast as the year sustainability went mainstream.

In the Next Sustainability Wave, Bob Willard notes one to five percent of corporations are estimated to now be pursuing sustainable products and services (13). This percentage continues to trend upward and is anticipated to reach a secured, committed market demographic within the next five years.

The same shift is apparent elsewhere at the corporate level. Katrina, Iraq and Enron have broadsided the mainstream consciousness. Corporate sustainability reporting is now becoming de rigueur as a means to enhance the credibility of companies with respect to their communities (shareholders and workers), ecological footprint and economics (profitability in the short term, and increasingly, goodwill in the long term).

For those in the Burbs, the $40 billion CAD spent annually on home improvement now includes a full range of green options. Home Depot now offers their eco-products line including alternative energy technology solutions in partnership with BP Solar. Lowes features LEED Gold stores to show they walk the talk. Walmart is investing millions to increase energy efficiency, integrate planted roofs and increase daylighting because market research has determined that greener stores yield substantially higher sales per square foot. Competitors are following suit. The green consumer has emerged as a market force. The Burbs have been engaged through their purchasing power to address climate change. They also have an increased awareness of local sustainable solutions with community mentor buildings and the efforts of pioneering neighbours.

For the Burbs the reforestation of sites is paramount. This applies equally to property owners and municipalities which own and maintain lands. Each have the opportunity to introduce massive amounts of carbon absorption with tree foliage. The canopy created in ten years or less also provides a moderating effect for buildings, outdoor recreational areas and planting to reduce water consumption. At the 43rd north parallel the solar angles are such that positioning of a mixture of deciduous and coniferous species – both of which are native to the region – allow for solar gain into buildings in cooler seasons and shading opportunities when the sun is higher. The use of coniferous trees on north elevations as wind breaks also assists with reduction in heat loss due to the protection afforded from prevailing winter winds. The benefits vary with the existing positions of buildings on sites. However, the amount of property typically provided around houses allows for planting solutions that can be adjusted to maximize benefits for several orientations.

Planting material is regional and drought resistant. In several jurisdictions the use of potable water for irrigation of Burb properties is now banned. For others watering schedules and quantities are being gradually reduced. Where grasses are used, slow growth mixtures are recommended to reduce the amount of lawn cutting. In several US jurisdictions site planting without traditional lawns are required in order to minimize mechanical maintenance and conserve water.

For planting strategies and species the municipality can play a key role by including the resources in site plan reviews. Performance criteria for water consumption, carbon absorption, growth rates and cross-pollination opportunities can also be listed so that alternatives meeting the criteria can be submitted for review. In this way innovation in planting is ensured while guidelines for front yards can afford a degree of consistency along streets and boulevards. Municipal property also affords the opportunity to lead with robust, long-term mixed tree planting. The results of such investment are compelling. Premier neighbourhoods in Toronto including the Kingsway and Leaside are prime examples demonstrating the benefits of extensive boulevard tree planting for nearly a century.

Perimeters of Burb properties also provide opportunities to introduce hedge rows. In addition to providing habitat for birds and small mammals, the planted perimeter provides for areas to reintroduce composted material.

Water conservation measures include management of stormwater and recycling of potable water. Building strategies include introduction of water meters with remote readouts in prominent locations in each residence to increase awareness of consumption. Fixtures are low consumption type and water reused through grey water recycling systems. On-site treatment of grey water is also available seasonally in Ontario using multi-tiered vegetated filtration systems. Year-round use requires the incorporation of such systems as water and plant features in solariums.

Stormwater management on site is accomplished with infiltration galleries, deposits of clear stone placed below the frost line – 4 to 5 feet below grade in Ontario – to which surface drains can be used to return stormwater to ground sources. The water can alternately be directed to cisterns for combination with grey water recycling systems, for use in on-site irrigation and for evaporative cooling systems. For homes with level or low slope roofs extensive (light-weight) vegetated systems are also available to incorporate to absorb precipitation and enable it to be reintroduced into the atmosphere. Light-weight approaches are appropriate particularly for retrofits where opportunities to increase the structural capacity of loadbearing systems are limited. It is primarily the added load of stored moisture that needs to be factored in when considering the overlayering of planted systems on existing roofs.

Surfaces on properties for vehicles also represent opportunities for increasing environmental productivity. The use of pervious pavement systems using recycled concrete, granulars and reinforced turf are being implemented. Conventional asphalt material can now be taken up and distributed to civil project involving road resurfacing. Pervious asphalt pavements are also being developed to increase local absorption of stormwater. Of course, municipalities need to also introduce new dimensional criteria when retrofitting aged roads, With general reductions in vehicle sizes and increased movement toward enhancing the walkability of communities, street widths are being reduced where not needed for collector or arterial functions. Again, reduced impervious area adds greater opportunity for local return of stormwater to the ground water source.

As stormwater is increasingly retained and reused on site the burden on municipal pipes lightens. This prompts the opportunity for Town works groups to consider introducing infiltration galleries in public boulevards. Such localized stormwater management solutions, in concert with aggressive tree planting hold the potential to radically reduce the amount of run-off from the parks that suburban developments are being transformed to become.

1.4 House as Platform

With the house reconnected in the renewed park environment the buildings also represent opportunities to be evolved beyond shelter to become platforms for generating energy. Following the examples of green community mentor buildings, the Burb property and house become an energy garden. Home owners can choose to store energy in on-site back-up systems, be independent suppliers of energy to the power distribution grid or participate in new partnership models to garner the collective benefits of delivering the energy they generate from renewable sources on site. Okotoks is an excellent pioneering model for this last opportunity.

As houses are increasingly improved through conservation measures the need of energy at home for heating and cooling is reduced. The revenue opportunity for the home owner grows as available energy output from each site grows.

Whether it be wind generator, solar photo-voltaic collector and inverter, battery bank or other emerging technology the opportunity to "plug-in" alternate energy technologies to the grid via the house will grow. And with local community examples available residents will have the confidence to participate in such initiatives and harvest new sources of income from their properties.

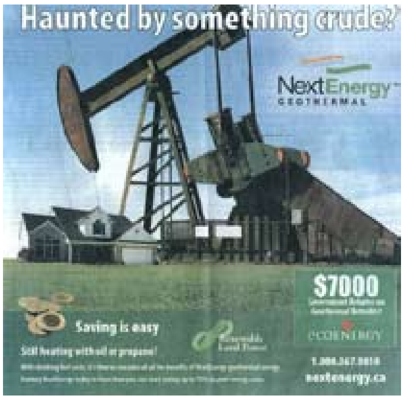
1.5 House as Portal

Community leadership involves renewing streets, boulevards, pipes in the ground, power lines and maintenance processes with innovative solutions that reduce the burden on traditionally centralized infrastructure plants. Municipalities already expend in the order of 40% of their annual energy budget on operating water and sewage processing facilities. Cost increases are expected to accelerate with rising energy prices and the added costs of carbon taxes on conventional power generating systems upstream.

To address these trends, municipalities are increasing their awareness of their carbon output as a result of providing infrastructure and services to their constituents. In Cobourg, the GHG emissions of municipal facilities and services are now being measured to establish a baseline model upon which can be developed alternate models for operation and service delivery. In co-ordination with this type of effort the provincial electrical generating utility Ontario Power Generation (OPG) is providing net metering for residents. The intelligence of this system enables the utility to alter the rates at which residents are billed throughout the day to be able to manage demand more effectively with variable rates to assist in tempering energy use peaks. The province is also actively promoting a culture of conservation to assist residents with practical ways to even out energy consumption. Introducing compact fluorescent lights and arranging energy audits are examples.

At the Northumberland County building an ice storage facility is planned to use off-peak (overnight) power to charge a cooling sink that will then provide interior cooling over the following day when power rates and demands are at their peak. The overall energy demand has been tempered, the costs to the County and constituents have been lowered and the use of the on-site geo-thermal system has significantly reduced GHG output. The building energy systems are also designed to provide real-time data on systems operations and performance. This enables facility status to be continually monitored and adjusted to optimize performance. In the four months since opening the facility data has already confirmed the building to be primarily providing heat by harvesting and recycling of energy from occupants, equipment and lighting. As the cooling season approaches, systems adjustments will again be made and monitored. The data can be made available as part of the mentoring role to increase the understanding of how such systems perform.

(14 – photo credit – Next Energy Geothermal)



In the Burbs, residents will be able to interact with utilities in similar ways. For example, an on-site geo-thermal system for a 1,900 square foot home will require in the order of three 100' deep vertical wells or an equivalent linear footage of horizontal piping on the property to provide heating and cooling. Add to the system an ice storage battery and cooling is economically available using the same power purchasing strategy as the County. The technologies are proven and available off-the-shelf. Regional organizations such as the Canadian Geo-Exchange provide installer knowledge through workshops. On-site training is increasing monthly to meet the rapidly increasing demand for this alternate approach to providing energy at home. As residents in more mature Burbs begin to experience increased maintenance with traditional fossil fueled heating and cooling appliances that are reaching the ends of their useful life cycles, such alternate approaches with working local examples will become increasingly affordable.

As energy demand from homes decreases municipalities will be able to adjust long-term forecasts for centralized infrastructure upgrades and expansions.

The geo-thermal solution is an excellent example of integrating local natural resources on the house property to create a micro-system that services heating and cooling on site. And it is just a start. Consider for example the integration of a solar photo-voltaic system. The property and house now become a portal for outgoing power to the community. Combined with a well insulated, sealed envelope and heat recovery ventilation system the house demands can be reduced to downsize the geo-thermal / solar thermal or biomass system. Using the heat energy of occupants, IT equipment and appliances as the primary heating source for the dwelling the house now converts to a multi-functioning power plant and shelter.

The economics of these residential solutions are compelling. Alternate energy approaches are emerging to make subdivisions more sustainable and marketable. Marshall Homes in Oshawa west of Cobourg, and Rodeo Homes in Newmarket are examples. After securing their own energy demands residents may soon alos have the opportunity to partner to contribute the latent heat energy in the ground or solar exposure on their property for a negotiated, renewable rate of return. The subdivision becomes an energy garden that contributes to the local community or regional power distribution grid in much the same way as a district energy system or wind farm. Equipment can by owned and maintained by residents or by the alternate energy utility in the same way as conventional gas fired hot water heaters are provided and serviced in Ontario.

This arrangement is not unlike increasingly intelligent wireless infrastructure for voice / data systems being introduced by developers as subdivisions are opened up. Strategically located servers within developments provide secure two-way communication access throughout the community. The house is evolved to set-top box or PDA interfacing with centralized utilities to convey energy and data about environmental performance. The Burbs become connected on a new level to the community in the movement to local interconnected micro-energy solutions.

This decentralization of infrastructure is also evident in emerging technologies addressing on-site sanitary systems. In lieu of effluent being piped through increasingly aged pipes to centralized processing plants, local solutions are available and being considered for residential developments. Containerized peat cassettes are used to accept effluent and process it on site. When the peat mixture has reached uptake capacity the cassette is replaced and the peat distributed to farms for fertilizer. Such applications are being pioneered in rural locations in Ontario.

1.6 Both/And … Balanced Solutions

To engage the Burbs, both/and solutions are required and are emerging. Economics is becoming increasingly balanced with environmental priorities. Products are also becoming value-added through their environmental benefits. For example, consider the replacement of a conventional natural gas fired hot water storage tank with an instantaneous heater. Energy is used to heat water only when needed, space is gained with a smaller heating appliance, costs for heating are reduced and greenhouse gases are also reduced by using less energy. Taking this example a step further and integrating it with a solar collector and electronic inverter to power the heater effectively eliminates GHG emissions through the integration of a renewable alternative energy source. Canada currently offers funding for assessing baseline energy use and also provides assistance for incorporating the solar photo voltaic system. Green auditors are also emerging providing comprehensive door-to-door assessments of waste, water energy and transportation performance and recommendations for improvements with paybacks. For a family of four this can amount to monthly savings in the order of $500 AUD.

To continue the mentoring role of community buildings and municipalities TSH is also developing the greenscreen tool. This web-based software will provide a multi-disciplinary overview of the issues that are encountered with buildings and developments at the project initiation stage. The tool allows projects to be assessed and a baseline scenario generated and adjusted to determine measures that will move the project toward a more sustainable solution.

Also in the early stages of development is the greenleaps program. This networking tool is intended to link municipalities so that mentor building project information can be shared. This would include links to real-time date streams from operating facilities. The intent here is to link each municipal participant with both a community that is more advanced and another which is in the early stages of development. In effect, the links provide means for participants to leap forward with more readily available sources for technologies and built solutions by learning through direct partnerships with those having the applied experience.

The rural Ontario homestead summarizes well the re-emerging concept of house integrated with renewed working parkland. Masonry structure and envelope served to provide a moderated interior environment. A central fireplace warmed the building mass in a radiant heating system application. Surrounding trees were planted for shade and as wind breaks. Gardens were tended to produce food and receive composted material. Drives and parking areas were gravel to allow for natural percolation of surface water. Inside the dwelling, a cellar cistern collected rainwater captured from the roof. Piping arrangements in the house included for hot, cold and non-potable water to each fixture. A root cellar and larder were incorporated to store dry goods and preserves over winter.

Several of these features were carried to town dwellings and properties as migration to urban environments grew through the early part of the twentieth century. In addition to the comforts and practicalities of the residence the walkability of the town also afforded a close-knit community where shops, schools, churches, arenas and factories were a few minutes stroll away.

Today, in the Burbs a similar level of comfort and security has been achieved. Yet the detachment of buildings from lands and developments from the rest of communities are for wanting. Opportunities to reconnect the Burbs and engage residents in climate change solutions abound. Viable, affordable technologies proven in community mentoring buildings now exist locally to serve as catalysts for moving this transformation toward a more livable, sustainable community.

The pioneering house next door will also inspire residents to reconnect their home experience with the environment and their suburban enclave with the community. And it is being done with investment in emerging technologies and services. New online tools such as tshgreenscreen will assist communities in assessing their level of sustainability and in developing action plans. Greenleaps (Green local environmental action partnerships) is also being developed for municipalities as an online network of local communities and their partners in other countries to take those action plans and enable communities to make quantum leaps forward by learning from the experiences and successes of their partners.

The Burbs represent a huge opportunity to demonstrate the successes to be reaped from Both/And thinking, balancing environmental stewardship with economic prosperity for over 40 million greener backyards.

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BUILDING SUSTAINABILITY OR SUSTAINABLE BUILDINGS?

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Summary

The take up rate of building rating systems such as BREEAM, LEED and Green Star has grown rapidly in recent years. These systems have provided the market place with simple ordinal scales for the relative performance of buildings. At the same time, they have become the de facto definition of sustainable buildings in the market place. This paper argues that we should not become complacent that highly performing buildings under these systems are the pinnacle of sustainable buildings. We need to acknowledge that whether a building is seen as sustainable depends on what issues are considered, how they are considered, and how trade-offs are managed. There are important issues that are not considered under these schemes, and actions that are arguably beneficial from a sustainability viewpoint that are not rewarded. The argument is supported by a comparison of the three systems mentioned, and against other recognised sustainability assessment tools.

1. Introduction

Today, green rating programs are becoming tools for current and future construction where major owners and developers of buildings are using them as a benchmark. There has been a presumption that a highly rated building is a building with lower energy consumption and lower environmental impacts then a non-rated building.

The following paper argues that we should not become complacent that highly performing buildings under these systems are the pinnacle of sustainable buildings. The paper compares LEED, Green Star and BREEAM and illustrates that the concept of a ‘green’ or sustainable building is socially constructed rather than absolute. Given that tools such as these are becoming the de facto green building standards in the industry (as evidenced by their inclusion in planning requirements, government building requirements and tenant requirements) there needs to be an understanding on how the definitions of a green building are developed, ‘what’ and ‘how’ issues are considered and how trade-offs are managed. Although the tools have an ability to differentiate between environmental impacts that affect different buildings, the paper discusses limitations surrounding their use.

The paper is a warning against complacency, rather than a critique of the green rating tools.

2. An overview of the rating tools and their use

2.1 Green Star

Green Star is an Australian benchmarking tool developed by the Green Building Council of Australia. Launched in 2003, Green Star drew from existing rating systems including BREEAM and LEED, but it is tailored to the Australian marketplace and environmental context. Green Star includes tools for office design, office as-built and office interiors. An office asset tool is in pilot study. Planned tools include retail, health, residential and education. The tool uses ten categories: energy, management, water, indoor environmental quality transport, ecology and land use, emissions, materials, innovation. Ratings (stars) have six levels, but only three are eligible for certification. Green Star uses category weighting factors that vary across states/territories to allow for differing environmental concerns and imperatives.

There are currently 70 Green Star certified projects in Australia. In Melbourne the council’s Environmentally Sustainable Office Buildings (ESOB) Policy (Melbourne Planning Scheme Clause 22.19) requires a 4 Star Green Star Certified Rating for office developments with a gross floor area of more than 5,000m^2.

Of the 72 points assessable for environmental impact 57% of them can be assessed as continuing environmental impacts over the life of the building, whilst the remaining 43% comes from one-time impacts from construction.

2.2 LEED

The LEED (Leadership in Energy and Environmental Design) was developed in 2000 by the US Green Building Council (USGBC). Currently, it is used to assess new commercial constructions, major renovations, existing building operations, commercial interiors and core and shell. LEED uses six categories to assess buildings: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation. Each category has specific design goals worth points - some of which are mandatory. The points awarded are totaled to earn projects one of four ratings: certified, silver, gold or platinum.

Currently, over 400 buildings have been LEED rated in the US and more than 3400 buildings are LEED registered (seeking certification). In the US, the tool has become a standard for 'green' design of buildings with many organisations beginning to use LEED as a minimum requirement. For example, the GSA (General Services Administration) responsible for the office space of all US government workers requires all new buildings to be LEED certified (and are 'encouraged' to aim for silver level certification) (Bowen, 2005).

To achieve certification the project team registers with the USGBC, who then requests detailed design documentation and results of energy modeling performed. Certification is then awarded by the USGBC, upon the awarding of at least 26 of the 69 points available. Of the 49 points assessable for environmental impact (excluding the 5 innovation credits which are unique to individual projects, and IEQ credits because their impacts are health related rather then environmental) 69% of them can be assessed as continuing environmental impacts over the life of the building, whilst the remaining 31% comes from one-time impacts from construction (Eijadi *et al.*, 2002).

There are several localised variants of LEED, including LEED Canada, LEED India and LEED Mexico. In addition to this several buildings outside the US have achieved the US LEED certification.

2.3 BREEAM

BREEAM (Building Research Establishment Environmental Assessment Method) was developed in 1990 in the United Kingdom. It is a building environmental assessment method that covers a range of building types including; offices, homes, industrial units, retail units, and schools. Other building types can also be assessed using 'Bespoke' (custom-made) BREEAM.

To assess a buildings performance, BREEAM uses nine categories: management, energy use, health and well-being, pollution, transport, land use, ecology, materials and water. The rating tools will award points for performance against criteria that are added together for an overall score then awarded a "Pass", "Good", "Very Good" or "Excellent" based on its overall building performance. It provides assessment opportunities for pre-design, design completion and occupied buildings.

In the United Kingdom, there are close to 100,000 buildings BREEAM certified and over half a million registered for assessment. The BREEAM assessment process and rating tools are updated and regularly in accordance with UK Building Regulations. Planning authorities are referring to BREEAM and EcoHomes Standards (the homes version) as a way of assessing planning applications. Many organisations, such as English Partnerships, have implemented sustainability standards for all new homes, retail, office, and industrial buildings built on its land (approx. 6,000 hectares), stating a BREEAM rating of 'Very Good' must be achieved (The Merton Rule, 2006)

2.4 SPeAR

SPeAR is an assessment tool developed in 2003 to assist in balancing the many factors that affect a sustainable project.

SPeAR has 4 "core" indicators: economic, environmental, natural resources and societal and is based on the DETR's publication in May 1999 of 'A *Better Quality of Life: A Strategy for sustainable Development for the United Kingdom'*. These core indicators are then broken down into a series of primary indicators.

A set of base sub-indicators, which can be custom made for individual projects, are then rated on a scale of -3 to +3. The tool then averages the score for all sub-indicators to produce an overall performance for that indicator. These results are then displayed on a rose diagram. Undertaking a graphical visualisation rather than a numerical rating clearly illustrates where the project is weak and strong, hence can be used to guide the team on where to focus.

3. What issues do the rating tools consider?

Generally, the rating systems consider a narrow range of categories to measure the green rating of the building, with the exception of the SPeAR tool, which considers a wider range of issues. Generally, the other tools can be broken down into a number of categories as shown in Table 1. This additionally shows a breakdown of the percentage weightings of each of the categories (where applicable, these are raw, unweighted scores). None of these three tools consider social or economic factors as part of their criteria.

Table 1: Percentage of credit points available. Based on Table 9, Fowler & Rauch (2006)

	Technical Content							
	Energy	Land-use and ecology	Water	Materials	Indoor Environment Quality	Operations & Maintenance	Other	Economic and social issues
BREAAM	25%	15%	5%	10%	15%	15%	15%	-
LEED	25%	20%	7%	19%	22%	-	7%	-
Green Star	21%	6%	9%	27%	18%	16%	4%	-

The similarities in the weightings do not necessarily imply that they consider the same range of items under these category headings. For example under Green Star 69% of the available energy credits are given for the buildings CO_2 emissions to be further reduced below a conditional requirement (as measured in kg CO_2/m^2/annum), whilst LEED offers 50% of the energy credits to 'optimise energy performance', which is based on the total energy cost, and make no direct reference to the actual CO2 emission level of the building. In addition LEED and BREEAM make a credit available for using Green Power, whilst in Green Star this is not specifically referenced; rather it would fall under the reduction in the buildings CO2 levels.

The amount of available credits for water usage is similar across the three standard rating tools. The actual awarding of points is different however. LEED, for example, does not award points for water metering while both BREEAM and Green Star do so. One category that LEED considers that neither BREEAM of Green Star considers is the heat island effect.

Much variation can be found in the use of environmentally friendly products, both in the amount of credit points available and in how the points are awarded. Whilst BREEAM will offer only 10% of its total credit points Green Star offers 27% of its points for using environmentally preferable products. This is slightly misleading however, as LEED has a conditional requirement for use of 'refrigerant management', whilst not offering any credits for it. Regardless LEED offers no recognition for the use of low GWP rated products, while both BREEAM and Green Star offer credits for this. LEED is, however, the only rating system of the three to consider the use of locally sourced materials as a sustainable measure. BREEAM is the only rating tool considered that awards credits for a reduction in NO_x emissions.

One measure that is considered by SPeAR, but disregarded by other building rating tools is the diversity and social responsibility aspect. This includes such things as responsible sourcing of skills, use of local personnel/skills, building accessibility, cleaning program, communal space and leisure facilities, distinctive cultural character, building adaptability and flexibility (including IT), sustainability economics and cultural heritage.

The inclusion of these indicates the difference between a sustainable rating tool, and a green-rating tool. LEED, Green Star and BREEAM are not sustainable rating tools. Rather, they are a tool that should be used as part of an overall sustainability strategy. However, due to the lack of a standard integrated approach they appear to have been adopted as a measure of sustainability.

The innovation credits available present further issues, depending on the rating tool used. Whilst Green Star's innovation credits require significant effort (an initiative or technology that is a 'first' in Australia or the world for example), the LEED innovation credit is much easier to achieve. In previous projects it as been awarded for such tasks measures as having an acoustic consultant, or performing a condensation analysis. When considering the effort to perform sophisticated energy modeling to achieve energy credits, it may be that LEED is too lenient in awarding innovation credits.

4. How are issues considered?

There is a large variation in the methods and models used by the different rating tools. Here we present the methodologies behind the energy credit. This shows that the variation is such that a building that is considered to have excellent energy performance as measured by one tool, may not necessarily be considered so excellent by the other two, due to the underlying methodologies used.

4.1 Energy

Energy credits in LEED are based on energy cost consumption based on the standard given in ASHRAE 90.1 – 2004. Initially the Energy Cost Budget (ECB) is calculated according to ASHRAE 90.1, and is the product of the baseline kilowatt-hour usage for the year and the energy cost ($/kWh) summed with the gas usage for the year, multiplied by the gas cost ($/MJ). The Design Energy Cost (DEC) is then calculated by multiplying the proposed energy and gas usage for the year, by the energy cost. The Energy savings percentage is then calculated via

$$\text{Energy Savings Percentage} = 100 \times \frac{ECB - DEC''}{ECB} \tag{1}$$

Where;

DEC'' = DEC – Renewable Energy Contribution.

This can misrepresent the actual environmental impact of buildings due to variations in energy cost. Scheuer and Keoleian (2002) presented an analysis of a real-life building, assumed to have a 75-year life span. Their results, reproduced in Table 2, show that, for an increase in the electricity cost, in order to achieve 1 LEED point the corresponding energy savings decreases significantly. Therefore planners are actually rewarded for having higher energy costs. The energy costs can be based on local utility rate schedules, ASHRAE adopted rate schedules or the LEED reference manual; this gives an incentive to use the highest cost out of these options.

Table 2: Energy usage for different electricity prices (Scheuer & Keoleian, 2002).

Electricity Price ($/kWh)	% elec. red. needed for 1 LEED point	Life span GJ energy saved
0.04	21%	215 669
0.07	18%	184 859
0.10	16%	164 319

This can also lead to inequities in the energy savings, as the cost multiplier is different for electricity and gas. For example an 18% reduction is electricity will produce 1 LEED credit, whilst it would take a 46% reduction in the amount of gas to achieve 1 credit. This large reduction in gas would likely produce substantially greater reductions in total primary energy consumption.

In Green Star the energy credit is calculated directly on the carbon dioxide emissions. The electricity consumption (kWh/annum) is multiplied by a greenhouse gas coefficient (kg-CO2/kWh) dependant on location and added to the gas consumption (MJ/annum) multiplied by a second, local, greenhouse coefficient. The greenhouse gas coefficients will depend on the location of the building. For example, the electricity greenhouse gas coefficient is 1.325 kg-CO2/kWh in Melbourne, compared with 0.936 kg-CO2/kWh in Perth, based on the production of electricity in Melbourne primarily occurring through the burning of brown coal. This emission of CO2 is then normalised by the nett lettable area of the office. Up to 20 points are awarded dependant on the percentage above standard the building is. This can directly impact the green rating of the building; the exact same building built in Melbourne and Sydney can actually have completely different rating.

BREEAM awards points for the building demonstrating a percentage improvement above the requirement for CO_2 emissions as set out in the 2006 Building Regulations. The calculations can be performed using a BREEAM approved tool such as the Simplified Building Energy Model (SBEM).

5. How are trade-offs managed?

Once again there is significant variability in how different issues are weighted between tools. In LEED issues are not weighted. This means that each category is simply awarded the number of points to reflect how important the USGBC thinks that credit is worth. This leads to certain inequities. One designer notes that they received 1 point for installing an advanced heat recovery system ($1.3 million), and 1 point for installing a bike rack ($395) (Schendler *et. al.* 2005). A life cycle analysis by Scheuer & Keoleian (2002) showed, however, that there is a large variation in the energy benefits per LEED point of each criteria – for example the energy criteria has a far greater environmental impact than material selection. In addition, this weighting is constant throughout the US – there is no consideration given to the location the tool is applied, despite the differing conditions through the US.

In Green Star a weighting is applied to the raw scores. The weighting factors vary with location – for example due to the scarcity of water in Melbourne it has a higher weighting then for a building in the Northern Territory. The raw score for each category is converted to a percentage. This is then multiplied by the number of weighted points available, to give a weighted score. For example a project may receive 4/13 points available for water usage (31%). In Victoria water is given 15 weighted points, and therefore the project receives 0.31x15 = 4.6 weighted points.

BREEAM operates similar to Green Star in that categories are weighted. They are 'pre-weighted' however, in the sense that the BREEAM manual simply refers to weighted scores to be added, rather then applying the weighting after the raw scores have been calculated.

SPeAR follows a different methodology. *All* sub-indicators are rated on a scale of -3 to 3. These scores are then averaged to produce an overall rating for that indicator. SPeAR, however, is not looking to produce a numerical rating at the end. Rather it simply wants to measure the performance of each indicator individually, to allow designers to focus on areas of the building with poor sustainability.

6 – Other Issues

6.1 Controversies

Proposals to award credit points are often subject to controversy. The pressure of industry lobbying groups, as well as the backing of companies with financially vested interests, has the potential to lead to a subjective assessment of these criteria.

6.1.1 Green Star timber controversy

The following is the current Green Star credit for timber:

"Two points are awarded where 95% (by cost) of all timber products used in the building and construction works have been sourced from any combination of the following:

- Reused Timber
- Post-consumer recycled timber
- Forest Stewardship Council (FSC) Certified Timber"

The FSC is an international organisation promoting the responsible, sustainable management of the world's forests. This credit is currently opposed by lobbyists from the logging industry. The main contention of the logging industry is that the current requirement is too restrictive, and that it should recognise other credible forest certification schemes, as well as changing the level of credits available (1 credit for 60% compliant timber, and 2 for 90%). This is due to the limited supply of FSC timber in Australia.

Due to this lobbying the GBCA has proposed to change the Green Star timber credit to recognise any recognised Forest Certification's Chain of Custody standard, as well as change to 1 credit for 60% compliant timber, and 2 credits for 95%. This has lead to criticism of the GBCA of reacting to the demands of industry lobby groups, and finically vested interests, instead of using independent, expert advice.

6.1.2 LEED PVC controversy

Currently the LEED system offers no credits for a reduction in the use of PVC materials. This differs from the Green Star system where 1, or 2 points are awarded for a 30% or 60% reduction (by cost) in the use of PVC by replacement with alternative materials. During the early course of LEED development a credit was proposed to award the minimisation of PVC. At the suggestion of this, industry groups came to the defence of PVC. The USGBC then referred the matter to their technical committee, which concluded that for environmental impact the evidence is that introducing a credit that rewards the avoidance of PVC could steer designers to use materials that are worse for the environment, except in the case of resilient flooring, where PVC materials were the worst of the materials studied (Altshuler *et al.* 2007).

6.2 "Point mongering"

"Point mongering" refers to when the sole focus of the design team is on gaining credit points regardless of whether it adds environmental value to the building. The driving force behind this is the prestige of obtaining a high level rating making the building or company 'green'. Design teams can become obsessively focused on getting credits regardless of whether they add environmental value.

One installation considered installing a reflective roof. LEED encourages this as a means to offset the "urban heat island" effect. The proposed system was in the Rockies, which, at 8000 feet, is not greatly affected by heat issues. The design team had two options - show it is not relevant, shrinking the pool of available points or take the credit knowing that the environmental savings are negligible. Related to this is the cost of some achieving some credits. In reference to LEED, Eijadi *et. al* (2005) showed that, of the 64 credits (excluding the innovation credits) 34 (53%) could be classified as either standard practice, or having a minor cost. With the focus on achieving a green-rating this could lead to designers focusing on 'easy' credits, rather then considering the actual environmental effect of the design.

Table 3 Breakdown of LEED credits (Eijadi *et al.*, 2005)

Category	LEED Points	Standard Practice	Design Effort: Minor Const. $	Significant const. $
Site	14	5	5	4
Energy	5	0	2	3
Water	17	0	2	15
Environment	15	1	10	4
Materials	13	0	9	4
Innovation	N/A	N/A	N/A	N/A
Totals		9%	44%	47%

There is qualitative data to support these observations. In a study of 35 LEED certified buildings 70% and 63% of the available credits for environment and site were awarded, whilst only 42% of the available energy credits were used, on average (Scheuer & Keolin, 2002).

A similar issue has been observed in Melbourne. There has been a significant rise in the number of buildings that are installing blackwater treatment plants. This is factored in Green Star's potable water calculator, which gives up to 5 points for reducing water below a best practice benchmark. This rise may be attributed in part to the current water shortages in Melbourne; however its efficacy at the city-wide scale is questionable (van Wyk, 2007).

6.3 Variation in energy-related environmental impacts of certified buildings

There has not been much research conducted on the relationship between certification and a building's environmental impact. Today green rating programs are becoming tools for current and future construction where major owners and developers of buildings are using them as a benchmark. For instance, there is a presumption that a certified building is a building with lower energy consumption and lower environmental impacts. However the rating tools were not designed to scientifically assess a buildings environmental impact, but functions as such by default, due to the lack of other standards and tools.

In fact, research indicates a significant overlap in the variability distributions for different LEED certification levels. This proves that being LEED certified may not always mean that energy-related environmental impacts have been significantly reduced. Research was performed using Monte Carlo based computer simulations (Crawford-Brown *et. al.* 2007). These simulations illustrate in many instances that individual buildings certified at different levels of LEED could have the same level of environmental impact. Figure 2 below illustrates this using simple probability distribution functions for the simulated mercury emissions for 1,000 LEED Silver buildings and 1,000 LEED Certified buildings (as an example). The grey area indicates the overlap area between the two certification levels.

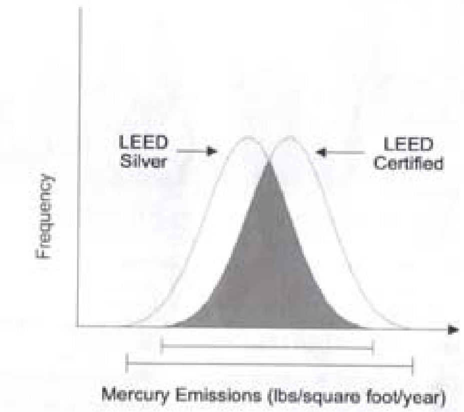

Figure 2 Simulated mercury emissions of Silver buildings compared to Certified buildings.

6.4 Eligible Buildings

The restrictions on what buildings are eligible to be rated are very restricting. For example the Green Star office tool requires that 80% of the GFA must be Class 5 Commercial Office space, and the whole building must be rated, not the part building. This had lead to the case where a multi-purpose retail/residential/office building such as Swinburne place cannot achieve a Green Star rating, when in fact the very nature of an all-encompassing multi-purpose building certainly promotes both environmental and social aspects of sustainability. A similar issue occurred with the Marine & Freshwater Research Institute. Its mixed nature meant that it was ultimately not awarded a Green Star rating. LEED and BREEAM seem to be much more forgiving in this sense; the LEED for New Construction rating can be applied to a much broader range of buildings, whilst BREEAM offers a custom (bespoke) rating tool for buildings that do not fall into one of the available categories. Once again a tool such as SPeAR is far more versatile here – it can be applied to any building or construction through its bespoke nature.

7. Discussion

There is no doubt that green building rating tools have helped to promote the concept of sustainable design. However the variation between the tools is such that the concept of a 'sustainable' building is blurred. As shown for the energy credit, different rating tools can use completely different measures for assessing the environmental impact – from energy cost, to CO_2 emissions, to kWh/year. In addition the software program used to perform the energy modeling can product varying results, as shown by a sample of BESTEST results (Judkoff, 1995; Sturn, 2007)

There seems to be a misunderstanding in the concept of a 'green' building and a 'sustainable' building. There is a fundamental difference between the two. A green building generally only considers environmental issues, whilst a sustainable development considers social and economic factors as well. A building may very well be classified as a green building; but how sustainable is it if the lifespan of the building is only 10 years, or if the materials have been sourced from overseas? Does a new building positively affect the local community, or the constituents of the building? These are all important questions to be considered. A building such as the Salk institute which has wide laboratories across two buildings fosters collaboration between researchers by having no walls between laboratories, and placing chalkboards in appropriate locations for researchers to write notes on. Figure 1 graphically illustrates the difference between a sustainable rating tool, and a green rating tool.

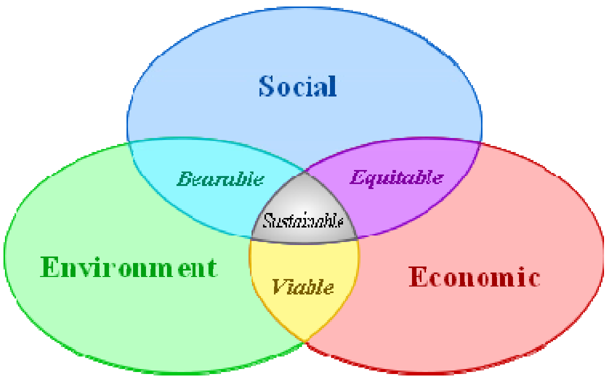

Figure 1 Relationship between green building and sustainable building

Related to this concept of sustainability within buildings is the architecture used. If a building is to be used for a period of over 50 years, it needs to have a certain level of usability, as well as a design that will be relevant over the time period. An example of this is the Melbourne Arup office located at 1 Nicholson St, which was constructed in 1959, and yet is still a functional and relevant building. Whilst it may not be the pinnacle of energy-efficient design, its simple glass cladding, along with appropriate orientation (no windows on the east and west faces) mean that the building is still able to be used as office space now. Another example is the UN building in New York. This was completed in 1950. Its east and west facing walls are covered in thermoplane glass designed to reduce heat absorption. On the otherhand, will newly rated buildings, still be used in 50 years?

The very nature of 'rating' a building promotes a form of 'elitism' with building. Essentially, a building needs a label to be ranked as 'green' when in fact there are many examples of sustainable buildings, which have no green rating at all. The rise of rating tools may lead to these building been received negatively in the public opinion, when in fact they may be highly performing buildings. An example of a highly performing unrated building is the DRW headquarters in Dusseldorf. In New York two buildings have recently been completed – the LEED gold accredited Hearst building, and the unrated New York Times building. Both buildings implement excellent green measures, yet the New York Times building is unrated. This doesn't make it less sustainable, however the popularity of green rating tools, may give that impression in the public eye. Furthermore, there are many examples of green buildings that were constructed many years ago such as the CIBSE/ASHRAE building in New York that have excellent sustainable performance, and yet pre-date rating tools by many years.

The rating tools mentioned all base their ranking of the environmental performance of the building on the basis of a set, fixed criteria. Whilst this is a tool that gives an easy way to rank, and compare building performance, a more accurate method would be to include additional assessment by means of Life Cycle Analysis (LCA). LCA investigates the environmental damages associated with a design across the life cycle of the product; from its harvesting and manufacturing to its destruction, or recycling. Doing this would greatly enhance the effectiveness of measuring the actual environmental performance of a design decision.

8 Conclusion

BREEAM, LEED and Green Star are three of the most widely used building rating tools available. Due to lack of a viable alternative they have become associated as a rating tool for sustainable buildings, when in fact they only consider the environmental impact of buildings, and not the societal and economic benefits. This is in contrast to a tool such as SPeAR. We have discussed the application of BREEAM, LEED and Green Star and showed that, whilst the issues they consider are similar, there is a wide variation, both in the methods used to asses these criteria, and in the weighting given to each criteria. It is argued that there is not a direct relationship between the certification level of the building and its actual environmental impact, and that in fact, the very nature, and popularity, of rating a building brings down other sustainable buildings that do not seek certification

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DESIGNING FOR SUSTAINABILITY OF BUILDING - HONG KONG CONTEXT

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Keywords: Sustainability framework, benchmark, indicators, microclimate, economic sustainability, environmental sustainability, social sustainability, ecological footprint.

Summary

The framework of sustainability for the built environment has been established internationally. Yet, there still exists gap between the high-level principles and its implementation to achieve the design of sustainable community. To close the loop, indicators that describe the degree of sustainability are required. This paper discusses how such indicators can be established for the unique context of Hong Kong under the principles of triple bottom line, and use a case of public housing development to demonstrate the concepts. Key elements of the framework include:

Social sustainability: Connectivity, Amenities, Neighbourhood and context, Culture and community heritage

Economic Sustainability: Character, Flexibility for Change, Re-use of Existing Foundation, Efficient Servicing Strategy

Environment Sustainability: Enhanced Health Environment, Natural Ventilation, Microclimate, Energy Conservation, Enhanced Comfort Environment, Water Saving

The case for study is the Hong Kong Housing Authority's Yau Tong Estate Phase 4 Shopping Centre and its neighbourhood (the Development). The project symbolizes the commitment of the Hong Kong Housing Authority to the environment and the society, and showcases an example of an integrated approach to green building. Numerous sustainable design features, from architectural to system design, are incorporated to support the principles of the Sustainability Framework developed.

1. Introduction

Sustainable development is of fundamental importance world-wide. In Hong Kong, the building industry is becoming the most important development and creates the greatest impact to the environment. A good building environmental design is to protect people and minimise its impact to the environment. From commercial to residential, low-rise to high-rise, public to private buildings, inclusion of environmental consideration into a building design would always bring us a sense of integration of intelligence and consciousness into our environment.

There are three key aspects of the sustainability framework, namely Economic Sustainability, Environmental Sustainability and Social Sustainability (Fig. 1)

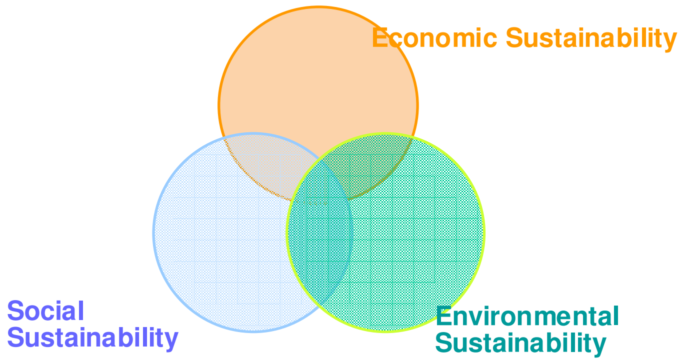


Figure 1 Sustainability Framework.

Economic Sustainability for a building development includes the identification of economic viability of the development, maximizing economic opportunities, and reducing operation and maintenance cost.

Environmental Sustainability focuses on the effective use of natural resources, optimizing energy efficiency of building systems, and reducing environmental impact to the surrounding environment.

Social Sustainability is related to the consideration of enhancing community coherence, social interaction and cultural enrichment of the development and the neighbouring environment.

To illustrate how the indicators can be established for the unique context of Hong Kong, the Redevelopment of Yau Tong Estate Phase 4 is selected as a case study to demonstrate the concepts.

2. Case Study at the Redevelopment of Yau Tong Estate Phase 4

Yau Tong Estate Phase 4 is the last phase of the comprehensive redevelopment of Yau Tong Estate. It is located at the junction of Cha Kwo Ling Road and Ko Chiu Road, directly abutting the southern end of the Mass Transit Railway (MTR) Yau Tong Station with the MTR underground tunnels traversing the site. It lies to the west of the existing Lei Yue Mun Plaza across the Yau Tong estate road.

The Development is a shopping centre with a total gross floor area of 54,300m² (Fig. 2). It is designed to serve the local district with a population of around 80,000 persons at its full occupation. There are also further opportunities to serve the potential future development at Yau Tong Bay, the existing industrial area, tourist attraction at Lei Yue Mun in the vicinity and a larger catchment from beyond through the MTR network. It comprises in essence –

a) A public transport interchange (PTI) on Level 1, including five bus bays, one cross border coach bay and two mini-bus bays;
b) Parking spaces for private vehicles and loading and unloading vehicles on Level 3;
c) A Community Hall on Level 2;
d) Retail space on Level 4 to Level 7;
e) Taxi stands and private car drop-off on Level 4; and
f) Common facilities for Yau Tong Estate on Roof Level, including basketball courts, community farm, children play areas, etc.;

Figure 2 The Redevelopment of Yau Tong Estate Phase 4.

3. Sustainability Design Approach

The design of the Development is to embrace and create synergy for a sustainable community focusing on vibrancy, health and social coherence. The design therefore has been approached with agendas covering economic, environmental and community aspects.

3.1 Economic Sustainability

To maintain competitiveness of the development throughout its life, the design elements introduced to bring retail success and major increase in value are –

3.1.1 Character of a regional type shopping mall

The sloping nature of the site and its proximity to the existing MTR structures results in a relatively high development cost. To improve the revenue generation and achieve economies of scale, the size of the development has been increased from 27,750m² to an optimum size of 54,300m² thereby generating additional gross annual revenue in the scale of US$5.7M and integrating with of the existing Lei Yue Mun Plaza as a regional type shopping centre with a total size of 60,000 m².

3.1.2 Flexibility of change

The layout design should have the capacity and flexibility to cater for changes to cope with ever-changing retail trends. A regular structural grid of 8 metres by 12 metres is applied to optimize flexibility and efficiency in retail planning; located the atrium close to the centre of the development to create shops of optimum depths on all frontages; and, aligned route of arcade primarily along the central atrium and connecting bridges thereby maximizing exposure and commercial attractiveness for all commercial tenants.

3.1.3 Re-use of existing foundation

Foundation works had been completed based on a previously approved layout design. Increase in size of the development of over 60% requires installation of additional foundation. By rationalizing the structural grid to align with the existing foundation as far as practicable and optimizing the use of the spare capacities of existing piles, only less than 20 percent of the building load is required to be supported by the additional foundation. In addition, an existing refuse collection point in the site shall be relocated being an enhancement of the open space design. Taking the opportunity, the remained foundation will be re-used for a new amenity building to serve local residents.

3.2 Environmental Sustainability

In response to the global agenda for environmentally sustainable development, the design embodies impetus towards maximizing environmental comfort, resources conservation and mitigating environmental loading on the neighbourhood. The areas for improvement that have been identified are -

3.2.1 Natural ventilation for PTI and carpark

The Development has been designed to utilize natural resources (e.g. wind) to provide a healthy environment for the users. For instance, natural ventilation will be utilized at the PTI and carpark with reduced length of PTI's enclosure through open foyer design and maximized opening on carpark walls. As a result, associated capital and running costs of the mechanical ventilation system can be reduced.

3.2.2 Enhancement of pedestrian wind microclimate

Furthermore, to receive the onshore wind from the waterfront of Yau Tong Bay in the hottest month, a portion of the existing vacant Shopping Spine structure over the MTR station that borders the public open space at Level 4 will be removed to enhance pedestrian wind microclimate.

3.2.3 Hybrid ventilation for shopping arcade

Energy conservation is another key theme for the design of the Development so as to minimize environmental impact. To reduce the energy consumption for air-conditioning, hybrid ventilation will be utilized at the shopping arcade. This combines the use of mechanical ventilation in extreme seasons (e.g. peak summer) and natural ventilation in mild seasons (i.e. spring and autumn). Motorized openings will be installed at lower level of the atrium for entrainment of cool ambient air. Similarly the same type of openings will be incorporated at the skylights for hot air to exhaust out (Fig. 3).

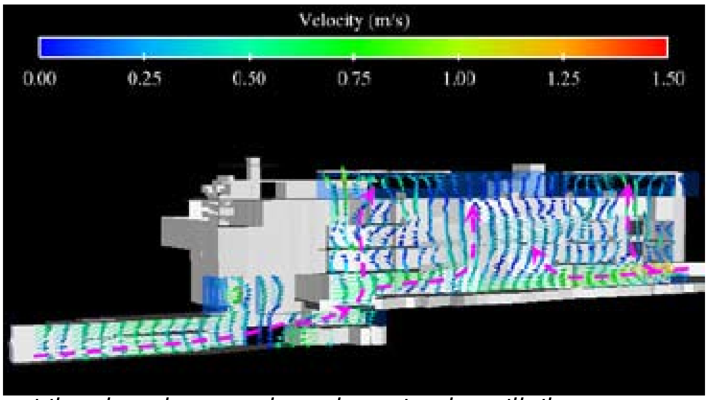


Figure 3 Airflow pattern at the shopping arcade under natural ventilation.

3.2.4 Use of water-cooled air-conditioning system

The design of Yau Tong Estate Phase 4 has also considered the use of more energy-efficient building services systems. Water-cooled air-conditioning system is better than air-cooled air-conditioning system in terms of energy efficiency. In addition, the Electrical and Mechanical Services Department, HKSAR Government (EMSD) is currently promoting the use of water-cooled air-conditioning system in Hong Kong and Yau Tong District is one of the pilot areas. In this connection, water-cooled air-conditioning system is proposed for the Development to enhance energy conservation.

3.2.5 Solar control

Two key features of the atrium of the Development are the large glass wall on the northwestern facade and the skylight over the atrium. Although they allow daylight infiltration to reduce energy consumption for artificial lighting, solar penetration at the same time would increase the cooling load of the building. To strike a balance between solar gain, acceptable daylight level, and offering an open view towards the harbour, several measures are examined to optimize energy efficiency. They include the consideration of high performance glass and vertical fins for the glass wall as well as provision of solar shading device for the skylight.

3.2.6 Green roof

In Hong Kong, the usability of the open space is largely influenced by climatic conditions, in particular the outdoor thermal environment. The outdoor thermal comfort is affected by the site microclimate, such as local wind speed, air temperature, solar radiation and relative humidity etc. To provide a better thermal environment to public, some phenomena, in particular the urban heat island (UHI) effect should be avoided. To reduce heat island effect and to enhance thermal comfort condition, the current design of the development has achieved 35% of the overall greening.

3.2.7 Water conservation – use of reclaimed water

The use of reclaimed water would reduce fresh water consumption and generation of wastewater. Condensate from air-conditioning system has been identified as the major source of reclaimed water which could be used for irrigation purpose. Such condensate will be treated with UV sterilization due to risk of human contact.

3.3 Social Sustainability

Upon completion, this development will emerge as the urban living room of Yau Tong area housing more than 80,000 people. Providing a physical environment, space and urban form that responds to the social and cultural need, enhancing people's access, amenity, comfort and memory map are inherent for a sustainable community.

3.3.1 Connectivity

The project has adopted Universal Design concept to achieve maximum connectivity to draw commuters of divergent sources into the heart of retail and leisure at Yau Tong. This includes a fully glazed elevated spine to connect to the MTR Station; express linkage to PTI through banks of escalators and elevators, footbridges connecting Levels 5 and 6 to the adjoining Lei Yue Mun Plaza for convenience, safety and comfort to residents of Ko Chiu, Lei Yue Mun and Yau Tong Estate in their day-to-day commuting; and a pedestrian precinct on Level 4 from the open plaza, through the main atrium onto Ko Chiu Road (Fig. 4).

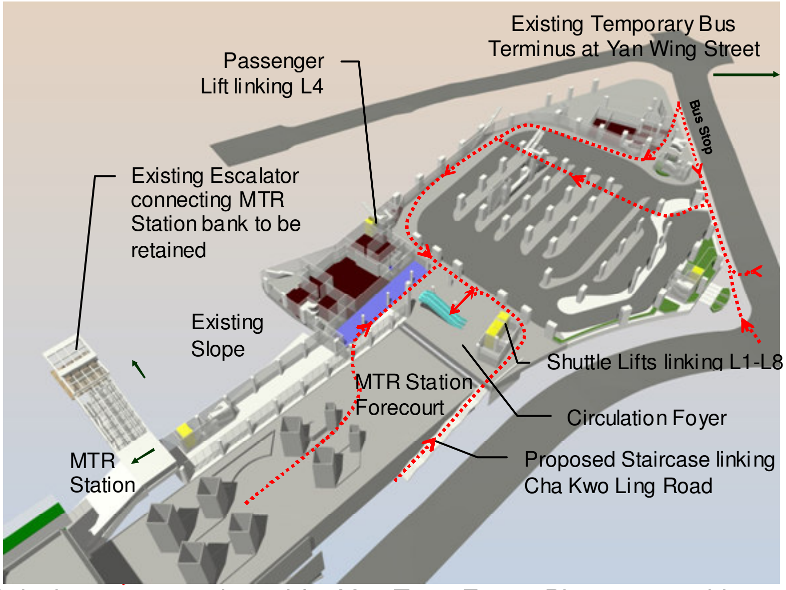


Figure 4 Universal design concept adopted for Yau Tong Estate Phase 4 to achieve maximum connectivity.

3.3.2 Neighbourhood and context

External space at the public domain of Yau Tong Estate is extremely limited. Through a removal of the existing Shopping Spine structure, decking over the existing escalators linking the MTR station and relocating the existing Refuse Collection Point, a sizable civic and community plaza of 3,600 m^2 outside the main entrance of the shopping centre is regenerated, with an amount of greening at approximate 35% of the gross area. To sensitively, interface the building entity with the adjacent built fabric and reduce the physical impact on the residential context, the building mass of the development is set back at the estate road level to create a receiving entrance to the plaza.

3.3.3 Community and cultural heritage

Sense of belonging is the driving force behind sustainable community. Community engagement is involved in the evolution of the plaza design. To unveil the heritage and uniqueness of Lei Yue Mun, imagery of rock cutting industry and artifact of historical importance are translated into dynamic architectural form; decks of al fresco dining were created to take advantage of the tourist attraction at Lei Yue Mun.

4. Indicators of Savings

A comprehensive environmental design study has been carried out for the Redevelopment of Yau Tong Estate Phase 4 by Ove Arup & Partners Hong Kong Limited. Performance assessment on the sustainability design for the development has been conducted. Several indicators on energy conservation and reduction in environmental impact have been identified.

4.1 Enhancing Health Environment

4.1.1 Natural ventilation at PTI

The dispersion behaviour of vehicle exhausts at the PTI has been analyzed under prevailing wind conditions (southeasterly and southwesterly). With mitigated open foyer design, it is illustrated that natural ventilation would be capable of maintaining acceptable air quality for at least 50% of the PTI area according to the requirement of Environmental Protection Department, HKSAR Government (EPD) under windy condition.

4.1.2 Natural ventilation at carpark

The natural ventilation performance of the Carpark has been assessed based on the criteria as required by Australian Standard AS 1668.2-2002. Based on the design calculation, it is found that natural ventilation alone could satisfy the ventilation requirement of 46% of the carpark area. Consequently, the energy consumption by the mechanical ventilation system and thus greenhouse gases emission can be reduced.

4.2 Energy Conservation

4.2.1 Hybrid ventilation

Natural ventilation with motorized openings to be installed at low level of the atrium and at the skylights will be utilized for the shopping arcade in mild seasons (i.e. spring and autumn), when the climatic condition including the ambient temperature and humidity satisfy the design conditions to meet indoor thermal comfort criteria as required by ASHRAE Standard 55-2004 (Fig. 5). The estimated cost saving is approximate US$24 thousand per year.

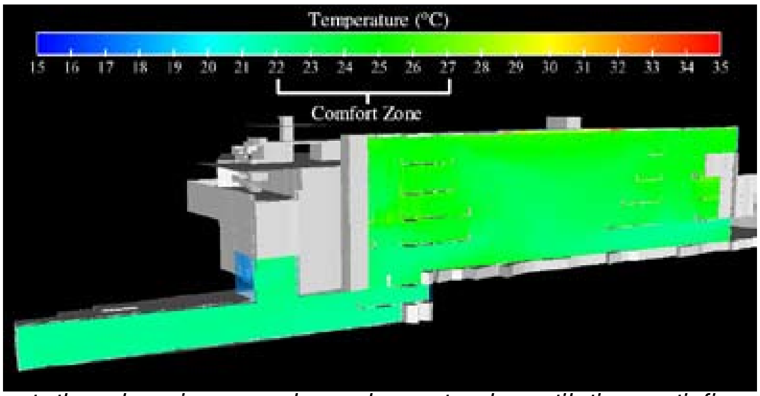


Figure 5 Temperature at the shopping arcade under natural ventilation satisfies the requirement by ASHRAE Standard 55-2004

4.2.2 Water-cooled air-conditioning system

Water-cooled air-conditioning system will be utilized for the Shopping Centre. Such system is better than air-cooled air-conditioning system in terms of energy efficiency. Taking into account the air-conditioning period with the utilization of hybrid ventilation, the estimated annual operation cost saving is about US$ 676,000.

4.2.3 Solar Control

Several solar control measures for the Arcade including vertical fins, high performance glazing for the northwestern curtain wall and solar shading devices for skylight were examined. Table 1 shows the matrix for comparison of solar performance for different fin and glazing options for the northwestern curtain wall. As much as 25% of annual solar heat gain can be reduced if combined measures are used.

External motorized blinds controlled by timer or weather sensors was also proposed to reduce solar load for the Arcade. The blinds, being made of fabric materials, can filter a significant amount (up to 60%) of solar radiation while at the same time allow diffuse daylight infiltration to the Arcade.

Table 1 Comparison of solar performance for different fin and glazing options for the curtain wall.

Annual Solar Heat Gain Reduction at the shopping arcade (compared to single glazed clear glass with no fins)		Fin Option		
		No fins	1m fins at 2.5m interval	1m fins at 1.25m interval
Glazing Option	Single glazed, clear glass	-	10%	21%
	Double glazed, clear glass	9%	12%	22%
	Low-e double glazed	19%	20%	25%

4.3 Enhancing Comfort Environment

Green roof has positive effect on building environment, especially in thermal aspect. Planted roof would reduce the roof surface temperature, thus enhancing both outdoor and indoor thermal comfort. Fig. 6 shows the surface temperatures of a hard roof of a public housing block and a planted slope. It can be observed that the temperature difference could be up to 30℃ (Fig. 6). Green roof would also increase thermal insulation such that thermal loading for the building could be reduced. In general, green roof can reduce the cooling load for the floor underneath by around 15% according to the findings by the National Parks Board (NParks) and Centre for Total Building Performance (CTBP), National University of Singapore (NUS) (2002).

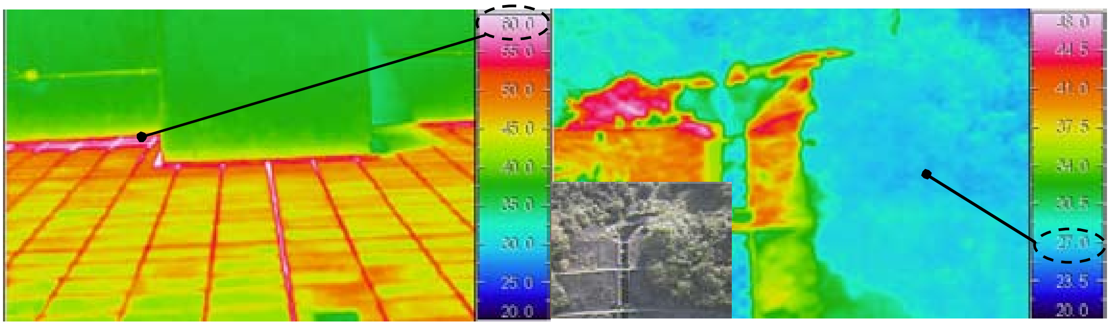


Figure 6 Comparison of temperatures of hard roof and surface covered with plantation

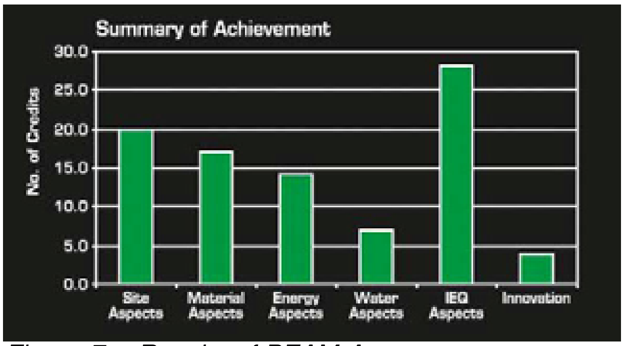
4.4 Water Conservation – Use of Reclaimed Water

Condensate from air-conditioning system will be reclaimed for irrigation purpose for water conservation. The amount of reclaimed A/C condensate would adequately cater for irrigation at Levels 1, 3 and 4, podium roof, as well as the soft landscape on L4 open plaza. Assuming the amount of water required for irrigation to be 2 L/ m² / day, the estimated annual cost saving for fresh water consumption is approximate US$2,400.

5. Performance Assessment – Building Environmental Assessment Method (BEAM)

A preliminary environmental evaluation for the Design and Construction of the Yau Tong Estate Phase 4 was conducted using Building Environmental Assessment Method (BEAM). It is the private sector initiative that gives recognition for enhanced environmental performance in the planning, design and construction of buildings in Hong Kong. The assessment was carried out based on BEAM New Building Developments (Version 4/04) to address the possible sustainability issues throughout the building life.

Results of the assessment show that the Development would achieve the highest Platinum rating under BEAM with anticipated score of 90.4 credits out of a possible 117.2 credits available, ie 77% of the available credits (Fig. 7). The design of the development is recognized by BEAM for best environmental practices in 6 key aspects: Site, Material, Energy, Water, Indoor Environmental Quality (IEQ) and Innovation. They encompass the important features of green roof, thermal comfort, recycling of reclaimed water and community engagement in this development.



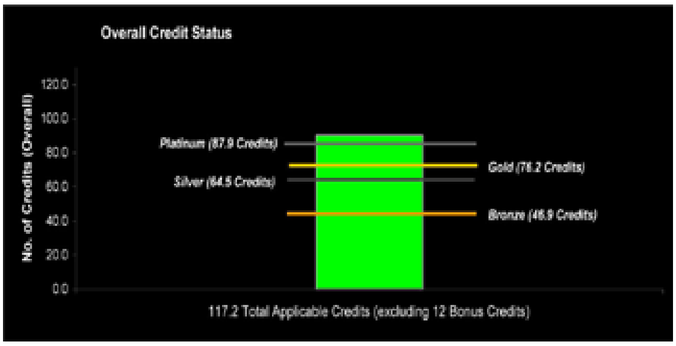


Figure 7 Results of BEAM Assessment

6. Ecological Footprint

6.1 Definition of Ecological Footprint

The ecological footprint is the predominant methodology used to highlight the impacts of consumption within the context of ecological limits. The methodology has been increasing in popularity since its initial publication by Wackernagel and Rees (1990). The footprint is a means of measuring a population's level of consumption by calculating the notional and direct land area needed to support them with the resources they consume and absorb the wastes they generate. The ecological footprint is measured in global hectares (gha) which means that the land can be located anywhere in the world and is representative of a standardized unit of average global productivity. In this manner the ecological footprint reallocates the environmental impact to the end user no matter where in the world the impact takes place. Ecological footprint calculation can take either a bottom up approach according to Chambers et al. (2001), or top down approach as suggested by Wiedmann et al. (2006), or use a combination of both.

Independent of the methodology used to conduct an ecological footprint study, one of the most important messages that it conveys is that we only have one planet with a finite land area therefore clearly demonstrating that we are constrained by ecological limits. Different from traditional environmental indicators, such as the Kyoto climate change targets, for which impacts are measured within a defined boundary such as a country, the ecological footprint takes into account all impacts on a population no matter where in the world the impacts are taking place. The ecological footprint is therefore taking a consumer rather than territorial approach in measuring environmental impacts.

6.2 Integrating the Ecological Footprint into the Design Philosophy

The average footprint in rural China currently stands at 1.6 global hectares per person (gha/capita) and that of an individual living in Shanghai is already around 7gha/capita. For a country that is urbanizing rapidly like China, it is important to make effort to reduce the impacts by all new cities. Lei and Wang (2003) stated that Hong Kong's Ecological Footprint in 2001 was 6.1 gha/capita, or 2.2 times the world average. If the situation remains unchanged, we would need at least 180 times the existing land and sea area we have to support our current lifestyles.

Olgyay and Herdt (2004) proposed two indicators on measuring ecological footprint for buildings, namely Index of Building Sustainability (IBS) and Index of Efficiency in Sustainability (IES). The IBS reflects the fraction of the annual carrying capacity of the project's land that is consumed by a building. On the other hand, IES is the quantity of land required to meet a sustainability goal. These two metrics can be applied to assess both construction and operation impacts. Smaller indices mean less impact to the environment. These indices could be used as indicators to architects and / or building designers to design high performance building with minimal impact.

Energy consumption by air-conditioning plays an important part in ecological footprint as it involves the use of fossil fuel. Based on the Hong Kong Energy End-use Data (2007), approximate 37% of total energy was consumed by commercial buildings, from which 28% (equivalent to 29,897TJ) was due to air-conditioning. And the study by Panizo (2000) stated that fossil fuel energy consumption accounts for approximate 20% (equivalent to 1.25gha/capita) of the total ecological footprint for Hong Kong. It may be concluded that the ecological footprint for fossil fuel consumed by air-conditioning in commercial buildings is 0.13gha/capita.

Through optimizing the design of Yau Tong Estate Phase 4, energy consumption by air-conditioning has been reduced through utilization of natural ventilation and water-cooled air-conditioning system. With a combined annual energy saving of 23TJ for air-conditioning, 0.0001gha/capita of land could be conserved. These measures not only reduce the demand on fossil fuel but also the generation of greenhouse gases.

7. Conclusion

Indicators for different aspects of the sustainability framework including Economic, Environmental and Social was established for the unique context of Hong Kong and demonstrated using the case study of the Redevelopment of Yau Tong Estate Phase 4 of Hong Kong Housing Authority.

The sustainability design approach for the case study was illustrated. Performance indicators for enhancing health and comfort environment as well as energy and water conservation were identified. This project symbolizes the commitment of the Hong Kong Housing Authority to the environment and the society through an integrated approach to green building design, from architecture to building systems.

Ecological footprint, which accounts the impacts of consumption by a development within the context of ecological limits, has also been incorporated into the design philosophy of Yau Tong Estate Phase 4. With the utilization of natural ventilation and water-cooled air-conditioning system, energy consumption by air-conditioning has been minimized. As a result, the generation of greenhouse gases is reduced with reduced demand on fossil fuel.

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EXPLORING PRINCIPLES OF REGENERATIVE TOURISM IN A COMMUNITY DRIVEN ECOTOURISM DEVELOPMENT IN THE TORRES STRAIT ISLANDS

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Keywords: regenerative design, ecotourism, Torres Strait, community design

Summary

Many critics are beginning to look towards a theory of development that moves beyond sustainability predicated on efficiency, towards sustainability based on active and positive contribution. One such exploration is termed 'Regenerative Design'. Regenerative design diverges from this perception of sustainability in three key ways. Firstly, it shifts the frame of reference from minimal to positive impact. Secondly, it questions human/environment relations based on the Cartesian separation of subject and object. Thirdly it attempts to reconnect environmentalism with a socio-political dimension, which has been lacking in much sustainability discourse.

What does this look like in practice? Can we develop regeneratively? These are the questions explored in this paper through the lens of a project carried out in the Torres Straight Islands in April 2007. The project team comprised architecture students from the University of Melbourne who visited Moa Island with the aim of designing an ecotourism facility. Extensive research was conducted prior to departure, which assisted the students during the one week intense charrette with community Elders and representatives. The local Kubin community was presented the opportunity to accept and comment on the preliminary designs, before the students returned to Melbourne to develop their ideas.

In Moa, the students learnt first hand about the complex issues surrounding community led design. The main challenge was to establish a clear understanding about what the facility needed to provide, in order for it to make a positive contribution to the entire community. It was initially difficult to gain this understanding as each community representative presented a unique set of problems which had either a social, economical, political or environmental agenda. This paper introduces the concept of regenerative tourism and reflects on the process of trying to develop architecture that becomes an active participant in its context.

1. Introduction

This paper introduces the ideas of 'Regenerative Design' and more specifically 'Regenerative Tourism' using a case study from the Torres Strait Islands in the concept stage of design.

1.1 Regenerative development

The development and exploration of regenerative development comes from a frustration with the inadequacy of the approach and pace of movement towards a more sustainable future. It is around 45 years since Rachel Carson's "Silent Spring" was published, warning us of the environmental impacts of our excessive use of chemicals. Kenneth Boulding's "Spaceship Earth" came out in 1966 reminding us that we only have one planet. This concern for over-consumption was echoed six years later in the 1972 Club of Rome Report "Limits to Growth" (Meadows et al. 1972). Yet our chemical use continues to grow while the average Australian has an ecological footprint that would require four earths to sustain. A more worrying demonstration of our failure to deal with these problems is that over 100 year ago Svante Arrhenius (1896) calculated that increasing carbon dioxide emissions from human activities will lead to global warming, and it is now sixty-eight years since Guy Callendar (1938) warned that global warming is already underway. It is 27 years since the first report from the Inter-governmental Panel on Climate Change (1990) yet our greenhouse gas emissions continue to rise. In fact, the recent Millennium Ecosystem Assessment report concluded that: "…the results of human activity are putting such a strain on the natural functions of Earth that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted". (Millennium Ecosystem Assessment, 2005:2) This report showed that nearly two-thirds of the essential services provided to us by nature are in such decline that collapse is likely.

The research to date that investigates this inertia in the movement towards sustainability has found that it is based on the Cartesian logic that places humans outside of, and in opposition to, nature. This approach maintains a reductionist approach to sustainability and attempts to solve problems within the same framework that has created them. There needs to be a different approach to the issue of sustainability and many environmentalists have called for this in the form of a paradigm shift in values; for example Schumacher, 1974; Naess, 1995; Sachs, 1995; Devereux, 1996; Capra, 1996 and 2002; Bossel, 1998; AtKisson, 1999; Kumar, 2002; du Plessis 2006 and 2007.

Apart from the failures outlined above, the problem might also stem from our understanding of what is meant by the term 'sustainable development'. Sustainability, depending on the point of view, is about sustaining, keeping things as they are – or not letting them get worse. The problem, and the cause of its contestability, and possibly the inertia, lies in what people are trying to sustain. The use, misuse and consequent renegotiation of the term 'sustainability' has resulted in a reduction of its potency. In particular, its connection with the conceptually divergent goals of economic growth and production under the popularised Brundtland definition of 'sustainable development' has led to skepticism of the value and meaning of this term. Furthermore, the framework of minimising impacts, or perhaps even more problematically offsetting impacts, is seen as both ineffective and presumptuous since it continues to grant indulgences on behalf of the planet.

It is for this reason that the authors began to investigate the concept of Regenerative Design. The idea of 'regenerative design' was first proposed by landscape architect John Tillman Lyle (Lyle 1994). Rather than the stability of sustainability, Lyle presents regenerative design as a dynamic process of participation, feedback and continual change over time. Lyle intends the concept to be applied not only to individual circumstances, but rather to the design of entire cities and landscapes. Thus, Lyle sees regenerative design as not only a change in process and product, but change in attitude towards our very relations with our environment (Lyle, 1994, pp. 7-8).

It is important to differentiate the position articulated in this paper from some others that are emerging within the discourse of regenerative design (for example Eisenberg and Reed 2003). The idea of regenerative design proposed here is more closely aligned with a position developed by Steven Moore. In 'Technology and Place: Sustainable Architecture and the Blueprint Farm', Moore provides a more critical analysis of regenerative design (Moore 2001). It is inspired by the apparently divergent figures of the social ecologist Murray Bookchin and the architectural critic Kenneth Frampton. For Moore, regenerative design offers the opportunity of reconnecting environmentalism with a socio-political dimension. This has been lacking in much sustainability discourse, particularly within the arena of sustainable architecture. Thus, notions such as transparency, local control, everyday practice and democratic negotiations are a core part of Moore's eight principles for regenerative design.

As an example, Moore distinguishes 'regenerative' from 'sustainable' technologies in two ways. Firstly, and most directly related to Lyle's conception of regenerative design, he argues that they must not only maintain a balance between production and consumption, but also result in a 'net increase in life-enhancing conditions' (Moore 2001, p. 131). Secondly, he argues that regenerative technologies must be 'socially visible and politically transparent' (Moore 2001, p. 130). By this, Moore intends to confront the idea of technology as a black box and reconnect people with the relations and means of production as well as making the technological intervention itself haptically and visually transparent. He also proposes that technologies grounded in place are inherently more democratic since the forces required for production (wind, sun etc) cannot be centrally controlled and dominated.

1.2 Regenerative development and ecotourism

The application of the idea of regenerative design to the tourism context is both pertinent and problematic. On the one hand tourism, as the world's largest industry, is seen as the answer to many social and environmental problems, particularly in developing countries (McMinn 1997). As well as the obvious environmental impacts of travel, there are also well-documented social impacts from tourism such as the loss of local traditions, the erosion of family structure, crime, and unequal distribution and consequent fighting over economic benefits (International Ecotourism Society, npd). On the other hand, the tourist experience is inevitably temporary and frequently superficial. The pace of the tourist schedule rarely allows for anything but a fleeting glimpse of life lived elsewhere. It is a tantalising experience with an 'other' underpinned by the notion of excess.

Ecotourism is burgeoning sector of the tourism industry, hailed as the fastest growing tourism sector at the end of the twentieth century and into the new millennium (Honey and Rome 2002). Ecotourism is generally associated with pristine, remote places that exhibit cultural and most particularly ecological difference. In fact, the International Ecotourism Standard explicitly includes a 'direct personal experience of nature' as a core principle of such tourism developments (Ecotourism Australia and the Cooperative Research Centre (CRC) for Sustainable

Tourism 2004). Other key features of the concept include low impact operation, education about environmental issues, and a positive contribution to conservation and to communities (Buckley 2003).

Green Globe 21 is a method used to assess the 'ecological' properties of a resort, operation or ecotourism offering. It does this through a series of requirements that, once met, lead to a label that can be used by the ecotourism operator. A review of the principles of Green Globe 21 demonstrates the synergies between ecotourism and sustainability with substantial effort focused on reducing impacts on the ecological, social and cultural context. However, there are other aspects of the principles that potentially move beyond the limitations of efficiencies, such as natural area focus, interpretation, education and ecotourism benefiting local communities.

Nevertheless, these potentially regenerative aspects of ecotourism are not well developed, particularly as they relate to the accreditation requirements of the international Green Globe certification program. For example, while great detail is provided on the requirements and benchmarks for ecologically sustainable practice, there is very little information to support what is intended by the notion of the 'presentation of natural values'. The inclusion of local communities and cultural differences within the ecotourism agenda also has potential to address some of Moore's concerns such as transparency, local control and democratic negotiations, but the requirements for ecotourism accreditation do not articulate the full potential of this regenerative agenda. Instead they restrict themselves to such issues as 'liaison with the local community' rather than full democratic participation.

While such issues are difficult, if not impossible, to integrate within the constraints of an certification system, there are moves within ecotourism to increase local control through, for example, the idea of community based ecotourism (CBE)where the community retains substantial control over the project and the benefits that arise from it (International Ecotourism Society npd). This is an important issue to address the negative and often unforeseen impacts that can arise in ecotourism projects and to facilitate the potential for net gains rather than losses, particularly within the localised social and economic context.

2. Regenerative concepts and the Moa Case study

There is no definitive answer or universally agreed definition for regenerative design. This paper engages and explores the concept by looking at an ecotourism project for the island of Moa in the Torres Straight Islands. As with 'sustainability', regenerative design is a contested concept with a common horizon of intent underpinned by a diversity of meanings and applications. However, regenerative design diverges from sustainability in three key ways. Firstly, it shifts the frame of reference from minimal to positive impact. Secondly, it questions human/environment relations based on the Cartesian separation of subject and object. Thirdly it attempts to reconnect environmentalism with a socio-political dimension, which has been lacking in much sustainability discourse. These concepts and their implication for architecture are further articulated in Owen 2007a, Owen 2007b, Owen and Hes 2007, Owen 2008.

2.1 Background on Moa

The Torres Strait Islands are located between the tip of Cape York and the southerly coastline of Papua New Guinea. Over 150 islands encompass approximately 48000km2 of shallow seas (Green 2006, p.3). Moa Island is located in the West Torres Strait and is one of 14 islands reserved for island communities (Finch 1977, p.1) Generally each island has one community; however Moa is unique with both Kubin and St Pauls communities.

Moa has a total population of 439 residents, with 201 people residing in Kubin and the remaining 238 living in St Pauls (ABS 2006). The population balance between the two communities is relatively equal, despite Kubin Community Council (KCC) having jurisdiction over 152km2 of land, while St Pauls controls only 17.7km2 (State of Queensland Government 2007). The two communities are connected by a 15km dirt road and each contains the essential services that allow it to operate independently. (Observation and Occasional paper 17, p.86)

Despite the presence of two communities on Moa, it is only the Mualgal people in Kubin who are considered to be the traditional owners of the land, with their ancestors coming from Muralug and living in "seven different villages scattered around the island" (Nawia 1991, p.1). This story of origin is markedly different to St Pauls village, which was set up as a reserve by the Queensland Government in 1904 following the forced repatriation of Pacific Island laborers. The issue of traditional land ownership is the cause of some animosity between local people in Kubin and St Pauls, particularly with regards to discussions about future development in Moa.

Education is valued in both the Kubin and St Pauls' communities, however facilities are limited. Individual primary schools teach children in Moa up to year seven. For years seven to twelve, local teenagers attend school on Thursday Island or boarding schools in Cairns and Townsville (Occasional Paper 17 2006, p.78-79). The process of sending teenagers away from Moa for educational purposes is both supported and opposed by the older generations. While education is considered to be "the pathway to improved opportunities for children", the forced distance between family members and exposure to western ideas is seen to "erode traditional culture" (Occasional Paper 17 2006, p.75).

Employment opportunities in Moa are limited, with the 2006 census identifying labouring, community and personal service workers and clerical and administrative workers as the three most common occupations. While the percentage of people working as clerical and administrative workers in Moa is on a par with the Australian national average, the percentage of people employed as labourers is three times higher, while community and personal service workers are twice as high. In contrast, the percentage of people working as professionals, managers and technicians or trades workers was over two times lower than the Australian national average (ABS 2006). These statistics support Noel Finch's claim that there are "not sufficient opportunities on the islands to cater for the higher education qualification gained by children who studied in the mainland" (Finch 1977, p.59).

The result is a problem identified as 'population mobility' and is of major concern to community elders, who claim that "young men go off to live on the southern mainland and with their going destroy the ability of the island to retain knowledge inherited from the past" (Lawrie 1970, p.xxii). This attitude exists even with emigration within the Torres Strait, as each island has a unique cultural heritage retained in traditional stories and legends passed by Elders (Finch 1977, p.22). Margaret Lawrie, who visited the Torres Strait in 1965-68 to record stories on behalf of traditional owners, explains that "ownership of stories is restricted to an island and to the groups and individuals within that island…[they] are limited in their telling to the island of origin" (Lawrie 1970 p.xxii). This means that youth who have chosen to relocate within the Torres Strait cannot technically adopt the culture of another island.

A research study conducted in 1999-2003, entitled 'Careers and Aspirations: Young Torres Strait Islanders', begins to identify the extent of population mobility based on a sample group of 105 Indigenous people aged 15-24. When the research group returned in 2003, only 59 of the original sample group interviewed in 1999 remained (Arthur, Hughes, McGrath and Wasaga 2004, p.1). Results from the 2006 census support the argument that there is a high rate of mobility amongst 15-24years olds, with only 15 percent of the population in Moa being within this age bracket, compared to 35 percent 5-14year olds and 24 percent 25-54year olds (ABS 2006).

The decision of young Indigenous people to relocate to mainland Australia for improved education or employment opportunities is one that contributes to the erosion of traditional culture. Other factors attributed include the widespread adoption of western culture and the diminishing role of the extended family in providing discipline and life skills in the older children (Occasional Paper 17 2006, p.78-83).

Background to the project

The field trip to the Torres Strait islands was organised by the Faculty of Architecture, Building and Planning at The University of Melbourne in association with the UNESCO Observatory. It was offered to students as an opportunity to gain experience working on a real architectural project in an environmentally and culturally sensitive context. The brief was for an ecotourism resort in Moa which carefully addressed the "cultural, sustainability, technical, socio-economic and environmental issues important to the people of Moa and the Torres Strait" (Joubert 2007). The field trip took place in April 2007, where eleven students and four academic staff were accommodated in Kubin for eight days and guided around the island by a group of local people introduced as community representatives (known here on as 'the working committee').

The first stage of the design process began in the weeks leading up to departure as the students researched the Torres Strait islands and existing ecotourism facilities. While the group successfully uncovered substantial quantities of information relating to the Torres Strait region, specific details on Moa were difficult to locate. This, combined with the working committee's decision to temporarily withhold details of the brief, made it difficult to assess which precedent studies were relevant. Consequently students arrived in Moa feeling unprepared.

The working committee claimed that their decision to withhold details about the project, until the students were in Moa, was made to avoid problems arising from preconceptions about what the community needed. The working committee wanted the students to be informed through experiences of the culture and environment.

The consultation period for the project was prolonged by the complex nature of the social/political setting in Kubin, generated by a lack of communication between the working committee and the (KCC). The sensitive nature of issues surrounding traditional land ownership and development in Moa resulted in the working committee proposing a top-down approach to developing the resort. Rather than actively involve the whole community from the beginning of the project, the working committee was concerned that the idea of developing an eco-tourism resort would not be widely accepted, because "it is difficult for the community to have an opinion of something that they have had no experience with" Their intent was to seek community involvement once a "picture" of what the resort could look like was generated "to give them something to get excited about" (Ben*).

When full details of the proposal were disclosed to KCC, they demanded transparency within the design process along with a longer consultation period that actively involved the whole community. This added to the constraints already impacting on the time available for the student's to conceptualise their designs. Consequently, this project only reached its concept development stage and thus the reflection on regenerative concepts is based on the opportunity presented to meet the needs of the Moa community.

1 – Adding value

The first point of differentiation between sustainability and the concept of regenerative design is the only one that is universally shared amongst all proponents of regenerative design. The premise is simple – that our actions should result in net benefits to our ecological and social environments. The application is more complicated, but it is based on what William Reed has described as 'building capacity rather than things'.

The net benefits of the ecotourism resort, relate to a number of long and short term goals set by the working committee in response to the local issues concerning employment, education, population mobility and loss of culture. At its most fundamental level, it is intended that the resort will increase the employment opportunities available on the island and discourage the current emigration patterns. A committee member described the current situation as a "loss loss situation", with youth who remain in Kubin encountering a "loss of opportunity" while those who leave have a "loss of culture". It is intended that by reducing the need young adults to leave, the community can start to work on strengthening the youth's connection to the local culture.

Detailed discussion with the working committee about their aspirations for the ecotourism resort revealed that the design brief was not large enough to support even their short term goal to prevent emigration from Moa by generating local employment. The absence of appropriate teaching facilities would prevent the necessary training from taking place in Moa. Following this realisation the group agreed that part of the design process was expanding the brief to include a cultural centre which would be a subsidiary facility to the ecotourism resort. Such a facility would enable long term goals to be set which would result in further net benefits for the island. These would include more general training courses to aid the skills shortage in Moa and the possibility of incorporating secondary school facilities to prevent emigration and improve literacy and numerously skills amongst adults.

In addition to the social and educational benefits of the resort, it is intended that the facility will add value through economic empowerment to the local population. It is proposed that this will be achieved through employing local people to operate the resort and utilising local labour and materials in the construction of the resort. It is intended that the resort will boost the local economy, providing opportunity for the creation of new businesses that compliment the resort and its visitor program. The working committee saw opportunities for expansion in supplies, entertainment, day trips to neighbouring islands, fishing and local arts and crafts.

2 – Working with nature

Many proponents of regenerative design invoke an ethic of care and a connection with the spirit of place as a necessary condition to challenge our current position. Not everyone is comfortable with embracing this perspective for fear of being labelled a new age hippy and dismissed as 'flaky eco-la-la', to use Murray Bookchin's condemning term. Nevertheless, the dominant mechanistic and reductionist attitude towards our world is something that regenerative design seeks to challenge. Working with nature is an important aspect of life in the Torres Strait. It is formally recognised as Ailan Kastom (Island culture) which is responsible for "govern[ing] how Islanders take responsibility for and manage particular areas of their land and sea country; how and by whom natural resources are harvested and allocation of seasonal and age-specific restrictions on catching particular species"(Green 2006, p.4).

The strong connection between Islanders and their land and sea country made it essential that the ecotourism resort be well integrated with the natural environment. During the consultation period, the working committee identified a number of key values which assisted in the design of the ecotourism resort. Twelve design principles were established from these key values, of which nine embodied the need for the ecotourism resort to work with and celebrate the natural environment. These principles can be best described through a narrative that outlines both the key features of the building form and the integrated visitor program. It is impossible to separate these two things as the resort was designed to support the visitor program, which was intended to deliver a connection with the spirit of place.

<u>The visitor:</u> A maximum of five visitors arrive in Moa in the late afternoon to commence a five day trip in Moa. The trip is marketed as part of a niche tourism package which operates for six months of the year. The working group specified the maximum number of visitors as part of their ethic of care, ensuring the quality of the visitor experience, while limiting the socio cultural impact of tourism in Moa. The program operates for only six (Ben).

<u>Connection/Ecological footprint:</u> The visitors are greeted by their local guide at the airport and are advised to collect their luggage and meet outside the terminal to begin their walk to the resort. To encourage greater responsibility on the part of each visitor with regard to the quantity of 'stuff' they bring to Moa, it is intended that the visitor travel to the resort on foot, carrying their own bags. As tourists we often take more than is necessary.

<u>Journey/Diversity:</u> With backpacks on, the visitors follow their guide out of the airport enclosure and across the road to an opening in the vegetation and the beginning of a raised boardwalk. The raised boardwalk to the resort is intended to immerse the visitor in the natural environment. While walking to the resort at a leisurely pace, the

group encounter a number of notably different ecosystems along the path of the boardwalk, from Melaleuca and Sedge to Pandanus and Acacia and Mangroves. The site for the ecotourism resort was chosen for the diversity of the ecosystems surrounding it.

Context/Technology/Local knowledge: Arriving at the resort, the symbolism and integration of nature in the design of the buildings is clear. The visitors acknowledge the role which the traditional housing typology has played in influencing the design of the accommodation huts. Each one is built using light weight materials to minimise heat gain and is oriented towards prevailing breezes to cool and ventilate its occupants. Natural light illuminates the interior space of the huts, which have been decorated to illustrate important totemic symbols of the Torres Strait region. The presence of traditional weaving and thatch over a recycled timber frame on concrete stumps, indicates that the construction is intended to be a contemporary interpretation, rather than a traditional reproduction. The inclusion of guttering and rainwater tanks, a solar hot water system over the amenities hut and photovoltanic panels expresses the self-sufficient aspirations of the resort. The seven huts are arranged around a performance area with open platform activity areas overlooking the ocean and the community beyond. The resort was design to integrate with nature. The accommodation huts are raised to prevent interference with natural tide patterns, flora and fauna. Local knowledge of materials and construction techniques will be combined with local technologies to ensure that the resort has no negative impacts on the surrounding environment.

Relationships: Once settled in, the local guide returns to the group and provides information about the available modes of transport on the island. Bicycle and walking are described as being the most accessible, especially around Kubin Village. The guide provides details of the daily program which is well structured and involves much integration with the local population, participating in activities that are formed through daily rituals. It is not intended that visitors remain in the resort during the day. The rigid visitor program, as designed by the working group, combines a variety of activities to encourage visitors to learn about the local culture and environment.

3 – Socio-political aspects

While the dominant mechanistic and reductionist attitude towards our world can be criticised, this same thinking has also provided environmentalists with a secure foundation of scientific 'proof' of planetary changes such as global warming. Nevertheless, there are so many things for which science cannot account. In particular, the socio-political dimension, which is the focus of the third point of difference, requires value judgements which can never be quantified. Sustainability does not exclude the socio-political dimension, but it defines it as a distinct realm; one of the four 'pillars' or three 'legs' depending on how the pie is sliced. Conversely, regenerative design is concerned with the complex web of relationships that form an integrated whole. This is an aspiration rather than a reality and unfortunately social relationships are too readily glossed over or presented as universal and homogenous. Throughout the design process, attempts were made to ensure that the socio-political aspect of the project was not overlooked. While in some respects this may sound contradictory when considering how the design process was initially dominated by a single group of people, the working committee aspired to represent needs and concerns of the community with each member pursing a social, economical, political or environmental agenda. There were various interesting and unexpected consequences as a result of this approach.

Firstly, prior to the arrival of the student group, it appeared that the members of working had not clearly established, as a team, their expectations of what a new facility should achieve. This may have been because of the high level of secrecy surrounding the proposal. Consequently upon commencement of the briefing and consultation period, various different perceptions of the resort started to emerge, creating confusion and contradiction as well as a platform for discussion and debate.

Secondly, while the various agendas were each theoretically represented by a member of the working committee, the issues were addressed on varying levels based on the strength of the individual personality. The committee members assuming responsibility for the economic and social aspects of the facility were strong, and sometimes officious, while in contrast, issues relating to environmental awareness were promoted by the student group.

Thirdly, it was often the case during the consultation period that the individual committee members could not easily incorporate their perceptions for the resort with that of another person. This is where the design process was valuable, as it brought out the varying dimensions of difference that existed amongst the various stakeholders and encouraged negotiation.

The vastly different ideas motivating Ben* and Penny* are an example of how regenerative design is concerned with the complex web of relationships. Ben's focus was on generating income and his ideas were closely aligned with the short term benefits associated with mass tourism. He sought to promote activities and experiences that could be marketed to high paying guests and some of his early suggestions included "tourist/antique shops alongside the beach…a gazebo, golf course, tennis courts, sauna…and a restaurant selling $17 steaks". Aside from being contextually inappropriate, his ideas gave no consideration as to how the infrastructure for achieving the experience could be designed or its possible environmental impact. He perceived the necessary 'ethic of care', that the design should invoke, as being transferable to someone else, preferably those being paid to maintain the facility during its six-month non-operational period, "when the land is left to heal".

In contrast, Penny* perceived the ecotourism resort as a tool that could be used to address the many social problems concerning employment, education, population mobility and loss of culture. To her, the facility was an opportunity to create an education and training centre supported by a small scale tourism venture. However, her ideas gave no attention to addressing the other related issues such as: possible adverse effects of tourism on the culture, management, governance, financing, ownership and maintenance.

By considering the socio-political dimension, the design process delivered a project that took aspects of both points of view.

Conclusion

Regenerative design is still evolving and maturing in its ideas and applications. Unlike sustainability it is not premised on an idealised end point but rather recognises the necessity of the process of development along variously divergent and convergent paths. This research aims to help in this evolution and maturation by adding concrete examples to the debate.

The student group in Moa set out to design an ecotourism resort that carefully addressed the "cultural, sustainability, technical, socio-economic and environmental issues important to the people of Moa and the Torres Strait". With limited resources and time constraints, the design process became more significant than the design outcome, in demonstrating what the issues were and how a new facility could address them. The Regenerative Design frame work assisted in this task by establishing realistic goals. The design process can be related to all three principles. In the case of the first principle, to be truly beneficial to the community, the ecotourism resort needed to add value to the lives and prospects of young people living in Moa, by getting them actively involved. This means adding capacity and capital to the current infrastructure and the first stage of this was achieved through the expansion of the project brief to include subsidiary facilities for education and training. Secondly, to be accepted by the community, the ecotourism resort needed to have a connection to place, which in this case meant reflecting the importance placed on Ailan Kastom (Island culture). Rather than promote the 'object' of the ecotourism facility, the design process engaged the community in a narrative that describes the articulation of the design through their environment. Finally, the socio-political aspect of the design process caused debate and enabled the varying dimensions of difference that existed amongst the various stakeholders to be challenged and negotiated, enriching the proposal.

A strong desire to find solutions to the many social problems concerning employment, education, population mobility and loss of culture in the Torres Strait, led to the perception that the any proposal must be surrounded by secrecy. The top-down design approach proposed by the working committee was not intended to place limits on what could be imagined, but instead assist in generating a picture that promotes exploring new possibilities. Wider application of the regenerative principles could encourage future ventures to start with a bottom-up approach that values working collectively to develop a vision.

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TECHNOLOGY DEVELOPMENT AND LIVABILITY DEMONSTRATION OF GREEN COMMUNITY CONSTRUCTION IN DIFFERENT AREAS OF CHINA

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Summary

China is one of the countries with the largest scale of community construction in the world. Great challenges are faced by China to improve the built environment of community in the viable, liveable and sustainable way. Based on the research achievements from the key state R&D program “Study and demonstration on construction techniques of eco-building in different areas in China” completed by our research group, this paper systematically introduces the latest technology development and a series of construction demonstration programs in the field of green community in different areas of China.

Firstly, the paper analyzes the great challenges faced by urban and rural community construction in China, including the Influence of community construction during the urbanization process and the development of towns and villages.

Secondly, the paper establishes the planning framework of green community construction in different areas, introduces the outcomes of technology integration system (including 16 key techniques in four fields) of green community construction in different areas. The four fields are: integration of construction and planning techniques for green community, integration of key techniques for green community construction, integration of green construction techniques for eco-building in community, and integration of evaluation indicators for environmental improvement in green community.

Thirdly, the paper introduces a series of technical application and construction demonstration programs of green community, e.g. ecological energy-saving community in Huazhuang town, eco-village and green volunteer community in Huairou district, energy-saving straw-bale housing in Baishan city in northeast areas, eco-planning and energy-saving techniques for community in forests district in Hailin city, and eco-community construction and habitation environment improvement in Jiangyin city.

Lastly, the paper proposes the strategies and suggestions for further development of green community in China.

1. Great Challenges Faced by Urban and Rural Community Construction in China

China is one of the countries with the largest scales of building construction in the world. There are more than 45 billion M^2 existing buildings in China (rural buildings accounting for three-fourths) and 1.6 billion M^2 new buildings constructed in 2006 alone. Currently, how to improve the built environment in the viable, liveable and sustainable ways are great challenges for China. Continuous growth on building construction in China improves the living conditions of residents but threatens the eco-environment in both urban and rural areas.

1.1 Influence of Community Construction during the Urbanization Process

(1) The amount of land resources declines rapidly with the expansion of building construction during the urbanization process. It is reported that the amount of farmland per capita was 933.38 M^2 in 2004 (Wang Xiaoming, et al. 2005), less than 40% of the world average level. For example, 40% of the farmland used for urbanization was taken as “Development Zones”, exclusive area designated for foreign and domestic investment for manufacturing.

(2) Urbanization in China is growing rapidly, resulting in the rapid growth of urban population (Wang Guangtao, 2006). In the past two decades, the urbanization rates have been growing by 1% annually and reached 43.9% in 2006. The development trend of urbanization rates in China is shown in Figure 1. Urban

population in China is predicted to increase from 577 million in 2007 to 828 million in 2020, while the rural population will decrease from 737 million to 622 million. The urbanization rate will reach 57% in 2020. Meanwhile, the number of metropolitan regions, composed of adjacent cities, will continue to increase and may exceed 12 by 2020.

(3) The energy consumption of building construction and maintenance has been increasing. The total area of existing buildings in China is up to 45 billion M^2, and another 30 billion M^2 new buildings will be added by 2020. The direct energy consumption for building construction accounts for about 27.6% of the total energy consumption in China whereas the percentage goes up to 46.7% if the energy consumed for producing construction materials is also accounted. During the construction process, steel consumption accounts for about 30% of national steel consumption; cement consumption about 25% of national cement consumption; water consumption about 47% of urban water consumption. The energy consumption level in China is much higher than that of developed countries. For example, heating energy consumption in unit building area is 2-3 times of that of developed countries given similar climate. The average life cycle of new buildings in China is less than 30 years, which is far shorter than the standard life cycle of 50 years. Only 5% out of the 2 billion M^2 buildings constructed in 2003 are designed with energy-saving efforts.

(4) The poor quality of waste water treatment and garbage disposal, which do not meet the national standards, results in worsening pollution of water resource and community environment. The recycle rate of disused building materials is low. In 2004, 6 billion tons of disused building materials were produced nationwide, including 2 billion tons of disused concrete, which were barely recycled.

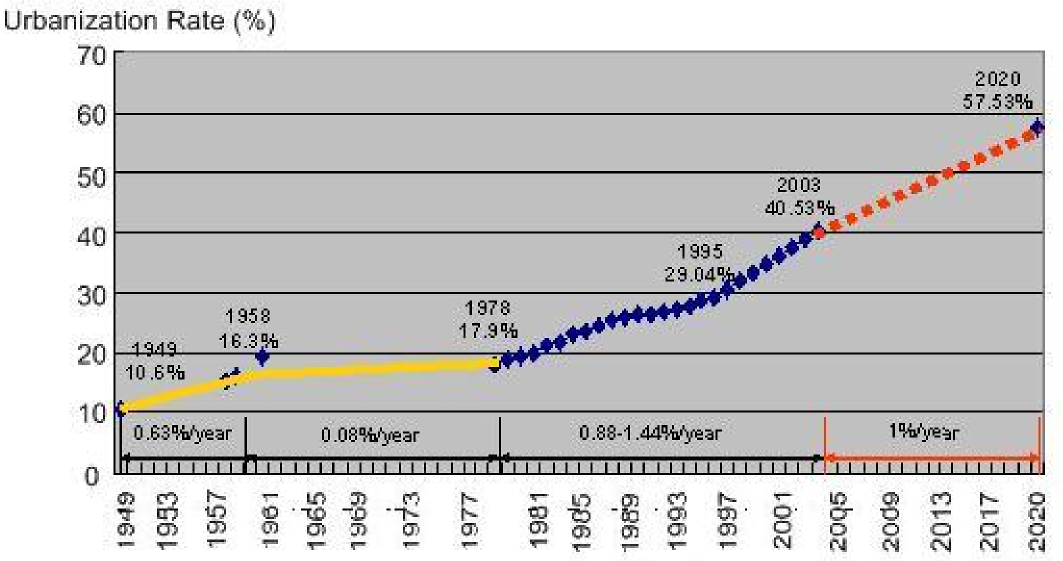

Figure 1 Development trend of urbanization rate in China

1.2 Influence of Community Construction during the Development of Towns and Villages

(1) The scale of community construction in towns and villages is huge: there are 3.207 million natural villages, 634,000 administrative villages, 22,000 market towns, and nearly 20,000 administrative towns, with 200 million farmers living in the countryside. The land for building in rural areas amounts to almost 170,000 km^2. The area of housing construction in towns and villages accounts for more than half of the national housing construction area. More than 600 million M^2 housing has been constructed in villages and towns every year. In 2005, the total area of existing building in towns and villages was 30.95 billion M^2, 83.2% of which was housing covering 25.76 billion M^2. The housing construction investment for villages was up to 256 billion RMB. In 2006~2020, 6 billion M^2 of new buildings will be built in villages and towns in China (Wang Xiaoming, 2008).

(2) The infrastructure construction of communities is underdeveloped in towns and villages. In 2003, infrastructure construction lagged behind significantly in 90% of Chinese villages and towns; 90% of rural families did not have flush toilets; only 53% of rural families had sanitary toilets; only 57% of body waste was treated properly; 90% of garbage was not classified and treated accordingly; 40% of rural households had no tap water supply and drainage facilities; 50% of rural area lacked basic roads; 60% of rural area had no facilities for public activities; and 60% of rural area had no emergency facilities for fire.

(3) The eco-environmental quality in rural areas is deteriorating. In rural areas, the green rate is less than 15%; biodiversity decreased rapidly and some species are even facing extinction; local traditional characteristics and historical cultural values are severely destroyed.

(4) Anti-disaster capability of rural infrastructure is far below that in urban areas. During the snowstorm disaster in early 2008, about 11 million M^2 of housing collapsed and 43 million M^2 housing was destroyed, most of which were rural buildings.

Chinese government has initiated a massive social project to build modern rural communities since 2006, offering great opportunities for improving the liveability of the rural environment.

Combining different characteristics in different areas, Chinese government is conducting the research and demonstration of green community construction. This has profound importance to the promotion of resource-saving and environmental friendly society, the realization of affordable society, and sustainable development of construction industry.

2. Technology Integration and Demonstration of Green Community Construction

2.1 General Introduction

China is a large and diverse nation with many regions different in economic and social development levels and natural resources. Different types of green community should be constructed according to the different economic situation with the principles of sustainable development.

From 2005 to 2006, the key state R&D program, "Study and demonstration on construction techniques of eco-buildings in different areas in China", was carried out by Huazhong University of Science and Technology (HUST) and China Academy of Social Science (CASS). This program aims to establish technological integrated system and demonstration platform for green community in five China National Sustainable Communities (CNSCs) with the technology support from five renowned universities in China. The five CNSCs are Huazhuang Town in Wuxi City Jiangsu Province, Jiangyin City Jiangsu Province, Huairou District Beijing City, Hailin City Heilongjiang Province and Baishan City Jilin Province, and the five universities are Huazhong University of Science and Technology, Tsinghua University, Jilin Architectural and Civil Engineering Institute, Harbin Institute of Technology and Nanjing University.

This program integrates four fields of green community construction technologies, including 16 key techniques; 9 green community construction projects with 12 demonstration sites have been completed in five cities. The program has achieved significant economic and social benefits in land and energy saving, environmental protection, etc.

We have established the planning framework of green community construction in different areas, as shown in Figure 2.

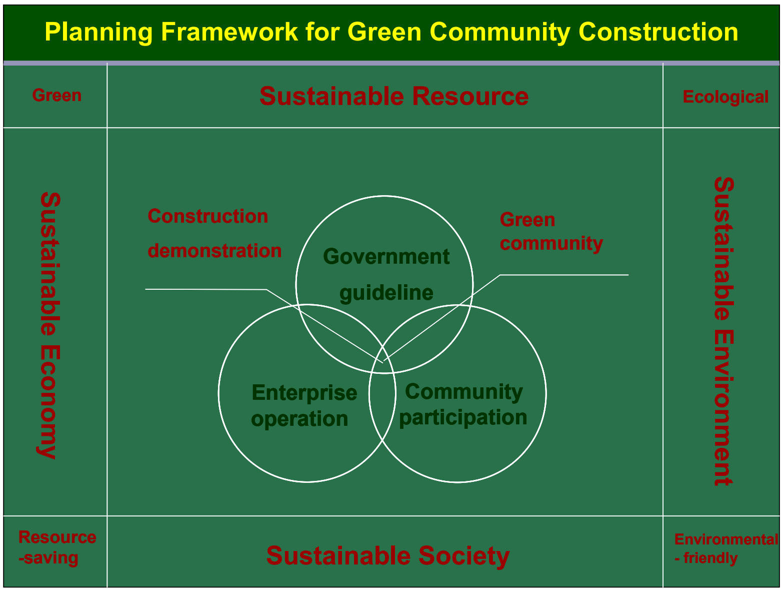

Figure 2 Planning framework for green community construction

2.2 Technology Integration of Green Community Construction in Different Areas

In this program, we have developed 16 key techniques in four fields according to the characteristics of different areas in China.

2.2.1 Field I: Integration of construction and planning techniques for green community

1) Construction guidelines for ecological and energy-saving community

The guidelines consist of five components: a) general principles; b) action plans for constructing ecological and energy-saving community; c) energy-saving actions for constructing ecological and energy-saving community; d) improvement of environment qualities in ecological and energy-saving community; e) process management for constructing ecological and energy-saving community.

2) Eco-planning guidelines for frost forested area construction

The guidelines consist of 4 components: a) optimal land planning; b) harmonious ecological landscaping; c) rational functioning of scenic areas; d) ecological facilities in scenic areas.

3) Planning for old village renewal and green volunteer homestead

The plan is composed of 6 parts: a) land planning for village renewal; b) road construction planning for village renewal; c) architectural style planning; d) greening system and environment planning; e) energy-saving planning; f) action planning for green volunteer homestead; g) eco-planning for green open space in communities.

2.2.2 Field II: Integration of key techniques for green community construction

4) Key techniques for green community construction

Three key techniques are integrated in the construction process: a) planning for green community; b) energy-saving for community buildings; c) ensuring ecological environment.

5) Integrated system of key techniques for green community construction in small towns

The integrated system includes 6 techniques: a) land planning for community construction; b) buildings insulating; c) energy-saving for windows and doors; d) clean energy sources such as solar energy; e) waste treatment and recycling; f) water quality assurance.

6) Eco-building construction technology for rural areas

Six practical technologies are applied in the following areas: a) low-cost construction; b) utilization of local materials; c) land saving; d) materials saving; e) water saving; f) energy saving.

7) Energy-saving and green construction techniques for scenic areas

The following main techniques are developed: a) heating system based on solar energy; b) hot water supply based on solar energy; c) heat preservation for buildings in low temperature areas; d) use of local building materials.

8) Straw-bale housing construction techniques for frost areas

A group of specialized techniques have been developed for straw-bale housing construction: a) wall materials of straw-bale; b) weight-bearing structures; c) peripheral structures, i.e. windows; d) maintenance and repairing.

2.2.3 Field III: Integration of green construction techniques for eco-building in community

9) Green construction guidelines for eco-building in community

The guidelines are composed of 7 modules: a) introduction; b) guidelines for selecting construction sites; c) guidelines for construction planning and design; d) guidelines for construction process; e) guidelines for buildings maintenance and operation; f) guidelines for buildings demolishing and reusing; g) guidelines for benefits evaluation of green construction.

10) Green construction control and evaluation for eco-building in community

The green construction management consists of three sections: a) goal management of green construction; b) process control of green construction at various stages; c) benefit evaluation index system of green construction (USGBC, 2002).

11) Construction regulations and standard for straw-bale housing

12) Construction techniques for eco-villages

A low-cost technology system has been established: a) local materials and environment; b) suitable energy sources; c) water treatment; d) gardening and afforestation; e) ecological transportation.

2.2.4 Field IV: Integration of evaluation indicators for environmental improvement in green community

13) Evaluation indicator system for residents in green community

The evaluation indicator system has been set up based on 4 sub-systems: a) evaluation of current ecological living conditions and energy saving; b) assessment of satisfaction level of local residents with regard to ecological environment; c) evaluation of energy-saving methods; d) suggestions of construction projects.

14) Evaluation indicator system for human settlement of community in rural areas

The evaluation indicator system consists of five different components: a) housing construction; b) landscaping and environment; c) application of technologies; d) infrastructure and community management; e) community cultural development.

15) Evaluation indicators for eco-building in rural areas in northern China

The evaluation indicators focus on five aspects: a) land-saving and outdoor environment; b) energy-saving and energy usage; c) water-saving and water resources usage; d) materials-saving and materials usage; e) indoor environment quality evaluation.

16) Evaluation indicator system for eco-efficiency in green community

The evaluation system consists of five sub-systems: a) eco-capabilities and pre-warning system assessment; b) energy saving efficiency evaluation; c) land saving efficiency evaluation; d) environment benefits evaluation; e) social benefits evaluation.

We have established the technology integration system of green community construction in different areas, which is shown in Figure 3.

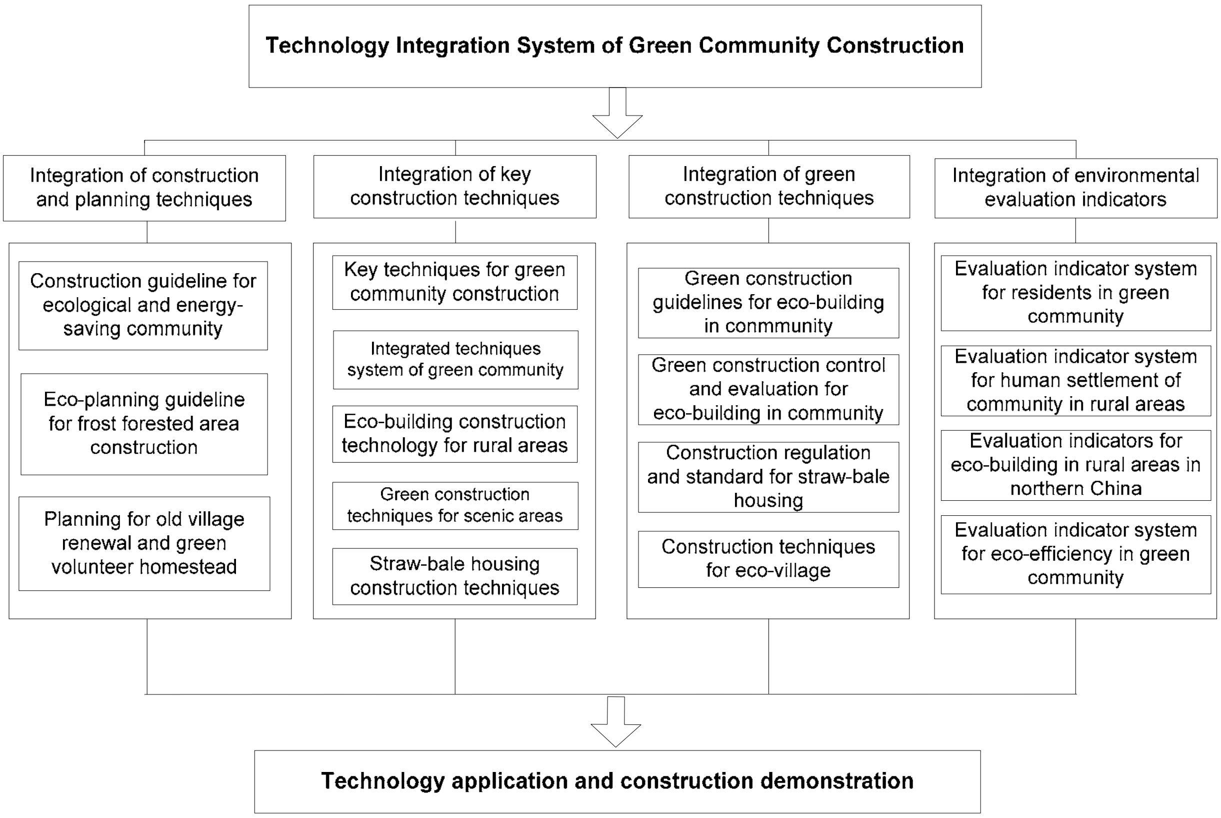

Figure 3 Technology integration system of green community construction in different areas

2.3 Technical Application and Construction Demonstration of Green Community in Different Areas

2.3.1 Objectives

Guidelines: sustainable development theory and modern construction techniques for green community.

Focus: establishing technology system of energy-saving and management method in different areas in China.

Purpose: setting up the demonstration of green community construction in different areas in China.

2.3.2 Content of green community construction and demonstration

Subject 1: Study and demonstration of ecological and energy-saving community construction techniques in Huazhuang town

Subject 2: Study and demonstration of Huairou eco-village construction and green volunteer homestead project

Subject 3: Study and demonstration of techniques for ecology and energy-saving straw-bale building in northeast countryside

Subject 4: Study and demonstration of eco-planning and green energy-saving techniques for eco-building in northeast forest and tourism area

Subject 5: Study and demonstration of improvement techniques for human settlement in rural areas of southern Jiangsu province

2.3.3 Outcomes of green community construction and demonstration

Demonstration 1: Eco-planning of green open space of communities such as Kaifa community in Huazhuang town (Figure 4)

Demonstration 2: Utilization of solar energy techniques in Shuiqingmuhua community in Huazhuang town

Demonstration 3: Digitalization construction and management for rural communities such as Luoxia community in Huazhuang town

Demonstration 4: Reduction, reuse and recycle for domestic refuse in Wuxi Yiduo Co. Ltd. of Environmental Heat-power Station

Demonstration 5: Utilization of green-energy techniques of light-electric curtain wall in Wuxi Wangxing Curtain Wall Decorative Engineering Co. Ltd.

Demonstration 6: Eco-village construction and green volunteer homestead in Huairou district (Figure 5)

Demonstration 7: Straw-bale housing construction in northeast areas in Baishan city (Figure 6)

Demonstration 8: Eco-planning and energy-saving techniques in northeast areas in Hailin city (Figure 7)

Demonstration 9: Eco-community construction and human settlement improvement in Jiangyin city (Figure 8)

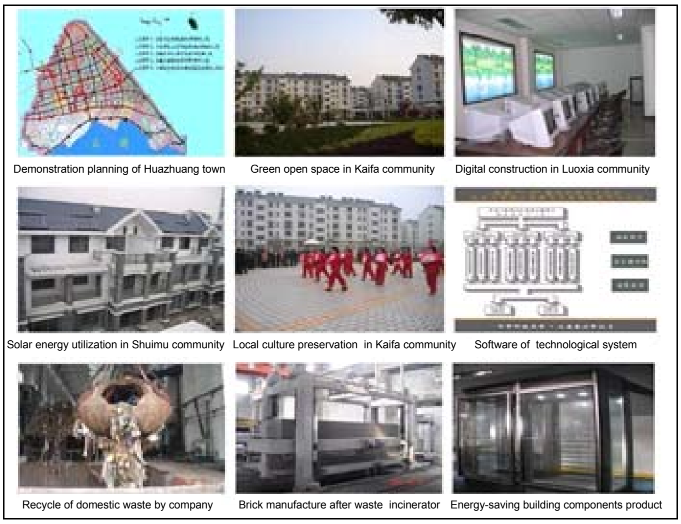

Figure 4 Ecological energy-saving community in Huazhuang town

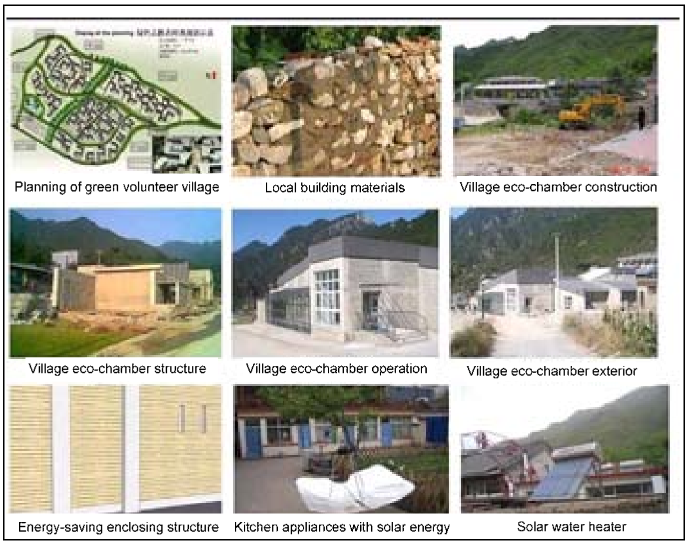

Figure 5 Eco-village and green volunteer community in Huairou district

Figure 6 Energy-saving straw-bale housing in Baishan city in northeast areas

Figure 7 Eco-planning and energy-saving techniques for community in forests district in Hailin city

Figure 8 Eco-community construction and habitation environment improvement in Jiangyin city

3. Strategies for Chinese Green Community Development

The development of Chinese green community is at its early stage and the technologies for green community construction require systematic research and improvement. Presenting green community in different areas as examples, this paper offers a group of demonstration models for promoting green community construction in China. Five strategies and suggestions for further development of green community are proposed as follows:

1) To meet the demand for construction techniques in different areas

Efforts should be made in 4 areas to meet the demand for construction techniques in different areas: a) to promote the R&D of construction techniques for green community in different area; b) to encourage public participation in green community construction; c) to research and develop green construction materials of community and indoor equipments; d) to set up the demonstration platform for green community construction in different areas.

2) To promote resource-saving and environmental-friendly green community construction

This strategy can be implemented by taking three measures: a) to save land for building construction; b) to save energy of building construction; c) to exploit resources in an ecological manner.

3) To promote the improvement of human settlement and functional qualities of buildings

This goal can be accomplished by focusing on 6 areas: a) to develop and promote guidelines for green community planning and construction; b) to improve residential area quality through green community construction and vice versa; c) to enhance the functional qualities of old residential buildings; d) to take into account local residents' preferred lifestyle and financial circumstances; e) to promote ecologically-friendly construction modes for green community.

4) To set up long-term operation mechanism by community participation

Participation of different parties should be encouraged to set up a long-term operation mechanism for green community: a) experts in relevant fields should be consulted on a regular basis; b) support from local businesses should be encouraged; c) members of local communities should be involved; d) favorable governmental policies should be set

5) To advance construction technology for green community and to promote international cooperation and exchange for liveable research projects

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E-BUSINESS ADOPTION: CASE STUDY ON MELBOURNE CITY COUNCIL CH2 BUILDING

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Summary

Web portals, online databases and E-business tools will play an increasingly important role in the building and construction industry for implementing and formalising sustainable design practices. This paper first offers a framework to identify and address a gap in the research literature on the incentives and impediments to the uptake of new E-business practices. We then focus on an E-business application for green building design using a case study involving the Melbourne City Council. Interviews with key stakeholders were designed and implemented to assess the usefulness of web sites and portals during three building stages: (1) design, (2) construction and (3) occupation. Results focus on the new Council House 2 Building (also known as CH2), one of 250 buildings for which the Melbourne City Council (MCC) has planning and operations responsibility. Finally, we extract lessons learned from this 'World Leader Status' Green Building to offer best practices that will support uptake and innovation of E-business in the design and early construction phases as well as the use of web portals and other online tools for decision-making in construction management procedures, commissioning purposes and ongoing facilities management.

1. Preface

This research project arose on the premise that little attention had been paid to understanding in great depth the social, cultural and economic reasons for the relatively slow adoption of e-business (defined in Table 1.1 below) in the vast majority of design, construction and facilities management (FM) industry. In Australia, much of the research investment has been devoted to the adoption of "high end" e-business tools and practices and, in particular, the development of computer software. This project sponsored by the Cooperative Research Centre for Construction Innovation (CRC-CI) aims to redress such balance.

Table 1 Construction E-business Definition

E-business in construction definition
E-business in construction involves any electronic exchanges of information in relation to the various stages of the design, construction and operation asset life cycle which includes: 1. internal organisational driven activity for firm core and support business including industry specific and generic business software applications, websites, email and electronic banking 2. externally linked online web based portals involving: design collaboration and document management; online tendering; procurement; purchasing and invoicing; and information 3. on-line or internal organisational facility management systems

In order to develop a greater awareness in the construction industry as to the value of e-business to organisations, a number of case studies were commissioned by the Cooperative Research Centre for Construction Innovation (CRC-CI) Project Titled "eBusiness Adoption in Construction" (London 2006). Six industry case studies were undertaken between two research teams from the University of Newcastle (UoN) and RMIT University to identify emerging web based tools and technologies and their adoption process in real life scenarios; including case studies with four Government organizations and two private sector organisations.

At an initial stage, the objectives of the project were to confirm and investigate the nature of the constraints to e-business adoption through theory and practice; then to identify strategies and techniques to raise awareness and increase adoption and diffusion in the industry based upon literature review and case study review of varying levels of e-business adoption environments; and then finally, to propose a technology adoption profile based upon the results of the case studies. A summary of the initial literature review is described below.

Table 2 Literature Review – Summary of Inhibitors and Drivers

Inhibitors to eBusiness adoption	
1.	The lack of awareness of what e-business is and what it involves and further to this a lack of awareness or reluctance to see potential business benefits (Ingirige 2002; NOEI, 2001; Parish, et al, 2002).
2.	Informed resistance to innovation based on values and attitudes (Frank, Zhao and Borman, 2004)
3.	The lack of security and the perception of an insecure environment; the need for a regulatory and legal framework; lack of systems (Bennet, et al, 2003)
4.	Market incentive, pressures and rewards and uncertainly regarding the financial returns from investments in various resources versus economic benefits (Tetteh, 2001; Veeramani, 2002)

Drivers to eBusiness adoption	
1.	Rewards, incentives and initiatives by governments including seeding programs, investment incentives and tax rebates (NOIE, 2001)
2.	Managerial characteristics or philosophy of the firms (Storey, 2004)
3.	SME's characteristics related to flexible specialisation; it is the flexibility of SMEs that can make adoption of ICT easier compared to larger more bureaucratic and inflexible organisations (Sotery et al, 1995)
4.	Production related factors assisting e-business adoption; for example e-business technologies have the potential to transfer complex design information accurately, thereby eliminating data transfer error as well as minimising delays as information is conveyed (NOIE, 2001)
5.	Reduction in transaction costs; small vendors and suppliers can bid on jobs using standardised forms on the site making bidding on jobs relatively inexpensive; costs in transferring information during the tender process is reduced. The website is also beneficial to large manufacturers as it creates an electronic auction market enabling organisations to receive a wide range of competitive quotations from vendors

One of the major research achievements derived from the case study review was the development of the concept of eBusiness adoption pathways for the building and construction industry. Although not described to great length in this paper, the theoretical framework became the basis for case study review and the development of the technology adoption profile which is fully described in London (2006).

2. Theoretical Framework

The theory underpinning the research investigation and case study review process was based upon Rogers' theory of Innovation Diffusion (1962; 1995). Whilst not referring specifically to the diffusion of e-business as innovation, Rogers' work does provide an initial framework through which examination of the diffusion of e-business through building design, construction and operations can be examined. Rogers' defines the diffusion of innovations as the process by which knowledge of an innovation is transmitted through communication channels, over time, among the members of a social system. The four key elements comprising Rogers' diffusion theory are defined as the: (1) *Innovation:* an idea, practice or object that is perceived as new; (2) *Communication channel*: can be mass media and/or interpersonal networks and is the means by which messages about the innovation gets from one individual to another; (3) *Time:* comprising both the innovation-decision process and the relative time which an innovation is adopted by an individual or group – an innovation's rate of adoption; and (4) *The social system*: a set of interrelated units that are engaged in joint problem solving to accomplish a goal.

Within this framework, diffusion is largely measured through the degree of adoption within a social system. Adopters are categorised by Rogers' as innovators, early adopters, early majority or laggards. These adopter categorisations are differentiated primarily in relation to diffusion as a temporal process - diffusion happens in time, whilst the other key elements of innovation, communication channels and social systems exert variable influence upon the temporal diffusion process depending on their specific qualities (London 2006). According to Rogers for example, communication channels vary in importance according to the type of adopter; mass media and expert knowledge has more influence on innovators, whereas personal networks are more important for late adopters (Rogers, 1995). The key processes in Rogers' diffusion theory are thus the adoption-decision process and the rate of adoption - comprising multiple phases and influenced by various factors. As noted earlier in relation to a discussion of the inhibitors and drivers for e-business, the adoption-decision process is a key phase through which an individual (or group) passes from: (1) First knowledge of the innovation; (2) Forming an attitude towards the innovation; (3) Making the decision to adopt or reject the innovation; and (4) Implementing the innovation and confirming the decision taken.

This transition from first knowledge of the innovation to its implementation, measured as a temporal process, encompasses the innovations rate of adoption. This may be affected by various factors relating to the key elements of Rogers' theory including; the specific attributes of the innovation in question – its relative advantage, compatibility, complexity, trial ability and observability (Rogers, 1995). Also influential is the type of innovation decision being made including whether the decision is optional/individual, collective/organisational and authoritarian/hierarchical. This factor parallels the recognition of organisational culture and managerial philosophy as a driver to e-business adoption. The following case study investigates E-business adoption pathways looking at scenarios at the design, construction and facility management stages.

3. Case Study: Melbourne City Council

The Melbourne City Council (MCC) presently has been involved in the planning and operation of over 250 buildings. This study uses the new Council House 2 Building (known as CH2) as the main case study to gain further understanding of how the uptake and innovation of E-business can be used in encouraging sustainable development in Design, Construction, Commissioning and Facilities Management. In comparing the original Council House Building to the new Council House 2 Building, design strategies aimed to achieve up to 80% reduction in energy use and up to 70% reduction in water use. MCC has established an Intranet browser to describe innovation strategies to its employees while also using their public website to make ongoing research reports more easily accessible - including CH2 AusIndustry's research findings with white papers and industry reports (Morrison, et al., 2005).

Results of this case study show that since the Council House 2 (CH2) building project began, the Internet, web portals, online databases, and tools have become influential and will continue to play an important role in achieving implementation of sustainable design in Australia. Although at the time when the Case Study took place the CH2 project had completed its design and construction phases, the project's underpinning environmental values are expected to continue over the life cycle of the building. In addition to addressing the uptake of E-Business through the design and early construction phases, this study also looks at how (1) web portals and other (2) online collaborative tools can be used and developed for construction management procedures, commissioning purposes and facilities maintenance operations in the rapidly increasing area environmental responsibility at social and corporate levels.

CH2 is a ten storey building designed by a multi-disciplinary team lead by the City of Melbourne's principal design team and a local architectural firm. Construction of CH2 commenced in 2005, with key contributions from the City of Melbourne including: Design, Project and Facilities Management. External consultants included: Architectural, Services Engineering, Environmental, Structural and Civil Engineering, Acoustics, Quantity Surveying, Builders and subcontractors.

4. Results Analysis

A premise is that online design and planning tools are already available but its use is not yet widely spread. Initial discussion with respondents took place to identify online tools that are preferred by industry in Australia. The study was then set to identify particular impediments and incentives for the uptake of E-business. Interviews were carried out with project stakeholders. For further detail on the full interview agenda and content analysis, refer to Aranda-Mena (2006) for full case study report. Refer to London (2006) for multiple case study analysis.

Interview results indicated that web portals with comprehensive and appropriate sustainability information related to the building and construction industry are not yet in full use across the industry. The broad scope of this project considers the world-wide potential for developing new sustainable products, tools, technologies and joint ventures to show what is possible. More specifically, the MCC Case Study aims to show how online tools, portals, resource databases for decision-making, payments, communication, presentation, reporting, and analysis are becoming increasingly available to industry. CH2 has proven to be a driver for innovation and collaboration, as a test bed for use, application, and piloting of new online business tools with contribution to the wider design, construction and facility management industries.

4.1 CH2 Goals

The overall CH2 goals have been achieved, including: (1) increasing the understanding and awareness of green building benefits; (2) increasing confidence in the selection of *green* and *eco-preferred* products; (3) increasing trust in the long term benefits; (4) facilitating information to justify the higher initial costs against life cycle costs, thus strengthening a business case; (5) alleviating the current situation of poor local availability of green building supply; (6) increasing understanding/communication across disciplines and with the client, and (7) indicating incentives for sustainability and general impediments to innovation. However, room for improvement still exists.

4.2 Areas for Improvement

The following issues need to be addressed: (1) lack of consistency in rating tools, regulations, and planning requirements; (2) behavioral issues related to industry/consumers *not acting on long-term value;* (3) lack of advice/tools not about products but about *management of investment;* and (4) lack of advice as to existing *building stock being poor* and its applications for re-use.

According to the AusIndustry's CH2 Materials Report (Morison, et al., 2005), no internationally successful program for labeling construction material has been achieved yet, despite several attempts. The main problem with labeling construction materials is that it is subject to context and location, especially in terms of life cycle and performance expectations. Greater success has been achieved using specification or material choice support tools such as EcoSpecifier and the US Environmental Building News, and guidelines such as the Aurora Material Selection Guideline and the US Federal Government's environmentally preferable purchasing (EPP) database. Labeling of materials is almost always completed by a third party independent from the manufacturer or its professional organisations, and usually includes some kind of certification.

4.3 Observations

To assist in improving construction, commissioning, and facilities maintenance, good policies and programs, real-time data, standards, benchmarks and online tools for decision-making are needed. For FM, most of the current online systems and tools can predict potential performance, but do not assess actual performance during construction and operation including affordability and costs.

As to the business case, the CH2 Total building costs $51.045 million, including $11.3 m on Sustainability Features (i.e. 22.1% of costs). The payback period claim is estimated that in 10 years time the sustainability features will have paid for themselves. Further benefits that could reduce this payback period include: (1) healthier staff – less time lost to colds, flu and other illnesses; (2) increased workplace effectiveness; (3) less costs for public domain and infrastructure; and (4) the value of this building as a guiding light in sustainable building.

In general, it is clear that the Melbourne City Council is making a considerable effort that will lead Australia towards cutting Greenhouse Gas emissions and reducing the use of Non-renewable Energy.

A follow-up study would suggest revisiting Melbourne City Council to ask pertinent questions such as: (1) Which online tools have been useful in facilitating the CH2 green building agenda?; (2) Ecospecifier was developed and tested during the design and building of – has it changed because of CH2?; (3) To what extent has this type of project contributed to laying the foundations for the use of the Internet to support the Green Building Agenda?; and (4) For the Architect, Engineer, Construction Manager, Commissioning Manager, and Facilities Maintenance Manager: how do you see your contribution in general terms in achieving the Green Building Agenda? (5) What is the role of planners in incorporating transport and land use considerations to further facilitate the green building agenda within the larger regional and urban context?

5. Discussion: Value Propositions

What current online tools such as Internet portals to facilitate designer's decision-making are preferred in industry? In aiming for a six Green Star pilot project, and becoming the first office building project in Australia to achieve such a rating, as stated previously, the CH2 building has become a technology test-bed and provides opportunity for innovation and research. For example, DesignInc, The Centre for Design at RMIT University, EcoRecycle Victoria and the Society for Responsible Design - in combination with the developments of the Australian Environmental Labelling Association Inc. in setting up the Good Environmental Choice Label - have helped standardise and identify environmental products and environmentally-preferred materials for design and construction through internet portals such as EcoSpecifier. The Melbourne City Council and other project players have taken up the enormous research task of sourcing and providing a decision-making tool for hundreds of products that have had to meet increasingly stringent standards in order to possibly be 'given the go-ahead' for the high-profile CH2 project.

The following table represents the set of tools used throughout the project. Web portal development took place during the course of CH2. These online business tools are organized into the following categories:

- Design: EcoSpecifier
- Construction: ACONEX
- Facilities Management: LOGOMETRIX

This section discusses the use of Internet portals as a decision mechanism for the selection of products, materials, construction suppliers and service providers. In the case of CH2, a great deal of the process was completed through research involving internet web searches. A six star rating was achieved when the design team only aimed for a five star certification, and it is believed this was partially due to the principal consultants attending an initial two-week workshop, followed by weekly design meetings that ran for eight months, to ensure a truly collaborative effort and integrated design approach.

5.1 Scenario 1: Design

Material selection and other decisions that have an impact for the life of the building are taken at the design stage. Even as recently as 1999, very few *Internet portals and search engine* tools were available to aid design teams in their research into green materials. Portals with ecologically sustainable products are now on the rise. In the case of CH2, one of those portals had only about 80 products listed at the beginning of the project, and there were no other local resources available. At the beginning of the CH2 design process, it was claimed that no internationally successful program for labeling sustainable construction material had yet been achieved, despite several attempts. This led to intensive research and academic partnerships for the development of an Internet portal which has increased its database from 80 environmentally certified products to over 1000. Involved research parties undertook the enormous task of vetting all potential products and materials that might be used on the project. The site then became a joint initiative of the Centre for Design at RMIT University, EcoRecycle Victoria and the Society for Responsible Design.

A rolling research and development program was designed, commencing in 2000. The key elements of this program were to: (1) establish a methodology for side-by-side comparison of products through the environmental performance questionnaire (EPQ);(2) establish a peer-review process to ensure transparency and accountability, and limit liability, through the involvement of the Commonwealth Scientific and Industrial Research Organisation (CSIRO); and (3) shortlist potential products and issue a questionnaire as a condition of consideration to suppliers for completion. There would be ongoing issues of the EPQ to other suppliers throughout the project as relevant; (4) establish in-house systems that would enable effective storage, referencing and use of data through easy access and inter-personal communication; and (5) integrate data into effective decision-making in the project in a timely manner through coordination and project reviews.

By 2004, the EcoSpecifier website had received over 100,000 visits and feedback from industry has shown that the site is the industry's leading resource on environmentally preferable materials. Currently, a commercial database of over 1000 building products exists that has been independently vetted against sustainability criteria, and provides guidance on the environmental impact of commonly available building products. As a brief summary, the tool is: (1) An online guide; (2) Used to source and increase use of environmentally preferred materials in the construction sector; (3) Helps architects, designers, builders, specifiers and consumers shortcut the materials sourcing process to find products that reduce environmental impacts and create healthier and more productive living and working environments; (4) The most comprehensive list of environmentally preferred commercially available in Australia; (5) Used to select materials with least environmental cost; and is (6) Used to gain an understanding of the principles of selection in order to identify, research, and develop alternative materials.

The site's ongoing development has seen major upgrades including powerful new functionality in the site's search engine, access to full product data, manufacturing details, and case study links for types of facilities. This includes education, commercial, health and aged care, industrial, laboratory, residential, and retail facilities.

5.2 Scenario 2: Construction

This phase of the project involved the selection of subcontractors and service providers. Issues that usually arise during this phase involve collaboration with suppliers and subcontractors and a good document management practice is paramount. Project members decided to use a web-based platform for collaboration throughout the design and construction process. Based on principles of trust and innovation, a commercial document management provider was selected. The chosen application was designed for use across various project phases. The key reasons the project team engaged in use of the tool was that the online collaborative information management service was secure and easy to use, it also promoted collaboration by allowing the reception, transmitting and management of construction correspondence, drawings, and other data, with limited printing and paper flow. Results indicated that the project extranet simplified document control, resources and project management; it also provided an easy way to save time and money on the project, technical support and training; and finally, it added confidence to the project. The firm, Aconex, is currently working with the Facility Management Association (FMA) to research current and future information management practices in the industry. For CH2, Construction Management was able to handle information more efficiently and improving project collaboration; as the Aconex tool could be used and designed for every phase of the project life cycle, minimising construction waste, and ensuring improved transparency, so that sustainable construction processed, techniques and materials would be timely implemented.

5.3 Scenario 3: Operations

An important phase of a project that often does not receive the attention it deserves is the commissioning phase (ASHRAE Guideline 0-2005). Personnel from CH2 and building users were involved in this phase for about six months and continue to be involved throughout the occupancy of the building. Understanding the initial operating of the building, post-occupancy evaluations, and monitoring of existing buildings is a meaningful world wide trend in the improvement of green buildings and facilities (Stumm 2000). In the case of CH2, a great deal of learning from the eventual occupiers took place and FM staff have been involved in the early stages of commissioning in order to better understand the maintenance requirements related to the number of innovations and sustainable technologies adopted. Issues here, include the selection of building fitouts, contracting and efficiency of mechanical/electrical/plumbing systems, understanding how reused water moves throughout the building in terms of use for the innovative shower towers that cool the air and water through evaporative cooling, use of renewable energy systems (i.e. photovoltaic cells and wind turbines) on the building, as well as natural ventilation strategies related to providing optimal comfort levels year-round.

In CH2, over 2000 sensors are now installed and are informing building operators building behaviours on regular basis. Other innovations that facilities managers are willing to implement in the green building industry include electronic energy audit tools, sustainability checklists to improve operations, and web-based tools that record and collect data for benchmarking and historical purposes.

Another e-business innovation that members of the FM community have discussed implementing includes a list (i.e. describing “Five things the individual occupant can do to make the building more sustainable”) that can be updated on the intranet site, depending on the base data and real-time data available, that could display various sustainability indicators: on energy, waste, transport, health, and others. Although not thoroughly investigated in this case study, interviews also noted that Facilities Management may undertake a study comparing post occupancy surveys and operations surveys which had been collected by CSIRO for CH1, in order to better understand the performance of CH2 in relation to occupant use.

The web based system, Logometrix, developed by Hansen Yuncken was chosen as a sustainability tool for measuring key performance indicators (KPIs) of CH2 facilities and services. The system can be accessed by registered Local Government Authorities (LGAs) or city councils over the internet and allows for strategic decision-making based on monitoring of real-time data and measurements of facility performance (i.e. through key indicators including energy use, water consumption, waste collection, and other aspects of end-users and building occupiers’ behavior). The facilities manager can then set the building as a benchmark in facilities management against other participating councils, through use of a browser interface, that can ensure that a comprehensive survey is conducted within a consistent ‘best practice’ framework – using the tool to ensure data is collected on specified parameters related to service delivery, physical, community and environmental performance. For the development and principles underpinning the Logometrix tool (http://www.logometrix.net), see Brackertz and Kenley Special Issue: Sustainable Communities (2002a, b). As noted by interviews, the Melbourne City Council Facilities Management team has been using this tool for two years allowing users to assess performance of buildings (i.e. CH2), and how they meet the environmental requirements and agreed upon goals of the users and designers.

6. Conclusion

This study has discussed the role of web portals to facilitate decision making during three building stages (1) the design process – especially on the selection of sustainable materials, (2) the construction process – especially on the collaboration between client, contractor, subcontractor and suppliers and (3) facility management – especially on building commissioning and occupation.

As a cause of the recently introduced green building and environmental legislation, new possibilities for energy savings, improved employee green practices are amongst the incentives and the areas adding market value of e-business within the industry. Although it is hard to ascertain whether CH2 will remain within its $51 million budget (including $11 million on sustainability features) due to delays in the completion of the project, the Melbourne City Council has claimed that up to $11 million could be recovered within 10 years due to energy cost savings and productivity gains. In this case study, e-business practices enabled informed and building performance decisions. Web-based tools were here reviewed and summarised.

Identified practices which are likely to accelerate e-business adoption include: (1) using case studies to demonstrate use of specific online tools; (2) facilitating training; (3) allowing time and space for error when introducing new practices; (4) increasing organisations awareness of research publications on e-business uptake; (5) offering follow up expert consultation; (6) establishing quantitative correlations on the use of specific e-business practices and improvements on green building performance; (7) highlighting collaborative decision-making; and (8) using e-business as a communication tool to ensure improved service to the client.

It’s been proposed that building projects like CH2 are the test-beds for innovation and in this particular case it certainly has been the catalysts for the development and uptake of the e-business tools and technology adoption model here investigated.

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SUSTAINABLE PROPERTY INVESTMENT – THE FUTURE OF THE NEW ZEALAND MARKET

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Summary
Over recent years the global market for sustainable commercial property has substantially increased in importance and profile, with rapid growth occurring overseas which in turn has led to substantial changes in the property market. The New Zealand property industry has recently been introduced to the concept of sustainability, and although at an early stage there are signs of an accelerated uptake of sustainability in the industry. Even though targeted measures have been taken by the New Zealand Green Building Council and government, there is perhaps considerable hesitation and scepticism existing in the property market from both an investor's and a building owner's perspective. The research presented in this paper discusses the results of an investigation into market perception of sustainable buildings from the investment community in New Zealand. Property investors from New Zealand were surveyed about their perception of sustainable buildings in New Zealand and their actions with regard to their own commercial portfolios, as well as the relationship between sustainability and property investment decisions. The paper provides an insight into the rapidly evolving area of sustainability and office buildings, with the emphasis placed on the valuation process that seeks to assess a hypothetical purchaser's perspective of the relationship between sustainability and property.

1.0 Introduction
The market for sustainable commercial buildings is gaining momentum in the design and construction arena, however development and investment in sustainable buildings by the private sector remains limited (Reed & Wilkinson, 2005), particularly away from government pre-commitment. It seems there is limited information available detailing the financial viability of operating new or refurbished sustainable buildings, commonly referred to as 'the business case for sustainability' and relatively little research has been conducted into the relationship between sustainability and the market value of commercial buildings. To-date much of the emphasis has been placed on owner-occupied sustainable commercial buildings or the value perspective of sustainability from a tenant's perspective. However in order for sustainability to gain industry-wide acceptance it is critical that the majority of building owners and investors are assured of depth in the market, as well as the financial certainty and viability of sustainable buildings. Clearly if the continued supply and uptake of sustainable buildings is to continue in the property market, then it is essential that the links in the relationship between market value and sustainability are identified and understood. This process, in turn, will promote investment in sustainable office buildings.

Currently the market for sustainable buildings in New Zealand is being encouraged through government legislation and policy; however investment by the private sector in sustainable buildings generally has been slow to develop. This is partly due to the lack of proof confirming the economic viability of sustainable buildings, for example where the absence of detailed market evidence, sales data and lease transactions of sustainable buildings have restricted support for the argument that sustainable buildings are feasible (Lutzkendorf and Lorenz, 2005). The lack of concrete evidence about the correlation between value and sustainability leaves the investment industry uncertain about the financial benefits of sustainability (Madew, 2006). To-date much of the emphasis has been placed on normative research on owner-occupied sustainable commercial buildings, even though the majority of buildings in the market are owned by investors. This study investigates the financial business case for sustainable buildings from an investment perspective, where emphasis is placed upon the importance of using existing valuation methodology to accurately assess the financial viability of sustainable buildings in the current marketplace. This paper discusses the first stage of an on-going research project that was undertaken in New Zealand in 2007.

2.0 Investment Drivers for Sustainable Buildings

There has been substantial research into the design and construction of new sustainable buildings and the benefits from these buildings, particularly from a social and environmental perspective. However it has been argued there is an apparent "lack of mechanisms to align environmental and social issues with economic return" (Lutzkendorf and Lorenz, 2005, p.215). The lack of connection between sustainability and economic return affects the main stakeholders who invest in the property market, namely large financial, banking and superannuation vehicles. These are the key drivers in the property market. In many ways it may be argued that the case for sustainable buildings is being pushed by the demand side of the market, such as by occupiers. Existing research tends to be based on the 'circle of blame' reasoning shown in figure 1, where it may be argued that the occupiers and their demand for more sustainable space will break this circle and increase the take-up of sustainable buildings in the market.

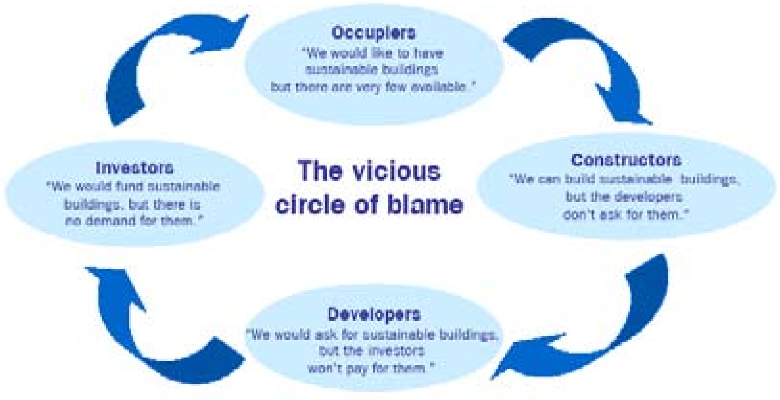

Figure 1. Circle of Blame (Source: Cadman,D.,2000).

However, some sectors of the investment community, given the correct drivers for sustainable buildings, may take it upon themselves to develop and invest in sustainable buildings. In order for this to happen, a solid business case should be developed where the financial benefits of sustainable buildings are fully understood by the investment sector in the market. Hence the 'circle of blame' in figure 1 is modified in the diagram in figure 2 where the determination of the investment value of sustainable buildings by valuers enables the investors to break the circle of blame. Note there is now a resulting flow-on effect through the stakeholder chain from development to occupation, identifying the market value of sustainable buildings by valuers helps to facilitate communication and an understanding of the value of sustainable buildings through the stakeholder chain. By empowering the investors with the knowledge and ability to actively invest in sustainable buildings, the market development for a more sustainable environment and hence the identification of the value of sustainability can be achieved.

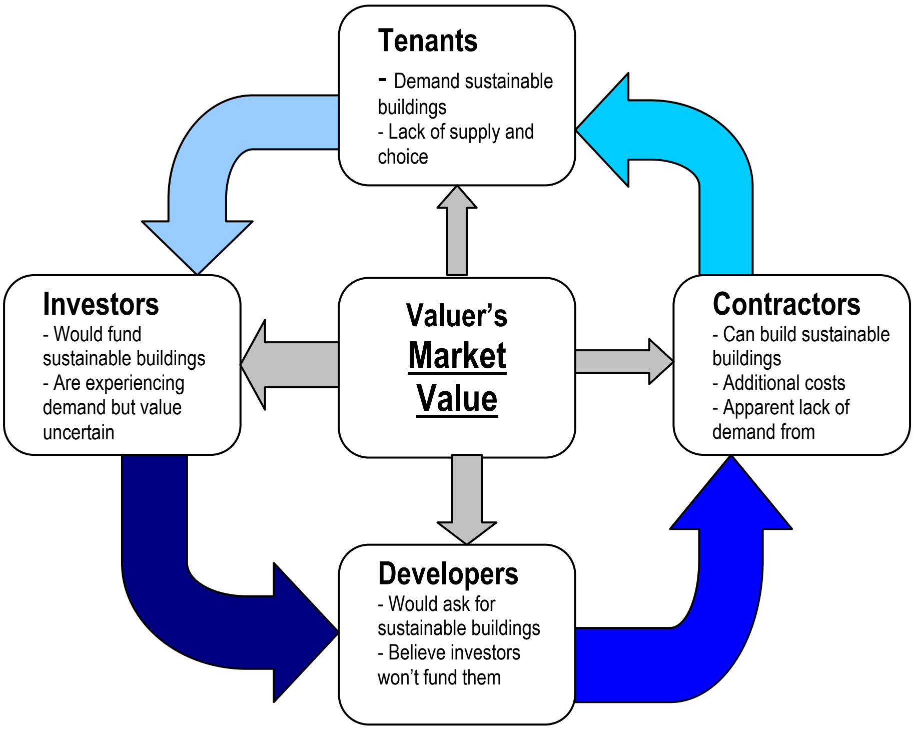

Figure 2. Communication between valuers and stakeholders
(Source: Cadman, D. (2000) Circle of Blame Modified by Myers et al. (2006))

New Zealand is lagging behind the major markets of Australia, United Kingdom, Canada and the USA, with sustainability for the built environment only being introduced in the mainstream property market in the last two years. However, the more advanced experience of other countries has yet to shed light on the financial viability of sustainable buildings and identify the links with market value. To assess why this may be the case the following model has been adopted from McColl-Kennedy et al, Marketing: Concepts and Strategies (1992), which assesses the product life cycle of sustainable buildings and identifies the current stages in the life-cycle of the Australian and New Zealand property markets.

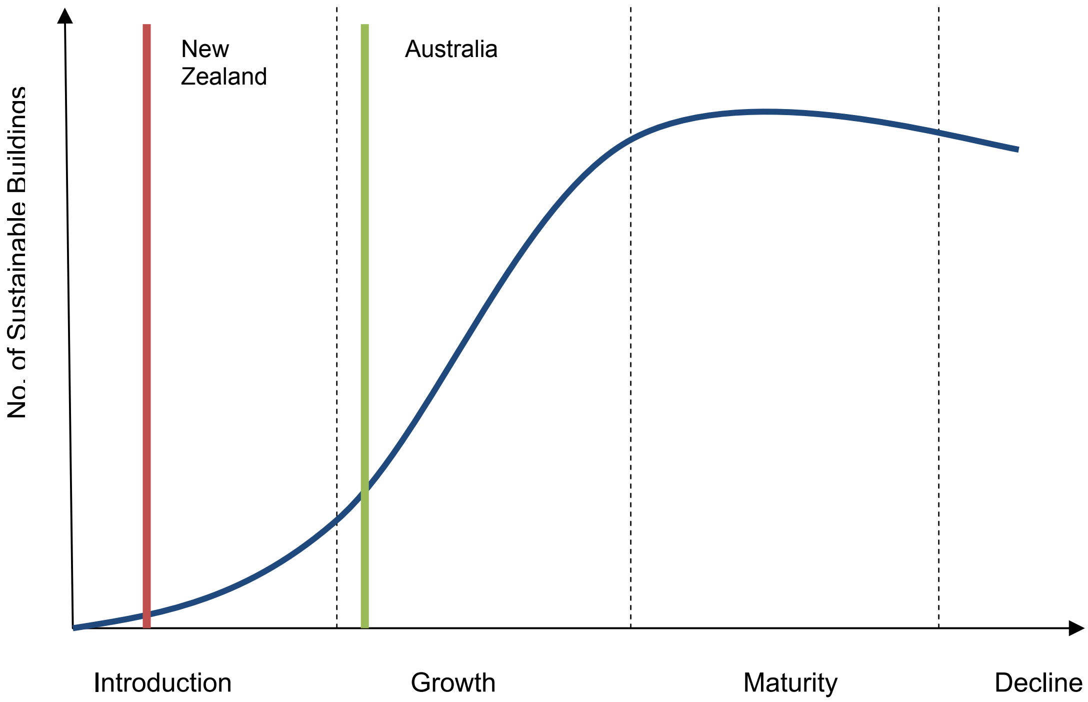

Figure 3: New Zealand and Australia's status in the 'Sustainable Building Market Life Cycle'

The figure above identifies the different stages of market development of Australia and New Zealand, Australia being somewhat more advanced than New Zealand, as the concept of sustainability in the built environment became more prevalent in the property industry early in this century. Thus it is provisionally identified that Australia is now entering a Growth phase, whereby there is increased acceptance of sustainable buildings by the industry spurring more development. New Zealand is still at the elementary stages of the Introduction phase, however with close ties to Australia through the majority of investment funds and institutions, New Zealand will most likely see an accelerated advancement through the Introduction phase.

Australia maybe entering the growth phase, as may the other major world markets, however there is still no conclusive evidence of the financial relationship between sustainability and value. This maybe because of where the markets are currently located along the product life cycle, the impact of financial benefits are not often perceived to their full extent until the Maturity phase is reached. The Growth phase indicates that many perceive a potential profit or value in developing sustainability in their portfolios. Once the Maturity phase is reached, it is commonly attributed that there is a certain financial value linked with this phase. However for the Maturity phase to be reached the property market needs to be convinced of the financial value of sustainable buildings. The purpose of study is to identify which elements in the relationship between sustainability and market value and thus have the greatest ability to impact the value. By identifying the market perception of two markets at different stages in the life cycle gives further insight into relationship elements that may influence the market value of sustainable office buildings.

3.0 Market Forces

Investors and developers need to know the extent to which sustainability is impacting property worth if they are to respond effectively to sustainability issues (Sayce and Ellison, 2003). This will require an analysis of how market value is determined for commercial office buildings. ‘Market value’ is defined by the International Valuation Standards Committee (IVSC) as “the estimated amount for which a property should exchange on the date of valuation between a willing buyer and a willing seller in an arm’s length transaction after proper marketing wherein the parties had each acted knowledgeably, prudently and without compulsion” (IVSC, 2008). Industry valuers undertake current valuation practice by the calculation of the present value of future income streams, which in turn determines the market value of the property. Investors, owners, developers and lending institutions rely on the valuation reports produced by valuers that state the market value of the asset. The crucial nature of decisions made in the finance industry requires a standardised methodology for the determination of a property’s market value.

Assessing the market value of income producing assets is commonly undertaken through two methodologies, namely (a) the capitalisation of income approach and/or (b) the discounted cash flow (DCF) approach. In Australia and New Zealand the discounted cash flow technique has commonly been used for determining the market value of office buildings through the analysis of cash flows of the property over a period of time (API, 2007).The determination of market value, whether using the capitalisation of income or DCF approaches, relies heavily on the current market rents and yields of comparable properties. A valuer undertakes a range of comparative analyses of other properties when identifying market rents and yields for the subject property. Thus key determinants of market value depend greatly upon the property market climate. The valuation community relies heavily upon comparable transacted evidence to determine the market rents and consequently identify market value. This heavy reliance on comparable evidence has been criticised widely (Aldridge, 1989; Burton, 1992; Crosby, 1997) and the increasing shortcomings of this reliance upon comparable rents is a key issue when identifying market rents for sustainable buildings. In addition there is a lack of evidence documenting rent transactions in the New Zealand market due to the limited number of sustainable buildings. In turn this makes it inherently difficult for valuers to assess an appropriate market value for sustainable buildings. There are also a variety of potential shortcomings evident when assessing conventional buildings for a market rent which was highlighted by Whipple (1991), Crosby (1992) and Teale (1995). A valuer needs to ascertain other market variables to assess whether the market evidence being used is appropriate for comparison, where some of these variables include: the level and availability of stock, vacancy levels, quality, landlord or tenant market, economic determinants, market pessimism and willingness of tenants’ to pay rental levels dependent upon tenant requirements.

Changing occupier requirements suggest that a focus upon sustainable space is an increasing prerequisite. A report published by Jones Lang LaSalle highlighted a substantial change in market perception amongst the occupiers, whereby the majority of occupiers across Asia Pacific were willing to pay more for sustainable space (Jones Lang LaSalle, 2007). On the other hand, Lorenz (2007) concluded that the financial benefits for sustainable buildings needed to be included within the property valuation process; these suggested benefits could be identified through gauging the gradual changes in market participants’ perceptions for favouring sustainable buildings. The investigation of the financial case for sustainable buildings focusing on market rents is only one element of the valuation equation. Thus the investor and developer's perception of sustainable buildings is equally important as they influence the market for sales and investment decisions. Therefore the initial investigation was to identify market perceptions from the viewpoint of owners and investors.

4.0 Research Methodology - Investor Market Perception in New Zealand

The objective of the survey was to identify the mindset of the investment industry in New Zealand, to determine or construe how sustainability will affect the property market in New Zealand. Once the interviews were undertaken the author broke down the responses into a literature analysis first and then applied some statistical methods to interpret the responses and understand the reality of investment in sustainable building in New Zealand. The survey was constructed in an attempt to understand the real investment intentions of major investors in New Zealand. The initial questions aim to gain an understanding of overall and general opinion of sustainability and then work towards the company's investment priorities. The surveys were undertaken between June and November 2007 and involved interviewing key property investors in the New Zealand market. Participants were asked nine unstructured questions relating to their organisation or company's key investment priorities and perception of sustainable buildings. The top 30 investment companies were identified and contact and interview times were made with CEO's and other high ranking employees through email, phone and in person. The response rate initially was 70% however, on further review it was determined that a number of interviewees were inappropriate and created bias in the survey, thus they were consequently removed, leaving a final response rate of 61%. The literature and statistical analysis of the results identified a group of outliers, and when further scrutinized it was found they made up a separate group to the majority of investors. Members of this group were not considered to be true investors in the property market, in that their interest in the building was short term rather than long term. A number of respondents interviewed were primarily developers with minimal long term investment priority; whereas the aim was to interview major investors who had a primary focus on owning and operating buildings in the longer term.

5.0 Data Collection and Analysis

Investor responses as to their perception and understanding of sustainability were delineated into three core respondent groups as detailed in table 1. Although all respondents had some knowledge of sustainability and its meaning their views of how it would affect their business were varied. Table 1. highlights the divergence in responses, with a majority of companies having a very positive outlook about sustainability (43%), a middle group who saw the long term positive nature of sustainability (36%) and a neutral or negative group (21%) who believe that sustainability does not affect choice when assessed financially.

The positive group see sustainability as a revenue generator, particularly the financial opportunities that can be gained from a branding, marketing and reputation for being more sustainable. Key opportunities identified by respondents were the ability to be market leaders and to gain significant market share through having differentiated assets (more sustainable) and creating that competitive advantage over the existing building stock. The majority of investor respondents could see this advantage being driven by both global and local drivers that would affect occupancy requirements of tenants, thereby creating an enhanced demand for sustainable space. It was acknowledged that the international investment community are starting to grade their portfolios and are interested in assets that provide more than the standard level of office quality.

The median positive group assessed sustainability as being something that would be nice to have but not at an expense. The belief was that sustainable buildings in the current market were additionally expensive to develop, without proven results of the financial return and ability to assess the risk involved to take on the challenge of sustainable development. Although realising the need to have more sustainable building stock, however not having excess capital to develop or extensively refurbish buildings, this group chooses to make more long term solutions by assessing their buildings and embrace sustainability where financial paybacks are proven. This group saw the potential for more long term gains rather than taking on the risk by being in a market leadership role. The risks and costs involved in being a market leader did not demonstrate significant advantage, and until the financial paybacks had been proven by undertaking sustainable practices only small steps would be taken towards incorporating sustainability into their property portfolios.

The last group held either a neutral or a negative view of sustainability for the property industry. Investors tended to believe that sustainability was not very important at present and only required consideration if the property had government tenants and was located in Wellington. They believed the demand was limited and not high or broad enough in the industry to change the occupancy requirements overall, particularly when price came into effect. They believed that tenants would continue to make decisions about premises solely on price (rental), and not on whether it had sustainable attributes. The only benefits they perceived that sustainability would offer them were reducing operating costs and recycling, although this did not equate to significant added value for the asset.

The vast majority of investors surveyed saw sustainability in a positive light, as long as it proved to provide financial benefits to the company. Little was mentioned about achieving corporate social responsibility (CSR) goals, helping the environment or reducing carbon emissions. Essentially investors are still interested primarily in the financial bottom line and how sustainability can be used to improve that bottom line.

Table 1: Company Perception of Sustainability and Buildings

Respondent group	**(a) Awareness & Importance**	**(b) Effects**	**(c) Why**
Very Positive Companies: 43% of total respondents	• Very High • Immediate Action	• Market leadership opportunity • Response to market demand • Global drivers	• Market competitiveness • Optimisation of property management • Market driven returns • Sustainability = premium
Positive Companies: 36% of total respondents	• Understand concept to be increase building efficiency • Medium to long term applicability • Sustainability desirable but not at a cost	• Upgrading of portfolio over time • Paybacks and financial requirements	• Medium to long term gains • Keep up with market
Neutral and Negative Companies: 21% of total respondents	• Not very important at moment • Only an issue for Wellington • If you want government tenants	• Limited to efficiency in operational expenditure • Recycling	• Sustainability is not affecting choice when financial aspects come into play • Wait for significant tenant demand

After identifying the investor's perception and understanding of sustainability, as well as potential benefits and drawbacks, the survey then asked if they were undertaking sustainable actions in their own portfolios. Table 2 shows a different response in comparison to the results in table 1, being approximately divided into thirds; 36% of investors actively undertaking sustainable initiatives in their portfolio, 29% of investors assessing the benefits and planning for sustainability and 36% currently not undertaking any action. Investors actively pursuing sustainability and implementing strategies throughout their portfolio have a strong corporate stance on sustainability, often linked to international parent companies where reporting and operating directions come from more advanced countries. In addition, the need to maintain their presence in the market as a leader who provides premium property has resulted in the accelerated uptake of sustainability by these companies. The majority of action being taken has a current focus on new development; however existing buildings in their portfolios are being upgraded and retrofitted.

The middle group of respondents are companies starting to assess the viability of sustainability and are looking at medium to long-term focus and upgrade plans. There are restricting factors for them, mainly financial, that are hindering their progress of adapting sustainability. At this stage they are looking at strategic planning, assessing appropriate buildings and the building's drivers for sustainability. This incorporated not only the physical attributes of the building, but asset drivers, focused on the retention or attraction of tenants and maximising future income streams. The corporate goals of the investor are not currently playing a large role in encouraging sustainable buildings and accelerating the uptake. The scepticism in the inactive companies is apparent with many viewing sustainability as a passing fad that will not have a significant grasp on the market. Lack of investor action is linked to market immaturity, lack of financial evidence supporting financial benefits of sustainability and the possible market depth and longevity. Overall investors are certainly watching the market and the overall progress, although there is a risk then there are still a number of major accepting investors who are embracing this risk and aiming to achieve market leadership and high market returns. It was evident that organisations that have strong corporate social responsibility reporting and objectives are aligning these with their business and property operations. Perceived gains were not necessarily as a result of tenant demand, but were from the organisation's position in the market and opportunity of providing and owning premium property.

Table 2: Company incorporation of sustainability into portfolio

Respondent group	(a) Activeness	(b) Action Taken	(c) Why
Active Companies: 36% of total respondents	• Currently implementing sustainability in portfolio • Strong stance on sustainability	• New Buildings • Upgrading and retrofitting of existing buildings	• Market leadership • Premium property • Market driven returns
Beginning to Act Companies: 29% of total respondents	• Assessing financial viability of sustainability for company • Medium to long term applicability planning	• Strategic planning for assets • Initial audits and assessments on selected buildings (appropriately profiled) • Paybacks and financial assessments	• Medium to long term gains • Sustainability desirable but not at a cost • Keep up with market
Inactive Companies: 36% of total respondents	• Low level of activity • Some strategic planning • Watching market	• Strategic planning • Analysis of cost-benefit ratio • Market research	• Lack of financial evidence • Uncertainty of market depth • Sustainability a fad

Tables 1 and 2 demonstrated the differences between the perception of sustainability and the actions of the organisations, from a ratio of 4:3:2 in perception to approximately thirds in actively undertaking sustainability, highlighted in figure 4.

Figure 4.Comparison of Industry Perception of Sustainability and Industry Implementation of Sustainability

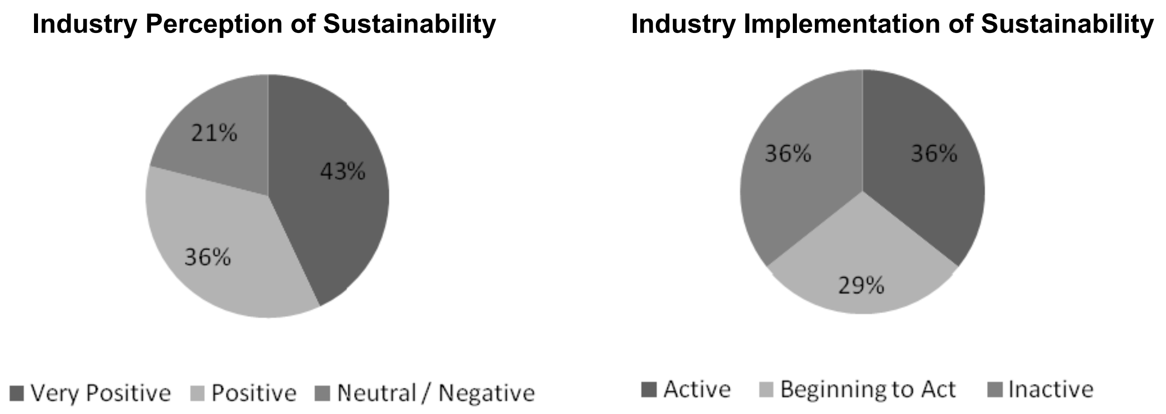

Table 3 and figure 5 highlight the importance in the property portfolio and whether investing in sustainable buildings is a priority. Initially looking at whether sustainable buildings are an important part of the organisation's portfolio, there was an overwhelming majority of 57% that declared sustainable buildings were not a consideration in the portfolio. 21.5% responded that sustainable buildings were not currently important and 21.5% declared that sustainability was an important part of their portfolio. This related to current investor priorities, where the second part of the survey identified intentions to invest in sustainable buildings. This resulted in a change in the ratio, with 57% of respondents claiming to want to invest in sustainable buildings, 21.5% who would consider investing but focused on their existing assets and finally 21.5% who would not consider investing in sustainable buildings at all. The results provided an insight into where investors believe the future direction of sustainable property. The majority (78.5%) of investors believed that sustainable buildings will be an investment requirement for their portfolios, either through new or existing buildings.

Table 3: Importance of Sustainability in your portfolio

(a) Are sustainable office buildings an important part of your portfolio?
(b) Is investing in sustainable buildings a consideration for your portfolio?

Respondent group to question 3 (a)	Respondent group to question 3 (b)	Why
Sustainable buildings are an important part of portfolio: 21.5% of total respondents (Call Group A)	Currently investing in sustainable buildings: 57% of total respondents Change +21.5% from Group B investors +14% from Group C investors	• Fundamental to remain in as a market leader • Premium property portfolio • Market driven returns • Response to tenant demand • Corporate Social Responsibility – company goals
Sustainable buildings not currently important: 21.5% of total respondents (Call Group B)	Consider investing but focused on existing assets: 21.5% of total respondents Change +21.5% from Group C investors -21.5% to Group A	• Analyse current assets and align with tenant requirements where required • Sustainability desirable but not at a cost • Keep up with market • Similar to other technological advancements
Sustainable buildings are not a consideration: (Call Group C) 57% of total respondents	Not considering investing in sustainable buildings: 21.5% Change -21.5% of total respondents -14% to Group A -21.5% to Group B	• Lack of financial evidence • Costs • Lack of demand • Market might be ready in 5-10 years time

Figure 5. Comparison of Industry Importance of Sustainability in Portfolios

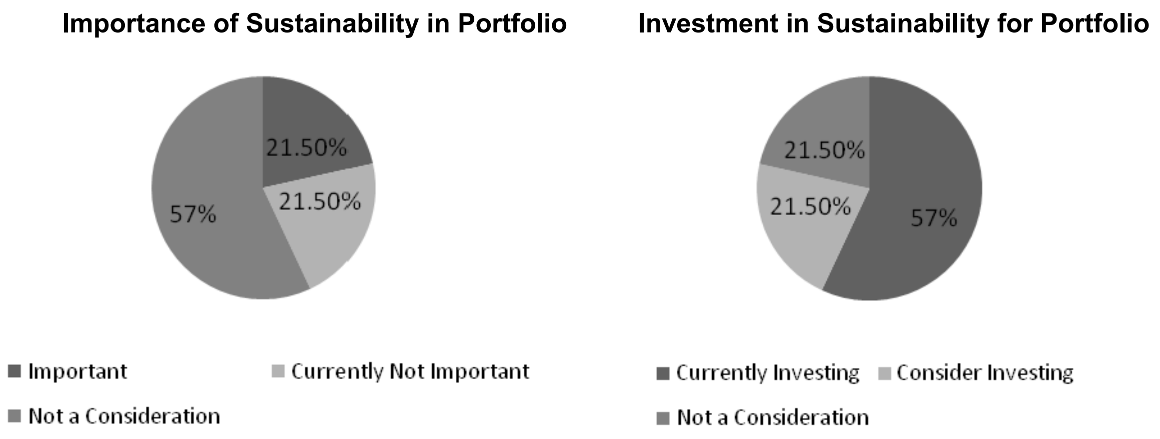

Table 4 presents the responses about whether a changing investment strategy will equate to different values for sustainable buildings, and whether investors are willing to pay a higher price for a more sustainable building. The investors want to have a sustainable building and what they are willing to pay to become a part of that sector is outlined in table 4. Overall 71% of respondents indicated they would pay a higher price to purchase a sustainable building, whilst only 29% stated they would not. The respondents, who affirmed they would not invest in sustainable buildings at a higher price, reasoned that the market was not mature enough to determine how much more should be paid for a sustainable building. In addition it was stated that the market for sustainable space is still very immature and there is a severe lack of evidence. From these companies' perspective, the financial evaluation of the operation of a sustainable building without having significant market evidence to pay a higher price subjects the company to a higher level of risk.

Table 4: Commitment of Investor to pay a higher price for Sustainable Buildings

Respondents	Respondents' Comments
Respondents who **wouldn't** pay a higher price currently 29% of respondents	• Market maturity • Caution about paying premium prices simply because some of the building characteristics are 'sustainable' • Rental quantum needs to be documented and researched further • Sustainable buildings subject to higher levels of depreciation due to the acceleration of technologies
Respondent who **would** pay a higher price currently 71% of respondents	• Only if market demonstrates growth in this area • Definitely if building had a rating ensuring that blue chip tenants would want the space and thus gaining better rents, if not now definitely in the future • Based on the potential reduced vacancy and reliable income stream • If lower operating costs are sustainable then by virtue of the resulting higher net building income a higher purchase price would result • The purchase of a conventional building would mean that in the future a significant upgrade would be required to remain competitive • Building will achieve better rents thus pay a higher price • Operating expenditure will be lower, thus creating more value and accepting a higher purchase price for the same cap rate • The effect will be more obvious as the market matures, however will there be high levels of obsolescence and deprecation in the existing stock • Otherwise in the future you will have to look at spending money to bring up ordinary assets to spec in the market and the opportunity of significant gain might be lost

Although the majority of respondents replied they would pay a higher price for sustainable buildings there were a number of associated conditions, which further supports a level of uncertainty that investors feel in New Zealand about sustainable buildings. The expectation was that a sustainable building would result in higher rents, reduced vacancy, premium or government tenants, reduced operating expenditure and a reduction in future capital expenditure all affect the return on investment ratio and the value of the property. Hence the argument that investors would pay a higher price is based on the perceived financial return they would receive from the property, which essentially is like any other investment. Some investors believed they would pay more just to have a sustainable building in their portfolio based on the understanding it is not necessarily physical financial return but certainly an intangible element of value for both the property and the organisation. How much physical financial value versus the intangible value of a sustainable asset is still yet to be thoroughly researched and the values identified.

6.0 The Future of Sustainability in New Zealand Property Stock

Overall the perception in the New Zealand investor market was that sustainable buildings will play an important role in property portfolios in the future. Although there is uncertainty about the value and market for sustainable buildings at present, investor optimism was clearly identified. However the level of uptake and investment in sustainable buildings would be accelerated if evidence for the financial case for sustainable buildings was proven. New Zealand investors seem to be embracing sustainable buildings in a different way to other global property industries. The inherent traits of New Zealanders as entrepreneurs, in addition to having the benefit of observing the development of sustainable buildings elsewhere in the world over the last decade and identifying the benefits accruing to market leaders worldwide, has resulted in an optimistic mindset and increasing adoption of sustainable buildings in the local market. The response in New Zealand has been accelerated by the release of the benchmarking tool (e.g. *Green Star NZ*), being the first and only sustainable rating tool for commercial buildings in New Zealand.

The future for sustainable buildings in New Zealand is positive and with the envisaged increased government requirements, both nationally and internationally, the development of sustainable buildings should continue. Nevertheless how these buildings are treated in a market sense is still yet to be fully understood, although the potential of a two-tier market is highly likely. Perhaps there will be a tier that encapsulates the sustainable buildings and then the second tier that is the rest of the building stock which is not thus far deemed sustainable. It appears likely that preference will be given by larger tenants for the upper tier of sustainable stock, which will in turn create new rental benchmarks, reduced vacancy and other perceived premiums. At the same time the remaining building stock may see a 'non-sustainability discount', possibly created from increased levels of vacancy, lack of tenant demand, lower rents and increased depreciation. This may be particularly evident in Wellington where government may decide only to occupy sustainable space, although that impact might be detrimental to the office stock in the Wellington area (note that the government occupies approximately 41% of office stock in Wellington). Potentially there may not be evidence that sustainable buildings will have premiums, but instead have a slower rate of obsolescence in comparison to non-sustainable buildings which will become obsolete at a faster rate. With preference being given to more sustainable stock, the potential for increased vacancies and lower rents will lead to a requirement for non-sustainable buildings to undergo extensive upgrades to keep up with the majority of the market. Although market rental and sales evidence might or might not prove that sustainable buildings achieve higher rents and prices, preference, vacancy and letting up times in addition to the impact of obsolescence and depreciation creates other avenues of investigation and research that is vitally important to the determination of market value of sustainable office buildings.

7.0 Value Case – Further Research

As with many other industry sectors the property sector is yet to fully embrace sustainability, although in New Zealand there seems to be a quite positive outlook at present towards sustainable buildings. However the majority of investors still appear hesitant to invest in sustainable buildings as they lack the appropriate tools to identify the investment benefits. It has been argued there are no 'real' proven incentives to invest in sustainable buildings as most of the benefits accrue to the occupier rather than the investor (Lawther et al., 2005), where the findings of this research appear to support this argument. To further discourage the investment community there are currently only "inappropriate financing models which focus predominantly upon immediate financial return, or lack of access to capital" (Lawther et al, 2005, p.58), which is in addition to other unsuitable cost and payback related tools.

In conclusion the valuation industry is yet to accurately identify and quantify the added value related to sustainable buildings, where the level of sustainability in a building is not yet fully reflected in the valuation process. At times this may restrict investors from identifying the financial benefits of sustainable buildings and consequently inhibit the investment and development of necessary infrastructure. A common thread throughout the interviews undertaken in New Zealand for this study was the resounding need for more information about the financial impact of sustainable buildings from an investor's point of view. The investment communities need evidence, analysis tools and methodologies that identify and prove the impact of sustainability on market value, which in turn will assist in advising investment decisions about sustainable buildings. In reference to the more developed markets of Europe, Lorenz (2007) emphasised the needs and key roles of valuation professionals and the valuation process itself to achieve a broader market penetration of sustainable buildings. Once value is identified in sustainable buildings, it should result in the demonstration to all within the property industry and those also in the investment and banking industries about the value of sustainability.

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BARRIERS FOR GREEN BUILDING PRACTICE IN CHINA

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Summary

There has been significant progress in the green building practice in China during the past decade, especially encouraged by China's Ministry of Construction by organizing several large-scale government-supported programs. The current establishment of the national renewable energy law and various energy efficiency regulations on the local level are also taking important roles to push the improvement of energy performance in buildings. However, compared to all the opportunities both on the technological level and policy level, the adoption of green building practice into the building sector in China is rather slow and limited to demonstration projects.

This paper investigated the finance, design and management processes of several green buildings in China in order to analyze the barriers that prevent the acceptance and wide adoption of green building practice in China. The selected cases included national demonstration projects, local government-supported experimental projects and voluntary projects. The focus of this paper is not to present details of successful green building cases in China, but rather, through how these projects were initiated and made possible both financially and technically, to identify the factors in the current building finance, design and management processes in China that are obstacles to major market adoption of green building practice. Identification of these barriers will lead to an intriguing discussion of what can be done to get over the barriers for effective improvement in green building development and sustainability in China.

1. Drivers of green building practice in China

Along with the huge volume of construction in China, there has been progress in the green building practice during the past decade, especially encouraged by the Chinese government. The major drivers that are pushing for green building practice are similar to the ones that are driving improvement of the overall energy effectiveness and efficiency in various sectors in China.

1.1 Deterioration of environment

Huge amount of fossil fuel consumption for electricity generation, industry, building operations and transportation, accompanying the country's rapid economic development and urbanization, has caused serious air pollution problems in most Chinese cities. Water scarcity and water contamination are also common problems that are impacting the everyday life of a large proportion of the population. China is facing the conjuncture of choking on its own development. The severe deterioration of environment in China has already made it impossible to continue ignoring the pollution problems associated with energy consumption. Buildings, as consumers of huge amount of electricity, natural gas and water, are under the pressure of improving their performance to alleviate environmental impact. Media exposure of pollution problems country-wide and the everyday experience of deteriorating environmental quality also led to growing public awareness that is needed for building the capacity for change.

1.2 Energy security

China is facing energy shortage to meet the ever increasing demand from industrialization, urbanization and the concentration of global manufacturing. It is now the second largest oil importer after the US. The energy security issue is now pushing China to seek for more and more energy sources globally; it led to an illusion, just like that in the US, that China can get oil from all around the world to feed its increasing energy needs. However, the soaring oil price and the concern of energy security did force China to improve its energy efficiency. Chinese government is investing in the development of green power "not only as a solution but also to improve its profile as a responsible international player" (Bezlova, 2006). In order to improve energy security, the government is also raising energy price to slow down the soaring energy consumption increase and to encourage energy efficiency improvements. The prospects for green building practice in China, which focuses on reducing energy demand in buildings, improving performance of building systems and exploring alternative energy supply strategies, have never been better.

1.3 External pressure

Pressure from outside China on its greenhouse gas emissions reduction and environmental pollution alleviation also forced the Chinese government to take on actions to adopt a more sustainable development path, though there is no obligation from the Kyoto Protocol for China. In the building sector, the global green building practice also started to have an influence on China, through knowledge and technology transfer, although the level of awareness of the public in China is still low.

2. New regulations, evaluation tools and organizations

In respond to the aforesaid three drivers, it is obvious that Chinese central government is playing an important role in promoting green building practice. Among the various efforts, establishing new regulations was among the most effective. An example is the China Medium- and Long-Term Energy Conservation Plan (ECP), issued by the National Development and Reform Commission (NDRC) of the State Council in November 2004, which has chapters directly targeting at building energy consumption reduction. It is the strongest push for green building practice in China so far.

The ECP notes that "during the Eleventh Five-year Plan period (2006-2010), new buildings should be strictly subject to the design standard of 50% energy conservation. Several major cities such as Beijing and Tianjin shall take a lead in implementing the 65% energy-saving standard." More specifically, the construction industry and building-related sections of the ECP call for:

1)Accelerating the reform of building heat supply systems and the promotion of energy-saving construction technologies and products. In China's large and medium cities, a charge system based on thermal metering will be widespread in district heating of residential and public buildings; small cities will be pilot of such practices.

2)Carrying out energy conservation retrofits on existing residential and public buildings in the northern regions where space heating is required shall be conducted in combination with urban reconstruction. Large cities are expected to improve 25% of building, medium cities 15% and small cities 10%. Buildings should use such materials as energy-saving doors and windows and new wall materials. In addition, the application of renewable energy such as solar and geothermal energies in buildings should be speeded up.

3)Conducting comprehensive energy conservation renovations of existing hotels and restaurants.

4)Expanding the use of high-efficient and energy-saving lighting systems, tri-phosphorus fluorescent lamps, high intensity gas discharge lamp and electronic ballast. Decreasing the usage of incandescent lamps, and gradually eliminating high pressure mercury vapor lamps. Implementing lighting product energy efficiency standards in public facilities, hotels, commercial buildings, office buildings, stadiums and gymnasiums and residential buildings.

5)Promoting high-efficiency energy-saving household and office electric appliances such as refrigerators, air conditioners, televisions, and washing machines; reduce appliance/technology energy consumption while in stand-by mode; implementing energy efficiency standards and labeling; and standardizing the market of energy-saving products.

Besides efforts on the central level to establish new regulations and tighten the existing codes for both national-wide and specific regions (e.g. the new residential building energy codes for "Hot-Summer Warm-Winter" (HSWW) climate zone in 2003), on the province- and city-level there have also been similar efforts to push the energy conservation and energy efficiency in buildings to a higher level. In addition to regulations, voluntary green building evaluation systems are being developed in China, though still at research and experimentation stage and the impact is still minimal, considering the low public awareness and the overwhelming pursuing for profit and rapid development. Also, the huge difference in climate and economic development conditions among regions in China pose significant challenge for the implication of evaluation systems to be able to reflect local requirements and priorities. It is actually a challenge for many green building evaluation tools in the world.

An example of voluntary evaluation tools in China, which is comparatively influential, is the Evaluation Standard for Green Building, issued by the Chinese Ministry of Construction, together with General Administration of Quality Supervision, Chinese Inspection and Quarantine, established in March 2006. China Academy of Building Research and Shanghai Academy of Building Research were the two major contributors in editing the standards. The standard concerns all new buildings, building extensions and renovations, including residential and public buildings. It consists of building performance monitoring and economic evaluation, for the entire building life-cycle. The main categories of criteria are: land conservation and environment protection, energy conservation and use, water conservation and use, materials conservation and resource use, indoor environmental quality and management (residential building) and life cycle performance (public building). The US voluntary evaluation system, the Leadership in Energy and Environmental Design (LEED), had significant influence on the framework and contents of this standard. According to the performance of the building, the developer will get a rating, on a scale of 1 to 3 (star system).

Before this standard was published, some developers use “green building” only to attract consumers. With current evaluation criteria, it is much more transparent and easier for the public to understand the actual performance of buildings. One year after this standard was in use, developers can only use the phrase “green building” to promote their development if it fulfilled the 6 categories of criteria in the standard.

Among the various forces to promote green building practice, several organizations also played a positive role, e.g. the China Sustainable Energy Program (CSEP) – Towards a Sustainable Energy Future for the People’s Republic of China and the China-U.S. Center for Sustainable Development. Though their focuses vary, their common goal is to coordinate the cooperation among the business community, governments, universities, research institutions and non-governmental organizations, and the cooperation between China and developed countries (mainly the US), to assist in China’s transition to a more sustainable future. They engaged with senior government officials and leading industry representatives who are charting the future development path for China, and initiated demonstration projects and developing new solutions by providing initiatives and grant-making. Another constructive role these organizations are playing is in supporting capacity building and technology transfer through linking Chinese experts with "best practices" expertise from around the world, to help Chinese agencies, experts, and entrepreneurs solving challenges for themselves.

3. Case studies of green building practice

In the effort of transforming the building sector in China towards more sustainable, there were several projects that were built with high performance standards, including national demonstration projects, local government-supported experimental projects and projects by private developers.

3.1 Energy Efficiency Demonstration Building, Ministry of Science and Technology of China, Beijing

This 10-storey, 12,960-square-meter building was developed by the Ministry of Science and Technology of China. It was completed in February 2004 at only US$770/square-meter.

This was a Sino-US collaboration project demonstrating the integration of multiple energy efficiency strategies. The high-performance envelope system integrated strategies included light-color composite block exterior wall, polyurethane waterproof roof insulation foam and super-light inorganic roof vegetation soil, thermal break aluminum frame with high-performance low-e glass, outdoor horizontal fixed shading device to control solar radiation for all south-facing windows, and reflectors for deep daylight penetration. The conditioning of the building adopted natural ventilation, multi-stage absorption chiller, ice-storage system, variable flow air conditioners and heat recycler on roof. The lighting system was featured with daylight sensors, occupancy sensors, and energy efficient lighting fixtures with 0-100% digital dimming ballasts. Other green strategies included variable-flow water supply system, storm water reclaimed at roof garden (70% roof area) and underground storage, waterless urinals and water-efficient toilets, automated building control for lighting, ventilation, thermal and security systems, and low VOC paint.

The actually measured annual energy consumption is 72.3% less than that required level by China Building Energy Efficiency Standard. According to the Chinese Ministry of Science and Technology (Yang, 2005), this building registers annual power consumption of 38.4 kWh/square-meter, 30% of the power needed by conventional office buildings in Beijing. A 15-kW roof PV system generates over 5% of the building’s power consumption in cost. 75% construction waste was reused, and over 90% building materials were harvested and/or manufactured locally. The annual electricity savings is 900,000 kWh. Annual savings on power and water expenses are over 700,000RMB (US$89,000). Building cost increased by 4 million RMB (US$510,000) on energy efficiency and green strategies (8%), but the payback period of the first-cost increase is only 7 years, based on the 2004 energy price.

3.2 SIEEB – Sino-Italian Ecological and Energy efficient Building, Tsinghua University, Beijing

This 10-storey, 20,000-square-meter building was developed by China's Ministry of Science, Technology and the Italian Environment Ministry and Tsinghua University. It was completed in July 2006 at US$1,700/square-meter, and will host a Sino-Italy education, training and research centre for environment protection and energy conservation.

Overall this building used some hundred energy efficient technologies and products developed by research institutes or manufacturers both in China and abroad. Nearly fifty US, German, Japanese, Denmark and Chinese manufacturers contributed their latest energy efficient technology and products to the building. Dozens of products or technologies were used for the first time in China. The envelope components, as well as the control systems and many technologies were the most updated Italian production, within the framework of a design philosophy in which proven components were integrated in innovative systems.

The building shape was derived from an analysis of the site and of the specific climatic conditions of Beijing. Located in a dense urban context, surrounded by some high-rise buildings, the building optimized the need for solar energy in winter and for solar protection in summer. The integration of a green roof and a solar PV roof on the recessed floors not only reduced energy consumption but also produced energy. The green roof helped to retain storm water. There are also grey water reuse systems in this building. Other building envelope and system strategies adopted included reflecting and semi-reflecting lamellas and louvers, gas engines coupled to electric generators for electricity generation with rejected heat for heating and cooling purposes, displacement ventilation and radiant ceiling systems, and a high efficiency lighting system.

The SIEEB project was the result of cooperation between the Italian Ministry for Environment and Territory and the Chinese Ministry of Science and Technology, and was also part of the "Clean Mechanism" project by Italian Environment Ministry. It was regarded as a platform to develop the bilateral long-term cooperation in the environment and energy fields and a model for showing CO2 emission reduction potential in the building sector in China. It was also the result of an international collaboration among consultants, researchers and architects. This integrated design process was a most distinctive part of the project and a key issue for the success. (Cucinella, 2006)

3.3 Green Demonstration Building of Shanghai Research Institute of Building Science

This 3-storey, 1,900-square-meter building was developed by Shanghai Research Institute of Building Science. It was completed in September 2004 at US$570/square-meter.

The Green Demonstration Building of Shanghai Research Institute of Building Science was a key project of the "Green Building Technique and Systems Integration" research by Shanghai Science and Technology Committee. As a demonstration project, the green building contained multiple green energy technologies, including solar thermal technology, photovoltaics, natural ventilation, and daylight. Four types of exterior wall materials and three types of roof materials with different U-value were used for different orientations. Horizontal adjustable exterior shading on the south façade and vertical adjustable exterior shading on the west were installed to reduce energy consumption by 47.8%. Solar thermal collector and photovoltaic systems were placed on the pitched roof, harvesting 0.2 kWh/square-meter solar thermal and generating 5 kWh/square-meter electricity annually. Integration with solar collectors, low-temperature floor heating and hot-water-driven desiccant dehumidification systems were adopted for winter heating and summer cooling. Desiccant dehumidification system reduced the air-conditioning energy consumption by 20%. 80% of the building construction materials are 3R material, such as concrete hollow blocks produced by recycled aggregates. The building also adopted an ICAST rain recovery system. The annual site energy consumption of this building, based on software simulation, is 56 kWh/square-meter, with the annual primary energy consumption level at 153 kWh/square-meter. (Zhen, 2005)

3.4 Tianpu Solar Building - Beijing Olympics scientific and technological demonstration project of new energy comprehensive utilization in buildings, Beijing

This 6-storey, 8,000-square-meter building was developed by Beijing Tianpu Solar Energy Industrial Company Ltd., completed in 2003.

This is a mix-use commercial building, with functions including office, apartment, exhibition, restaurants and recreation. It featured a 1,200-square-meter evacuate tube solar thermal air collectors integrated with the roof and a 50-kW photovoltaic system integrated with the south-facing facade. In the winter, the solar-heated hot water is stored in the underground reservoir and used for heating when needed; and in the summer, it is used to drive an absorption chiller to produce chilled water for cooling. Heating and cooling are provided through radiant panels to ensure thermal comfort of end users.

This building was the first demonstration project in China for the comprehensive utilization of solar energy. Because of good insulation and high-performance envelop, its heating demand is 40% less than that of a typical commercial building in Beijing; cooling demand is 28% lower. 80% of the building's energy consumption is supplied by solar income. The PV system generates 40,000 kWh of electricity per year. The lighting system and sometimes even computers and TVs in this building are powered by electricity from PV. Annual electricity consumption is 2 Million kWh less than an average commercial building with similar size and the same type. The solar thermal system generates 9 tons of domestic hot water per day on average, which results in savings of 13,000 cubic-meter natural gas annually (Gen, 2006).

4. Barriers for green building practice in China

Despite the strength of the push from Chinese government through policy and legislation, the adoption of green buildings into the main-stream practice in the building sector in China is still rather slow, so far largely limited to demonstration projects. The process through which the aforesaid green building projects were initiated and made possible, both financially and technically, reflected obstacles in the current building finance, design and management processes in China to large scale market up-take of green building practice.

4.1 The image of "green building"

In recent efforts in promoting green building practice in China, the image of green building was simplified as energy-efficient building, the understanding of which was often associated with application of high-tech building systems. It was also among the reasons that result in the perceived high cost of "green building" or "energy-efficient building". However, another important aspect of green building design and a critical element to achieve the "zero energy building" goal, the passive strategies, have not got enough attention. Climatic design, use of thermal mass, siting for passive heating and cooling, natural ventilation, daylighting and use of landscaping and trees for shading were all used extensively and smartly in traditional Chinese architecture, while in current green building practice, the value of these passive strategies didn't get recognized at a level that they deserved. Such passive strategies are generally the most inexpensive way to provide a comfortable and healthy building environment with minimal energy load, and will effectively contribute to demand reduction and energy conservation. The reason partially relies in the fact that high-tech active strategies are considered with higher “business value” that will help manufacturers and developers to promote their products and properties. The introduction of most green building demonstration projects in the media is not doing a good job promoting passive strategies.

4.2 First-cost-oriented business mind set

Decision making process in real estate and business is dominantly first-cost oriented in China. It is actually the case for a majority of countries and regions in the world. In China, this may be further exaggerated because of the speed of economic development. Business decisions tended to be immediate profit-driven. The primary impediment to a large-scale adoption of sustainable strategies in the building sector is “the perception that green buildings cost more, without any kind of comprehensive understanding of the real value that will be generated” (McDonough, 2007). Though research have demonstrated payback from green building and green building strategies through life-cycle cost including operation energy savings, as well as occupant-related benefits including improved health and workplace productivity, attraction and retention, it is still a challenge to communicate to the developers and building owners about the promising benefits from investing in green buildings. In addition, China is still a labor-intensive economy, in which the occupant-related benefits are difficult to be communicated to and accepted by developers and business owners. This is also the reason why the green building practice in China currently didn’t get much beyond the demonstration level. For demonstration projects, cost is often less a concern in the decision making process.

4.3 Fragmented delivery process

Due to the fragmented nature of the construction industry, project delivery is complex. Sustainability has added to this complexity, which in many respects are linked to the far wider issues of educating the public and promoting investment. In some projects, stakeholders participation came at the later stage of construction. However, implementing sustainability issues should start at the strategic and concept planning and project programming stage, when the technical and economic feasibility of alternatives will be compared in order to select the best possible approaches. There is a need to make clear the importance of stakeholder involvement in the early design of projects. Sustainability decisions made at the beginning of a project life cycle tend to have a far greater influence than those made at later stages, since design and construction decisions will influence the continuing operating costs and, in many cases, revenues over the building’s life cycle. Also, the use of holistic building concept and integrated design process need to be encouraged. Basic understanding of this concept will lead to appreciation of integrated design team, which encourages involvement of stakeholders from the beginning.

4.4 Finance and incentives

One strategy to promote market acceptance of green building practice, that has been proved effective, is by providing incentives or low-interest loans for the adoption of green building strategies. This kind of multi-instrument finance and incentive systems has not been established in China. At present, financial and taxation policies have not given enough support to energy conservation renovation, research and development of energy saving equipment and their application, nor to rewards for energy conservation. In some cases, incentives or financial support were provided to certain demonstration project, but only on a case-by-case basis.

The strong central control on real estate development is not only through the direct regulation of policies and codes, but also through the influence on loans from bank systems. Most of china’s financial institutions are still state-owned. Their decisions on loans are largely constrained by policies. At the central level, China's Ministry of Construction and Ministry of Finance are the major influencers of green building finance. For example, the National Project of Building Energy Conservation, as one of the 10 national energy conservation projects, will invest heavily by year 2010. In China, the centralized political system sets the priority of development. Some important projects can be encouraged and financially supported if they are considered important to achieve the national development goal.

Similar to the situation of finance and incentive systems, the insurance industry in China did not recognize or understand the value of green buildings, such as fewer health claims because of fewer employee illnesses. Insurance companies kept their traditional way of business and formulas of risk estimation, and did not provide discounted rates for green building features like energy-efficient lighting, heating and cooling systems, because they are less risky under the current and future conditions of energy shortage and insecurity.

4.5 Policy and policy implementation

The central power of the government could help enforce energy efficient practices, but that is not as simple as it sounds. First of all, in China, economic development still is the top priority over other things, including efficiency improvement and environmental protection. Many local governments and local industries are focusing on quick return-on-investment. They are reluctant to invest in improvement in energy and environmental performance, which is more about long-term competitive strength and sustainability. Secondly, China is a large country with regions at dramatically different development stages. There are increasing gaps between the more developed and developing areas in China, literally between the coastal areas and the inland. Centralized policies might not fit situation in different regions, and face local resistance. When the centralized government enforces strict energy efficiency policies, these policies often face obstacles and resistance from local authorities in the less developed regions. Some local governments reject energy efficiency policies with the excuse that they must focus on economic development or that energy efficiency policies will limit economic development. Compared to inland China, businesses in cities in the coastal area are more market-driven, though the policy influence is still strong. The coastal area has advantages in promoting green products and businesses.

The implementation of policies and regulations is another challenging issue. The new codes and standards, which fall well behind those developed countries, were purposely designed to encourage compliance. This is understandable, but does little to promote the use of the best available materials and technologies on the international market. Energy conservation laws and regulations are not complete. The “China Energy Conservation Law” was promulgated and put into effect in 1998. However, the lack of compliance and slack enforcement of the law is rampant; the supporting regulations are incomplete, and the exercisability of the law also remains to be improved. Although the building design codes for various climatic zones, targeting 50% energy saving, have been formulated and promulgated successively, only less than 5% of newly-constructed urban buildings as a whole in the country comply with the design codes of building energy conservation.

4.6 Knowledge and technology gap

In China, the knowledge about the importance of energy conservation is insufficient; guideline policy to give priority to energy conservation has not been fully implemented. The development and dissemination of energy conservation technology is inadequate. Also, the capacity building in energy conservation regulatory and service institutions lags behind. These factors all contributes to the difficulties for the implementation of policies and regulations. Similarly, the capacity in China to analyze energy savings and renewable energy opportunities in buildings and to develop policies to capture those opportunities is yet to be built. Improvement in knowledge and technology transfer will help to reduce the reluctance of businesses to try green building strategies that they are not familiar with, and even go further to undertaken in-house study and explore innovative measures that will both make business sense and benefit the environments and employees.

Mutually profitable cooperation and exchanges between China and several developed countries, e.g. US, Germany, Australia, etc., in the fields of ecological technology and green building design and development will be helpful to reduce the knowledge and technology gap. However, the international cooperation at present is mostly focusing on make prototype buildings, while not on the training of local professionals and exerting impact on local building components and materials industries. Since there is not yet a ready supply of 'green architects, builders, materials providers', in many cases, the 'green materials and services' still relies on import, which makes the upfront cost of green building even higher and more difficult to popularize.

4.7 Social awareness

Though there is global pressure on China’s GHG emissions reduction, small portion of the public in China are really conscious of global climate change. For the construction industry in China, sustainability is still a relatively new concept, though there is generally an increase in awareness. However, this awareness is not across the whole spectrum of the building sector. Low level of public awareness has resulted in a lack of understanding of the need for sustainable design, therefore natural resistance to change. The economic barriers are also inextricably tied to the low awareness situation.

In China, though corporate social responsibility (CSR) topics are discussed, environment-related CSR is very little in practice. Many global corporate tend to make less efforts in their operations in China or other developing nations. Corporate executives are usually not personally concerned about global warming. Most developers in China make decisions according to market needs. Very few of them think about social responsibility of creating better built environment for the public. Many landmark buildings designed by some star architects often do not care about promoting the green building concept, while caring more about the branding and image. It is a challenge for the central and municipal governments as well as business owners to choose the “right” architects. On the other hand, employees do not have the awareness about condition of their work environment, energy consumption and global warming.

5. Conclusion and suggestions

In China, there have been already a number of demonstration green buildings in several cities. The Ministry of Construction (MOC) has recently announced 25 demonstration projects for using renewable energy in buildings, as well as awarded 40 building projects and building technologies the title of “National Green Building Innovation Award”. Owners of some large-scale building complexes and high-rise buildings are among the first to consider building life-cycle cost, including operation expenses, and are willing to adopt energy conservation strategies. The Chinese government announced in March of 2006 a new five-year plan to rigorously implement eco-friendly construction standards, refurbish old buildings to improve energy efficiency, and enhance studies on eco-friendly technology, equipment and materials, which will become preferred options in construction projects and improve the legal system to facilitate building energy conservation. The MOC also signed a memorandum of understanding with the US Green Building Council "to address the impact of the built environment on China, the U.S., and the world".

However, green building is not yet common practice in China, even for the newly built office buildings. For example, for all the new buildings built in 2003, only 5% fulfilled energy efficiency standards. When it comes to energy efficiency, newly built buildings are not necessarily doing better than old buildings, though China has set the goal to reduce building energy consumption by half. Most of the green building demonstration projects in China were government-financed projects. The financial support from the government was the critical element to make these projects possible. The government will keep on playing an important role in promoting and financing green building project, before the market start to take over.

The identification of barriers that exist in the building finance, design and management processes, including the image of "green building", first-cost-oriented business mind set, fragmented delivery process, lack of systematic financial support and incentives, problems of policy implementation, knowledge and technology gas and the low public awareness, is the first step in initiating an intriguing discussion of what can be done to get over these barriers for effective improvement in the building energy performance and sustainability in China. Important strategies include:

1)Initiate an awareness campaign targeting the design professionals, stakeholders in the building sector, higher education and the general public, to build the capacity of a main-stream market acceptance. For China's building sector, the most critical thing is to convey the understanding to various stakeholders that clean environment and economic development can be achieved at the same time, and actually one helps the other.

2)Keep developing green building policies and regulations and emphasize on effective implementation, including providing support for the interpretation of codes and laws.

3)Build a business case of green building practice, collect credible evidence of the advantages and necessity of green building practice, specific to China's building market, and emphasizing life cycle cost savings and benefits of green buildings.

4)Develop a systematic series of financial leverages to promote green building practice, including incentives, tax breaks, low-interest loans, as well as insurance programs, that will accelerate the major transform in the building market toward green practice.

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HOW SUSTAINABLE BUILDING AFFECT TO REAL ESTATE MARKETING IN TAIWAN?

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Summary

The majority of the housing performance measurement focuses on primary function encompasses aspects of its use, access, space, connectivity, community, private, security and price etc. However, Environmental crises such as ozone layer depletion, global warming, and ecosystem destruction and resource depletion have increasing importance in our daily life (Langston & Ding, 2001). In Taiwan, Much construction strategy of government recently centers on the concept of ecologically sustainable development, such that establishment of Taiwan Green Building Evaluation System, Green Building Material Labeling systems, Performance Certification Labels etc. This paper adopts a non-monetary approach of the value-evaluating analysis to explore sustainability influence to the real estate marketing. The intention is to provide appropriate information of the environmental values, users' health and well-being to be considered when building owners, design teams, tenants or developers on the decision-making process of a housing development and as a principle for consumers making a purchase decision.

1. Introduction

In recent years as the transitions of the values and living type attitude in Taiwan, the house is developed and already marched toward maturing stage gradually, and the option of a house product becomes a variety of choices. At the same time, as the international sustainable building development and the sustainable and energy-saving policies advocated in Taiwan, modern consumers do not focus only on the residence to live, but also consider added values of the residence such as environmental factors including lighting, ventilation, noise…and so on. Thus if can apply the concept of sustainability, energy-conservation and healthy to use in the planning and design stages of the building that can improve living environment quality and implement the development of the sustainable house effectively (Hill, & Bowen, 1997). It is namely this main idea of research.

House can be defined as a residence product from a real estate investment view. Several marketing studies have explored the effects of patronage decision on consumers that when consumers have the higher perceived value of goods; it will promote their purchase intentions (Sirohi, Mclaughlin, & Wittink, 1998; Grewal, Krishnan, Baker, & Borin, 1998.) Moreover, it also showed that when consumers experience higher psychological cost, will reduce their purchase wills (Baker, Grewal & Levy, 1992; Wakefield & Baker, 1998; Wakefield & Blodgett, 1999). Remarkably, however, in the consumer's opinion, have a positive relationship between the perceived cost and the high performance of sustainable building. Therefore, this study utilizes the consumer's evaluation to examine the effects of the cost-benefit analysis upon the sustainable building performance, and whether to influence consumers' willingness or not.

2. Method

2.1 Applying the concept of Cost-Benefit Analysis for Measurement of Sustainable Performance

Cost-Benefit Analysis (CBA) estimates and totals up the equivalent money value of the benefits and costs to the community of projects to establish whether they are worthwhile. The principle is to calculate various kinds of cost and value of benefit. It is a formal discipline used to help appraise, or assess the case for a project or proposal, which itself is a process known as project appraisal; and an informal approach to making decisions of any kind.

Vogtländer (2002) proposed an assessment indicator with regarding environmental cost-benefit to clarify the environmental eco-efficiency on the performance of products or serve. So, it is to put emphasis on reducing the consumption of resources and the impact of the environment to offer the additional value and interests of the products.

Ding (2005) firstly start to apply the cost–benefit analysis (CBA) approach to develop a multi-criteria approach for a sustainability index focuses on identifying, quantifying and incorporating environmental issues into the decision-making process. The sustainability index combined objective factors, e.g. costs (financial return) and energy usage, together with subjective issues such as external benefits and environmental impact. Both financial return and energy consumption are relevant to the resource input in project development. The other two criteria (external benefits and environmental impact) focus on the effects building development has on the natural and man-made environments. Aimed to optimize financial return, maximize resource consumption and minimize detrimental effects to the natural and man-made world.

2.2 Conceptual model

The paper applies marketing researches, such aspects as the consumer's patronage decision is effected by perceived merchandise value (Sirohi, McLaughlin & Wittink, 1998), and the relationship between perceived cost and patronage intentions (Baker, Grewal, and Levy, 1992). The research adopts the previous evidence that the role of value or perceived cost as an intervening factor between product and choice to frame this approach model that the sustainable building product directly affects the house-purchase choice, or consider an intervening factor of the residential benefit. A proposed conceptual model showed in figure 1.

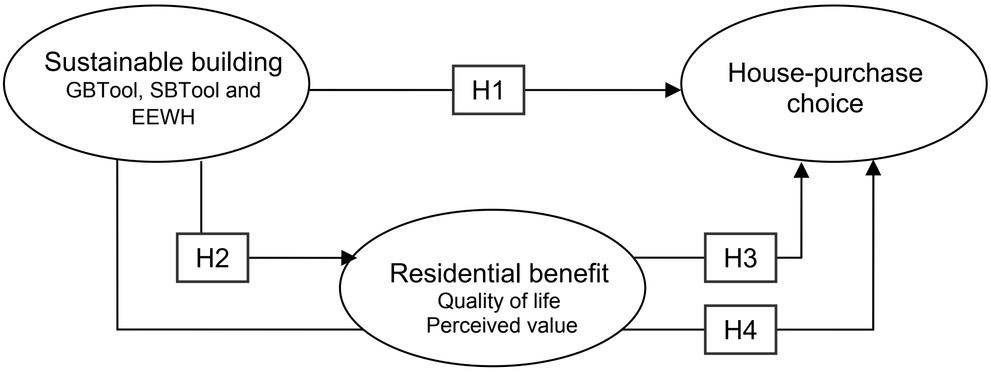

Figure 1 A proposed conceptual model

2.3 Questionnaire

This questionnaire contents four parts. The first part is 'sustainable building' that sorted out assessment issues of Taiwan Green Building nine indicators (we also called the 'EEWH' system), GBTool and SBTool to frame twenty-five items. The second part is 'intervening factor of the residential benefit', which base on the proposed sustainability index model of Ding that include two aspects of 'quality of life' and 'perceived value'. Quality of life refers to the positive contribution and benefits of a project in terms of improving living standards arising over the operational life of a project under the global environmental changes. There are eleven items adopting the front question sentence way. The third part is 'house-purchase choice', the mainly intention to understand consumers on acceptance of sustainable building and their purchase wills, it has eight items. The fourth part is the basic data of consumers which items include sex, marital status, age, education degree, job, income, house type and location etc... This research uses Likert Scale as the questionnaire rating scale (Babakus & Mangold, 1992) to investigate. Question presented using a scale of 1-5 to express the level of all issues in evaluation process. The respondent is asked to indicate his or her degree of agreement with the statement or any kind of subjective or objective evaluation of the statement, so mark high form important and satisfied.

2.4 Hypothesis

There are less researches can extract the respective dimensions from 'sustainable building', 'residential benefit' and 'house-purchase choice' parts, and the 'sustainable building' part consists of many assessment items. So, this paper will adopt factor analysis to analyze the investigated data of the questionnaire. For the above-mentioned conceptual model, the following is to set up the four hypotheses (Baker et al., 1992; Sirohi et al., 1998)

A living environment will directly affect consumer's purchasing decision derived form the literature (Lin, 2004). About 91% of the consumers agree to use the construction company of green marketing. In Taiwan, a study found that up to 91% of consumers believe that the developers adopting green marketing will pay much more concern on the environment. The consumers' perspective toward the image of these developers and their concern about the green marketing factors of residences are linear and proportional. On the consumers' attitude toward "green residences", there are up to 62.8% of consumers willing to pay 1-5% of extra price to buy a residence that is more natural and healthier; and further, 23.7% of the consumers would even like to pay 6-10% of the prices more (Fang, 2005), it is obvious the partiality attitude to "ecological housing", "green building" of most consumers is front. Thus, it is proposed that:

H1: There will be a position relationship between 'Sustainable building performance' and 'House-purchase choice.'

Sustainable development concerns attitudes and judgment to help ensure long-term ecological, social and economic growth in society. Applied to project development, it involves the efficient allocation of resources, minimum energy consumption, low embodied energy intensity in building materials, reuse and recycling, and other mechanisms to achieve effective and efficient short- and long-term use of natural resources (Ding, 2005). Figgea (2004) proposes a new approach to measure corporate contributions to sustainability called Sustainable Value Added, and it takes into account both, corporate eco- and social efficiency as well as the absolute level of environmental and social resource consumption (eco- and social effectiveness). The overall result can be expressed in any of the three dimensions: economic, environmental and social aspects of sustainability. Thus, it is proposed that:

H2: There will be a position relationship between 'Sustainable building performance' and 'Residential Benefit.'

Baker (1992) found when consumers experience higher psychological cost, will reduce the will of patronizing. However, there is a analysis between housing quality (including a location and a building quality component) and losses in property price that the prices for high-quality houses have remained more stable than the prices for average or low-quality houses within an overall market downturn(Lützkendorf, 2007). So the residential benefit will obviously influence consumers' house-purchase choice. Thus, it is proposed that:

H3: There will be a position relationship between 'Residential Benefit' and 'House-purchase choice.'

There a real breakthrough in green marketing that sustainability can be made the distinguishing factor of choice and a precondition is that sustainability must be communicated in terms of a reliable indicator, preferably in terms of money (Vogtlander et al., 2002). The hypothesis with intent to understand whether will influence the will of buying sustainable building because the cost-effective is considered in the house decision at the current Taiwan. Thus, it is proposed that:

H4: The sustainable building performance will consider the intervening factor of Residential Benefit and has a positive effect on 'House-purchase choice.'

From the result, 'Sustainable Building' can consist of six factors, such as Integrated Environmental Performance, Operating Performance, Waste Reduction, Environmental Loading, Energy Saving and Maintenance; 'Residential Benefit' can include both Quality of Life and Cost Recovery factors. And, tests of 'House-purchase choice' are affected by Sustainable Building is supported by the data and 'Sustainable Building will be through the Residential benefit variable to affect House-purchase intention,' especially the Quality of Life factor as an indirect variable. Therefore, this research shows that the homebuyer will not only satisfy a living demand but also consider the additional Residential Benefit from Sustainable Building on making the House-purchase choice.

3. Analysis

3.1 Sample

This research samples and fills in the questionnaire with the people of 20 to 61 years old. This questionnaire time is from September of 2006 to January of 2007, grants 400 shares altogether, through filtering further, reject and leak and answer, cancel and fill out and select repeatedly, fill out and have illogical invalid questionnaires to answer apparently, it amounts to 280 to count the effective questionnaire; the effective rate of recovery is 70%.

3.2 Factor Analysis

Applying Principal components analysis (PCA) of Factor Analysis, twenty-five items of 'Sustainable building performance' dimension can be extracted to six main factors. The highest factor's explained variance is 25.133%, others are 7.365%, 6.609%, 5.734%, 5.419% and 4.611% in order, and showed there are six factors which Eigenvalues are greater than 1. So it is suitable to keep six factors to explain

'Sustainable building performance' dimension and named 'environmental performance', 'operating performance' , 'waste reduction' , 'environmental loadings', 'energy-saving' and 'maintenance', and the total explained variance is 54.871%, shown in Figure 2.

	Factor	Eigenvalue	Explained variance (%)	Cumulation(%)
1	environmental performance	5.781	25.133	25.133
2	operating performance	1.694	7.365	32.498
3	waste reduction	1.520	6.609	39.108
4	environmental loadings	1.319	5.734	44.842
5	energy-saving	1.246	5.419	50.261
6	maintenance	1.060	4.611	54.871

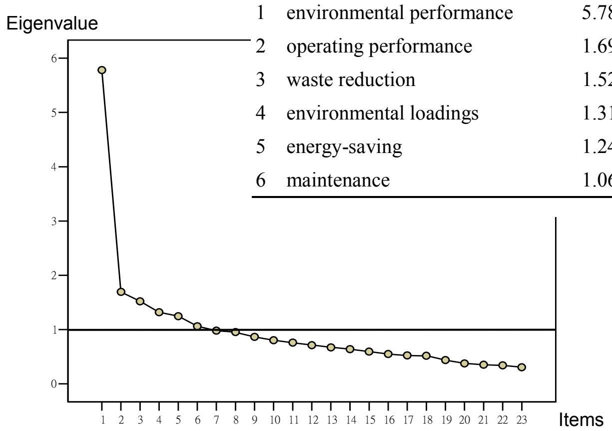

Figure 2 Scree and Eigenvalue of 'Sustainable building performance' dimension

As the same procedure, eleven items of Residential benefit dimension that can be extracted to two factors of 'quality of life' and 'perceived cost return' which explained variance are 46.047% and 11.553% respectively, and the total explained variance is 57.601%.

About the House-purchase choice dimension, only one factor can be extracted, and named 'house-purchase choice.' The total explained variance is 51.653%.

3.3 Satisfaction Analysis

From the satisfaction analysis of measures shown in Figure 3, the means of three factors, of 'environmental performance', 'operating performance' and 'waste reduction', are higher than other factors and their score all are above 4. But, the means of energy-saving and 'perceived cost return' which present the lower level of agreement.

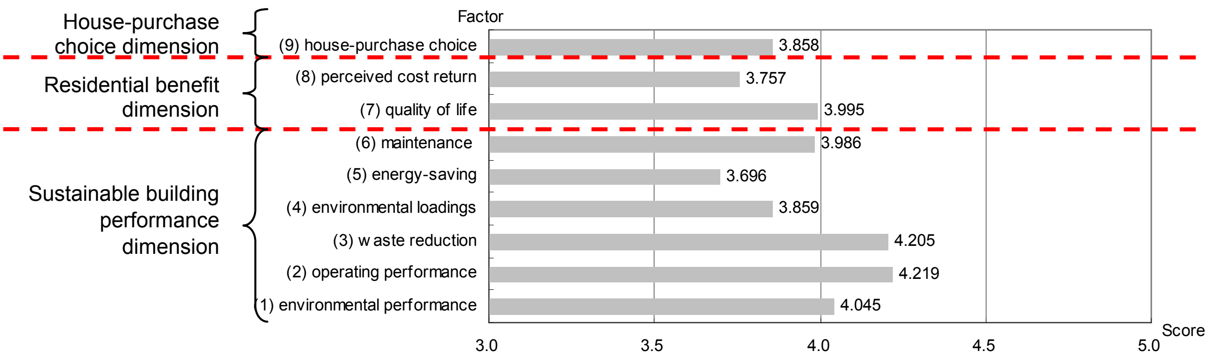

Figure 3 Means of the Factors

4. Validation hypotheses

The hypotheses were tested using correlation analysis, path analysis, AVOVA and linear regression analysis.

4.1 Correlation analysis

In table1, factors inter-correlation indicated there is a statistically significant between the majority factors of 'Sustainable building performance' dimension (environmental performance, operating performance, waste reduction, environmental loadings, energy-saving and maintenance) and 'House-purchase choice' dimension. Thus, this provides most support for hypothesis 1: There is a position relationship between 'Sustainable building performance' and 'House-purchase choice.'

There is also a statistically significant between all factors of 'Sustainable building performance' dimension (environmental performance, operating performance, waste reduction, environmental loadings, energy-saving and maintenance) and two factors of 'Residential benefit' dimension (quality of life and perceived cost return). Thus, this provides total support for the hypothesis 2: There is a position relationship between 'Sustainable building performance' and 'Residential Benefit.'

Quality of life and perceived cost return of 'Residential benefit' dimension have a significant effect on House-purchase choice, and the correlation coefficients are greater than 0.6. This is due, of course, to verify the hypothesis 3: There is a position relationship between 'Residential Benefit' and 'House-purchase choice.'

Table1 Factors inter-correlation

Dimension	Factors	Sustainable building performance						Residential benefit		Purchase
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Sustainable building performance	(1) environmental performance	1.000								
	(2) operating performance	0.554(**)	1.000							
	(3) waste reduction	0.391(**)	0.371(**)	1.000						
	(4) environmental loadings	0.387(**)	0.429(**)	0.266(**)	1.000					
	(5) energy-saving	0.346(**)	0.348(**)	0.185(**)	0.274(**)	1.000				
	(6) maintenance	0.235(**)	0.137(*)	0.223(**)	0.163(**)	0.096	1.000			
Residential benefit	(7) quality of life	0.554(**)	0.452(**)	0.408(**)	0.372(**)	0.403(**)	0.177(**)	1.000		
	(8) perceived cost return	0.349(**)	0.254(**)	0.242(**)	0.306(**)	0.257(**)	0.131(*)	0.562(**)	1.000	
Purchase choice	(9) house-purchase choice	0.412(**)	0.328(*)	0.334(**)	0.398(**)	0.326(**)	0.097	0.649(**)	0.578(**)	1.000

** p<0.01 for a two-tailed test
* p<0.05 for a two-tailed test

4.2 Path analysis

Via above-mentioned correlation analysis, has accepted hypothesis 1, 2 and 3, is still unable to verify directly the hypothesis 4: The Sustainable building performance will considered the intervening factor of 'Residential benefit' and has a positive effect on the House-purchase choice and acceptance. Also, House-purchase choice has two factors of quality of life and cost return. Therefore, the next discuss adopt the path method and through three measures to test the effect of the intermediary role for House-purchase choice in the model.

4.2.1 Residential benefit Dimension

The four factors of environmental performance, waste reduction, environmental loadings and energy-saving of 'Sustainable building performance' to have the positive influences on 'Residential benefit' which effects are of 0.324(**), 0.172(**), 0.152(**) and 0.193(**), and on 'House-purchase choice' which effects are of 0.202(**), 0.164(**), 0.233(**) and 0.163(**). Moreover, 'Residential benefit' has a high effect of 0.528(**) on 'House-purchase choice'. Apparently these provided the partial support (environmental performance, waste reduction, environmental loadings, energy-saving and maintenance) for the hypothesis 4: The sustainable building performance considered the intervening factor of Residential Benefit and has a positive effect on 'House-purchase choice', as showed in Table2.

However, the two factors of operating performance and maintenance of 'Sustainable building performance' have a low effect on 'Residential benefit' and 'House-purchase choice'. It meant that the two factors (operating performance and maintenance) reject hypothesis 4.

Table 2 Total influence of Sustainable building performance on House-purchase choice

Factor	Sustainable building performance affect House-purchase choice	Sustainable building performance via Residential benefit	Total effect of Sustainable building performance on House-purchase choice
Sustainable building performance (independence variable)	direct effect	indirect effect	Sum of both direct and indirect effect
environmental performance	0.202(**)	0. 171	0.373
operating performance	-0.002	--	--
waste reduction	0.164(**)	0.091	0.255
environmental loadings	0.233(**)	0.080	0.313
energy-saving	0.163(**)	0.102	0.265
maintenance	-0.009	--	--

** p<0.01 for a two-tailed test
* p<0.05 for a two-tailed test

4.2.2 Quality of life Factor

The four factors of environmental performance, waste reduction, environmental loadings, energy-saving and maintenance of 'Sustainable building performance' to have the positive influences on quality of life factor which effects are of 0.321(**), 0.184(**), 0.105(**) and 0.196(**), and on 'House-purchase choice' which effects are of 0.202(**), 0.164(**), 0.233(**) and 0.163(**). Moreover, 'quality of life' factor has a high effect of 0.473(**) on 'House-purchase choice' dimension. Apparently these provided partial support (environmental performance, waste reduction, environmental loadings, energy-saving and maintenance) for the hypothesis 4.

4.2.3 Perceived cost return Factor

The three factors of environmental performance, waste reduction, environmental loadings and energy-saving of 'Sustainable building performance' to have the positive influences on 'perceived cost return factor' which effects are of 0.253(**), 0.184(**) and 0.134(**), and on 'House-purchase choice' which effects are of 0.202(**), 0.233(**) and 0.163(**). Besides, 'perceived cost return' factor has just a medial effect of 0.312(**) on 'House-purchase choice' dimension.

However, the three factors of waste reduction, operating performance and maintenance of 'Sustainable building performance' have not a significant effect on 'perceived cost return' factor and 'House-purchase choice' dimension. It meant that hypothesis 4 is not supported by half factors of 'Sustainable building performance'.

4.3 Structural model

The results and parameter estimates (total effects) are show in table 3. We show in figure 4 are significant total effects between 'Sustainable building performance' and 'House-purchase choice' that is considered the direct effect and indirect effect of the intervening factor of Residential Benefit.

Table 3 Final model results of total effects

Factor	support factors	Path coefficient	Discriminant
H1: There is a position relationship between 'Sustainable building performance' and 'House-purchase choice.'	environmental performance	0.202(**)	Partial support
	waste reduction	0.164(**)	
	environmental loadings	0.233(**)	
	energy-saving	0.163(**)	
H2: There is a position relationship between 'Sustainable building performance' and 'Residential Benefit.'	environmental performance	0.324(**)	Partial support
	waste reduction	0.172(**)	
	environmental loadings	0.152(**)	
	energy-saving	0.193(**)	
H2-1: 'Sustainable building performance' has a position relationship on 'quality of life' factor.	environmental performance	0.321(**)	Partial support
	waste reduction	0.184(**)	
	environmental loadings	0.105(**)	
	energy-saving	0.196(**)	
H2-2: 'Sustainable building performance' has a position relationship on 'perceived cost return' factor.	environmental performance	0.253(**)	Partial support
	environmental loadings	0.184(**)	
	energy-saving	0.134(**)	
H3: There is a position relationship between 'Residential Benefit' and 'House-purchase choice.'	residential benefit	0.528(**)	Support
H3-1: 'Quality of life' has a position relationship on 'House-purchase choice.'	quality of life	0.473(**)	Support
H3-2: 'Perceived cost return' has a position relationship on 'House-purchase choice.'	perceived cost return	0.312(**)	Support
H4: The sustainable building performance considers the intervening factor of Residential Benefit and has a positive effect on 'House-purchase choice.'	environmental performance	0.373(**)	Partial support
	waste reduction	0.255(**)	
	environmental loadings	0.313(**)	
	energy-saving	0.265(**)	
H4-1: Sustainable building performance via 'quality of life' factor to affect House-purchase choice.	environmental performance	0.354(**)	Partial support
	waste reduction	0.251(**)	
	environmental loadings	0.283(**)	
	energy-saving	0.256 (**)	
H4-2: Sustainable building performance via 'perceived cost return' to affect House-purchase choice.	environmental performance	0.275(**)	Partial support
	environmental loadings	0.290(**)	
	energy-saving	0.205(**)	

** p<0.01 for a two-tailed test
* p<0.05 for a two-tailed test

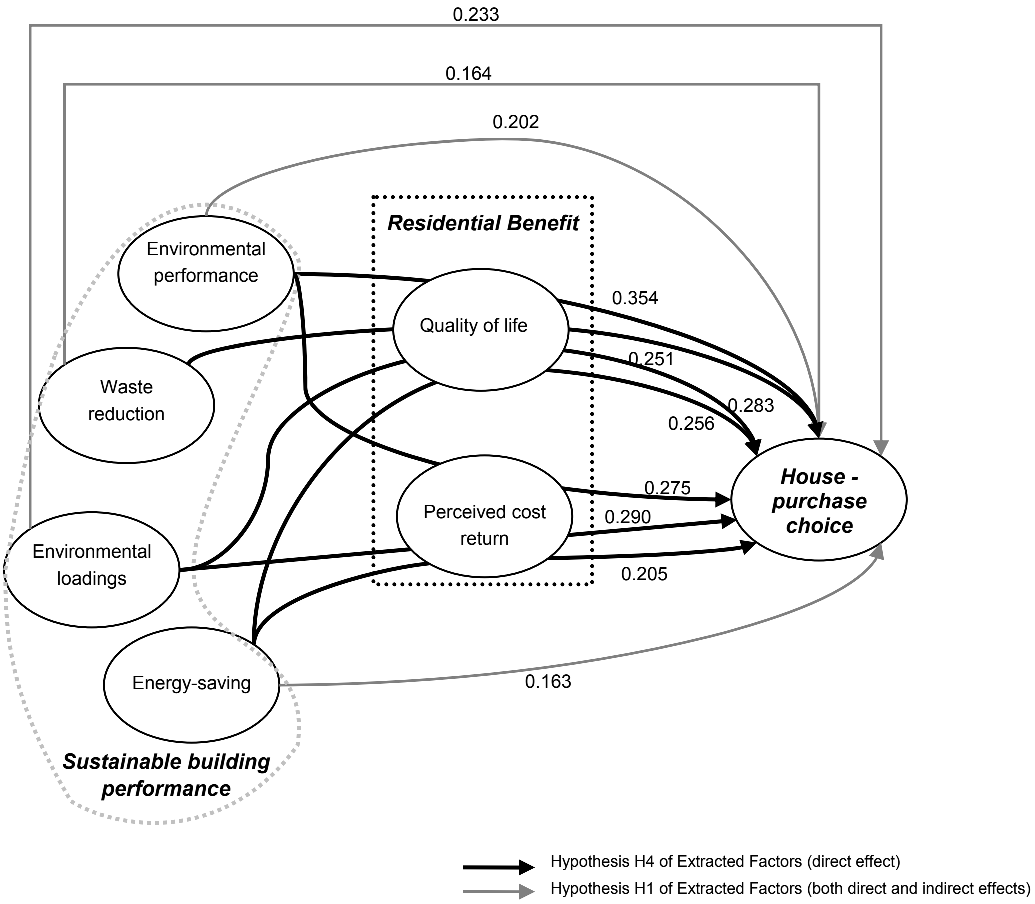

Figure 4 A structural model of effects between Sustainable building performance with House-purchase choice.

5. Conclusion

In this paper we applied the marketing studies to measure the effects of the purchase intentions and willingness of the consumer and the cost–benefit analysis approach (Grace, 2005) on the real estate marketing to structure our conceptual model and hypothesis: the sustainable building product directly affected the house-purchase choice, or considered an intervening factor of the residential benefit.

From the result of factor analysis: 'Sustainable building performance' could be simplified with six factors of environmental performance, operating performance, waste reduction , environmental loadings, energy-saving and maintenance, and 'Residential benefit' also was extracted two factors of quality of life and perceived cost return.

The results verified hypotheses that 'a position relationship between the Sustainable building performances with House- purchase choice.' Meanwhile, it also testified the effects of which sustainable building performance via an intervening factor of Residential Benefit affecting House-purchase choice is specifically higher than the direct effect of which Sustainable building performance affecting Residential Benefit. Besides, the path coefficient for quality of life on affecting Residential Benefit is larger than perceived cost return. Therefore, it is helpful for House-purchase with the highlight of indoor environment quality, surroundings quality, community amenity, sanitation, security, and reducing energy consumption etc.

The results of satisfaction analysis indicated the two factors of operating performance and maintenance obtained the high scores, but the perceived cost return show a low score. It meant the house-purchase consumers have an affirmative attitude on the operating performance and maintenance of 'Sustainable building performance', but they regarded with increasing building cost or expense. Therefore, perceived added cost is a key determinant is meeting house-purchase customers' desires.

Overall, the government, building owners, design teams or developers must highlight and clarify the residential benefit concept of cost return and quality of life when promote the sustainable building policy and implement green building system in Taiwan future real estate marketing.

Acknowledgement

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ECONOMIC INCENTIVES AND BUILDING RATING SYSTEMS IN ITALY

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Summary

The field of performance rating and labelling is proving to be a very cost-effective way to improve the performance of new and retrofit buildings, since it can induce the industry to raise performance standards. Concerning government agencies and public bodies, the availability of a building environmental assessment tool would improve the policies aimed to promote sustainable building. An innovative system based on financial and economic incentives to promote green building has been launched in Italy, involving public institutions, banks and assurance companies. The core of the incentives system is Protocollo ITACA, a rating tool based on SBTool.

1. Introduction

A modern approach to reducing the environmental impact of buildings tends to involve a broad multi-issue approach, and is usually referred to as a sustainable building model that is the focus of much theoretical and practical activity in both design and performance assessment. The field of performance rating and labelling is proving to be a very cost-effective way to improve the performance of new and retrofit buildings, since it can induce the industry to raise performance standards. Researchers and government agencies consider performance rating and labelling systems as one of the best methods of moving the marketplace towards a higher level of performance. By means of these systems it is not only possible to assess the energy performance and the use of renewable sources but also the performance with regard to other environmental issues like the water and material consumptions, the solid waste and the effluents, the indoor environmental quality, the quality of service. Systems that assess the environmental performance of buildings and provide a certification offer an approach that can induce the private sector to raise performance standards and that allows in the same time the public administration to develop effective policies in the field of sustainable building. Consequently, several are the potential users of a building environmental assessment tool: public bodies, investors, customers, designers, construction companies.

Concerning government agencies and public bodies, the availability of a building environmental assessment tool would improve the policies aimed to promote sustainable building. It means that a clear definition of the green building requirements and the possibility to measure the performance would force the construction industry toward a higher level of sustainability. Regulations could be enforced including this tool and financial incentives could be fixed using the assessment tool to grant the green designs. In the market a financial inducement is likely to be effective in an environment where financial return is a primary objective. Using the core elements of an building environmental assessment tool, the government agencies and the public bodies would have a method to control in a objective and complete way the performance of new constructions and refurbishments. The core elements of the assessment tool could be used as part of building codes, regulations, urban plans or as a basis to grant high performance buildings with financial incentives or tax reductions.

The availability of a building environmental assessment tool in the market could allow the investors, real estates purchasers and tenants to choose the higher performance buildings. A building that has undergone a design process that results in a high level of energy efficiency is likely to be of higher quality, and will have lower operating and maintenance costs. Capital cost and design time increases are modest, and such buildings have been shown to attract desirable tenants. All these factors are very likely to combine to result in a higher long-term asset value. A significant number of other actors should become users of the assessment tools. These include real estate brokers, major development companies with an interest in high performance; banks, architectural and engineering associations. There is also a growing realization that a major jump in performance levels, at least in market economies, will depend on changes in market demand, and that such change cannot occur until building investors and tenants have access to a relatively simple method that allows them to identify buildings that perform to a higher standard. Engineers and architects can also use the system to predict the environmental performance of their designs, before contract documentation is finalized.

2. SB Method and SBTool

iiSBE (international initiative for a Sustainable Built Environment) manages an international activity to develop and test a new method (SB Method) of rating the sustainable performance of buildings, continuation of the Green Building Challenge process. SBTool is the software implementation of the method. The GBC process was begun with *Natural Resources Canada*, but in 2002 responsibility was handed over to the *International Initiative for a Sustainable Built Environment* (iiSBE), an international non-profit organization. In the GBC process, the basic method and software has been developed in consultation with participating national teams, which then modify the generic system to suit their local conditions, and test it on case study buildings. Currently several countries are involved in the process.

The SBTool is a second-generation assessment system; one that is designed from the outset to allow adaptation to the very different priorities, technologies, building traditions and even cultural values that exist in various regions and countries. In order to use the system, national teams must adjust the values and weightings embedded in the system, thereby assuring results that are relevant to local conditions, and then test the assessment system on case study buildings in each country.

SBTool provides approximate assessments of a broad range of potential environmental performance parameters, all related to performance benchmarks that are relevant to the region and building occupancy. SBTool is primarily designed to act as a framework for scoring and weighting, using data that is generated in external models that perform detailed studies or from other similar sources. The final result of the assessment is a score that express the potential environmental performance of the building compared to the minimum acceptable performance for that use and geographic area (benchmark).

One of the most important characteristics of the SBTool is that it is the result of a wide international process, and is designed to be adaptable to specific regional conditions. This means that it is a methodology that could be validly applied in different countries, while maintaining an overall consistency in structure and method. The advantages of having a global standard for building performance assessment are very strong. If meaningful information about performance is to be exchanged between countries, then a uniform definition of performance parameters must be developed, even if the calculation tools providing data on, for example, energy consumption and emissions, vary between countries. Further, the rapid growth of global corporations, and their desire to work to a recognized international standard, give to SBTool a significant commercial importance in the medium term that could help to move the market toward a better sustainability.

3. Protocollo ITACA

In 2001, a working group on green building was established by ITACA, Federal Association of the Italian Regions. One of the main objective of the association is to promote and disseminate the good practices for the environmental sustainability and to develop common policies. The aim of the working group on green building was to establish an objective set of requirements to define “what is” a green building and to study an evaluation method to measure “how green” a building is. The need was expressed by the Public Administration: to improve the green building practice, through different incentives, it is necessary to fix requirements and a rating system. The ITACA working group was composed by the representatives of the Italian Regions, by Environment Park and iiSBE Italia, the local chapter of iiSBE.

The working group decided to base the ITACA new rating system on SBTool, a unique rating tool in that it has followed an approach that places gives local authorities the ability to adapt the tool to their own conditions and priorities. In this respect the needs of Italian Regions is similar to the international pressures that led to an adaptable SBTool framework; a necessity to have a tool that could be adapted to regional characteristics. For this purpose, the weight and benchmark approach has proven to be useful. The result has been the “Protocollo ITACA” that has been officially approved by the Conference of the Presidents of the Italian Regions on January 2004. Actually the “Protocollo ITACA” is the reference rating system of the regional authorities in Italy.

As a consequence of these factors, the “Protocollo Itaca” is strongly based on SBTool. It is hierarchically structured in the same way, with Performance Issues, Performance Categories, Performance Criteria, Performance Subcriteria. The weighting system is the same of the SBTool as the scoring system. All performance criteria and sub-criteria are set within performance scales ranging from –1 to +5, where 0 is the minimum accetable performance in the industry practice. Performance scores refer always to an explicitly declared benchmark. The final result of the application of the protocol is a score ranging from –1 to +5 for the whole building.

4. Economic incentives for SB and Protocollo ITACA

An innovative system based on financial and economic incentives to promote green building has been launched in Italy, involving public institutions, banks and assurance companies. The core of the incentives system is Protocollo ITACA.

Economic incentives are an important mean to encourage stakeholders in the building sector to adopt more sustainable approaches in design, construction and operation

The Protocollo ITACA has an institutional and public value, considering that it is the reference building environmental assessment tool for the Italian regions. Since 2004 the Italian public administrations have at disposal a tool to implement new policies to promote sustainable building, having the possibility to “measure” in an objective way the environmental quality of buildings. By means of an agreement with ITACA, iiSBE Italia has taken the responsibility to update and maintain the Protocollo ITACA, acting as scientific support to the association of the Italian regions. In this way it is assured the connection between the national level (Prototcollo ITACA) and the international one (Green Building Challenge), fact that gives scientific accreditation to the Italian rating system. Many Italian Regions have already adopted the Protocollo Itaca (Piemonte, Lombardia, Friuli Venezia Giulia, Marche, Toscana, Basilicata, Calabria, Liguria) for different scopes. The most recent development concern the use of Protocollo ITACA in both public and private funding programs for sustainable building. A compact and simple version has been developed (12 criteria) for the institutional applications, to facilitate the application of the rating system and its diffusion.

The most important application of Protocollo ITACA is in the framework of the “Social Housing Plan 2006-2012” of the Regione Piemonte. For the first time in a public funding program, it is mandatory for all the building to reach al least a score of 2 (new contruction) or 1 (renovated building). Considering the extra construction costs connected to a better environmental performance, the Region will give an economic incentive of 5.000 euro per apartment. The incentive could be higher in the case of scores superiors to 2 (new constructions) or 1 (renovated building). The “Social Housing Plan 2006-2012” of the Piemonte Region foresee the construction of 10.000 apartments. The total amount of funds for sustainable buildings is 54.000.000 euro. The total public funds available in the social housing plan is 750.000.000 euro. A similar approach has been followed by the Marche and Liguria Regions in their Social Housing Plans. Also in this case it is requested a minimum performance to be included in the plan. The funds for sustainable buildings are 20.000.000 euro per region.

On the private side the Intesa San Paolo Group bank (the major bank group in Italy) has launched in January 2007 a new bank product concerning green building, “Aedifica Bioedilizia”. The purpose is to promote sustainable building by means of funds available for construction companies. Intesa Sanpaolo Group offers preferential rates and conditions reserved to high performance buildings:

- for the company, during the construction stage, euribor 6 months spread range between 0.80% and 1.75% on installment rates depending on the rating expressed by the company
- for private purchasers at loan contracting stage: depending on the specific type of loan
- credit check fees amounting to 0.20% of funding with a minimum 300,00 Euros
- exemption from penalty on installment plan refunds

To obtain the reduction of the interest rate, it is necessary to have the building (that has to be funded) reaching a rating score of at least 2 (for new buildings) or 1 (for renovated buildings) as a result of the application of Protocollo ITACA. If the score is lower, the building is considered not “green” enough to obtain the reduced interest rates from the bank. Should the original eco-sustainability criteria not be complied with, a one-off fee shall be due, amounting to 0.40% of the granted loan and all previously refunded installments.

To further improve this approach, the Piemonte Region has stipulated an agreement with the Intesa San Paolo Group and other 6 banks concerning the possibility for users to obtain reduced home loans. In this case the construction company asks for the interest rate reduction in the name of the future tenants. The Protocollo ITACA has to be applied to assess the environmental performance of the buildings that contains the apartments to be funded.

Also the assurance companies have been involved in the incentives system. Companies are now proposing reduced cost for different kind of policies:

- for builders: construction risk policy and post-built policy;

- for tenants: fire policy and public liability policy.

The discounted policies can be obtained only by buildings rated by Protocollo ITACA (minimum score of 2 for new constructions and of 1 for renovated buildings).

Considering the role of unique scientific support for ITACA on rating systems, iiSBE Italia will act as certification body in the framework of these funding programs. iiSBE Italia is requested to assess the consistency of the assessments carried out by the construction companies that apply for the interest rate reduction or for the economic incentives.

5. Issues

Designers and construction companies are not used to rating system and green building in general. In contexts where green building is new the rating system must be simple, intelligible and easy to apply. A complex and heavy system, also if more correct from a scientific point of view, could cause the failure of the policy. In the context of policies based on economic incentives, training programs for professionals should be foreseen as appropriate supporting tools (handbook, guides, software) and support desks.

The establishment of target performances is a major issue. Too high performance targets in comparison with available funds can produce a failure of the policy. In the same time too loose performance levels don't allow to reach the objective of raising the standard practice. Before launching a policy it is necessary to carry out several studies on green building (existing or simulated) to understand in the specific context what could be the extra cost correlated with the different levels of performance.

It is fundamental to use a rating system adapted or developed in the context of application. The performance scores must be correlated to the local practice and availability of technologies and materials. The use of an "imported tool" would cause major problems.

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A HOLISTIC APPROACH TO THE REDUCTION OF GREENHOUSE GAS EMISSIONS IN A COMMERCIAL OFFICE BUILDING UTILISING TRIGENERATION

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Keywords: existing building, energy, emissions reduction, trigeneration, cogeneration

Summary

In approaching the refurbishment of the landmark building, 101 Miller Street North Sydney, all aspects of the buildings services were reviewed, including the proposed installation of trigeneration technology, to achieve unprecedented levels of greenhouse gas efficiency from a refurbished commercial office tower. This paper describes how an approach of selective improvement and upgrade of the existing building's services, along with the use of trigeneration technology, improved the energy efficiency, electrical demand management and power supply reliability of the building. The application of trigeneration and its integration into an existing building infrastructure is described. The technical and regulatory complexities of the installation of natural gas powered generators into the existing building envelope and the implications this had for the final system design are highlighted. The paper concludes that the targeted adoption of trigeneration technology, labeled 'Green Transformers' by the City of Sydney Council, has an important role to play as a transitional technology in reducing the greenhouse gas emissions of Australia's existing building stock in the short to medium term.

1. Introduction

101 Miller Street, North Sydney is a landmark 37 700 m^2 office building in the North Sydney central business district. The building was occupied by a single tenant from the completion of original construction in 1992 for 15 years. The tenants' decision to vacate the premise from mid 2007 presented both a significant challenge and rare opportunity for Mirvac to undertake a holistic refurbishment of the building to maintain its premium landmark status and to achieve unprecedented levels of greenhouse gas efficiency from a 15+ year old building.

The design and development process was undertaken with the goal of achieving a 5 star Australian Building Greenhouse Rating (ABGR – now known as NABERS Energy). Accordingly, the building owners have entered into a precommitment agreement with the New South Wales (NSW) Department of Environment and Climate Change to achieve the 5 star rating within approximately 12 months of practical completion of the refurbishment.

2. 101 Miller Street Background

Original construction of 101 Miller Street was completed in 1992. Over the next 15 years the plant was serviced and maintained regularly so that at the time the building was vacated in mid 2007 the plant was generally in very good condition.

During the period 2002 – 2005 the building improved its NABERS Energy rating from 3 to 4 stars through careful tuning and management of the building air conditioning and control systems. This was considered by the building management to be virtually the optimal performance that could be gained from the existing plant and represented excellent performance on the NABERS Energy rating scale.

With the building empty by mid 2007, the owners embarked on a major refurbishment to maintain its landmark status for the next stage of its life.

Figure 1 101 Miller Street

The decision was taken to take the building offline for the refurbishment for a period of approximately 12 months. The following key sustainability goals were set for the refurbishment:

- 5 star NABERS Energy rating (Base Building), representing best building performance.
- Registered for Green Star (Office Design Version 2)
- Provide future tenants with services capable of achieving a 5 star NABERS Energy tenancy rating.

Electricity reliability in the North Sydney area, along with potential tenant concerns about infrastructure, grid demand and the availability of back-up power sources all played a key role in informing the design process.

3. Plant and Services Upgrade Plans

In planning the services upgrade the following issues were identified:

- The existing Variable Air Volume (VAV) air distribution system was in excellent condition, meaning major changes to the HVAC system were neither justifiable nor desirable.
- The lifts system control and motors had suffered accelerated wear due to previous single tenant usage pattern.
- A significant portion of the building upgrade costs were to be invested in the refurbishment of the ground floor lobby and commercial office floors.
- The energy and greenhouse gas efficiency measures needed to be carefully targeted to provide maximum cost and energy benefit whilst still achieving the ambitious targets set.
- Demand reduction is a significant issue for the utility provider in the North Sydney area and as 101 Miller Street is one of the area's major power users, efforts to reduce energy demand would be well received.

In order to maximise the efficiency of the existing plant and services the following energy reduction measures were targeted:

- All new electric motors to be high efficiency type.
- Upgrade primary and secondary condenser water system to variable volume type.
- Upgrade cooling towers fans to variable speed type.
- Upgrade of outside air system to provide increased volume of outside air for free cooling modes.
- Upgrade of power factor correction equipment to reduce maximum demand.
- Upgrade existing cooling water chillers to higher efficiency chillers.
- Upgrading of the existing Building Management System (BMS) to incorporate changes to the control systems necessitated by the plant upgrades and to provide enhanced energy sub-metering and overall control.
- Upgrading of the carpark ventilation systems with variable speed drives and carbon monoxide level based control.
- Installation of high efficiency T5 fittings, high frequency electronic ballasts and intelligent lighting control system with daylight sensing and future motion control.

Modeling of the base building NABERS Energy rating confirmed that the upgrade changes made would increase the rating from 4 to 4.5 stars, representing an increase in greenhouse gas (GHG) efficiency of about 16%. Whilst this was an impressive result for a 15 year old building with a traditional VAV type air conditioning system, it was clear that additional steps would be needed to achieve the targeted 5 stars.

The measures noted above optimised the energy efficiency of the plant and therefore maximised the considerable economic and embodied energy investment in the existing plant.

Mirvac had previous experience with trigeneration from Vision Estate in Glenfield, NSW, a residential housing estate developed in partnership with GridX Power, an Australian energy provider. The system at Vision Estate represented a world first for mass replicable housing, consisting of three onsite natural gas power generators supplying electricity, thermal cooling and heating to a residential estate.

Following on from the success of the Vision Estate project, Mirvac began investigating the potential to install a trigeneration system at 101 Miller Street, and found that this would provide the large increase in greenhouse gas efficiency targeted for the project.

Significant issues needed to be overcome, including the need to adhere to a tight project timeframe, physical space limitations, integrating the system with the grid power and the existing power distribution infrastructure.

4. Trigeneration Solution

Trigeneration refers to the simultaneous generation of electricity, heating and cooling from a single source, such as natural gas.

In the trigeneration system at 101 Miller Street, electricity is generated using a natural gas fired electricity generator. The waste heat from the generator is used to provide thermal cooling for the air conditioning services through the use of an absorption chiller. Absorption chillers use the waste heat to provide the energy to drive the cooling process rather than an electrically-powered compressor in conventional chiller systems. The absorption chiller system is used to supplement the standard electric chillers in the building and accounts for approximately 60% of total cooling capacity.

Gas fired electricity generation without trigeneration loses up to a third of input energy as waste heat whereas a trigeneration plant utilises that waste heat to provide cooling and heating. The combustion of natural gas as opposed to coal fired electricity generation is significantly more greenhouse gas efficient.

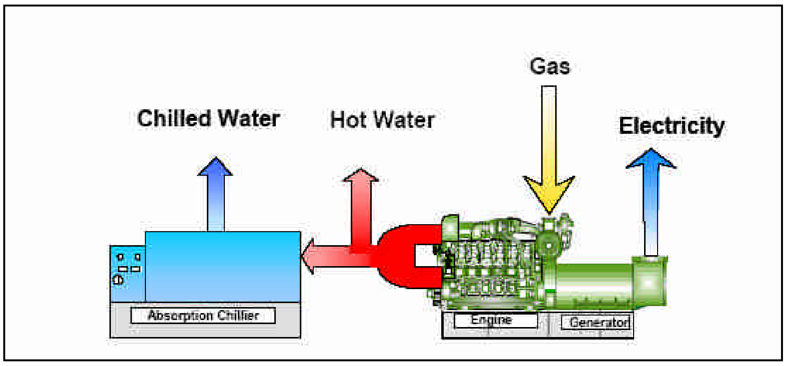

Figure 2 Trigeneration system schematic

Mirvac partnered with Cogent Energy Pty Limited to design, install and operate the trigeneration plant at 101 Miller Street. The installation at 101 Miller Street consists of 2 x 1.2MW natural gas generators and 2 x 750kW absorption chillers and associated control and switchgear, providing peak power of 2.4MW and 1500kW of cooling capacity.

Considerable time and consultation was undertaken with Energy Australia (EA), the grid operator, to agree and finalise the way in which the trigeneration system would interface with the grid. The option to export power to the grid was considered, however due to concerns expressed by EA with regard to potential upstream issues this was eventually discounted. The benefit of being able to export to the grid is that the gas engine can continue to run at maximum efficiency during low load periods by exporting surplus energy.

Consequently the size of the plant was limited by the need to ensure the natural gas generator maintained an efficient operating load. Notwithstanding this, the benefits to future tenants and the surrounding areas will include;

- Parallel import operation of the natural gas generator plant to ensure backup from the grid in case of natural gas generator failure.
- Targeted best practice 5 star NABERS Energy performance.
- Lower power costs for the building owner and tenants.
- Reduction in North Sydney peak demand by up to 3MVA @ 0.8 power factor, reducing stress on power supplies in the area.

Careful planning was required to physically fit the plant into the building as well as to ensure compliance with stringent standards regarding Nitrous Oxide (N_2O) emission, which are produced by the natural gas generator. A significant lead time of over 12 months was required to obtain an Environmental Protection

Agency (EPA) license for the site. N_2O emission modeling was undertaken to demonstrate that emissions were within required EPA limits.

A potential barrier to implementing trigeneration more broadly is the lack of regulatory certainty regarding treatment of exhaust gases, particularly for larger generators. Greater clarity in this area will provide necessary confidence to encourage investment in this low carbon emission technology.

The support of the NSW Department of Planning in the form of a $400,000 grant to assist in the cost of installation was obtained in recognition of the positive impact the installation would have in reducing grid peak demand in the area. The first new tenants at 101 Miller Street are expected to commence occupancy in June 2008 and the trigeneration plant will be providing demand reduction benefits by the 2008/09 summer period.

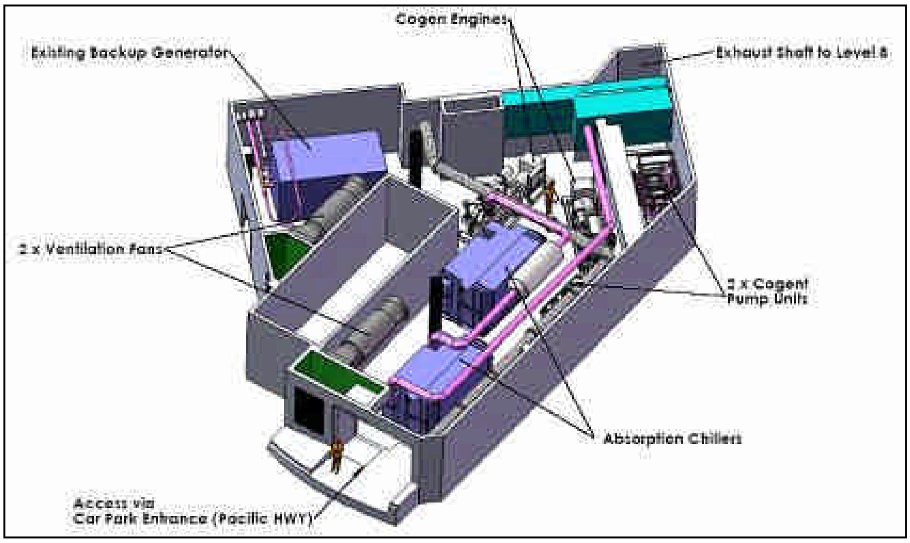

Figure 3 Trigeneration System Plantroom Layout

5. Conclusions

The evaluation and application of a wide range of good engineering practices and technologies within an existing building has resulted in a highly efficient building achieving best practice levels of GHG performance using low risk, proven technologies with a track record of success. Additional benefits include a reliable low cost energy supply for the base building and tenancies, along with power grid demand reduction.

The establishment of a carbon pollution reduction scheme, along with a raft of complementary policy measures is placing a new level of pressure on the built environment to improve GHG efficiency in short time frames. Improving the GHG efficiency of the existing building stock will play a central role in reducing sector-wide emissions.

High costs, and difficulties associated with major refurbishments of existing building services will continue to be a major barrier to progress on emissions reductions. With these barriers in mind, trigeneration and cogeneration technology is a realistic option in some cases to supplement energy efficiency measures in the existing building stock and beyond.

Trigeneration importantly provides replicable, immediate-start technology, to assist in driving the property and energy sectors towards a low carbon future. This highly efficient system provides industry with an important buffer, by significantly reducing GHG emissions in the immediate-term, while awaiting the development and commercialisation of future low emission technologies over the medium and longer-term. Australia's abundance of natural gas means that the technology is applicable broadly and well into the immediate future. The additional demand reduction and reliability benefits of decentralised power generation provide additional incentives for utility providers and planners to encourage the targeted adoption of these technologies.

To encourage the use of cogeneration and trigeneration technology, a number of regulatory and integration issues, including grid export, and exhaust emission levels need to be clarified and certainty provided. The ability to export trigeneration energy to the grid should be encouraged to provide flexibility and maximise the efficiency in the running of the plant, whilst ensuring the integrity of the grid.

The "Sustainable Sydney 2030 – City of Sydney Strategic Plan" recently released by the City of Sydney Council identified cogeneration and trigeneration, termed Green Transformers, as being key component to their vision of cutting emissions by 70% on 2006 levels by 2030. The trigeneration system at 101 Miller Street provides an example of how this vision can be realised.

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THERMAL STORAGE-AN EVALUATION OF THE THERMAL PERFORMANCE OF THE BRIGHTON EARTHSHIP

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Keywords: thermal storage, autonomous, sustainable building, rammed earth, earthship

Summary

The Brighton Earthship is an autonomous building, built on the outskirts of the city on the south coast of the UK. Based on the design philosophy of Mike Reynolds it incorporates 'glass and mass' to permit solar gain and develop long term thermal storage. The thermal store is constructed of rammed chalk utilising end of life car tyres as formers to build the wall. The Earthship was built as a demonstration project and visitor centre for the Low Carbon Network and is the first of its type to be built in the UK.

This paper describes the design principles of an earthship and in particular the use of thermal mass to achieve seasonal energy storage. It reports on long term thermal measurements within the thermal store and demonstrates the heat transfer pattern between the store and the internal space.

1. Introduction

The resources of planet earth, energy, water and materials are finite and must therefore be treasured and used wisely. The term earthship was coined by the architect Michael Reynolds whose design philosophy is to produce buildings that produce no stress or depletion of these resources. Earthships are designed to be autonomous through rainwater harvesting, grey water recycling and on site treatment of black water before disposal and to optimise the use of waste stream and re-used materials for construction. The philosophy is captured by the statement 'The EARTHSHIP is a participant in the prevailing systems of the planet Earth. It causes no conflict, no stress, no depletion, no trauma' (Reynolds 1990). The vision of the earthship inventor included the provision of affordable houses that could be constructed by 'self-builders' from easily available materials, preferably waste from other activities. It uses old car tyres as the basic building block, rammed with the earth removed from the construction site.

The Brighton Earthship has taken these design principles for the construction of a visitor centre within Stanmer Park Brighton. It has been constructed, primarily with volunteer labour, by the Low Carbon Network. It is the first of its kind in the UK and the Centre for Sustainability of the Built Environment (CSBE) at the University of Brighton has monitored its progress and installed instrumentation to evaluate its thermal performance.

The thermal performance of the building is based around the principles of glass and mass. It incorporates large areas of south facing glass backed by a thermally heavyweight structure. The thermal mass is provided primarily by the tyre wall to the rear of the building. This wall is constructed from used tyres rammed with chalk, thus adopting a waste product as a construction material.

The thermal store is at the rear of the building (to the north in the northern hemisphere) with the front elevation constructed primarily of glass to admit maximum solar radiation. The angle of glass in the front elevation is optimised to maximise the transmittance of winter solar radiation as illustrated in Fig. 1.

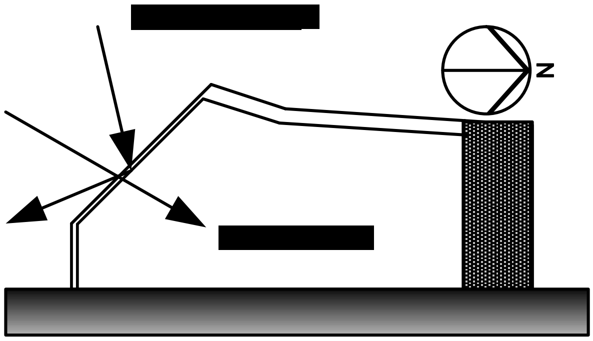

Fig.1 Solar transmittance to earthship

2. The Brighton Earthship

The original earthship design was developed and constructed in Taos, New Mexico, however since then there have been several demonstration projects in other countries. The Brighton Low Carbon Network, responsible for the construction of the Brighton Earthship, was formed after a talk given by Mike Reynolds, in April 2000 in Brighton. Funding and planning permission allowed work to begin in Stanmer Park, on land owned by Brighton and Hove City Council in July 2002. Initial training for the construction was provided by the American construction team.

The Brighton Earthship (Fig.2) is essentially made up of three main rooms, the conservatory and the main living area including kitchen and bathroom internal partitions, usually referred to as the 'nest', and the hut which provides additional living accommodation.

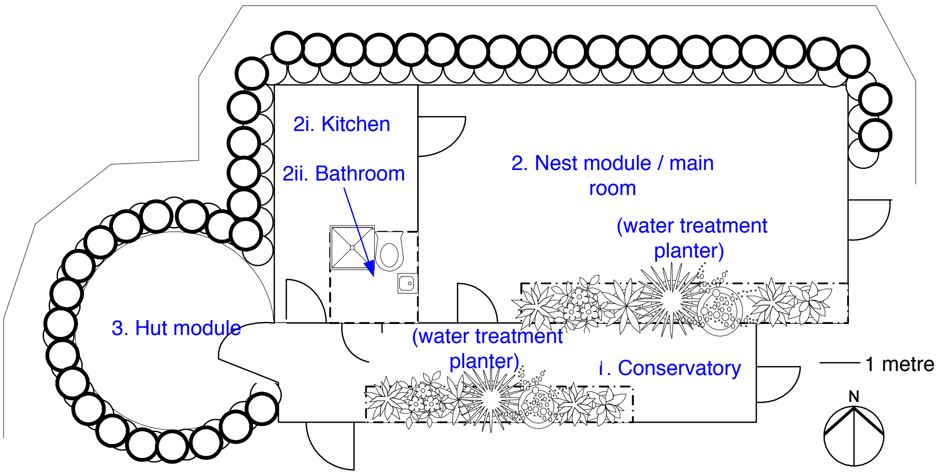

Figure 2 Plan of the Brighton Earthship

The internal area of the main part of the building is 80m^2, with the hut adding a further 12m^2. The thermal store which wraps around the back of the main area is approximately 135m^3 of rammed chalk.

2.1 Temperatures measurements in the tyre wall

The construction of the thermal storage to the rear of the building consists of the tyre wall plus a further thickness of approximately one metre of rammed chalk before a layer of insulation and waterproof membrane separates the structure from the surrounding earth.

Temperature sensors were installed in the tyre wall to the rear of the main living space. They were positioned at heights of 0.63m, 1.26m and 1.89m above floor level inside the building and at depths of 250mm, 500mm and 750mm into the thermal store, as illustrated in Fig. 3. There is therefore a matrix of nine sensors installed to establish temperatures in the thermal store in the living area. A second matrix of sensors have been installed in the kitchen wall.

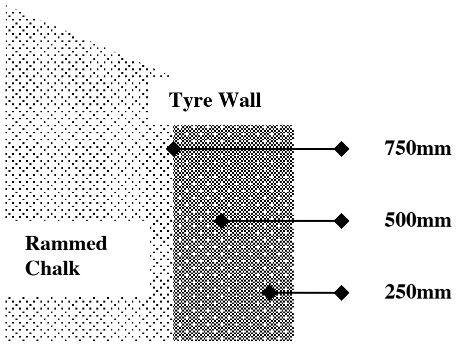

Fig.3. Temperature sensors in the thermal store

3. Thermal Storage

The thermal capacity of building materials is often utilized to maintain thermal comfort in buildings. Thermally heavyweight construction dampens swings in internal temperature taking longer to preheat and longer to cool down than lightweight buildings. It is often used to advantage for domestic buildings storing daytime heat gains to be utilized later in the day when space heating is required. It has a further advantage in the summer of absorbing peak gains and reducing the likelihood of overheating in highly insulated buildings. Thermal capacity therefore is commonly used for diurnal heat storage and can be beneficial in reducing space heating energy consumption.

Earthship design utilizes the thermal capacity of the construction materials that have been selected to develop seasonal rather than diurnal heat storage. The thermal store is charged throughout the summer absorbing solar radiation and incidental gains from the inside of the building. Heat from the store is gradually released during the winter months maintaining comfort temperatures inside of the building.

Anecdotes from occupants of the original earthships in Taos New Mexico have suggested that it has taken over two years to achieve thermally comfortable conditions in winter. The thermal store has taken two years to become fully charged. In practice however it is possible to charge the store using portable heaters prior to occupation.

The flow of heat into and out of the store will be dependent upon many factors including the exposed area, the temperatures maintained and the activity within the building. One of the aims of this research is to understand more of the interaction of the thermal store to enable better consideration of the required size of the store for use within the UK climate.

4. Results

The Brighton Earthship has been constructed as a visitor centre and as such experiences different internal gains from those of an occupied house. It also has different requirements with respect to thermal comfort conditions and ventilation compared with a family dwelling. Monitoring at this stage however is simply to identify the natural thermal performance of the building and the thermal store.

4.1 Average temperatures in the tyre wall

In Fig. 4 the average of all nine sensors in the tyre wall is presented, indicating the overall performance of the thermal store. During the period between November and early spring the store temperature dropped by over 5^{o}C and rose to a peak of over 9^{o}C above this by late summer. At the end of the first 12 months monitoring the store remained 2^{o}C higher than at the beginning. In addition the minimum temperature of the store during the second March was higher than the first, indicating that the store is charging.

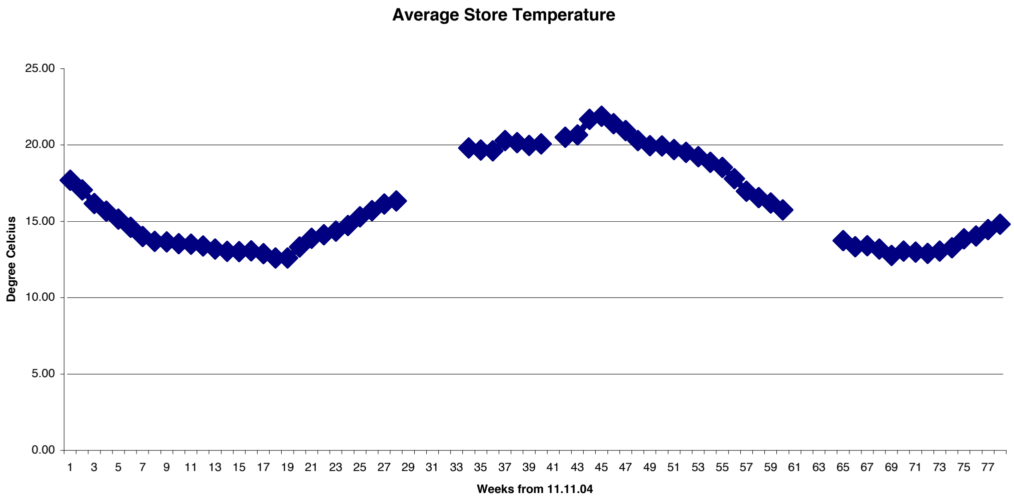

Fig. 4. Average temperatures in the thermal store

4.2 Vertical temperature gradient in the store (floor upwards)

The average temperatures within the store provide an overall view of when the store is receiving and when it is supplying heat. Further analysis of the individual temperature sensors within the wall demonstrate the pattern of heat storage.

The vertical temperature gradient within the store, measured at 0.63m, 1.26m and 1.89m above the floor, demonstrates the means by which the store is being charged as seen in fig. 5.

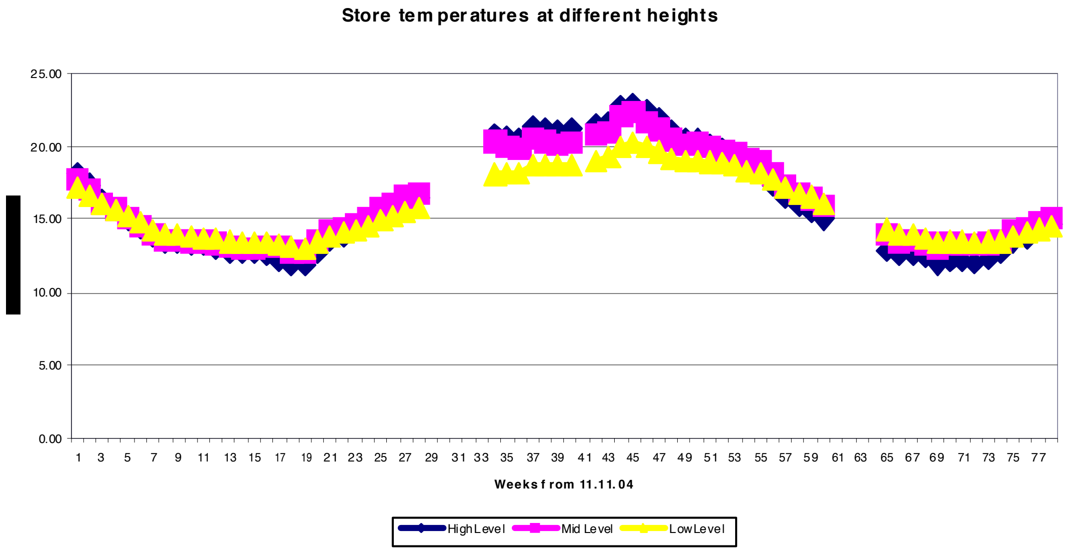

Fig. 5. Vertical distribution of temperature in the thermal store

Initial temperatures of all sensors are very similar demonstrating the uniformity of conditions. However as monitoring progresses during the winter it is the higher points in the store that show lower temperatures. Further, during the summer months the higher points in the store prove to be higher than the others.

Temperature swings at the top of the store are greater than in other parts, reaching a maximum of over 23^{o}C in September and a minimum of just below 12^{o}C in March.

These conditions may be explained by the configuration of the store and the internal space, because the earthship is built on a sloping site with the top of the store being ground level at the back of the building and consequently exposed to the external climate (Fig. 6). However the top level of the thermal store is highly insulated and should therefore be largely unaffected by the external climate. The resulting conditions are therefore in need of further investigation.

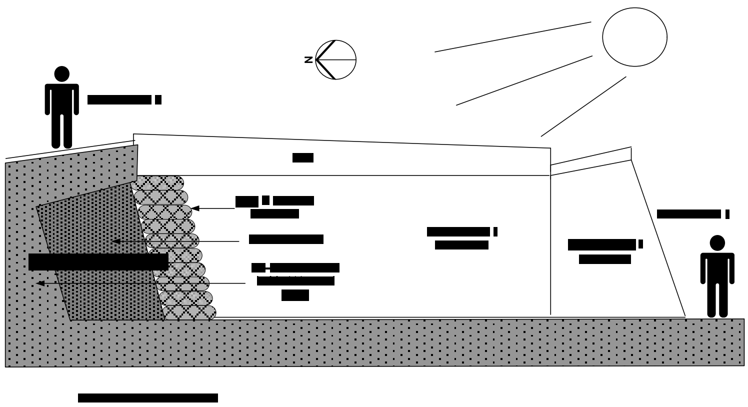

Fig. 6. Exposure of thermal store at ground level

4.3 Horizontal temperature gradient within the tyre wall

The temperature gradient measured by the sensors at different depths away from the wall surface is an indication of whether heat is flowing into the store from the room or back from the store into the room. (Fig. 7)

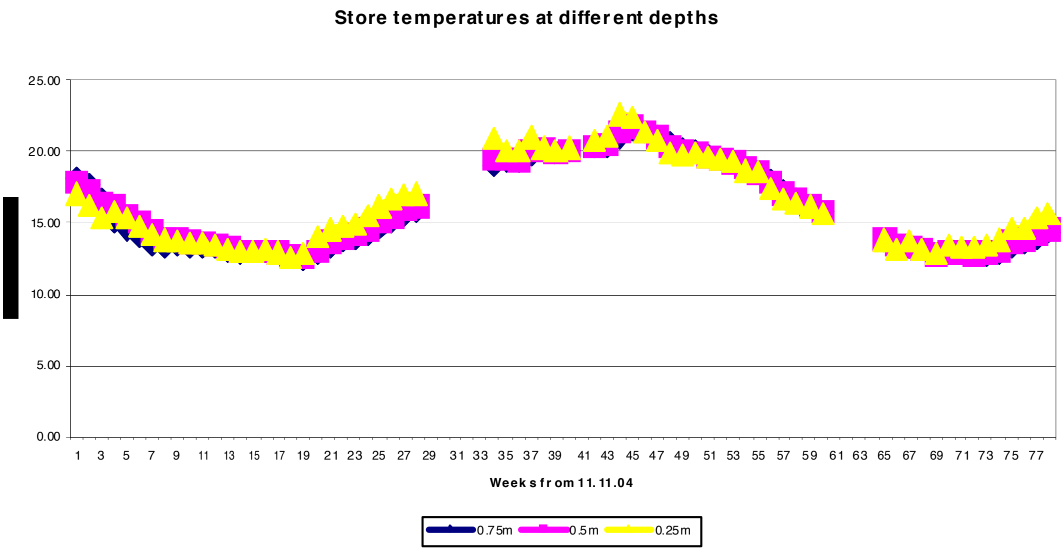

Fig. 7 Horizontal temperature gradient in the thermal store

The initial pattern of temperatures gives little indication as both shallow (250mm) and deep (750mm) sensors are lower than the one at 500mm and the relative conditions change until early February when temperatures at all depths are very similar until early spring. At this point there is a clear gradient from shallow to deeper sensors with the temperature nearest the surface being highest and changing more rapidly. The thermal store is therefore charging, with heat being conducted from the higher surface conditions to the lower temperatures within the wall. The current analysis has been based upon weekly average temperatures within the store but further analysis of diurnal fluctuations will give a more detailed understanding of how the thermal store is charging and discharging.

At the beginning of October, the direction of the gradient appears to change, with the shallow temperatures being lower than the deeper ones. Heat is being conducted from the store towards the room in order to maintain stable conditions within the space.

4.4 Energy stored in the tyre wall

It has not been possible to evaluate the full extent of the thermal storage as it has only been practical to install sensors up to a depth of 750mm into the wall and in a limited number of positions. Further, the analysis to date has been based primarily on the sensors buried in the wall to the rear main room. However, it is reasonable to assume that the results are indicative of conditions within the entire thermal store which wraps around the kitchen, as well as the back and side of the main room. This represents a total volume of 135m^3.

Estimation of the thermal capacity of the wall at this stage is based simply upon published figures for the thermal capacity (1.1 kJ/kg ^{o}C) and density (2500 kg/m^3) of chalk (ArupGeotechnics 2002). It is appreciated that there are dangers with using these simple assumptions because of the composite nature of the wall including tyres and chalk, and of the lack of data with respect to the density of compaction or moisture content of the finished wall. However they enable the order of magnitude of energy storage to be considered.

Based on the above assumptions, the thermal capacity of a 135m^3 chalk store is 370MJ/^{o}C. The Brighton earthship store, which showed an average 2^{o}C rise over the first year of measurement, has therefore captured 740 MJ more than it has released over that time period.

The continuing monitoring and analysis will include both internal air temperatures and incident solar radiation, but given the unpredictable occupation pattern and level of activity it has not been considered appropriate to attempt this analysis to date.

4.5 Energy flows into the tyre wall

During the weeks from November through to the end of March the average temperature of the thermal store dropped steadily by a total of 5^{o}C. This represents a reduction of 1850 MJ. At its peak by mid September the store temperature had risen 9^{o}C and had therefore taken in 3330 MJ, but by the end of October had dropped 2^{o}C and emitted 740MJ.

Examination of the temperatures at a horizontal depth of 250mm into the wall shows them to be above the temperatures at 500mm and 750mm throughout the period when the average temperatures are rising. This demonstrates that the heat energy is flowing into the wall at this stage storing the incident solar radiation and internal gains.

5. Conclusion

The Brighton earthship has provided the Centre for Sustainability of the Built Environment at the University of Brighton the opportunity to gain real time measurements within the thermal store of a building designed on the principles of ‘glass and mass’. The unfinished nature of the building has meant that the results are not representative of an occupied building, however the results clearly indicate the nature of energy flows to and from the store.

The next stage in the analysis is to evaluate energy flows accounting for the external climate conditions including incident solar radiation and the temperatures within the occupied space. Monitoring will continue at least until steady cyclic conditions are achieved within the store and an assessment of whether additional winter heating will be required for an occupied building.

Development is also in progress to produce a computerised thermal model of an earth sheltered building in order to enable further analysis and optimisation of the thermal capacity and heat transfer properties of the store.

ACKNOWLEDGEMENTS

The EU Interreg programme for the funding of the Durabuild project which undertook 12 case studies of which the earthship was one.

Members of the Durabuild team, Kath Shaw and Marta Lam and the Low Carbon Network, especially Mischa Hewitt the earthship project manager for their contributions to the research.

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ENERGY PERFORMANCE EVALUATION IN THE CASE OF APPLYING EXTERNAL INSULATION AND FINISH SYSTEM TO THE WALL-SLAB JOINTS IN APARTMENT BUILDING ENVELOPE

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Keywords: thermal insulation, thermal bridge, energy, floor radiant heating, IIS (Internal Insulation System), EIFS (External Insulation and Finish System

Summary

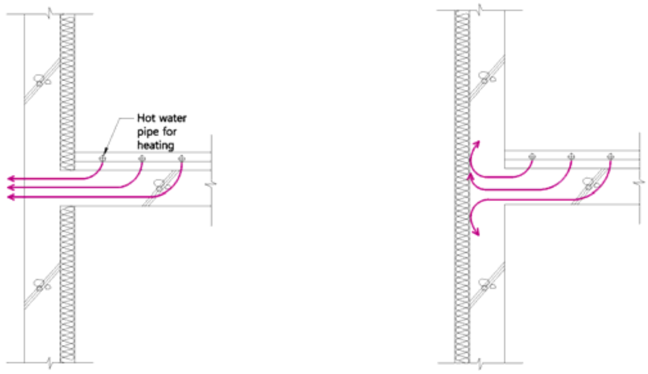
In apartment buildings, which are the most common type of residential buildings in Korea, hot water pipes used for heating are installed on the slab. The IIS (Internal Insulation System) is typically applied in most Korean apartment buildings. Consequently, there are many cases in which the layer of insulation is disconnected by the structural components at the joints of the wall-slab and wall-wall in the envelope. These joints become thermal bridges where the risk of inside surface condensation and heat loss increases. In particular, the amount of heat loss is significant at joints that are adjacent to hot water pipes used for heating. It is expected that the EIFS (External Insulation and Finish System) is the solution to this problem. In this study, a survey is carried out on the condition of EIFS in the current market. The front wall-slab joint and the side wall-slab joint of an apartment building that has been recently completed were selected as typical thermal bridges. The annual heat loss through each joint in both cases of applying IIS and EIFS was evaluated by a heat transfer simulation. From the results, it was found that the application of EIFS to the front wall-slab joint could reduce the amount of insulation by 47.2% and reduce the annual heat loss by 4.2%. In the case of the side wall-slab joint with EIFS, a 29.7% decrease of annual heat loss was obtained by increasing the amount of insulation by no more than 4.9%.

1. Introduction

Due to greenhouse gases and global warming problems, endeavours have been made in many countries around the world to construct more energy efficient buildings. In the past, the emphasis was placed on energy conservation within buildings for economical reasons alone. However, environmental reasons have recently become an important global issue. In Korea, the degree of self-sufficiency in energy is no more than 3.2%, yet it is ranked as the 10th largest annual consumer of energy in the world. The energy consumption in Korea has been increasing by 5.1% every year since 1990. In 2005, energy consumption in buildings constituted approximately 25% of the total domestic energy consumption, while the energy consumption in apartment buildings, which are the most common type of residential buildings in Korea, constitutes about 36% of the total energy consumption in buildings.

Compared to commercial buildings, apartment buildings have lower internal heat gains from occupancies, lighting and equipment and are dominated by the envelope load. Therefore, the heating load is significantly larger than the cooling load in the Korean climate, while thermal insulation is a very important factor to consider. In addition, the conductive heat transfer should be reduced through the envelope because hot water pipes that are used for radiant heating are typically installed on the slab in Korean apartment buildings. The internal insulation system (hereafter IIS) has been typically applied to most Korean apartment buildings since the first modern apartment building was built in the early 1960s. Thus, there are many cases in which the layer of insulation is disconnected by structural components at the joints of the wall-slab and wall-wall in the envelope. These joints become thermal bridges where the risk of inside surface condensation and heat loss increases. In particular, the amount of heat loss is considerable at joints adjacent to hot water pipes for heating. Conversely, the external insulation and finish system (hereafter EIFS) can prevent the occurrence of the thermal bridge, by fully continuing the insulation at the joints of the wall-slab and wall-wall in the envelope. In addition, this is expected to increase the heating efficiency because thermal mass such as a concrete wall is placed inside the insulation (see Figure 1).

Because apartment buildings are the most common type of residential buildings in Korea, whereby the same or similar details are repeated, it is expected that there is significant potential to save the heating energy consumption by applying the EIFS. However, there are very few apartment buildings where EIFS has been applied. It is a consequence of the reluctance of the construction industry to take risks involved in a new system and the lack of concern for energy conservation. Thus, in this study, the aim was to verify the feasibility of EIFS in terms of energy conservation. The condition of EIFS in the current market was surveyed. The front wall-slab joint and the side wall-slab joint of the recently completed "E" apartment building were selected as the most common type of thermal bridge. The annual heat loss through each joint in both cases of applying IIS and EIFS was evaluated by a heat transfer simulation.



(a) IIS *(b) EIFS*

Figure 1 Heat flow path at the wall-slab joint

Table 1 Elements of EIFS

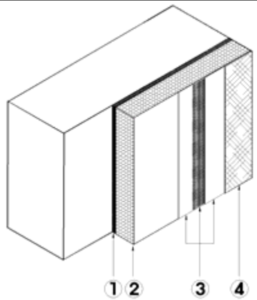
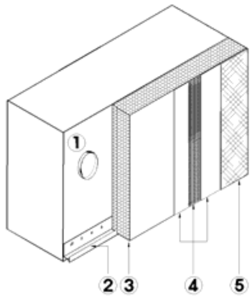
Adhesively fixed system	Mechanically fixed system
	
① Adhesive ② Insulation board ③ Base coat with reinforcing mesh ④ Finish	① Adhesive ② Track ③ Insulation board ④ Base coat with reinforcing mesh ⑤ Finish

Table 2 EIFS on the market

Manufacturer	Insulation material	Fixing method		Ventilated system
		Adhesively fixed	Mechanically fixed	
A (Korea)	Polystyrene foam	O	X	X
B (Germany)	Polystyrene foam	O	O	X
	Mineral fibre	O	O	O
	Mineral foam	O	X	X
C (USA)	Polystyrene foam	O	O	O
D (Japan)	Polystyrene foam or Phenol foam	X	O	X
	Mineral fibre	O	X	X
	Mineral fibre or Glass fibre or Phenol foam	X	O	O
E (Japan)	Glass fibre	X	O	O

2. Present condition of EIFS on the market

EIFS is installed on the structure in the order of insulation board → base coat with reinforcing mesh → finish from inside to outside. On the basis of the fixing method, EIFS can be divided into two types, that of an adhesively fixed system and a mechanically fixed system. In the adhesively fixed system, the insulation board is fixed with adhesive. In a mechanically fixed system, tracks are inserted into the insulation board which is fixed with tracks and a small amount of adhesive. A ventilated EIFS is also available, which eliminates moisture through an air cavity and is an integrated system combining the insulation board with the finish material. In Korea, the adhesively fixed system is most often applied, and polystyrene foam is used for insulation material (see Table 1 and Table 2).

3. Annual heat loss evaluation in both cases of applying IIS and EIFS

3.1 Evaluation overview

The front wall-slab joint and the side wall-slab joint at the typical floor of the "E" apartment building were selected for the evaluation. IIS was applied to the "E" apartment building, which was recently completed in Seoul, Korea. The annual heat loss through each joint in both cases of applying IIS and EIFS was calculated by a three-dimensional annual transient heat transfer simulation. The Physibel Voltra 6.0W was used as a simulation tool. The Physibel Voltra 6.0W is a multi-purpose commercial code based on the finite difference method.

3.1.1 Modeling

The front wall-slab joint and the side wall-slab joint are shown in Figure 2. Both of these are typical thermal bridges that appear repeatedly in apartment building envelopes. For the front wall-slab joint, it was assumed that the expanded balcony type floor plan was applied. A PVC framed double glazing window system was applied to this joint. Vertical section drawings for both cases of applying existing IIS and EIFS are shown in Figure 3. In the case of the existing IIS, it can be seen that mineral fibre insulation of thickness 60mm and depth 1,515mm is additionally installed under the slab to reduce heat loss due to the thermal bridge. Figure 4 shows the simulation model. As Physibel Voltra is for a three-dimensional transient heat transfer calculation only, simulation model was built by extending two-dimensional section as shown in Figure 3 to the direction of z axis by 1,000mm. The guardrail, which supposedly has almost no influence on heat loss, was ignored and the section of window frame was simplified for the convenience of calculation. Vertical section drawings of the side wall-slab joint in both cases of applying existing IIS and EIFS are shown in Figure 5. In the case of the existing IIS, it can be seen that expanded polystyrene extruded insulation of thickness 15mm and depth 480mm is additionally installed under the slab to prevent inside surface condensation caused by the thermal bridge. Figure 6 shows the simulation model. It was assumed that mineral fibre insulation was applied to the wall of both joints, considering that the requirements for fire-resisting qualities have been increasing. In addition, it was assumed that the adhesively fixed system was applied in the case of EIFS.

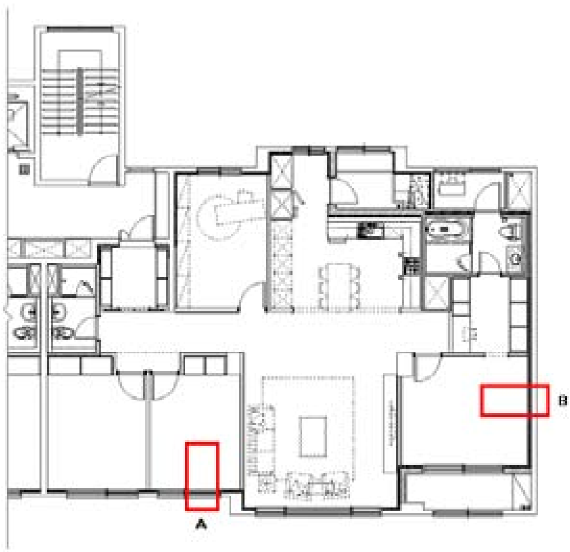
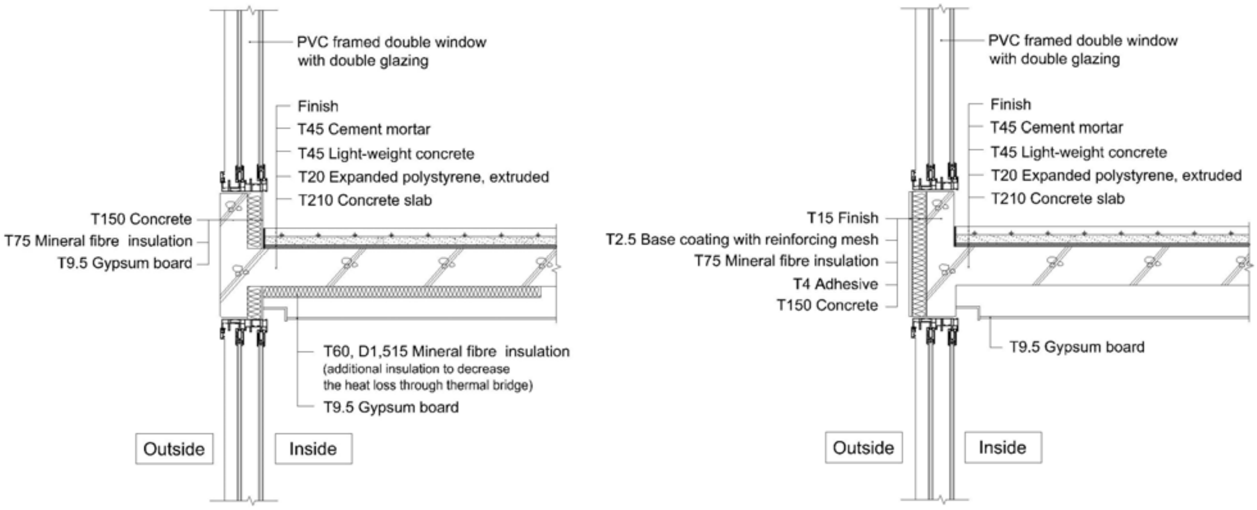


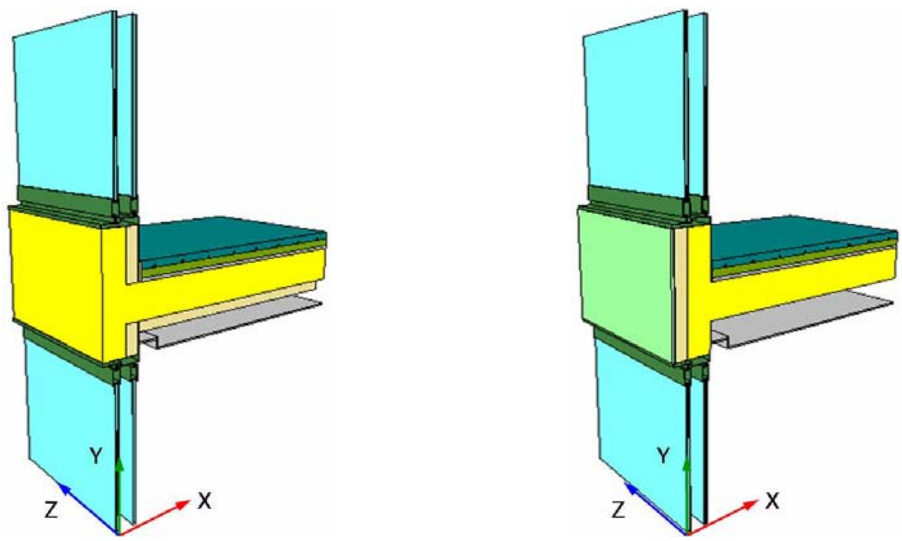
Figure 2 Typical floor plan of "E" apartment building, including hot water pipes for heating

(A: front wall-slab joint, B: side wall-slab joint)



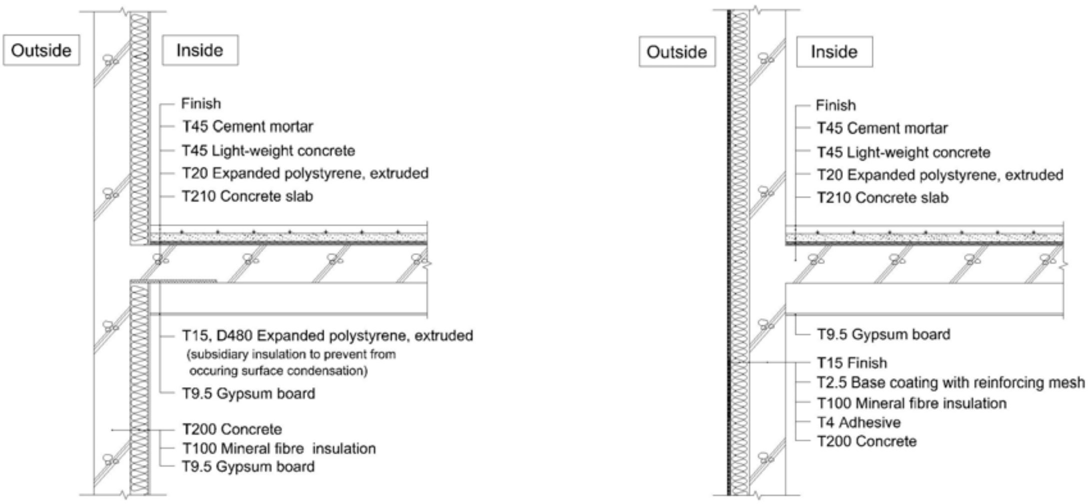
(a) IIS *(b) EIFS*

Figure 3 Vertical section of the front wall-slab joint



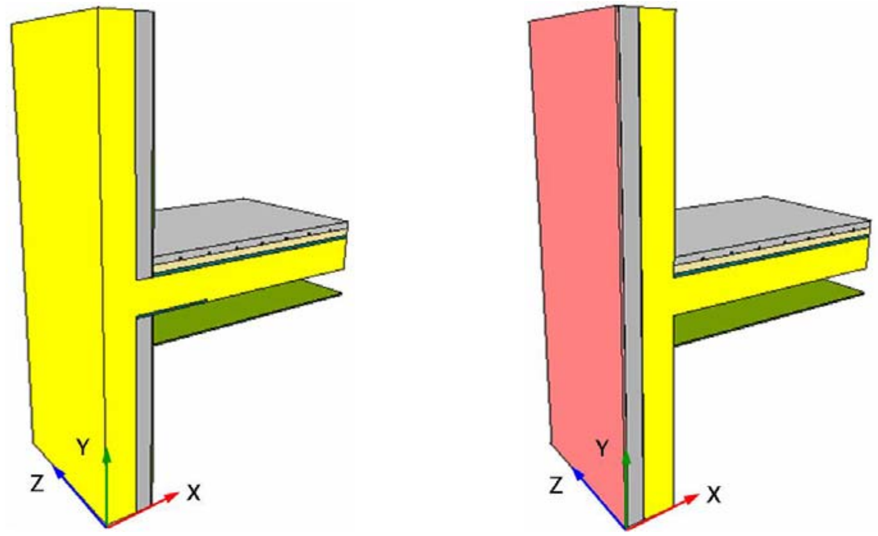
(a) IIS *(b) EIFS*

Figure 4 Simulation model of the front wall-slab joint (x: 1,839.8mm, y: 2,690.0mm, z: 1,000.0mm)



(a) IIS *(b) EIFS*

Figure 5 Vertical section of the side wall-slab joint



(a) IIS *(b) EIFS*

Figure 6 Simulation model of the side wall-slab joint (x: 1,849.5mm, y: 2,690.0mm, z: 1,000.0mm)

3.1.2 Simulation conditions

After modelling the area to be evaluated with CAD data, the annual heat loss at the inside surface of the simulation model was calculated under the condition that hot water was supplied according to the heating schedule. Here, heat loss implies the sum of the heating load and the lost heat through the envelope among the heat supplied by hot water for heating. The annual hourly standard weather of Seoul was used for setting the outside temperature. Boundary conditions are shown in Table 3. Air cavities were set as BC_FREE, which is the boundary condition type for enclosed cavities of unknown air temperature. In this condition, convective and radiative heat transfer is calculated using equations below.

$$q_c = h_c \times (\theta_a - \theta_s) \quad (1)$$

q_c : Convective heat flow density(W/m^2) h_c : Convective heat transfer coefficient (W/m^2°C)

θ_a : Air temperature(°C) θ_s : Surface temperature(°C)

$$q_r = F_{ij} \times h_{rb} \times (\theta_i - \theta_j) \quad (2)$$

q_r : Radiation density(W/m^2)

F_{ij} : Geometric view factor from surface i to surface j $(0 \le F_{ij} \le 1)$

h_{rb} : Black radiation heat transfer coefficient(W/m^2°C)

θ_i, θ_j : Surface temperature(Surface i and j)(°C)

A hot water supply schedule for radiant heating is shown in Table 4. It is difficult to create a schedule for the generalization of hot water supply because there is an individually controllable heating system for each residential unit and the thermal requirements of the residents are considerably varied. The hot water supply schedule was therefore generalized, based on the previous study regarding a hot water supply pattern for the apartment building with the lowest outside temperature in Korea. Water temperature while heated was set to 65°C. Hot water cools gradually while not heated and its temperature should be calculated. However, water temperature of every time step must be specified to make its temperature function in Physibel Voltra. Due to this limitation of Physibel Voltra, water temperature while not heated was compelled to set to the inside air temperature for adding no heating or cooling loads. Considering that the objective is to compare the IIS with the EIFS under the same condition, modelling in this manner is supposed to be allowed. Calculation parameters and material properties are shown in Table 5 and Table 6, respectively. In order to increase the accuracy of the calculation result, all the properties of materials for EIFS only were measured at the Korea Testing and Research Institute for Chemical Industry.

Table 3 Boundary conditions

Month	Inside		Outside	
	Temperature (°C)	Surface heat transfer coefficient (W/ m^2°C)	Temperature (°C)	Surface heat transfer coefficient (W/ m^2°C)
Dec. to Feb.	20.0	5.8	Dry bulb temperature in standard weather data of Seoul	34.0
Mar. to May Sep. to Nov.	23.0	5.8		28.4
Jun. To Aug.	26.0	5.8		22.7

Table 4 Hot water supply schedule for radiant heating

The lowest outside temperature of the day (°C)	Operating frequency (Times/Day)	Operating hours (Hours)	Time	Hot water temperature (°C)
Below -10	3	8	4~7, 11~13, 17~20	65
-10 ~ -5	3	7	4~6, 11~13, 17~20	
-5 ~ 15	2	4	4~6, 17~19	

Table 5 Calculation parameters

Item	Calculation parameters
Time step interval	30minutes
Start-up calculation duration	6days
Maximum number of iterations	10,000
Maximum temperature difference	0.0001°C
Heat flow divergence for total object	0.001%
Heat flow divergence for worst node	1%

Table 6 Material properties

Material		Thermal conductivity (W/m°C)	Density (kg/m^3)	Specific heat (J/kg°C)
Common materials	Concrete	1.720	2,240	879
	Lightweight concrete	0.114	650	1,173
	Cement mortar	0.930	1,950	921
	Gypsum board	0.326	940	1,130
	Mineral fibre insulation	0.035	50	838
	Expanded polystyrene extruded insulation	0.029	43	1,220
	Polyvinyl chloride	0.170	1,390	900
	Glass	1.000	2,470	750
	X-L pipe	0.324	930	1,600
Materials for EIFS only	Adhesive	0.353	1,493	717
	Base coating	0.181	1,761	914
	Finish	0.196	1,521	965

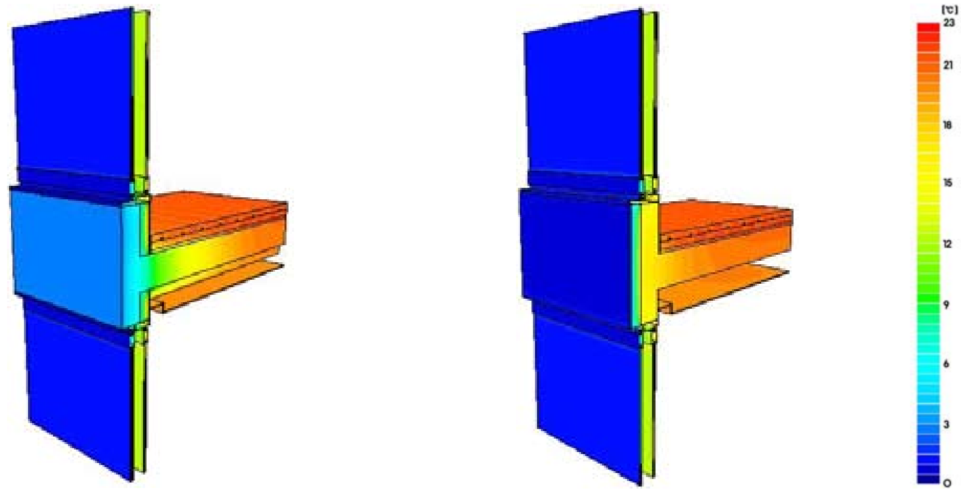
3.2 Annual heat loss evaluation results

3.2.1 Front wall-slab joint

The volumes of insulation installed in the simulation models are 0.159 m^3 for IIS and 0.084 m^3 for EIFS, indicating that EIFS has 47.2% less insulation. Thus, it is expected that the heat loss of EIFS might be more than that of IIS, even though the heat loss could be reduced with EIFS due to the thermal bridge. However, the annual heat losses of IIS and EIFS are 1,586,945.3 MJ and 1,520,282.4 MJ, respectively, which indicates that EIFS has 4.2% less annual heat loss (see Table 7). Consequently, the heat loss through the thermal bridge adjacent to hot water pipes used for heating is significantly large in the existing IIS. Thus, it is concluded that the application of EIFS to the front wall-slab joint is very efficient in terms of both the amount of insulation and energy conservation. Figure 7 shows the temperature distribution of the front wall-slab joint at the time (05a.m. 6th Jan.) of the lowest outside temperature (-12.3°C) in the year.

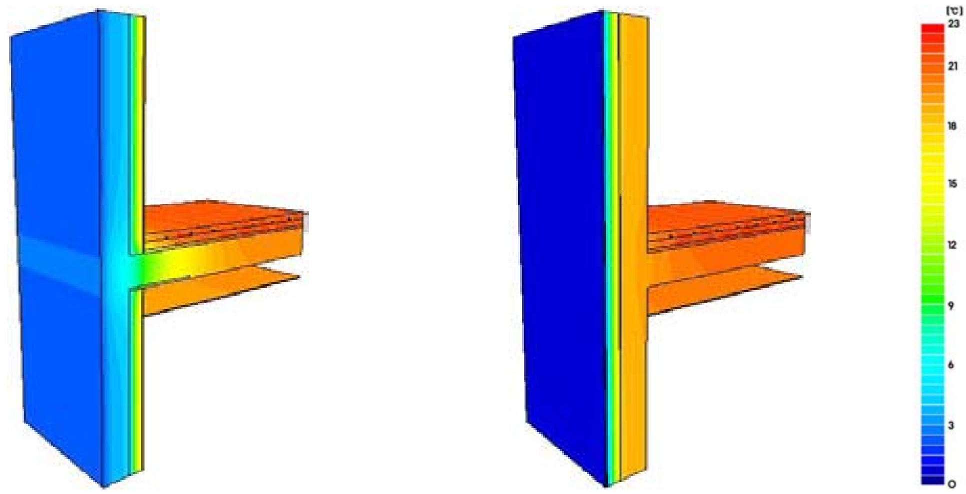
Table 7 Monthly and annual heat loss (MJ) and the volume of insulation (m^3)

Month	Front wall-slab joint		Side wall-slab joint	
	IIS	EIFS	IIS	EIFS
Jan.	288,655.3	276,252.4	83,393.9	58,459.5
Feb.	212,831.5	203,638.1	62,510.4	43,757.8
Mar.	212,386.6	203,176.6	64,584.4	44,664.4
Apr.	132,722.3	127,136.2	38,083.8	27,734.6
May	75,539.8	72,300.2	20,615.1	15,500.5
Jun.	51,851.6	49,391.8	18,540.6	12,455.5
Jul.	27,721.2	26,504.9	9,153.9	5,999.1
Aug.	18,311.3	17,608.4	4,642.3	2,872.2
Sep.	29,271.5	28,067.5	7,998.5	5,222.9
Oct.	98,198.1	94,334.3	25,970.1	19,303.1
Nov.	186,382.9	178,907.9	54,092.1	37,861.2
Dec.	253,073.2	242,964.1	74,279.5	52,055.8
Sum	1,586,945.3 (0.0%)	1,520,282.4 (-4.2%)	463,864.6 (0.0%)	325,886.6 (-29.7%)
Volume of the insulation	0.159 (0.0%)	0.084 (- 47.2%)	0.286 (0.0%)	0.300 (+ 4.9%)



(a) IIS (b) EIFS

Figure 7 Temperature distribution of the front wall-slab joint at the time of the lowest outside temperature



(a) IIS (b) EIFS

Figure 8 Temperature distribution of the side wall-slab joint at the time of the lowest outside temperature

3.2.2 Side wall-slab joint

The volumes of insulation installed in the simulation models are 0.286 m^3 for IIS and 0.300 m^3 for EIFS, indicating that EIFS has 4.9% more insulation. The annual heat losses of IIS and EIFS are 463,864.6 MJ and 325,886.6 MJ, respectively, indicating that EIFS has 29.7% less annual heat loss (see Table 7). Thus, it is concluded that the application of EIFS to the side wall-slab joint is very efficient, because a 29.7% decrease of annual heat loss is obtained, with an increase in the volume of insulation by no more than 4.9%. Figure 8 shows the temperature distribution of the side wall-slab joint at the time (05a.m. 6th Jan.) of the lowest outside temperature (-12.3°C) in the year.

4. Conclusions

In apartment buildings, which are the most common type of residential buildings in Korea, hot water pipes used for heating are installed on the slab. IIS is typically applied to most Korean apartment buildings. Consequently, there are many cases where the layer of insulation is disconnected by the structural components at the joints of the wall-slab and wall-wall in the envelope. These joints become thermal bridges where the risk of inside surface condensation and heat loss increases. It is expected that EIFS is the solution to this problem. Based on the market survey, the general types of EIFS were investigated. The front wall-slab joint and the side wall-slab joint of a recently completed apartment building were selected as typical thermal bridges. The annual heat loss through each joint in both cases of applying IIS and EIFS was evaluated by a heat transfer simulation. From the results, it was found that the annual heat loss through the thermal bridge adjacent to hot water pipes used for heating was significantly large in the existing IIS, even though additional insulation was installed under the slab in order to reduce heat loss. It was found that, compared with the existing IIS, for the front wall-slab joint with EIFS, not only was the amount of insulation reduced by 47.2% but the annual heat loss was also reduced by 4.2%. The side wall-slab joint with EIFS, compared with the existing IIS, was found to reduce the annual heat loss by 29.7% with no more than a 4.9% increase of the amount of insulation.

The aim of this study was to verify the feasibility of EIFS in terms of energy conservation. In order for EIFS to be widely used in apartment buildings which tend to be high-rise, it is considered that the durability and the construction methods required to facilitate the installation should be confirmed.

Acknowledgements

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STUDIES ON SOLAR ENERGY FOR RESIDENTIAL USE IN AUSTRALIA WITH CONSIDERATION OF CLIMATE CHANGE SCENARIOS

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Keywords: solar energy, solar irradiance, demand and supply, climate change, residential buildings, AccuRate.

Summary

The potential for solar power to meet residential energy demand under climate change scenarios is investigated in this paper. While the residential energy demand is determined by the various factors directly associated with buildings and their environment, the extent to which this demand can be met by solar energy will clearly depend on the level of solar irradiance and the orientation at which the solar panel is mounted. Observations of direct normal solar irradiation and diffuse irradiation by Australian Bureau of Meteorology are utilized to map total solar irradiation on horizontal or tilted panels in Australia, offering a straightforward, though specific approach to estimate the supply capacity. The mapping shows that the supply capacity is both temporally and spatially dependent, with the difference in yearly total solar irradiation of up to 30% at different locations in Australia. To maximise the supply, the solar panel orientation should also be properly selected. Meanwhile, the software platform, AccuRate, is applied to simulate the demand, having given a typical building design with five star energy rating subject to a typical climate environment in Australia. More consideration about the effect of global warming in A1FI climate change scenarios on the demand is also taken into account. Observations of the demand and supply over time show that, in addition to the trend and seasonal changes, there exists significant noise that is stochastic in nature. The reliability of solar energy supply to satisfy the demand is then considered. Design options in regard to the panel size requirement to balance the supply and demand are investigated by considering cases in Melbourne and Alice Springs in Australia. The result may provide an effective approach to understand the practicality of solar energy use and minimum requirement for solar panel design, in terms of the size and orientation at a specific location to balance residential demand with a high degree of confidence.

1. Introduction

Effective design and utilization of solar energy for residential buildings depend on the understanding of the extent of supply capacity by solar power, which is spatially and temporally sensitive. It is also related to the understanding of residential energy demand. While the demand is determined by building design, occupants and their environment, the supply capacity is essentially associated with the solar irradiance received on designed solar panels in addition to its efficiency.

1.1 Energy Demand of Residential Houses

It has been estimated that Australian households are ultimately responsible for over half of the total energy use in Australia, either directly or indirectly through the consumption of products and services (ABS 2001). The direct household energy consumption accounted for 27% of the total in 1997-98. Fig. 1 shows the percentage of each component of energy use in Australian residential buildings during 2005-06. It was found that space heating and cooling accounted for 42%, hot water 24%, and appliances 34%.

The energy demand required for electrical appliances, cooking and water heating is largely unaffected by the design and thermal performance of building envelop. Climate may have secondary impacts on the energy

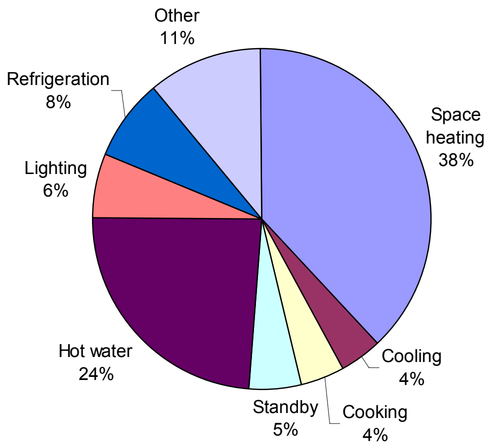

Figure 1 Residential energy consumption by end use 2005-06 (CIE (2007) and Pears (2007))

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demand of refrigerators, freezers and hot water systems. There are other behavioral factors, such as the temperature level selected for laundry and the usage frequency of dryers, which may also have an influence on the energy demand. Demand for space heating and cooling has been considered as the largest energy end use in residential buildings. Heating and cooling loads of a specific residential building can be predicted by building energy performance models, such as EnergyPlus[2] and AccuRate[3]. Climate change may also have a significant impact on the demand for heating and cooling as a result of the increase in temperature. It may consequently affect the energy rating of buildings, depending on where they are located.

1.2 Solar Irradiation

Solar irradiation, which attenuates when travelling through the atmosphere, may be related to mixed gases, ozone, and water-vapour according to the models such as the so-called Meteorological Radiation Model (Muneer et al, 2000; 2006), and it is also often estimated on the basis of cloud cover. The Australian Bureau of Meteorology (BoM) provides cloud observation in oktas, which represent the cloud coverage by scores ranging from one to eight, with one indicating no cloud and eight indicating the sky fully covered with cloud. More detailed information may include the first low cloud, second low cloud, middle cloud, high cloud, and total cloud amount. Cloud coverage may also be described by average daily or monthly sunshine period or duration.

Models to estimate solar irradiation by using recorded weather data are generally divided into two categories, i.e., sunshine-based and cloud-based (Iziomon et al, 2002). Traditional *Page model* [Singh et al, 1996] is sunshine-based. There are variant models that modify the *Page model* to consider the nonlinearity of the ratio S/S_0, the effects of latitude, solar altitude (Lin et al, 1999) and atmospheric water vapour content (Iziomon et al, 2002).

Sunshine-based models provide a simple approach for estimating solar irradiance on a horizontal surface over daily and monthly periods, but may be inaccurate when a tilted surface is considered. The total daily solar irradiation on a tilted surface is a function of the normal direct irradiation as well as the corresponding solar altitude that varies over day time. Therefore, knowing the daily or monthly average value correlated to sunshine duration does not give a direct answer to the total daily solar irradiation on a tilted surface. In this case, the more proper approach is to assess solar irradiation based on cloud cover information by using a smaller time scale, such as hourly intervals. The *Kasten model* (Iziomon et al, 2002) provides a relation between total solar irradiation and cloud amount. More empirical models were developed by Gul et al, (1998) and Ehnberg et al (2005).

However, a more straightforward approach is the direct use of solar irradiance data acquired by the observation stations operated in each State and Territory. When the normal direct irradiation and diffuse irradiation are included in observation, the total solar irradiation on a tilted surface may simply be estimated by Eq.(2). Though the results from the approach are specific to those observation locations, spatial interpolation may be applied to obtain the total solar irradiation at other locations.

2. Assessment of Supply Capacity of Solar Power

2.1 Irradiance Distribution in Australia

BoM data available to us consists of hourly climatic data, which includes direct solar irradiance on a plane normal to the beam (G_{ND}) and diffuse solar irradiance on a horizontal plane (G_d). The data covers 77 locations including 64 in Australia, as shown in Fig.2. Some major cities have dual observation stations.

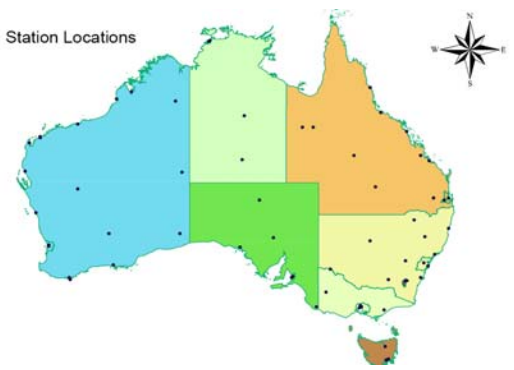

Figure 2. Locations of observation sites for the data

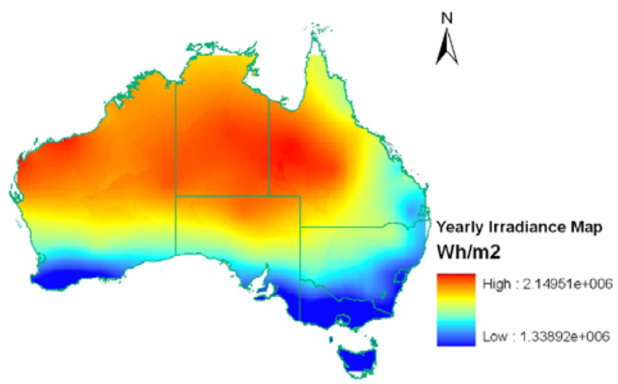

Figure 3. Maps of yearly solar irradiance on a horizontal surface

[2] See information in www.eere.energy.gov/buildings/energyplus/.
[3] See information in www.hearne.com.au/products/accurate/.

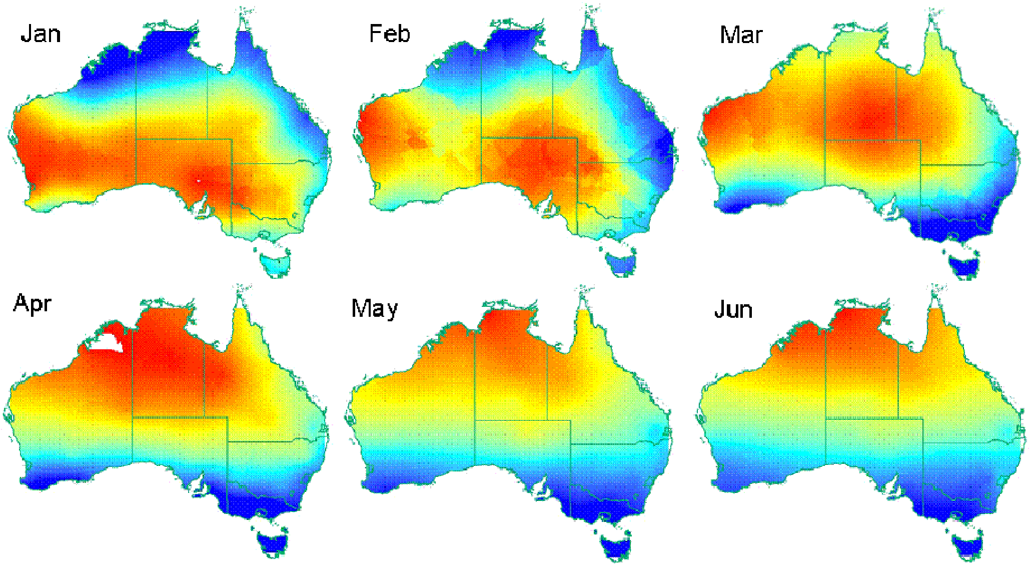

Figure 4. Maps of monthly solar irradiance on a horizontal surface from January to June[4]

Most data were recorded for a period of 10 years between 1978 and 1987 with some as early as 1961. The total solar irradiation can be simply given by:

$$G_{D\theta} = G_{ND}\cos\theta + G_d \frac{(1+\cos\alpha)}{2} \qquad (1)$$

The total solar irradiation is relevant to solar altitude, which depends on the locations and varies over a yearly period. Fig.3 maps the yearly solar irradiance on a horizontal surface in Australia, and Fig. 4 describes its seasonal changes. The difference of the total solar irradiation at different location or during different seasons can be fairly significant. Fig. 5 presents the average monthly solar irradiance in cities located within 7 climate zones, defined in Building Code of Australia (BCA). Although the pattern generally follows the common sense that there is higher irradiation in summer and lower in winter, it is not always true in tropical areas, such as Darwin.

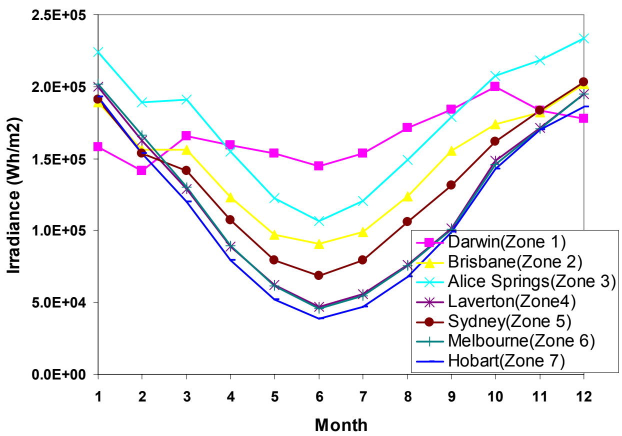

Figure 5. Monthly average solar irradiance in citieslocated in 7 climate zones defined by BC

2.2 Solar Irradiation and Supply Capacity

Fig.6 shows the average total daily solar irradiance on a horizontal surface in Melbourne, Alice Springs and Darwin, and Fig.7 presents the average cumulative electricity amount that could be generated on a 1m^2 horizontal panel over a year by assuming that the efficiency of the solar panel is 13%. The cumulative supply capacity in Melbourne is about 30% lower than in Alice Springs and Darwin.

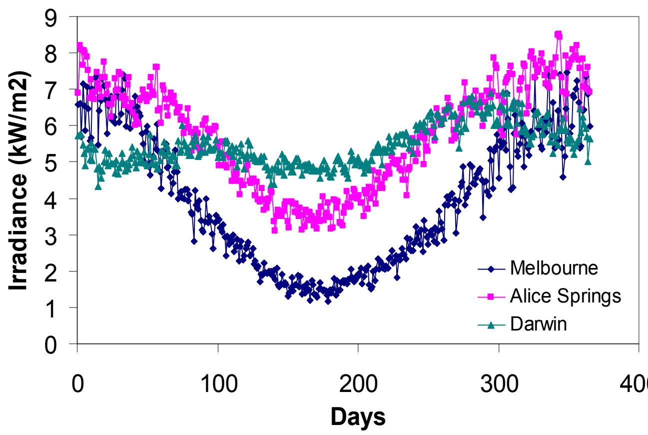

Figure 6. Average daily solar irradiation on a horizontal surface

It should be emphasized that the azimuth and tilt angle of a panel have a considerable influence on the total solar irradiation on its surface. While it is generally understood that

[4] The colour describes different scales in each diagram to highlight the spatial difference, rather than the difference amid months.

the solar panel would receive more irradiation when facing north (or azimuth angle =0), the selection of tilt angle becomes quite important for solar panels to achieve maximum exposure to solar irradiation. In fact, the pattern of average total daily irradiance on a solar panel may be completely changed as a result of the variation of tilt angle, as shown in Fig.8. It is generally understood that the total solar irradiation obtains a considerable increase when the panel surface is allowed to maintain normal to the solar beam.

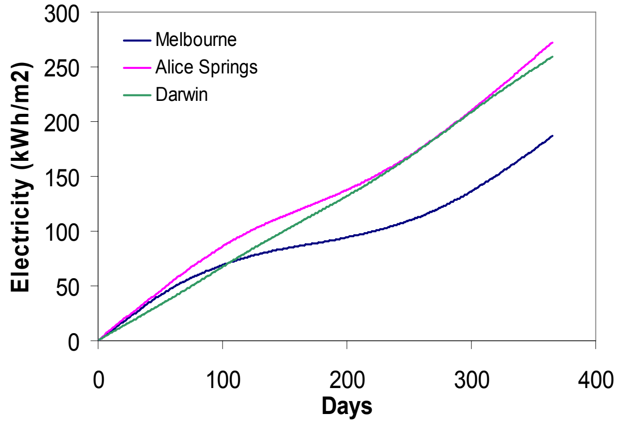

Figure 7. Cumulative supply capacity of a 1m^2 horizontal solar panels

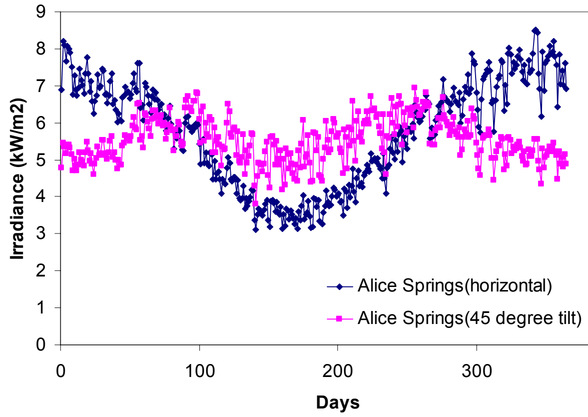

Figure 8. Average total daily solar irradiance in Alice Springs.

Assuming the efficiency of solar panels is 13%, the cumulative supply capacity of north-facing solar panels with different tilt angles in Melbourne and Alice Springs is shown in Fig.9. The results illustrate that a proper change of tilt angle may increase the supply, but the increase of tilt angle would not always be able to achieve more capacity.

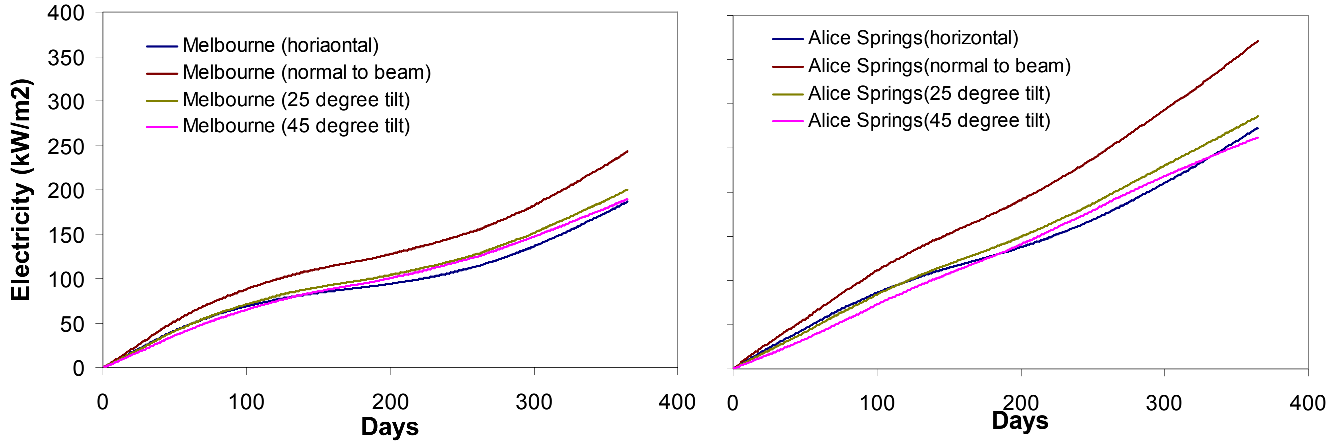

Figure 9. Cumulative supply capacity of north-facing solar panels with different tilt angles in Melbourne and Alice Springs

3. Energy Demand Simulation of Residential Houses with Effects of Climate Change

AccuRate, software developed by CSIRO to simulate residential energy use, is to be applied to simulate the energy demand. The current version of AccuRate only deals with heating and cooling energy. The other components of the house's energy demand were estimated from data available from the Australian Greenhouse office's Your Home technical manual (AGO 2008).

To illustrate the process involved in accessing energy demand of residential houses, a conventional single-storey house with a floor area of 224 m^2 (and a conditioned floor area of 173 m^2) was modeled by AccuRate. The house has four bedrooms (master bedroom with ensuite and WIR), a kitchen/family area, a living room, a laundry, a separate bathroom and toilet, a rumpus room and a double garage. The house satisfies the 5-star energy rating requirement in Melbourne and Alice Springs. The hot water system is solar hot water system boosted by electricity (40%). Given the location of houses in addition to above details, AccuRate may output hourly heating and cooling space energy requirements. These were first converted to the energy consumption by multiplying the requirements by the assumed efficiencies of a reverse-cycle heat pump in heating or cooling mode. A daily profile of hourly energy consumption for appliances and hot water (i.e. excluding heating and cooling) was simulated. The profile was then added to each day of heating and cooling energy consumption to create a file of total hourly energy demand, which may also be aggregated to the total daily demand for Melbourne and Alice Springs, described as BAU, i.e. business as usual, in Figs.10. Typically, there is relatively more demand in Melbourne for heating in winter, while more demand in summer for cooling in Alice Springs. Occasionally, there is also high demand for cooling in hot days in Melbourne.

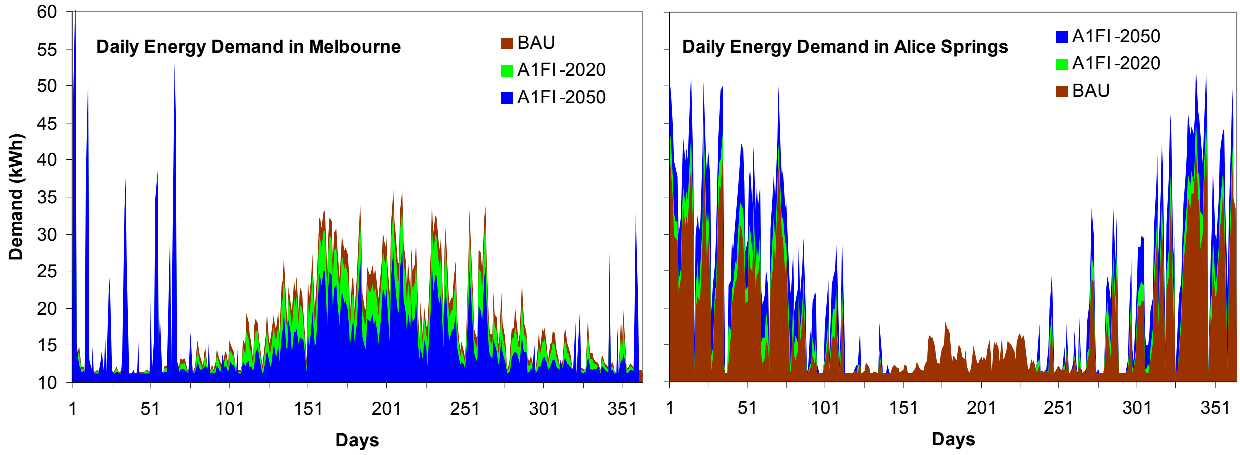

Figure 10. Residential energy demand for a typical four bedroom house in Melbourne and Alice Springs: 1) BAU, 2) A1FI climate change scenario in 2020, 3) A1FI climate change scenario in 2050

Considering the emission scenario A1FI defined by IPPC Special Report on Emission Scenarios (SRES) (IPCC 2000; CSIRO, 2007), OZClim[5], developed by CSIRO, is used to project climate change in Australia for 90th percentile temperature variation in 2020 and 2050, respectively, as shown in Fig.11. The temperature increase is 0.6°C and 2.0°C for Melbourne, 0.9°C and 2.9°C for Alice Springs (North Territory).

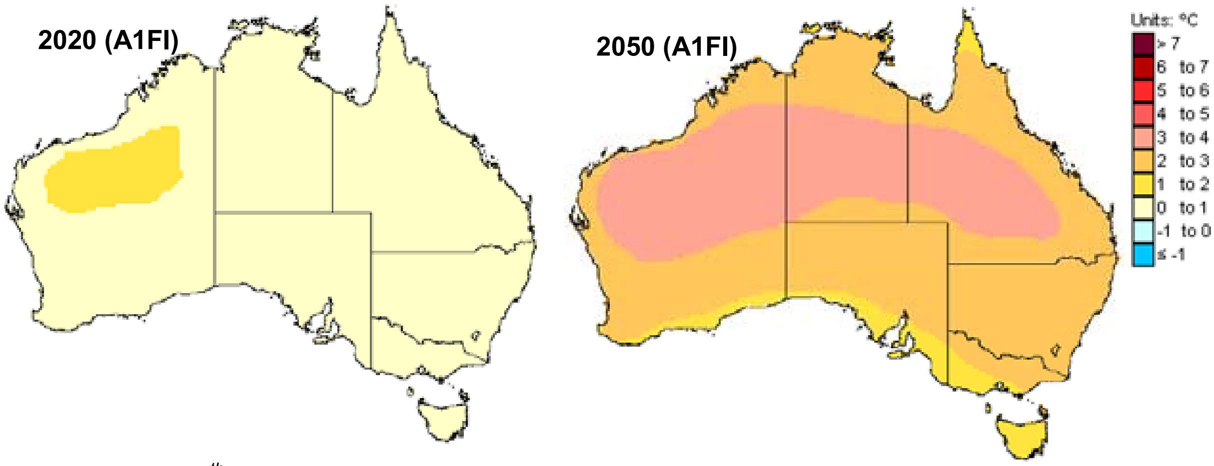

Figure 11. 90th percentile temperature variation projection in 2020 and 2050 by OZClim

Table 1 describes the effect of climate change on the yearly energy demand. In Melbourne, the energy demand decreases with the global warming scenario, 5.5% and 13.5%, respectively. However, in Alice Springs, it increases 6.3% and 23.3%. The increase in Alice Springs is quite significant. As shown in Fig.10, the decrease in Melbourne is caused by the reduction of energy use for heating in winter as a result of increasing temperature, while the increase in Alice Springs results from more demand of energy consumption for cooling in summer. Based on the current practice in the energy rating for residential houses, the 5 star rating for the typical house is also affected by the climate change, as shown in Table 2. While the energy rating in Melbourne increases, it may drop significantly in Alice Springs.

Table 1. Yearly energy demand in three climate scenarios

Location	BAU (kWh)	2020 - A1FI (kWh)	2050 - A1FI (kWh)
Melbourne	6759	6384	5844
Alice Springs	6569	6985	8102

[5] See information in www.csiro.au/ozclim.

Table 2. Energy rating in three climate scenarios

Location	BAU	2020 - A1FI	2050 - A1FI
Melbourne	5.1	5.7	6.6
Alice Springs	4.9	4.4	3.3

4. Reliability of Solar Power Supply

The fundamental questions in solar power design are what size of a solar panel would be required enough to balance the residential energy consumption demand, and how reliable the supply is. Assuming that a solar panel has 13% efficiency, the minimum size requirement of the solar panels to balance total yearly demand can then be estimated by the comparison of the demand with the supply capacity discussed in section 3. Table 3 gives the minimum panel size, which is not only related to the location of the panel, but also the orientation of the panel. The panel with tilt angle of 45° will reduce the panel size requirement in Melbourne, but it increases in Alice Springs. By maintaining the panel normal to the solar beam may reduce the size by 23% in Melbourne and 26% in Alice Springs when comparing with the size required for the horizontally placed panel. Meanwhile, as a result of climate change, the size requirement of a horizontal panel reduces by 5.5% and 13.5%, respectively, in Melbourne. However, it increases by 4.4% and 23.3% in Alice Springs.

Table 3. Panel size required to balance total yearly demand

Orientation	Melbourne (m^2)			Alice Springs (m^2)		
	BAU	2020-A1FI	2050-A1FI	BAU	2020-A1FI	2050-A1FI
Horizontal	36.18	34.18	31.29	24.11	25.64	29.74
45° tilt, facing north	35.67	33.70	30.85	25.07	26.65	30.92
Normal to solar beam	27.82	26.28	24.06	17.73	18.85	21.86

It should be emphasized that the balance of total yearly demand and supply does not mean that the solar power may maintain the daily supply to meet the demand. Both demand and supply over a year are affected significantly by stochastic fluctuation. Ideally, the panel size has to be large enough to meet the maximum daily demand in a year. However, considering the uncertainties involved in the demand and supply, it seems more logic to determine the size requirement on the basis of the concept of reliability, which is defined as the probability to balance the daily demand given a panel size. The reliability is fitted with lognormal probability distribution. Its density functions are given by Fig.12, where three climate scenarios are considered. For Melbourne, the density function shifts to the side in smaller size values, while it moves to another side for Alice Springs.

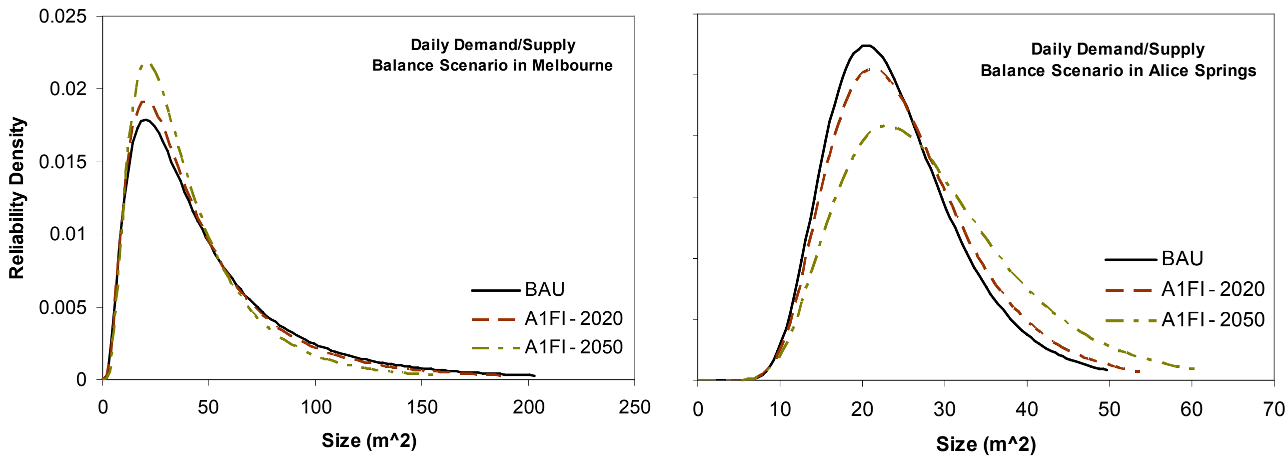

Figure 12. Reliability density in Melbourne and Alice Springs, given a solar panel size, in three climate scenarios

Considering three climate scenarios, Table 4 displays the estimation of horizontal solar panel size required to balance the daily demand with 90% reliability in Melbourne and Alice springs. The lower and upper bound of the estimation with 95% confidence are also described. The low radiation in winter has significantly increases the requirement of solar panel size in Melbourne. It is quite substantial for a four bedroom house and not much feasible for implementation in practice.

Table 4. Horizontal solar panel size required to balance daily demand

Climate	Melbourne (m^2)			Alice Springs (m^2)		
	90th percentile	Lower bound	Upper bound	90th percentile	Lower bound	Upper bound
BAU	106.87	91.82	125.75	35.23	33.06	37.72
2020-A1FI	97.48	84.24	113.99	37.33	34.95	40.07
2050-A1FI	81.46	71.42	93.80	43.75	40.66	47.33

Table 5 considers the effects of solar panel orientation on the size requirement. Once again, it indicates that the panel with tilt angle of 45° will reduce the panel size requirement in Melbourne, but it increases in Alice Springs.

Table 5. Panel size required to balance daily demand with consideration of orientation

Orientation	Melbourne (m^2)			Alice Springs (m^2)		
	90th percentile	Lower bound	Upper bound	90th percentile	Lower bound	Upper bound
Horizontal	106.87	91.82	125.75	35.23	33.06	37.72
45° tilt, facing north	77.82	69.16	88.32	40.24	37.07	43.93
Normal to solar beam	71.66	62.50	82.97	25.88	24.22	27.78

The high size requirement to balance daily demand in Melbourne is problematic for practical applications. Considering that the unconsumed energy can be used to charge batteries, it is not necessary to have the supply meeting the daily demand. Provided that the size of panels is large enough to ensure the balance between cumulative supply and demand, the size requirement may be reduced without compromising reliability.

Similar to the approach applied to the assessment of the panel size requirement to balance daily demand, the size to meet cumulative demand with 90% reliability over a year is described in Table 6. As seen, the size is considerably reduced, especially, in Melbourne.

Table 6. Panel size required to balance cumulative demand with consideration of orientation

Orientation	Melbourne (m^2)			Alice Springs (m^2)		
	90th percentile	Lower bound	Upper bound	90th percentile	Lower bound	Upper bound
Horizontal	47.34	44.50	50.59	29.29	28.79	29.84
45° tilt, facing north	42.99	41.01	45.21	37.99	36.38	39.79
Normal to solar beam	34.89	32.98	37.07	23.04	22.47	23.66

5. Conclusions

Observations of direct normal solar irradiation and diffuse irradiation by Australian Bureau of Meteorology were utilized to map total solar irradiation on horizontal or tilted panels in Australia, which is then converted to solar energy supply capacity to meet the demand. The study demonstrated that the supply capacity is both temporally and spatially dependent, with a difference in yearly total solar irradiation of up to 30% at different locations.

Energy demand of residential house is determined by the various factors directly associated with residential houses and their environment. AccuRate, developed by CSIRO, was used to simulate the demand for a typical 4 bedroom residential house with five star energy rating. The demand is affected by climate change. To understand the extent of the influence, the temperature increase in A1FI climate change scenario for 2020 and 2050 are taken into an account for the demand assessment. While the energy demand in Alice Springs climbs with the increase of temperature as a result of climate change, demand declines in Melbourne. This is due to the considerable reduction of energy consumption for heating in Melbourne, while the temperature increase may push up the demand in Alice Spring for cooling in summer. It is also interesting to mention that the energy rating for the house in Melbourne increases, while it drops quite significantly in Alice Springs as a result of climate change.

The size of solar panels may be estimated by the balance of total yearly demand and supply, but it ignores the stochastic nature in both residential demand and solar radiation. Demand and supply are fundamentally stochastic processes in addition to seasonal fluctuation patterns. The failure of solar energy supply to satisfy the demand describes the exceedance probability over a certain period, while the reliability represents the probability of supply to meet demand, given the size of a solar panel. Lognormal distribution function is applied to fit the reliability of daily supply. 90% reliability or 10% exceedance probability is considered to estimate the size requirement of solar panels. However, meeting daily demand is a very strict requirement, which is actually not necessary when batteries can be utilized to store the unconsumed supply. In this case, the size of solar panels is determined by the maintenance of the balance of cumulative supply and demand. As given in the example in Melbourne and Alice Springs, the size requirement is significantly reduced.

However, according to the estimation, the size requirement of solar panels is still quite significant, especially in Melbourne. With current technology, it is not practical to purely rely on solar energy to meet residential energy demand. Other renewable energy may also be applied to offset the demand, Nevertheless, continued efficiency improvements in solar power technology will increase the feasibility of solar power to meet the major proportion of residential energy consumption.

Acknowledgement

Authors would like to thank Dr Greg Foliente and Dr. Matthew Inman for their valuable comments.

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POTENTIAL OF ENERGY CONSERVATION AND PRACTICAL COUNTERMEASURES OF BUILDINGS FOR THE FUTURE BY A CASE STUDY OF JAPANESE CITY

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Keywords: statistics, long-term prediction, commercial building, energy conservation

Summary

In Japan, despite slowing in the population and maturation of domestic economy activities, energy consumption of commercial sector increases remarkably. Therefore, the countermeasure for commercial sector holds important clues to the energy conservation and CO_2 emission reduction. In this paper, the potential of energy conservation in Osaka(one of the typical mature cities in Japan) are discussed.

Firstly total floor space and specific energy consumption of commercial buildings in Osaka for the previous years were estimated. As a result, the factor that have increased energy consumption was the specific energy consumption.

Secondly we predicted total floor space of buildings in Osaka towards 2030.

Next we analyzed the specific energy consumption using a database. Specific energy consumption of actual buildings varies widely. We predicted energy consumption of commercial buildings in Osaka assuming that the dispersion of actual data of specific energy consumption was the difference between an inefficient building and an efficient building for energy consumption. And we studied the practical countermeasure equivalent to the minimum energy consumption by energy simulation.

Based on the above study, it was possible that energy consumption as of 2030 will be 0.5-0.7 times of current status if energy efficiency of all buildings as of 2030 is as high as the highest level of existing buildings.

1. Introduction

Each consumption-intensive country should promote the reduction of energy consumption and CO_2 emission to fight climate change. In Japan, despite slowing in the population and maturation of domestic economy activities, energy consumption of commercial sector increases remarkably. It is caused by particularly commercial sector along with household sector. Therefore, the countermeasure for commercial sector holds extremely important clues to the energy conservation and CO_2 emission reduction. In this paper, the potential of energy conservation in Osaka ; one of the typical mature cities in Japan, towards year 2030, are discussed.

2. Methods Description

2.1 Status of floor space and energy consumption

We estimated total floor space of buildings -office, shop, hotel and hospital-of previous periods(1991-2003) in Osaka using census and statistics. We calculated the office floor space by multiplying the number of office workers and working space per worker, the shop floor space by multiplying selling space of notification basis and the scaling factor, the hotel floor space by multiplying the number of guest rooms of notification basis and floor area per room, and the hospital floor space by multiplying the number of hospital beds of notification basis and floor area per room.

Secondly, we estimated energy consumption of commercial sector by sales data of utility company and statistics, and allocated in proportion as floor space of each building category.

Next, we analyzed specific energy consumption of each building category from the database "ELPAC" which is made up by academic society and economic organization in Japan.

2.2 Prediction of energy consumption

We predicted floor space of office, shop, hotel and hospital in Osaka by developing the regression model of working space per office worker, selling space, the number of guest rooms and the number of hospital beds, using estimated figures of time series . And we applied the figures predicted by a think tank or assumed to the number of office workers and explaining variable of the regression model.

2.3 Potential of energy conservation

We studied some actual countermeasure to verify potential of energy conservation obtained from the prediction, using the model Yamazaki developed(2002).

3. Results

3.1 Status of floor space and energy consumption

3.1.1 Transition of floor space and energy consumption

We estimated energy consumption and floor space of buildings -office, shop, hotel and hospital-of 1991-2003 in Osaka. Figure 1-4 show the results of office, shop, hotel, hospital.

Both of the floor space and energy consumption of hotel has been increasing. However, regarding office, shop and hospital, despite of leveling-off of the floor space in this 12 years, energy consumption has been steadily increasing. The cause of leveling -off of floor space is economic and population growth. (One thing which I would like to mention here is that health facilities for recuperation of hospital has been converted to welfare facility.) Therefore it means that specific energy consumption has been increasing.

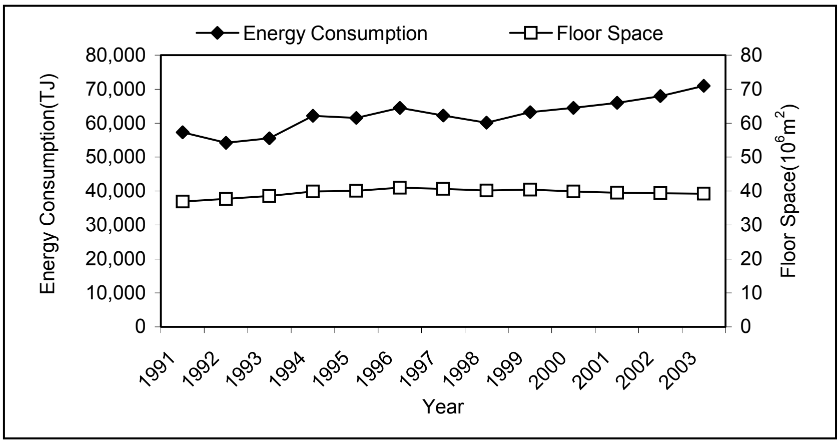

Figure 1   Energy consumption and floor space of office in Osaka.

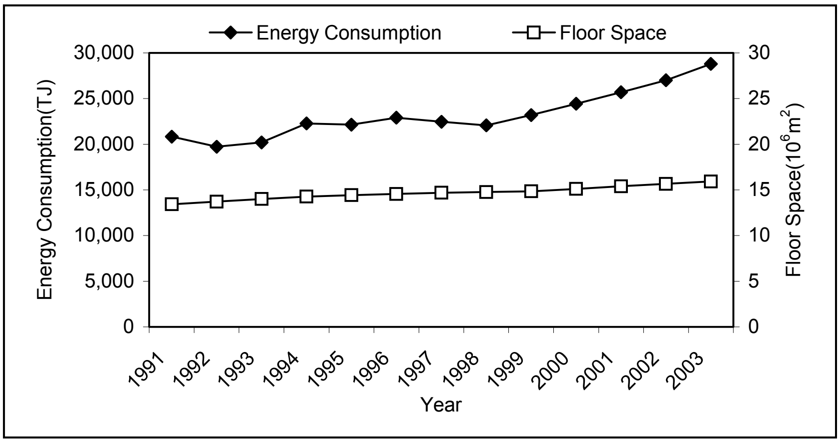

Figure 2   Energy consumption and floor space of shop in Osaka.

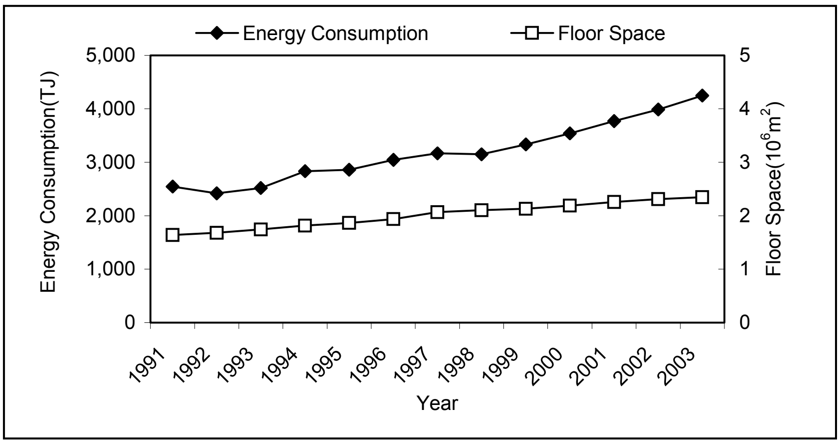

Figure 3 Energy consumption and floor space of hotel in Osaka.

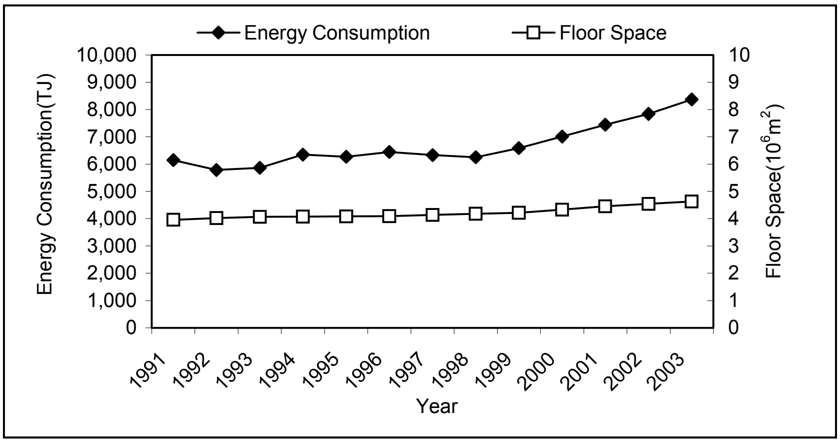

Figure 4 Energy consumption and floor space of hospital in Osaka.

3.1.2 Status of specific energy consumption

We analyzed specific energy consumption using a building and energy database(ELPAC). Figure 5-8 show the results of office, shop, hotel, hospital. As shown in the figures, the maximum value is three or four times of minimum value. The energy performance in addition to the condition and so on have an effect on the specific energy consumption of buildings. It can be considered that the dispersion of actual data of specific energy consumption was the difference between an inefficient building and an efficient building for energy consumption.

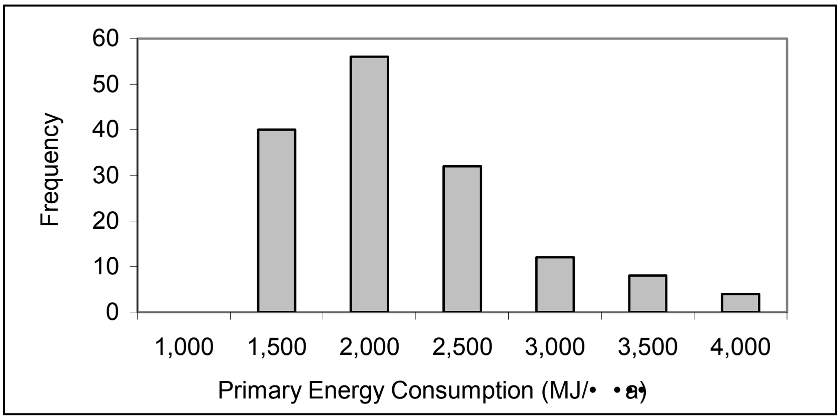

Figure 5 Primary energy consumption of office in Osaka.

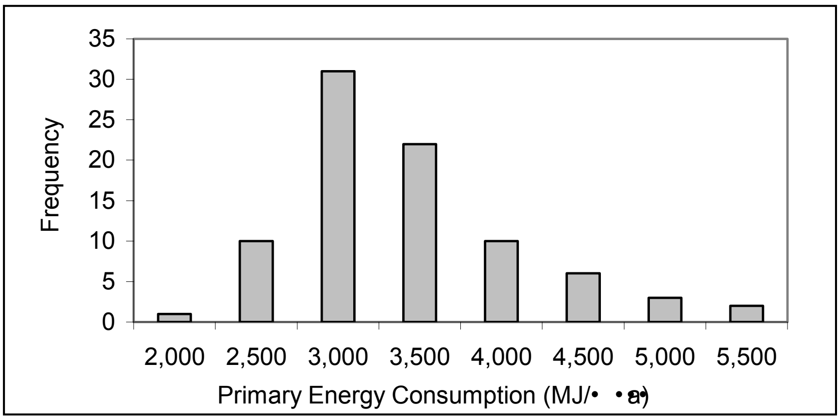

Figure 6 Primary energy consumption of shop in Osaka.

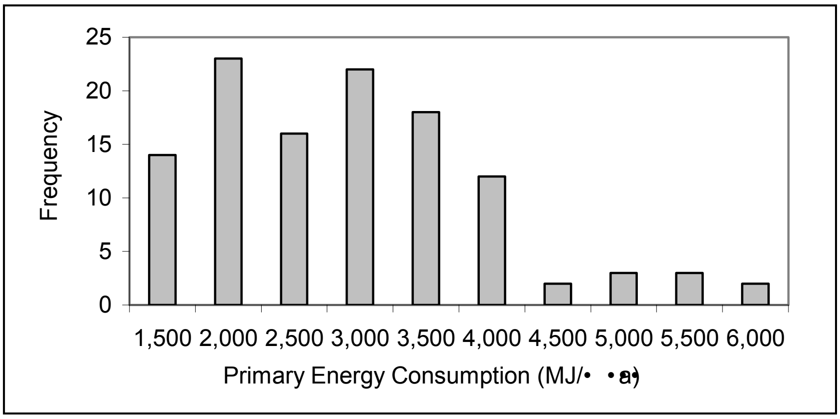

Figure 7 Primary energy consumption of hotel in Osaka.

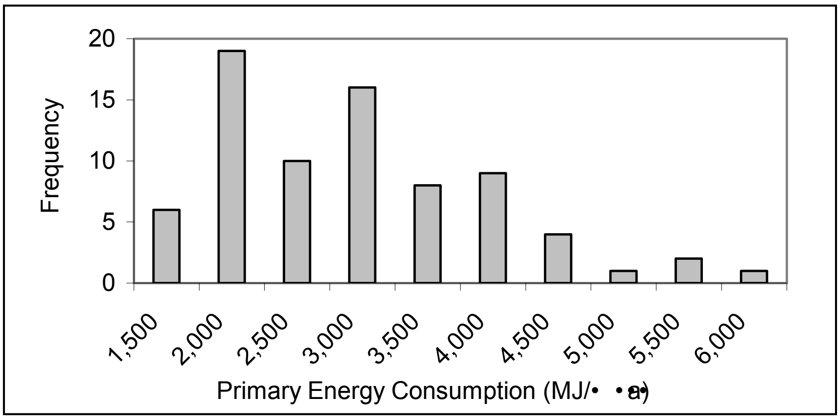

Figure 8 Primary energy consumption of hospital in Osaka.

Next, Figure 9 shows the statistic score obtained from figure 5-8.

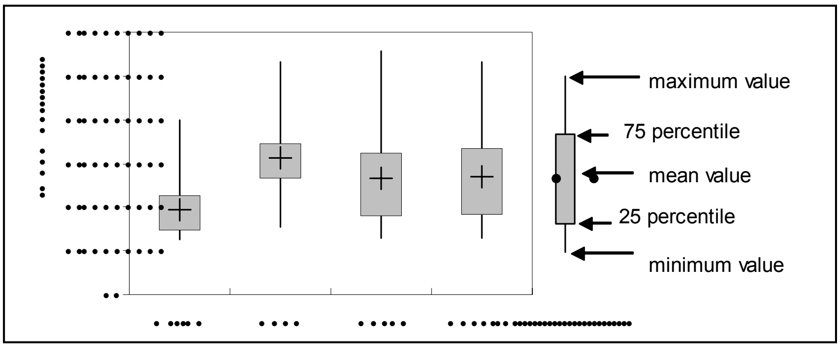

Figure 9 Statistic of Primary energy consumption of each building category.

3.2 Prediction of floor space and energy consumption

3.2.1 Prediction of floor space

We predicted the total floor space of each building category. The regression models relative to office, shop, hotel and hospital are as follows.

$$Sp/Wrk = 1.79 \times \ln(Yr - 1990) + 21.8 \qquad R^2=0.89 \qquad (1)$$

Sp: Floor space (m^2)
Yr: year

$$Ss = 0.377 \times Income + 163521 \qquad R^2=0.34 \qquad (2)$$

Ss: Selling space (m^2)
Income: Annual income of households(billion yen/a)

$$Rm = 35149 \times \ln(GRP) - 579845 \qquad R^2=0.55 \qquad (3)$$

Rm: The number of guest rooms
GRP: Gross regional production

$$Bd = -3082 \times \ln(Year - 1987) + 124833 \qquad R^2=0.50 \qquad (4)$$

Bd: The number of hospital beds
Yr: year

The predicted floor space using the models given above are shown in Figure 10-13. It is indicated that floor space of office and hospital will be level-off and floor space of shop and hotel will be increase slightly. However, as above mentioned, health facilities for recuperation of hospital are not categorized as hospital but as welfare facility which is not subject in this study.

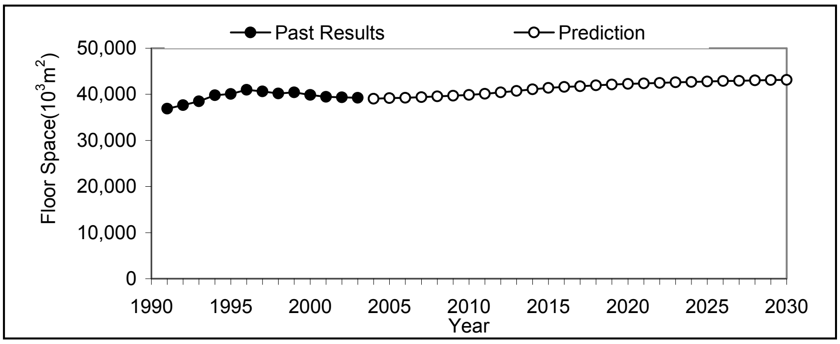

Figure 10 Past results and prediction of floor space of office in Osaka.

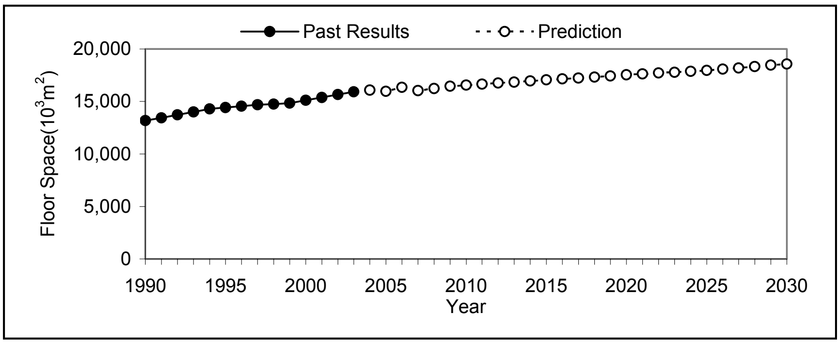

Figure 11 Past results and prediction of floor space of shop in Osaka.

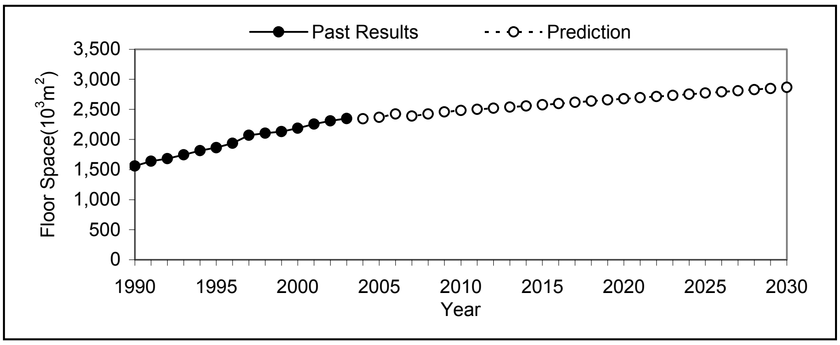

Figure 12 Past results and prediction of floor space of hotel in Osaka.

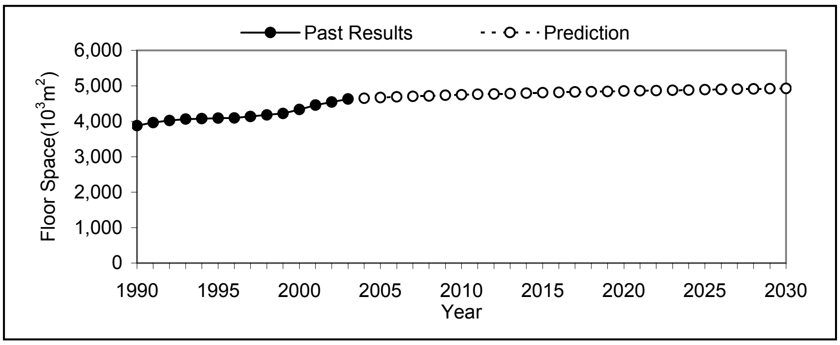

Figure 13 Past results and prediction of floor space of hospital in Osaka.

3.2.2 Prediction of energy consumption

We predicted energy consumption by multiplying the specific energy consumption and the floor space predicted of each building category. We assumed here 3 cases of energy efficiency. Case B is on condition that the average specific energy consumption as of 2030 will be at the same level as the average as of 2004. Case A is the case of the minimum value as of 2004, and Case C is the case of the maximum value as of 2004. Table 1 shows the condition of each case.

Table 1 Specific energy consumption (MJ/m^2a) for prediction

Building type	2004	2030 (2030/2004)		
		Case A(Min.)	Case B(Ave.)	Case C(Max.)
Office	1,950	1,259 (0.65)	1,950 (1.00)	3,998 (2.05)
Shop	3,132	1,538 (0.49)	3,132 (1.00)	5,300 (1.69)
Hotel	2,649	1,282 (0.48)	2,649 (1.00)	5,557 (2.10)
Hospital	2,680	1,286 (0.48)	2,680 (1.00)	5,312 (1.98)

Figure 14-17 show the prediction. The figures in each graph indicate the ratio of energy consumption (2030/2004). Case B is the result caused by only floor space increase. In Case A(Minimum Case), energy consumption can be kept in from 0.51 to 0.71 of current level. However, in Case C(Maximum Case), energy consumption will extend approximately twice.

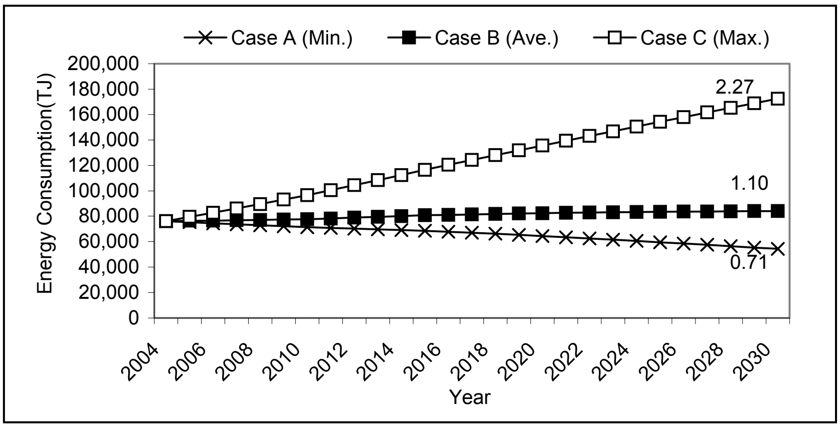

Figure 14 Prediction of energy consumption of office in Osaka.

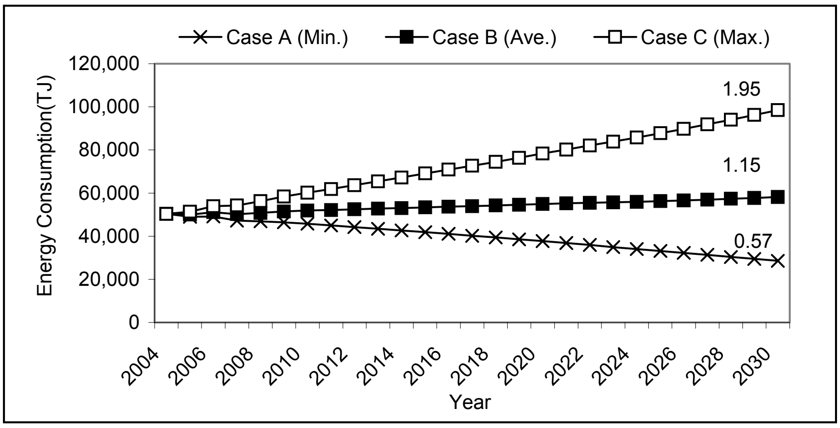

Figure 15 Prediction of energy consumption of shop in Osaka.

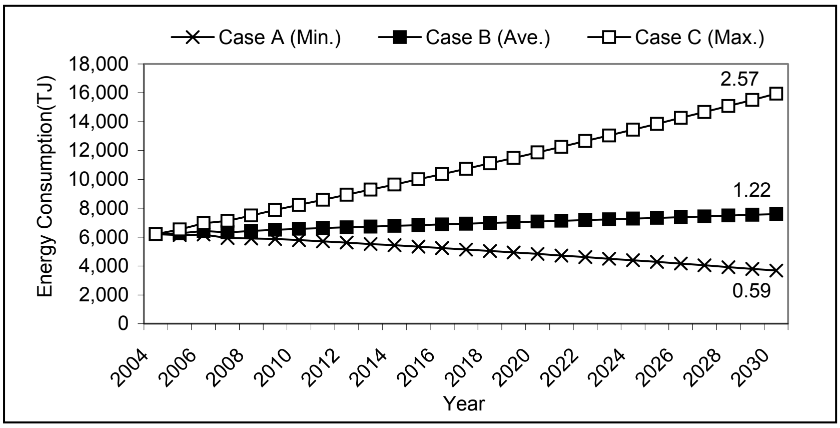

Figure 16 Prediction of energy consumption of hotel in Osaka.

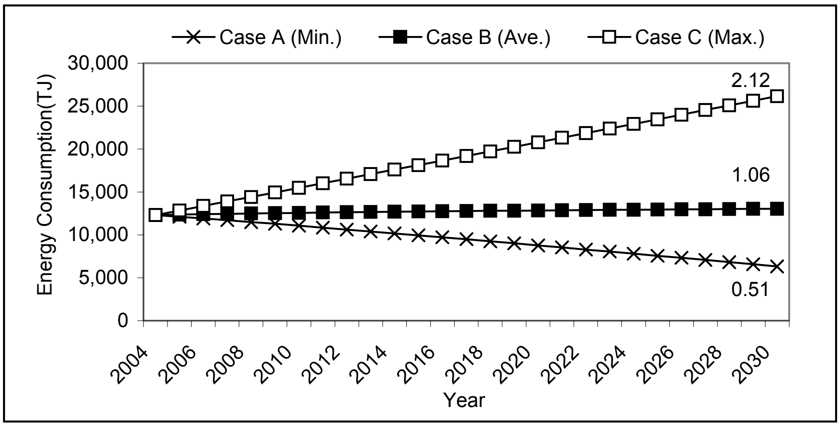

Figure 17 Prediction of energy consumption of hospital in Osaka.

3.3 Potential of energy conservation

We studied some actual countermeasures to verify the potential of energy conservation obtained from the prediction using the simulation model Yamazaki developed(2002). Table 2 shows the countermeasure and each performance as an example of office. As shown, it is possible that energy consumption can be kept in 0.72 times of current level. Additionally if other countermeasures are adopted, the efficiency can be more increased.

Table 2 Actual countermeasure for energy consumption

	Model of Case B	Model of Case A
Coefficient of heat transmission of external wall(W/m^{2}K)	2.14	0.66
Windows area ratio(-)	0.35	0.66
Coefficient of heat exchange for outdoor-air inlet(-)	0.35	0.70
indoor calorific value(W/m^2)	40	20
Coefficient of Performance (Cooling)(-)	2.58	2.87(10%UP)
Coefficient of Performance (Heating)(-)	3.13	3.48(10%UP)
Primary energy consumption(MJ/m^{2}a)	1,887	1,363
Ratio	1.0	0.72

4. Conclusion

In this paper, we estimated the total floor space and energy consumption from 1991 to 2003, and analyzed the specific energy consumption using a building and energy database. Next, we verified the possibility of the achievement by the prediction and simulation. This work has demonstrated as follows.

1) According to the prediction of floor space, when energy efficiency of all buildings as of 2030 is as high as the highest level of existing buildings, energy consumption as of 2030 will be 0.5-0.7 times of current level.

2) However, when energy efficiency of all buildings is no more than the lowest level of existing buildings, energy consumption as of 2030 will be twice of current status.

3) It is possible as a practical matter to achieve the energy efficiency of 0.7 times of current level. We verified that that the actual countermeasure are, for example, the improvement of coefficient of heat transmission of external wall, windows area ratio, and so on.

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TITLE: THE WARREN CENTRE'S 'LOW ENERGY HIGH RISE' PROJECT

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Keywords: existing office buildings, energy efficiency, non technical barriers, evidence based initiatives

Summary

The Warren Centre for Advanced Engineering's Low Energy High Rise project is engaging the commercial building sector and facilitating their development of an evidence-based suite of initiatives to avoid the non technical barriers and advance the uptake of cost-effective energy efficiency.

Key Low Energy High Rise project outputs to date are: a detailed literature review; an industry developed list of non technical barriers to energy efficiency upgrades; a comprehensive research survey of building performance and management practices; and industry's preliminary ideas for the suite of initiatives that will be further developed as the major project output.

A distinguishing feature of the Low Energy High Rise Project is the comprehensive survey being conducted as a core element of the project. The work of industry stakeholders involved in developing the suite of initiatives will be underpinned by current evidence on both building energy performance and management practices gathered from the wider industry in response to the project's survey.

The Low Energy High Rise project is currently conducting the most comprehensive survey of building energy performance and management practices in a minimum of 160 Australian office buildings over 5000m2. While analysis of data from the survey has not yet been undertaken this paper provides background on the project; outlines the development of the non technical barriers; the content of the survey; the initial ideas industry has advanced for the suite of initiatives; and the approach that will be taken to further develop and refine the contents of the suite of initiatives. It will canvas areas that the research can be expected to point to and that will be available to be presented in detail to SB08, along with the refined suite of initiatives.

1. Introduction

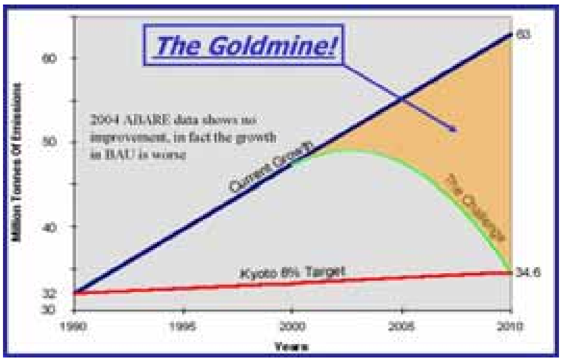
1.1 Background

1.1.1 Intent

The Warren Centre for Advanced Engineering's Low Energy High Rise project is engaging commercial building owners, investors, tenants, contractors and suppliers to develop a suite of evidence based initiatives to avoid the non technical barriers and advance the uptake of cost-effective energy efficiency in existing commercial office buildings.

1.1.2 Context, Issues and Opportunities

The 1999 Australian Greenhouse Office Report, Australian Commercial Building Sector Greenhouse Gas Emissions 1990 – 2010, provides the most recent data on energy use and greenhouse production from the commercial building sector. There have been no annual updates to demonstrate improved commercial building energy efficiency rather, the AGO Report projections to 2010 indicate that "the commercial buildings sector is expected to increase it greenhouse gas emissions to nearly twofold from 32 Mt of CO_2 per annum to 63 Mt between the years 1990 and 2010 under the Business as Usual scenario", see Figure 1 at right.[1]



The AGO Report noted "existing and announced greenhouse abatement and energy management initiatives may be

[1] Australian Commercial Building Sector Greenhouse Gas Emissions 1990 – 2010 Executive Summary Report 1999

expected to produce an impact of 1.4Mt of CO_2 per annum only due to their current low level of penetration or application". The study noted that voluntary measures could deliver higher levels of abatement than policy and measures in place in 1999.

Case studies exist to demonstrate that commercial building upgrades can deliver energy efficiency improvements of 20% and greater, cost effectively. Investa Property Group, achieved a 9.9% reduction in electricity consumption and a 13% reduction in gas consumption in 2005 through its energy management program which applies to 36 buildings across their office portfolio. Total financial savings from Investa's energy management program in 2005 were $600,000.

We are at the current point in the property cycle when the emphasis is on building upgrades. Many buildings are at the end of their 20 – 25 year cycle and are due for refurbishment. NSW Department of Water and Energy inform us that refurbishing a building from 2.5 stars to 3.5 stars would deliver 20% savings, which, across the whole national commercial office building stock (tenancies and base buildings) represents about 1.1 million tonnes of CO_2 equivalent per annum. An improvement from 2.5 stars to 5 stars would deliver 50% savings or 2.75 million tonnes of CO_2 equivalent per annum. These improvements equate to roughly $100 million and $250 million per year in energy savings.

1.1.3 The Low Energy High Rise project management structure

The project has a large Steering Committee drawn from industry stakeholders to oversee the project's progress and a smaller Planning Group that meets regularly to manage the project on behalf of the Steering Committee. The Planning Group comprises: Sue Salmon (Project Director), Mary Casey (McLachlan Lister), Jamie Wan (Bassett Consulting Engineers), Dr Paul Bannister (Exergy), Robert Quinn (National Project Consultants), Keith Bashford (The Warren Centre), David Hood (David Hood & Associates), Dr Martin Poole (Epuron), Robert Mitchell (The Warren Centre).

The work of the project is performed by teams of volunteer stakeholders organised according to the current needs of the project. Initially three working groups were formed representing 1) building owners, 2) tenants and 3) intermediaries. These groups provided input the Literature Review and the survey content as well as 'barrier identification'. As the project moves into 'initiative identification and analysis' the volunteer-working group members will form into smaller groups including representatives of each of the three initial groups, to focus on developing one or more initiatives.

Some 95 people (representing 73 organisations) are engaged with the project either through its Steering Committee or one of its working groups).

1.1.4 The Low Energy High Rise sponsors and participants

The following organisations are making a tangible contribution to the project's resources either through intellectual or financial contributions, or both: A. G. Coombs Group, Aeris Technologies Ltd, AGL, AMP Capital, ARUP, Australia Post, Australian Constructors Association, Australian Property Institute, Bassett Consulting Engineers, Bendigo Bank, Bligh Voller Nield, Bovis Lend Lease, Brisbane City Council, City of Sydney, Colliers, Colonial First State Global Asset Management, Commonwealth Bank, CSR Bradford Insulation, David A Hood & Associates, Davis Langdon, DEGW Asia-Pacific, Demand Management & Planning Project, Australian Department of Environment & Water Resources, NSW Department of Environment and Climate Change, DLA Phillips Fox, Ebsworth and Ebsworth Lawyers, Edge Environment, Energetics, Energy Conservation Systems, Envirolite, EPURON, Eureka Funds Management, Exergy Australia, FiveD, General Property Trust, Glenside Group, Haden Engineering, Hastie Group, Investa Property Group, J.P.Y.N Enterprises, Jones Lang LaSalle, Key Services, KODO, Low Energy Supplies & Services, McLachlan Lister, Mirvac Group, National Projects Consultants, NSW Fire Brigades, Optus, Qld Environmental Protection Agency, Resource Connections, Schneider Electric, Shelston IP, Spotless Group, Steensen Varming (Australia), Stockland, Sustainability Victoria, Sustainable Built Environments, Syneca Consulting, Szencorp, Team Catalyst, The Cox Group, The Warren Centre, Thunderbolt Design, Total Energy Solutions, United Group, University of Sydney, UTS, Vericap Finance, Westpac.

Implementing the Low Energy High Rise project survey has significantly expanded the project's engagement with the property sector. Each building nominated by the building owners to participate in the survey identified a portfolio manager, asset manager and building manager as well as one tenant to complete the surveys for each building. As a result a further 400 plus people in the industry have been introduced to the project, are contributing the factual basis for the development of the suite of initiatives and will have an opportunity to contribute to the development of the initiatives.

1.1.5 The Warren Centre's methodology

The LEHR project is being conducted by the Warren Centre for Advance Engineering, which is in the Engineering Faculty of Sydney University. It is an independent, industry linked institute fostering excellence and innovation in advanced engineering throughout Australia. It is a self funding, not for profit think tank controlled by industry representatives.

The Warren Centre's objective is to help create wealth in the nation by stimulating development of new engineering technology and encouraging integration of innovation and engineering technology into development of public policy and wealth creation. The Centre provides independent comment and advice to Government and industry.

The Warren Centre's unique approach is to bring together leading people in a selected field of engineering technology to work as a major project team to:

- Focus on removing barriers to commercial success in that field
- Develop new insights and knowledge in the technology; and
- Accelerate the technology's application in Australian industry.

Over 25 years Warren Centre projects have been observed to deliver beneficial change to the community. The Centre achieves change by facilitating the stakeholders (representing particularly academic, industry and government interests) in the issue at hand through a process wherein the stakeholders accept their common interests, agree the current situation and construct a vision of where they would like to take those common interests. Together the stakeholders then define a pathway from the 'now' to the vision, the barriers to moving along that pathway, and strategies to overcome those barriers. In practice it is the stakeholders that do the thinking, not The Warren Centre itself. The very significant impact of that is the high degree of implementation of recommendations from the Centre's work.

It is an objective of all Warren Centre projects to engage as many of the stakeholders in the project as possible, within the limitations of effective project management. While this will typically add to project cost and time it is generally paid back in full by the implementation achieved.

By involving the key decision makers in understanding the barriers and developing the solutions, these major projects result in important breakthroughs in technology and impact on Australian engineering practice and business enterprise.

2. The non technical barriers to energy efficiency upgrades

2.1 Identification of the non technical barriers

The starting point for developing industry agreement on the non technical barriers to energy efficiency was the Literature Review that was conducted at the start of the Low Energy High Rise Project. It was critical that the project build on work already undertaken so the project's Supply and Demand Working Groups added to, rejected, refined and prioritized the wide range of barriers identified in the Literature Review. The Literature Review itself set out the barriers that had been identified in the National Framework for Energy Efficiency (2004) and the Productivity Commission (2005). It categorized barriers as either Market or Organisational Failures. Market Failures were further categorized as Transaction costs; Lack of information; and Principal Agent Barrier and Externalities. The Organisational Barriers were in turn broken down into Behavioural, Institutional, and Cultural barriers.

Each Working Group adopted a different approach to their evaluation of the barriers identified by the Literature Review. The Supply Working Group had a higher level of shared understanding of the industry and experience of the barriers and was more readily able to respond to and evaluate each barrier. The Demand Working Group, which comprised tenants and those who provided services to tenants in office buildings, understandably did not have a high level of shared industry knowledge and confined their discussion to barriers the Literature Review identified that applied to tenants.

2.2 Barriers Identified by the Working Groups

The following table sets out the Working Group's list of agreed non technical barriers. In refining the suite of initiatives, the industry will assess the proposed initiatives against the identified barriers. To enhance the impact of the initiatives, initiatives will be evaluated on their capacity to affect a number of barriers simultaneously.

Low Energy High Rise Barrier Description
Low Energy High Rise Project - DEMAND WORKING GROUP BARRIERS
Lack of information (SKM 2006)
Expected payback time for commercial tenants is around 3 years (SKM 2006)
Building occupants do not fully recognise the health and productivity benefits from having better indoor environment quality (SBLP, 2006).
Lack of visibility of both energy efficiency measures and their benefits (Pears 2007).
Lack of information on the positive effects of green designs on the productivity of organisations working in office buildings (Kosholeva 2007)
The split money flows between payers and users (AEC 2005)
High investment hurdles (AEC, 2005)
Perceived risk with reliability, operation, maintainability, suitability of new technologies (SKM 2006)

Low Energy High Rise Barrier Description
The budgeting issues (Jopson 2006) (Energy is a low order item of low value)
Low management priority (SKM 2006)
There is no specific function with the organisation of commercial tenants that focuses on energy use. Sometimes there is a specific energy manager, but often it is a sustainability, facility or communication manager (Sheehan 2007).
Tenants are left out in the design process (Kosholeva 2007)
Corporation culture that is not comitted to green issues, out of sync with staff issues.
Market does not have clear understanding of what each Australian rating tool measures (SBLP 2006).
Transaction costs for project management, securing capital budgets, and investigating alternatives (SKM 2006)
It often takes 18 months to 2 years of occupation before you have a reasonable set of energy bills to base your occupancy ratings on (Field 2007).
Lack of interest by staff in a tenant organisation in energy efficiency
The people that make decision on tenancy accommodation are affected by the function of their firm, their institutional context, opportunistic behaviour and personal preferences (Ross, 2003).
Lack of prestige for energy managers (AEC 2005)
Major refurbishments take a long period of time (> 1 year) and require tenants to operate the building at least for a year before the ABGR can be re-checked (Hennessy 2004)
The CBD office market is not rational neither perfectly competitive, because of a lack of a coherent centralised market place and incomplete and poorly disseminated information processes (Ross 2003).
Higher rent premium (APEC 2005)
SUPPLY WORKING GROUP BARRIERS
Competition for capital (LEHR SWG 2007)
Whole building refurbishment is v. difficult due to varying timing of tenant lease expiry for a given building (LEHR SWG 2007)
Unwillingness to upgrade existing equipment to higher EE before end of serviceable life (LEHR SWG 2007)
Lack of awareness of building energy use (where it goes - breakdown) (NEEF 2004)
Limited understanding of potential cost effective energy actions (NEEF 2004)
Poor commissioning and maintenance of service systems (NEEF 2004)
Lack of knowledge transfer/feedback between designers and operators (LEHR SWG 2007)
Split incentives and split responsibilities between developer, owner and tenant (NEEF 2004, LEHR SWG 2007)
Short-term costs versus life-cycle costing (LEHR SWG 2007)
Absence of reward for outstanding design (LEHR SWG 2007)
Existing low cost of energy (NEEF 2004)
Inertia to change (NEEF 2004)
Risk Aversion (PC 2005)
Energy Efficiency is not integrated into core business (LEHR SWG 2007)
Short time horizons (PC 2005)
Client design briefs to consultants and builders do not take energy efficiency into consideration (NEEF 2004) (LEHR SWG 2007)
Accounting practices favour revenue streams over cost reduction strategies (NEEF 2004)
Limitations with network providers contraining opportunities for building energy efficiency e.g. wind,solar feed-in (LEHR SWG 2007)
The use of 'rules of thumbs' and routines affecting the ideal choice (PC 2005)
Insufficient time in design and retrofit planning stages to explore alternative design options (LEHR SWG 2007)
No mandatory disclosure of energy performance (LEHR SWG 2007)
Lack of information on past total energy consumption limiting assessments (NEEF 2004)
Jurisdiction specifc standards increasing complexity of design and construction (NEEF 2004)
Implementation cost of EE technologies & processes which entail additional costs.(PC 2005)
Lack of education and vocation programs (NEEF 2004)
Lack of specialised knowledge such as building controls (LEHR SWG 2007)
Lack of knowledge of benchmarking data (such as past energy data) and rating tools. (LEHR SWG 2007)
Reduced incentives for private providers to supply information (PC 2005) (LEHR SWG 2007 added control of IP)
Lack of effective incentive schemes (LEHR SWG 2007)
No repeat purchasing of building services equipment (PC 2005)
Risk and uncertainty reducing the level of investment or restricting access to finance (PC 2005)
Uncertainty within an organisation on outcome of energy efficiency projects (NEEF 2004)

Low Energy High Rise Barrier Description
Loose fit (flexible) design in base building overtaken by value management (LEHR SWG 2007)
Services designers often ignored (NEEF 2004)
Adverse selection, whereby supplier can promote products as energy efficient, even if they are not (PC 2005)
Lack of understanding of the consequences of rapidly changing expectations re environmental impact of buildings (LEHR SWG 2007)
Lack of standard cost-benefit analysis (NEEF 2004)
Services can encourage energy waste as part of the service / Perception that high energy use . Energy waste is a prerequisite for quality - combine - *"Perception that high quality includes high energy service and high level of waste"* (LEHR SWG 2007)
Decision makers not resourced to implement energy efficiency projects despite short paybacks (6 - 12 months)(LEHR SWG 2007)
Historical budget allocations (EEF 2004)
Procurement policies do not encourages innovative technologies (LEHR SWG 2007)
Industry cynicism about potential performance of new energy efficiency technologies(LEHR SWG 2007)
Management not responsive to significant energy efficiency opportunities identified in due diligence reports (LEHR SWG 2007)
Cost of obtaining information on energy efficiency (PC2005)
No means of capturing the benefits of being the first mover (PC 2005)
Moral hazards for energy eficiency auditors after contracts are signed (PC 2005)
BCA strategies seen as a monetary waste hence endeavour to avoid BCA upgrades (LEHR SWG 2007)
Satisfying rather than exceeding the brief (LEHR SWG 2007)
Decision making that satisfies minimum requirements rather than aiming for best practice (LEHR SWG 2007)
No legislation driving compliance with “energy efficient” parameters (LEHR SWG 2007)
Middle management inertia irrespective of senior management commitment to energy efficiency (LEHR SWG 2007)
Conservative approach during design phase (high inbuilt safety factors i.e.over-engineering) leading to energy inefficiencies (LEHR SWG 2007)

3. Low Energy High Rise project research survey

The Low Energy High Rise Project Steering Committee and Planning Group recognised from the outset that the project needed to be evidence based to effectively drive market transformation. The empirical data allows the project to understand what is happening in the market and what actually works and to make this the basis for the development of the suite of initiatives.

3.1 Development of the research survey

As soon as the project concept was resolved in consultation with industry, the project Planning Group commenced work immediately on early drafts of the survey. The initial draft survey was then presented to the Supply and Demand Working Groups for comment as well as the Steering Committee and a wider industry group that had expressed interest in the project. Once the survey content was resolved three companies were asked to respond to a tender to create and manage the survey online. National Project Consultants and Exergy Pty Ltd won the tender for this work.

3.2 Contents of research survey

The Low Energy High Rise project survey is designed to develop an assessment of the performance of the current market with a specific emphasis on the ability of given physical building types and management structures to deliver energy efficiency. The intention of the survey is to identify the empirical performance range and theoretical performance limits associated with:

- Building type, servicing, and age
- Management, ownership and maintenance structure
- Tenant / landlord relationship

To this end the project has designed three different surveys to be completed by people in four different roles who are involved and have influence over energy management in an existing office building – the tenant, the building manager, the asset manager and the portfolio manager. The three surveys are: a tenant survey; base building survey and manager survey.

The intent of the base building survey is to understand the relationship between building technology and performance. The management survey seeks to understand the relationship between building management and building energy performance. The tenant survey seeks to understand the extent to which tenants are managing energy in their tenancy and influencing landlord approaches to energy management. The manager and tenant surveys are confidential to the respondents however the base building survey is accessible to the building manager, asset manager and portfolio manager involved in the management of each building.

The online survey generates a building identifier number for each building as the basis for managing the large number of responses being provided by a “representative tenant”, a building manager and potentially an asset and a portfolio manager depending on whether the building is individually owned or owned by a portfolio where all three management roles are likely to be involved in managing the building.

Topic areas in the base building survey include: building details; building performance data; refurbishment history and plans; building architecture; building services; dominant air conditioning type; lighting; building management system and monitoring; car park; water use; building operation; leasing details; energy and water management; maintenance.

Topic areas in the management survey include: level of authority; authority over energy matters; responsibility limits; incentives; attitude; response activities such as what level operational changes have you made in the past year to maintain or improve energy efficiency in relation to the buildings you are involved with; knowledge and qualifications; barriers and incentives.

Topic areas in the tenant survey include: tenancy details covering lease commencement year, expiry, extension options; plans to relocate; program for improving energy efficiency and choices of lease type to influence landlord energy services.

3.3 Implementation of the research survey

The domain for the study is office buildings of 5000 m2 NLA and above capturing 75-80% of capital city CBD buildings graded D or higher with 160 buildings determined as the statistically valid number to participate based on this domain. Building nominations were sought for 180 building nominations to allow for some attrition.

Predominantly buildings nominations were sought from building owners to ensure that the various management layers were aware of and were given authority to participate in the survey. Contact details for a “representative tenant” were also sought from owners to simplify the process. To ensure that buildings nominated for the survey were widely representatives, nominations were sought from the private sector and public sector covering large and small portfolios with buildings in capital cities and regional centres.

Government portfolios participating include: Queensland Public Works, NSW State Property Authority, ACT Department of Territory & Municipal Services, Department of Defence, SA Department Transport, Energy & Infrastructure, Victorian Department Treasury & Finance, WA Dept Housing & Works, and the NT Government Property Management Unit. Private sector nominations came from a wide range of organizations. Building nominations were made via a nomination form that identified the portfolio manager, asset manager, building manager and tenant for each building. Important steps in implementing the surveys included:

- Ensuring that all named on the BNF have been made aware they are participating in the survey
- Provide all with user names & passwords to access the surveys
- Providing incentives to engage the respondents
- Setting deadlines for survey completion and providing feedback to building owners on who had / had not completed the surveys.

The most recent assessment of survey completion on 2nd April, 2008 showed that 70.21% of base building surveys, 52.49% of manager surveys and 44.79% of tenant surveys had been completed. Further work is in train to ensure high levels of completion for each survey type.

3.4 Analysis of the survey data

Once high levels of survey completion have been achieved the data will be analyzed including by:

- Testing the quality of the data by questioning its completeness and assessing its credibility
- Looking at cross correlations of everything against everything
- Identifying correlations that align statistically by drawing together things that produce results, things that happen together, whether or not they produce a result e.g. gross lease/good building energy performance/ this management approach/ this type of building and
- Identifying responses that point to good / poor energy performance

The results of the survey will be presented in a research report to the industry sponsors and then to all project participants and the wider industry.

Once the survey results have been determined the information will be provided to the groups developing the suite of initiatives to ensure a strong relationship between the proposed tools in the suite of initiatives and the survey outcomes.

4. Development of the Suite of Initiatives

4.1 Initial process to develop suite of initiatives

Work has commenced on developing the suite of initiatives including at a meeting of the Low Energy High Rise project's Steering Committee and Planning Group, a Brisbane meeting of project participants and at a joint meeting of the Supply and Demand Working Groups. The table below shows the draft list of initiatives that have been suggested by the three meetings. The initiatives have been further categorized for easier reference.

Broad Area of Impact	Examples of Individual initiatives
Change BUSINESS DECISION MAKING PROCESSES.	Tax Breaks Govt. Funding Incentives Depreciation – accelerate Valuation Protocols Energy Efficiency in Due Diligence Carbon Credits will change accounting rules.
Change the MARKET DYNAMICS	Green Leases National Standards for lease agreements Mandatory Green Power Purchases Mandatory ABGR ratings Mandate the landlord pays for energy use Regulate to prohibit low efficiency products Legislate emissions limits Re-commissioning Programs Plan for Green Business Landlord Guarantee re Max Energy use Focus of lower graded buildings Whole Precinct projects (extend the boundaries)
SIMPLIFY and reduce FRAGMENTATION.	Resolve conflicting regulations (National) Standards for:- Energy Efficiency Maintenance Measurement Up-grade triggers Capped Energy Consumption
INFORM and ENCOURAGE –	Green Guides, Information Packs Case Studies Lead by Example Energy Benchmarking Visualization Techniques Visual rating and metering Mandatory Disclosure
BUILD CAPACITY	Education Training Skills Development Replicate Programs Empower Tenants Accredit Building Operators

4.2 Refined process to direct further development of the suite of initiatives

The Low Energy High Rise Project's Planning Group has recognised that the draft initiatives were directed at what Government and others could do, rather than what industry can control. The aim now is to refine and direct the process for developing the suite of initiatives by:

- Working on four scenarios aimed at taking an average building and improving its energy efficiency to ABGR 4 – 4.5 stars

- Ensuring the initiatives reflect what really happens in the industry
- Working below the Government policy level & focussing on what the industry can effect and implement

The four scenarios that will be developed reflect industry experience and will be:

- An existing building with a minor capital expenditure budget
- A floor by floor upgrade in an existing building
- Complete building refurbishment
- A new Sustainability Manager in a portfolio required to introduce sustainability and to improve building performance

The issues the working groups will consider in developing each scenario will cover:

- Obtaining the budget
- Managing required resources and time
- Securing internal competence
- Securing external competence
- Managing relationship with tenants before, during and after the necessary activities in each scenario
- Getting the scope of works right
- Executing the scope of works successfully
- Commissioning the scope of works correctly
- Maintaining the ongoing level of building energy performance

The expected output from the scenario development exercise will potentially be:

A few new key enabling tools produced by industry that will:

- Be evidence based
- Relate to each other and have exponentially increased results because they are synergistic

These new enabling tools for the suite of initiatives may include:

- A list of tenant rules to go into lease contracts
- An overarching, step by step process for initiating upgrades
- Guidance on using and interpreting ABGR ratings
- Overarching technical and financial guidance on improving building energy performance
- A different business model to collect energy efficiency opportunities in a group of buildings with different owners to the market as an investment opportunity
- A well constructed gross lease

5. Project's next steps and the new information that can be presented to the Sustainable Buildings 08 Conference

The Low Energy High Rise Project will implement the approach outlined above to develop the suite of initiatives that will be the key project output. These new enabling tools will be assessed against evidence from the survey and further refined. We recognise that it will be critically important to cross correlate the site of initiatives with the evidence from the survey to show empirically that the new tools will work.

The project aims to identify a group of buildings from the survey that are demonstrating aspects of the suite of initiatives and identifying how they are being executed in practice. The project will then use this knowledge to develop models of the processes, for example a particular management structure that is shown to be effective.

The Low Energy High Rise Project Planning Group expects that detailed results from the survey and a more refined suite of initiatives will be complete and able to be presented to the SB08 Conference.

ENERGY PERFORMANCE OF BUILDINGS IN THE AUTONOMOUS PROVINCE OF SOUTH TYROL, ITALY

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Keywords: Region of South Tyrol, energy performance of buildings, social housing

Summary

The province of South Tyrol shows promising tendencies in the field sustainable buildings and specifically in the field of energy performance of buildings.

A major driving force for this process is the regional energy certification system for buildings which was launched in 2002, long before the European directive on Energy performance of building had to be implemented by the European countries. The system has led to a significant increase of the share of low energy construction (space heat requirement up to 50 kWh/m²a), from approx. 2% in 2002 to nearly 60% in 2007 in the residential sector.

Another important column for low energy construction is the activities of the regional entity for social dwelling. In fact, already for the working program of 2001-2007 which included 2550 dwelling units, the IPES (Istituto per l'edilizia sociale della provincia autonoma di Bolzano) committed to erect buildings with a maximum calculated annual space heat requirement (SHR) of 50 kWh/m². Some 10 buildings, with around 130 apartments according to 1% of the stock of IPES have been refurbished to a SHR of between 50 and 70 kWh/m²a in the last years.

Outstanding the forward-looking general working program, IPES has realized several lighthouse projects for sustainable building. One of those projects, is IPES's first passive house. The building with 8 dwellings is since July 2006 under monitoring by EURAC.

1. RUE, RES and sustainable construction in the Province of South Tyrol

The Province of South Tyrol with its approximately 500.000 inhabitants has an outstanding position in Italy regarding environmental, RUE and RES issues. Many figures are comparable to those of the neighboring country of Austria which again can for several aspects be regarded as forerunner in Europe.

Over 700 hydro power plants are in operation in South Tyrol producing more electricity than the annual consumption. In 2005, 4.000 small biomass heating plants (20-100 kW) and over 30 biomass district heating plants (0,8-34 MW) were installed. Further, one third of all Italian solar thermal installations were in operation in South Tyrol, resulting in a collector surface of about 0.33 m² per capita (Autonome Provinz Bozen 2008).

In fact 45% of South Tyrols energy consumption (excluding from traffic) is covered by renewable energy sources. It is the declared goal of the regional government of the autonomous province to increase that figure to 75% by 2012 and 100% by 2020 (Laimer 2006, Autonome Provinz Bozen 2008).

One of the major approaches to reach that goal is the reduction of energy consumption for space heating. Since January 2005, the regional government requires a maximum SHR of 70 kWh/m²a for new buildings. This decision has its funding amongst other on the fast success of the certification scheme for energy performance of buildings described below. Currently strong attention is given to energetic refurbishment of buildings, comprising measures such as the publication of brochures, the establishment of an information line and the retention of the regional subsidy scheme after the introduction of then national tax relief scheme for energetic refurbishment.

2. The regional energy performance of buildings certification scheme, CasaClima

Even before the European “Energy performance of building directive” (EPBD) was released in December 2002, the Autonomous Province of South Tyrol had introduced an energy certification scheme for buildings. In the beginning, the certification was a voluntary measure.

But already by January 2005, the regional government required a maximum space heat requirement (SHR) of 70 kWh/m²a for new buildings, applying the CasaClima certification for documentation. The success of the first years of the voluntary scheme and the new availability of specialized planers and craftsmen paved the way for this initiative of introducing a minimum requirement. Since beginning of 2008 the CasaClima scheme represents the implementation of the EPBD for the Autonomous Province of South Tyrol.

2.1 Classification of energy performance

Through the scheme, buildings can be classified according to their space heat requirement. This allows constructors, potential buyers and tenants to estimate heating costs of a dwelling and enables the comparison with other constructions, also regarding the buildings envelope and thermal comfort. The “Department for air and noise”, which at first stage was in charge of the scheme, therefore developed a standardized calculation method. Buildings are classified in categories. For reasons of facilitated comprehension the categories as well as their graphical representation are similar to those typical for household appliances (see figure 1). The categories reach from CasaClima Gold (10 kWh/m²a) over CasaClima A and B (30 and 50 kWh/m²a) to thermal protection classes C (70) to F (160).

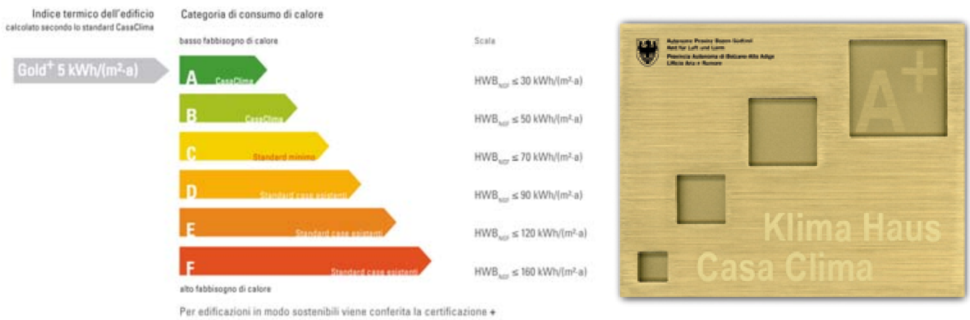

Figure 1: Energy Efficiency Categories and CasaClima insignia

2.2 Additional label for sustainable construction

To underline the fact that not only energy consumption for heating is crucial for sustainable development in the building sector, the option of having a building certified as “CasaClima plus” was established, whereas the plus stands for “sustainable construction”. To attain this classification buildings have to fulfill the following set of requirements. The space heat requirement must be below 50 kWh/m²a. The latter must be provided without the use of fossil fuels except in case of connection to district heating or an already existing system. Further, restriction regarding the use of materials are set. EPS, XPS and PU may not be used for walls and pitched roofs, no PVC may be used for flooring windows of doors and finally the use of tropical wood is prohibited. Additionally to those restrictions, the object has to have at least one of the following features. (i) a PV-system, (ii) a ST-system, (iii) rain water usage, (iv) a wood, clay or straw construction or (v) a green flat roof.

2.3 Development of low energy construction in Sputh Tyrol

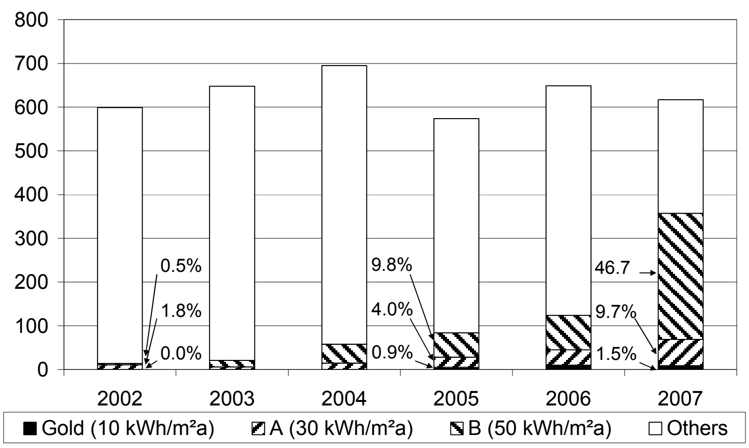

Figure 2: Repartition of CasaClima on new residential buildings in South Tyrol (Schmitt et al. 2007 ‘KlimaHaus …’)

The CasaClima project had the declared goal of increasing low energy architecture in South Tyrol which it did with outstanding success. The number of buildings certified as CasaClima B or better since the introduction of the scheme has grown from 14 in 2002 to 357 in 2007 (Schmitt et al. 2007 ‘KlimaHaus …’). Since the already ambitious class C was introduced was introduced as minimum requirement in 2005, the share of buildings underbidding this with at least CasaClima B has grown from 15% to 58%.

2.4 Accompanying measures to the CasaClima initiative

In order to increase the demand side in South Tyrol a set of measures is conducted: On the one hand the owners of buildings of category B, A and Gold obtain an insignia for the front door, which they are in general proud to show (see figure 1). In the beginning days the insignia further represented a good starting point to involve people who were not yet familiar with the topic. In special cases, such as outstanding buildings or energy performance, the insignia was submitted by the very popular official in charge for environmental affairs of South Tyrol.

On the other hand the CasaClima project launched an annual award for the “best CasaClima”. Five different categories are nominated i.e. dwellings, commercial buildings, tourism, energy plus and refurbishment. The award usually generates good media attention thus increasing the popularity of the project and probably is a further motivation for architects for best practice in sustainable architecture.

The supply side as well is considered intensely by the CasaClima project. One of the major tasks of the CasaClima Agency is the organization and the conduction of educational courses for planers and craftsmen. The Agency first was founded to conduct promotional measures and has meanwhile overtaken also other tasks of the “Department for air and noise” concerning CasaClima. By 2007, around 8000 planers and Craftsmen had visited basic courses (3200 in 2007), around 650 planers had achieved CasaClima Expert (110 in 2007) (Schmitt et al. 2007 ‘KlimaHaus …”).

The Agency further organizes a conference accompanying the “KlimaHouse fair”. Animated by the success of CasaClima, the trade fair of Bolzano decided in 2005 to host this annual fair which has become since, with 36000 visitors from all over Italy, an event of national importance for sustainable construction.

3. The activities of the regional entity for social housing IPES (Istituto per l’Edilizia Sociale) in the field of sustainable building

The IPES is a public body that, with its some 200 collaborators, on the one hand acquires, maintains and administrates around 12000 own apartments and on the other hand manages the provincial funds for housing subsidies.

Since long IPES is committed to low energy architecture and has built multiple lighthouse projects in South Tyrol, also for eco-buildings. In general the motivation for these projects was to investigate the feasibility of innovative standards for social housing, but also to explicitly be a pacemaker for energy savings in housing in South Tyrol (Minotti 2006). This commitment is not least due to the strong engagement of the former President Mrs. Franzelin, who is very sensitive to environmental issues, and in particular did highly favor lowered energy costs for the IPES clientele.

In the last working program of IPES, that was in set up under her presidency, a maximum space heat requirement of 50 kWh/m²a was decided for the 2550 new dwelling units to be built in the years 2001-2007. However, already in the beginning of the 90’s IPES had notable tendencies towards innovative low energy construction. For instance when in 1990 a house was planned that would later be certified as “category C” (70 kWh/m²a) by the CasaClima scheme.

Regarding low energy, one of nowadays most important objects is the passive house in Bronzolo that was accomplished in the first half of 2006 and since then is monitored by EURAC.

4. The IPES passive house Bronzolo

The IPES passive house Bronzolo (PHB) is one of the first multi-family buildings in passive house standard in Italy The planner of the building services calculated for the project a space heat consumption of 9 kWh/m²a according to the aforesaid certification scheme. Due to that and the fact, that is features all above mentioned sustainability requirements (see section 2.2), it was labeled “CasasClima Gold plus”. As the building is IPES’s first construction attaining passive house standard, the management decided to conduct a monitoring campaign. This should principally verify the design figures and provide technical support in case of deviations.

Figure 3: South façade of the IPES passive house in Bronzolo

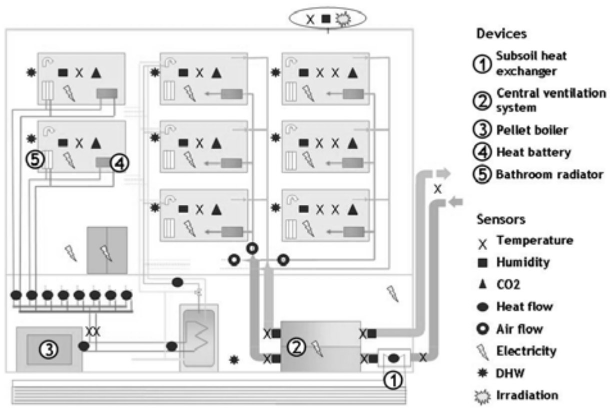

Figure 4: Scheme of monitoring devices and sensors

4.1 Description of the building

The object is a solid brickwork construction with 28 cm external mineral foam insulation. The compact structure contains 8 apartments on three floors with a total living area of 576 m². The basement comprises the building services room, the garage and storage rooms. The green flat roof has a beam structure and a wood construction to create inclination with an average thickness of around 60 cm filled with cellulose. Main features to avoid thermal bridges are e.g. the placement of the foundation walls on foamglass and the static and thermal separation of garage ceiling and basement ceiling. The balconies are suspended as they could not be field mounted for obligatory reasons. According to the producers of the windows, a particularity of the building is the construction which enabled the mounting of the windows after the finalization of external works, which could have damaged the frame.

4.2 The monitoring system

The building is equipped with a monitoring system showing a high level of detail (see figure 4): Each apartment has a multiple sensor measuring temperature, CO_2 and humidity to evaluate living comfort. Energy requirements of the single apartments are registered with heat flow counters and electricity meters. Furthermore, heat flow counters, temperature, humidity and air velocity sensors register the functioning of the building services. Finally, the common electricity consumption is measured as well as climatic conditions by means of a weather station.

A first two years monitoring of the building was assigned by IPES to EURAC before finalization of the building in May 2006. The monitoring period started in July 2006 and has since provided data for two summer and two winter periods.

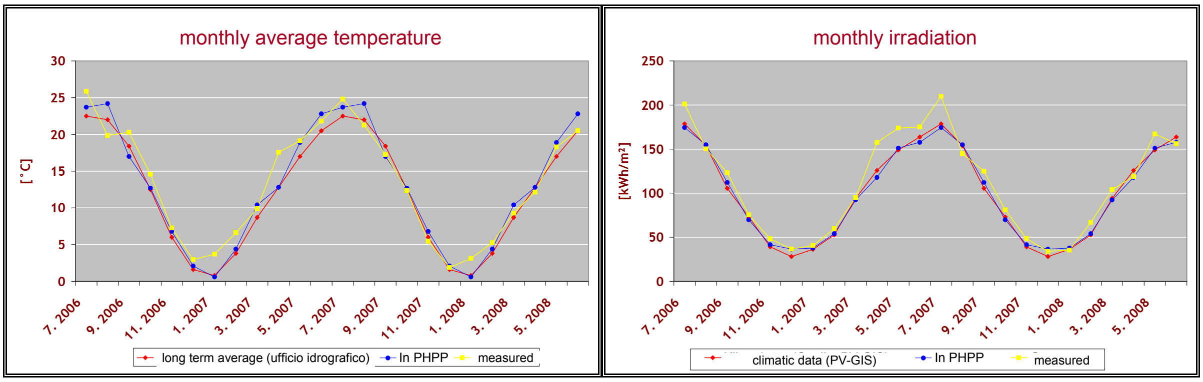

Figure 5: Climate conditions (temperature at the left and irradiation on the right side) during the monitoring period, compared to long time average and PHHP planning values.

4.3 Summer behavior

July 2006 appeared to be extremely hot in Bronzolo, with an average temperature of 25.9°C compared to the long term average of 22.5°C (see figure 5). Inside the building the average temperature in July was of 28.9°C with a maximum of 31.2°C, which demonstrates clearly that a very well insulated building envelope does not obligatorily prevent from overheating, and that in the case of the PHB overheating is an important issue (Schmitt et al. 2007).

There is no central cooling device installed, which is yet typical for dwellings in the region, though summer temperature peaks can easily compete with southern regions in Italy. However, for social housing cooling systems are hardly realizable. Therefore IPES and EURAC discussed other possible solutions to overcome the situation of overheating. In fact it was found out, that the distributed user instructions did not include the explicit recommendations for intensive airing at night and the use of the installed shading elements that need to be activated manually. This possible lack of information was made up by the distribution of new instructions. Further it was found out that supply air was actually heated up by nearly 2 K through the high temperature in the building services room and possible leakages in the ventilation system which was partly due to the poor functioning of the ventilation of the service room. This was removed through the installation of a new ventilation system for the latter. In 2006, the effectiveness of the measures could not be assessed because outdoor temperatures rapidly and persistently felled in August.

In the year 2007 indoor temperatures again rose considerably above comfort level with 3520 h/a (40%) of average indoor temperatures above 25°C. Though in a survey most of the tenants confirmed using the shading elements and practicing night ventilation in summer, it is not clear to what extend they actually do. A recent dynamic simulation of the building revealed, that if the air exchange rate of forced ventilation was increased only from 0.8h^{-1} to 1.2 h^{-1} when outdoor temperatures are lower then indoor temperatures, the number of hours in which indoor temperatures surpass 25°C could be lowered to 1139 h/a (13%) (Castagna et al. 2008). Such an increase of forced ventilation is actually not feasible in this case, since the system was simply not designed for that. But the outcome emphasizes that in this case an intense night airing and according cooling of thermal mass could significantly increase living comfort without the need for active cooling. Finally measurements have shown that there is potential for mitigation of overheating in summer through electricity saving measures. The consumption per square meter between the apartments highly differs and in general average temperatures in July (26.5 – 29 °C) are distributed in function of occupancy level (CO_2-level) but also in function of electricity consumption (1.2 - 3.5 kWh/m²) which do not necessarily go hand in hand (see figure 7).

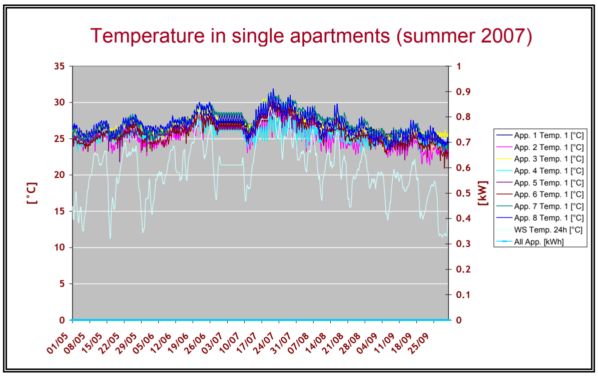

Figure 6: Indoor temperatures during summer 2007

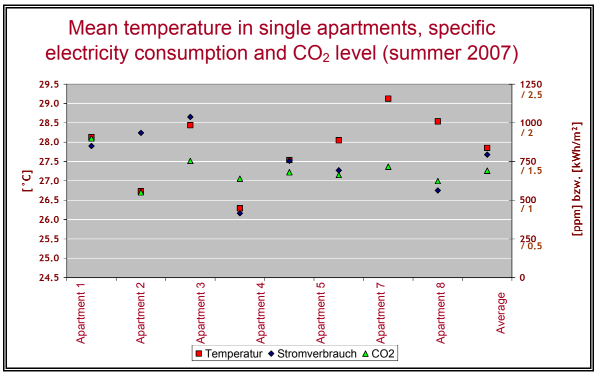

Figure 7: Mean indoor air temperature of single apartments, compared to specific electricity consumption (kWh/m²a) and CO_2 level (ppm)

4.4 Winter behavior

The winter performances have so far proven not to be entirely satisfactory. Though the winter 2006/2007 was comparatively mild in South Tyrol (2100 degree days instead of 2700 long term average), the space heat consumption (SHC) of the PHB was with about 25 kWh/m² higher than predicted. Figure 8 shows the SHC of the single apartments of the PHB for both the winters 06/07 and 07/08 in comparison to the SHC of passive houses measured in the European CEPHEUS project (Feist 2001).

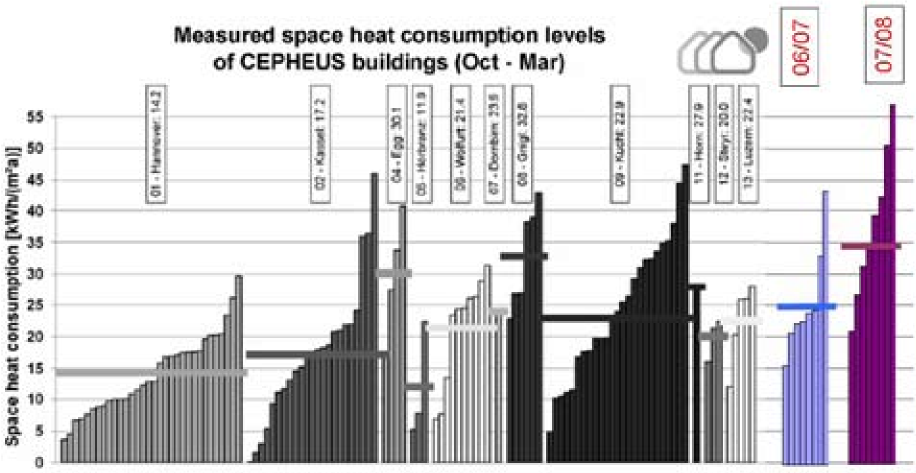

Figure 8: Space heat consumption for the PHB in 2 monitoring periods, compared with other passive houses in Germany as documented in the CEPHEUS study by Feist (2001)

The elevated SHC in 06/07 was attributed to losses through manual ventilation, the fact that indoor temperatures were in average 2 K higher than in design calculations and possibly to drying of the concrete in the first year of occupation.

The even more elevated SHC in 07/08 is partly due to the fact that the winter had more degree days (2500) and that average temperatures in the apartments were even slightly higher. But mostly it is due to malfunctioning of the ventilation system. On one hand a casual programming caused a periodic (night and weekend) switch off of the ventilation and on the other hand an unexpected clogging of the heat exchanger of the geothermal plant occurred. Both has led to a significant reduction of the supply air stream which on the one hand probably caused further manual ventilation and according losses and on the other hand remarkably reduced the efficiency of heat distribution (preheating batteries of supply air for each apartment) during the malfunctioning. A normal efficiency for the concerned period would have lead to a similar SHC for 06/07 and 07/08.

5. Conclusion

Concluding, it can be sustained that IPES has had an important share in the development towards sustainable and low energy construction in South Tyrol. The wide use of renewable energy sources and the political commitment for further enhancement of sustainable energy use in the region, are of course important background, but without the IPES's confident and highly visible practical realization of low energy buildings in the early phase, also the outstanding development of the CasaClima initiative might have been a little slower.

The CasaClima project had the declared goal of increasing low energy architecture in South Tyrol which it did with outstanding success. The success of the first years of CasaClima as voluntary scheme and the new availability of specialized planers and craftsmen paved the way for the initiative of introducing a minimum requirement, and still development goes on: Since the already ambitious class C was introduced as minimum requirement in 2005, the share of buildings underbidding this with at least CasaClima B has grown from 15% to 58%.

Energy performance of buildings certification schemes allow in a neutral way consumers to estimate the thermal comfort and running costs for heating. This is supposed to raise awareness and thus increase the market for low energy architecture from the demand side. In the case of CasaClima, this is probably not sufficient to explain the results. The strong political devotion and a package of accompanying measures created a regular hype around CasaClima. In fact "CasaClima" has been elected South Tyrols "Word of the Year 2007".

Looking at a most ambitious buildings, as the IPES' passive house in Bronzolo, which is one of the first multi-family passive houses south of the Alps, IPES has even tried to go one step further.

The monitoring of both the achieved comfort levels and energy consumption showed good results: Comfort levels, both regarding temperature and humidity as well as CO_2 levels, are within comfort levels for most of the year. Energy consumption is – if mathematically compensating the periods of malfunctioning – are also within the range of other "real" passive houses (see figure 8).

Summer behavior shows periods with high temperatures – but not in all apartments the same degree, what suggests that also user behavior has a not negligible influence on the results. As in other regions, where air conditioning systems are not commonly used in residential buildings, even if outdoor summer temperatures can reach high values, the behavior of tenants regarding shading, night ventilation and internal loads prevention is critical for summer comfort. Unfortunately there are not yet available data for comparison with other IPES' buildings' summer behavior.

Also tenants evaluate living in a passive house positively. Despite the above described small cases of malfunctioning and a few other inconveniences the tenants mostly rated the ventilation system as of very satisfactory and measurements have shown that it has in general been working well e.g. for what regards air humidity in winter, which was not lowered below comfort level.

Within IPES, there is however and will be an important discussion whether ventilation systems with heat recovery should or not become standard for new buildings, a indispensable feature for very low energy and passive architecture according e.g. to the CasaClima agency. This discussion will accompany, in the next years, other institutions and housing companies in South Tyrol, since similarly to Germany and contrary e.g. to France the installation of ventilation systems is not standard for housing constructions.

Acknowledgements

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CHANGING THE CULTURE OF COMMERCIAL BUILDINGS IN AUSTRALIA: THE ROLE OF GREEN LEASES

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Summary

Innovative new 'green' commercial building developments are emerging across Australian cities. This is a positive change. However, to advance the overall sustainability of Australia's commercial buildings sector two key issues need to be addressed. The first is the importance of focusing on the sustainability of the whole building - the base building and the tenancies. The second is the importance of focusing on existing buildings, as new buildings are a small proportion of the total building stock.

In addressing these issues, tenants hold the key. Their decisions and actions have significant potential to enhance or undermine the sustainability performance of commercial buildings, both new and existing. The potential to create change through tenant decisions and actions is significant given the emergence of corporate sustainability as a key business driver. However, this will require a culture change in the way leases are negotiated. One way of facilitating this process is through the use of 'green' leases.

A green lease is different from a standard lease in that it incorporates ecologically sustainable development (ESD) principles to reduce the building's environmental impacts. This paper focuses on the way green leases for office tenants can be used to create culture change within tenant operations and offices, as well as influencing building managers and building owners. It looks in detail at the *Green Lease Guide* developed by Investa for use with tenants of commercial properties.

1. Introduction

1.1 The Importance of Commercial Buildings

Commercial buildings have a significant environmental impact. The Australian Greenhouse Office (AGO, 1999) estimated in 1990 that commercial buildings were responsible for about 32 million tonnes (Mt) of greenhouse gas emissions. Emissions are currently increasing at about 3 to 4% per annum, which means they are approximately ten percent of Australia's total greenhouse emissions. Commercial buildings also account for about ten percent of urban water consumption (NABERS, 2006).

There is much attention now being paid to new 'green' commercial buildings to reduce this impact. More and more new buildings are being constructed to meet five and even six star Green Star (and up to 5 star NABERS ratings). However, new buildings only make up a small percentage of the commercial building stock. Urgent action is needed to improve the environmental performance of the existing stock if we are going to achieve the necessary reductions in resource use and greenhouse gas emissions. In many cases, the benefits from the operational energy reductions achieved with new developments will not even compensate for the embodied energy involved in their construction, as illustrated below.

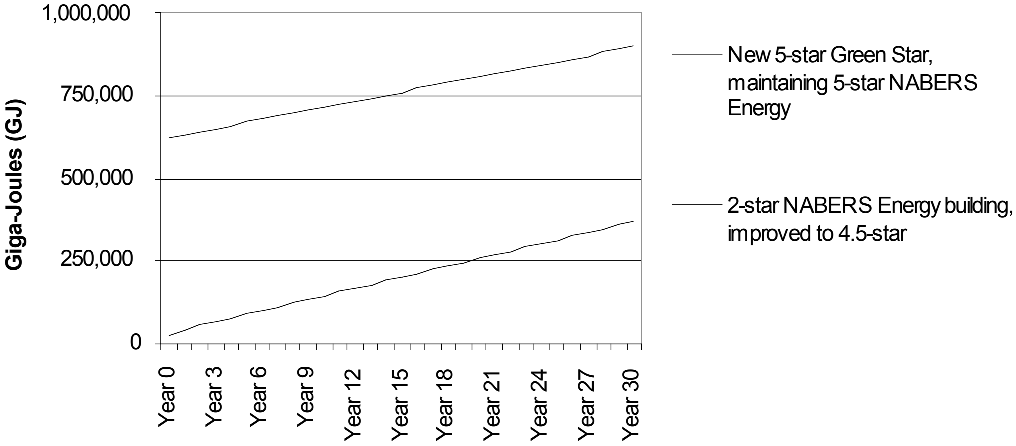

Figure 1 Lifetime energy comparison of new and upgraded buildings

Figure 1 illustrates this point with two alternative options for a hypothetical 25,000 m^2 building on a site in Sydney, Australia. In the first option, an existing building is upgraded from a 2 to 4.5 Star NABERS Energy rating, in a manner consistent with that which has been undertaken in a number of buildings in Investa's portfolio (Investa, 2007b). An alternative option would be to demolish then construct a new building that meets a 5 Star National Australian Built Environment Rating Scheme (NABERS) rating. Embodied energy is calculated at 25 GJ/m^2, a fairly typical figure. Over 30 years, the new 'green' building will have used more than twice as much energy as the upgraded existing building would have (Roussac, 2006).

A typical commercial office 'base building' is merely a skeleton which an interior designer uses to create an office. Occupants relate most closely to the light, colour and amenity of their fitouts, not the base building, and the tools they are given to perform work, such as their workstations, tables, meeting spaces, partitions and offices.

For a building to be 'green' it must have a green interior, not just a green base. An interior designer (who understands factors that affect indoor environmental quality) working in close collaboration with the occupants should be able to create a 'green' office tenancy in almost any building that meets relevant Australian Standards. This is even more clearly the case if the base building owner commits to vigilant maintenance of base building services such as heating, ventilation and air conditioning systems.

It's a common misconception that to be 'green' a building has to use contemporary design and state-of-the-art technology. In fact, some of the best performing buildings are older buildings where the building manager has taken measures to optimise performance and has supported tenants to do the same. Some green outcomes are better achieved through improved building management practice, while others might require capital expenditure on either the base building or tenant fitout.

Fitouts and refurbishments are responsible for the consumption of a large amount of resources. Investa estimates that the average life of a typical office fitout in its portfolio is just over ten years. Treloar et al. (1999) estimated that the total life cycle energy consumption of fixtures, fittings and furniture at a churn rate of 5.6 fitouts over 40 years (i.e. a life of just over seven years) was close to, if not more than the operational energy use for the case study building. Clearly, fitouts also need to be designed with the environment in mind.

1.2 The Role of Tenants

Tenants therefore have a vital role to play in improving the sustainability of the commercial building stock. However, they often do not have the same drivers to go green as do building owners who have a building life-cycle perspective. To achieve significant advances requires a cultural change and often an increase in expertise and resources. As with many issues, there is often a gap between espoused values and observed actions. This can be for a variety of reasons.

Many tenants may be interested in committing to a greener building. However, it is often unclear how to incorporate 'green' commitments and requirements into a lease. The perceived degree of uncertainty around the success and cost of green measures is also a deterrent. Other tenants may be unaware of the benefits of occupying a greener building. Consequently, tenants often fail to take up green measures even though it would in fact be in their business interest to do so. Unless tenants are aware of the benefits, what to specify and how to implement green commitments, they will usually opt to occupy a building with a conventional lease, especially if there are additional upfront costs associated with a green lease.

One example of the business benefits to tenants is that for each one star improvement in a tenancy NABERS Energy rating, tenants will save about $3.70 per square metre in annual energy costs.

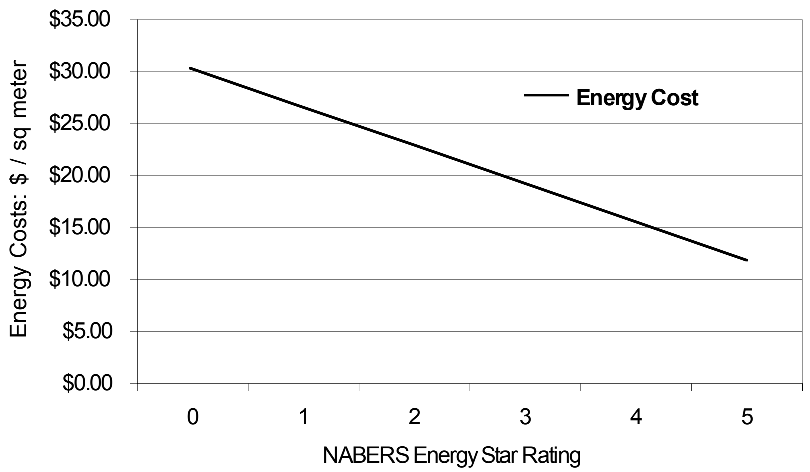

Figure 2 Relationship between ABGR rating and energy costs

As another example, about 60% of tenants' energy costs are for lighting. Tenants can have a very direct impact on this by asking for efficient lighting systems and making sure they are used efficiently.

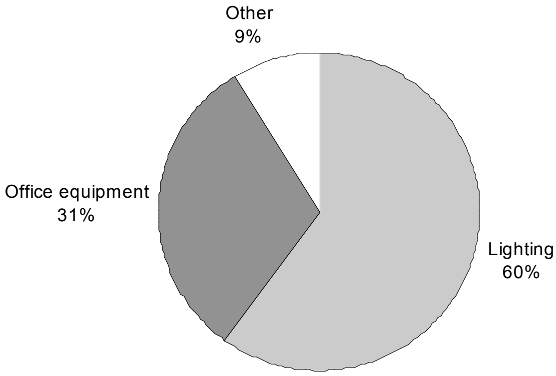

Figure 3 *Energy costs in a typical commercial tenancy*

The *Green Lease Guide* attempts to address these barriers by demonstrating the benefits of green commitments and providing practical information about implementation.

2. Green Leases

2.1 What is a Green Lease

A 'green lease' is different from a standard lease because it incorporates ecologically sustainable development (ESD) principles to reduce the building's environmental impacts. The green property market is still immature, resulting in uncertainty in the marketplace about what 'sustainability' or 'going green' means, what are the most appropriate 'green' measures that might be adopted in a building and the costs of implementation. People are familiar with what to expect from a standard building lease, but both parties may not know what to expect from a green lease.

Incorporating new requirements into a green lease requires knowledge and cooperation. A balance needs to be struck between cooperative and prescriptive approaches to negotiating environmental outcomes. Some Australian governments have implemented prescriptive type green lease requirements by specifying minimum NABERS ratings for properties they lease.

Leases can be issue specific, such as a minimum NABERS water rating, or a comprehensive package of measures as outlined in the *Green Lease Guide*.

The important considerations of a green lease for a tenant include:

- What do they want – what does 'green' mean and what are the targets
- What is the starting point – use measurement and rating tools to establish the baseline
- How to achieve the desired outcomes – obligations of tenant and landlord
- Who gets the benefits
- What has been achieved – auditing progress
- How to resolve disputes – who decides who is responsible for not achieving a target.

2.2 Green Rating and Evaluation Tools

A range of tools and aids exist to help in assessing and improving the environmental performance of existing buildings for tenants. In Australia these include:

- NABERS Energy rates a building's *actual* yearly greenhouse emissions. Almost a third of the national Australian office market (by net lettable area) has been rated using NABERS. Ratings can be obtained for the base building, an individual tenancy and the building as a whole.
- NABERS Water compares actual energy and water use to benchmarks. Indoor Environment and Waste rating tools have also recently been released.
- Green Star Office Design for office refurbishments, Office Interiors for new fitouts and a suite of associated tools for other development types.
- Ecospecifier also provides information of environmentally preferred products and materials.
- Good Environmental Choice Australia has an eco-labelling scheme for a range of products.

There are also a range of efficiency star rating labelling schemes for energy and water to assist in selecting efficient appliances, fixtures and fittings.

2.3 Benefits of a Green Lease

A Green Lease has a number of significant potential benefits for tenants:

- *Enhanced reputation*
  - Organisations are increasingly expected by shareholders and the community at large to demonstrate corporate social responsibility—'doing the right thing' in respect to the environment, employees and the community.
- *Attract and retain talented employees*
  - The importance of attracting and retaining talented employees is increasing in the face of a predicted decline in Australia's workforce (Colliers International, 2006)
- *Enhance employee well-being and productivity*
  - Research indicates a link between a good indoor environment in offices and improved employee well-being.
- *Enhance and protect organisational knowledge*
  - Workplace design influences the way staff share and develop knowledge.
- *Reduced liability*
  - It is an employer's duty of care to ensure a safe and risk free working environment.
- *Increased profitability*
  - All of these benefits can create significant cost savings for an organisation. In addition, there are direct cost savings such as lower electricity bills. Other building costs that tenants may not directly pay for (waste management, water use, air conditioning, etc.) are lower in a green building and a case can be made for passing these on.

3. The Green Lease Guide

3.1 Background

Tenants often see 'green' as synonymous with 'new'. This is not good for the environment, because it's crucial that we preserve and enhance as much of the built environment as possible, and it's not good for tenants – because in general, it's wrong.

Following the environmentally sensitive fitout of its Sydney head office, Investa sought to educate the market about the benefits of incorporating environmental considerations (many of which have well-being and productivity spin-offs) for tenants. It was found that tenants often lack the resources and expertise to deliver the environmental initiatives they would like to see integrated into their tenancies.

Investa has a variety of precedent leases (i.e. base leases that are developed to reflect the agreement specifics) for use in different markets and to reflect the terms agreed between landlord and tenant. All Investa precedent leases have a set of clauses that establish environmental objectives and an attached schedule which specifically sets out the commitments made by each party.

Despite the lease presenting commitments in a very cooperative form, in most cases tenants would not commit to specific actions in the schedule for a variety of reasons, including:

- environmental features being low on the negotiation priority list;
- an unwillingness to add non-traditional commitments to the deal;
- other landlords not negotiating Green Lease provisions; and
- failure to recognise benefits of high quality building management and fitout design.

The Guide was a response to these challenges. Among its objectives were the following, to:

- showcase best practice and help tenants avoid costly design mistakes (both for them and the landlord – if their fitout ultimately leads them to fall out of love with the building).
- help strategic decision makers articulate their design requirements, and hold project teams accountable.
- fuel demand for quality building management.
- take the focus beyond energy to address a broad range of environmental factors.

The Green Lease Guide is introduced as early as possible in a lease negotiation, ideally when the tenant is evaluating a series of accommodation options. Its target audience is strategic decision makers within companies – it's not a 'technical' document.

The Guide has been designed to:

- step tenants through all the environmental issues they'll face in undertaking a fitout;
- give tenants guidance on options, their costs and benefits;
- represent a quantum leap in Green Lease thinking and explain the role of the landlord;
- provide information and images that can be used for related educational initiatives; and
- contribute to a significant and measurable reduction in environmental impacts from commercial office tenants.

3.2 The Guide's Structure

The Guide comprises three main sections, each containing a number of topics. Each of the topics has an associated checklist to guide good practice and is given a rating from one to three stars for money savings, employee well-being, and reputation and corporate image.

Every one of the commitment options presented in the Guide is replicated in a succinct schedule that appends to the lease. The schedule serves as a summary of all the commitments made by each party and, because it does not contain any legal clauses, it is suitable for attachment to any standard commercial lease. In addition to making it accessible to any organisation that wants to use it, it provides the added benefit of allowing the lease clauses and green commitments to be negotiated independently of each other.

3.3 Green Lease Certificates

A recent improvement has been the development of a Green Lease Certificate to support the green leasing process. The Certificate expresses the level of commitment both the tenant and landlord have agreed to. It has been attractively designed so tenants will be inclined to display it. Its purpose is to give tenants recognition for their Green Lease commitments. It can also be used by Asset Managers and Facilities Managers as a marketing tool to promote their buildings and management attributes.

The Green Lease Certification process works as follows:

- Once the tenant has signed the Green Lease and it has been returned to the Asset Manager, a certificate template is marked up to reflect the commitments made under the lease.
- The certificate is then signed and presented to the tenant for display.
- The Certificate is reviewed and amended (as appropriate) on each anniversary of the lease.

4. Case Study: 50 Ann Street, Brisbane, Australia

Commercial lease negotiations between landlords and tenants in Australia typically focus on rent, the timing and mechanisms for rent reviews, lease term and incentives like rent free periods and fitout contributions. In short, the negotiations focus on financial aspects that impact both parties directly. Financial considerations that impact one party only are generally not addressed in the lease negotiations. This means that the negotiations will consider the cost of operating the base building (because this is passed either directly or indirectly to the tenant), but not the cost of operating the tenancy which is a matter for the tenant alone.

One of Investa's most significant recent negotiations was the renewal of 25,382m2 for 13 years with the Queensland State Government at the building known as "State Law" at 50 Ann St, Brisbane. The negotiation was unusual in that both parties took a 'total occupancy cost' approach to exploring opportunities to overcome split incentives. Split incentives arise when a party invests capital without a means of generating a return on its investment, because the revenues/ savings accrue directly to another party. For example, a landlord may invest in energy efficient lighting, but the tenant captures the resultant energy cost savings.

A broad ranging review of the building was undertaken to identify a variety of environmental efficiency initiatives, both within the base building and also the tenancy areas. The result was a series of recommendations including a comprehensive tenancy lighting upgrade. The majority of these were proposed as part of the lease offer, including a landlord 'incentive' specifically allowing for the upgrade of lighting and installation of occupancy based controls at the landlord's expense. The projected savings were then able to be factored into the lease analysis by the tenant.

One important factor that gave the tenant confidence to budget for the projected savings was the offer of a guarantee. The guarantee included an undertaking by the landlord to take the tenancy NABERS Energy rating from an unofficial rating of 2.5-stars to 4.0-stars, or perhaps even 4.5 depending on the participation of staff. In doing so, the tenant would save more than $150,000pa in energy costs, principally through the upgrading of light fittings and installation of a managed lighting control system (MLS).

To give confidence that the forecast savings would be achieved, Investa guaranteed that if the tenant's energy consumption exceeded the guaranteed maximum amount, they would be reimbursed for the additional energy expense and the amount of Green Power required to offset the additional greenhouse emissions would be procured on their behalf. This offer was subsequently made available to all tenants and is now referred to as the Investa Greenhouse Guarantee, incorporating the following features:

- If the tenancy performance is better than the guarantee, the tenant keeps the savings.
- If the bills are higher than guaranteed, the tenant is reimbursed for the difference.
- If the environmental impact is greater than guaranteed, it will be offset with Green Power™.

For most tenants, the guaranteed outcomes are delivered without any capital outlay or increase in operating expenditure, with the cost of energy-saving equipment and systems financed through ongoing energy savings. The Investa Greenhouse Guarantee has been designed to make the transition to energy efficient tenancies as painless, cost-effective and risk-free as possible.

The lighting upgrade project was complemented by various other energy and water saving initiatives that in the past three years have delivered year-on-year emission reductions and water savings of more than 30 percent for the building as a whole.

- Tenant energy & maintenance savings of $185,000pa.
- Tenant ABGR to increase from 2.5 Stars to 4.0 Stars.
- Tenant greenhouse emissions reduced by 1,206 tonnes pa (equivalent to taking 270 cars off the road).
- Various base-building ESD initiatives.
- Building valuation increased from $75m to $87m ($10m due to market cap rate compression, $2m due to the lease).

Investa's sustainability platform and willingness to commit to a series of base building environmental efficiency initiatives were major factors in the tenant’s decision to negotiate exclusively with Investa and directly contributed to the $2 million valuation uplift for the property.

5. Conclusions

There is clearly a place for new flagship new green commercial office buildings. However, they are not the sole answer to addressing the impact of buildings on the environment. New green commercial buildings can only truly lay claim to the “green” mantle if they are green on the inside, as well as the outside. A green base building must be supported by a green office fitout to deliver its full potential. Furthermore, much can be done to significantly reduce the impact of existing buildings, and in many cases this may be more effective than new construction.

What is needed is a way to transform the culture of building owners and tenants towards a greater appreciation of the value of green buildings. This will reduce the environmental impact of Australia’s building stock, help tenants achieve the optimal outcome from their workspace and, as a consequence, help landlords maximise the value of their commercial office assets. Green leases provide a way to facilitate that process.

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A Study of the Demand and Marketing Strategies for Promoting Ecological Communities in Taiwan under the Trend of Global Climate Changes

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Summary

In facing of the problems of global climate change and along with the promoting of the concept of sustainable development, developing ecological community has become an important policy goal in Taiwan. However, how the concept of ecological communities should be promoted to the potential homebuyers remains an unanswered research question. This paper explores a planning approach for promoting the concept of ecological communities. Through an examination of the pilot ecological community project in Tainan Salun High Speed Rail Station of Taiwan, this study identifies the target markets and the demand of services of ecological communities. By incorporating research methods involving interviews, field survey, and a questionnaire survey, this study finds that the demand of the facilities and services of ecological communities is related to the household income and the values of ecological communities perceived by homebuyers. Based on the results of the empirical studies, this study develops a set of marketing strategies for promoting the development of ecological communities.

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1. INTRODUCTION

The concept of ecological community has received widespread attention in Taiwan in the past decade. This concept outlines a vision for building a living environment that integrates the considerations of ecological integrality, economic efficiency, and social equity. However, since the concept of ecological community has proposed a new type of community development and lifestyle that is different from the current housing market products, how this concept can be efficiently implemented in current community planning and real estate practices in Taiwan has become a critical issue. Employing research methods involves field investigation, in-depth interviews and questionnaire survey, this research attempts to explore two research questions: (1) How decision-makers in community design and land development should identify the key elements and facilities in building eco-communities in Taiwan? (2) How should we develop suitable marketing strategies to promote eco-communities in the existing real estate market? Through our empirical study, a set of workable strategies are suggested in order to promote the concept of ecological community in Taiwan.

2. LITERTURE REVIEW

2.1 Sustainable Development

The concept of sustainable development provides a theoretical foundation of the construction of ecological communities. With the promotion of the concept of sustainable development and ecological design, the notion of ecological communities has received much attention in Taiwan. Sustainable development is a broad concept. According to the Brundtland Commission (1987); sustainable development refers to "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). This popular definition introduces the concepts of long-term environmental sustainability and inter-generational equity, but it also suffer from attacks because it over emphasize an anthropocentric approach. The other widely cited definitions of sustainable development include those proposed by the International Union for the Conservation of Nature (IUCN) and the World Conservation Union (WCU). The International Union for the Conservation of Nature (IUCN, 1986) pointed out that "Sustainable development should seeks to respond to five broad requirements: (1) the integration of conservation and development, (2) the satisfaction of basic human needs, (3) the achievement of equity and social justice, (4) the provision of social self-determination and cultural diversity, and (5) the maintenance of ecological integrity." While the World Conservation Union in its 1991 report, Caring for the Earth, defined sustainable development as "improving the quality of human living within the carrying capacity of supporting ecosystems" (WCU, 1991). These popular definitions, together with related interpretations of sustainable development, provide a new framework for examining many critical housing and community development problems associated with current land development patterns and our behavior toward the use of natural resources.

2.2 The Concept and Key Elements of Ecological Communities

The concept of ecological community includes the meaning of ecology and of community. It was born out of a need to integrate the concepts of sustainable development and ecological design with the concept of community design and management. The notion of ecological community includes an important meaning of "succession," which applies not only in ecology aspect, but also in economic and social aspects. As noted by Roseland (2000), a sustainable (ecological) community is a community that uses its resources to meet current needs while ensuring that adequate resources are available for future generations. US environmental protection agency defined the meaning of community from an eco-community point of view, and pointes out that the key idea is that the people involved in any "community" have a common interest in protecting an identifiable, shared environment and their quality of life (USEPA, 1999). In summary, an ecological community resembles a living system and community governing institution where human, natural, and economic elements are interdependent and draw strength form each other. In addition, rather than being a fixed community development pattern, an ecological community will continually adjust itself to meet the social and economic needs of its residents while at the same striving to preserve the ecological integrity of its supporting ecological system. This new approach of community design and governance provides an alternative of community development that is suggested by many researchers to be able to avoid many of the current planning problems, such as the destruction of natural capital, unmanaged urban sprawl, declining quality of life, loss of species, and increasing in social inequality. Since "community" is the key element of spatial planning and regional governance as well as one of the most important action units to promote sustainable regional development, implementing the concept of ecological community may help build a sustainable future that aims at achieving the goals of maintaining environmental integrity, promoting economic efficiency, and promoting social equity and environmental justice.

Based on a review of related literature and our interviews, the basic planning principles of ecological communities can be summarized as follows: (1) managing development based on the limit of carrying capacity of regional ecosystem; (2) establishing the interdependent relationship between community development and ecological system; (3) minimizing ecological footprint by reducing the consumption of land and other resources; (4)encouraging compact development to reducing the conversion of natural and open lands to urban and developed uses; (5) using public space efficiently and fairly; (6) maintaining diversity and expanding the ideas of promoting diversity from bio-diversity to social diversity; (7)empowering communities to sustain prosperity and expand economic opportunity; (8) accumulating social capitals and building a stronger sense of community; (9) fostering a bottom-up community planning approach and mobile local citizens and their government (see e.g., Van der Ryn and Calthrope 1991; Calthorpe 1993; Beatley, 1998; Roseland, 2000; Lee 2003; ODPM 2004). Based on literature review and previous experiences, the key elements of construction an ecological community can be summarized in Table 1.

TABLE 1: The key elements of ecological communities

Local development planning and local environmental improvement:
land development plans that encourage compact development patterns; land use planning that encourages compatible mix-use; land use plans and measures that conserve environmentally sensitive areas; comprehensive community landscaping and community greening
Local transportation planning and management:
provision of public transit systems; manage the supply and demand of parking spaces; planning of pedestrian network and activities; supply of bicycle networks; livable street design
Community environmental management:
household waste recycling and waste reduction; supply of green infrastructure (e.g., a sewerage system; green ecological corridors); recycled product purchasing
Energy efficiency:
green building programs; renewable energy use programs; energy conservation programs; water conservation and gray water programs
Community socioeconomic Development:
housing development that attracts residents from diverse socio-economic backgrounds; economic development that encourages local employment; community self-help programs that improve safer environment
Organization/administration/governance:
community self-management and self-help programs; community citizen participation and education programs; the involvement of chief executive officers of local governmental agencies; involvement of the business communities; community partnership programs and various partnership networks.

3. RESEARCH METHODOLOGY

To achieve the purposes of this paper, this research employs a case-study approach. The ecological community project in the Salun Special District around Tainan High Speed Rail Station of Taiwan was selected as the case setting. This case is a pilot project currently actively supported by the Taiwanese government in order to build an eco-city and several ecological communities around the newly constructed HSR station in the Tainan County. It aims at creating a new generation of new town and community development model in Taiwan that incorporating the concepts of eco-cities and eco-communities. The research methods applied to the case study are as follows:

Field Investigation: field investigation was employed to analyze the environment of the research area, local and regional resources, local settlement patterns, demand of public facilities in communities, industries, and social-economic background of the research area. Apart from taking notes and mapping during on-spot observations, photography was also employed to record the environmental images and spatial characteristics of the research area.

In-depth Interviews: this research selected people with an interest in living in ecological communities for in-depth interviews. A modified snowball sampling method was used in which appropriate key subjects were selected and interviewed, and then further interviewees were suggested based on the recommendation of these initial research subjects. Initial research subjects were identified based potential homebuyer lists provided by local and regional real estate agencies and local governments. It is hoped that through in-depth interviews, researchers are able to investigate the demands and needs of the proposed ecological community. A total of 46 research subjects were interviewed.

Questionnaire Survey: questionnaire survey was used to investigate the basic need of the ecological facilities and services of the proposed ecological community as well as the individual's willing-to-pay for living in the proposed ecological community. The survey was the major information collation method for exploring the facility demand of the ecological community.

4. PLANNING FOR ECOLOGICAL COMMUNITY IN THE TAINAN SALUN SPECIAL DISTRICT

4.1. The SALUN Pilot Project and Planning for Ecological Community

This study uses the Salun ecological community project as research case. The Salun Special District, covers 299 acres and centers on the Tainan Salun High-Speed Rail Station, is selected as the research area. It is one of the four special districts designated to promote comprehensive land development around the newly constructed Tainan high speed rail station. It is also the first rail station area in Taiwan that attempts to build a new town, employing the concept of eco-city and eco-communities. Currently, the special district around the station area is mainly agriculture use. The proposed land use plan has classified this special district for several major land uses, including 27.7 % of the land for residential use, 15.8 % for industrial use, and 3.64% for commercial use.

FIGURE 1 The layout of Salun eco-communities (Sources: the Commission of Economic Development, National Taiwanese Government)

In terms of location characteristics, the Salun special district is close to Tainan High-Tech Science Park and Kaohsiung High-Tech Science Park. It is located within 40 minutes driving distance of the CBD (Central Business District) of Tainan City. In general, the site is a good candidate for building a new town that can serve both as an industrial incubator center and a dormitory city for high-tech professionals and/or other middle to high socio-economic-classes of professionals in the region who desiring for a better community living environment. Currently, the infrastructure system and the land subdivision have been completed, and most of the land is waiting for development. The residential land in the Salun special district is suitable for developing high quality eco-communities for the professionals mentioned above. To promote a planned land development patterns and to manage the growth of the new town, the Tainan County government has attempted to develop a prototype and related guidelines for ecological community development in the Salun HSR Station area. The proposed ecological community plan integrates the suggested planning principles of ecological communities mentioned above and also considers the feasibility of the real estate market. The layout of the proposed ecological community plan is shown in Figure1.

This study attempts to develop workable planning and marketing strategies for promoting the development of ecological communities in Taiwan. The empirical process includes: an environmental analysis, STP analysis, the willing -to-pay analysis for the proposed ecological community services, and the development of planning and marketing strategies. Based on literature reviews and interviews, the following community planning criteria are suggested for the proposed ecological community:

(1) Site: A community size of 10,000 or more square meters with pedestrian and Bike routes connected to the community center and transit stations is suggested.

(2) Types of housing stock: Middle to low density housing with diverse housing types, including multifamily housing, apartments, and 3.5-story townhouses; the average housing density is suggested as 100-125 housing units per block and 250-300 housing units in a community to be serviced by a community service center and shared facilities (this is a necessary scale to support the efficient provision of community services). The major housing size is suggested as 250-400 square meters per housing unit with shared community public gardens and space.

(3) Ecological Infrastructure and Technologies: Green open space networks; gray water circulation systems; shared community farmland and gardens; bike routes and pedestrian walkways connected to major activity sites; and community e-learning center are preferred.

4.2 Strategic Planning for the Salun Ecological Community

A strategic planning approach is used in this study. Compared to the traditional planning approach, the strategic planning approach is more flexible, adjustable, process-oriented, and more likely reach a good consensus. For a new product like an ecological community, this approach provides a useful tool to define the target market and develop useful strategies that may lead to useful community actions.

Based on the experience of related literature and our previous studies, the process of strategic planning for promoting the ecological communities in Salun of Taiwan is divided into four steps as shown in FIGURE 2.

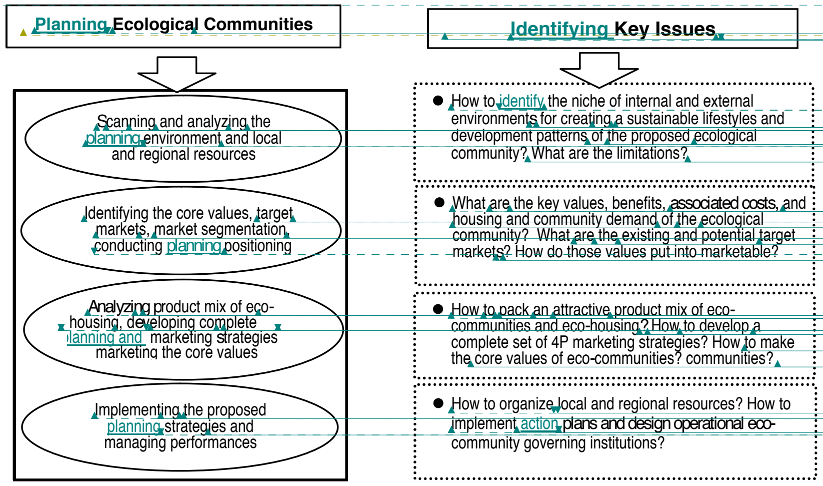

FIGURE 2: Steps and key questions to develop marketing strategies for promoting Ecological Communit

4.2. Identifying the demand of facilities and services of Ecological Communities

To explore the demand of facilities and services as well as to explore the willingness to pay of potential customers for the provision of ecological community facilities and services, this study conducted a questionnaire survey of 86 research subjects. The research subjects were identified and surveyed based on lists provided by local and regional real estate agencies. The result is shown in Table 2 (Wu 2007).

TABLE 2: Demand of Facilities and Services of the proposed Ecological Communities in Salon of Taiwan

	Facilities	Degree of demand	Facilities demanded (within 10 percent increase of total construction cost)	Facilities demanded (within 20 percent increase of total construction cost)
Energy system	Day lighting	4.21	√	√
	Photovoltaic's electricity	3.86		√
	Biomass fuels	3.21		
Water System	Rain water storage	4.11	√	√
	Gray water recycling	3.85		√
	Bio-climatic design	3.46		
	Artificial wetland	3.78		√
Waste sorting	Organic waste nutrient recycling	3.93	√	√
	Waste management	4.06	√	√
Greening and Permaculture	Green roofs	4.08	√	√
	Green walls	4.12	√	√
	Community gardens & orchards	4.23	√	√
Transport	Livable pedestrian streets	4.27	√	√
	Bicycle paths	4.08		√
Food distribution	Bulk food buying	3.87	√	√
Community open spaces	Spacious common areas	4.09	√	√
	Parks and courtyards	4.31	√	√

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Ecological lifestyles	Sustainable building materials	3.79		√
	Healthful food and drink	4.26	√	√

Notes: 1. The number represents the average score of the item evaluated by the research subjects, the rage of score is from 0 to 5, the higher the value is close to 5, the strong the effect the item is.

2. √ indicates that the facility or service is desired by the surveyed home-buyers given the proposed increase in total construction costs.

5. DEVELOPING MARKETING STRATEGY FOR ECOLOGICAL COMMUNITY

Based on field observations, interviews, and questionnaire survey, this study proposes the following 4P marketing strategy for the ecological community:

Product Strategies

Our product strategies consider the ecological community as a product mix and try to sell the product mix to the target market. A product mix is a combination of products that can be offered to satisfy the need of desired customers. According to our survey results, three levels of the products are considered (see FIGURE 3). Each level adds certain customer values, and the three levels together form a customer value hierarchy. First, the most fundamental level is the "core product," which is the essence of the product that the customers really want to obtain. This research identified the core product of the proposed ecological community as: "healthy, ecological living, healthful editing, and the common interests for their children." Developers should keep in mind that they should be these core product providers. The second level is the "tangible product," which includes the community amenities and ecological infrastructure of the proposed ecological community such as ecological housing, green infrastructure, community open space, landscaping, community gardens, etc. The third level is where the developer and marketer could prepare as augmented products that can provide some extra satisfaction for the consumers. In the ecological community project in particular, the augmented products may include affective appeal, emotional support, environmental education, an image of a pure nature, the model of community development.

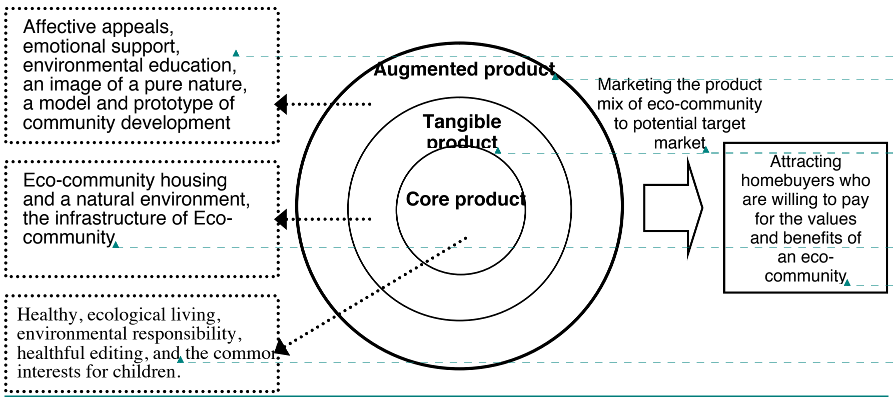

FIGURE 3: The three levels of the ecological community product

Price Strategies

Based on our questionnaire survey and interviews with potential eco-housing homebuyers, this study finds that the demand of ecological community is related to the increase in total construction cost and household income. The increase in total cost is depending on the ecological infrastructure and facilities provided. Figure 4 presents a conceptual diagram based on the results of our survey. In general, if a household's monthly family income is above 150,000 NT dollars, they may accept more than twenty percent increase in total construction cost for building an ecological community with more ecological infrastructure and ecological technologies. If a household's monthly income is between 800,000 NT and 150,000 NT dollars, they may accept about ten percent increase in total construction cost which can only afford to build some basic ecological community infrastructure and ecological community technologies. However, if a household's monthly family income is below 80,000 NT dollars, then the household may not prefer or may not be affordable to own an ecological housing product.

The survey result shows that the ecological community housing with related infrastructure, services, and green building facilities will primarily attract customers with a middle- to high-income who strongly appreciate the value of nature, health, and well managed community life. Price strategy thus depends on the attributes of potential customers and the context of the complete product package. Given the high competition of the real estate market and the increased demand for better living quality in Taiwan, current

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homebuyers are not only considering the attributes of eco-housing, but also desire for a better community environment and community management, as well as a lifestyle in praise of health and slow.

Place and Promotion Strategies

Since there is no real housing product that meets the full concept of ecological community in the current housing market, the project proposed in this study is based on some assumptions and scenarios. Place strategies and promotion strategies are discussed here together and are thus focused on how to communicate the basic concept, the simulated environment, and the scenarios to the potential consumers and the general public. There are two key missions here that marketers must address: (1) the demand of the target market that is associated with the buyer's socio-economic characteristics and lifestyle; and (2) public and environmental education that helps consumers understand the values and benefits of the ecological community.

These promotion strategies, therefore, should package the require information and key concepts of the ecological community products together and make people aware, understand, appreciate, and purchase these concepts as a total product mix. Also, the goals of promotion should include building a well-known and positive image of the proposed ecological community. The tools of promotion mix should include five elements: (1) advertising, (2) sales promotion, (3) public relations and publicity, (4) personal selling, and (5) direct marketing. The following are our suggestions based on our survey.

1. Providing public education and citizen participation programs (such as eco-community workshops) that introduce to the general public the meaning and importance of developing ecological community.
2. Enhancing the introduction capacity and knowledge for marketing eco-communities, including the training of personnel and provision of training programs for sales.
3. Building a simulation and demonstration system for packaging the core concepts and values of ecological community and marketing them through advertisements and diverse communication channels to the target market.
4. Using media marketing frequently to attract the perception of the desired target market. For example, use such media tools as ecological newspapers, introduction brochures, and median interviews with well-known stars and scholars who favor eco-communities.
5. Creating websites of ecological community that are connected to websites of schools, NGO, foundations, and local government to distribute the updated information about the development ecological community worldwide.
6. Utilizing event planning as a tool for ecological community promotion, such as regional and local special EXPO or cultural and recreational events to attract homebuyers and investors.
7. Designing an attractive and positive image of the proposed ecological community and the locality, including meaningful logos, an attractive name of the ecological community, and identification systems that emphasize the core value and special characteristics of the ecological community.
8. Establishing long-term partnership relationships with business and different government agencies to build useful cooperation relationship that can help promote and maintain the ecological community

6. CONCLUSION

This study presents a planning and marketing approach for promoting ecological communities. Through empirical study of the pilot ecological community project in Tainan of Taiwan, the result shows that successful implementation of the ecological community concept will require an integrated and comprehensive marketing approach, including identifying the core values and the target market of the proposed ecological communities, packing an attractive the product mix of ecological communities, finding a suitable market positioning, preparing a financial study of the relationship between the project costs and the supply of green infrastructure and facilities, and developing a complete set of marketing strategies.

By incorporating research methods including interviews, field survey, and questionnaire survey, this study finds that the demand of the facilities and services of ecological communities is related to the household income and the values of ecological communities perceived by homebuyers. Therefore, marketing the benefits and the key values of ecological communities to the potential eco-housing homebuyers and the general public should be an important task. Based on the empirical study, this study identifies the product mix of ecological communities and suggested a complete set of marketing strategies for promoting them. Ecological community cannot be developed overnight; promoting the values and concepts of ecological community and creating a positive and attractive image of ecological communities through the help of marketing approach could be a good start.

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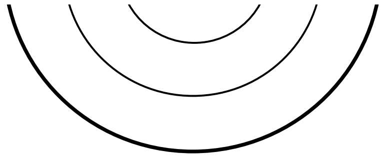

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2. Preparation of Manuscripts

2.1 Fonts and Formatting

As you read these guidelines, please refer to the sample layout at the end of this document. Place all text, figures, and tables within an area measuring 170 mm wide and 240 mm high. On A4-size paper (210 mm x 297 mm), this is equivalent to left and right margins of 20 mm and top and bottom margins of 25 mm.

Do not number the pages; the organizer will arrange the page numbering later. Use only the fonts (typefaces), character point sizes, and line spacing specified in the subsections below. ***Do not use any font other than Arial***. Do not use characters from two-byte character sets such as Chinese, Japanese or Korean. For special characters such as Greek letters, use symbol fonts.

For numerical expressions, we recommend that you use the Equation Editor tool included with Microsoft Word or MathType (Design Science, Inc.). Unless indicated otherwise, use single line spacing (10-point) for all paragraphs, noting the number of blank lines to be inserted between the main elements of the paper.

We suggest that you use the Microsoft Word template file provided. It contains pre-formatted styles for each of the components of the paper. If you apply these styles to the respective components of your paper, it will be formatted automatically according to these guidelines.

The names of the styles to be applied to each component of the paper are indicated in the formatting instructions below.

2.2 First Page

On the first page, include the title, information about the authors, the keywords, and the summary. The Title (11-point Arial bold, all capital letters, centered, style name “Title”) should be a maximum of 25 English words, without any abbreviations. Please use the same title used for the abstract you submitted previously. Leave two blank lines after the title (10-point Arial, style name “Body Text”).

List each Author on separate lines with the given name(s) followed by the FAMILY NAME (10-point Arial, centered, style name “Author”). ***Indicate the speaker’s name only in bold*** (style name “Speaker”). Append a superscript footnote number after each author’s name that will be linked to the author’s affiliation. Leave one blank line after the authors’ names (10-point Arial, style name “Body Text”). List the authors’ Affiliations comprising the academic or institutional/company affiliation, city and country followed by e-mail address (10-point Arial, flush left, style name “Affiliation”). Do not include mailing address and telephone or facsimile numbers. Start each affiliation on a new line, preceded by the superscript footnote number linked to the author’s name. Leave two blank lines after the last affiliation (10-point Arial, style name “Body Text”).

Choose up to eight Keywords from your paper and list them as shown in the template file, separating each word with a comma and single space (10-point Arial, style name “Body Text”). Insert two blank lines after the list of keywords.

Begin the Summary with a level-1 heading (11-point Arial, bold, flush left, 11-point line spacing, style name “Heading 1”). Insert one blank line (5-point line spacing) after the heading (this space is automatically inserted when the style “Heading 1” is applied). The body of the Summary (10-point Arial, flush left, style name “Body Text”) should total about 200 words in English. Insert one blank line (5-point line spacing) between paragraphs in the body of the Summary. (This space is automatically inserted when the style “Body Text” is applied to the preceding paragraph.) Do not indent the first line of any paragraph.

2.3 Full Text of the Manuscript

Follow the summary with the **Full Text** of your paper (10-point Arial, flush left, style name “Body Text”). Insert one blank line (5-point line spacing) between paragraphs in the body of the Abstract. (This space is automatically inserted when the style “Body Text” is applied to the preceding paragraph.) Do not indent the first line of any paragraph.

2.4 Headings

Limit headings to three levels and number them according to the decimal system when appropriate.

2.4.1 Main heading: **1. Heading Level 1** (11-point Arial, bold, flush left, 11-point line spacing, 10-mm hanging indent, style name “Heading 1”). Capitalize the first letter of all major words.

2.4.2 Subheading: **2.1 Heading Level 2** (10-point Arial, bold, flush left, 10-point line spacing, 10-mm hanging indent, style name “Heading 2”). Capitalize the first letter of all major words.

2.4.3 Third-level heading: 1.1.1 Heading level 3 (10-point Arial, flush left, 10-point line spacing, 10-mm hanging indent, style name “Heading 3”). Capitalize the first letter of the first word.

Insert a single blank line (10-point line spacing) before all headings (the three heading styles provide this space automatically). Insert a half-space blank line (5-point line spacing) between all headings and the text, graphic or table that follows. Position heading numbers flush left, followed by a tab and the text indented 10 mm. To avoid leaving a heading stranded at the bottom of a page, force the heading to the top of the following page by inserting a blank line.

If you apply the styles provided, all these formatting requirements are provided automatically.

2.5 Graphics (Drawings and Photographs) and Tables

Insert graphs, line drawings, and photographs into the finished document as digital objects. Use a resolution of at least 300 x 300 dpi (dots per inch) for photographs and drawings. Center the figure on the page, placing it as close as possible to the text in which it is mentioned; do not append figures at the end of your paper.

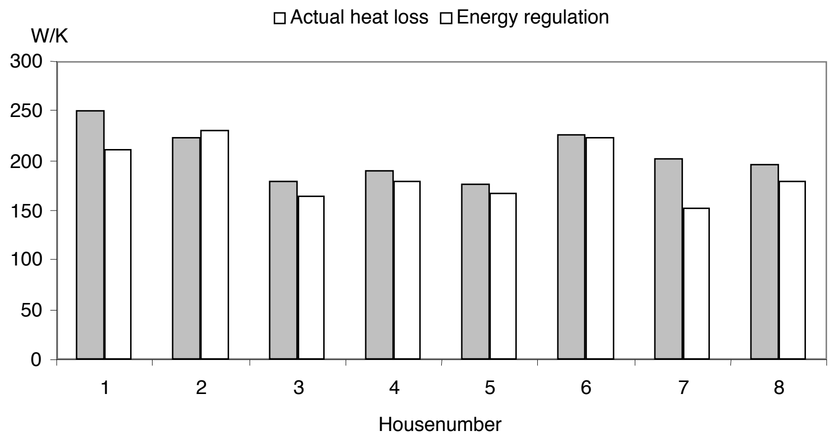

Figure 1 Comparison between actual heat loss and maximum allowed heat loss in 8 Norwegian log houses.

Provide a figure number (in consecutive Arabic numerals) and caption below each figure and photograph. For the captions of figures and tables, use 10-point Arial italic with 10-point line spacing (style name "Caption"). To ensure legibility, do not use point sizes smaller than 8 points for text appearing within figures and tables. See the sample layout at the end of this document.

Provide a table number (in Arabic numerals) and caption centered above the table (10-point Arial, centered, 10-point line spacing, style name "Table number"). ***Avoid vertical lines in tables where possible***. See the sample layout below. For ease of file transfer, use compact formats for images. The following image has satisfactory resolution in jpeg format (137 KB).

Table 3 Results for Axial Load

Yield Line Number	Normal BM (Nmm)	Yield Line Length (mm)
1	-13.793	5.771
2	-25.058	11.660
3	-18.315	11.832
4	-10.334	11.813
5	-4.335	11.638

2.2.2 Heading Level 3

Use the equation editor (integrated within Microsoft Word) to insert equations as text wherever possible. Alternatively, insert equations as images. When using the Windows platform, apply either Arial or Symbol fonts in equations; when using the Macintosh platform, apply Times, Helvetica or Symbol fonts. Reference each equation with a number in parentheses at the right margin of each equation. Insert one blank 10-point line (style name "Body Text") above and below each equation. See the sample layout below.

$$w = \frac{M}{Q}\left\{\frac{\sin\left[k\left(h-x\right)\right]}{\sin\left(kh\right)} + \frac{x}{h} - 1\right\}$$
(1)

2.7 Units

Use SI units exclusively. Indicate decimal locations with a period; do not use a comma.

2.8 Using References

List references in the text according to the author-date method. When the author reference is a natural part of the sentence, you can indicate the reference as follows:

Nørstrud (1990) described a similar format which was used for the second Symposium on Building Physics in the Nordic Countries.

When a paper has many authors, mention only the principal author followed by "et al." instead of listing them all. If an author appears in the reference list with different publications from the same year, the publication years may be modified as follows: 1990a, 1990b, etc.

Append a list of references (note: no heading number is used) to the end of the document. Authors are listed alphabetically with the first author's surname and initials followed by the initials and surnames of co-authors. Authors' names are separated by a comma except for the last two authors' names, which are separated by "and." Include all authors in the reference list. The year of publication follows the authors' names, followed by the title of the article, paper, book or report and either the name of the periodical in which the article is printed, the name of the conference and location at which the paper was presented, or the name of the publisher or the institution behind the publication. If the reference is to a monograph, indicate the title in italics. If the reference is to an article in a periodical, indicate the name of that periodical in italics. Complete the reference to periodicals with volume and page numbers. Also indicate the editors of conference proceedings. Use a full stop to separate all entries used to describe a reference. Format the reference list as body text (style name "Body Text"), inserting a blank line between each entry in the reference list (provided automatically if the style is used).

An example of a reference listing is provided below.

References

Gann, D.M. 1996, Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan. *Construction Management and Economics*, 14, pp. 437- 50.

Yashiro, T. 1998, Localization of industrialized construction method for blocks of flats. In Proceedings of the Sixth East Asia-Pacific Conference on Structural Engineering & Construction, National Taiwan University, pp. 1029-34.

Yashiro, T. 1999, 'International uncertainty' for procurement of innovative technology in construction projects. In Ogunlana, S. (ed.), *Profitable Partnering in Construction Procurement*, E & FN Spon, pp. 419-28.

Appendix A. Submission Guidelines

You may submit your paper via email to SB08papers@asnevents.net.au between 02 January 2008 and 30 March 2008. If you want to revise the file after you have submitted it to our website, you can do so by re-submitting the file (with the same name) to the same address *before* 20 March 2008.

Submit your paper as a Portable Document Format (.pdf) file. Note that Microsoft Word does not make this conversion, but will direct you to third party software to make the conversion. Name your file "SB" followed by your abstract number (one to four digits) followed by the file extension ".pdf". For example, given the abstract number "1024", you would name your file as follows:

SB1024.pdf

Please note the file size must not exceed 1 MB.

When creating your PDF file, please do not include any characters from two-byte character sets such as Japanese, Korean, or Chinese. You may embed all fonts in your file. When using Acrobat Distiller, select "Print Optimize" or "Print" in the job option. Check the status of the fonts with Acrobat or Acrobat Reader as follows: Open the PDF file with

Acrobat and choose "File" –> "Document Properties" –> "Fonts" to display the list of embedded fonts.

We recommend that you print your PDF file to confirm the quality of the PDF conversion.

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MILDURA RIVER HOUSE: PERFORMANCE A "LUXURY" SUSTAINABLE HOME

Luke MIDDLETON[1]

[1] EME Group, Middle Park, Melbourne, Australia, luke@emegroup.com.au

Oral presentation preferred

Keywords: sustainable housing, thermal performance measurement, thermal performance computer modelling, thermal mass vs. insulation

Abstract

This is a twelve month monitoring project; this paper will present the first five months of measured data of environmental conditions in new luxury home and compare this with computer simulated predictions of two types of software: the housing industry standard rating tool, First Rate and the more sophisticated modelling software EnergyPlus.

The aim for this house is to reduce energy consumption by at least 50%, improve air quality and provide significant reductions in mains water usage. The premise is that intelligent efficiency is holistic focusing on an interaction between site, people, landscape, building envelope, seasons, activities and orientation. Ecological sustainability can only succeed when underpinned by an active participation with these systems, and this project sets out to encourage and make this participation convenient and enjoyable.

This project addresses the challenge of achieving sustainable function in a 'luxury' home. This is a timely opportunity as more people aspire to the costly environmental qualities of size and grandeur. This project is a symbiosis of sustainable design with a luxurious living, underpinned by embedded environmental design components including: in ground Labyrinth cooling with night heat purging, insulated and non insulated rammed earth walls and low e double glazing with strategic window positioning.

This paper illustrates two major issues when using energy modelling software. Firstly, regarding the 'FirstRate' software, the actual building performance is significantly better than what was predicted by the software, which rated it as 5.5 Star. Secondly, regarding the more sophisticated simulation software EnergyPlus, the actual performance still outstrips the predictions.

1. Introduce project

The project is located in the township of Mildura on the banks of the Murray River. The climate is semiarid, experiencing large fluctuations between day and night time temperatures. In summer the temperatures can reach in excess of 42C, whilst in winter sub-zero temperatures are experienced overnight. On average throughout the year the night time temperature can be 15-20C below the day time temperature. (figures obtained from Special Services Unit of the Bureau of Metrology)

The clients brief was heavily steeped in Asian aesthetics and Feng Shui principles. A report prepared by a local Feng Shui consultant stipulated in detail the location and orientation of functions throughout the home. The obvious appeal of Murray River views were also a priority of the client. This required expansive views to the east thereby necessitating large areas of glass along the east elevation.

The design response was to provide large framed views to the east, reducing the area of window to less than 60%. Generous glazing was provided to the northern end of the building. Western and southern facades are massive insulated rammed earth walls with minimal glazing. Internally the public and private spaces were divided with a long rammed earth wall running north south, providing good internal thermal mass (^).

Other integral design components include, roof profiled to improve heat stratification, Labyrinth cooling with night heat purging, landscape design to provide mediation zones and shading, low energy diffuse lighting throughout and Rain water harvesting

Figure 1 Mildura House

1.1 Aims of the paper

This paper will present the performance of the home over five months. These results will be compared with the results predicted by computer modelling software. The paper will compare two types of computer simulation evaluation software, First Rate and Energy Plus with the actual performance of the home.

The aim is to demonstrate the limitations of computer simulated thermal performance for a luxury home with a creative non-typical design located in a semi arid climate. In particular, the performance of the various thermal mass objects, the labyrinth cooling system and thermal stratification.

With the advent of increased regulation regarding the performance of buildings, namely 5 star energy ratings in the instance of housing, there has been and will continue to be a significant growth in the use of computer modelling software. For real reductions in housing energy consumption it is essential to continually test against the actual performance of homes. This paper adds to previous research in this area such as the monitoring of the Ecohome at Cairnlea estate Melbourne between June 2004 and May 2005 prior to its occupation. The results of this research will assist in the improved understanding the computer climatic modelling software, it's benefits and limitations. Without this vital auditing process inefficient homes and cities will continue to be built.

Furthermore, this research focuses on creative non-standard design solutions that cannot be realistically and fairly assessed by industry standard rating tools.

2. Data collection

2.1 Physical Monitoring

Sensors were obtained from Cornerstone Technologies and programmed to take temperature and humidity readings at half hour intervals.

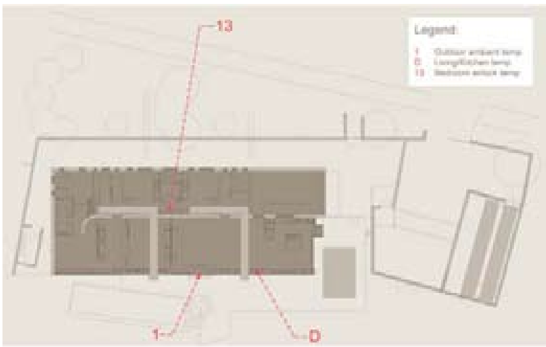

Figure 2 Sensor locations

Half hourly measurements of temperature and humidity were obtained at strategic locations. Internally two sensors monitored the air temperature and humidity. As can be observed in Fig. 2, Logger D was located within the living space on the eastern wall to represent the peak temperatures that would be likely to be experienced within the space due to the large windows in the vicinity. Logger 13 was located in the predicted coolest zone of the house in-between the guest bedrooms. This zone has minimal glazing and is surrounded by the thermal mass of rammed earth walls. Sensor 1 was located outside above the bay window (2.6m metres above floor height).

LOGGER GENERAL SPECIFICATION

Center 340 thermorecorder -

Measurement Range: -30°C ~ 70°C ; -22°F ~ 158°F

Response time: 20minutes to 95% under slow air.

Accuracy: ±0.7°C(± 1.3°F)

Resolution: 0.1°C / 0.1°F

2.2 FirstRate software

The house energy rating is the method used to measure the energy efficiency of a house.

The house energy rating measures the energy efficiency of a house by allocating a point score to each element of the house e.g. floors, walls, windows, etc. and provides an overall rating on a scale from 0 to 6 stars, with half star increments.

An energy efficient house rates 5 stars or higher. The house energy rating is independent of the size and type of housing. This means that large and small houses, attached and detached dwellings each have the potential to achieve a good energy efficiency rating.

2.3 EnergyPlus software

The building was modelled in ECOTECT and outputted to EnergyPlus.

The model was constructed from detailed plans and elevations of the finished home. All as built materials were included in the model, including actual configuration of floor, wall and ceiling insulation, construction materials, window frames and double glazing units. The surrounding landscaping including significant river red gum trees to the east were modelled to emulate the shading of the building that occurs.

The Labyrinth Night Purge Cooling system was added in Energy Plus.

3. Results

3.1 Physical Monitoring

The results contained in this report are for the period 16 October 2007 until 26 March 2008. During the five month testing period the house was vacant during the period 10th - 25th November and 13th - 30th January.

The occupants were pleased with the comport levels for the majority of the time. During prolonged heatwave periods the backup air-conditioning system was used. Over the 162 day period of monitoring the backup air-conditioning was required for less than 6 percent of the time the building was occupied.

This summer period was unusually hot and there was one period of six consecutive days and another period of eight consecutive days with day time temperature reaching 40+ degrees Celsius (refer figure 3 and 4).

3.2 First Rate

The building was rated by Gary Kruithof of Dynamic Design. It achieved a 5.5 star rating with a score of 14 points including a deduction of 4 points from the Area Adjustment. The rating assumed Climate Zone 27. The winter score was 32, whilst for summer it scored -14.

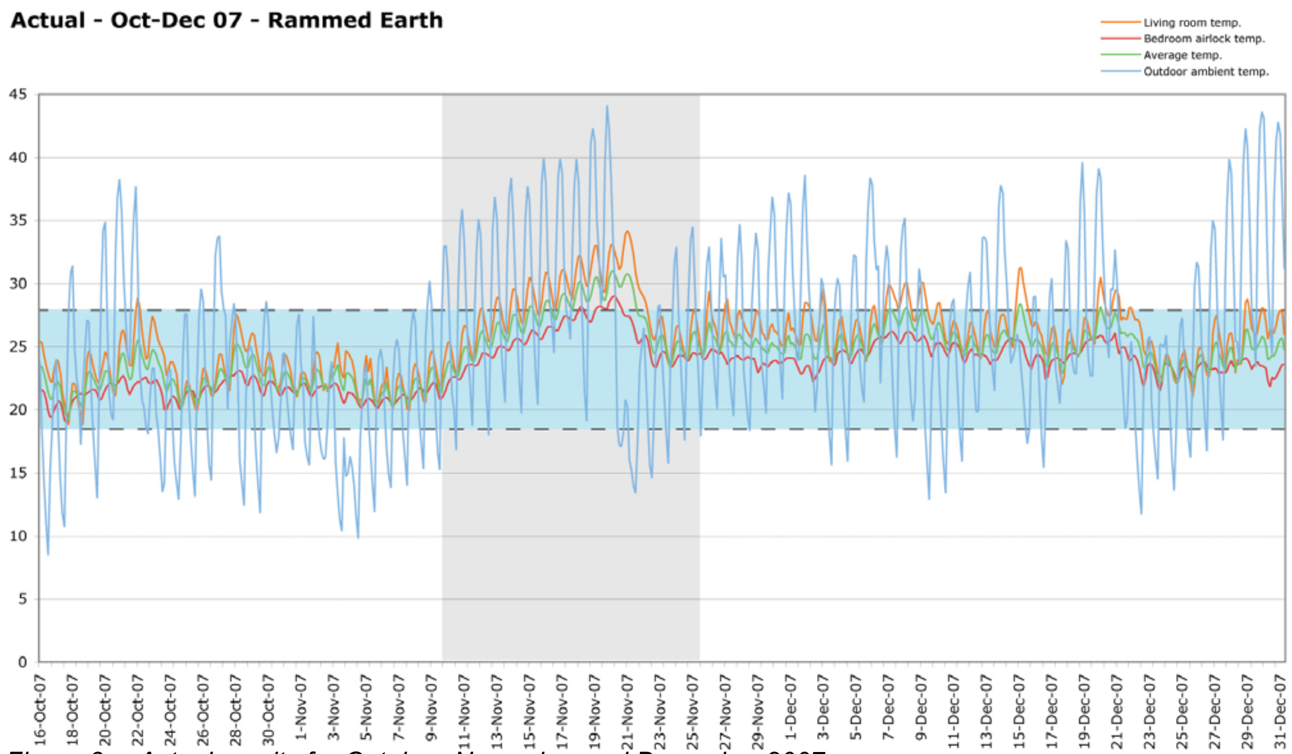

Figure 3 Actual results for October, November and December 2007

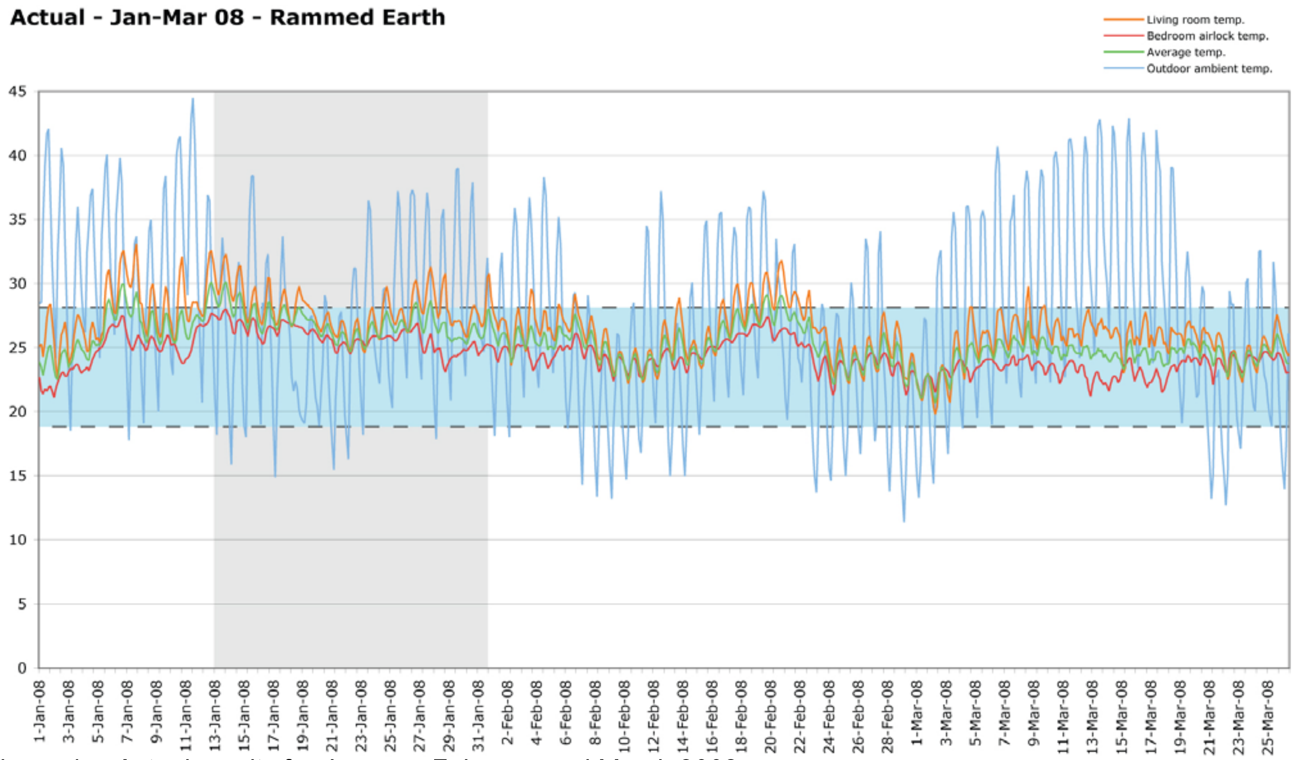

Figure 4 Actual results for January, February and March 2008

3.3 Energy Plus

The EnergyPlus results predict that the building significantly mediates the extreme outdoor temperatures providing a comfortable environment for the majority of the summer months (refer figure 5 and 6). It can be seen in figure 5 and 6 that consecutive hot days and warm nights force the internal temperature up as the thermal mass has no chance of purging heat energy.

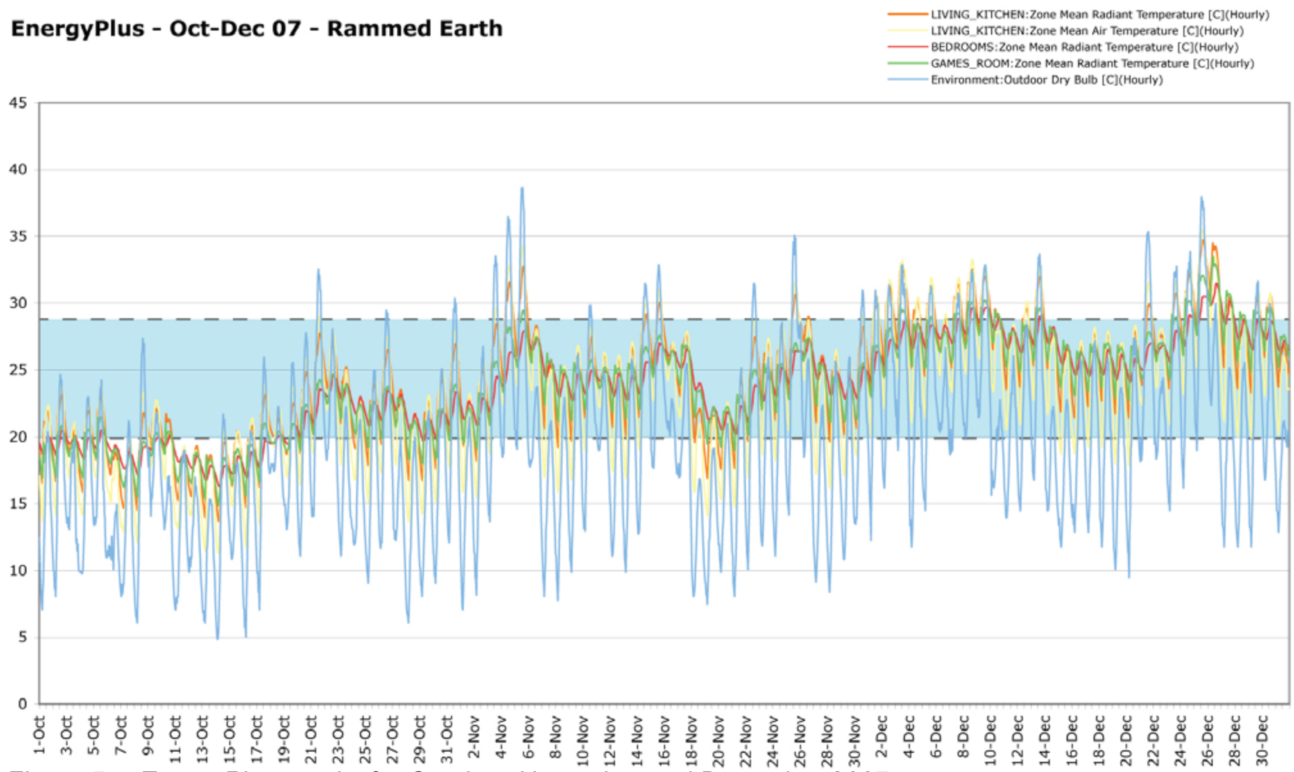

Figure 5 EnergyPlus results for October, November and December 2007

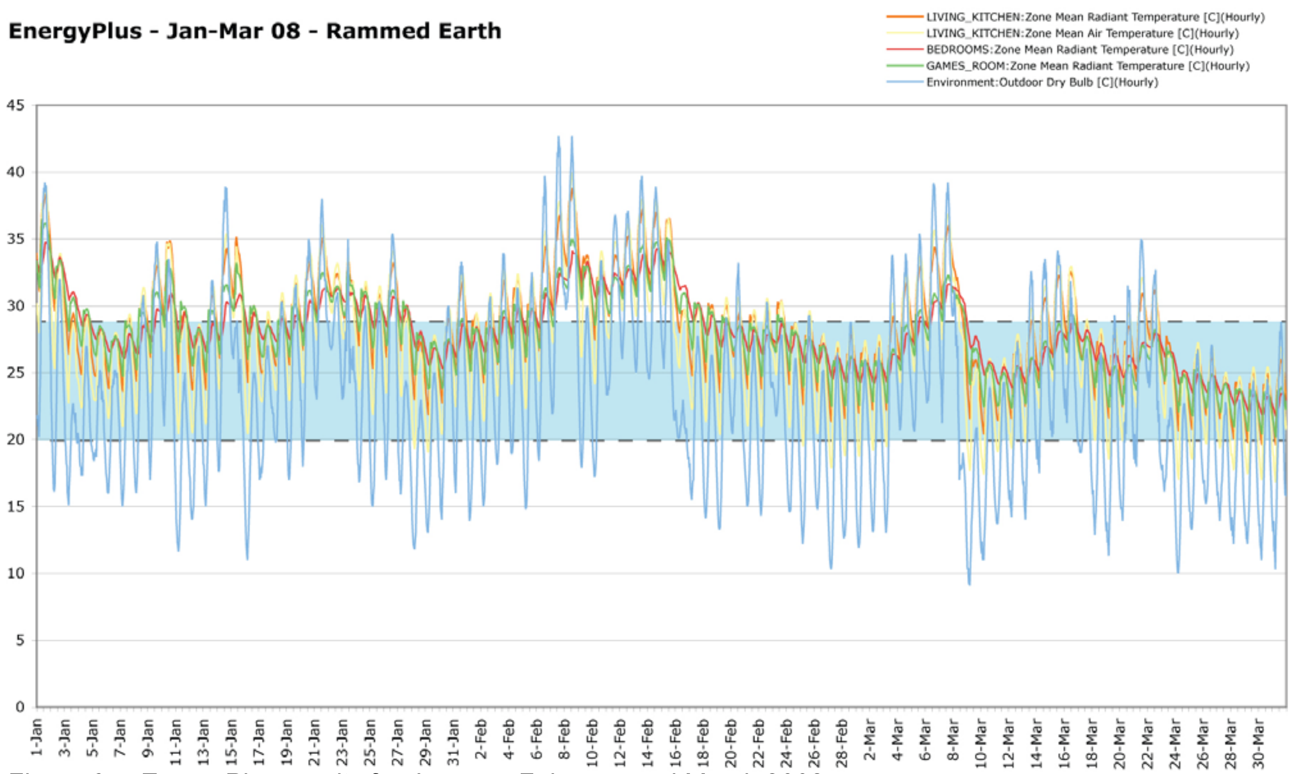

Figure 6 EnergyPlus results for January, February and March 2008

4. Discussion

The results clearly illustrate that the building performs better than the EnergyPlus modelling. Further it is obvious that the FirstRate software vastly under estimated the thermal performance of this home. Especially if you consider it's performance against the Ecohome at Cairnlea estate Melbourne.

4.1 Analysis of results

During the October period the actual outside ambient temperatures, seen in Fig. 3, were on average 5 degrees higher than the weather file inputs for the EnergyPlus model that can be observed in Fig. 5. Despite this, the measured internal temperatures remained within the comfort range. The EnergyPlus model predicted greater day to night temperature fluctuations and higher peak temperatures than actually occurred. During October there was no backup air-conditioning used.

A comparison of Fig. 3 and Fig. 5 also shows the simulated and actual results for November. For the majority of November the house was unoccupied and no night purging occurred. It can be observed that from the 13^{th}-16^{th} the increase in outdoor temperature triggered a steady rise in the internal temperature as there was no chance for thermal mass to cool through night purging.

The EnergyPlus model, in Fig. 5, provides for night time purging with the labyrinth from 8pm to 6am. When a period of similar outdoor temperature, is compared with the actual results it can be observed that despite the provision of night purging, the simulated indoor temperatures are higher than those observed in the actual results. For instance in the simulated results when the temperature rose to 36.5C outside the internal living room temperature was 31.6C whereas the actual results show that when the outside temp rose to 36.9 the internal living room temperature was 28.9C.

The results observed in December followed a similar pattern to October. Whilst the actual outdoor temperatures (Fig. 3) were far higher than the EnergyPlus weather file (Fig. 5), the internal temperatures were lower than were predicted by the computer model. It should be noted that during the excessive and prolonged heatwave experienced at the end of December the occupants utilised the backup air-conditioning. The air-conditioning thermostats are located within the guest bedroom precinct (i.e. the cooler part of the building) and were set at 25 degrees to provide a temperature of 26-7^{o}C in the living spaces.

4.2 Actual versus predicted comfort

It can be seen from these results that the passive systems provide a greater level of comfort than predicted by the modelling software. Within the zones surrounded by thermal mass day to night temperature fluctuations were reduced to less than 3 degrees (outdoor temperature fluctuation 20^{o}C). In the living spaces where the design criteria necessitated significant areas of glazing the internal temperature variants was generally limited to less than 5 degrees. By contrast, the EnergyPlus model predicted the living spaces to fluctuate by up to 7.5 degrees.

Actual results show that during the majority of the monitoring period the temperature remained within comfort levels. The most significant increases occurred during periods when the house was unoccupied when no night purging occurred or on consecutive days of extreme heat where the temperature was over 35^{o}C for a prolonged period as in Fig. 4 from 2^{nd}-5^{th} and 15^{th}-19^{th} February. During some of these periods backup air conditioning was used to obtain comfortable indoor temperatures. In March Mildura experienced 16 days over 35^{o}C, 8 of which exceeded 40^{o}C, this is the longest period that backup air conditioning was required. It is important to note that whilst the temperature exceeded comfortable levels on some days it was still several degrees cooler than external temperatures. For instance Fig. 3 shows that on 15^{th} November when the outdoor temperature reached its maximum of 37.7^{o}C it was only 29.6^{o}C in the living room and only 25.5^{o}C in the bedroom. On 16^{th} when the outdoor temperature reached its maximum of 40^{o}C it was 30^{o}C in the living room and 26.6^{o}C in the bedroom.

The measured results include extended periods when the building was not occupied. It can be seen during these periods that the thermal mass gradually increased in temperature, as it had no chance to purge the heat energy at night. Even during these periods the actual results are far better than the predicted EnergyPlus results (which also included for the operation of the labyrinth for heat purging over night).

4.3 Advantages and limitations of EnergyPlus

The complex nature of algorithms within the simulating software provides far more data about what is contributing to the outputs, than could have been obtained by physical measurements.

For example the contributions to the temperature of a zone can be broken down into solar gain, ventilation gain, conduction/convection gains, ventilation and so on. Simulation provides useful design insight, as parameters can be varied one at a time and the corresponding change observed in the data output.

The hypothetical (simulated) results are reliant on the accuracy of the inputs. They are also limited by the algorithms, which are approximations of physical circumstances. In some cases the modelling software outputs are limited as they provide more general information. For example, the EnergyPlus outputs are limited to average temperatures within a zone as opposed to temperatures at a specific point within that zone.

The EnergyPlus software cannot attempt to predict the habits of occupation that could improve or inhibit the performance of the building.

4.4 Advantage and limitations of physical monitoring

The measured data represents the true, all-inclusive physics of the situation, including the physics of the sensors (accuracy, calibration, lag etc). It shows the true measurement at that time and represents everything that is going on, much of which is likely to be uncontrollable and often unknown.

The physical monitoring of air temperature and humidity within a room or zone can include logging devices at various locations with in a zone close to windows such as at the ceiling level and at occupation level to provide a better understanding of real comfort levels. (Unlike the Energy Plus results which have only average temperature outputs)

A sensor may provide distorted outputs due to unplanned circumstances such as sunlight directly hitting the sensor or a heat source such as a computer being placed near the sensor (although careful analysis of the figures combined with common sense should reveal such anomalies.

The sensors provide raw data according to temperature and not a breakdown of the energy sources such as solar radiation, radiant heat and shade air temperatures that make up the resultant temperature.

4.5 Comparative modelling

There is some correlation between the actual performance and energy plus output, so, to discover a further level of insight we modelled the same building in lightweight brick veneer construction, no labyrinth and single glazed comfort plus glass (rating the building as 5 star). The actual building has double glazing with one layer being low e. This exercise revealed a massive difference in the predicted energy consumption between the as built home (5.5 star) and the alternative modelled (5 star) (refer Table 1)

Table 1 Predicted Energy Consumption of Home as Built (5.5 star) versus Standard Brick Veneer Construction (5 star)

summary

	heating	cooling	total energy	
rammed earth	3,645,201	6,262,071	12,576,956	
lightweight w comfort plus clear glass	10,417,755	11,850,640	22,268,395	
saving in energy	7,051,662	4,056,098	11,107,759	watt hours per year
percentage reduction in energy	293.5%	145.4%	188.3%	
saving in energy with earth tube		4,398,410		watts per yr

5. Conclusions

It is clear from the measured results that the computer modelling of passive building design has significant limitations. The effectiveness of thermal mass and insulated thermal mass does not seem to be accessed effectively by First Rate and even the more detailed modelling capacity of EnergyPlus does not accurately predict the actual performance of this home.

Moving beyond the success of this project, the ongoing monitoring aims to inform and improve the occupants' operation of the building. With more detailed understanding of specific temperatures throughout the house and within the labyrinth and rammed earth walls, the occupant can make informed decisions about the opening and closing of windows and the operation of the labyrinth duct system. From a design point of view these results are invaluable in consolidation of the original principles and will provide information to improve similar design approaches.

Further studies include: additional temp loggers to understand temperatures in and along labyrinth, temperature within the rammed earth wall versus surface temperature, and air temperature adjacent to better understand thermal lag and the effect of air temp versus solar radiant energy on the thermal mass, and internal temperature loggers at high and low level to better understand the effectiveness of heat stratification within the roof form.

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SUPPORTING DEVELOPMENT TOWARDS MORE SUSTAINABLE BUILDING: PERSPECTIVES ON THE DEMONSTRATION PROJECT AS A STRATEGY FOR CHANGE

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Summary

This paper explores the mechanism for development towards more sustainable building in Sweden. The proposed mechanism is based on a retrospective study of the evolution of more sustainable building practices during the last decades, with focus on the west of Sweden and using elements from theories on ecological modernisation as a way to understand change. The retrospective study presents actors, networks and important break-points. Three conceptual pairs have been used to discuss factors that make sustainable building practices progress: governance and learning, exemplifying and legitimising, and symbol and performance. It is argued that we might experience a shift towards governance and voluntary action developed through practical experiences. Catalysing successful demonstration projects lead the way, set up visions and goals and influence development of policy and regulation. The focus on energy efficiency has led to a broad acceptance with a rebound synergistic effect back to other building qualities. However, it is important to look beyond current achievements and to reconsider other important aspects of sustainable building: water and material issues, renewable energy and social issues.

1. Introduction

The aim for this paper is to contribute to a framework for understanding the evolution of sustainable building practices, and eventually to support these processes. The focus is on learning processes at a building project level and the system boundary is the building. The study underlines the importance of experiments and demonstrations for the development.

A tentative retrospective study of sustainable building practices in Sweden from the 1960s until today outlines important events, identifies actors and networks and recognizes institutional, societal, political and individual motivations to engage in more sustainable building. The study draws on the authors' personal experiences and their research on sustainable building in Sweden (e.g. Rubino, 2007, Eden 2008), on interviews with influential actors (Femenías, 2004), and on literature studies. Our theoretical framework draws on theories of innovation in construction (e.g. Fernie et al, 2005), ecological modernization (Fudge and Rowe, 2001; Jensen and Gram-Hanssen, 2008); and social theories (e.g. Guy and Shove, 2000). The study has a normative approach to sustainable building recognising environmental limits and natural carrying capacity, demand management, environmental efficiency as well as social welfare issues and equity (Fudge and Rowe, 2001). A systems approach provides an understanding of the continuous (exogenous and endogenous) processes of change and development. The study does not take a normative approach to ecological modernisation which is used as a means to understand change.

2. The Building Sector in Sustainable Development

The slow uptake of energy efficient measures has been discussed in Sweden (e.g. Nässén and Holmberg, 2005) and in other parts of the world (e.g. Lovins, 1992). These articles point to the potential for increased efficiency, although a gap still persists between what is achievable through best available practice, and that which is considered mainstream building practice. New technologies are available but are not adopted on a larger scale. The reasons behind this slow uptake are numerous and complex referring to widely differing factors from problems inherent in the organisation of work in the building sector, i.e. heterogeneous actors in unique project settings, to low-energy prices or contemporary non-sustainable architectural ideals. The perceived impression is that the sector is unable to handle the necessary changes and that change can only be through incentives and stronger regulation. However, it has become widely accepted that the implementation of sustainable building is not only a technical question but is also dependent on social acceptance and institutional factors (Guy and Shove, 2000; Jensen and Gram-Hanssen, 2008).

2.1 Reconstructing Building Practices

The building sector, in Sweden and other countries, has in recent years been in focus for general reconstruction programmes initiated by the perceived image of the sector as inefficient and reluctant to adapt to modern demands. It is interesting to observe that the sector was described in the same way in 1947. A document of that year, SOU 1947:7, states that the Swedish building sector is not investing in research and development by their own means and suggests governmental funding for building related research as this will have strategic importance for the society as a whole.

> Building activities produce mainly articles to be used during a very long time. It is therefore understandable that clients and contractors show some reluctance to try new and relatively unknown materials and methods, and prefer to proceed under known conditions and with known materials. Considering these foundations, the building industry could with good reason be characterized as one of the most conservative of industries.
> SOU, 1947:7, pp 10-11, (in Swedish, the above is the authors' translation from Swedish)

The above should be placed in a historical perspective. At the time of the establishment of the Royal Swedish Academy of Sciences in 1739, scientific research was focused on everyday practical implementations of results (www.kva.se). The development through the industrial revolution led to a distinct separation and in many cases antagonism between science and practice. Many of the epoch-making industries were the result of practical developments combined with good organisation and management. However, scientific research has since become increasingly important for industry. Early governmental investigations point to the problem of transferring laboratory results to practice, a process that will profit from small scale experiments and later full-scale tests before being diffused in practical implementations. Based on a neo-classical economy perspective of markets, the persistent idea has been that scientific results automatically will lead to innovation (e.g. TSERC, 1987). This instrumental approach to energy efficiency has not been efficient and is partly explained by the R&D chain in the building sector seldom being chronological or linear and that development is seldom triggered by science but through the search for solutions to problems in practice.

2.2 Ecological Modernization in Sweden

The Swedish government has since the late 1990s developed a policy framework based on ecological modernisation as a means to respond to environmental pressure and the need for a socio-economic revival (Fudge and Rowe, 2001). Ecological modernisation is described as a framework to explain increasing environmental considerations in society and the changes caused by these processes. Ecological modernisation is often linked to the mainstreaming of sustainable development based on continued economic growth and the use of environmental technology without fundamental changes to individual actions and beliefs. The concept can be a paradox as structural changes are argued to be necessary while only selective remedial measures are promoted (Hajer, 1995 quoted in Smith and Kern, 2007). Jensen and Gram-Hanssen (2008) see no link between ecological modernisation and models for weak or strong sustainability arguing that ecological modernisation can lead to either depending on the actual actors and processes.

Fudge and Rowe (2001) in their study of ecological modernisation in Sweden found this process to be mainly codified as environmental protection and that norms may favour unduly expert focused and even ‘technocratic’ paths to the pursuit of sustainable development. The industry has always been a key player in Sweden’s pursuit of sustainable development and the building sector has been given a key role in the aim to rebuild society for sustainable futures.

Fudge and Rowe (2001) refer to three major stages in the maturation of ecological modernization, which are recognized in Sweden although not chronological. The first stage focuses on technological innovation, a critical attitude towards the state, and a bias towards market solutions. The socio-economically successful economic expansion in the late 1980s and early 1990s had a strong technological and environmental drive. The second stage, from the late 1980s to the mid-1990s, took a more moderate view on technological innovation, the state, and the market instead emphasizing on institutional and cultural dynamics supported by the emergence of the ‘Brundtland report’ in 1987. The second stage has in Sweden found difficulties gaining support in the conservative and rather expert-led governmental institutions. In the third and current stage the debate has broadened to include the role of consumption and global processes, in which market dynamics and economic agents are increasingly important. At the same time the nation-state is transformed towards a more decentralised and consent style of governance. The third stage thinking, which can be identified in governmental aims and policies, has proved to have difficulties in practice. The relatively few enlightened individuals have not been able to catalyse the broader shift.

Similar critics of an overly technocratic ecological modernisation have been made in the Netherlands (Smith and Kern, 2007). What is now observed in the Netherlands is a transition discourse to reinvigorate ecological modernisation, a process based on a more reflexive approach that institutionalises processes for deliberative social choice between alternative scenarios of development. This transition approach combines long-term visions, policy learning, and adaptive governance. The transition discourse proposes: multi-stakeholder civic arenas for debate and progress towards sustainable socio-technical systems; practical niche elements for exploring potentials; institutions that promote social learning; and supportive policy development and innovation. The innovation model is based on evolutionary economics and perceived as more institutionally complex and varied and results less automatic, than in technology push-models. The transition approach has not managed to influence radical change and reinvigorate the Dutch ecological modernisation. Incremental reforms persist and older discourses seem solidified.

3. Reconstructing the ‘History of Sustainable Building’ in the West of Sweden

As a background to this tentative history of sustainable building the comparatively good quality of the Swedish building stock seen in an international perspective must not be underestimated, both in terms of environmental and social aspects. Already in the 1950s the Swedish building regulations prescribed 10 cm of insulation in outer walls. And when other European countries only just start to discover the advantage of exterior insulation of walls (instead of interior insulation) this had been praxis in Sweden for decades. Another example is car free housing areas which have been built in Sweden since the 1960s. Social perspectives on housing and living qualities for everybody has been studied and implemented through governmental policy and regulation since the 1930s as part of the ‘Folkhems’ project of making Sweden a modern state.

3.1 The 1960s – The Seeds

The environmental movement of the 1960s can be linked to the social movements of the era. The publication of Rachel Carson’s book *Silent spring* in 1962 is widely accredited to be one of the starting points of the environmental movement in western countries.

Nature as source of inspiration in architectural design and vernacular building traditions can be traced back long in history. Architects such as Frank Lloyd Wright have been renowned for their environmental inspiration. However, the claim that all good architectural design is essentially ecological has been proven weak if implemented as the single strategy to achieve a resource efficient design. Still, these ideas of an environmental architecture taught to architect students in Sweden in the 1960s are the seeds of current development (Interview with Hans Eek, 2001 – the architect of Sweden’s first passive housing and founder of The Passive House Centre in Sweden).

3.2 The 1970s – The Experimental Era

The 1970s were marked by the oil crises resulting in a broad awakening for energy issues. In Sweden, the energy crises led to massive governmental campaigns which aimed for oil independence and resulted in strengthened building regulation, subsidies, and low interest loans for up-grading of building envelopes. National programmes funded experiments and demonstration projects for developing energy efficient building and renewable energy technology. The strategy was to replace oil mainly with electricity (direct heating in buildings) or nuclear power (for district heating). The decision to invest in and continue to use nuclear power is still debated.

The period is usually described as an era of experimentation. Inspired by developments in USA, France and Germany., Swedish pioneering architects became involved in low-energy building, solar buildings and in socially responsible architecture. Experiments received finance through national programmes but they were also the result of individual investments. One of the pioneers at the time, Hans Eek made important experiences in Mrs Henriksson's house. Mrs Henriksson decided to support the development of ecological building by asking Hans Eek to design a highly experimental private house. Mrs Henriksson's house was very unsuccessful – the many and untried technical solutions never worked. Hans Eek says that the main problem was the architect behaving as a miserable engineer.

In 1972, the first and pioneering UN conference on human environment was held in Stockholm. The conference laid the framework for future international cooperation on environmental issues. In the summer of 1976 an influential exposition was held in Stockholm. The ARARAT (Alternative Research in Architecture, Resources, Art and Technology) exposition, organized by a group of architects, displayed and discussed alternative technologies and ecological housing experiments.

3.3 The 1980s – The Transition Era

The early 1980s experienced a backlash for the broader interest in low-energy building and renewable energy caused by an economic downturn and the election of conservative governments in many countries. A reduction in demand and an overproduction of oil also resulted in falling energy prices. In the US, Jimmy Carter was succeeded by Ronald Reagan who basically stopped the experimental era in low-energy technology. In 1987, the publication of the Brundtland report re-launched the politically driven development and contributed to a wider use of the concept of sustainable development as a new approach to environmental policy. The key was to link environmental concern with socio-economic development and this opened the door to the coming transition from low-energy to sustainable buildings.

The Swedish Government continued to invest in experimental and demonstration programmes for energy efficient building concepts in the 1980s. The well-known Stockholm project involved the construction and monitoring of some 200 apartments between 1983 and 1985 (Guy and Shove, 2000). The project provided exemplification through cases, but without any practical implications.

As a contrast to such mainstream and more realistic approaches, the grass-roots and pioneers of the 1980s contributed to the emergence of the Swedish eco-villages. In 1991 the Swedish National Board on Housing, Building and Planning made a definition of the concept eco-village stating the importance of local perspective, small scale, social aspects as well as an eco-cycle perspective on material and energy resources (e.g. www.ecoby.org). The eco-villages have a strong grass-roots perspective engaging the community in the realization of the project. The first eco-village built in Sweden was Tuggelite, completed in 1984. The eco-village can be seen as emerging from the collectivist movement of the 1960s and 1970s, as reactions against contemporary urban and semi-urban lifestyles (Jensen and Gram-Hanssen, 2008).The initiators of the first eco-villages experienced a lack of documented knowledge and practical experience which led to problems. Several Swedish eco-villages has reported high energy use but claimed other less tangible qualities such as every-day aesthetics and strong social networks.

The Swedish National Housing Exhibition, Bo85, opened in 1985. Inspired by ecological influences of the time Bo85 promoted individual conservatories, combining passive energy and social space. However, this resulted in poor energy efficiency. In 1987, an important experiment with air-solar collectors was completed in Göteborg (architect Christer Nordström), in the refurbishment of a housing block from the 1950s. The project showed good results in terms of reduced energy use and important experiences were made connected to the social benefit of a collective green house attached to the house, but not part of the energy system. The project remained a one-off project partly due to the reorganisation of the public housing company.

During the 1980s the sick building syndrome highlighted the problems of building materials with emissions to the indoor environment and the problem with ineffective ventilation which probably contributed to the increased interest in naturally ventilated and ecological buildings.

3.4 The 1990s – The Eco-Cycle Era

The 1990s marked a broader awakening to environmental issues and ecology. The Rio de Janeiro Earth Summit 1992 and the resulting Agenda 21 document led to a shift from ecological building to sustainable building, which has proved to be a more broadly acceptable concept, turning to resource efficient technological solutions and not primarily life-style changes. During this decade environmental issues gradually became institutionalised and part of the daily routines in Swedish construction through voluntary environmental management systems and through deregulation of construction. Larger architectural offices, developers and contractors built up in-house environmental expertise. Some measures, such as waste separation, became praxis.

In the 1990s new examples of ecological building emerged based on eco-cycle ideas for recycling of wastewater, the use of locally produced and natural materials, and an increasing interest in naturally ventilated buildings. The scale of the examples that are built is still single-buildings and housing but the decade also revealed an increasing interest in urban issues. A wave of naturally ventilated schools was initiated through the example of Fredkullaskolan built in 1992. In 1995, the eco-village Understenshöjden outside Stockholm was completed. The project received significant attention for its living qualities and aesthetics. Later the project was subject to a partly erroneous and biased accusation of large energy use and technical problems in the Swedish media (Gluch and Femenías, 2002). This was probably to be the last project where non-professional actors (the community) had the main influence in planning and realisation.

At the end of the decade a number of larger public housing companies and building contractors engaged in environmental issues and produced a number of demonstrational projects without great influence on mainstream practice. The projects mixed tested and untested technology, usually in relation to occupant behaviour. The lack of systematic thinking in briefing, planning and follow-up and the lack of performance indicators make those experiences difficult to systemise.

The Swedish Government has also invested in large demonstration programmes to stimulate environmental technology. The Local Investment Programme, 1998 – 2002, supported several retrofit projects of housing from the 1960s and 1970s in relation to socioeconomic regeneration of the areas. The results from these projects show good results in environmental terms and social sustainability with less vacancies and satisfied tenants. However, due to insufficient planning for learning, among professional actors and tenants, and diffusion of experiences the investments have not contributed to long-term change (Stenberg et al, forthcoming).

3.5 The Current Decade – The Passive House Era

The new decade has shown the continued legitimacy of sustainable building practices. An important feature of this evolution is the governmental initiative, Building-Living Dialogue a cooperation between leading private and public organisations with voluntarily agreements to take concrete measures for sustainable building and educational actions towards practitioners. A vision was established in 2000 with goals for reduced energy with at least 30% by 2025, goals for reduced use of fossil fuels, declaration of building materials and phasing out of chemicals.

In the early 2000s two larger flagship projects were built: Hammarby Sjöstad in Stockholm and Bo01 in Malmö, aiming at sustainable housing on brownfield close to the city centres. Although using programmes and assessment tools, the projects failed to reach high environmental performance although resulted in other lasting qualities, including a good urban design.

Recently a new upswing of the local development of sustainable building in Göteborg has occurred, with public-private investments and co-operation between research and practice. One example is Universeum, which is a science centre (completed in 2001) with innovative technology for cooling/heating. The project planning involved researchers and practitioners building local capacity for continued design. The spectrum of environmental measures in Universeum include urine-separating toilets, local wastewater treatment, renewable building materials and solar energy. Two projects in Göteborg (completed 2000 – 2001) have been of large national and international importance: First, the retrofitting of a housing area from the 1970s in Gårdsten, addressing social and environmental issues (design by Christer Nordström). The project has resulted in 40% less energy use and 30% less water use and socio-economic benefits, and received the World Habitat Award in 2005. Second, Sweden's first passive housing, a terrace housing project in Lindås (initiator Hans Eek). Measurements show that both projects approach the energy goals for 2025 set by the Building-Living Dialogue. The factors for success include committed clients, the early involvement of actors, education of all actors to understand set goals, cooperation with researchers, and the focus on performance, evaluation and dissemination of results. After a few years without follow-ups, the projects seem to be catalysts for the wave of interest in energy-efficiency and passive building methods which Sweden is experiencing today.

An on-going research project Demo04/06 at Chalmers University of Technology connects researchers and a network of professional actors involved in five local case studies with demonstration capacities. Demo04/06 provides an arena for mutual exchange and learning, on the one hand between practitioners and on the other hand between practitioners and researchers, and reaches beyond the arena boundaries. Two of the evolving cases connected to the arena develop the passive house concept. The Harbour house is a new multifamily housing project by a commercial developer owned by Göteborg municipality. The developer and all their consultants are engaged in the Building-Living Dialogue. Brogården in Alingsås, outside Göteborg, is a retrofit and regeneration project with social ambitions of housing from the 1970s. Important factors in that project is a strong political engagement in the municipality, an enlightened client, Hans Eek as consultant, and partnering contracts for involved actors. Both passive house concept projects have goals for energy use below those set up in the Building-Living Dialogue vision for 2025.

4. Discussion

Jensen and Gram-Hanssen (2008) in their study of sustainable building in Denmark base their discussion on three elements: governance (new types of cooperation and roles for actors), standardisation (use of standards, tools to define and legitimize) and visibility (measurement of energy and material flows). Governance and visibility can be traced as important elements in ecological modernization processes. The authors define standardization as a central concept for construction and for the modernisation of processes in general. Based on our retrospective study, we have found three pairs of elements important to the Swedish development: first, governance and learning; second, exemplifying and legitimising; third, symbol and performance.

4.1 Governance and Learning

The study shows that development of sustainable building in Sweden has a strong basis in bottom-up activities even though with time these activities have benefited from government support. It is the individual project and the learning produced by practice that has pushed development forward. Seen in a wider perspective than that of immediate commercial success, the contribution of earlier projects to the development, although often unsuccessful as individual projects, cannot be underestimated. Later years show a clear shift from government driven processes towards market led governance for change. Important thresholds have been reached through the intensified focus on energy efficiency and the success of contemporary demonstration projects which has legitimised the interest in sustainable building practices.

Some elements inherent in a reflexive ecological modernisation described as transition (Smith and Kerr, 2007) can be observed in recent development in Sweden with voluntary agreements and multi-stakeholder arenas for exchange and progress. It could be discussed if the strong reliance on government actions in earlier decades created dependence and a weakened innovative force. Further studies will be needed to see if the current development will manage to overcome commercial competition and sustain a self-supporting evolution.

Experimental activities and demonstration projects have an important role in the development even though these investments could be more efficient. Evaluations of government support for earlier experiments and demonstrations claim positive advance in the accelerated introduction of new energy efficient technology although recognising deficiencies in explicit knowledge accumulation and dissemination (e.g TSERC, 1987). The transfer of results over organisation boundaries will also need a process of experimentation in which the external and explicit evolution of knowledge will have to be internalised by new actors and tested in a new context. However, the implementation gap, i.e. insignificant impact from demonstration projects on mainstream building practices, is more than a knowledge problem. There has often been an overestimation of the influence of key individuals and rational choice on decision-making. This overlooks the complexity and unpredictability of the implementation process and fails to provide reliable explanations regarding the relationship between practice, performance and context (Fernie *et al.,* 2006, Rubino, 2007).

4.2 Exemplifying and Legitimating

What this paper highlights is that sustainable building is defined through practice, through building projects. Contemporary successful commercial projects show what is possible and consequently legitimise those kinds of investments. New visions and goals for the advance of sustainable building are formulated in innovative projects, not in policies or through regulatory systems. Contemporary projects prove that considerably higher energy efficiency can be reached than is prescribed in current Swedish building regulations.

This retrospective study reveals different approaches to sustainable building. Even if different approaches, by different actors have been emphasized in different historical periods, these varying approaches co-exist at the same time. Jensen and Gram-Hanssen (2008) argue that the lack of a common definition of green building is not necessarily bad. Instead, a variety of approaches can be useful as it can motivate different kinds of actors and more easily adapt to differing project contexts. However, it could also be argued that these varying and sometimes competing approaches have impeded development as pioneers and more realistic actors have acted independently and have not wanted to learn from each other.

The study also point to the importance of emerging tools for legitimising more sustainable building practices, including building material declarations, environmental programmes, environmental policies and life cycle costing. Furthermore, the study reveals a shift from solution fixed and closed concepts of sustainable building towards function, quantitative performance and systems thinking. This is supported by a change in Swedish building regulation s from prescriptive solutions to system goals. The strong sense of place, local solutions, and homogenous and closed concepts in earlier examples has limited the broad transferability. This development also points to a shift from product issues to process issues recognising the importance of good quality process ingredients, i.e. the participation of a larger range of actors and stakeholders through all stages of a project in an integrated approach and the recognition of extra time for innovation, in the making of successful sustainable building. However, one should probably not overestimate the unduly positive outcome of a specific process or ideal design process.

4.3 Symbol and Performance

What can be considered as more sustainable building? The definition is evolving through time and as was discussed earlier it has to be defined in relation to normal praxis or norms in each national or regional context. In Sweden, some measures e.g. water-efficient appliances are normal procedures and do not have to be emphasised as part of sustainable building practices.

The importance of tangible dimensions of sustainable building has often been discussed, as a means to raise awareness that will lead to action (Guy and Shove, 2000; Jensen and Gram-Hanssen, 2008). Recently, the tangibility of sustainable building has gone from the often criticized symbolic attributes to performance indicators, a shift that has further supported the legitimacy of sustainable building. However, there are still problems connected to indicators such as kWh/m^2, and in the comparison between different locations (e.g. difficulties in delimiting flows or including household electricity use or not) and their accuracy to actually indicate sustainable development (e.g. in relation to the increasing space occupied per person). It has also been observed that individual measurement of energy as a means to stimulate lifestyle changes is not as effective as was planned as occupants experience difficulties in understanding the figures (Stenberg *et al*, forthcoming).

5. Concluding Remarks

This explorative study points to increasing governance in developing more sustainable building in Sweden and this may be an indication of a transition to a new phase in the ecological modernisation of Swedish building practices. The successful performance of contemporary low-energy buildings should not be seen as the ultimate goal of this development, we have to proceed beyond the passive house era. Energy, even though important, is not the only aspect of sustainable building. We see a need to reinvent and further study other important aspects of sustainable building such as water use, building materials, transport, renewable energies etc. as well as health, well-being and social issues linked to democracy and participation (Stenberg *et a*l, forthcoming) qualities in the built environment that are more difficult to assess, defend and motivate. Furthermore, the sector should be encouraged to innovate more, invest in experiments and demonstration to learn and establish new routines. The Government has to rethink their role in these processes, how they could support bottom-up initiatives and learn from them. Finally, the holistic approach in this study is motivated as sustainable building cannot be seen as one technology, which makes it more difficult to study but in fact responds to a complex reality.

6. Acknowledgements

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THE GREENEST BUILDING IN THE NETHERLANDS,
- NO EXTERNAL FUEL, ELECTRICITY, WATER OR SEWAGE

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Keywords: Integral design, self-sufficiency, fine wire heat exchangers, very low temperature heating, aquifer, seasonal heatstorage, parabolic multipurpose solar collectors, vacuum sewer

1. Abstract

Every decade the Dutch horticulture has a great exposition event, the 'Floriade'. The next Floriade 2012 will contain a greenhouse characterised by ergonomic office workplaces in a green surrounding. Normal offices are located within the greenhouse in different climates including particular vegetation.
This literally and environmentally greenest office is also the greenest building in the Netherlands, lacking public utilities, except ICT. The size of the building is 42,500 m2. A low glasshouse roof on the south side climbs up till six floors of office on the north side. Large parabolic solar collectors dominate the silhouette of the building. (Figure 1) The seasonal surplus of heat and cold from the solar power system is stored in the aquifer approximately 50 m beneath the building. The building is equipped with a heating system based on very low-temperatures (24-25˚C), enabled by fine wire heat exchangers recently invented. The cooling of the indoor climate in summer is based mainly on the same system. The vacuum sewer system and organic waste collection are aspects of ecological innovation. By means of an anaerobic bioreactor and a micro-turbine, electricity can be produced on location with addition of organic waste. The filtered exhaust gases are used as nutrients up till 1,000 ppm, in order to take care of the CO_2 balance. Pure water can be retained within this process, which takes two or three days. An important, little known aspect of the greenhouse/landscape office is the healthy work environment. It appears from research that houseplants have a surprisingly wholesome effect. We know the process of purifying the air of CO2 and producing O2 from the biology lessons, but reducing stress, skin irritations and headache are a little known contribution of plants to the improvement of the living environment. The parabolic solar collector roof construction is the most striking innovation.

Figure 1 Artist impression – The forest is reflected in the glass by the forward tilted glass north facade and thus camouflaging the height of the building. Parabolic solar collectoring are skyline from a far.

During a 24 hours period a new coating on mirrors enables the harvesting of boiling water and PV electricity on a sunny day and cold and condensing water by clear night sky. In a country of regulation the Dutch government needs to decide on the building permit for this building that will not be plugged into public utilities. The paper will discuss most issues related to the Floriade 2012 greenhouse.

2. Definition of a problem

The export of Dutch greenhouse horticulture products amounts to 7 billion euros a year. In the Netherlands greenhouse cultivation largely depends on natural gas. These greenhouses account for almost 10% of the national natural gas consumption. A greenhouse uses 50 m3 natural gas/m^2 year. With increasing environmental awareness and rising fuel prices new innovative methods had to be found. This paper presents the results of this innovation in horticulture translated integral design into a multipurpose greenhouse/office building. Office islands in the different climate zone with corresponding spheres have to adduce proof that working in glass and green is healthy and relaxing. The offices in the Middle East and the Amazone climate will have 'stand alone' climate working places.
Does the greenhouse/landscape office have any weak points then? Certainly, the metabolism of the sedentary human being and that of the plant is very different. So how do we make pleasant green workplaces in various climates? This is a very special problem, the biggest challenge of the greenest office.

3. Statement of requirement

The ambition of the initiator/client is the most important design factor of each building. Two clients design a spear point project to surprise the International Floriade visitor in the year 2012. A special program point was the greenhouse/office – healthy work places in the green as part of the 10,000 m^2 exhibition greenhouse on the ground floor. (Figure 2) The groundbreaking innovation of the recently developed "Zonneterp" Greenhouse Village was to serve as a footing – the beginning of the Edible City.

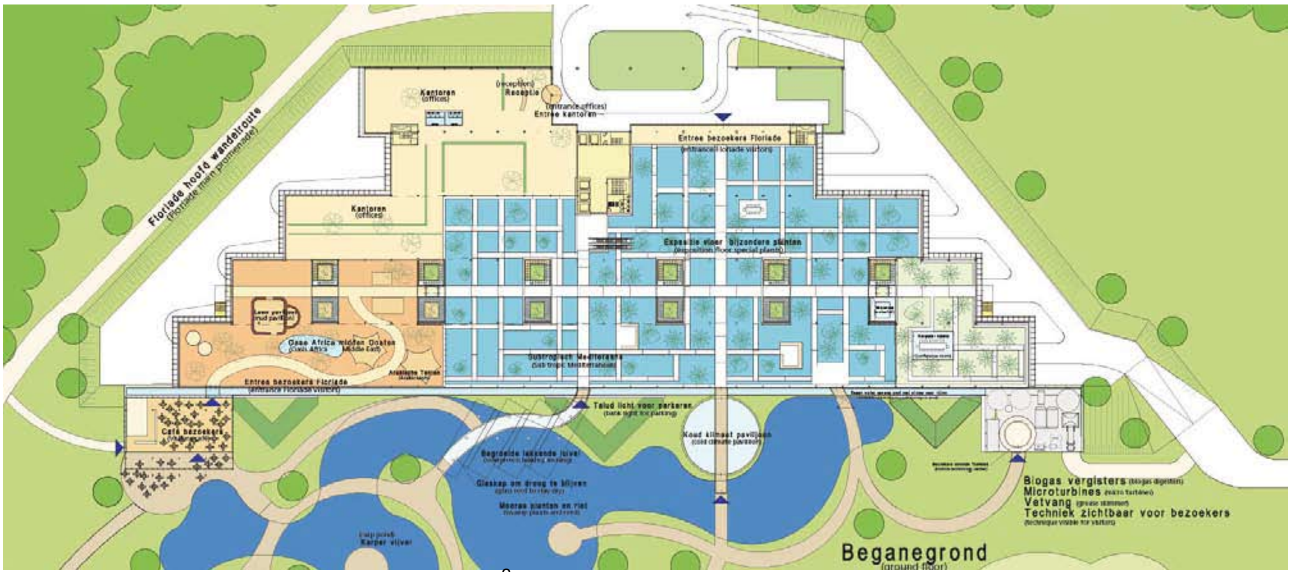

Figure 2 Floor plan – ground floor 15,50 m^2 with four indoor climates.

4. Integral design

Integral design is the lifting of all building functions with an added value by weaving into a permanent entity. In order to be able to elucidate in the space of eight pages "the greenest building", illustrations are more efficient than written text; a drawing tells more that a thousand words.

4.1. Location

The location is a natural environment (setting) close to the city of Venlo at a junction of two highways towards Germany and Belgium. This needs to become the "Genius Loci" of the Floriade. In addition, the invisible location-properties of the sand layers and groundwater are important for installing seasonal heat storage of 8 ˚ to 28˚C in the aquifer. (Figure 3)

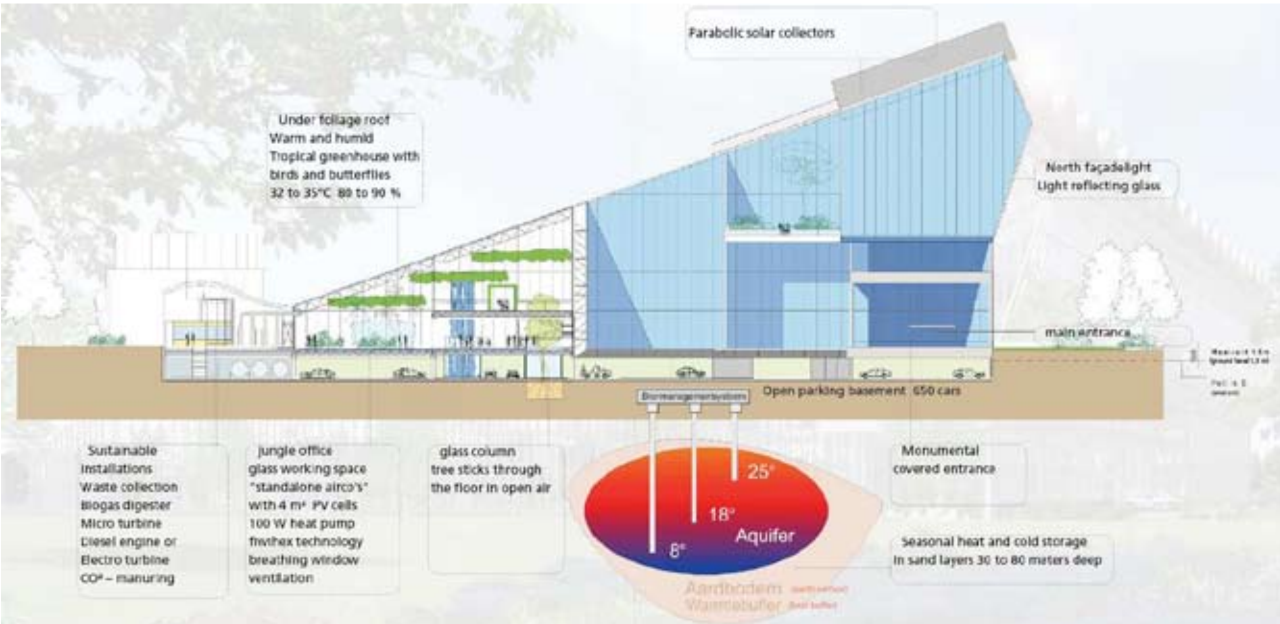

Figure 3 Section – installation – tropical zone – parking – aquifer = seasonal heat / cold storage

4.2 Energy self-sufficiency

The sun is the source of heat and the radiation at night towards the clear sky the cold source. The characteristic properties of sustainable installations are that they are based on the physics of the open country more than on mechanical engineering. New fine-wire-heat exchangers enable very low temperature heating and cooling within the closed greenhouse. Two fine-wire-heat exchangers have been developed; water/air and air/air heat exchangers.
The ø 1/10 mm copper wire is around 8 x as efficient as a plate heat exchanger. A greenhouse receives around 7x as much solar-energy heat as the thermal loss at night and in winter. Each greenhouse functions as a hothouse, and the closed greenhouse certainly functions as a solar collector, which needs to be cooled down by means of the aquifer.

Figure 4 Longitutional section 250 m

4.3 Parabolic solar collectors

Multifunctional parabolic solar collectors as supporting reflecting roof plates have a vertical solar collector for hot water of 70 to 80˚C in the bent focus of the parabola. (Figure 4 and 5) On this solar collector black thin-walled "Helianthus" pv-cells are pasted on both sides (1,20 m wide). The solar collector also cools down the pv-cells (max. 80˚C) that provide more electricity and promotes a longer, useful life span. By applying spectral selective coating on the mirrors, more IR (infrared) radiation can be achieved on clear nights. This yields more cold for the aquifer, but also condensation and glazed frost, i.e. drinking water and irrigation water in dry climates. A closed greenhouse requires little irrigation water.

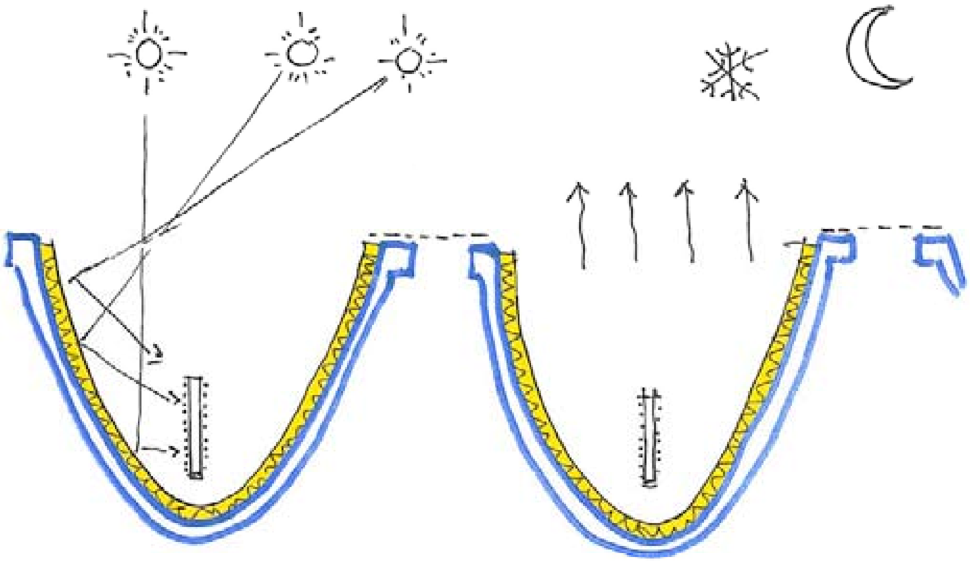

Figure 5 Schematic section parabolic solar collectors; deliver heat output during the daytime and cold output and water from condensation during the night (glazed frost)

4.4. Organic waste

Vacuum sewerage (faces and urine) and a complete organic waste collection and- disposal is a condition for closed carbon -nitrogen cycles. (Figures 6, 7, 8, 9, 10) By means of anaerobe fermenting methane gas is made for the drive of a micro turbine during a period of 2,5 days in a bioreactor that provides itself with electricity. The filtered exhaust fumes are used as fertilization for the greenhouse plants. With CO_2 concentration of 1,000 ppm the plants growth within the closed greenhouse increases by 20% and the building is totally CO_2 neutral. Apart from the cooling, which can be limited by adjustable outside awning a closed greenhouse has two advantages: the relative humidity can be kept high and equable without appreciable water from the outside and there is considerable less bother from insects. The end product is compost that can be used as mould.

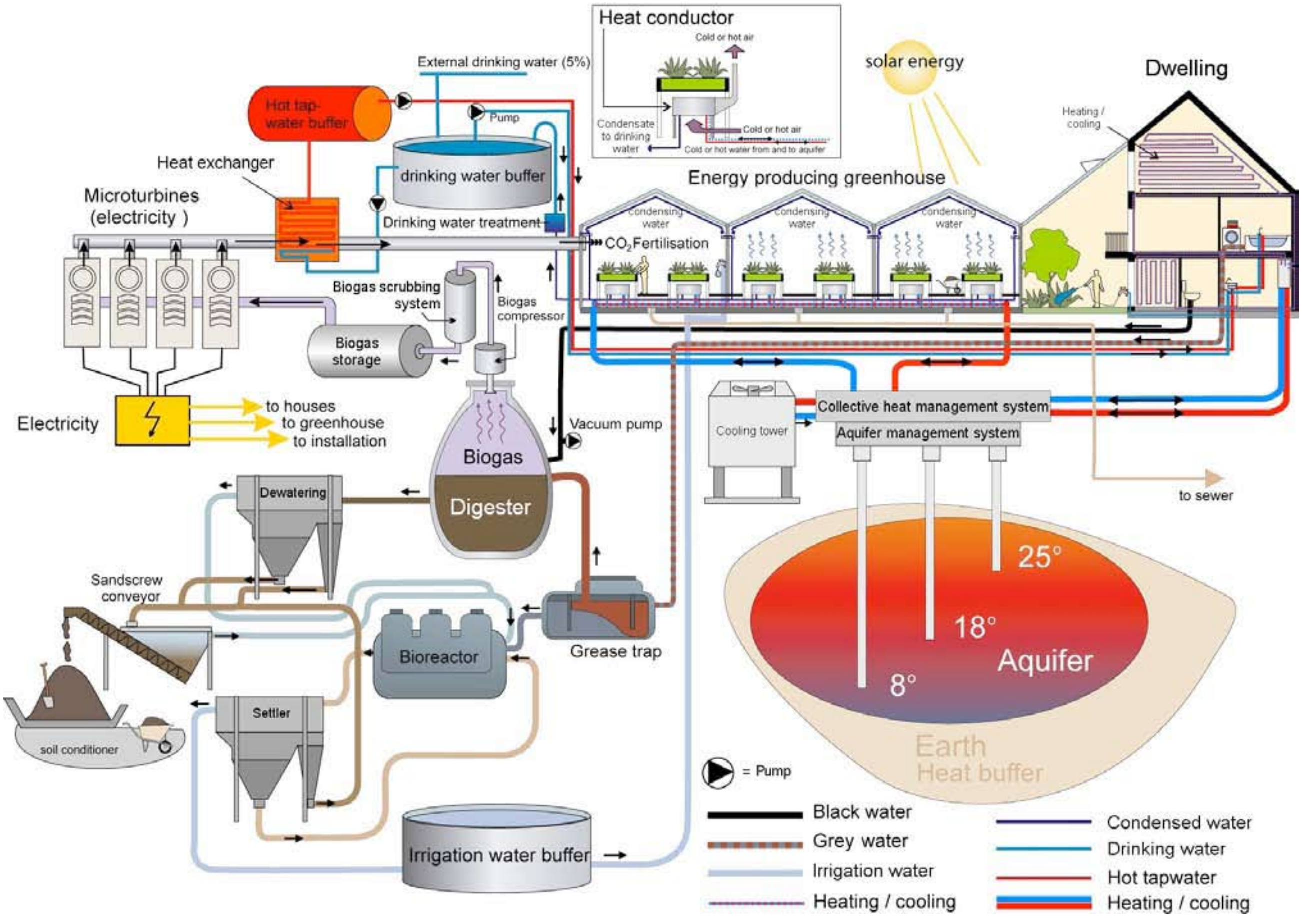

Figure 6 The complete installation of heat and cold in the closed organic waste processing inclusive of CO2 neutral greenhouse. The dwellings will be replaced by offices in the integral design.

4.5. The edible city

In the Netherlands 2 ha of closed greenhouse with aquifer and energy storage is adequate to heat 8 ha equivalent of a neighborhood of some 200 houses. A greenhouse of 8 ha produces sufficient organic waste to also provide these houses with electricity. “The Edible City” requires new town planning and development plans.

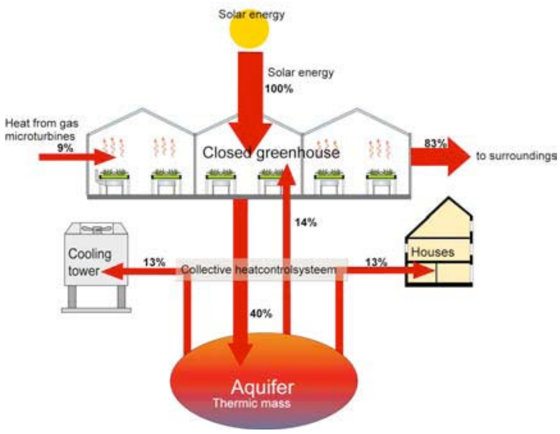

Figure 7 Energy balance

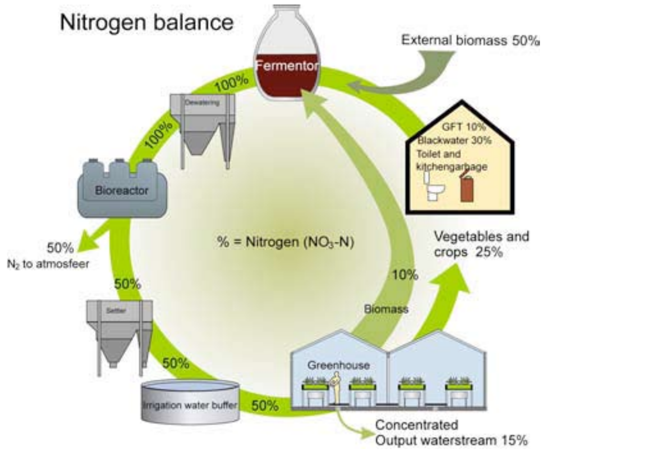

Figure 8 Nitrogen balance

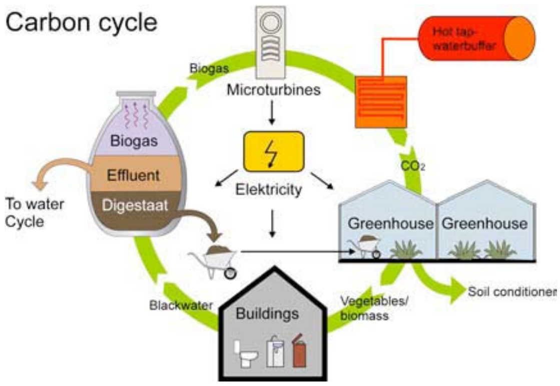

Figure 9 Carbon Cycle

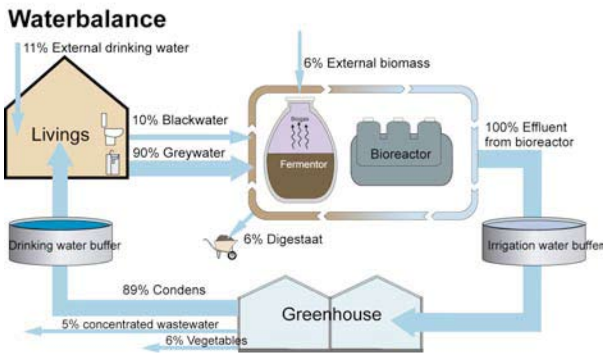

Figure 10 Water balance

5. Indoor climate

5.1. Air heating

The desired indoor climate, the temperature, humidity and ventilation with four diverse continental climates is achieved by complete design without heat pumps and cooling machines. The basic heating and cooling is the slow radiation heating, supplemented with fast reacting air heating and air cooling which is also used in “Zonneterp” Greenhouse Village. However, a transition is needed from the effective utilitarian fine-wire-heat exchanger in the closed greenhouses to silent heating and cooling on office work places with a noise level of < 25 dB in the cell offices. (Figure 11 and 12)

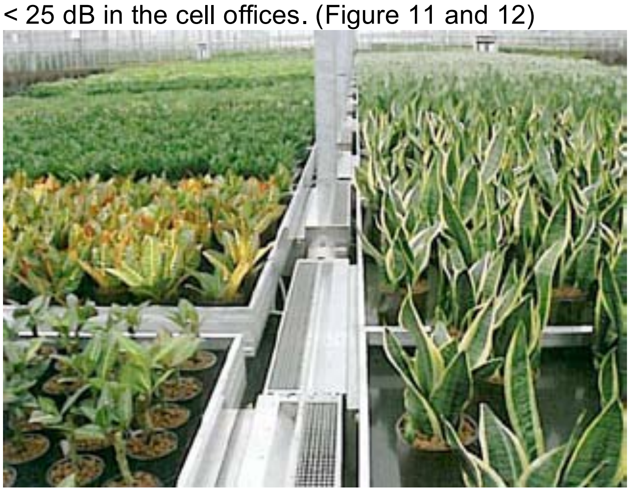

Figure 11 Fiwihex – heating / cooling

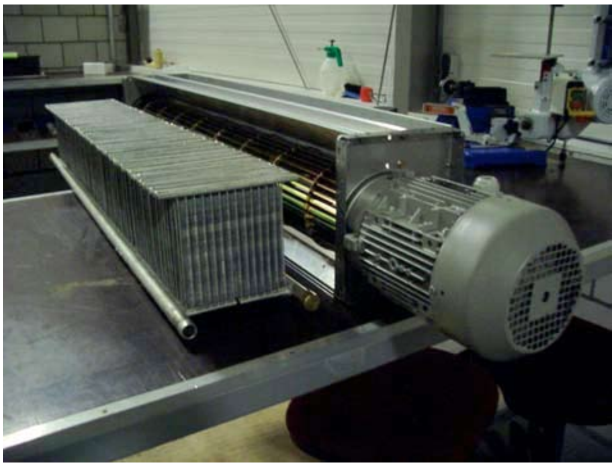

Figure 12 Fiwihex box of heat exchanger and a tangential blower

5.2 Radiant heating

The temperature control for radiant or air heating takes place from the seasonal heat storage in the ground. For the benefit of the concrete core activation heat and cooling the weather forecast can sometimes offer help during big weather changes. The concrete core activation by oxygen tight floor heating pipes in floor and ceiling. The concrete core activation is relatively fast and effective in a new, very stiff, hollow concrete floor, which can span 18 m. wide of the garage in the basement. The 18 m has also become a plan size with a large degree of freedom for layout. This new floor has as its characteristic a large cavity of 0,6 m with diagonal reinforcement bars, which connect 100 mm top slab walking floor and 100 mm bottom slab ceiling floor. The large cavity is reachable from above for wires and the underneath has a sound-absorbent structure. No false ceilings are required. The equable indoor temperature benefits from the thermal mass of the concrete. The auxiliary quick heating / cooling by means of air. (Figure 16)


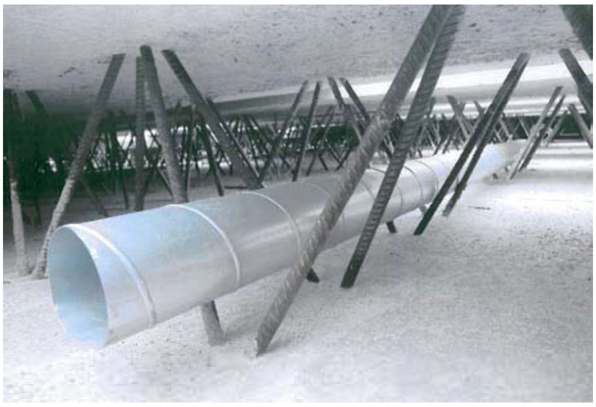

Figure 13 New type of concrete double floor has an extraordinary span of 18 to 20 meters

5.3 Ventilation

The greenhouse has four artificial indoor climates, subtropical, Middle Eastern, Amazon, and the polar circle area. Research has proven that plants have a beneficial effect on patients. The plants produce carbon dioxide but the offices have “breathing windows” ventilation (BW) as a supplement (Figure 14, 15 and 16). This is an intelligent, balanced way of ventilation, which measures the CO_2 of the indoor climate and ventilates according to one’s needs. Adjustable, but at f.i. a CO_2 level of 600 ppm the ventilation stops. The fine-wire-heat exchanger in BW exists of 15 km ø 1/10 mm copper wire and weighs 500 gr. The dimensions of the heat exchanger are 100/200/450 mm, so that it can be cleaned in the shower or in a dish washing machine.

Figure 14 First prototype of a Breathing Window

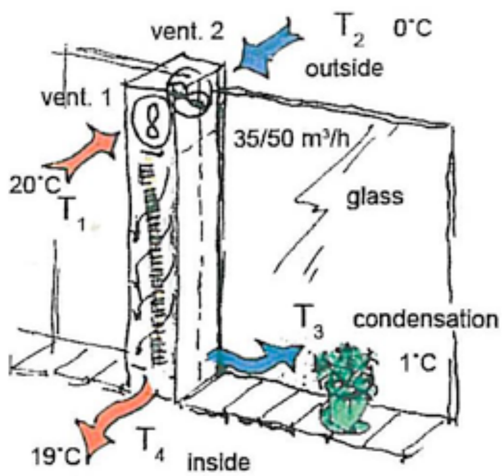

Figure 15 - the Concept of a Breathing Window

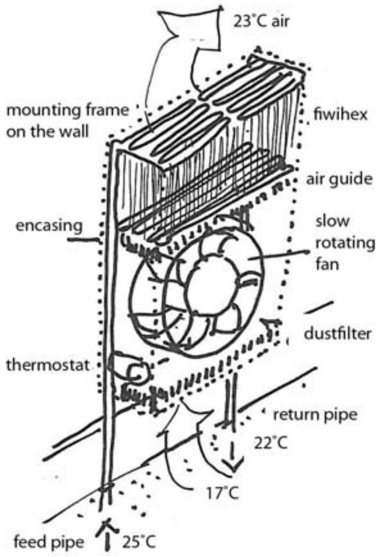

Figure 16 new Very- Low- Temerature Heating Device

5.4 Characteristic values in metabolism

By far the most difficult condition is the sustainable indoor climate. The metabolism of a sedentary person and a standing plant are different, this is also the biggest challenge for the architect. (Figure 17,18 impressions).

Figure 17 Interior

Figure 18 Exterior

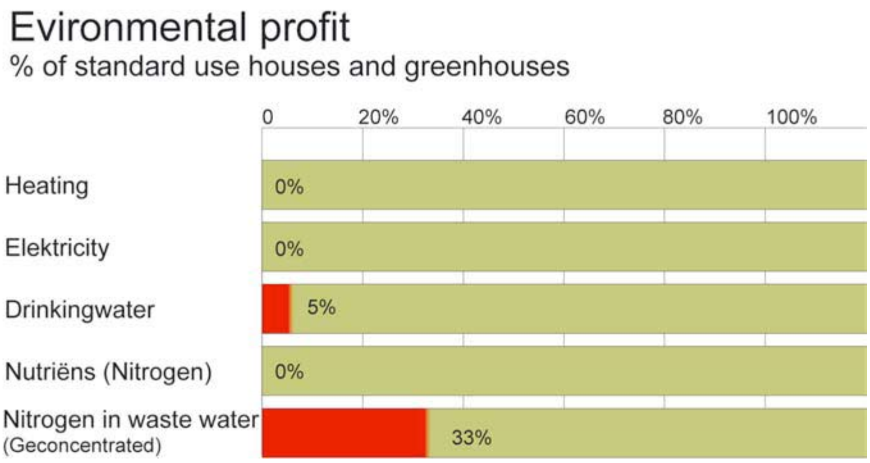

Figure 19 Self-sufficiency or general utilities

6. Conclusion

By innovation in various fields and the integral designing, a self-supporting building can come into being without general public utilities.

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Evaluation of Ecobalance Performance of Building Composite Materials by LCA Multi- Eco-indicators

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Keywords: building composite material, short- cut fiber, carbon fiber, glass fiber, LCA multiple eco-indicators, ecobalance performance, global environmental impact analysis, radar chart visualization

Summary

Carbon, and glass short-cut fiber reinforced cement composites (FRC), and glass short –cut fiber reinforced plastics (FRP), both among advanced composite materials are becoming widely used in building field. In order for these composite materials to be “ecomaterial” gentle both to the global environment and to the human beings, supporting sustainable buildings, an appropriate evaluation should be made from various points of view. This paper deals with research on evaluation of ecobalance performance for these FRC and FRP, based upon LCA multi-ecobalance-indicators such as long service life, resources circulation, reduction of harmful substances, resources and environmental capacities, health safety, and materials efficiency, each of which are quantified as five rating indices. Comparison and evaluation of the environmental load of total materials requirement and energy consumption per unit volume in production based upon LCA fundamental data of fibers and matrix component materials. Global environmental impact analysis is also done from the viewpoint of the global warming and acid rain. Radar chart visualization is shown for typical FRC. Although PAN based-CFRC and GFRP are both excellent composites from the viewpoint of tensile strength and long service life, GFRC is considered to be the best ecomaterial from the viewpoint of the global environmental impact analysis.

1. Introduction

The establishment of sustainable buildings and housings taking into account the balance among the environment/landscape, safety/long service life and economy is the premise of the realization of environmentally harmonized sustainable society in which the flow of rational resources circulation is made possible, and the global environmental problems are becoming resolved. As fundamental materials supporting sustainable buildings and housings, building materials have to be “ecomaterials “gentle both to the global environment and to the human beings. In order for us to supply from the materials side for the basis to establish sustainable environment-conscious buildings, cities, and societies (eco-buildings, eco-cities, and eco-societies), we have to convert building materials into ecomaterials (ecomaterialization) or develop ecomaterial-type building materials (Fukushima (2003a), Fukushima (2004a)). A number of ecomaterial-type building materials have been gradually developed. When we select them as building materials, the judgment of how to evaluate the degree of environmental harmony or ecobalance performance is required (Fukushima (2006). On the other hand, environment-conscious materials design (ecomaterials design) for the selection of ecomaterial-type building materials, and environment-conscious life-cycle design (eco-life-cycle design) as the design considering life- cycle processes, paying special attention to the balance among long service life , resources circulation, and ecobalance performance, are as well important for application of ecomaterial-type building materials for sustainable buildings and housings(Fukushima(2003b) and Fukushima(2004b) .

The concept of composite materials was known empirically from old age. However, technology of composite materials has drastically progressed recently with the development of advanced artificially fibers such as carbon, aramid, and glass. Fiber reinforced composite materials as masterpieces of artificial materials, are becoming more and more important in building field. Due to their excellent material properties such as lightweight, high strength, high corrosion-resistance, carbon, aramid, and glass short-cut fiber reinforced cement composites (FRC) are used as excellent exterior materials, for example, for external thermal insulation systems in sustainable buildings, replacing asbestos fiber reinforced cement composites, which are becoming prohibited due to the problems of causing, for example, mesothelioma and lung cancer. On the other hand, short –cut glass fiber reinfoeced plastics (FRP) are becoming widely used for kitchen units, bath units, and water supply tanks etc. In order for these advanced composite materials to be ecomaterial, supporting sustainable buildings, an appropriate evaluation should be made from various points of view (Fukushima (2005) and Fukushima (2007)). Part of the results of this research was reported in 7th Ecobalance conference in Tsukuba, Japan (Fukushima et.al. 2006b)).

This paper deals with research on evaluation of ecobalance performance for these FRC and FRP, based upon LCA multiple eco-indicators. As the part of the quantification of the resources and environmental capacities of these composites, comparison and evaluation of the environmental load of total materials requirement and energy consumption and per unit volume in production, based upon LCA fundamental data of fibers and matrix component materials, are shown. Global environmental impact analysis is also done from the viewpoint of the global warming and acid rain. Based upon six items of ecobalance performance, radar chart visualization is shown for GFRC as typical FRC.

2. Research Methods

2.1 Six evaluation indicators of ecobalance performance

In order to evaluate ecobalance performance, it is necessary to set LCA evaluation indicators from various points of view. For example, only the life-cycle inventory (LCI) as an integrated evaluation method of energy consumption and carbon dioxide (CO_2) generation rate in the total life cycle is insufficient. Comprehensive evaluation based on other LCA indicators as well as LCI is required. Ecobalance performance can be evaluated by the quantitative expression of six evaluation indicators of service life, resources circulation, reduction of harmful substances, resources and environmental capacities, materials efficiency, and health safety. LCI indicators are included into the category of the improvement of resources and environmental capacities. The objective of this research is also to evaluate quantitatively evaluate the characteristics of this category of fiber reinforced composites.

Table 1 Setting Methods of Rating Numbers of Various Evaluation Indicators

Evaluation Indicator	Rating number				
	1	2	3	4	5
Characteristics of Long service life					
1) Structural materials and Components	15-30year	30-45year	45-60year	60-75year	75-100year
2) Exterior and interior materials	5-10year	10-15year	15-20year	20-25uear	25-30year
Characteristics of Resources Circulation					
Recycling Indicator = Recycling Ratio× RecyclingNumber	0-1	1-2	2-3	3-4	4-5
Reduction of Hazardous Substances					
Rate of Generation of Dioxin （ppm）	8-10	6-8	4-6	2-4	0-2
Characteristics of Resources/Environmental Capacities					
Improvement Ratio of Resources/Environmental Capacities	0-3%	3-6%	6-9%	9-12%	12-15%
Characteristics of Materials Efficiency					
Improvement Ratio of Materials' Efficiency	-10- -5%	-5-0%	0%	0-5%	5-10%
Characteristics of Health Safety					
Number of Human Race Feeling Health Damage per 1,000 ones	80-100	60-80	40-60	20-40	0-20

In BEES4.0 of National Institute for Standards and Technology of U.S.A (Lippiant 2007), 10-12 evaluation indicators including the global warming, acid rain and solid wastes etc. are set to evaluate comprehensive environmental performance of many building materials. Although six evaluation indicators shown here are partly correlated with these 10-12 indicators of BEES, these are selected, paying special attention to life-cycle ecobalance, not limiting only to the environmental performance in production. For example, if we can expect long service life, we can reduce the amount and number of generation of solid waste, so that the environmental load is greatly improved. On the other hand, if we can expect the resources circulation after designed service life, the environmental load is greatly improved as well. From the viewpoint of the conservation of natural resources, the improvement of materials efficiency or resources productivity using recycled or unused materials contribute to the reduction of mass consumption of natural resources. As the other three most important evaluation indicators, we have also to taking into account the reduction of hazardous substances, the improvement of resources/environmental capacities, and the health safety. Table 1 shows the stetting methods of rating numbers of various evaluation indicators by five indices. For example, standard service life of structural materials such as concrete is set as 45-60years, and that of exterior and interior materials such as FRC and FRP as 15-20years （Fukushima 2006）.

2.2 Conditions of sustainable production of building materials

For pursuit of the environmental harmony, we consider the general concept of ecobalance performance, paying special attention to life-cycle processes of building materials as follows:

Ecobalance Performance = Demanded Performance and Service× ｛Service Life(SL)｝ / {(Life Cycle Cost(LCC))×(‘Total Materials Requirement（TMR）)×(Life Cycle Environmental Load(LCEL))}

(1)

This means that we endeavor to obtain the demanded performance and service of building materials and components, and/or system by minimizing life–cycle cost, total materials requirement and life cycle environmental load, and also making service life as long as possible, on the contrary to the previous concept of industries that pursuit for the maximum performance and service by minimizing only initial cost in the 20th century (Fkushima2005). Various evaluation indicators of ecobalance performance are treated based upon this rather comprehensive concept. In this paper, TMR and LCEL are specially considered in order to quantify the LCA indicator of the improvement of sources /environmental capacities.

3. Research Results and Discussion

3.1 Characterization of total materials requirement of composite materials

Based upon unified mix proportion of the same water cement ratio of 40%, cement sand ratio of 25% shown in Table2 , and the same fiber length of 6mm, and various fiber volume content(V_f) of 1,2,3%, properties of PAN –based carbon and glass short-cut fiber reinforced cement composites (PAN-CFRC and GFRC) are characterized. On the other hand, total materials requirement (TMR) per tensile strength and TMR per compressive strength are also calculated for E-glass short-cut fiber reinforced plastic (GFRP for SMC bath tablet use), and for ordinary concrete, based upon their mixed proportion shown in Table 3and 4. Characterization of TMR of composite materials is summarized in Table 5. Fig.1 shows the comparison of TMR of PAN-CFRC, GFRC, and GFRP.

Table 2 Unified Mix Proportion of Matrix Mortar of FRC

Water cement ratio W/C (%)	Sand cement ratio S/C (%)	Unit Mass (kg/m³) Water（W)	Cement（C)	Sand（S)	High Performance Water Reducing Reagent (C×1.0%)	Defoamer (C×0.05%)
40	25	488	1220	305	12.2	0.6

Table 3 Mix Proportion of GFRP

Unit Mass (kg/m³) E-glass	Unsaturated Polyester Resin	$CaCO_3$	Other Additives
600	589	665	46

Table 4 Mix Proportion of Ordinary Concrete

Slump (cm)	Water Cement Ratio W/C (%)	Air Content (%)	Sand Gravel Ratio S/G (%)	Unit Mass (kg/m3) Water (W)	Cement (C)	Gravel (G)	Sand (S)	Admixture (g/m^3) High Performance Water Reducing Reagent (C×0.6%)
18	60	4	46	180	300	968	818	1,800

Table 5 Characterization of Total Materials Requirement (TMR) of Composite Materials

Type of composite	Fiber Volume Content (%)	TMR (kg/m^3)	Tensile Strength (N/mm^2)	Compressive Strength (N/mm^2)	TMR per Tensile Strength (kg/m^3/(N/mm^2))	TMR per Compressive Strength (kg/m^3/(N/mm^2))
PAN-CFRC[1)]	1	2,052	2.14	—	959	—
	2	2,040	2.89	—	706	—
	3	2,012	3.84	—	524	—
GFRC[2)]	1	2,049	2.10	—	975	—
	2	2,047	2.66	—	770	—
	3	2,050	3.35	—	612	—
GFRP[3)]	24-28	1,900	3.43	—	554	—
Ordinary Concrete[4)]	—	2,264	—	23,900	—	0.095

Notes:1) PAN-carbon short-cut fiber reinforced cement composite (Fiber Length: 6mm, Fiber Density: $1.75cm^3$) 2) Alkali-resistant glass short-cut fiber reinforced cement composite (Fiber Length: 6mm, Fiber Density: $2.55cm^3$) 3) E-glass Short-cut fiber reinforced Unsaturated Polyester Resin (Fiber Length: 2-3mm, Fiber Density: $2.5g/cm^3$) 4) Structural Design Strength: $F_c=24N/mm^2$, Durability Design Strength :$F_d=24N/mm^2$

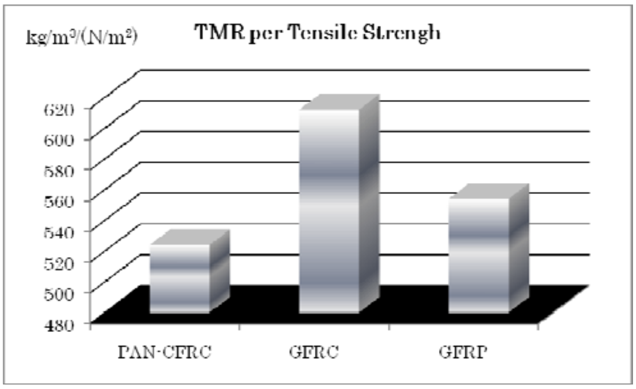

Figure 1 Total materials requirement (TMR) per tensile strength of composite materials

We can find out the tendencies of characteristics of TMR of various composite materials as follows:

1) TMR based upon unified mix proportion is almost the same value of about $2050kg/m^3$ both in PAN-CFRC and in GFRC, but become smaller with fiber volume content (V_f). TMR of GFRP is smaller value of 1,900 kg/m^3 than those of FRC, but that of ordinary concrete is rather greater value of 2,264 kg/m^3 than those of FRC.

2) TMR per tensile strength has the tendency of the decrease with V_f in each FRC. When we think about the case of 3% of V_f, however, PAN-CFRC has the smaller value of 524 $kg/m^3/(N/mm^2)$ than that of 612

kg/m3/ (N/mm2) of GFRC. TMR per tensile strength value of 554 kg/m3/ (N/mm2) of GFRP is smaller than those of PAN-CFRC and GFRC.

3) TMR per compressive strength value of 0.095 kg/m3/ (N/mm2) of ordinary concrete is much smaller than TMR per tensile strength of FRC and FRP.

4) Materials efficiency obtaining demanded compressive strength is rather greater in concrete than that obtaining demanded tensile strength in FRC and FRP.

3.2 Characterization of energy consumption and hazardous gas generation of composite materials

Based upon unit energy consumption and waste gases of various component materials shown in Table6, and mixed proportion of composite materials as shown in Tables 2, 3, and 4, unit energy consumption and unit waste gas amounts are calculated. Results are shown in Table 7.

We can find out that PAN-CFRC and GFRP have rather greater UEC compared with ordinary concrete and GFRC. On the other hand, the amount of SO_x and NO_x generation of GFRC becomes comparable to PAN-CFRC.PAN-CFRC has the greatest amounts of UEC waste gas generation in other composite materials.

Table 6 Unit Energy Consumption (UEC) and Waste Gas Generation of Component Materials of Composites

Type of Component Material	Energy Unit (MJ/kg)	CO_2 (kg/kg)	SO_x (kg/kg)	NO_x (kg/kg)	Data Resource
PAN-Carbon Fiber	478.5	29.7	0.00682	2.00946	The Japan Carbon Fiber Manufacturing Association
Alkali-Resistant Glass fiber	29.8	1.85	0.000926	0.00069	The Japan Glass Fiber Manufacturing Association
E-Glass Fiber	474.81	32.42	0.03855	0.21259	Japan Reinforced Plastic Society
Natural Fine Aggregate (Crashed Sand)	5.6	0.2888	0.00069	0.0047	Ecomaterial Forum
Natural Gravel (Crushed Stone)	5.6	0.2756	0.00064	0.00044	Ecomaterial Forum
Ordinary Portland Cement	29.9	2.059	0.00246	0.01421	Japan Cement Association
$CaCO_3$	0	0	0	0	Japan Reinforced Plastic Society
Unsaturated Polyester Resin	973.31	77.52	0.009734	0.28985	Japan Reinforced Plastic Society
Electric Power (KWH)	3.6MJ	0.424	0.00037	0.0000261	Japan Environmental Management Association for Industry

Table 7 Unit Energy Consumption (UEC) and Waste Gas Generation of Composite Materials

Type of Composite	UEC (GJ/m3)	CO_2 (kg/m^3)	SO_x (g/m^3)	NO_x (g/m^3)
PAN-CFRC	62.4	4117.08	4073.86	123653.66
GFRC	40.0	2698.63	2898.63	18153.13
GFRP[1)]	65.0	4802.00	599.56	20893.61
Ordinary Concrete	19.5	1176.88	1176.88	8183.88

Notes:1): E-glass Short-cut Fiber Reinforced Unsaturated Polyester Resin

3.3 Global environmental impact analysis

Results of evaluation of global environment impact of composite materials based upon Table 7 are shown in Fugues 2, 3, and 4. Evaluation of the global environmental impact by acid rain was done by the reduced amount of SO_x waste gas generation by the following equation:

Reduced Amount of SOx waste gas generation = SOx waste gas generation+0.7 NOx waste gas generation (Lippiant 2007)

(2)

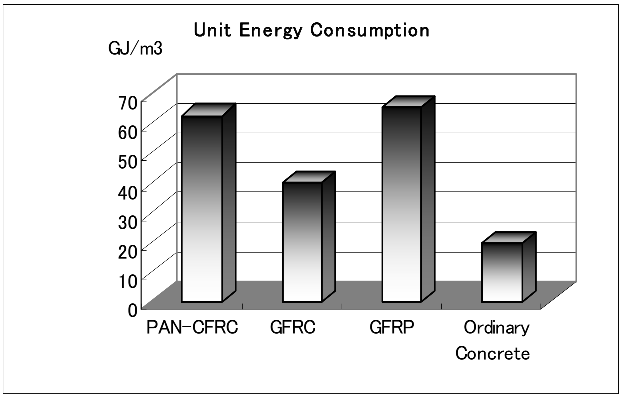

Figure 2 Evaluation of global environmental impact of composite materials (Part 1:unit energy consumption).

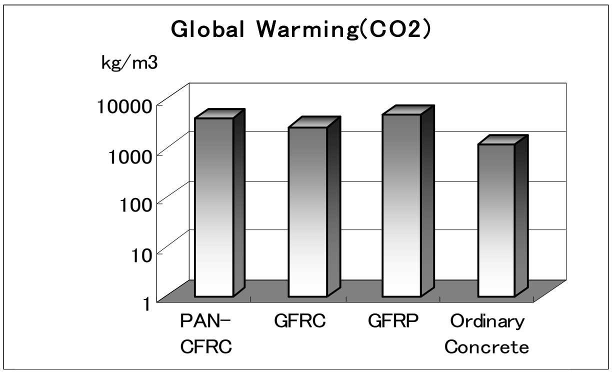

Figure 3 Evaluation of global environmental impact of composite materials (Part 2: Global warming).

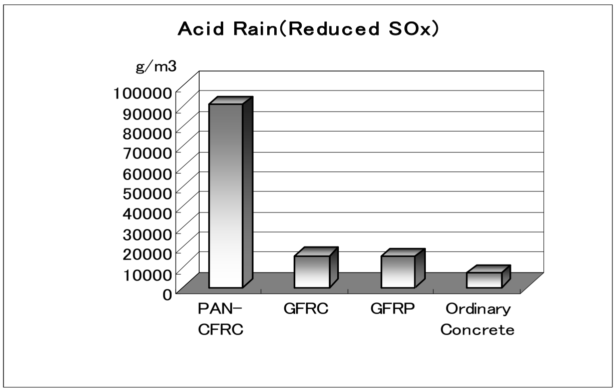

Figure 4 Evaluation of global environmental impact of composite materials (Part 3: Acid rain).

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From these results, we can say as follows:

1) PAN-CFRC and short-cut GFRP are excellent composite materials. From the viewpoint of the ecobalance performance, however, they give the considerably greater environmental burdens to the global environment, compared with GFRC and ordinary concrete.

2) From the viewpoint of the gentleness to the global environment, GFRC is the best among various fiber reinforced composite materials.

3.4 Evaluation of six items of ecobalance performance by five rating indices

Each item was evaluated by the following consideration:

3.4.1 Long service life

Standard service life of reinforced concrete as structural composite component is 60years, so that its rating index is 4.また、Those of external CFRC and GFRC are 30years, so that their rating indices are 5. Service lives of carbon and glass continuous fiber reinforced plastic reinforcements as structural materials are 100 years, so that their rating indices are 5.

3.4.2 Resources circulation

Resources circulation was evaluated by the product of recycling rate by recycling number. Recycling rate of external GFRC is 70%, and recycling number is 5, and evaluation of resources circulation is 3.5, so that its rating index is4.

3.4.3 Materials efficiency

If we replace the binder of CFRC from ordinary Portland cement to 90% ecocement and 10% waste GFRP powder, comparable flexural strength is obtained with that of CFRC only using ordinary Portland cement as the binder, and materials efficiency is improved about 10 %. Consequently its rating index is 5.

3.3 Visualization of ecobalance evaluation by radar chart of GFRC

Figure 5 shows the visualization of ecobalance performance by radar chart of GFRC. From this figure we can say that GFRC has balanced ecobalance performance except for rather low rating number in the items of resources circulation and materials efficiency.

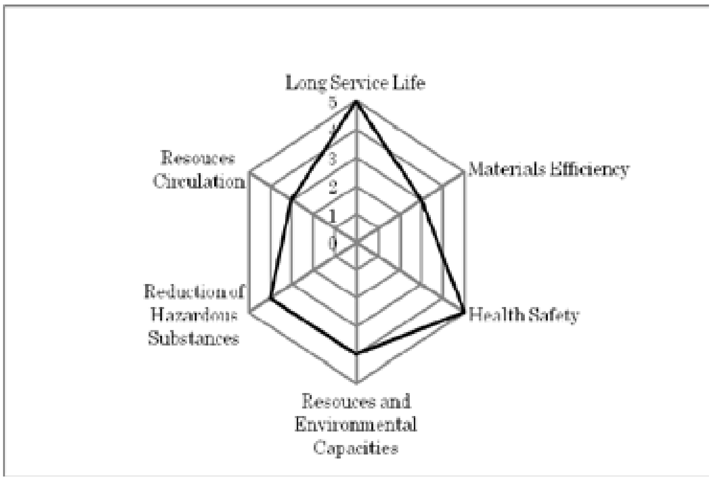

Figure 5 Visualization of ecobalance evaluation by radar chart of GFRC

4. Summary and Conclusion

In order to begin with estimate the environmental load in production of various short-cut fiber reinforced composite materials(FRC and FRP), based upon LCA fundamental data of fibers and matrix component materials, comparison and evaluation are done for these composite materials, from the viewpoint of total materials requirement and energy consumption and waste gas generation, compared with the case of ordinary concrete. The following remarks can be made:

1) Total material requirements per tensile strength have the tendency of the decrease with fiber volume content in each FRC.

2) Although PAN-CFRC and short-cut GFRP are excellent composite materials from the viewpoint of total materials requirement obtaining demanded tensile strength, from the viewpoint of the gentleness to the global environment, GFRC is the best among various short-cut fiber reinforced composite materials.

Acknowledgement

I would like to express heartfelt thanks to many Japanese associations and societies such as Ecomaterial Forum, The Japan Carbon Fiber Manufacturing Association, Japan Glass Fiber Manufacturing Association, Japan Reinforced Plastic Society, Japan Cement Association, and Japan Environmental Management Association for Industry, for their kind help to supply data of unit energy consumption and waste gases of various composite component materials.

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The Effect on the Indoor Air Quality Control Using Plants and Natural Materials

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ABSTRACT

Recently the pollution of indoor air in newly built houses by noxious gas emitted from construction materials, adhesive, furniture, etc. is emerging as a serious social problem. Thus, the present study purposed to prove the effect of purifying polluted indoor air using plants and natural materials. For this purpose, we measured the effect of purifying indoor air of HCOH, CO, CO_2 using a 1/3 size mock-up model composed of a living room and a balcony. According to the result, plants and natural materials were highly effective in purifying polluted air in the balcony space and the effect reached the living room adjacent to the balcony. The results suggest that air pollution in newly built houses called sick house syndrome can be solved through natural purification using plants and natural materials and, based on the results, we may develop a system for pleasant indoor environment in the future.

KEYWORDS: Sick house syndrome, Indoor air pollution, Plants, Natural materials, Balcony, Natural purification

1. INTRODUCTION

Recently sick house syndrome is emerging as a social problem in Korea. That is, most of construction materials, adhesive and furniture used in newly built houses emit volatile organic chemicals (VOCs) such as formaldehyde and pollute indoor air, threatening the residents' health.

Recognizing the seriousness of the problem, the government is making efforts to establish relevant systems and environmental standards, and house constructors are also examining various ways of reducing indoor air pollution.

Thus the present study purposed to examine how effective plants and natural materials in apartment balconies is in purifying polluted indoor air of construction materials, furniture and the outside air. For this purpose, we manufactured two 1/3 size mock-up models, placed selected plants in the balcony, and measured and analyzed changes in the balcony and the living room temperature, humidity and noxious elements such as HCHO, CO, CO_2.

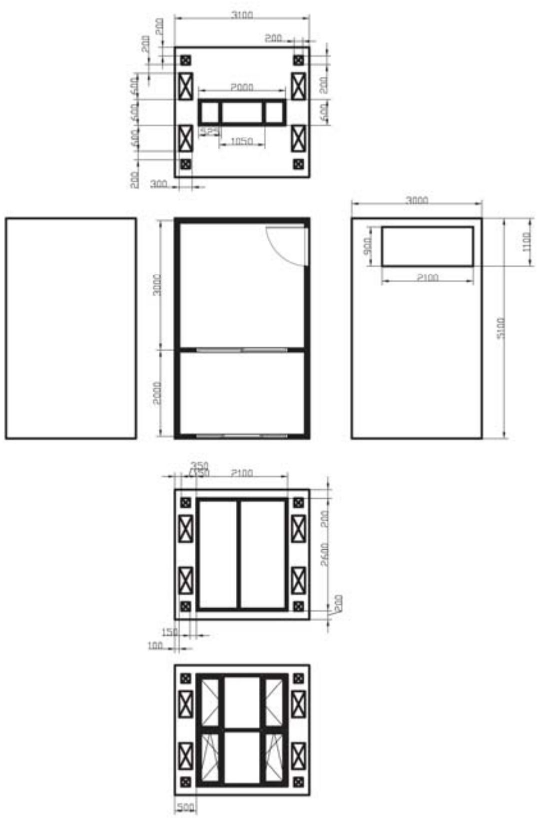

Figure 1. Floor plan, elevation of mock-up model

Figure 2. Actual appearance of the model

2. STRUCTURE OF MODEL AND EXPERIMENT METHOD

As in Figure 2, 3 and 4, the structure of the mock-up model has dampers (C, D, E, F) and vents for natural ventilation (A, B, G, H) to control air flow between the balcony and the living room so that the environmental condition of the balcony can affect the living room. The design intended to reduce noxious elements and create pleasant environment in the living room through the systematically organized environment-friendly plants and natural materials in the balcony.

2.1 Experiment 1: Measuring change in formaldehyde content

The names and layout of plants in the experiment chamber are as in Figure 2. In Figure 1, the balcony with plants in a chamber was named AT and the living room AR, and in another experiment chamber of the same size and condition, the balcony was named BT and the living room BR.

In the model, we opened and volatilized a bottle containing 10cc of formaldehyde at the rear part of the middle of AR and BR at 6:00 pm on June 22 2004 and measured the concentration of formaldehyde at 10:00, 14:00, 18:00 on the next day (23rd of June), at 8:30 on the 24th) and at 9:00 on the 25th. Each measuring was made in order of AT-BT-BT-AT-AR-BR-BR-AR (the same hereinafter). Each space was measured five times, and the means of the results was used in analysis. The measuring device used was PPM formaldehyde meter TM400(PPM Technology, U.K.).

Table 1. Weather during the period of experiment (9/17-9/20)

Date	9/17					9/18						9/20					
Time	10	11	14	17	22	4	8	11	14	17	22	4	8	11	14	17	22
Weather	Clean	Clean	Clean	Clean	Clean	Rain	Rain	Rain	Rain Stop	Rain	Rain	Clean	Clean	Clean	Clean	Clean	Clean

Table 2. Weather during the period of experiment (9/24-10/4)

Date	9/24					9/25			9/26		9/27	9/28	9/30	10/1		
Time	8:00	8:40	10:00	13:30	17:00	9:30	14:00	17:00	9:00	17:00	14:00	18:00	18:40	8:00	11:00	14:00
Weather	Clean	Clean	Clean	Clean	Clean	Clean	Clean	Cloudy	Clean	Cloudy	Clean	Cloudy	Cloudy	Clean	Rain	Rain
Date	10/1		10/2					10/3							10/4	
Time	18:00	22:00	4:00	8:00	15:00	17:00	22:00	4:00	8:00	11:00	12:00	14:00	17:00	22:00	4:00	8:00
Weather	Rain	Rain	Clean	Clean	Clean	Clean	Clean	Clean	Clean	Clean	Clean	Clean	Clean	Clean	Clean	Clean

<Balcony> <Living room> <Cross-section>

Figure 2. Floor plan, cross-sectional view and plant layout of the model (23rd of July)
1.Carnegiea gigantea 2.Marianne 3.Victoria 4.Gymnocalycium baldianum 5.Moth orchid 6.Sansevieria 7. Benjamin 8.Golden crest 9.Aeschynanthus

Table 3. Weather during the period of experiment (10/6-10/7)

Date	10/6			10/7		
Time	12:00	14;00	17:00	11:30	14:00	17:00
Weather	Clean	Clean	Clean	Partly cloudy	Partly sunny	Partly sunny

2.2 Experiment 2: Measuring changes in temperature, humidity and formaldehyde, carbon monoxide and carbon dioxide contents

The composition and structure of the experiment chambers are identical with those in Experiment 1. The names and layout of plants in the experiment chambers are as in Figure 3. Experiment plants were placed on the 19th of September. Until the 17th of September before the experiment, the chambers were ventilated by opening the windows and water and nutrition were managed.

In order to measure changes in temperature, humidity, CO and CO_2, we obtained their base levels at 10:00 on the 17th with the windows opened and, at 10:30, injected 100% CO gas at 1kgf/cm2 for a second into six times into the center of the two living rooms. We used a solenoid valve that can adjust the concentration of gas injected through electric control (the same hereinafter).

Measuring was made at 10:00, 11:00, 14:00, 17:00 and 22:00 on the 17th, 4:00, 8:00, 11:00, 14:00, 17:00 and 22:00 on the 19th, and 4:00, 8:00, 11:00, 14:00, 17:00 and 22:00 on the 20th. The order of measuring was identical with that in Experiment 1. The measuring device was GRAY WOLF (gray wolf sensing solutions, USA).

Next, 1ml of formaldehyde was injected into the center of the living rooms using a pipette at 13:00 on September 17 2004, and its concentration was measured at 14:00 and 17:00 on the 17th, 8:00, 14:00 and 22:00 on the 18th, 8:00, 14:00 and 22:00 on the 19th, and 8:30 and 14:00 on the 20th. The measuring device was identical with that in Experiment 1.

<Balcony> <Living room> <Cross-section>

Figure 3. Floor plan, cross-sectional view and plant layout of the model (17th of September)
1.Gymnocalycium baldianum (Put on the vents connecting AT and AR [C, D, E, F]) 2.Money tree 3. Charcoal 4.Carnegiea gigantea 5.Sansevieria 6.Scindapsus 7.Golden crest 8.Victoria (hydro-ball) 9.Peace lily (gem stone) 10.Moth orchid (ocher brick) 11.Benjamin (quartz porphyry) 12.Ocher bricks (3 pieces) 13.Hydroponic grower -circulate 10L of water

2.3 Experiment 3: Measuring changes in temperature, humidity and formaldehyde, carbon monoxide and carbon dioxide contents

The composition and structure of the experiment chambers are identical with those in Experiment 1. The names and layout of plants in the experiment chambers are as in Figure 4. Experiment plants were placed on the 20th of September. On the 24th of September, the chambers were ventilated by opening the right and left window and water and nutrition were managed. Next, base levels were measured at 8:30 with the windows opened.

In order to measure temperature, humidity, CO and CO_2, we closed the windows at 9:40 on the 24th and injected 100% CO gas at 1kgf/cm2 for 6 seconds into the center of AR and BR at 9:50 on the 24th. Measuring was made at 8:00, 10:00, 11:00, 13:00 and 17:00 on the 24th, 9:00, 14:00 and 17:00 on the 25th, 9:00 and 17:00 on the 26th, 14:00 on the 27th and 18:00 on the 28th.

In the experiment with formaldehyde, 1ml of formaldehyde was injected using a pipette at 10:00 on September 24 2004, and its concentration was measured at 11:00, 12:30 and 18:00 on the 24th, 9:00, 14:00 and 17:00 on the 25th, 17:30 on the 26th, 14:00 on the 27th and 18:00 on the 28th.

<Balcony> <Living room> <Cross-section>
Figure 4. Floor plan, cross-sectional view and plant layout of the model 24th of September) 1.Gymnocalycium baldianum (Put on the vents connecting AT and AR [C, D, E, F]) 2.Money tree 3.Charcoal+Carnegiea gigantean (Carnegiea gigantea was put on charcoal) 4.Humata 5.Sansevieria 6. Scindapsus 7.Golden crest 8.Victoria (hydro-ball) 9.Peace lily (gem stone) 10.Moth orchid (ocher brick) 11.Benjamin (quartz porphyry) 12.Hydroponic grower - circulate 10L of water

3. EXPERIMENT RESULTS AND DISCUSSION

3.1 Experiment 1: Changes in formaldehyde content

As for changes in the formaldehyde content after 18 hours from the volatilization of formaldehyde as in Figure 5, the content in the balcony with plants (AT) was lower by 2ppm than that in that without (BT), and it lowered by around 5ppm after three days (25th of July). The content in the living room adjacent to AT (AR) was not much different from that in the living room adjacent to BT (BR). The reason that the effect of AT did not decrease the content in AR was that formaldehyde continued to volatilize from the formaldehyde bottle in the living room and as a result, plants removed only formaldehyde in AT.

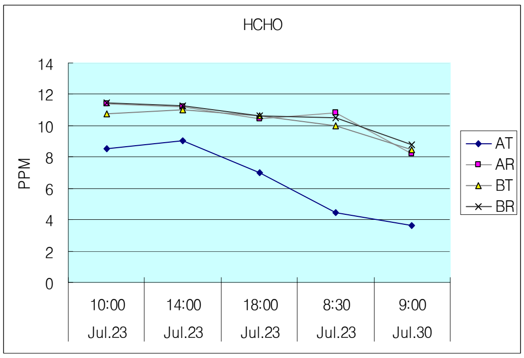

Figure 5. Changes in formaldehyde (HCHO) content in the model (7/23-7/25)

3.2 Experiment 2: Changes in temperature, humidity and formaldehyde, carbon monoxide and carbon dioxide contents

As for changes in the formaldehyde content after 1 hour from the volatilization of 1ml of formaldehyde in the living room` at 13:00 on the 17th of September (Figure 6), the content in the balcony with plants (AT) was 5ppm lower (reduced by 50%) than that in the balcony without (BT), and the content in AR adjacent to AT was also 3ppm lower than that BR, suggesting that it was affected by AT probably because a limited quantity of formaldehyde was volatilized in the living room. The content was high during daytime when temperature was high and low in morning and evening. In addition, it was low on rainy days (14:00 on the 18th) and cool days and high on sunny and hot days (14:00 on the 19th) (Figure 5).

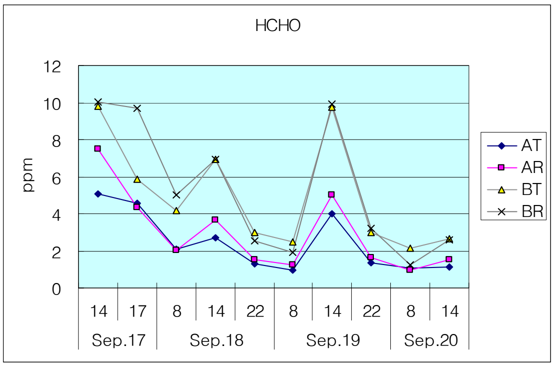

Figure 6. Changes in formaldehyde (HCHO) content in the model (9/17-9/20)

On the other hand, the temperature of the closed experiment chambers (AT, AR, BT, BR) was 5-7℃ higher than that of the open air during daytime but was not much different at night (Figure 7). There was no notable difference in temperature among the chambers. At the early stage of measuring, the temperature of AT (with plants) was 1-2℃ lower than that of BT (without plants) but soon the difference disappeared.

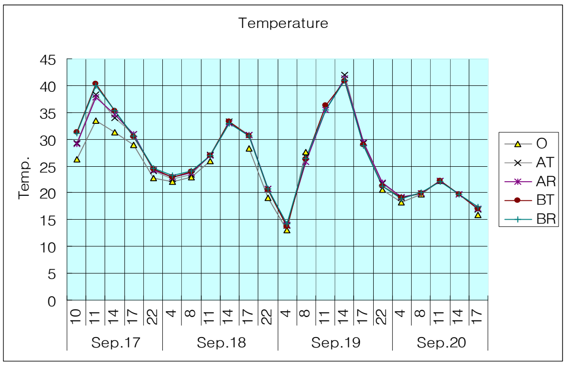

Figure 7. Changes in the temperature of the experiment chambers (9/17-9/20)

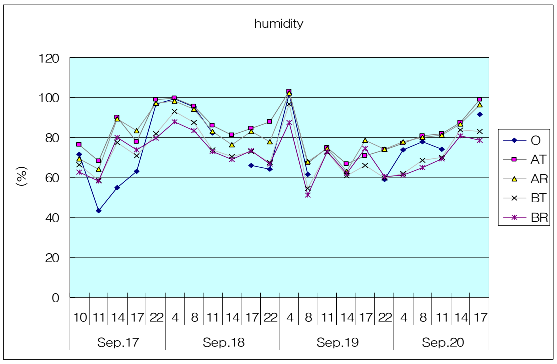

Figure 8. Changes in the humidity of the experiment chambers (9/17-9/20)

Humidity was 5-10% higher in AT (with plants) and AR than in BT (without plants) and BR. This is probably because of continuous evaporation of water by the hydroponics system and the transpiration of water in the culture media of the plants in AT (with plants) (Figure 8).

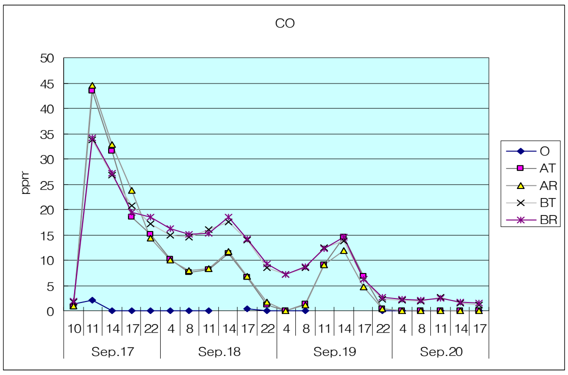

Figure 9. Changes in the carbon monoxide content in the model (9/17-9/20)

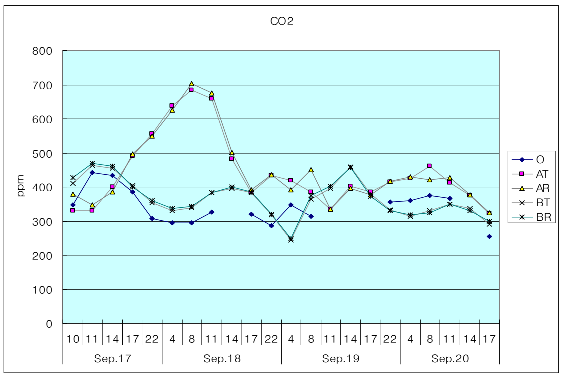

Figure 10. Changes in the carbon dioxide content in the model (9/17-9/20)

At the early stage of treatment (11:00), the CO content was around 45ppm in AT (with plants) and AR and around 35ppm in BT (with plants) and BR. However, after 8 hours (17:00) it became similar among the chambers (19-24ppm) and, from 22:00, fell down sharply to 14-15ppm in AT and AR and to 17-18ppm in BT and BR (Figure 9). It rose during daytime when temperature was high (14:00 on the 18th and 14:00 on the 19th) and fell down to 0ppm from around 22:00 on the 19th. However, the CO content in BT and BR continued to remain 2-3ppm.

The CO_2 content was 90-120ppm lower in closed AT (with plants) and AR than in the open air and closed BT and BR at the early stage (11:00 on the 17th) but became higher by 350ppm at night (4:00 on the 18th). The concentration of carbon dioxide after a day (after 14:00 on the 18th) varied within 30-100ppm regardless of time (day and night).

3.3 Experiment 3: Changes in temperature, humidity and formaldehyde, carbon monoxide and carbon dioxide contents

As for changes in the formaldehyde content after 1 hour from the volatilization of 1ml of formaldehyde in the living rooms at 10:00 on the 24th of September (Figure 11), the content was 5ppm lower (reduced by 50%) in the balcony with plants (AT) than in that without plants (BT) and 1-3ppm lower in AR adjacent to AT than BR, suggesting that AR was affected by AT.

The content was high during hot daytime (14:00-17:00 on the 25th and 14:00 on the 27th) and low in morning and evening. The result was similar to that in Experiment 2, but differences in the content among the chambers with different plant layout were more obvious in Experiment 3 (Figure 2 and 3).

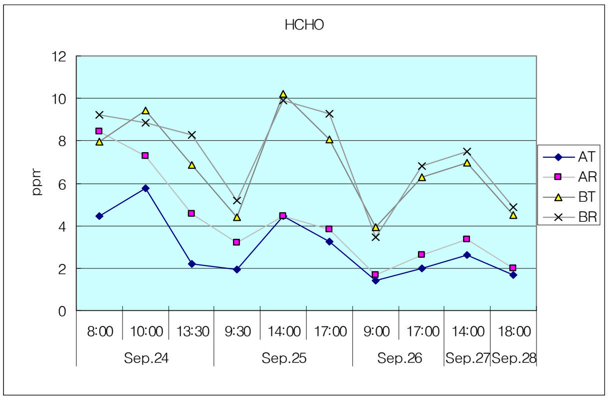

Figure 11. Change in the formaldehyde (HCHO) content in the model (9/24-9/28)

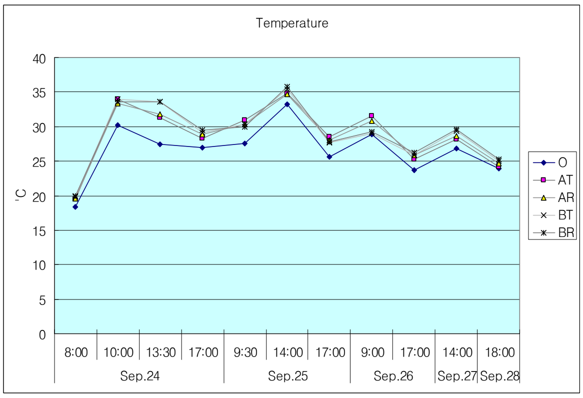

Figure 12. Changes in the temperature of the experiment chambers (9/24-9/28)

Temperature in the closed experiment chambers (AT, AR, BT, BR) at day and night was 2-7℃ higher than that in the open air. Temperature was not significantly different among the chambers but during daytime it was 1-2℃ lower in AT (with plants) than in BT (without plants) (Figure 12).

Humidity was 10-20% higher in AT (with plants) and AR than in BT (without plants) and BR. This was probably because of the continuous evaporation of water by the hydroponics system and the transpiration of water in the culture media of plants (Figure 13).

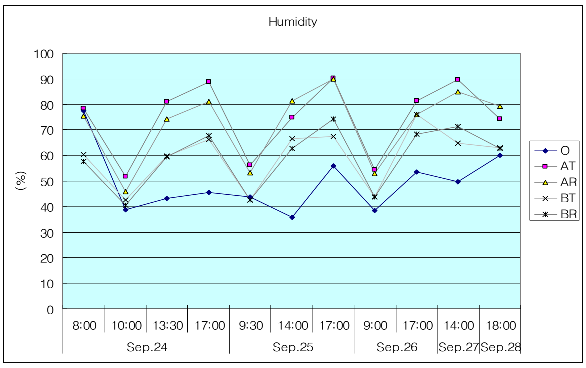

Figure 13. Changes in humidity in the model (9/24-9/28)

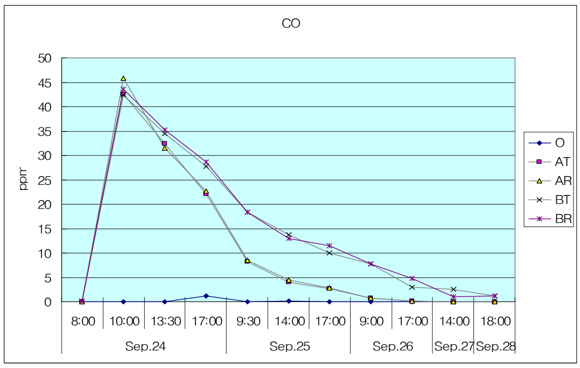

Figure 14. Carbon monoxide in the experiment chambers (9/24-9/28)

When measuring was made immediately after the injection of CO into AR and BR as in Experiment 2, the CO content in the four spaces was all around 43 ppm and then a clear difference was observed between the concentration in AT and AR and that in BT and BR. After two days had passed the concentration reached nearly 0ppm in AT and AR, but a small amount of CO was detected in BT and BR even after four days (Figure 14).

The concentration of CO_2 was around 80ppm lower in AT (with plants) than in the open air and BT at the early stage after plants were placed

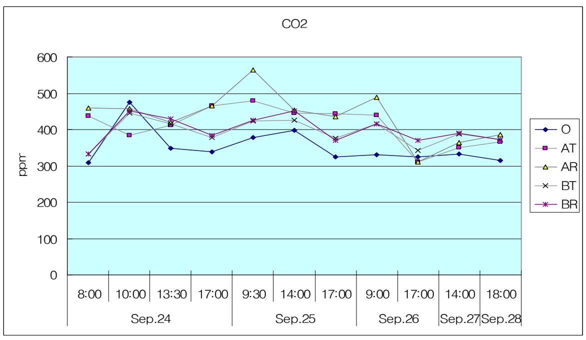

Figure 15. Carbon dioxide in the experiment chambers (9/24-9/28)

(10:00 on the 24th) but, over time, it became around 90ppm higher in AT than in BT at around 17:00, became similar at around 14:00 (daytime) on the 25th and became 60ppm lower at 14:00 on the following day (26th). That is, the concentration of CO_2 was low during daytime when carbon dioxide assimilation was active and high at night when plants respired (Figure 15).

4. CONCLUSIONS

As the three experiments above show, the reduction of formaldehyde was clear in the balcony with plants, which in turn reduced formaldehyde in the living room. However, if formaldehyde occurs continuously, it has to be removed continuously through appropriate deployment of plants and natural materials.

In these experiments with a reduced-size model, the temperature of the balcony with plants was affected by the temperature of the open air, and it went up to some degree in AT (with plants) due to the respiration of plants in the small closed space on hot days compared to rainy or cloudy days.

Due to the transpiration of plants, humidity was generally higher in AT (with plants). This was because of the continuous evaporation of water and the transpiration of water contained in the culture media of plants at high temperature by the hydroponics system in the balcony.

As shown by the results of three experiments, the concentration of CO in AT and AR was clearly different from that in BT and BR. This was because plants have the physiological function of reducing carbon monoxide and reduction in the balcony affected the living room.

When temperature was not so high and the weather was sunny, carbon dioxide assimilation was active and as a result the level of carbon dioxide went down, offsetting or exceeding the increase of carbon dioxide from respiration in evening and at night.

As expected, CO_2 decreased as plants in the small closed space absorbed carbon dioxide through carbon dioxide assimilation during daytime or when temperature was low in the rainy season. On hot days, however, plants lost their function as respiration was more active than carbon dioxide assimilation, had problems in their growth and withered to death due to high temperature. In this case, however, the concentration of carbon dioxide was not high enough to be harmful to the human body.

In this study we proved the purification effect of plants and natural materials against formaldehyde, carbon monoxide, carbon dioxide but this study has limitations in that it used a reduced-size model and was carried out only in summer and autumn.

Thus, in order to generalize the effect of experiment, it is necessary to carry out an experiment throughout the four seasons using a real-size model and a larger number of noxious substances and to study the application of the results to actual houses.

ACKNOWLEDGEMENTS

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DOES THE BUILDING SYSTEM PREDEFINE THE CUMULATED LIFE CYCLE ENERGY DEMAND?

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Keywords: cumulated energy demand, life cycle assessment, statistical evaluation

Summary

Cumulated life cycle energy balance components of single family houses, built with four different building systems have been analyzed. The components include the embodied energy, the energy need of maintenance and demolition of those building elements which directly influence the operational energy need and those, but only those components of the operational energy need which depends on the building – thus, on one hand the envelope of the building, on the other hand the transmission heat losses and the utilized solar gains have been considered. Statistical population of randomly generated technically feasible houses have has been calculated and compared. Significant differences between the mean values of cumulated energy demand of different building systems have been proven by statistical method, nevertheless the overlapping of the confidence intervals shows that the building system itself does not completely predefine the final result, only the higher or lower likelihood of the expected cumulated energy demand can be spoken of. Unlike the comparison of the data of a few arbitrarily selected sample buildings the applied statistical method facilitates the evaluation of the multitude of buildings.

1. Introduction

Many analysises, national regulation as well, as the Energy Performance of Building Directive of the European Commission and European Parliament focus on the operational energy demand of buildings. The requirements become more and more strict. Nevertheless the less is the operational energy demand the more important will be in both absolute and relative sense the energy need of the erection, maintenance and demolition of the buildings. Neglecting them the risk of false decision may become considerable.

One of the main subject areas of the recent research at the BUTE is the life cycle energy balance of buildings.

The analysis (Szalay 2008) of the relationship between the energy demand and other environmental indicators proved that energy demand is a suitable screening indicator in the environmental assessment of buildings. For typical building systems and heating fuels, energy is highly correlated with the global warming potential, the resource use in eco-indicator 99 and with the non-renewable cumulative exergy demand.

The life cycle of buildings consists of four phases:

- Production: acquiring raw materials, manufacturing and transporting building products to the site and erecting the building.
- Maintenance: small repairs and changing the building elements at the end of their useful life, this includes the production of the new elements.
- Operation: energy demand for heating, domestic hot water and lighting.
- Disposal: disposal of the old building materials in the maintenance phase and demolition of the building at the end of the effective life, separation, transport and processing of materials for reuse/ recycling/ incineration/ landfill and recultivation of the deposit site.

As far as production, maintenance and disposal is spoken of, distinction should be made between those building elements which have direct relationship with, and those elements, which have no or only an indirect influence on, the operational energy use. The first category includes the walls, roofs, exposed windows and movable shading or night insulation – in one term the envelope. Their thermal characteristics (U-value, transmittance, decrement factor….) govern the transmission and radiant heat flows between the building and environment. Considerable may be the embodied energy of the internal floor slabs, foundation and partitions, however they have no or only moderate effect on the operational energy by the heat storage capacity.

The operational energy must be divided in two categories, as well. These are its building related and user related components. Transmission heat losses and utilised solar gains depend on the size, shape and thermal properties of building elements (the solar access on the surrounding obstructions, too), providing climatic conditions and standard indoor temperature are given. The other components depend on the user behaviour. This is self intended in the case of domestic hot water consumption, whilst ventilation heat losses seem to be disputable. Nevertheless, if the air tightness of the envelope fulfils the requirements and the building is properly used, the air change rate depends on, and is adjusted to, the number and activity of the habitants.

Encompassing the rational use of energy in the followings the energy need of the building envelope and the building related operational energy will be analysed, thus the interrelated components of the life cycle energy balance.

2. Method

Based on architectural and functional considerations, the realistic ranges of the parameters describing the geometry of the “technically feasible” buildings and the relationships of these parameters have been defined (Szalay 2008). Thus, the building sample is neither arbitrarily selected, nor based on statistical data of existing buildings, but covers the population of the “technically feasible” buildings, since there is no guarantee that the data of the future buildings will coincide with those of the previous era. For this, the parameters describing the building geometry and the realistic ranges of these parameters based on functional and architectural considerations have been determined. The parameters were the floor area, the number of storeys, the perimeter to floor area ratio, the window ratio and frame factor and the density of partition walls in the layout. An algorithm has been developed for the random generation of a large building sample based on the realistic ranges of the geometric parameters. In each category 1000 buildings have been generated. Based on the geometric parameters the area of the building elements and the surface to volume ratio (ΣA/V) describing the dimensions and compactness of buildings have been calculated. In the base scenario, the buildings were built with an unheated cellar and unheated attic, the window ratio was 10-30 % of the façade area, 10 % of the windows faced North, 30-30-30 % South, East and West, respectively, and the windows were partly sunlit.

Several calculations have been carried out - here the interrelated components of the life cycle energy balance for four building system and for one and two-storey residential buildings are analysed. The results are presented for 1 year and 1 m^2 net heated floor area over a 50-year period in Hungary (basic climatic data: 72 000 heating degree hours, 2000 sunshine hours per year, 48 N latitude, continental temperate zone).

With regard to the embodied energy basically the Swiss ecoinvent database has been used, with certain modifications. The composition of the Swiss and the Hungarian electricity mix and the source of the natural gas differ significantly, hence these modules were changed. For products missing from the database new datasets were developed based on the material composition (Tiderenczl et al, 2006).

For the analysis, we have chosen four building systems, typical for new buildings in Hungary:

- insulating brick system;
- brickwork with external insulation;
- autoclaved aerated concrete system;
- timber stud system.

Although mixed systems cannot be excluded (for example, insulating brick walls can be combined with a wooden floor), in this study we always considered external and partition walls and floors as belonging to one system. It corresponds to the real market situation: the suppliers offer, and the builder usually prefer, complete packages and compatible elements.

Insulating bricks are specially designed porous hollow clay bricks that reduce heat flow. These bricks are suitable as a load-bearing structure up to 3-4 storeys and can just fulfil the new national energy performance requirements without additional insulation, issued in 2006 (the U value is between 0,35 – 0,43 W/m^2K, depending on the thickness). The brick density is between 600-800 kg/m3, depending on the number and arrangement of the voids. The porosity of these bricks is increased by adding materials that burn during firing (e.g. saw dust). The thermal transmittance of the brickwork can be further decreased by applying mortar and/or plaster with perlite, expanded clay or expanded polystyrene.

The system includes partition walls, lintels, girders etc. made of burnt clay. The floors are made up of pre-stressed reinforced concrete beams with clay covering, clay hollow blocks filling between the beams, and 4-6 cm concrete topping with reinforcement.

Clay bricks with a density of 1200-1400 kg/m^3 are suitable from energy point of view as external wall only if an insulation layer is added. Blocks with a thickness of 30 cm are applied in load-bearing walls. This system is not linked to any special floor constructions, the walls can be combined with all kinds of floor. We considered prefabricated reinforced concrete beams with hollow concrete blocks between them, typically used in the practice.

Autoclaved aerated concrete (AAC) is made from sand, lime, cement and water with an aerating agent with autoclaving. AAC is a lightweight material of low heat conductivity. The current Hungarian thermal requirements for external walls can be fulfilled with single-layer AAC walls of 30 cm. The aerated concrete system includes load-bearing and partition walls, lintels and reinforced wall or roof boards. Reinforced concrete beams with AAC block filling with concrete topping was considered as floor system.

Among the industrially prefabricated systems, applied for single family houses the most common one is the timber stud system. Wall panels consist of solid timber studs with a usual spacing of 60-80 cm connected with top and bottom plates. The spaces are filled with mineral wool insulation. Wood-based panel sheating provides bracing. The thermal bridge effect of the wooden studs can be decreased if an additional insulation layer with battens perpendicular to the studs is applied. The spacing of the floor joists is adjusted to the walls. Wood-based subflooring ensures the stiffness of the floor. This system is suitable for low-rise buildings up to 2 storeys.

In the study, for all building systems the same building service systems were chosen which are typical for new buildings in Hungary and comply with the current energy regulation. For heating and domestic hot water production a low temperature modulating gas boiler was considered, with radiators and indirectly heated hot water storage tank. This is also the reference system defined in the current regulation on building energy performance (TNM 7/2006). Mechanical ventilation is not common in residential buildings in Hungary. No mechanical cooling was taken into account: in a properly designed and used residential building the summer overheating remains tolerable.

3. Discussion

Professionals as well as potential builders frequently raise the question, which building system is the more preferable from energy point of view? The answer is not going to be a simple one, since differences in all phases of the life cycle have to be pondered – and the answer may not be free of interest of different confronting lobbies. Certainly, increased thermal insulation can be argued for and everybody accepts, that the more efficient insulation decreases the operational energy use. On the other hand the opponents argue with the higher embodied energy which – according to their opinion – does not compensate the operational energy saving. Similar is the case of high quality glazing and windows. It is easy e.g. to understand that timber construction is environmentally friendly and due to constructional reasons, ab ovo has an insulation layer of considerable thickness – and even so the higher need of maintenance can be mentioned. Even if the interest of the market actors can be excluded, it is impossible to have a clear picture unless the subject of the discussion is not well defined, and the user related operational energy and the embodied energy of the foundation and internal partitions are mixed with the relevant components of the life cycle energy balance.

The aim of the analysis is to define the absolute difference and the proportion of the cumulated energy need of the envelope and the building related operational energy demand, using statistical data (mean value, standard deviation, confidence intervals) of the investigated “populations”, consisting 1000 randomly generated buildings in each category. Comparing the statistical data of the different categories - each corresponding to a building system, we examined, whether the differences are significant or of random character.

Based on the central limit theorem we determined that the results follow a normal distribution. The central limit theorem states that any sum of many independent and identically-distributed random variables will be approximately normally distributed if the sum of the variables has a finite variance. A chi-square test was performed to test for normal distribution. We proved that normal distribution provided a good fit to the observed data in most cases.

The results are shown in Figs. 1. and 2, for one storey and two storey single family houses, respectively. It can be seen that the density functions, expressing the sum of the building related operational energy and the embodied energy, influencing directly the operational energy need for the life cycle of the building overlap each other.

It has been proven by statistical analysis that disregarding the overlapping the differences between the mean values are significant at a confidence level of 99 % at any paired comparison of the building systems.

First, an F-test was performed to prove that the standard deviations of the two normally distributed populations do not show a significant difference. Then a t-test was necessary to analyse whether the means of the two populations were equal.

The building systems can definitely be differentiated, nevertheless the difference of the mean values does not exceed $\pm$ 6 % of the overall average in the case of one storey and $\pm$ 8.5% in the case of two storey houses. The dispersion seems to be higher, thus the scewness of the density functions is less (they cover a “wider” interval) in the case of insulating brick system, the narrowest functions belong to the timber stud system for both one and two storey houses. This is clearly reflected in the quartiles values. The upper and lower pairs of them border the interval which includes half of the population, whilst at the given level of confidence they mark the intervals which include 90% of the houses. Nevertheless these differences are of random character only, as it has been proven by F-test at 95%..

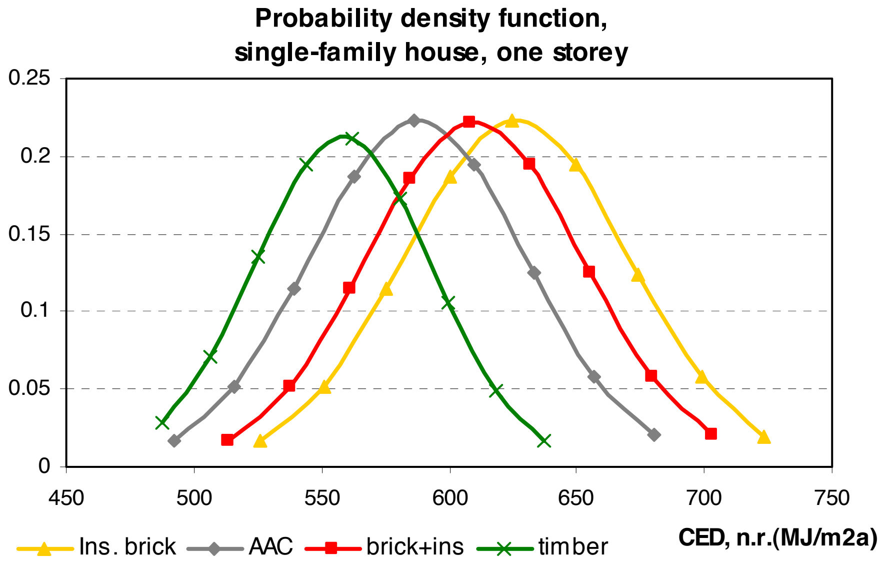

Fig. 1.

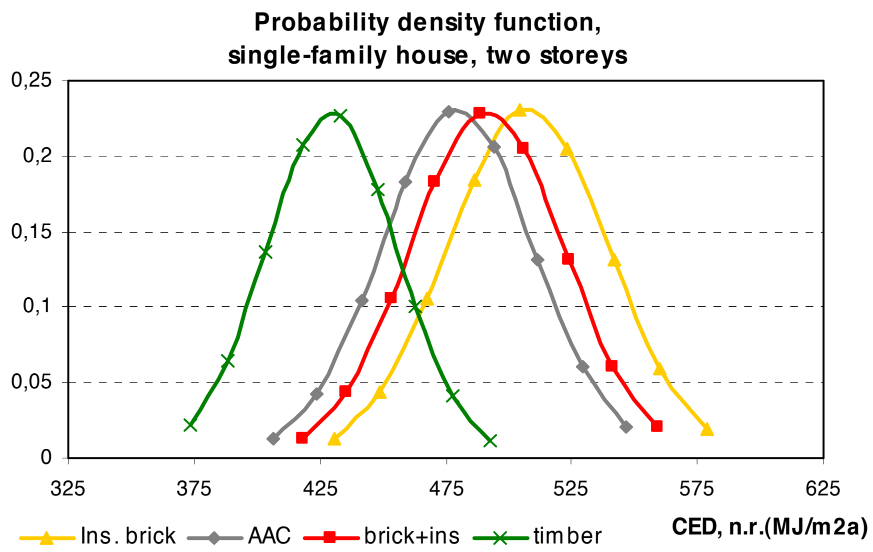

Fig. 2.

These intervals, as well as the density functions overlap each other. In the case of a section from 570 to 630 MJ/m^2a houses of all building systems appear. Taking the middle of this interval 600 MJ/m^2a one can see, that the most of the houses of insulating brick have higher, most of the timber houses have lower energy need, whilst in the case of aerated concrete this is roughly the mean value, nevertheless any of the analyzed building systems may be chosen if a cumulated energy demand between 570 – 630 MJ/m^2a is acceptable.

The chance to have a building of a cumulated energy demand less than 570 MJ/m^2a is very limited if insulating brick system is applied, whilst the risk that the cumulated energy need exceeds 630 MJ/m^2a can be neglected in the case of timber stud system.

More considerable difference in favour of the timber stud system is found if two storey houses are evaluated. It is due to the fact that the area of the floor slabs is smaller in comparison with that of a one storey building of the same total floor area, thus the role of the exposed walls prevails. Here the overlapping interval of all four density function is narrower: from 450 to 470 MJ/m^2a, however if the three silicate based systems are taken into account any of them can be chosen if 450 – 530 MJ/m^2a cumulated energy demand is acceptable.

As it could be foreseen, considerable is the difference between the one and two storey houses, due to the lower specific transmission heat losses and the lower mass of the envelope

Table 1 Statistical characteristics of one-storey single family houses (MJ/m2a)

	ins brick	AAC	brick	timber
mean	626	588	610	558
median	625	587	609	557
st. dev.	44	42	42	35
1. quartile	595	558	580	532
3. quartile	656	616	638	582
90 % lower	553	518	540	500
90 % upper	700	658	680	616
conf. int. +-	73	70	70	58

Table 2 Statistical characteristics of two-storey single family houses (MJ/m2a)

	ins brick	AAC	brick	timber
mean	508	480	492	430
median	508	480	492	429
st. dev.	32	30	30	26
1. quartile	485	458	470	412
3. quartile	531	502	514	448
90 % lower	455	429	441	387
90 % upper	561	530	542	473
conf. int. +-	53	50	51	43

More pragmatic data can be obtained from the cumulative distribution functions (Fig 3. and 4.). Taking a threshold value of the cumulative energy demand one can see, how many % of the population is to the left (i.e. the demand is less than the threshold) - the complementary % has higher demand. In the opposite way: if we want to know the threshold value, belonging to a given likelihood we should start from the vertical axis.

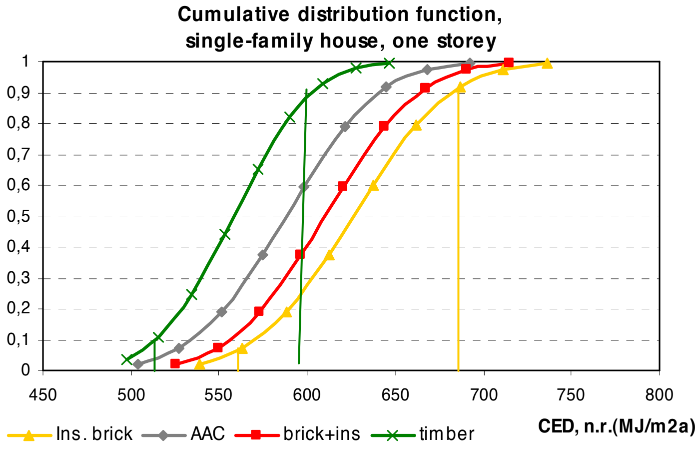

Fig.. 3.

It is possible to mark the confidence intervals: in Fig. 3 those for insulating brick and timber stud systems are shown, marking the intervals in which 80 % of the houses can be found. Even in the case of these two systems it can be seen, that they overlaps each other from 520 to 590 MJ/m^{2}a: about 15% of the houses built with insulating brick and about 35% of houses with timber stud system are in this interval. Self intended the confidence intervals of the other two systems ("in-between curves") overlaps with those of the very left and right curves.

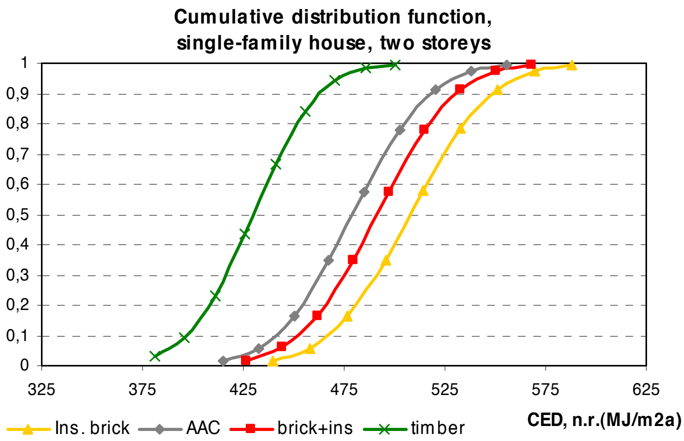

Fig.4.

4. Conclusions

Although the sum of building related operational energy and the embodied energy, directly influencing the operational energy need for the life cycle significantly depends on the building system, the average energy needs per system are in a relatively narrow interval. Thus as far as the building envelope is concerned from energy point of view, the difference between the mean values of insulating brick and timber stud systems is 12 % in the case of one storey and 17 % in the case of two storey houses if the total population of all feasible houses between 60-180 and 120-240 m^2, respectively are taken into account.

The overlapping of the confidence intervals shows that the building system itself does not completely predefine the final result, only the higher or lower likelihood of the expected cumulated energy demand can be spoken of.

It has been proven that the timber stud system offers the best chance to achieve low cumulated energy demand, nevertheless it is not excluded that its average value can be achieved with other building systems.

Taking into account the silicate based systems only, it can be stated that although the differences are significant, they are small and a given cumulated energy demand can be achieved in many cases with any of these building systems.

Unlike the comparison of the data of a few arbitrarily selected sample buildings the applied statistical method facilitates the evaluation of the multitude of buildings.

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BRIDGING THE GAP BETWEEN FINANCE AND SUSTAINABILITY IN CONSTRUCTION

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Keywords: sustainable, building, development, investment, risk, financial, feasibility, assessment

Summary

There is increasing demand within the construction industry for sustainable building development but there are many perceived barriers to its implementation, predominately financial, even though the benefits can be shown. The current challenge is not convincing stakeholders of these benefits but in providing evidence of the financial feasibility of sustainability.

Williams Boag Architects (WBa) has developed a simple-to-use software tool that enables building design professionals to assess the financial feasibility of a project at its outset, reassuring investors and developers that an ESD solution will provide equivalent or better net financial returns than a conventional development, thereby reducing the investment risk. The two key characteristics of the “SIFT” tool are that it assesses the financial potential of a high aspiration green development project; and the assessment occurs at the project’s inception, before any design work is undertaken.

SIFT can be used to define the potential for capitalising on life-cycle cost savings; inform clients at project inception stage before decisions are made; and as a powerful tool for assessing and comparing alternative building investment choices. With its core purpose to facilitate the implementation of ESD at the earliest stage of the process, SIFT considers the total cost of ownership, demonstrating the link between the recurrent and capital costs.

1 Introduction

Of all the challenges to implementing sustainability in building development the hardest ones for a consultant team to counter must be the perceptions that it will cost more and that there is a financial risk. These become constraints that undermine otherwise good intentions. By minimising the risks and identifying the associated financial feasibility at the outset of a project, some of the uncertainty about sustainable development can be reduced, reassuring potential investors and engendering greater confidence in innovative solutions so that a project commences with the best possible chance of achieving its green goals.

This paper presents a method that Williams Boag Architects (WBa) believes will answer this need. It is a simple-to-use software-based tool that enables building design professionals to assess the financial feasibility of environmentally sustainable buildings based on the limited information available at the inception of a project. It assumes that buildings are developed to their full ESD potential and assesses the investment implications. A report is produced for interpretation by the design team to prioritise sustainability opportunities for both environmental and financial success.

The tool has been developed in collaboration with Deakin University and Cundall Australia and, in an Australian first for an architecture practice, supported by an AusIndustry Start Grant.

We will look briefly at why we felt such a tool is needed, describe the tool and its reports, then demonstrate it against a real building to test its ability to identify and prioritise opportunities for sustainable development.

1.1 Context

Generally, sustainable buildings are considered to cost more to design and construct than conventional buildings (Williams, 2004). However, many studies have shown that not only is it possible to design a sustainable building that costs no more than a conventional building (Davis Langdon, 2007), but the additional financial savings and other benefits over the life-cycle of these buildings can be significant (Kats, 2003; GBCA, 2006; CoStar, 2008).

Traditionally, most emphasis has been placed on the upfront or capital costs. The design of buildings to take a more sustainable approach requires that clients and design teams take a more holistic approach. A sustainable building will have, by its nature, consideration for the life-cycle impacts associated with its construction and its operation.

1.1.1 Financial Constraints And Risks

Barriers to sustainable design are also significant barriers to innovation. Perceived issues include capital cost premiums, the risk of reduced long-term investment returns and building performance, lack of available information, hidden costs and split incentives (Sorrell *et al.*, 2004). These are all predominately financially driven and any attempt to promote sustainability must address them.

1.1.2 Client Needs

Hence the current challenge is typically not convincing stakeholders of the benefits of sustainable building, but in providing evidence of its financial feasibility, especially considering the emphasis given to financial aspects of projects (Higgins *et al.*, 2004). Clients are often unwilling to allocate funds to unproven or seemingly unnecessary technologies or design solutions (RICS, 2005, p.13). The lack of built examples creates uncertainty and reluctance. It is not until clients become aware of the life-cycle implications of design decisions that the financial benefits become convincing.

According to Williams (2004), the dilemma faced by clients is finding the right group of sustainable design strategies that are financially attractive, provide operating costs advantages and deliver benefits to occupants. A method is needed to demonstrate the potential benefits and financial viability of taking this approach. If the potential can be assessed at the pre-design stage, when minimal costs have been expended and at the lowest risk level, then development proponents are in a better position to evaluate the viability of the project.

1.1.3 Life-Cycle Approach And Benefits

By taking a life-cycle approach a client or financier is able to capture the many benefits that are associated with a sustainable building. Although developers may be reluctant to invest additional capital into a project if they have no interest in the building once it is complete, they may find that potential purchasers and tenants will pay more for buildings that will save them on operating costs throughout its life (McCartney, 2007; CoStar, 2008).

There is an opportunity to significantly increase the return on investment by capitalising on the life-cycle operating cost savings, however design teams need to be confident that any extra capital investment will be recouped within a reasonable investment cycle. By identifying the strategies that have an acceptable level of return the perceived risks are reduced. It has also been suggested that the risks associated with not taking a sustainable approach to building development may be even greater than the risks of doing so (Wasiluk, 2007).

1.2 The Task

So we have studies and reports that confirm costs for building green do not need to be higher, that value is often higher and that the predicted benefits exist, but there is a need to demonstrate these benefits for each particular project to those who make the ultimate decision on whether or not it will proceed, the financiers, investors and developers, sufficient to get the commitment and financing to progress with strong ESD goals.

2 SIFT

WBa has developed a tool that can be used prior to any design work being undertaken, to assess the financial feasibility of a sustainable outcome for a particular building proposition, that also indicates the extent of risks associated with the approach. In addition, it is possible to identify where the greatest potential exists within the project, allowing design teams and clients to prioritise and target these opportunities.

Traditionally, the judgement of the feasibility of a sustainable building approach has been on an intuitive basis, using the knowledge held by a handful of senior consultants, gained through past experience. WBa has formalised this knowledge and decision-making process into a tool that, wherever possible, is based on objective data.

2.1 Assessment Model

The purpose of the model is to unlock the financial potential of the recurrent costs of a building (e.g. energy and maintenance savings, rebates, income opportunities etc.) so that it can be used to benefit its initial capitalisation. It links ESD strategies with monetary returns, making the proposal attractive to financial institutions.

The model (illustrated in Figure 1) provides an assessment of the potential to create a best-practice sustainable building. The opportunities across various parameters (see Figure 2) are identified. The numerical outputs of this assessment are converted into an overall project score which indicates the likelihood of a good return on investment. This score is presented to clients and financiers, together with a report describing the areas of greatest opportunities and also where greatest risks lie. Clients and design teams can use this information to prioritise their efforts towards the desired outcome.

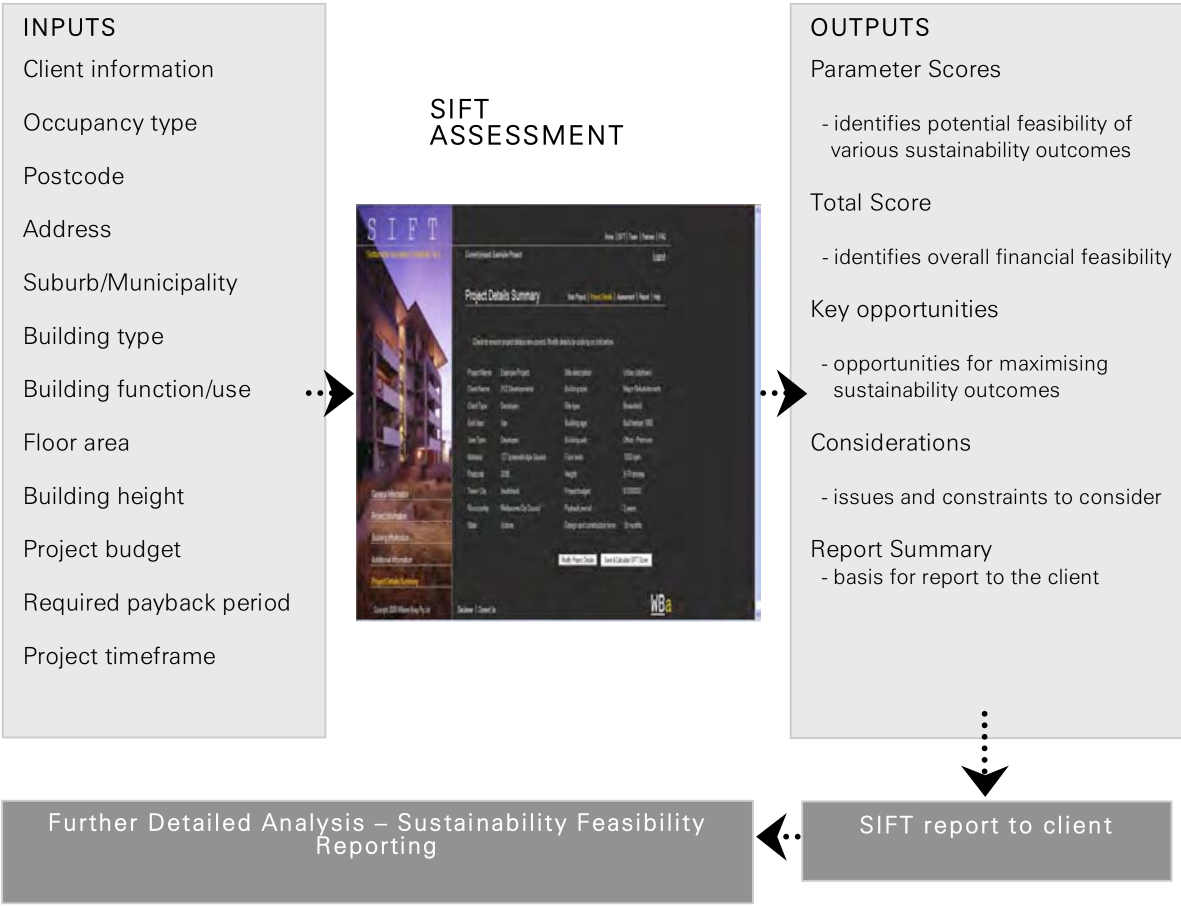

Figure 1   The SIFT assessment model

Initial validation has been performed by comparing the tool's outputs to the opinions of expert design team members for over ten projects. This process showed a close correlation between the opinions provided by the team of the likelihood for creating a best-practice, financially feasible sustainable outcome, and the outputs of the tool. Still in its late testing stages, the tool needs to be validated against built outcomes, however due to the long nature of building projects this process is likely to occur over an extended period of time.

2.2 Sustainable Innovation Feasibility Tool

The model has been realised in a web-based tool, the Sustainable Innovation Feasibility Tool or SIFT. SIFT is simple to use, requiring easily obtained inputs and enables the assessment of a project at its outset, and well before any design work is commenced. SIFT does not assess designs or design options for the level of sustainability attained. There is an underlying assumption that the design team has the expertise and drive to implement best-practice. The test is for financial feasibility only.

The assessment is performed at the earliest possible stage of a project. This may be at an initial client meeting or based on an advertised tender. Only limited information is required to perform an assessment, such as: the project budget, floor area, building function and location details (as shown in Figure 2). Using these very basic details, additional information can be gleaned, for example the climate is known based on the site address, usage patterns can be assumed from the building's function. Eighteen assessment parameters form the basis of the SIFT evaluation process. They were identified as key factors influencing sustainability and also as having a financial impact, either as a cost or an income potential. They are rated on a scale from zero to ten with a score of ten representing a maximum long-term financial benefit to be gained from implementing a high aspiration sustainable solution. These individual parameter scores are weighted and combined into an overall score for the project. The financial risks associated with a project with a higher score are thus considered to be lower.

• energy conservation	• reduced recurrent costs
• water conservation	• reduced replacement costs
• waste minimisation	• reduced maintenance costs
• reduced car-parking	• promotional/incidental use
• improved rental return	• external funding

Figure 2 Some of the SIFT model parameters of assessment

The tool contains benchmark data specific to particular building types and locations, obtained from various industry and government sources. This data is used to make the connections between each of the key inputs and the subsequent relationships with each of the assessment parameters.

For example, energy consumption data per square metre of gross floor area is used to determine the potential for integrating innovative energy saving solutions into the design. The quantity of energy consumed within a building is typically dependant on the purpose for which the building is used, the size of the space being heated/cooled/lit, the climate in which it is located and hours of operation. These inputs for a specific project (building type, GFA, location and occupancy hours) are used to determine the likely energy consumption for the proposal, based on the benchmark data within the tool, for a conventional building. If this energy use is considered to be high then the potential for cost savings from reducing energy consumption would be correspondingly high and so the higher the likelihood of achieving a financial return from implementing strategies, such as active or passive systems, to reduce this energy consumption.

The outputs of the tool include a detailed report that is used to inform the project of the possible environmental outcomes that can be achieved at minimal risk and maximum return, whilst also identifying those areas where potential for a financial return is unlikely or risky. Key opportunities or constraints specific to the project are also identified by the tool at this stage. This may include information relating to problems with availability of infrastructure to the specific site that may influence the ability to provide innovative, feasible design solutions. It may also include the identification of funding available for implementing otherwise cost prohibitive technological solutions. By identifying the areas with greatest sustainability potential, time and effort is saved by design teams, who can focus on those areas where greatest financial return can be achieved.

The tool is simple to use and some of the reporting is automated, but its benefit cannot be optimised without an understanding and committed design team to interpret the results and follow its guidance.

2.3 Case Study

As a demonstration of the application and benefits of SIFT, the tool has been applied to a building case study (shown in Figure 3). The project was selected because it has been substantially built and has been recognised by national and international awards for its sustainability initiatives. It was tested by SIFT as if it were a new unknown proposal, using the key project details available at its outset.

Project name: Oasis Housing Development

Building type: Multi-unit residential

Location: Inkerman Street, St.Kilda

Budget: $45m

Gross floor area: 9 100m^2

Local government: City of Port Phillip

Figure 3 Case Study – Oasis Housing Development, Melbourne

Figure 4 shows the SIFT assessment result for Oasis. With a SIFT score of 6 out of 10, this project is considered to have reasonable potential to be developed as a financially feasible best-practice sustainable building. SIFT finds it has potential across most of the assessed parameters. One reason why the potential may have been slightly reduced across some of the areas of assessment was due to the building not being owner-occupied. Clients are typically more willing to invest in innovative sustainability strategies if they are also likely to benefit from the consequent ongoing operational cost savings, and occupant behaviours are more reliably predictable when the occupants can be identified and included in a development's genesis.

Whilst certain factors may have reduced the overall financial feasibility from ideal, potential for the overall project still remained relatively high. The areas that were identified as having the greatest potential to contribute towards achieving a best-practice sustainable outcome, whilst maximising the financial feasibility of the project, included:

- conservation, re-use and collection of water;
- reducing construction and operational waste;
- reducing replacement costs of services, central plant and services reticulation;
- reducing recurrent costs;
- incorporation of natural ventilation;
- maximising the use of public transport;
- local regulatory requirements, including sustainable design assessment using the local authority's STEPS assessment tool.

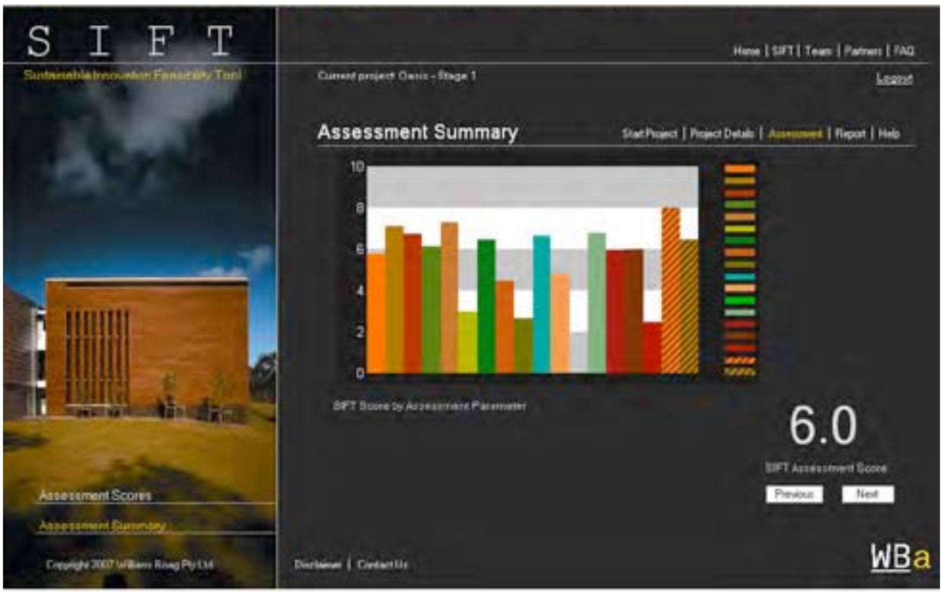

Figure 4 Assessment results of Oasis Housing Development case study

The SIFT tool allows a range of different building types to be assessed: residential, educational and commercial. Particular building types may have greater or lower potential than other building types due to factors such as level of servicing required for the function, hours of operation, scale or adaptive use possibilities. SIFT considers this variability and thus the score for particular building types will fall within a set range. For example, multi-unit residential projects are only capable of achieving a total score between two and eight (as shown below in Figure 5). A score of six is therefore quite high for this type of building.

Figure 5 Total score and possible score range for Oasis Housing Development case study

2.3.1 Built Outcome Validation

The SIFT assessment of the Oasis Project identified that it had reasonable potential and numerous opportunities for creating a financially feasible sustainable outcome. The assessment also identified the areas of greatest strength. The opportunities for integrating water conservation and re-use strategies and potential for achieving a significant return on investment for implementing them was assessed as being maximum (ten points out of ten). It is interesting to note that the built project includes an extensive grey-water treatment and recycling system, for which it has won numerous awards, including the United Nations World Environment Day Award 2000 and the Stockholm Partnership for Sustainable Cities Award 2002.`

Potential for incorporating strategies for natural ventilation was also found to be high and financially beneficial. In the actual buildings, the use of natural ventilation has been maximised through a system of vertical shafts and open areas throughout the building. This system allows every apartment to be naturally ventilated with hot air exhausted at the highest point of the building (Figure 6).

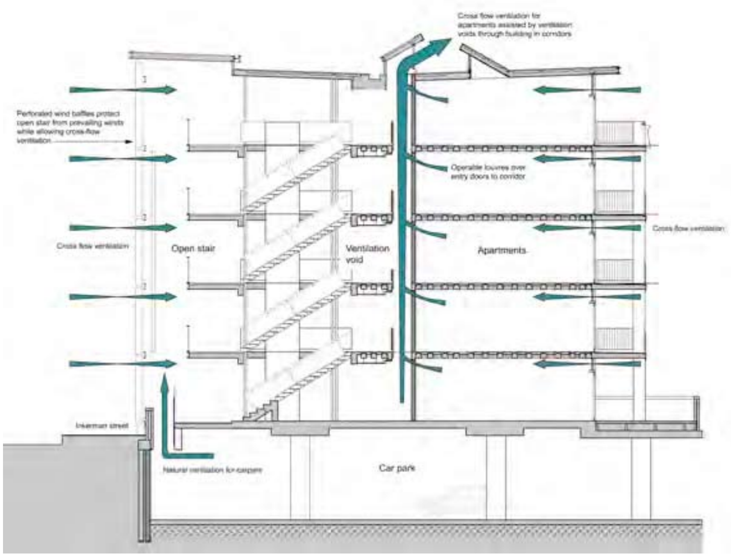

Figure 6 Oasis Housing Development ventilation strategy

The potential for a significant reduction in recurrent and replacement costs was rated high. One of the strategies used in the built project that embodies this is a centralised hydronic heating system. The advantage of this type of system is that it reduces operating, or recurrent, costs and also the costs associated with replacement of parts (Figure 7).

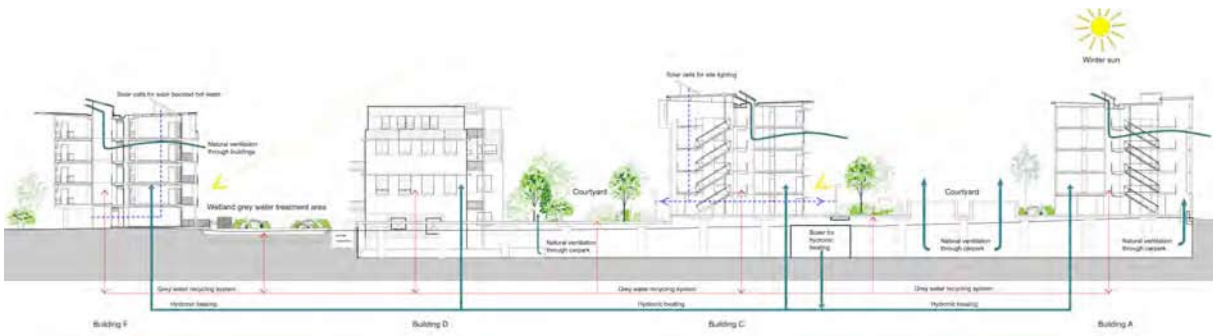

Figure 7 Oasis Housing Development centralised hydronic heating strategy

These examples illustrate a good correlation between what SIFT predicts is feasible and what was realised in the final commercial development.

2.4 Assessment Reporting

The tool provides an assessment of a project based on a total project score between zero and ten, and similar scores for each of the parameters. Whilst this output is useful in the first instance for identifying overall potential, it doesn't provide the level of information and detail required to address project opportunities or constraints and set realistic project goals. For this reason, it is necessary to expand these numerical values into a more descriptive explanation. The report is presented to clients and used by design teams to set project goals and focus on particular strategies. An excerpt of this report is shown below in Figure 8.

Detailed Opportunities

The following indicates potential opportunities that exist for maximising the financial feasibility of a sustainable building solution for this project.

Water

- The potential to reduce water use is high due to the large quantity of water traditionally consumed by this type of building.
- The potential for on-site rainwater collection is high due to the high availability of rainwater for this site chosen for the project and/or the large roof area of the proposed building.
- The potential for process water re-use is high due to the large quantity of water consumed and suitable for re-use.

Figure 8 Excerpt of report used to detail project opportunities

The final stage of the SIFT process involves the consultant team conducting detailed feasibility assessments of the possible solutions by quantifying the extent of life-cycle financial, social and environmental benefits associated with each and prioritising these for consideration in the building design.

2.5 Benefits

SIFT reduces some of the risks that are typically associated with sustainable building development by providing clients, investors and design teams with an understanding of the likely success factors for a particular project. By identifying these factors and areas of greatest and least potential at the earliest stage of a project, time and costs can be saved through the adoption of realistic and achievable project goals. It will help to avoid the common practice of overstating project goals only to have them dropped later in favour of capital cost savings when detailed analysis of a design proposal indicates the expected cost.

SIFT assessments can facilitate comparison of feasibility options or alternative building investment choices such as competing locations, such as different municipal areas or climate zones, the impact of varying payback period expectations and therefore rate of return, or alternative green building investment opportunities. SIFT assumes that a development is as environmentally progressive as possible so it is not a method of comparing the detail of a design.

The SIFT database captures the information and knowledge that is held by all members of the design team so that this information can be accessible to a much wider audience and applied to any project. The expertise and knowledge gained from previous projects is used to inform the database and improve future projects.

Initial validation has been performed by comparing the tool's outputs to the intuitive opinions of design teams for over ten projects. This process showed a close correlation between the opinions provided by the expert design team members of the likelihood for creating a best-practice, financially feasible sustainable outcome, and the outputs of the tool. Still in its late testing stages, the tool needs to be validated against built outcomes, however due to the long nature of building projects this process is likely to occur over an extended period of time.

2.6 Limitations

SIFT assumes a competent design or consultant team to interpret and implement results. It is not a checklist that guarantees results. SIFT does not rate how green a development may be; the base assumption is that the team will be striving for a high level outcome.

The outputs from SIFT are a numerical rating and descriptive advice. Although the assessment is a financial one it is about feasibility not actual cost so SIFT does not provide costings.

SIFT is currently only able to assess offices, multi-unit residential developments and primary, secondary and tertiary educational buildings across Victoria, Australia. Its coverage, of building functions and geographically, will be extended as data becomes more readily available and as the early stages are proven. A more streamlined tool is currently being developed that will enable the assessment of buildings worldwide.

3 Conclusion

Through considering of the whole-of-life consequences of design decisions, WBa's SIFT tool will enable clients, financiers and designers to identify early on the financial feasibility of achieving a best-practice sustainable development project. The tool makes it possible to identify the potential for creating a sustainable building, whilst prioritising the particular areas in which greatest potential exists for taking a sustainable approach to the design of buildings and systems that are also financially feasible. If the possible financial barriers and opportunities within a project are known, the risks associated with developing a sustainable building can be reduced.

SIFT differs from other ratings tools currently in the development industry in two key characteristics:

- It assess financial potential not green potential; and
- The assessment occurs before any design work is undertaken, on minimal data.

It is our hope that reducing risk will lead to increasing confidence and hence will encourage a greater number of building developers to take an uncompromising best-practice sustainable approach to their projects.

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INCORPORATION OF $LCCO_2$ ASSESSMENT TO CASBEE

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Keywords: CASBEE, $LCCO_2$, Assessment, Global Warming

Summary

Comprehensive Assessment System for Building Environmental Efficiency (CASBEE-2006) in Japan was already capable of assessing efforts to reduce the energy needed to operate buildings, utilize existing building structural frames and recycled construction materials, and extend the service life of buildings.

Such efforts can reduce CO_2 emissions from the production of construction materials (embodied CO_2), and reduce a building's Life Cycle CO_2 ($LCCO_2$) emissions, respectively. But Lifecycle CO2 was not directly counted in BEE (Building Environmental Efficiency) and CASBEE Rating.

New CASBEE-2008 incorporated a new item, "Measures for Global Warming," that can be rated by $LCCO_2$ emissions. $LCCO_2$ emissions are assessed in the simplified manner described in this report and reflected in item 1, "Measures for Global Warming" under "LR-3: Off-site Environment." These results also affect the radar chart, Building Environmental Efficiency (BEE), and CASBEE ranking directly.

As described above, new CASBEE is changed to explicitly assess measures for global warming. Further efforts to prevent global warming are expected to be promoted by the building sector.

1. Introduction

Global warming has become a very important issue. CASBEE-2006 was already capable of assessing efforts to 1) reduce the energy needed to operate buildings, 2) utilize existing building structural frames and recycled construction materials, and 3) extend the service life of buildings. Such efforts can reduce CO_2 emissions from the production of construction materials (embodied CO_2), and reduce a building's Life Cycle CO_2 ($LCCO_2$) emissions, respectively. Former CASBEE also had a column for optionally indicating $LCCO_2$ emissions, which was calculated separately by other LCA tool.[1)] But Lifecycle CO_2 was not directly counted in BEE (Building Environmental Efficiency) and CASBEE Rating.

New CASBEE-2008 incorporated a new item, "Measures for Global Warming," that is rated by $LCCO_2$ emissions. This paper outlines the new assessment.

2. Basic policy for reporting CASBEE efforts to fight global warming

An international trend in the building environmental efficiency assessment field is to require a more quantitative Life Cycle Assessment (LCA).

The LCA assesses various environmental aspects that are simultaneously related to multiple environmental impacts. For example, CFC emissions are related to ozone layer depletion and global warming, while energy consumption is related to the depletion of fossil fuels and global warming. The LCA assesses these impacts by integrating them into a single index in the result (such as the Life-cycle Impact assessment Method based on Endpoint modeling (LIME)).

Though CASBEE assessed energy savings using the Energy Reduction Ratio (ERR) in the "LR-1: Energy," which is related to the depletion of fossil, considering global warming is now a major concern, it was absolutely necessary to add new item "Measures for Global Warming" to the "LR-3: Off-site Environment" assessment.

3. Changes to the assessment steps in CASBEE

When the item "Measures for Global Warming (Global Environmental Measures)" was added to the "LR-3: Off-site Environment" assessment, the six items that comprised the LR-3 were re-organized and reduced to "Local Environmental Measures" and "Surrounding Environmental Measures " (Figure 1 and Figure 2). This allows explicit assessment of measures against global warming (reduction of $LCCO_2$ emissions) without significantly changing CASBEE's structure. It also allows these measures to be included in the calculation of Building Environmental Efficiency (BEE) and the evaluations of sustainable ranks "S: five stars" to "C: single star" (Figure 3).

4. Development of a simplified method for assessing $LCCO_2$ emissions in CASBEE

CASBEE aims to become as simple to use as possible, because many users for many types of buildings employ it. Accordingly, simplified "Standard Calculations" has been developed, which can estimate $LCCO_2$ emissions primarily based on items that already have been assessed in CASBEE. Moreover, if $LCCO_2$ emissions already have been accurately calculated using the published LCA tool,[1)-3)] then the calculated $LCCO_2$ emissions can be listed as "Individual Calculations."

The specific procedure for calculating $LCCO_2$ emissions is summarized below using an office building as an example.

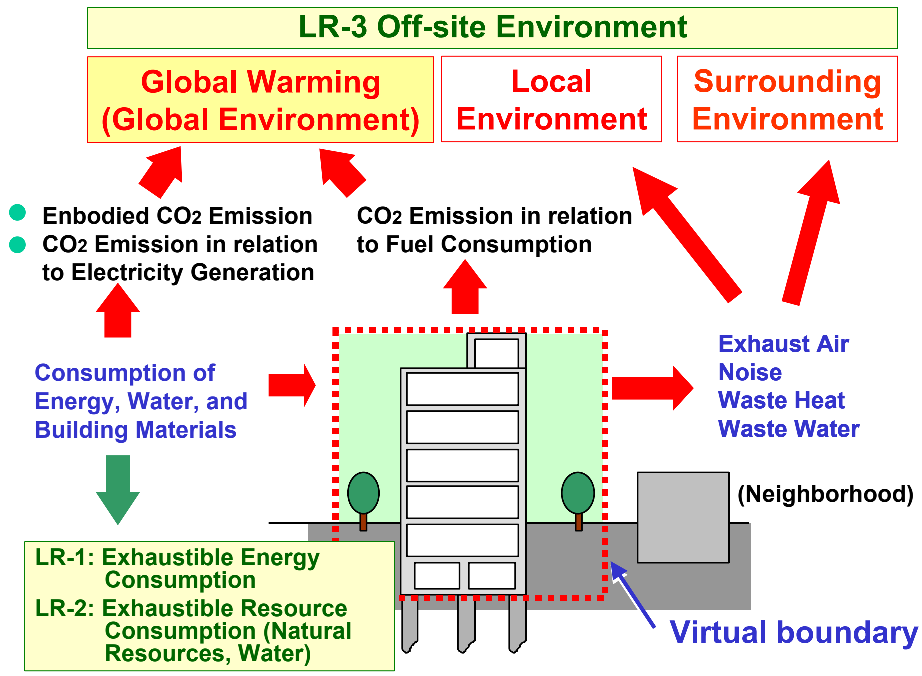

Figure 1. Arrangement of "Efforts to address global warming" and other items in the LR assessment

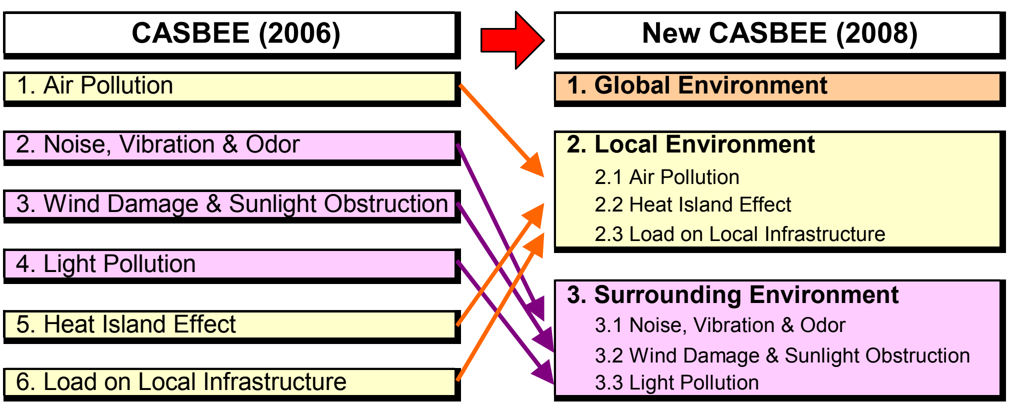

Figure 2. Re-arrangement of items in the "LR-3: Off-site Environment" assessment

Note: The ozone layer depletion is also a serious global environmental issue, but Japan already has implemented measures to this issue, so "measures for ozone layer depletion" falls under "2. Materials of Low Environmental Load" in the "LR-2: Resources & Materials" assessment.

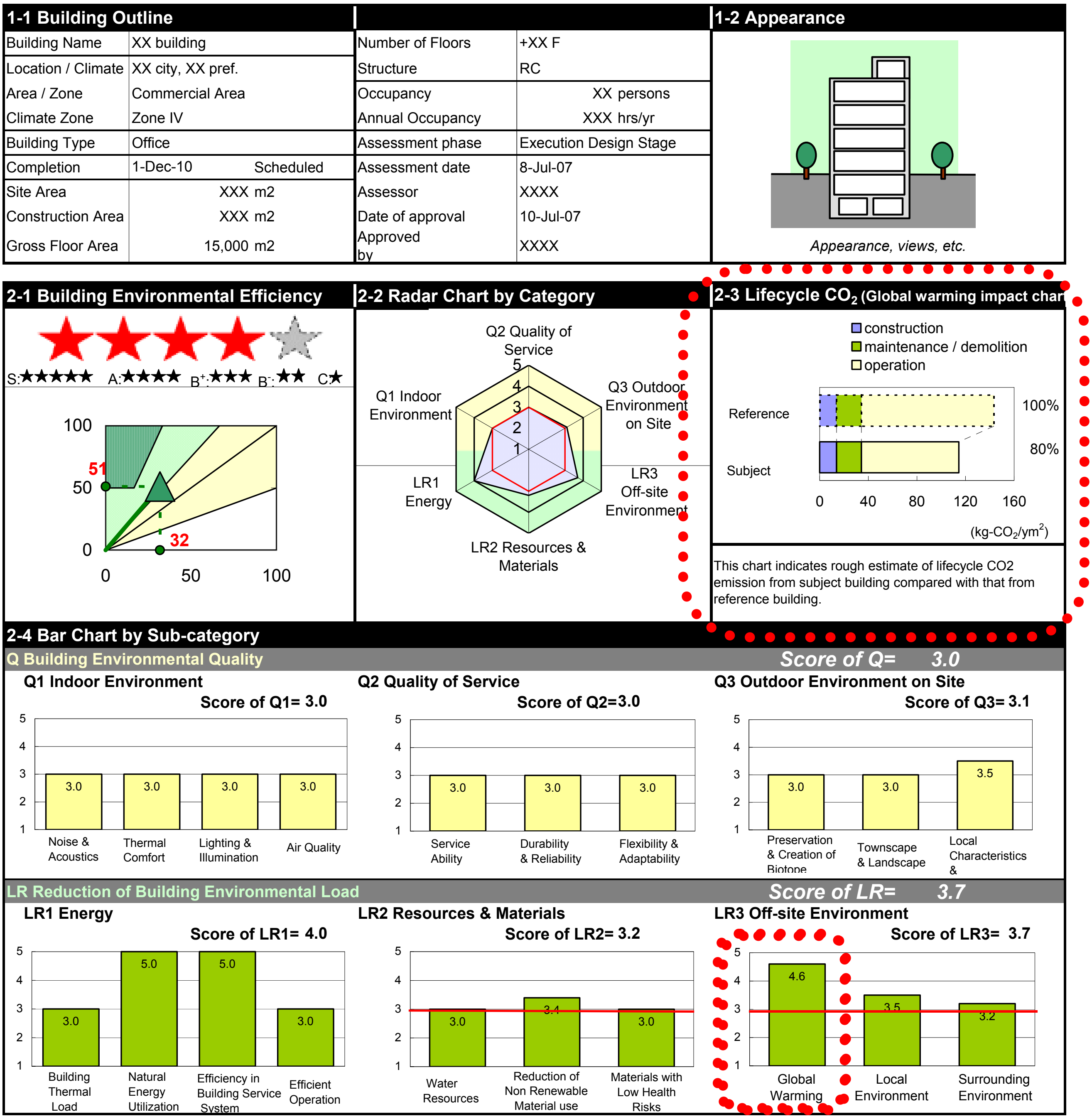

Figure 3. CASBEE (2008) Result sheet and Life Cycle CO_2 presentation

4.1 CO_2 emission units for building materials and energy

The CO_2 emissions units for building materials are listed in Table 1. Those for energy are listed in Table 2.

Table 1 CO_2 emission units for main building materials

Building Materials	CO_2 Emission Unit
Portland Cement Concrete	282.0 kg-CO_2/m^3
Blast Furnace Cement Concrete	206.0 kg-CO_2/m^3
Steel-frame	0.9 kg-CO_2/kg
Reinforcing Steel	0.7 kg-CO_2/kg
Mold Form	7.2 kg-CO_2/m^2

Note:

The data that is used for the Architectural Institute of Japan's LCA tool is also used for the CO_2 emission units for building materials.

Four types of emission units based on an inter-industry relations analysis are defined for the tool. This paper uses the "CO_2 emission units based on domestic consumption expenditures," which take into account the narrowest range of the ripple effect.

Table 2 CO_2 emission coefficients for energy

Energy	CO_2 Emission Coefficient		
Electric	0.555	kg-CO_2/kWh	
	0.0569	kg-CO_2/MJ	1kWh=9.76 MJ (primary energy)
City Gas	0.0506	kg-CO_2/MJ	
Kerosene	0.0678	kg-CO_2/MJ	
Grade A crude oil	0.0693	kg-CO_2/MJ	

Note: The CO_2 emission coefficients are based on the Law Concerning the Promotion of Measures to Cope with Global Warming.

4.2 Calculating $LCCO_2$ emissions for a reference building

(1) Factors assumed for the reference building

CASBEE uses a five-level rating system for each item and sets Level 3 as the standard level in Japan. The ideal standard building, in which all of the items in the CASBEE assessment are at Level 3, is assumed. $LCCO_2$ emissions from a subject building are compared to the reference value for this reference building.

(2) Service life of buildings

The service life of office buildings is set at 60 years. Efforts to extend the service life of buildings other than residential buildings are not considered.

(3) CO_2 emissions from construction materials

The quantity of construction materials used for ordinary buildings in Japan is determined from statistical data[4)] for each type of building and structure. The typical quantity of major construction materials used for the structural frames of office buildings is listed in Table 3 by the type of structure.

CO_2 emissions from construction materials during the construction, operation, renovation, and demolition phases (Table 4) are calculated using the Architectural Institute of Japan's LCA tool.[2)] The default values of the tool are used for the quantities of interior and exterior finishing materials, the equipment used, and the conditions for renovation and repair.

Table 3 Quantity of major structural materials

Building Type	Structure	Concrete m^3/m^2	Steel-frame t/m^2	Reinforcing Steel t/m^2	Mold Form m^2/m^2
Office	SRC	0.696	0.100	0.078	0.668
	RC	0.772	0.038	0.103	1.050
	S	0.567	0.136	0.070	0.433

Table 4 CO_2 emissions during construction, operation, renovation, and demolition phases

Building Type : Office Building	Structure			Measures
Phase	S	RC	SRC	
Construction Phase	817	831	835	kg-CO_2/m^2
Value per Durable Years (60 Years)	13.61	13.85	13.92	kg-CO_2/(m^2.a)
Operation, Renovation and Demolition Phase	1,214	1,240	1,223	kg-CO_2/m^2
Value per Durable Years (60 Years)	20.23	20.67	20.39	kg-CO_2/(m^2.a)

(4) CO_2 emissions due to energy consumption in the operation phase

Using statistics[5)] to determine the amount of primary energy consumed during building operations, the standard value of a CO_2 emission unit per floor area during operations is determined. The following values are used for an office building.

Primary energy consumption unit = 1,936 MJ/(m^2.a)

CO_2 emission unit = 109 kg-CO_2/(m^2.a)

(5) Calculating $LCCO_2$ emissions

Based on the conditions described above for a reference building, $LCCO_2$ emissions for the reference building are calculated using the Architectural Institute of Japan's LCA tool and applied as reference values according to building use and type of structure.

4.3 Method of calculating $LCCO_2$ emissions for the subject building

(1) Extension of service life

In item "2.2.1 Service life of building structural frames" of the "Q-2: Quality of services" assessment, apartment buildings are assessed in accordance with the "Rating of buildings for measures against deterioration" of the Japan Housing Performance Indication Standards. Based on the results of the assessment, the service life of an apartment building is set at 30, 60, or 90 years.

Because it is difficult to assess quantitatively and concretely the results of measures to extend the service life of a building, the effects of such measures are considered only for apartment buildings.

(2) Reuse and recycle

Reusing and recycling construction materials can reduce $LCCO_2$ emissions. Typical examples of this are the reuse of an existing building's structural frames and blast furnace cement.

The effects of reusing/recycling 100% of an existing building's structural frames and blast furnace cement are calculated using the LCA tool described above. The values are stored in a database, as shown in Table 5. In a practical sense, the effects are calculated from the ratio of utilization of an existing building's structural frames and blast furnace cement.

Table 5 CO_2 emissions after reusing/recycling building materials

Building Type : Office Building	Utilization Ratio	Structure			Measures
		S	RC	SRC	
Construction Phase					
In Case that Existing Structure is Reused	100%	392	400	394	kg-CO_2/m^2
Value per Durable Years (60 Years)		6.54	6.67	6.57	kg-CO_2/(m^2.a)
In Case that Blast Furnace Cement is Reu	100%	763	756	769	kg-CO_2/m^2
Value per Durable Years (60 Years)		12.71	12.60	12.81	kg-CO_2/(m^2.a)

(3) Energy savings in the operation phase

CASBEE assesses the energy savings of buildings using the Perimeter Annual Load (PAL) and the Coefficient of Energy Consumption (CEC) under the Energy-saving Law. CASBEE also assesses the Energy Reduction Ratio (ERR) of primary energy consumption of an entire building using the denominator and numerator of the CEC for the air-conditioning, ventilation, lighting and hot water supply systems, and elevators. The CO_2 emissions from energy consumption during building operations are estimated using the following procedure.

(i) Calculate the reference value of the CO_2 emission unit from the primary energy consumption unit using the statistical data in Section 4.2 (4).

(ii) The thermal insulation performance and sunshine shielding level of a building's exterior walls under the Energy-saving Law are specified by the PAL (MJ/(m^2.a)). Estimate the reduction in primary energy consumption due improvements in the performance of the subject building's exterior walls based on the difference between the reference value of the PAL and the calculated value for the subject building.

(iii) The energy efficiency of building equipment is prescribed by the CEC for the air-conditioning, ventilation, lighting and hot water supply systems, and elevators under the Energy-saving Law. Determine the ERR of the entire building using the CEC.

(iv) Estimate the reduction in primary energy consumption (MJ/(m^2.a)) due to the use of natural energy systems, such as solar power generation.

(v) An additional reduction (5% maximum) of primary energy consumption can be assumed by improving the monitoring and operational management systems so that building operations are more efficient.

(vi) Estimate primary energy consumption in case of taking measures for energy-saving by this procedure, and then convert this value into CO_2 emissions (kg- CO_2/(m^2.a)).

The factor for converting primary energy consumption into CO_2 emissions is determined from the average ratio by energy type for each building type and the appropriate CO_2 emission coefficient of energy from Table 2. For example, the conversion factor for an office building is 0.0563 kg-CO_2/MJ.

(4) Method of rating buildings for "global warming" impact according to $LCCO_2$ emissions

The subject building is rated on a 1-to-5 scale according to $LCCO_2$ emissions. A score of 5 (the highest) is given when the $LCCO_2$ emissions of the subject building are 75% or less of those of the reference building, while a score of 1 (the lowest) is given when the $LCCO_2$ emissions of the subject building are 125% or more of those of the reference building.

5. Case Study

Before New CASBEE-2008 was formally released, the case study was executed in 18 buildings. The relation of LCCO2 emission and BEE is shown in Figure 2. BEE value is relatively small in buildings of large LCCO2 emission, i.e. such buildings are un-sustainable.

Some buildings are able to reduce LCCO2 emission to about 70% and become "S" rank sustainable buildings. However, when there are little approaches in other issues, BEE is not necessarily high ranks even if the LCCO2 emission rate is low.

6. Conclusions

(1) A "Standard Calculation" function is added to CASBEE to estimate $LCCO_2$ emissions in a simplified manner based on input data that is similar to conventional data.

(2) As per the basic concept of CASBEE, the standard method of assessing $LCCO_2$ emissions is simplified wherever possible.

(3) A new item, "Measures for Global warming," has been added to CASBEE. This item allows $LCCO_2$ emissions to directly affect BEE value and CASBEE's sustainable ranks "S: five stars" to "C: single star."

(4) If $LCCO_2$ emissions already have been accurately calculated using the published LCA tool [1)-3)] then the calculated $LCCO_2$ emissions can be listed as "Individual Calculations."

CASBEE quantitatively determines $LCCO_2$ emissions and explicitly assesses measures to prevent global warming. Further efforts by the building sector are expected to promote them.

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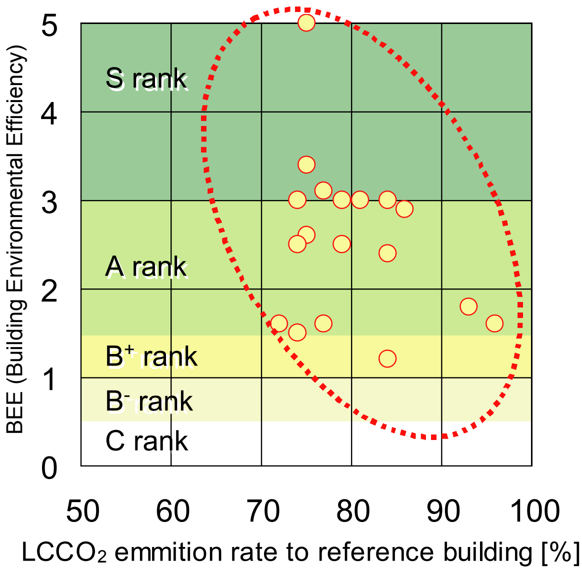

Figure 3. Relation of LCCO2 emission and BEE in case study

PLANNING THE ECO-CITY IN CHINA – CHALLENGES AND OPPORTUNITIES

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Summary

During the past two decades, China's GDP has been rapidly increasing. This achievement, however, has given rise to problems of net energy imports, environmental pollution and ecological destruction at home, cross-border pollution, and mounting carbon dioxide (CO2) emissions. To reduce the impacts of development on the physical and social/cultural environment, a sustainability approach is needed to be adopted.

Green building design is becoming mainstream in China. At policy and regulatory level, China has implemented mandatory building energy standard throughout country, aiming to reduce the energy use in buildings by 20% by year 2010. Recently, China has also implemented voluntarily its green building standard issued by the Ministry of Construction, the Assessment Standard of Green building. Yet implementing this standard into the design and construction details is difficult within the context of China. This paper addresses the detail approaches on design strategies and construction site management to achieve the requirements of sustainable development through case study.

Cases for study for Sustainable development of are the Changxindian in Beijing and TangShan in Beijing and Dongtan in Shanghai developments. These projects symbolise the commitment of China to the environment and the society, and showcases the integrated approach to green building, energy planning, utilization of renewable energy to support the principles of the Sustainability Framework developed.

1. Introduction

Due to the rapid urbanisation in recent years, China is now one of the biggest consumers of oil, gas and coal and the government is eager to see the country back away from a growing dependency on imported energy (THUBERC, 2007). Recent studies have also shown China to be the least energy-efficient of the world's major economies, using several times as much fuel for each unit of output as the United States, Japan or European countries according to the China Energy Statistical Yearbook 2006. China is also home to several of the world's most polluted cities – mostly due to power plants burning vast amounts of dirty coal to power the country's rapidly growing cities.

In order to change the situation, all of the efforts are being made to build a stable, economical, safe and clean energy supply system which safeguards China's energy security efficiently. The Central government, led by Premier Wen Jiabao and Vice Premier Zeng Peiyan, has setup a team tasked with ensuring the country's energy consumption and pollution reduction targets stated in the Chinese government's 11th (year 2006-2010) Five-Year Plan are met. China has set a goal of reducing energy consumption per unit of GDP by 20 percent by 2010. The National Development and Reform Commission is taking this lead on (1) allocating the target among provinces and industrial sectors, and (2) adopting energy efficiency improvement criteria for evaluating the job performance of local government officials.

As building industry is one of the biggest energy consuming sectors, improving energy efficiency of buildings is pivotal for China in achieving its goal of creating a resource-saving society, according to Minister of Construction (MOC). The MOC indicated that the country will focus on the building energy conservation, targeting at the energy resources, land uses, water and building materials (the four savings) (Wang, 2005).

In fact, the implementation of the energy law and the green building standards in the market has encouraged the adoption of energy efficient designs and renewable energy for building design. Green or sustainable buildings are now a key consideration in new building developments in China. State-of-the-art technologies have been tested and adopted in this biggest building market.

2. Cases Study of Eco-city

Figure 1 Planning of 21st Century Cities.

The overarching vision for both Tangshan, Changxindian and Dongtan is to create a world-class sustainable city that is responsive to the needs of economic growth, accommodates demographic trends and, at the same time, places environmental and social sustainability at the core of the developments objectives. These objectives are summarised as follows:

- To preserve the natural habitat
- To create an integrated, vibrant and evolving community
- To improve quality of life and create desirable lifestyles
- To create an accessible city
- Managing the use of resources in an integrated manner
- Working towards carbon neutrality
- Utilising governance to achieve long term economic, social and environmental sustainability.

3. Strategies to Make Eco-City Sustainable

3.1 Sustainability Framework

The early stages of the sustainability strategy has involved the following: the identification of high level objectives and prioritized themes; the development of design targets and feasibility studies to support the masterplan; testing the feasibility of achieving the targets; and producing integrated design solutions which include sub-strategies for topics such as energy, water resources, waste and materials. A set of specific sustainability objectives relating to social issues, economics, the environment and natural resources was identified. These objectives are detailed in the sustainability framework document, which provides a strategic decision making tool for the project (Fig. 2). In particular, energy management is the key aspect to be considered.

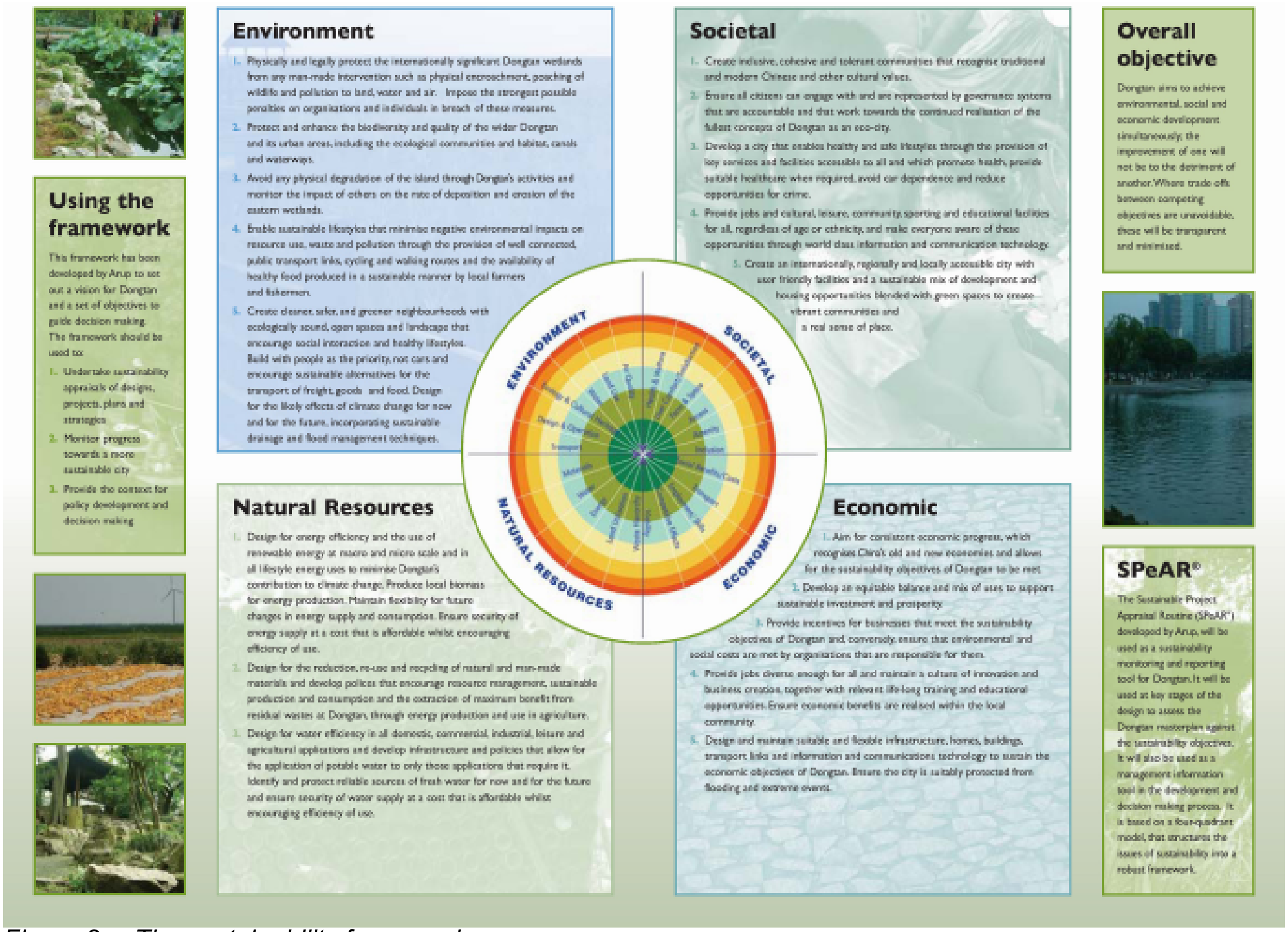

Figure 2 The sustainability framework.

3.2 Energy Strategy

The following specific targets for energy strategy have been set:

- To limit energy demand levels to a level representing a fair "Earth Share" as assessed using the Eco-Footprint methodology.
- An average reduction in overall electrical & transport energy demand of at least 66% across all energy consuming sectors compared with a defined "baseline".
- To provide Carbon Neutral Energy supply to all sectors.

The demand reduction target is based on the need to reduce the Business As Usual (BAU) new-build Eco-Footprint of Shanghai down to a fair "Earth Share". For the energy use within the Eco-city, this means a demand reduction of the order of 66% as compared wit the current standards in China. There will be other energy uses off site consumed by the manufacture of products, and for off-site services used by Eco-City occupants that are not covered by this target. The development will seek to influence the choice of these latter energy uses by Eco-City occupants, and may contribute to off-setting these to some degree by exporting energy generated onsite from renewable sources.

In addition to the above targets related to macro scale sustainability, it is intended to maximise air quality in the urban areas of Eco-city. This would require the elimination of combustion emissions, whether from heat generation plant, electricity generation plant, vehicle internal combustion engines or from open flame cooking (due to the adverse effect on indoor air quality) in the built up areas. This is subject to continuing discussions, and may need a phased introduction with the targets for the first phase being the elimination of building emissions from heat and electricity generation plant, and from public transport vehicles.

3.3 Implementation of Energy Strategy

Achieving successful implementation of low and renewable energy developments relies to a large extent on correct implementation of an energy hierarchy. The priorities, in terms of achieving the ultimate goal, are set out below in the order in which they should be implemented:

- Reduce demand (in particular for electrical energy).
- Maximise efficiency (by fully exploiting the heat by-product of electricity generation).
- Generate energy from renewable sources.

In addition to the above electrical energy demand, the design of Eco-city also intends to meet the energy needs of on-site transport from renewable sources. In strategic terms the energy reductions are achieved as follows:

- Reducing energy demand through best practice architectural design.
- Limiting the areas provided with energy intensive systems, and limiting the allowable installed capacity of energy intensive systems.
- Switching where appropriate to heat powered systems, instead of electrical powered systems.
- Influencing the product purchasing and lifestyle choices of the occupants.

3.3.1 Reducing energy demand

The buildings will be designed to reduce demand using best practice design for low energy buildings, including the following features.

- Modest window areas.
- Building orientations optimised for the type of building, e.g. more glazing to the north to reduce cooling requirements.
- Shading overhangs to avoid most of the direct solar gain in the summer.
- Passive cooling techniques using night ventilation provision coupled to room exposed thermal mass to minimise cooling needs (Fig. 3).
- An airtight building envelope to reduce summer hot air infiltration and winter heat loss through draughts.
- Entire structure contained within thermal insulation “overcoat” building envelope to enhance thermal insulation, and to avoid envelope thermal bridging.
- Internal heat gains minimised to reduce direct electricity use and to reduce the amount of air-conditioning needed.
- Low energy rated domestic & commercial appliances, and labeling systems to help purchasers and installers to select products that achieve sufficiently low energy demand.
- All electronics will have low standby power requirements.
- Lighting will have low energy fittings, “low voltage” & tungsten lamps will be avoided, and automatic daylight sensing will be used for non-domestic room lighting.
- Centralised air-conditioning systems will have low ductwork pressure, very good fan efficiencies, and hence low fan powers.

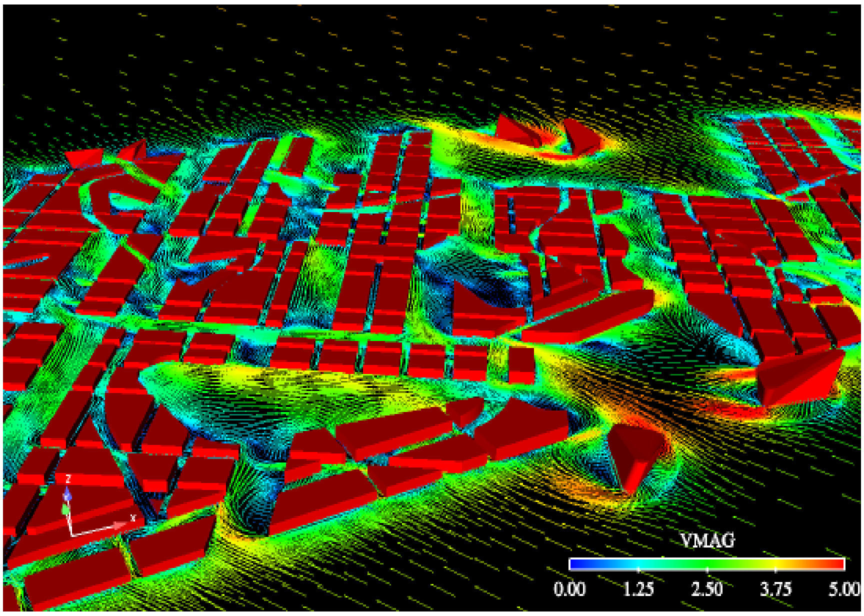

Figure 3 Wind analysis on different building disposition scheme.

Energy used in transportation also accounts for a great portion of energy demand. The target reduction is also 66% for on-site transport energy. This scale of reduction is needed for it to be practical for all on-site transport energy to be sourced from renewable energy power generation centre. Much of the transport energy reductions are related to “modal switch” created by the masterplaning, in other words, designing Eco-City in such a way that occupants and visitors regard walking, cycling and public transport as more convenient for access to facilities than private car use.

The aspiration for “Zero Tailpipe Emissions” from transport seeks to avoid local particulate and gaseous pollution. This may be achieved using either electrically powered vehicles, or hydrogen-powered vehicles, assuming current technology has developed sufficiently for a proportion of public transport to be hydrogen powered. The Eco-City Combined Heat & Power (CHP) plant has been sized so it has sufficient renewably generated electricity capacity to serve all the projected on-site transport: either as electric powered vehicles, or by using the electricity to create hydrogen.

In practical terms this way of manufacturing hydrogen may have to be done at a specialist facility remote from the Eco-city using electricity that is fed via the Grid from the CHP plant.

If some selected transport types prove unsuitable for running on direct electricity or hydrogen for Eco-City’s first phase, then the renewably generated CHP electricity intended for transport would be available for export. It would, in effect, become a carbon offset for any fossil fuelled vehicles.

A further renewable energy proposal worthy of more investigation is the provision of a bio-diesel vehicle service station at the car parks immediately outside Eco-City. If the bio-diesel were to be sold at a price that slightly undercut normal fossil fuel diesel price in China, it would encourage use of bio-diesel in vehicles traveling outside the eco-city: particularly for Eco-City occupants with a car, as well as for visitors and anyone making deliveries to the Consolidation Centre.

3.3.2 Efficient energy generation

Typically, buildings are demanding increasingly large amounts of electricity, and less heat; yet the former is the most inefficient form of energy to generate. Generating “high-grade” energy in the form of electricity from any source is inherently relatively inefficient due to basic laws of physics. Power stations have typical efficiencies ranging from 15% to 45%. Higher conversion efficiencies can be achieved when the by-product of electricity generation, namely “low-grade” energy in the form of heat, is produced and then used immediately. This makes much better use of the primary fuel.

The most efficient conversion is achieved when a large proportion of useable heat is produced alongside the electricity using a Combined Heat and Power plant (CHP). This can allow efficiencies of as high as 80% to be achieved. In practical terms the limitation is the extent to which the heat is useful and compatible with building demands. This means that wherever possible building systems that operate on heat should be chosen, and the amount of electricity needed should be minimised. In order to use this heat the power station needs to be in close proximity to the buildings, as they have to be linked with district heating pipework.

Thus, in principle the buildings for Eco-City will be designed to use heat for all space cooling, space heating and hot water demand. Systems that only use electricity will be restricted as far as possible.

Figure 4 Electricity supply infrastructure.

3.3.3 Renewable energy sources

The target of carbon natural can be achieved by employing renewable energy source. The primary energy sources have been prioritised as follows:

- Maximise large-scale on-site renewable electricity generation. This takes the form of large scale wind turbines positioned and PV farm. This reflects the fact that the largest proportion of energy demand is in the form of electricity.
- Maximise small-scale renewable electricity generation which is integrated into buildings. This is expected to be in the form of building mounted photovoltaic solar panels and micro wind turbines (Fig. 5).
- Energy from a centralised Anaerobic Digestion (AD) sewage treatment plant is expected. It is expected that the electricity generated will be sufficient to serve the energy demands of the water supply and distribution, and the sewage collection and treatment. This means that both these systems will be “net zero energy”.
- The majority of the electrical needs of the development will be met by a biomass fuelled Combined Heat & Power plant located in the Energy Centre. The low-grade heat produced as a result of this electrical power generation should satisfy all the developments heat requirements.

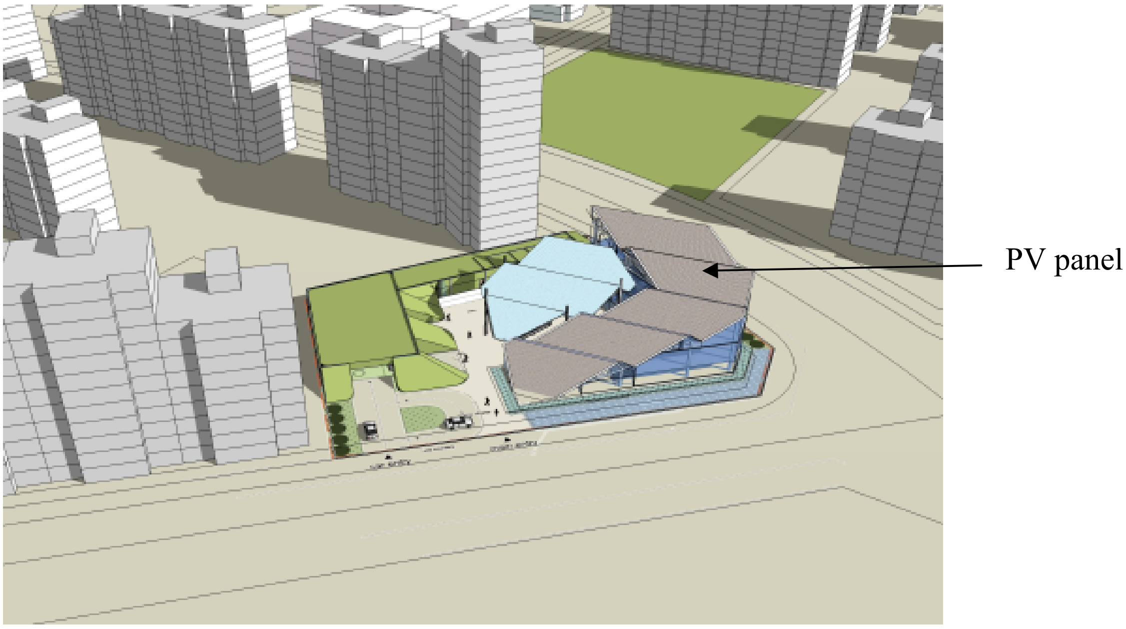

Figure 5 Local small-scale renewable electricity generation.

The aim is to use any surplus CHP renewable energy capacity to contribute to a “Carbon Offset” fund. It can contribute to reduce CO2 emission (Haeseldonckx, 2007). This might then be used to offset the carbon emissions incurred during construction and in the manufacture of materials for eco-city. Alternatively, this might be used to offset to some degree the carbon emissions identified in the Eco-footprinting related to off-site goods and services used by Eco-City occupants. In practical terms this means that the CHP would be able to sell its excess renewably generated electricity onto the Grid for supply to areas outside the Eco-city.

3.3.4 Occupant Influence

Eco-City occupants and their lifestyles will have a significant impact on the eventual energy use in the city. The proposed building design energy demand reductions will result in the majority of the remaining energy demands being directly influenced by occupant lifestyle.

Experience form around the world suggests that in practice the actual operational energy use of buildings is often much higher than estimated by the design energy use calculations. Therefore, to establish a more accurate benchmark, additional energy allowances have been included, based on monitored building energy data, in the operational energy use estimates for the BAU case.

Occupants normally choose their own entertainment systems, and there is a growing trend for large format televisions and music systems in main living spaces, and secondary televisions in other habitable rooms. These are often left on for extended periods, and even when not in use can consume significant energy in standby mode. Likewise, occupants tend to choose white goods, hot water appliances, showers, supplementary lighting, AC and cooking appliances, all of which have a significant impact on overall energy use. Most occupants are unaware of the significance of their choices: a key factor to achieving the Eco-City will be educating occupants. This will need to be combined with co-operation from product supply chains who need to ensure there is a full range of clearly labelled, and well marketed low energy products available. This may need to be managed through governance by introducing appropriate incentives and penalties.

It should be noted that the targets have been set against a baseline of actual demand including the Operational Rating of the buildings. The Operational Rating reflects the way buildings are constructed and operated, and is normally higher than the building design calculated energy consumption. The building design calculation, termed here as the Asset Rating, often uses local construction regulations and tends to simplify energy use in buildings. The difference between these two energy consumption figures comes about for a number of reasons: what is built is not to the standard anticipated by the building designer, and construction regulations tend to simplify energy use, often ignoring such aspects as building envelope air tightness and thermal bridging, and the way occupants use the buildings which rarely represents the idealized assumptions used in building design.

3.3.5 Overall

The overall targets have been set to achieve a 66% reduction in annual energy use compared with typical new build in China. To achieve this, the buildings are expected to reduce their electrical consumption by more than 75% and extensively use waste heat available from the electrical power generation. This energy will be provided from renewable sources such as biomass and wind, which is expected to result in negligible fossil fuel use, and also negligible net CO2 emissions. The electrical power generation is also intended to deliver some excess renewably generated electricity for use elsewhere in Shanghai, thereby providing an additional ‘carbon offset’.

3.4 Ecological Footprint Assessment

Aforementioned, the city has an objective to be zero-carbon in operational energy from the outset, through a combination of energy efficiency measures, renewable energy generation, a hydrogen powered transport, methane collection from organic waste, and self-sustaining local food production. In order to assess the level to which the city will achieve its zero-carbon objectives, a comprehensive Eco-footprinting calculation (Chamber et al, 2004) has been carried out using Integrated Resources Modelling (IRM), which was developed from the outset as a decision support tool based on resource supply and demand. The results from the assessment shows that Eco-City reduces the ecological footprint to 2.7 global hectares per person (gha/capita), which is 56% lower than BAU (6.2 gha/capita).

Energy demand for buildings and transport within the city limits will not require the use of fossil fuels apart from for cooking. Moreover, the energy centre will generate an on-site renewable off-set. In other words it exports spare site-generated renewable electricity for use by others in Shanghai so reducing their carbon emissions by an amount equivalent to the carbon emission of the cooking gas used in eco-city. Consequently CO2 emissions are entirely sequestrated into the renewable fuel sources and do not contribute to greenhouse gas effect, as they are part of a closed loop exchange cycle.

4. Conclusion

Due to the rapid urbanisation in recent years, China is now one of the biggest consumers of oil, gas and coal and the government is eager to see the country back away from a growing dependency on imported energy. Recent studies have also shown China to be the least energy-efficient of the world's major economies, using several times as much fuel for each unit of output as the United States, Japan or European countries. In order to change the situation, all of the efforts are being made to build a stable, economical, safe and clean energy supply system which safeguards China's energy security efficiently.

Eco-city symbolises the commitment of China to the environment and the society, and showcases an example of an integrated approach to green building, energy planning, utilization of renewable energy are incorporated to support the principles of the Sustainability Framework developed. Specific improvements have been made to Energy, these are:

- To provide carbon-neutral energy supply to all on-site sectors.
- To reduce overall electrical and transport energy demand by more then two thirds, shared across all energy consuming sectors compared with a defined "baseline".
- To provide net 100% of energy demand from renewable sources.
- To limit on-site operational energy demand levels to a level representing a fair "Earth Share" as assessed using the Eco-Footprint methodology.

Based on the results from the Ecological Footprinting Assessment, Eco-City reduces the ecological footprint to 2.7 global hectares per person (gha/capita), which is 56% lower than BAU (6.2 gha/capita). Energy demand for buildings and transport within the city limits will not require the use of fossil fuels apart from for cooking. Moreover, the energy centre will generate an on-site renewable off-set. In other words it exports spare site-generated renewable electricity for use by others in Shanghai so reducing their carbon emissions by an amount equivalent to the carbon emission of the cooking gas used in eco-city. Consequently and CO2 emissions are entirely sequestrated into the renewable fuel sources and do not contribute to greenhouse gas effect, as they are part of a closed loop exchange cycle.

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EVALUATION OF GLOBAL WARMING MITIGATION MEASURES IN THE RESIDENTIAL AND NON-RESIDENTIAL SECTORS OF A SUBURBAN CITY IN JAPAN

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Keywords: residential and non-residential sectors, suburban, low-carbon society, simulation

Summary

In Japan, CO_2 emissions from the residential and non-residential sectors have increased significantly. This paper focuses on reducing CO_2 emissions in suburban areas, where little attention has been paid to the management of CO_2 emissions even though the building stock in suburban areas accounts for a large percentage of the country's total. In this paper, we conduct a case study to estimate potential reductions in CO_2 emissions from the residential and non-residential sectors of Toyonaka city, Japan, considering technological advancements and dissemination of energy-saving technologies as well as the management of building stocks. This study on Toyonaka city, a typical suburban city, is relevant to addressing future challenges in finding ways for shifting Japanese suburban areas toward a low-carbon society. The results of the case study show that a CO_2 emission reduction by more than 50% of the current levels is achievable by combining these measures for the residential and non-residential building sectors and managing building stocks, along with an expected population decrease in Toyonaka city, which account for one-fifth of the reduction.

1. Introduction

Reducing CO_2 emissions has become an urgent challenge. The management of energy demand in the residential and non-residential sectors is imperative in Japan, as these sectors have been the main contributors to the current increase in national CO_2 emissions. The total floor area in the non-residential sector in major cities (23 wards in Tokyo, Osaka, and Nagoya) occupies 15% of the total floor area in Japan, while households in major cities account for 12.5% of households in Japan (Statistics Bureau. 2000). This means that the majority of buildings in the residential and non-residential sectors are built in suburban cities. Thus, it is important to find a vision for a future low-carbon society in Japanese suburban areas and pathways to realize the vision.

When we imagine the future of a suburban city in Japan, we cannot ignore the trends in decreasing and aging population and decreasing number of households. These changes might result in a decrease in the demand for housing and changes in the demand for businesses and services. In addition, due to the decades-long lifetime of buildings in the residential and non-residential sectors, buildings that are constructed in the next few decades are likely to still exist in 2050. While adapting to these trends, we have to manage our building stocks and infrastructure to reduce CO_2 emissions to a large extent. It is important to find development pathways with synergy between the management of carbon emissions and building stocks. For example, we can avoid declines in the quality and efficiency of administrative services that can be expected due to a decrease in the density of residents per land area by managing housing locations and density appropriately.

The purpose of this paper is to quantitatively evaluate various energy-saving measures and implementation strategies for building stock management, with the objective of creating future visions of a low-carbon society with CO_2 emissions reduced by more than 70% from the current level. For this purpose, we developed a simulation model that estimates energy use in the residential and non-residential sectors of Toyonaka city. We estimate CO_2 emissions in 2050 based on assumptions regarding technological advancements, dissemination of energy-saving technologies, and management of building stocks, with the purpose of quantifying potential reductions in CO_2 emissions by pursuing different pathways in the next decades. In this paper, we first introduce Toyonaka city and the current situation of its building stocks. We then describe the methodology of this study, including simulation models and cases designed in this study. We finally derive some implications based on the results of the case study.

2. Case study area: Toyonaka city

Toyonaka city has an area of 36.6 square kilometers with a population of 390,000 in 159,000 households. This city has prospered as a bedroom suburb of the Osaka urban area. The population size is decreasing, while the number of households has increased, especially those housing families with few members. The residential and non-residential sectors account for 58% of the current emissions from the city. The authority of Toyonaka city has currently explored the feasibility of reducing CO_2 emissions by more than 70% compared with 1990 levels by 2050 (Toyonaka city. 2007).

Figure 1 shows the regional partition of Toyonaka city. The city is divided into seven regions according to the Master Plan of the Toyonaka City (Toyonaka city. 2000). Table 1 shows the total floor area of buildings in the residential and non-residential sectors for each region. The North-central, Central, and East regions of Toyonaka city can be characterized by their high proportion of building stock in the residential sector. The Northeast and Western regions have a business district, while approximately 70% of the building stock is occupied by residential sector buildings.

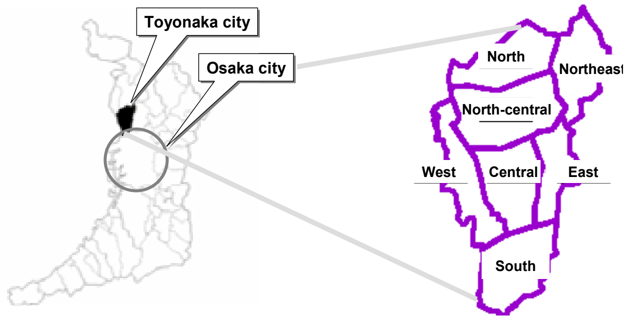

Figure 1 Location of Toyonaka city, Osaka, and regional partitions

Table 1 Seven regions of Toyonaka city

Regional Partition	Ratio of total floor area			Total floor area [1000 m^2]	area [km^2]
	Detached houses	Apartments	Non-residential sector		
North	38%	42%	19%	2,091	5.0
Northeast	15%	54%	31%	2,562	4.8
North-central	52%	35%	12%	3,930	7.0
Central	43%	42%	15%	3,414	5.2
West	31%	32%	37%	1,052	5.0
East	22%	67%	11%	1,605	3.9
South	46%	30%	24%	2,724	5.7

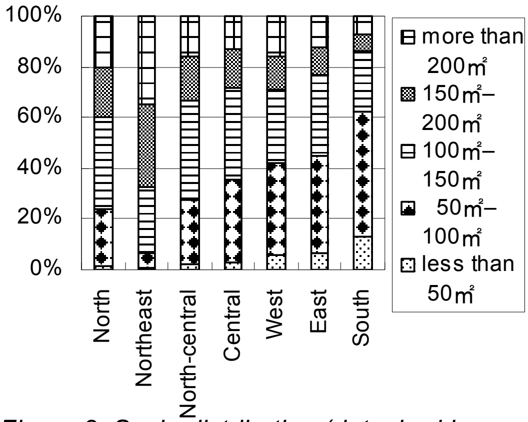

Figure 2 Scale distribution (detached houses)

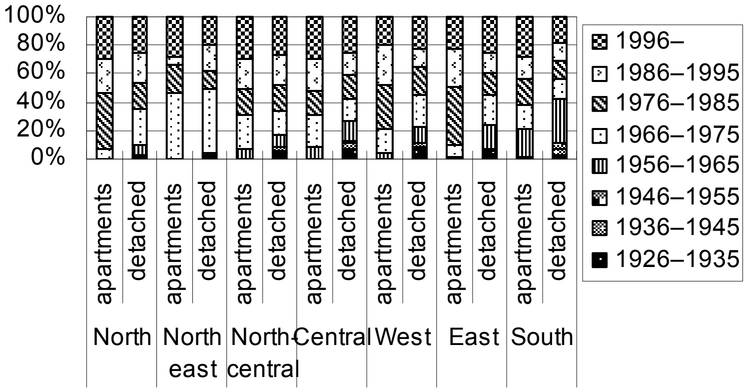

Figure 3 Distribution of the construction date houses in the residential sector

The existing building stock in each region has distinctive characteristics in terms of scale and age, as shown in Figures 2 and 3. Figure 2 shows the scale distribution of detached houses. Figure 3 shows the distribution of the construction date for houses. Differences have arisen as a result of the way these regions have been developed. In the North region, the building stock constructed after 1976 occupies approximately 80% of the total, as the region has been developed since 1976. The Northeast region is characterized by Senri New Town, which has many large apartment buildings constructed in the 1960s and 70s. This region has a business area consisting of high-rise office and commercial buildings, where the first Japanese district heating and cooling (DHC) system was introduced. The percentage of large buildings here is the highest in the city. The North-central and Central regions have the longest history in Toyonaka city. Approximately 40%

of the building stocks have accumulated in these regions, and they have been renovated at fixed intervals. In the West, there is less building stock because there is an airport in this region (Itami Osaka Airport). The East region, like the North region, has been developing since 1976. In this region, however, apartment buildings have dominated regional development, while relatively large detached houses were provided in the North region. The South region is characterized by a high proportion of small and old buildings, as the region rapidly developed from 1930 to 1960 and has been slowly renovated.

3. Methodology

In this study, we estimate CO_2 emissions from the residential and non-residential sectors of Toyonaka city in 2050. We develop five simulation cases in order to quantify the potential reduction due to stepwise improvements in home appliances and insulation performance as well as the incorporation of more radical actions for CO_2 reduction, or the implementation of building stock management that would lead to the development of a different landscape from that existing. We first explain the business-as-usual (BAU) case of this study in Section 3.1. We then explain the simulation cases in Section 3.2. We finally introduce the simulation model developed for this study in Section 3.3.

3.1 BAU case

Figures 4 and 5 show the population and household estimates of the National Institute of Population and Social Security Research (National Institute of Population and Social Security Research. 2004, 2005). For all cases, we assumed that population and the number of households will follow Figures 4 and 5 until 2050.

Table 2 lists the total floor area in the non-residential sector assumed in the BAU case. We assumed that the total floor area in all the principal usages except hospitals and schools will remain at 2000 levels until 2050. We assumed that the total floor area of the hospital building stock will increase according to increases in patient beds. Similarly, we assumed that the total floor area of schools will decrease according to the estimated decrease in the number of children. We also assumed that the geographical distribution of the residential building stock will remain as it is in 2000 until 2050.

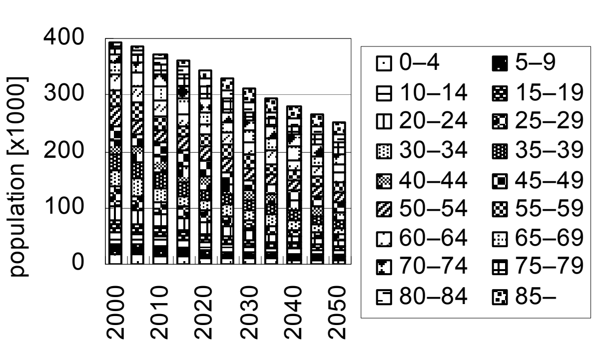

Figure 4 Estimated population

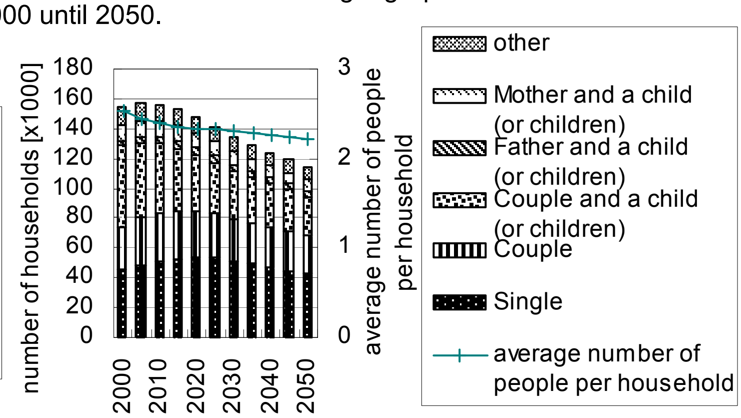

Figure 5 Estimated number of households

Table 2 Method of estimation

Item		Method of estimation
Population*		Followed the estimation of national Institute of Population and Social Security Research
Households*		Same as above
Area distribution of households		Constant
Total floor area in the non-residential sector	Offices	Constant
	Commerce	Constant
	Hotels*	Constant
	Hospitals	Estimated based on the capacity of a hospital bed
	Schools	Decrease due to the number of children in each region

*suppose that it stays constant in this city in 2050

3.2 Simulation cases

Table 3 lists the simulation cases. In Step 1, we assumed stepwise improvements in the energy efficiency of home appliances for the residential sector, and of lighting, office equipment, and heat source machinery for the non-residential sector (explained in Subsection 3.2.1). In Step 2, we assumed improvements in the insulation performance of building envelopes for both the residential and non-residential sectors (explained in Subsection 3.2.2). In Step 3, we assumed the incorporation of the building stock management such that the accumulation pattern of the building stock in each region will vary until 2050 (explained in Subsection 3.2.3). We designed three cases in Step 3 in order to examine the effect of different building stock management strategies on CO_2 emissions.

Table 3 Simulation cases

			Residential sector	Non-residential sector
Step1		Technical advance-ments	Improvements in the efficiencies of air conditioners, televisions, refrigerators	Energy-saving measures are introduced to all buildings when rebuild
Step2			Insulation performance gain (all buildings after 2010)	Insulation performance gain (less than 2,000 m^2)
Step3	Case 1	Manage-ment of building stock	Housing stock locating in South and West regions will be replaced with new stock in the other regions with the same shape and scale when they are disposed	In South and West regions, the total floor area of offices, commerce, and schools will be reduced according to the decrease in the number of households
	Case 2		Housing stock locating in South and West regions will be replaced with apartment buildings in other regions when they are disposed	Same as above
	Case 3		In addition to the changes assumed in Case 1, all the detached houses will be replaced with apartment buildings	Buildings for offices and commerce with a total floor area less than 2,000 m^2 will be replaced with a building larger than 2,000 m^2 while the total amount of the building stock remain constant as that in Case 2

3.2.1 Efficiency of available technologies (examined in Step 1)

Table 4 shows the efficiencies of air conditioners. The future efficiencies of TVs, personal computers, refrigerators, VTR/DVDs, and air conditioners were estimated by taking their lifetime function and volume of sales into account, and those of other appliances were kept constant.
Table 5 shows efficiencies of appliances in the non-residential sector.

Table 4 Efficiency of air conditioners

	COP of air conditioners									
	Cooling					Heating				
	2.2 kW	2.5 kW	2.8 kW	3.6 kW	4.0 kW	2.2 kW	2.5 kW	2.8 kW	3.6 kW	4.0 kW
2000	3.65	3.73	3.78	3.40	3.16	3.96	4.10	4.08	3.93	3.47
2050	6.22	6.10	6.21	4.89	4.99	6.71	6.53	6.52	5.70	5.58
2050Step1	6.47	6.25	6.36	5.26	5.19	6.76	6.51	6.60	5.68	5.65

Table 5 Available technologies in the non-residential sector

System alternative	Heat source					
	Cooling	Cooling COP		Heating	Heating COP	
		2000	2050		2000	2050
Absorption	Direct gas-fired absorption chiller	1.00	1.65	Same as cooling	0.83	0.83
Turbo/boiler	Water-source turbo refrigerator	4.50	8.00	Boiler	0.83	0.83
AHP	Air-source heat pump driven by electricity	2.89	5.00	Same as cooling	3.12	5.4
Individual	Individual air-conditioning system	2.60	4.00	Same as cooling	3.12	5.4
GHP	Heat pump driven by gas engine	0.95	1.60	Same as cooling	1.19	2.00
		Annual system COP				
DHC (Senri chuo area)		0.57	0.80			

3.2.2 Thermal insulation performance (examined in Step 2)

We distinguished four levels for thermal resistance of exterior walls in the residential sector, as listed in Table 6, based on Japanese government standards first established in 1980 and upgraded two times. Figure 6 shows the current proportions of the four insulation levels, as well as those assumed in the simulation cases that were estimated based on trends of newly constructed houses. For the estimation, we distinguished house types, insulation levels, and the date of construction, since the share of the four insulation levels depends on these elements. In the non-residential sector, we assumed two levels of thermal insulation of external walls, “No insulation” and “Insulated.” Current statistical data shows that approximately 15% of newly constructed buildings with more than 2,000 m^2 of total floor area are insulated. We assumed that all the newly constructed buildings after 2000 more than 2,000 m^2 will be insulated.

Table 6 Thermal resistance of exterior wall insulation

	Thermal resistance [m^2 K/W]	
	Detached houses	Apartments
Below 1980	-	-
1980 Standard	0.60	0.50
1992 Standard	0.86	0.77
1999 Standard	2.20	1.10

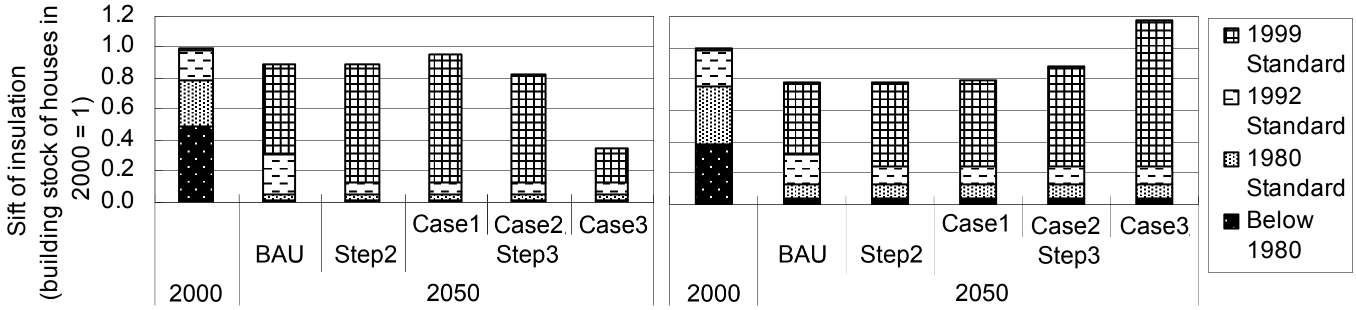

Figure 6 Shift in heat insulation of houses (Left: detached house, Right: apartment)

3.2.3 Shift in total floor area

As shown in Figures 4 and 5, the population and number of households in Toyonaka city will decrease in the next decades. If people continue to live where they currently live, the density of residents per land area will decrease considerably, possibly resulting in declining quality and efficiency of administrative services. We thus propose to implement the management of urban areas in the city so as to limit the space for new buildings. We assumed that the housing stock in the South region, where there are many old houses highly likely to be destroyed in the near future, and in the West region, where there is little housing stock (as explained in Section 2), will be replaced by construction in other regions.

In this study, we identified the following three directions that possibly contribute to reducing CO_2 emissions:

- Increasing multifamily housing in the residential sector
- Replacing detached houses with apartment buildings, due to a higher energy efficiency of apartment buildings than detached houses
- Replacing small buildings with large buildings in the non-residential sector (larger buildings have higher energy efficiency)

We designed three cases in Step 3, each considering one of these directions in order to quantify the potential benefit of the management of the building stock in Toyonaka city. Figures 7 and 8 show the estimated total floor area in the residential and non-residential sectors, respectively.

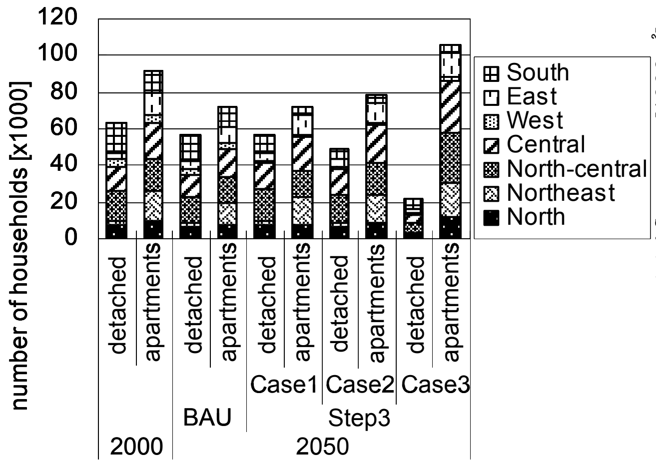

Figure 7 Estimated total floor area of buildings in the residential sector

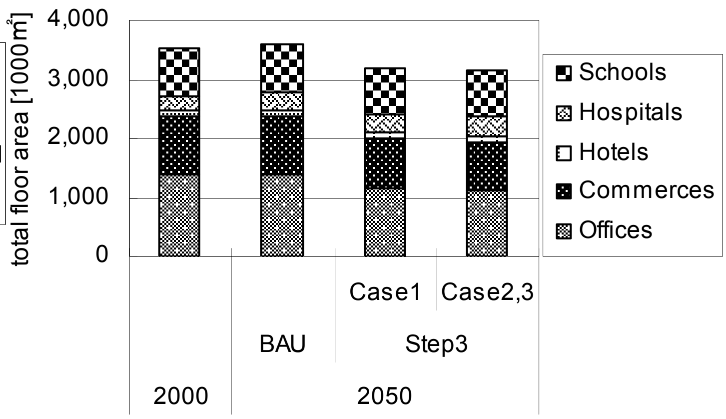

Figure 8 Estimated total floor area of buildings in the non-residential sector

In BAU scenarios, we assume that people continue to live where they do now. The total floor area of hospitals will increase by 36% from 2000. The total floor area of schools will decrease by 4% from 2000, because 5 elementary schools (from 41 in 2000 to 36 in 2050) are closed due to a decrease in the number of children.

In Case 1 of Step 3, we assume that the housing stock located in the South and West regions will be replaced in other areas. In the non-residential sector, the total floor area of office buildings, commercial buildings, and schools decreases according to the decrease in the number of households. The total floor area of office and commercial buildings will decrease by 17%. The total floor area of schools will decrease by 6% from 2000, because 7 elementary schools (from 41 in 2000 to 34 in Case 1 of Step 3) are closed.

In Case 2 of Step 3, we assume that the housing stock in South and West regions will be replaced by apartment buildings in other areas. In addition, office and commercial buildings with a total floor area less than 2,000 m^2 will be replaced by buildings with more than 2,000 m^2. The total floor area of both office and commercial buildings will be constant, as in Case 3 of Step 3.

3.3 Simulation model

We developed a simulation model for estimating the energy consumption and CO_2 emissions of the residential and non-residential sectors of Toyonaka city. The models for both sectors are developed based on the building clustering modeling approach (Yamaguchi et al. 2007). This methodology can be summarized as follows:

- Designing building prototypes, each representing a building stock category with particular characteristics in terms of energy use
- Performing simulations using these prototypical building models as input in order to predict the energy use in each building stock category
- Aggregating the total energy use by summing up the predicted energy use of all the building stock categories

Subsections 3.3.1 and 3.3.2 explain how this methodology is applied to the residential and non-residential sectors in this study.

3.3.1 Simulation model for the residential sector

The residential building stock is divided into 912 categories that are arranged under 19 household categories and 12 building categories—six for detached houses and six for apartment buildings—as well as four levels of insulation performance of building envelopes. For each building stock category, a prototypical building model was designed as input for the simulations. We then performed simulations to quantify end-use energy consumption, or electricity, city gas and kerosene, for each category, considering occupants' behavior, operation and performance of energy-consuming appliances, and requirements for air conditioning and ventilation. A detailed explanation of this model is given elsewhere (Shimoda et al. 2007).

3.3.2 Simulation model for the non-residential sector

The building stock in the non-residential sector was divided into 864 categories considering the principal usage (offices, retail, hotels, hospitals), size (4 categories for each principal usage), zoning of floor plan (9 categories), and heating systems used in buildings (6 categories). For each building category, a prototypical building model was developed as input for a simulation model that predicts the end-use energy consumption, or electricity and city gas. In the simulation model, the cooling, heating, hot water, and electricity demand profiles are simulated on an hourly basis. The end-use energy consumption is then quantified by simulating the operation of heat-source systems. A detailed explanation of this model is given elsewhere (Yamaguchi et al. 2007).

3.3.3 Validation

Figures 9 and 10 show the simulation result of the total end-use energy consumption of the residential and non-residential sectors of Toyonaka city, respectively. The simulation results show good agreement with the statistic score in both the residential and non-residential sectors.

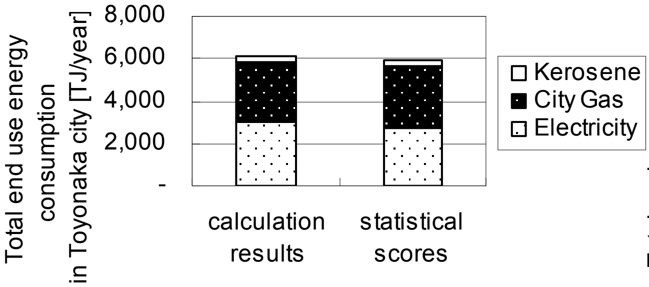

Figure 9 Comparison of calculation results with statistical scores in the residential sector

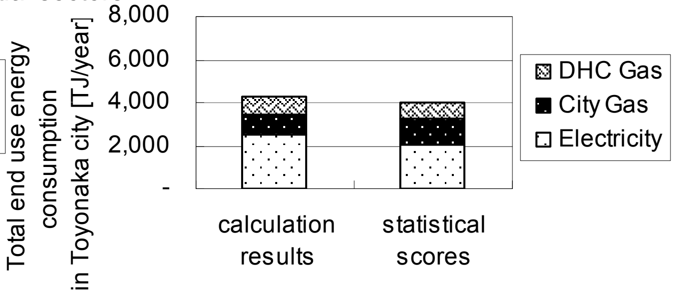

Figure 10 Comparison of calculation results with statistical scores in the non-residential sector

4. Results

4.1 BAU case

In the residential sector, the annual primary energy consumption in 2050 is estimated to decrease by approximately 40% from 2000. Figure 11 shows the decomposition of this decrease. The decrease results from decreases in both the population and number of the households, as well as improved energy efficiency in energy-consuming appliances and improved performance of insulation in building envelopes. The improvement in appliances and insulation performance is likely to be realized, as national standards have been established. This implies that these standards will contribute significantly to reducing CO_2 emissions. Regarding the number of households, although it decreases by 26%, the annual primary energy consumption will decrease by only 13%. This can be attributed to an increase in the proportion of elderly people and households with a small number of family members that have a higher energy demand than average.

In the non-residential sector in 2050, the annual primary energy consumption decreases by approximately 13% due to improved efficiency in energy-consuming appliances and heat source machinery as well as increases in DHC energy performance. Figure 12 shows the decomposition of the decrease.

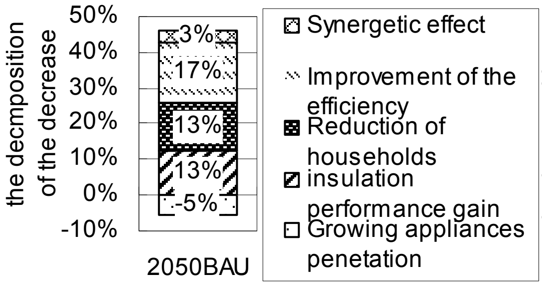

Figure 11 Results of factor analysis in the residential sector

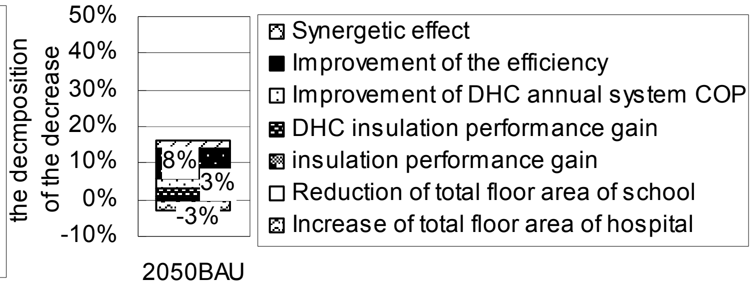

Figure 12 Results of factor analysis in the non-residential sector

4.2 Results of case study

Figures 13 and 14 show the annual primary energy consumption of the case study in the residential and non-residential sectors, respectively.

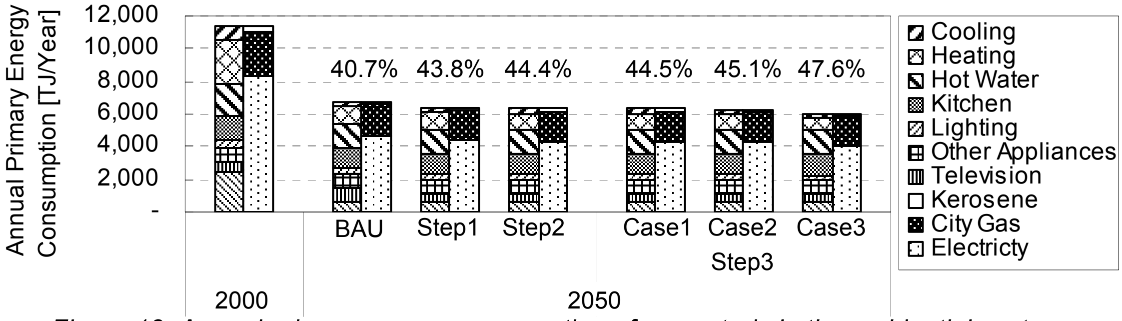

Figure 13 Annual primary energy consumption of case study in the residential sector

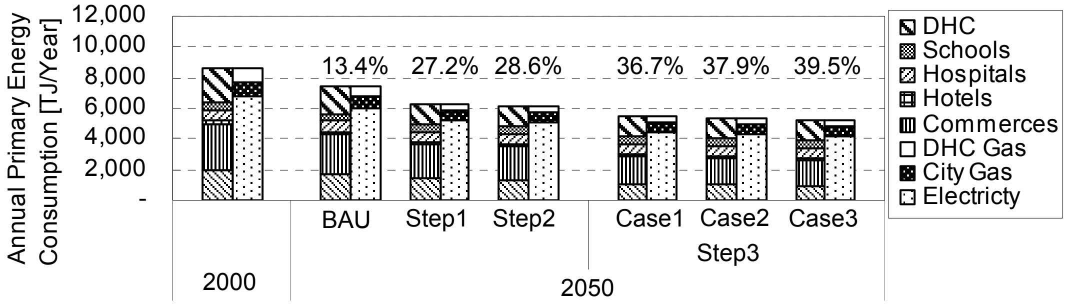

Figure 14 Annual primary energy consumption of case study in the non-residential sector

In Step 1, the additional reduction from the BAU case in the residential sector is 3.1%, based on the consumption in 2000. The gain is small because the improvement in the efficiency assumed in Step 1 is much smaller than that assumed between the BAU case and the baseline. In the non-residential sector, the improvement in the efficiency of energy-consuming appliances assumed in the BAU case results in an approximately 13% reduction in primary energy consumption. An additional 14% is gained by dissemination of energy-saving measures assumed in Step 1.

In Step 2, we assumed the accelerated adoption of the highest-level insulation standard in newly constructed buildings in addition to the BAU case following the current trend in the adoption of building insulation standards. The gain in saved energy is small. In the non-residential sector, as the improvement in the insulation performance is assumed to occur in all buildings, the increase in the saving ratio is not so large.

In Case 1 of Step 3, where we assumed a reduction in the total floor area of office and commercial buildings for the non-residential sector, the energy reduction ratio increased by 7.9%. In Case 2 of Step 3, in the non-residential sector, primary energy consumption decreased by 1.2% due to the decrease in the total floor area of office and commercial buildings. In Case 3 of Step 3, where we assumed that all the houses that are destroyed will be replaced by apartments for the residential sector, the annual primary energy consumption decreases by 2.5%. We assumed the replacement of small buildings with large buildings with more than 2,000 m^2 of total floor area in the non-residential sector, and the annual primary energy consumption decreased by 1.6%.

Figure 15 shows CO_2 emissions in 2050 for each simulation case, where the CO_2 emission rates of city gas and kerosene are 51.3 t-CO_2/TJ and 68.5 t-CO_2/TJ, respectively. The horizontal axis shows the CO_2 emission rate of grid electricity. While it is currently 0.358 kg-CO_2/kWh (Kansai area in Japan), the value in coming decades is uncertain. As shown in the result for Case 3 of Step 3, CO_2 emission can be reduced by approximately 44%, if the CO_2 emission rate of grid electricity remains at the current value until 2050. To achieve a 50% reduction in the total CO_2 emission, the CO_2 emission rate of grid electricity must be lower than 0.299 kg-CO_2/kWh even in Case 3 of Step 3. This value is not unrealistic because the local electricity company has provided electricity with an emission rate of 0.277 kg-CO_2/kWh, although great effort will be required to achieve this value.

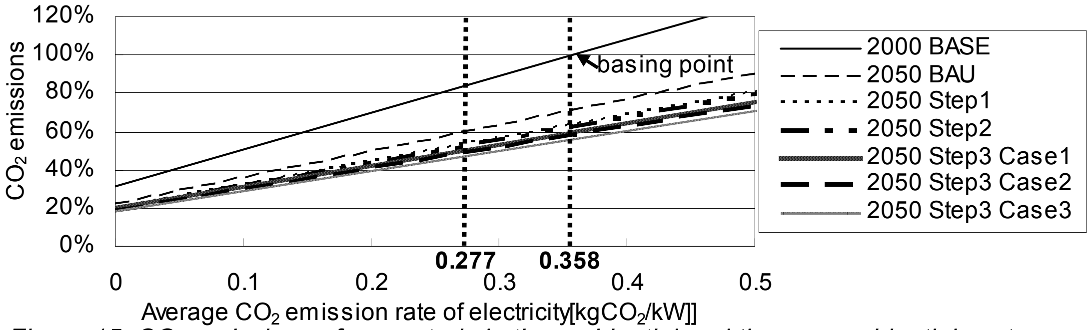

Figure 15 CO_2 emissions of case study in the residential and the non-residential sectors

5. Implications

We show that a 50% reduction in total CO_2 emissions in the residential and non-residential sectors is achievable by combining available options including implementing technological advances, improving insulation performance, disseminating energy-saving technologies, managing building stock, and improving the CO_2 emission rate of grid electricity. At least the first three options have a substantial direct potential for reducing carbon emissions. While policy instruments have been applied and are expected to be effective, it is important to enhance and widen the effort. The management of the building stock is less effective than the technical measures. However, it is must be implemented in order to achieve a 70% reduction in total CO_2 emissions. To achieve such a substantial reduction, we must consider more radical changes in buildings and infrastructure, e.g., further dissemination of photovoltaic and fuel cells. Although we did not consider these technologies in this study, it can be expected that there is a synergy between dissemination of these technologies and management of the building stock.

Conclusion

In this paper, we quantified the potential reduction in CO_2 emissions from the residential and non-residential sectors of Toyonaka city, a typical suburban city in Japan. The result of this study showed that in the residential sector, a substantial reduction in CO_2 emissions is feasible by implementing technological advances in home appliances and improving insulation performance, in addition to the smooth decrease in the number of households expected in the next decades due to the population decrease. For the non-residential sector, technological advancement, and dissemination of energy-saving technologies could lead to a substantial reduction in CO_2 emissions. This study also showed that a CO_2 emission reduction by more than 50% of current emissions is achievable by combining these measures for the residential and non-residential building sectors and managing the building stock. The management of the building stock would play a more important role, together with dissemination of emerging technologies (e.g., photovoltaic and fuel cells), if the city sets a higher target than a 50% reduction in CO_2 emissions. This study addressed key challenges for suburban cities in Japan that account for a large portion of the building stock.

Acknowledgment

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SUSTAINABLE DISTRICT IN BARCELONA

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Keywords: city, new equilibrium, superposition of uses, healthy neighbourhood, self-sufficiency, agriculture, reduction in trip length, intensity

Summary

Cities do not necessarily represent an unsolvable problem for a sustainable planning of life- they can even be part of the solution. Referring to determined parameters there is proposed a district that achieves a maximum self-sufficiency in water, energy and food supply and covers also with the resulting wastes on local level. For this purpose we chose a busy part of the town of Barcelona that currently runs a transforming process.
The strategies, to accomplish the objectives exposed, are:

- Creation of a new equilibrium among the built-up and the free areas.

- Intensive net occupation of the building.

- New relation among the different uses of the territory with the proposal of not bringing about any types of mobility.

- Spatial and functional integration of the agriculture as an urban use of fundamental necessity.

All these together objectives can also bring good connections with the adjacent neighborhoods and the city with its surrounding area in general. Moreover it will represent an environment of integrative and healthy characteristics for its inhabitants. This comes up from a wide range of yet existing initiatives of sustainable development in Barcelona.

1. Introduction

The concept of sustainability was originally defined in 1987 in the Brundtland Report in 1987 as ''development that meets the needs of the present without compromising the ability of future generations to meet their own needs'', becoming a cornerstone of global environmental discussion. In the framework of sustainable development, there has been an interdisciplinary approach towards environmental problems. This created an understanding of the mutual influence between natural and social processes on the one hand and between the interaction of nature and biophysical elements of the society on the other hand. Material and energy flow (called also social metabolism) and therefore influence natural processes like colonization. Cities often are an excellent example of these relations. It is expected that large urban centres will be a field of great interest in sustainable development studies.

Barcelona, the capital of Catalonia takes advantage of its strategic situation alongshore the Mediterranean Sea and close to the French border. It has not only managed to become the principal commercial and industrial centre of Spain, but gained international recognition as well. Having one of Europe's most important and busy ports and a big variety of industrial activities ranging from light to the high technology, it is nowadays one of the twelve most successful manufacturing cities in the world and the Mediterranean's most important trading and shipping route centre. Barcelona's Metropolitan Area is currently formed by 36 municipalities. Covering an area of 633 km2, the area was populated by almost 3 million inhabitants in 2004. The BMA is at present one of the 10 most densely populated metropolitan areas, with 4.785 habitants per km2, and the second most densely populated built-up area in Europe after Paris. Furthermore, its development in industrial and commercial terms is to such an extent that it contributes approximately 70% of the Catalonian GDP, hosting 58% of Catalan industrial sites.

2. Objective

The first objective of the proposal is the design of a neighbourhood, understood as a backdrop to daily life. It is conceived as part of an integrated system in which the pursuit of the maximum level of self-sufficiency in the provision of water, energy and basic foods and in the management of waste products. This will not imply the renunciation either of contemporary expectations of comfort nor of a strong urban character.The establishment of the proposal is realised in an urban area on which there are in motion diverse municipal plans of renewal or partial rehabilitation but without no strong criterion of coherence among them. It is tried to have a size of sufficient proposal to be able to investigate which is the most efficient scale of resolution of the problems that is tried to approach (energy, water, wastes, mobility, integration of the agriculture, social inclusion, …) in line with the parameters that historically have governed the growth and evolution of the city and with the current initiatives that the City council already has in motion (bets by a dense urban model, promotion of new habits of mobility for low environmental impact, experimentation with new forms of collection and valuation and appreciation of wastes, campaigns for the saving in the water consumption , …) with the following objectives:

1º to minimize the energy environmental impact and, especially, in those critical sections in its distribution (fossil fuel for mobility and thermal consumption for air conditioning) that, in Spain, occupies the 84% of this impact developing the established in the solar Decree that, among others things forces to obtain a ratio of cover in hot water sanitary production of 60% like minimum

2º to rationalize the uses of to water in a country with cyclic droughts and in process of sharpening that, in April of 2008, obliged the implementation of all kinds of measures to alleviate to water deficit of the City included the maritime transportation of to water

3º to manage the residues so that its revaluation returns them to include in the service life as Contract of "Neteja i Recollida de Residus 2009-2017 " already scores in the Nova that puts the emphasis in selective collection i, especially, of the organics fraction with less noise, minor environmental contamination and smaller consumption of water and in the development of law 15/2003 on no domiciliary collection of urban residues with the creation of a hierarchized network of Garbage (Green Points) based on the served population.

4º to facilitate a massive mobility of very under environmental impact i that guarantees a universal inner mobility and sufficient an outer connectivity dissipating the inequality that bring about the possession or not of a private car.

Barcelona and Catalonia are in an important process of change in all the aspects related to this project. Every some month new steps for a more sustainable city are approved.

The Mobility plan for Barcelona (and that for Greater Barcelona) has approved a prevision on reduction of driven car kilometres in the city for the next years. For new promotions equilibrium of emissions (micro-particles and NOX) is required and the promoter must finance new needs for public transport.

Limitations for free car parking are increasing. The Mobility Law (2003) has as principle priority of more sustainable transport modes over less sustainable.

Barcelona has worked during decades with mobility plans which restrict the free use of private car. Superblocks and local streets with very low traffic volumes. A principle of 75 % of all streets as local streets and speeds (if presence of vehicles) not superior of 30 km/h.

A new balance between use of public transport and private vehicle is related to equality of access at trip ends. Direct access from parking to dwellings and offices shall change to practice the walking at street surface. A local street with activities, human beings and better attraction as is found inside the parking.

5º to integrate the agriculture in the life and the urban form to assure an eating provision according to the nutritious needs and the local possibilities; to obtain the inclusion of the agricultural landscape in the urban landscape for being the possible receiving premises of gaseous, liquid, and solid wastes produced in the city once revalued and optimizing, at the same time, the production (so much of vegetable eating as not eating products) and for effects, on the health, by-products of the viewing, in the city, of the "weather" of the agricultural cycle and its seasonal demonstrations (sowing, growth, maturation, collects, …)

6º to establish the physical bases that facilitate the social inclusion, the sensation of ownership, the easy access to the basic rights (dwelling, schooling, health, mobility, …) to the services and the equipment generally and the promotion of the equality of opportunities. The used principles of planning are those lead that us to the attainment of the objectives indicated with the greater of possible means economy media and that cause the greater amount of possible synergies (definition of the new balance between the free ground and the occupied by the construction; qualification of the agricultural like entirely urban and consolidated ground like so; intensive use of the ground occupied by the construction; systematic and obligatory mixture the different city-planning uses in the construction on a same occupied ground; size of the unit of accessible action to I chirped in reasonable times; clear reading of the proposed set; respect by the local conditions of cultural, historic, geographical order, …

The general strategy considers the impact of the development during its various stages: during construction; the activity generated during its useful life (the quality of living space, interior mobility and exterior connectivity, provision for all social classes, work, and leisure) and its possible transformation as and when it should become obsolete.

3. Methodology

3.1 Description of the study area

3.1.1 Location

This study proposes the implantation of a new neighbourhood in one of the extremes of the city, in an area delimited by the railway which connects the centre of the city with its north-eastern periphery (Maresme and Vallès Oriental), and the Besòs river. The area is triangular in form and amongst its characteristic features is the planned location of a new high-speed rail terminal in one of its extremes and the lineal park of the Besòs River which acts as an important biological corridor between Barcelona and outlying towns. The site has an area of 166.40Ha, comprised of predominantly ex-industrial land.

Figure 1 Situation of the district inside Barcelona

3.1.2 Physical environment characteristics

Barcelona enjoys a typical Mediterranean climate, with mild temperatures whose annual average is around 16º C (30ºC in summer, 8ºC in winter). The average rainfall in the local area is of 628 annual mm. Despite this, the last ten years have been relatively dry, as it has rained above the average rainfall from the reference period in only one year. 2006 was no exception, as there were 476 mm of rain. The relative humidity is annually between 70-90%. Drought 2008

3.2 The creation of a multidisciplinary planning team

A team must be created that covers the fields of knowledge implied in urban planning. It was formed with the participation of experts in different areas: architecture, urban planning, mobility, landscape, agriculture, environmental chemistry, ecological economy, waste management, public health, physical environment, natural resources and energy management.

3.3 Definition of the variables which define a sustainable district

The variables that define a sustainable neighbourhood include the urban structure (urban characteristics, land use and skyline), the integration of agriculture and nature into the district, the sustainable management of water and energy resources, and the adequate management of wastes and emissions, and the mobility.

The detailed strategy contemplates the efficient use of scarce resources and proposes the implementation of passive solutions before active solutions based on renewable resources. The use of active solutions based on non-renewable resources will be employed as a last resort. Always bearing on mind the aim of being as much self-sufficient as possible and closing cycles.

4. Proposal

4.1 Neighborhood structure

The following assumptions have been considered in order to achieve the objectives: a scale of development with a critical mass such as can guarantee the viability of the operation; the balance between open space and built mass; a highly intensive net occupation with a balance between residential and non-residential uses; and a strong integration of agriculture in the urban fabric.

The neighbourhood has been designed for a population of 40,000 inhabitants. The 166.40Ha of the proposal are occupied as follows: 49.40 Ha. (30%) construction; 44.70 Ha. (27%) roads; 35.70 Ha. (21%) public green space, 36, 60 Ha. (22%) agriculture.

The implantation of the buildings in the territory follows an intensive model, with a high net population density similar to that of many areas of the existing city (240 inhabit/Ha). The equilibrium between residential and non-residential uses is sought through the systematic superposition of differentiated uses, at the same time liberating the individual from an imposed dependence on the private motor vehicle. The distribution of uses is: 800,000 m2 housing; 400,000 m2 public services; 560,000 m2 offices and tertiary; 50,000 m2 for light industry with other uses and 90,000 m2 for hotels.

The area occupied by buildings and roads constitutes slightly more than the half of the proposal and comprises uses compatible with residence, in their turn differentiated in *urban* and *non-urban* uses. Urban uses are those that, by their nature, support the definition of the city as a space of exchange (equipment, commerce, offices, small industry, hotel, business...) creating and receiving flows of people and/or merchandise and generating tensions between the interior, private world and the external public space.

The distribution of the built mass is realised in two distinct though complementary ways. The ‘urban’ uses occupy the level of the public space in predominately horizontal volumes, the continuity of the facades, the preponderance of the solid one set against the empty one and the clear separation between public space and private space with what a great effect of urban continuity is obtained, a great exterior-interior tension is created, the encounter is facilitated on the land and its possible accidents (topography, wooded masses, courses or sheets of water, ...) and with the existing urban weavings, being constituted in a continuous one with the wooded masses and in the base of the building in height that resolves its delivery to the floor. Besides the places of work these volumes should be capable of containing any of the habitual equipment of a neighbourhood.

In this part of the buildings, the use of dwelling is prohibited, but not other residential forms as the hotels that are integrated easily in the urban dynamics. The assembly of this part of the building will have space for the job more the school positions for the 70% of the population that resides in the unit more its spaces of provisioning and routine leisure.

The second distribution locates the dwellings, in the space superimposed upon the urban uses and with a typology in which predominates the vertical dimension, geometrically independent of the determining factors of the land, thus permitting the optimization of the orientation and the facilitating the conditions of habitability and privacy that the use of dwelling requires whilst also facilitating the adoption of passive strategies for the energy efficiency: direct solar contribution, natural lighting and ventilation

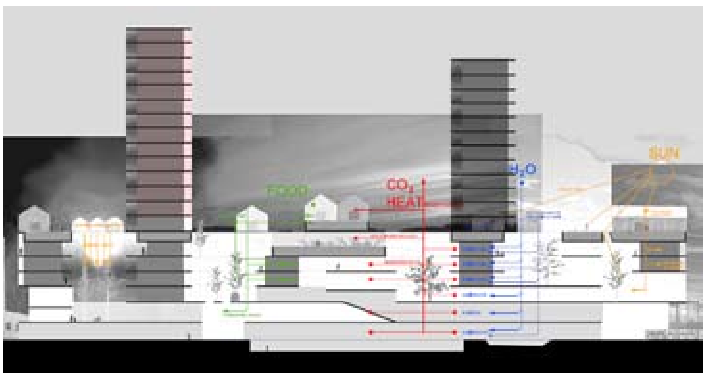

Figure 2 Superposition of uses and cycles

Figure 3 Neighborhood structure

4.2. The integration of agriculture

The project includes the agricultural land use as part of the urban set; planned with the concept of proximity agriculture and alimentary sovereignty (each community has the right –also the necessity- to provide themselves with all the possible food according to their agricultural capacity).

This relationship between agriculture and city is proposed due to several factors:

- Agriculture is the basis of human feeding. It is advisable, from all points of view, **to locate the agricultural production close to the consumption focus** in order to reduce transportation and middlemen.

- Agriculture within the city makes possible **to close the life cycle of organic wastes** (not only solid but also liquid) **and atmospheric emissions**, both produced in the urban environment. The organic fraction from the municipal solid wastes, together with black wastewaters, would be subjected to anaerobic digestion processes. From those, it could be obtained sludge (rich in nutrients), which would be composted to obtain water and manure (compost). Water could be used to irrigate the vegetation areas not used for alimentary purposes and compost could be used to enrich the soils.

- Agriculture facilitates **the visualisation of a *tempo* in the city** in the sense that it constitutes a **live landscape** which changes throughout the year, highlighting the passing of time through the seasons and the agricultural tasks (sowing, growth, blossom, harvesting…).

The project considers a **double spatial integration**. From one hand, non-residential buildings' roofs will host **greenhouses** dedicated to the **bulk production of vegetables**, and on the other hand, some well-lit areas dedicated to the **cultivation of ornamental and aromatic** plants will be inserted to higher residential towers. In both cases, the air from the activity in the buildings, enriched with CO2 due to human activity, will be injected in the agricultural spaces. This air is produced in the buildings (offices, shops, workshops, dwellings) and it will be recirculated into the greenhouses and the inserted cultivation areas, since the CO2 will favour the plants' growth, preventing the emission of this gas to the open atmosphere.

Furthermore, the project has assigned a total of 36,60Ha of land to **exclusively agricultural uses**, preferably **fruit trees** and also grape trees, in combination with some vegetable plants that have difficulties to grow in greenhouses or from the summer season.

The double combination of open-air crops and 'protected' crops, with a desirable distribution of them, implies many advantages: crop diversification which reduces business risks, possibility to combine profitable crops with less productive ones, assuring part of the crops in case of undesirable weather conditions (frost, hail…), more commodity in the execution of agricultural tasks and more capacity to plan the sowing tasks because crops in greenhouses grow more regularly.

Taking into consideration that the vegetable nutritional needs are a minimum of 0.4 kg of vegetables and 0.4 kg of fruits per person and day and that the double combination of greenhouses and open-air crops assures the availability of all kinds of vegetables and fruits (amounting to 450 Ton of vegetables per Ha in the greenhouses complemented with 40 Ton/Ha in the open-air crops), the local vegetable and fruit consumption would be satisfied in a high percentage. **Vegetables would be produced in a surplus** (with only 13 Ha of vegetables greenhouses the demand would be coped) and the surplus could be exported to neighbouring areas in the city. **The fruits demand (5.840 Ton/year) would be satisfied in a 25%.**

The commercialization of fresh products, which should be done in markets and establishments within the neighbourhood (but not in the production location), will promote the social activity and will induce to collateral consumption (bars, restaurants…), shaping an important focus of activity in the city.

The waste management system in the district would yearly provide the agricultural and green areas with approximately 5.840 Tm of compost, which would be enough to cope with their fertilizing demands.

Other benefit of agricultural plantations within the city, apart from the economic and productive, will be disposing of a landscape which will provide the territory with structure, colours and even smells. This landscape will change throughout the year, making possible the identification of the seasons and become a distinguishing element for the neighbourhood. The vast agricultural land area will make possible also the availability of familiar orchards or vegetable gardens of reduced dimensions (200 m2) and also keeping aside some agricultural lands for pedagogic purposes related with schools. The combination of plants growing at ground level (grape trees) with taller plants (trees) growing at higher levels, and the high availability of several tree varieties, will make possible multiple combinations between agricultural areas, buildings and green areas.

4.3 Water management

The basic principle of water management is to adequate the quality of water to the several water uses. In this sense, several strategies are proposed as follows: the use of rainwater harvesting systems (which priority is to be used for domestic water uses), ground water catchments (for vegetables irrigation) and treated wastewater (for other green areas). Moreover, efficiency in water use is also a premise, and grey water reuse is considered in all dwellings.

Table 1 Relation between water demand and supply

WATER DEMAND (m3/year)	WATER SUPPLY (m3/year)
Domestic uses: 730.000 Public services, offices, tertiary, light industries and hotels: 404.000	Water Harvesting Potential: 531.853 m3/year
Vegetables irrigation: 374.860	Ground water available
Gardens and ornamental plants irrigation: 114.240	Treated waster water available: 730.000

These results indicate a **DWSS of 0.73**, which means that 73% of the domestic water demand could be supplied by rainwater harvesting within the district. The irrigation demand could be easily satisfied with ground water and treated wastewater.

4.4. Waste Management

Waste water and organic solid wastes are sent together to anaerobic digestion. This process would make possible the obtaining of water (used later for irrigation), methane in the form of biogas and also sludge. The biogas is a form of energy recovery. Sludge could be used for agricultural purposes after being transformed into compost (process which reduces 30 % of its volume), applicable to the agricultural lands and green areas of the city. It is assumed that each person produce 1200gr/day.The waste treatment chain would provide the district with 7.920 m3/day of biogas, 5.840 Ton/yr of compost and 730.000 m3/year of treated wastewater.The waste management self-sufficiency indicator is expected to achieve values of 0.9, according to the municipal waste treatment facilities projected for the area. This would mean that 90 % of the wastes can be treated within the district.

4.5. Energy management

The energy consumption of the district would achieve figures of 145.920.000 kWh in domestic uses, 231.000.000 kWh in the other buildings uses and 1.788.000 kWh in street lighting each year.

Solar photovoltaic energy production on the area would provide about 730.000 kwh/Ha.

To the solar energy supply it should be added the embodied energy in the biogas produced from wastes (7920 m3/day) would have as much as 33.533.280 kWh of embodied energy.

4.6 Mobility

The scale of neighbourhood permits to undertake the diverse activities in a way unit seeking the synergies that contribute to the solutions. The equilibrium and proximity between the residential ceiling and the not residential one permits that, in a very high percentage, the displacements by mobility obliged and great splits of the doctor they can be carried out to I chirped, bicycle,… or, in its defect, with a brief journey of public transportation and reduction of parking places.

During the last years the trend in car use in the centric areas in Barcelona starts to decrease. The new Mobility Plan for the region and for the city has taken option for a reduction in the whole area of a first 6 % for 2012. This makes it probable to manage mobility in a new quarter with less car use and higher non motorized trips. As general Barcelona show 45% of pedestrian trips. The pedestrians rise to 70 % of the internal trips, in several mayor neighbor towns.

The new quarter of 40.000 inhabitants shall generate a total of 128.000 daily trips, most internal in the zone between dwellings, offices, industry and service functions.

Table 2 Associated mobility

Land use	Construct M2	Trip Generation	% internal trips	total trips	Internal trips	External trips
Dwellings	800.000	0,16	85%	128.000	108.800	20.000
Services	400.000	0,15	80%	60.000	48.000	12.000
Offices	560.000	0,1	75%	56.000	42.000	14.000
Industry	50.000	0,05	60%	2.500	1.500	1.000
Hotel	90.000	500 rooms	10%	2.000	200	1.800
Green area	360.000	0,05	90.5%	18.000	16.300	1.700

With a moderate modal split (13 % internal + external car trips) a total of 34.000 trips in cars are estimated or 26.400 car movements. 8950 cars will leave the quarter per day and come back again. This is equivalent of capacity of one lane per direction. (Table 2)

The external car trips are estimated to a mean length of 8 kilometers and the internal to 3 kilometers. The prevision of car use for the Sant Andreu quarter of half of the general objective of the mobility in the city and surroundings shall result in a saving of 13,5 million of car kilometers and 2322 T of CO2.

The modal split can be achieved by several options of city and public transport design.

- Integrated public transport within 250 meters from dwelling and workplace.
- No through streets in the quarter.
- No direct access from buildings to underground parking. The way to parking includes a short on street pedestrian trip.
- Automatic car parking from street level (50% saving of parking M2) and max.200m from arterial street.

The external trips in public transport rise to 36.400 (18.200 per direction) shall be distributed by train, metro, tram and bus in a proportion of 10 %, 40 %, 15 % and 35 %. (see service areas on graph 2). With 130 buses/day and direction or a bus every 6 minutes entering and leaving the area the demand shall be attended. The internal bus trips shall need an internal shuttle service of a bus every 4 minutes. To this must be added bus service to metro and train stations.

The pedestrians shall be stimulated by groups of living streets with concentration of activities, public transport access and way to parking entrances and exits. Every 250 to 300 m a square with this activity concentration shall be adapted to assure that pedestrians can feel in company.

Cyclists shall share the internal street area with pedestrians, goods distribution and cars to parking access, due to low speed local streets (20km/h).

4.7. Healthy neighborhood

Nowadays, the relationship between urbanism and human health is well-known. There are some hygienic principles perfectly assumed which tend to improve the sanitary conditions in dwellings and cities and also to minimize the urbanization impact on the health.

The project we propose involves a reduction of the atmospheric pollution, especially due to the expected reduction of the private car movements. An important part of the neighborhood citizens will be able to work in nearby places, many trips with shopping or leisure purposes will be done by foot and the use of public transportation systems, less polluting, will be enhanced.

There will also be a reduction of traffic accidents. Running over passer-byes will tend to zero since people and vehicles will not share the same physical space (at least there will not be highways at the same level). The accidents among vehicles will also be minimized since there will be a reduction in the number of crossroads and two-way routes.

The project strengthens the systematic contact with nature, facilitating the access to green and agricultural areas, which will be located nearby dwellings. The access to areas assigned to sport practices will be also facilitated in order to favour physical aerobic activities. The district will be designed to promote displacements by foot or bicycle through the idea of services proximity and walking distances This is according to the promotion of the use of the bicycle in the urban displacements and the enlargement of the areas pedestrian that carries out the City Hall as well as the actions to promote walking as a healthy activity developed the Catalonian health administration

It is important to highlight the relationship between urbanism and mental health. In cities, compared to rural areas, there is a higher incidence of some mental disorders, such as anxiety and depression, related with the urban life style: high levels of stress and less social support. Recently, it has been suggested that there is a relationship between living in urban areas and suffering serious mental disorders such as schizophrenia. In this sense, it has been stated that as the urban density increases, the schizophrenia prevalence also rises. It is probably a multifactor phenomenon affected by environmental and social aspects, all of them related, to a certain extent, to the urban form. In our project, the population density is low enough to favour the interpersonal contact and the proximity of nature, but not that low to difficult the existence of services and economical activity. In this sense, the dwelling modules are also designed to constitute small (or medium) communities, endeavoring the natural creation of social nets that can help vulnerable people and support them.

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11 STUDIOS IN ELEVEN CITIES – SCENARIOS FOR A SUSTAINABLE FUTURE

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Summary

HASSELL is an interdisciplinary design practice operating in 11 locations throughout Australia and Asia (Sydney, Melbourne, Brisbane, Perth, Adelaide, Darwin, Hong Kong, Bangkok, Shanghai, Chongqing, and Beijing). HASSELL has four core design disciplines: Architecture, Landscape Architecture, Planning and Interior Architecture

HASSELL has undertaken a design and research based project to compare and contrast the key issues facing these cities if they are to embrace a sustainable future. Key sustainability indicators were established for each location

Collated indicator data includes information on economic and demographic statistics, private vehicle usage and the ecological footprint of each city to form the basis of the study. Whilst the scope of the collated data is identical, large variations in different cities were immediately obvious.

The collated 'indicators' were then used as the basis for a three dimensional design response for each city. The design proposals have been developed collaboratively in a multidisciplinary environment to ensure holistic, visionary design responses emerge to the following question - *What could each city become by 2030 to make a meaningful contribution to reducing the impacts of climate change whilst creating vibrant 'liveable' urban environments?* The design schemes are deliberately provocative to reinforce the notion that significant shifts in attitude are as important as appropriate infrastructure models. The project highlights a variety of robust design outcomes each

suited to differing cultural contexts and climatic regions. The project has served not only as a vehicle to test leading edge design theory, but also celebrate the way in which a shared design culture can nurture a broad range of culturally appropriate responses.

1. Research Basis - methodology

Cities across the globe currently consume vast quantities of resources and produce enormous amounts of waste in a linear relationship that pays little heed to the ability of the planets biosphere to sustain such practices. This linear model is then matched with pressures associated with extraordinary migration from rural areas to cities as today's global population chooses to inhabit cities in proportions never seen in the history of our species.

Current development patterns follow a highly inefficient 'western' model based on a presumption that resources are infinite and the planets ability to absorb waste streams unlimited. This issue needs to be addressed by finding ways in which city development can be based on a more holistic 'metabolic' type model where resources and waste streams are integrated in a cyclical symbiotic system.

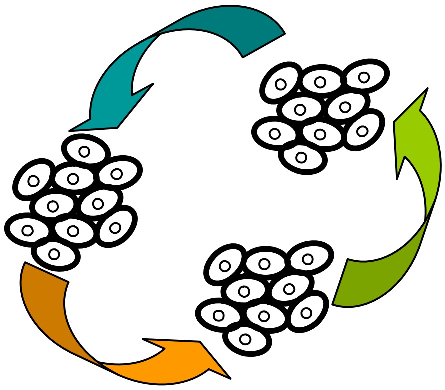

Figure 1 – A metabolic model for City Design.

Given this premise, a set of key indicators were established for each studio location to explore and allow immediate comparison across locations. This served to highlight differences between studios and geographic regions and allow a platform from which design responses could be developed.

The research deliberately represents collated data as 'indicators' because this allowed the study team to look at general trends rather than striving for precise information. The wide spread of data sources often meant specific comparison of detailed issues was difficult as much data was from disparate sources who had collated data for a wide range of differing purposes. This issue was often accentuated by the difficulties faced by our China based studios in gaining data that was collated in a manner to allow detailed comparison. This impediment was mitigated by ensuring that 'trends' were used as the basis for design proposals. The overriding purpose of the research was to permit exploratory design work that was aspirational in nature. In addition to allowing robust design responses, the indicators also permitted individual studios to focus on specific issues pertinent to each location. This approach has allowed different studios to better understand the context in which each design office operates and thus look to different regions for ideas and solutions to ongoing city evolution.

The collated data was organized on a per capita basis to acknowledge the fact that the impact of climate change is a challenge to be equally borne by all the citizens of the planet. Whilst the impacts of climate change differ from region to region, responsibility to act to mitigate damaging trends is best recognized when data is presented in a per capita manner. This is especially relevant to city design as cities are by their very nature a reflection of the collaborative industry of their citizens over any given period. Changes in individual behavior are as important as major alterations to infrastructure and development patterns.

2. Research Results

The indicators selected as part of this study for each city were:

- CO_2 emitted per capita
- Transport – Private car use per capita

- Population density
- Average Income
- Water use per capita
- Ecological Footprint per city

The tabulated results for each of these categories follow below.

	Adelaide	Bangkok	Beijing	Brisbane	Chongqing	Hong Kong	Melbourne	Perth	Shanghai	Sydney
CO_2 tons per person per year	**18**	**12.6**	**5.8**	**24**	**4.8**	**6.5**	**15**	**20**	**7.6**	**14**

Table 1 – CO2 per person per year. Key Issue – developed cities produce unacceptably high levels of CO_2 per capita.

	Adelaide	Bangkok	Beijing	Brisbane	Chongqing	Hong Kong	Melbourne	Perth	Shanghai	Sydney
Car Ownership Per 1000	**475**	**165**	**40***	**458**	**40***	**42**	**446**	**478**	**40***	**412**

Table 2 – Transport, private vehicle ownership. Key Issue – China has the highest aspiration index for car ownership in the world. Western vehicle ownership rates are unacceptable on a global scale.

	Adelaide	Bangkok	Beijing	Brisbane	Chongqing	Hong Kong	Melbourne	Perth	Shanghai	Sydney
Population Density per km^2	**1300**	**3631**	**3700**	**950**	**3200**	**6211**	**1500**	**1200**	**2590**	**2100**

Table 3 – Population Density. Key issue – low Australian population densities are matched with sprawling suburbs and transport networks dominated by the private motor vehicle.

	Adelaide	Bangkok	Beijing	Brisbane	Chongqing	Hong Kong	Melbourne	Perth	Shanghai	Sydney
Average income $US	**44,500**	**10,000**	**5,800**	**48,250**	**2,000**	**30,000**	**54,500**	**53,700**	**11,500**	**62,000**

Table 5 – Average incomes, Key Issue – the benefits of higher income are tempered by greater resource use and CO_2 emissions.

	Adelaide	Bangkok	Beijing	Brisbane	Chongqing	Hong Kong	Melbourne	Perth	Shanghai	Sydney
Water Use kL/person	**90**	**215**	**158**	**130**	**27**	**140**	**75**	**180**	**170**	**80**

Table 6 – Water use per capita, Key Issue – differing locations receive different amounts of rainfall that don't necessarily reflect annual scarcity.

	Adelaide	Bangkok	Beijing	Brisbane	Chongqing	Hong Kong	Melbourne	Perth	Shanghai	Sydney
Ecological footprint	**7**	**3.4**	**3.1**	**7.7**	**1.3**	**4.9**	**6.2**	**9**	**3.4**	**7**

Table 7 – Ecological Footprint. Key Issues – developing nations footprints are escalating as incomes increase. Australian cities must find ways to start reducing total footprint areas.

2. Research Conclusions

The collated indicators reinforced a well understood premise – that 'developed' Australian cities have evolved in a manner that sees high average incomes directly correlate to high CO_2 outputs based on having lower population densities and greater average travel distances by private car. Water use varies from city to city and tends to be an issue for local management depending on rainfall intensity and when the rain occurs. The indicators allowed our studios to examine their situation in direct comparison to other studios. This assisted in the selection of specific areas for the individual designs to focus. The ecological footprint indicator allows a range differing issues to be directly correlated. It provides an overall indicator of the total sustainable performance of each city.

From the collated indicators it is clearly demonstrated that the increased wealth evident in the developed Australian cities is directly linked to excess CO_2 production and very high ecological footprint measures. The need for a development model that decouples wealth generation and the opportunities associated with first world 'western' cities from environmental degradation is evident.

The design solutions seek to explore the individual issues facing each city and allow responses that are situation and site specific to emerge.

3. Design Response

HASSELL is a multidisciplinary firm and the design responses that form the basis of this study have been developed by personnel from across our core disciplines: architecture, landscape architecture, planning and interior design. The design responses have evolved in response to the following provocateur, "*What could each city become by 2030 to make a meaningful contribution to reducing the impacts of climate change whilst creating vibrant 'liveable' urban environments?*

In the quest for a metabolic city design model, it became immediately clear that sustainable cities will need to develop holistically in a manner that allows for substantial sharing of opportunity and resources across the traditional real estate boundaries that have been one of the core attributes of contemporary city development. Key design drivers included the following:

- Integrated landscape – making landscape a 'participatory' element within city-scapes. Moving beyond landscape driven solely by visual amenity to landscape that can act to filter air, water and waste. How will landscape and design support substantial energy generation systems and food production whilst providing opportunity for recreation and visual amenity?
- How can the ideals of industrial ecology be integrated into new city design? What city infrastructure needs to evolve around decentralized models to allow for better efficiencies and distribution networks? What systems could be better centralized for the same reasons? Key utilities require consideration – electricity generation, sewer networks, storm water control and collection, carbon minimization.
- Healing damaged natural systems – what natural systems have been disrupted by the current city model? Can these systems be identified and reintegrated to assist in nutrient filtration, waste management and visual amenity?
- Transport systems for minimum carbon waste. How could drastically reducing private car use positively benefit new city design? Design teams were cognisant of the many negative spatial impacts cars have on urban form and city spaces –exhaust pollution and greenhouse gas contribution are not the only issues associated with high private car ownership and usage rates.
- How can city design contribute to a sense of place and community? Diversity, equity, opportunity for employment, access to services, affordable housing and 'delightful' spaces all contribute to making up the matrix of a great city. Design solutions seek to be cognisant of these issues and ensure monoculture single zone approaches are avoided.
- Efficiency / density – there are many efficiencies to be gained by increased population densities in contemporary city centers. These include high quality transport options, efficient distribution of

resources and collection and redistribution of waste streams. However, the adverse impacts of extreme density matched with inadequate accommodation, sanitation and inequity need to be acknowledged.

- Integrated technology – it is recognized that industrial ecology and integrated design will be able to resolve many of the problems associated with resource and waste cycles within cities. However, integrated technological solutions are going to be required to assist and support natural systems to ensure local biological networks are not overwhelmed.
- Policy frameworks – design solutions must have the potential to be supported and encouraged by appropriate policy structures. Developing cities in a 'metabolic' manner will require adjustments to the jurisdictions of traditional city planning and development control to ensure an integrated approach to design and infrastructure provision.

Whilst the above mentioned issues shaped the design outcomes, our basic premise is that a collaborative approach that encompasses all the traditional urban design disciplines is going to need to be supplemented by a range of skills not commonly utilized by traditional linear city development models. Information from ecologists, sociologists, psychologists, agricultural scientists, futurists and many many others is going to be required to build robust sustainable cities. It is the role of design to evaluate the inputs from all these sources and develop outcomes suited to a sustainable future.

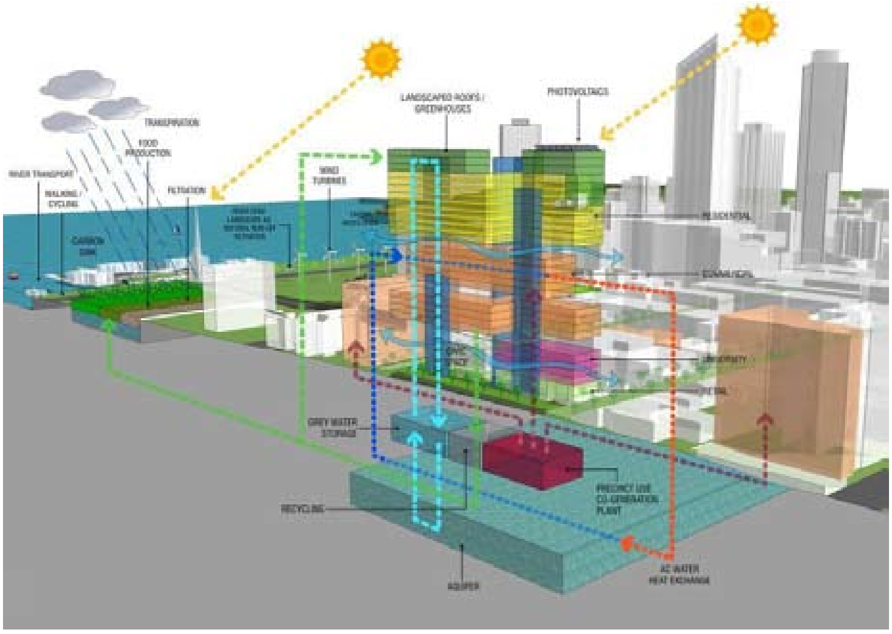

Figure 2 – An integrated approach to resource sharing and waste stream management.

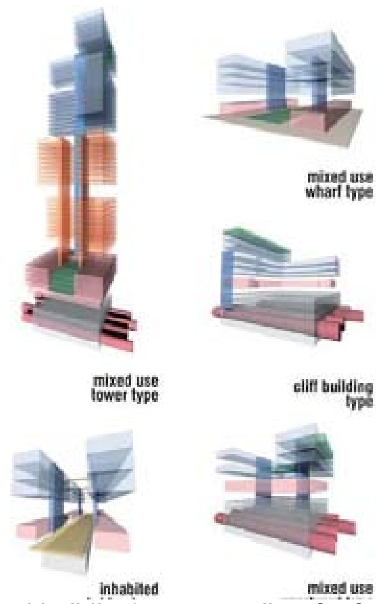

Figure 3 – exploring 'universal building' types to allow for future re-use and adaptation

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Figure 4 – Future Sydney? An integrated sustainable opportunity.

4. Comparisons and Conclusion

The design outcomes of this project have focused on central city areas as this tends to be the crucible of opportunity and where HASSELL have the most ability to influence new development models. This is not to say that there are not many issues at the fringes of rapidly expanding cities that are worthy of careful consideration.

This exercise has illustrated that the issues that face our 'northern' studios tend to be related to extraordinary population expansions in very short time frames. (Chongqing is experiencing approximately 10% population growth per annum). Putting plans in place to manage this type of growth is problematic as often no clear development framework is in existence. The growth of Australian cities appears to be deceptively manageable, however, old development models still control this growth and encourage wasteful, ecologically damaging systems to continue. The opportunity exists in Australia to start incrementally changing city development control systems to set up a sustainable future. Lessons learnt can be quickly shared to ensure a wide audience can be the beneficiaries of this experience.

Sharing experiences and articulating lessons learnt was a key project driver. The design outcomes are merely a first step on a journey to share knowledge across our studios and ensure our people better understand the issues facing our different locations. By sharing this knowledge we believe we ensure a holistic integrated design approach will develop better city outcomes.

Real change in city development is going to require new thinking and skills from across the design spectrum. For cities to aspire to development along 'metabolic' lines, policy and development controls are going to have to be modified to allow for decentralized access to services and resource flows. Sustainable cities will embrace the opportunities these new relationships offer. New cities will offer the opportunity for built form, open space, landscape, utility infrastructure and transport networks to act in a 'participatory' and restorative manner where each element acts to enhance the livability and sustainability of the overall city. We believe this project has presented the type of approach necessary to achieve such outcomes across a range of different regions. Further to this, the design solutions have demonstrated the manner in which a shared design approach can foster a broad range of culturally diverse solutions suited to a specific local context.

VANCOUVER'S OLYMPIC VILLAGE: DESIGNING A SUSTAINABLE COMMUNITY AT SOUTHEAST FALSE CREEK

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Keywords: Olympic village, community, accessibility, passive design, LEED™, mixed-use, energy, brownfield

Summary

Millennium Water is a model sustainable community that is being built on the last remaining large tract of undeveloped waterfront land at Southeast False Creek near downtown Vancouver. The Vancouver Organizing Committee for the 2010 Winter Olympic and Paralympic Games has designated the site as the Athletes' Village for the duration of the Games, at which time the area will temporarily house approximately 2,800 competitors.

Prior to its redevelopment, the site was considered a brownfield and underwent extensive environmental remediation. Following construction, Millennium Water will be a complete community, offering a variety of goods and services, transit options, and employment opportunities within walking distance of the residences. The development is based on environmental, social and economic sustainability principles.

The neighbourhood will be a leading edge community while maintaining heritage ties to the past, having been for many years an important urban industrial site. The area will be home to a diverse population, offering a mix of subsidized, rental and market accommodations. Housing will be designed to accommodate singles, families, seniors and people of varying physical abilities. With a target of LEED® Gold, Millennium Water is being built to meet a high standard of sustainability.

Figure 1 Digital rendering of Millennium Water, community centre in foreground.

1. Project Overview

1.1 Sustainability Highlights

The new neighbourhood will offer a variety of long-term environmental, health, social and economic benefits to the community. Building occupants will enjoy enhanced indoor environmental quality via fresh air ventilated from the outdoors and non-toxic finishes to minimize off-gassing of materials. Buildings will be heated by renewable resource - sewer heat recovery - distributed by a neighbourhood energy utility. Energy consumption will be reduced through passive design strategies. Potable water consumption will be reduced by way of rainwater collection and a greywater recycling system. Stormwater management strategies include a system of swales, retention ponds and cisterns.

There will be employment opportunities and day-care facilities within the neighbourhood with the goal of propagating a vibrant community. The project promotes alternative transportation and active living through proximity to transit, designated bicycle and pedestrian areas, and car share vehicles. Parks, gardens, green roofs, and urban agriculture will enhance local ecology, provide recreational opportunities and be a source of local food production. Community life is supported through public amenities: public art, a non-motorized boating facility, community centre, pedestrian plaza and commercial district.

1.2 History and Background

Millennium Water comprises seven hectares and is the first phase of the redevelopment of Southeast False Creek (SEFC) which totals 32 hectares. Beginning in the late 1800s, the SEFC site was for many years an industrial yard – its activities included sawmills, foundries, shipbuilding, metalworking and salt distribution – and in recent years the site has lain vacant, awaiting clean up and redevelopment. The Millennium Water project will begin the process of bringing life back to the area, transforming the site that was once a hub of industrial activity into a thriving community: a commercial, residential, and recreational hub in the heart of Vancouver.

Millennium Water will offer 130,000m² of commercial and residential space. The project will see the construction of 1,100 housing units. 250 are to be subsidized housing, 110 will be rental housing, and the balance regular market housing. The project is slated to be completed by the end of October 2009 at which time it will be temporarily handed over to Vancouver's 2010 Olympic Organizers (VANOC) for a six-month period. Following the event, the site will be returned to the owners for permanent occupancy. As the site has been designated as Vancouver's Athletes Village, construction must adhere to a very strict timeline – a significant challenge for design and delivery of a development of such a scale.

By 2020, the remainder of SEFC will be complete and its projected 7,200 residential units are expected to become home to between 12,000 to 16,000 people. The neighbourhood's approximate 560,000m² of development will include a full size community centre; a non-motorized boating facility; three to five licensed childcare facilities; an elementary school; five restored heritage buildings; public plazas and promenades; community gardens and 10 hectares of parkland.

Figure 2 Millennium Water Site within SEFC Official Development Plan Area

2. Olympic Athletes' Village

For six months following construction of Millennium Water, the neighbourhood will be used to accommodate athletes competing at the 2010 Winter Olympic Games. As Vancouver's Olympic Village, Millennium Water will temporarily house approximately 2,800 athletes for the duration of the Games. The neighbourhood will become a lively centre of activity, celebration, and ceremony in honour of the event, while meeting the daily needs of visiting athletes and their delegations.

Adaptability was necessary in designing the Olympic Village, since buildings had to meet VANOC's overlay requirements in addition to the conditions of the Official Development Plan for the area (ODP). The overlay applies to a six-month 'exclusive use period' in which the site will be controlled by VANOC. The overlay includes provisions for temporary housing, dining, fitness, and health care facilities and security among the numerous operational requirements of the Olympic Village. The design team had to find flexible solutions for creating buildings that would serve two distinct purposes: accommodating the event and also the residential legacy.

All of the ground floor commercial spaces will be fitted out to accommodate operational facilities for the athletes. Residential suites will be temporarily protected for the duration of the exclusive use period, in order to safeguard the furnishings such as hardwood floors and kitchens from damage.

Legacy features that have been included in project design include silhouettes of ski jumpers, hockey players and other athletes that will take shape in the vegetation on the buildings' green roofs. Street names in the new neighbourhood, including Athletes' Way will also evoke the legacy of the event and the Athletes' Village.

3. Design Standards & Regulatory Tools

3.1 Official Development Plan

The design for Millennium Water was subject to a number of stringent regulations. The project had to comply with standards and guidelines detailed in the Southeast False Creek Official Development Plan (ODP) bylaw, which was adopted by Vancouver's City Council in July 2005. The focus of the Plan is to develop a complete community that will serve as a learning experience for the application of sustainability principles to large-scale neighbourhood design. According to the ODP vision, the area will be transformed into a community 'where people live, work, play and learn in a neighbourhood that has been designed to maintain and balance the highest possible levels of social equity, liveability, ecological health and economic prosperity.'

The ODP describes general land-use parameters and regulations under which the project can proceed. The Plan mandates a set of environmental standards to govern the site's redevelopment including a Green Building Strategy, and specific design principles and targets for landscaping and urban agriculture, water and energy efficiency, alternative transportation, and waste management.

3.2 Green Building Strategy

The SEFC Green Building Strategy was developed by the City of Vancouver in order to mandate a level of sustainability in building design and to set a new precedent for local sustainable design. The Strategy applies to all new buildings that fall within the boundaries of the 32-hectare SEFC site. The Strategy sets a target of LEED® Silver for new construction according to the Leadership in Energy and Environmental Design Green Building Certification system. In addition to the LEED® qualification, the strategy outlines a number of criteria under the following categories: energy, parking, landscape, water and waste management. Any person applying for a building permit within the SEFC boundaries is required to provide documentation outlining their approach to meeting the requirements of the Green Building Strategy. The acceptance of development and building permit applications by the City of Vancouver is contingent upon the applicant's commitment to meeting the Strategy's requirements.

3.3 LEED® Green Building Certification

Millennium Water is targeting a higher standard than the mandated LEED® Silver. The project is targeting LEED® Gold at a minimum for all buildings, and the community centre is being designed to achieve LEED® Platinum certification. One of the multi-unit residential buildings, an affordable housing block for seniors, is targeting NET ZERO annual energy consumption and will likely achieve LEED® Platinum.

The SEFC redevelopment area is participating in the US Green Building Council's LEED® for Neighbourhood Development (LEED®-ND) pilot program. LEED®-ND integrates the principles of Smart Growth, New Urbanism, and environmental building design into a new standard for sustainable neighbourhood design. The study will evaluate neighbourhood development against a number of criteria under the following categories: Smart Location & Linkage; Neighbourhood Pattern & Design; Green Construction and Technology; Innovation & Design Process.

3.4. Safer Home™ Certification

Millennium Water is being built to meet criteria set by the Safer Home™ Certification Program, a home building standard that provides safety, comfort and adaptability for people of varying ages and abilities. This voluntary standard improves accessibility for people with diverse needs and provides the opportunity for aging-in-place. Safer Home™ design criteria comprises 19 points including widened hallways and stairwells, lowered light switches, removable under-sink cabinets, pressure/temperature control valves on shower faucets to name a few.

Safer Home™ is linked to the principles of Universal Design, allowing homes to be usable by all people to the greatest extent possible without adaptation or specialized design. Universal Design is based on the premise that people have changing needs throughout their lives. Safer Home™ is the only certification program in Canada that addresses the application of Universal Design in our homes. Building life is extended through the application of these guidelines as the design is adaptable to changing needs over time.

4. Passive Design

In order to reduce overall energy demand in buildings at Millennium Water, the design team focused on passive design strategies. The mechanical engineer took a systems approach to design, emphasizing sustainability by looking for synergies that would help reduce the need for mechanical systems. Passive design was seen as the first step in creating buildings that are thermally comfortable, efficient and provide a pleasant indoor environment for occupants. By including passive design techniques the design team reduced heating and cooling loads, lighting and mechanical ventilation systems.

Passive strategies on the project include enhanced envelopes, efficient glazing systems, wrapped balconies, through-suites with exterior access ways, light and shading controls, operable windows and natural ventilation. Building orientation was taken into account when designing the exterior facades to take advantage of, or respond to exterior environmental factors such as sun, wind and rain. Enhanced envelopes reduce energy loss. Rain screen systems were specified to insulate buildings from Vancouver's notoriously wet climate. Heat gain is controlled using operable shading devices and deep balcony overhangs on south and west facades. Double glazed windows with low-e coatings reduce heat gain and loss through the window systems. The project compromised with a 70:30 glazed to non-glazed ratio, which is low for Vancouver buildings, which often prefer 100 percent glazing in order to maximize views.

4.1 Passive Design Area Exclusions

The project paved the way for future sustainable design in Vancouver through an unprecedented agreement between the City and the developer. In order to encourage passive design strategies such as thicker walls for improved insulation, wider circulation areas, deep balconies for shading, and exterior corridors for improved air quality, the City granted area exclusions for any additional area required to meet passive design requirements. Specifically, any additional floor space area that was included in the design as part of a passive strategy was excluded from the calculations of floor area. The developer was thus able to include passive strategies without forfeiting developable area.

5. Energy Systems

5.1 Neighbourhood Energy Utility

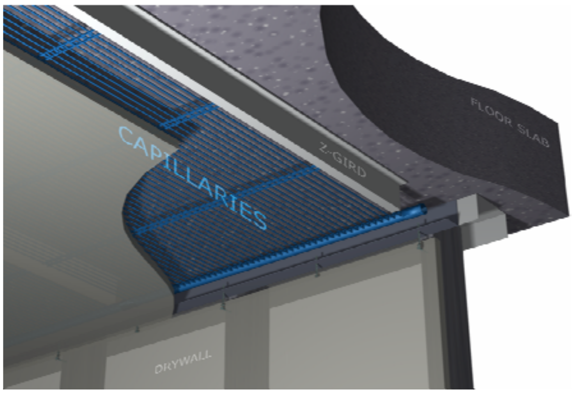
Buildings at Millennium Water will be heated by way of Southeast False Creek's neighbourhood energy utility (NEU). The NEU is a community energy system that will provide space heating and domestic hot water to all buildings in the Southeast False Creek redevelopment area.

The NEU is being designed with leading-edge technology to use a sustainable heat source – it will recover heat from the municipal sewer system. Sewage waste heat will be captured and used to heat water at the SEFC Energy Centre. The system uses heat pumps to upgrade low-grade heat to high temperature water, which is then distributed to buildings throughout the site. The Energy Centre will be designed as an interpretive facility to showcase the innovative use of sustainable technology, and is expected to achieve LEED™ Platinum certification.

This will be the first use of this technology in North America, and one of only four such projects in the world. The system, when completed in May 2009, will produce heat at a cost that is competitive with traditional building heat and hot water systems, but in a more sustainable manner. Emissions of greenhouse gases will be significantly lower and the NEU will have long-term flexibility to adopt new alternative heat sources to keep pace with anticipated technology advancements.

5.2 Ceiling-mounted capillary heating and cooling

Buildings at Millennium Water will be heated and cooled using what will be North America's largest in-ceiling radiant capillary heating and cooling system installation. Capillary heating employs the circulation of cold or warm water through narrow (3-4mm) plastic capillary tubes. Capillary tube mats allow large amounts of energy to be transferred with no draught or noise, even with low temperature differences between active room surfaces and room air. Capillary heating was preferred by the design team as it provides optimum thermal comfort with the added benefit of cleaner indoor air quality due to a reduction in airborne particles such as dust and allergens as compared to conventional forced air systems. Radiant systems exchange heat using water rather than air. Water is a better heating and cooling transport agent than air as it requires less volume to transport the same amount of heating and cooling capacity. The system is self regulated based on the room load. If the room is empty, no energy transfer happens, thus saving energy.



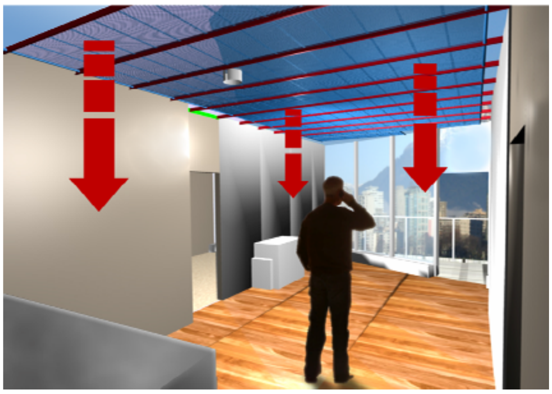


Figure 3 & 4 Ceiling capillary mat installation delivers radiant heating and cooling.

6.0 NET ZERO Housing

6.1 The Concept

The term NET ZERO is used to describe buildings that are designed to produce as much energy as they consume on an annual basis. Millennium Water will feature Canada's first NET ZERO multi-unit residential building. The design team is working with the City of Vancouver and Canada

Mortgage and Housing Corporation to support this project. The proposed NET ZERO building at Millennium Water comprises an approximately 6,900m², 68-unit social housing project for seniors.

6.2 Project Objectives: A model for carbon-neutral development

NET ZERO housing is a design approach that integrates five key principles of sustainable design: Health, Energy, Resources, Environment and Affordability. The Millennium Water NET ZERO project will be a test bed to promote practical, cost-effective energy efficiency and onsite energy production measures in a way that is transferable to future projects. The project will demonstrate how the combination of energy use reduction and efficiency measures integrated with renewable energy production can result in an annual zero net energy balance.

6.3 Design Strategies

The NET ZERO building required an ongoing integrated design process in order to meet its target. The primary strategy in reducing building energy demand in this building is through the application of advanced building technologies and passive design techniques including enhanced envelope design (triple-glazed windows, R-20 walls and R-30 roofs), rain screen envelope, high performance glazing systems and shading devices. The design team focused on an efficient, tight envelope as a starting point in order to reduce the need for mechanical systems.

The building is ventilated naturally using fresh air that enters through the slab and is released behind the refrigerator in order to temper the air on its way into the interior spaces. Fresh air ventilation, efficient insulation, through suites and shading devices eliminate the need for mechanical air conditioning in the building.

6.4 Renewable Energy

The building will rely on renewable energy systems to provide its own supply of clean, 'green' power. Heating loads will be met using waste heat from an adjoining supermarket. The remainder of the building's energy use will be offset using two rooftop solar thermal arrays – one on the roof of the building, and the other on an adjacent building. Solar thermal was found to be both the most cost effective and appropriate technology for Vancouver's climate, and as such, was the chosen technology that will allow the SEFC NET ZERO building to achieve its target performance.

6.5 Monitoring & Evaluation

Following occupancy, building energy performance will be extensively monitored in order to evaluate the achievement of the project and to inform future projects. As this project incorporates a combination of new technologies and strategies, it is imperative that the project be properly documented and its performance be evaluated once the building is in use. While the design and energy strategies were carefully modelled and strategically implemented based on assumptions about building performance and occupant behaviour, the success of the project will only become evident once the building is up and running. The performance of the building depends on its design but also largely upon the behaviour of its occupants and therefore considerable education will take place one to two years following regular occupancy.

6.6 Education and Public Engagement

NET ZERO building occupants will be educated about the building's systems and design so that they are aware of the goals for the building and how their individual choices can influence the building's performance. An awareness program will be implemented which is likely to include a video as well as a manual for occupants which will outline the building's design targets and demonstrate the importance of behaviour change and occupant buy-in in order for the building to meet its desired performance level. This includes information about the building design, renewable energy systems and the role of the occupant. Behavioural recommendations will amount to tips on how to reduce personal consumption through actions such as, for example, turning lights off when leaving rooms and not leaving the television running all day.

6.7 Meters

All Millennium Water suites will include metering devices that provide feedback on per unit electricity, heating and cooling and water consumption. The meters also show the associated cost of electricity and will predict the amount of monthly electricity bills. Greenhouse gas emissions associated with electricity use is also displayed. The meters are designed such that the user can set consumption targets. The devices include two strips that light up in green if you are within range of your target and red if you are exceeding your target consumption level.

In-suite meters are expected to help reduce individual occupants' electricity and hot water consumption significantly. Research shows that awareness programs and in-suite metering devices can influence users to reduce their consumption rates by 20%. Occupants, once armed with the knowledge of how many resources they consume and how small behaviour changes can reduce their consumption, their personal footprint (in GHG emissions) and in turn affect their monthly utility bills, are liable to commit to new patterns of use and reduced consumption.

Figure 5 Meters will be installed in every residential unit; display showing unit cost of electricity.

7. Land Use and Site Planning

7.1 Water Use Reduction

The development aims to reduce the use of potable water by at least 30% below conventional levels. Low flow fixtures and appliances will be installed universally throughout the buildings. Stormwater runoff will be reduced by 25% through a site-wide system of green roofs, swales and retention ponds. Building plumbing includes a greywater system in which rainwater is harvested and stored in a below-grade cistern, then treated and circulated through the building for reuse in irrigation and toilet flushing.

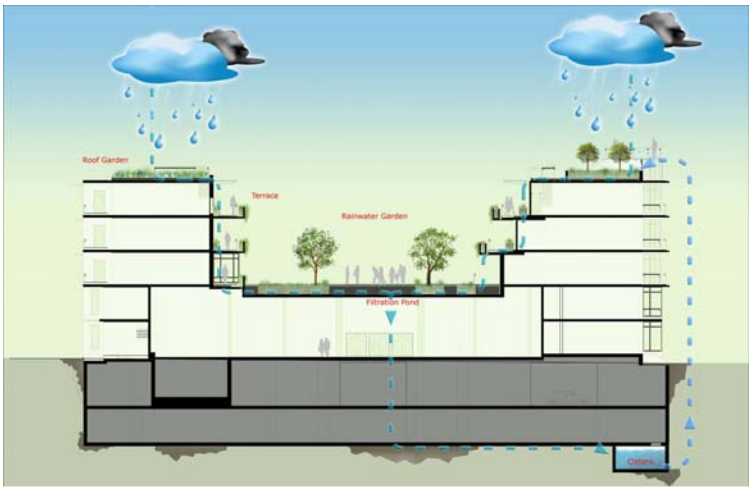


Figure 6 Rainwater harvest, storage and recycling schematic.

7.2 Landscape Design

Courtyard cooling ponds containing collected rainwater will contribute to passive design strategies through evaporative cooling. The landscape at Millennium Water is being designed to thrive without use of potable water, to control stormwater runoff, enhance native habitat, and provide opportunities for gardening. All buildings will have a minimum of 50% green roof coverage, with plantings arranged into motifs that celebrate the Olympic Games theme.

7.3 Urban Agriculture

Urban agriculture is incorporated into the landscape design, with the intent of creating opportunities for onsite food production and distribution. The City commissioned an extensive study on urban agriculture opportunities for SEFC. The report findings include recommendations for locations where food production might take place including community gardens, on private plots, rooftop gardens, balconies and window boxes, school gardens and inside buildings. Food distribution outlets could include farmers markets, home delivery, buying clubs, grocery stores and an emergency meal program.

7.4 Sustainable Transportation

The site is located adjacent to what will be Vancouver's newest major public transit infrastructure project, a light-rail line called the Canada Line that will connect Vancouver's airport to the city's central business district. In addition, the site is within walking distance of at least three regular bus routes. Streets and pathways are designed to encourage cycling and walking, with links to the city's system of cycling paths. In addition, most basic amenities (food & drug) will be available within walking distance of residences. 100 percent of residential parking will be in underground lots and priority spaces are designated for car-sharing vehicles. The waterfront will feature a non-motorized boating facility and connections to Vancouver's aqua-bus systems.

8. Green Marketing

The market suites at Millennium Water are being sold by North America's top condominium marketing firm, Rennie Marketing Systems (RMS). Through involvement with this project, RMS has come to see the value of green design and to recognize the growing demand for sustainable design in the marketplace. RMS devised a 'Green' version of its widely recognized logo as an endorsement of green design and the added value of sustainability. The Green logo is one way in which this project is a beacon of a larger market transformation that is taking place as consumers grow increasingly aware of how their buying decisions impact their environmental footprint. This particular development is an important vehicle for the future of sustainable building design because, largely owing to its link with the 2010 Olympic Games, Millennium Water is a high profile project, and as such, promises to garner significant media attention the world over. The new neighbourhood will demonstrate new technologies and large-scale application of sustainable design principles. It will show successes of applied sustainable design and inspire future planners and designers to adopt similar objectives at the outset of project development.

9. Conclusion

The vision for Southeast False Creek and Millennium Water required an unprecedented level of commitment to sustainable urban design for a development of such scale in Vancouver. Meeting this commitment presented a considerable challenge for the design team, one that was exaggerated by the strict deadline imposed by the timeframe of the Olympic Village exclusive use period. In order to rise to the challenge, the team had to make a concerted effort not only to meet established targets, but moreover, to approach the design process from the perspective of sustainability from the earliest stages of concept design.

Despite challenges, the integrated design process undertaken by the design team was successful and produced two notable results: established sustainability targets were achieved (and some exceeded); and team members, regardless of their level of expertise in sustainability, learned a great deal from the experience about the interplay between buildings, energy systems and the environment. Once completed, the neighbourhood will continue to be a source of learning to designers from around the world, and to the City of Vancouver and its residents, and will pave the way for future urban sustainability on a local and global scale.

DO CONSTRUCTION MANAGEMENT GRADUATE SKILLS MEET THE NEEDS OF A GREENER BUILDING INDUSTRY?

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Summary

Construction professionals with knowledge and understanding of sustainability and sustainable development are in increasingly high demand. This is as a result of the push to implement more environmentally sustainable management policies, practices and operations to meet current environmentally-focused legislation. It is, therefore, imperative that construction managers understand sustainability issues and adhere to increasingly stringent environmental policies. However, a study undertaken in 2001 showed that an understanding of environmental issues was near the bottom of a set of skills industry representatives thought important.

In this paper we present findings of a study aimed at establishing what priorities construction employers now place on environmental awareness and sustainability skills. We report whether an understanding and knowledge of environmental issues is considered to be more important now than previously. We explore the sustainability skills (knowledge and understanding) that graduates are expected to have, and contrast these with the expectations employers have of construction managers with 10 years or more experience. Lastly, we present employer views on the current and future trends in sustainability and the associated skills they believe that graduates will need to ensure that construction practices benefit society as a whole.

1. Introduction

The construction and building industry is an industry where employees with environmental awareness and a knowledge and understanding of sustainability and sustainable development are in increasingly high demand. This is as a result of advances and new technologies and methodologies in the industry and the push to implement more environmentally sustainable management policies, practices and operations to meet current environmentally focused legislation (Tinker & Burt, 2003); and green building accreditation schemes. Examples of such schemes include the UK's Building Research Establishment (BRE)'s Environmental assessment method (BREEAM), the Leadership in Energy and Environmental Design (LEED) in the US and Canada, and Green Star in Australia.

Construction professionals are involved in the oversight of a wide variety of construction projects. They design, engineer, coordinate and supervise the construction process from the conceptual development stage through to final construction. More specifically, construction and project managers oversee the delivery and use of materials, tools, and equipment; and the quality of construction, worker productivity, and safety. They are responsible for obtaining all necessary permits and licenses and, depending on contractual arrangements, direct or monitor compliance with building and safety codes and other regulations (Manthe & Smallwood, 2007; Smallwood, 2003). Therefore, it is imperative they understand sustainability issues and adhere to increasingly stringent environmental policies. Those who have grasped the concept of sustainability understand that human actions have complex environmental and normative consequences, in addition they display an ability to comprehend inter-relatedness; they also show an attitude of care or stewardship, and have the necessary skills to act on knowledge and feelings (Orr, 1992). Similarly, according to Strauss (1996), sustainability behavior is characterised by the motivation and knowledge to investigate and pursue courses of action that contribute to a more sustainable future. The importance of an in-depth knowledge and understanding of sustainability and building green practices has been steadily increasing over the last decade, despite this however, a study undertaken in Melbourne Australia, by Love, Haynes and Irani (2001), showed that an understanding of environmental issues was near the bottom of a set of skills industry representatives thought important for future construction managers.

In terms of generic skills, employers, professional bodies, governments and students themselves are looking for programs that develop skills relevant to employment (ACNielsen, 2000 Harvey, 2006; Hager & Holland, 2006; Precision Consulting, 2007). It is now also well accepted that universities are engaged in attempts to ensure that their graduates are equipped with the skills "… that are highly regarded by employers and are seen to contribute to the country's prosperity and social capital" (Precision Consulting, 2007, p. 1). Furthermore, lifelong learning skills are particularly important for staff ongoing professional development (Candy, Crebert & O'Leary, 1994). The literature on generic skills for the construction industry suggests that supervision and communication skills, motivation and leadership are the most sought after by industry. Research on construction manager skills by Smallwood (2003) found that working with others; integrating efforts of people and technical expertise were the most important skills for construction managers. In addition, administration, oral communication, controlling, coordinating, decision-making and leadership skills were important for all managers. In terms of graduates, Frame and Canter (2001) found that the graduate skills employers most valued were information technology, teamwork and personal and professional skills. Smallwood (2001) recommends that university programs should help students develop skills in resource management and expertise relevant to the construction industry and should "...empower graduates to improve the construction process i.e. customer service, health and safety, productivity and quality management"(p.11). However, no research has been undertaken that focuses in-depth on construction mangers' perceptions of environmental and/or sustainability skills sets of construction graduates.

Obtaining information about environmental awareness and sustainability skills is now imperative for higher education institutions dedicated to ensuring that graduates meet the needs of a greener construction industry; an industry that is now outwardly committed to sustainable development. The results of this research will be used to inform the value of what is currently being taught within Property, Construction and Project Management (PCPM) degree programmes at RMIT University in Melbourne Australia. It will assist in establishing the focus of topics that should be addressed within the curriculum to ensure that industry relevant sustainability issues are embedded within the degree programs.

In this paper we present the outcomes of a study aimed at establishing whether employer perceptions of environmental awareness skills, included in a list of 18 generic skills, have changed and specifically whether employers see environmental awareness as being more important now than 7 years ago; given the increased awareness of the need to focus on sustainable construction and building 'green'. As part of the survey a selected group of major employers were also asked to rank their perceptions of recent graduates and employees' (with 10 or more years experience) knowledge and awareness of sustainability issues. Next we outline the research methodology, discuss the findings and make suggestions about what skills are seen as important by employers to inform university curriculum development.

2. Method

A group of major construction and property employers (n=12) based in Victoria, Australia were invited to participate in a survey exploring their perceptions and expectations of the skills of graduates and employees with 10+ years experience. Respondents were sent the survey in advance by email. The survey was then conducted by telephone. The survey comprised four sections:

The first section looked at the generic skills of construction graduates and asked employers to consider both the level of importance they would attach to a number of skills using a likert scale of 1-5 and their perceptions of the current skill levels of construction graduates (see Table 1 for list of skills). This section was informed by the list of generic skills generated by Love et al. in 2001.

The second and third sections addressed sustainability skills, and asked employers to rate the importance of a number of factors for recent construction graduates (first year in industry) and then for construction employees (with 10+ years experience), using the same scale of 1 to 5. The sustainability criteria included social, economic and environmental sustainability issues relating to the building and construction industry (See Table 2 for list of sustainability skills).

Table 1 List of generic skills including environmental awareness

	Skills
1	Academic achievement
2	Accepting responsibility
3	Adaptable to changing working environment
4	Computer literacy
5	Time management
6	Exercise professional judgment
7	Practical building knowledge
8	Interpersonal
9	Leadership capability
10	Numeracy
11	Oral communication
12	Problem solving
13	Environmental awareness
14	Teamwork
15	Trust and honesty
16	Update professional knowledge
17	Work autonomously
18	Written communication

Table 2 List of sustainability-related skills

	Skills (subdivided into 5 themes)
	Management issues including corporate social responsibility
1	Drivers for sustainability within the industry
2	The importance of social impacts associated with construction
3	Awareness of stakeholders associated with a construction project
4	Communicating issues to stakeholders
5	Managing stakeholder concerns
6	Implication of mismanaging risks
7	Ethical, social & cultural requirements of diverse workforce/supply chain
	Procurement issues
8	Business case for sustainable procurement
9	Financial benefits of integrating sustainability into procurement
10	How to evidence sustainable development
11	Environmental and social risks within the supply chain
12	Risk-based approaches to sustainable supply chain management
	Water Management issues
13	Global and national water issues
14	How water impacts and affects the construction sector
15	Key legislation relating to water management on site
	Energy issues
16	Global and national impacts associated with energy use and production
17	How energy impacts and issues affect the construction sector
18	Key energy legislation
19	Managing energy on site
20	reducing energy use within the workplace
	Waste issues
21	waste management and waste minimisation
22	How waste impacts the construction sector
23	Key legislation relating to waste
24	waste management on site

The fourth part gave employers the opportunity to provide additional information by completing four open ended questions:

1. Do you want to make any comments on graduates' generic or sustainability skills?
2. What are the current trends in sustainability that you are experiencing in your industry?
3. What kinds of skills will graduates need to meet these trends?
4. What do you think will be the future trends in sustainability for your industry?

All responses were anonymous and confidentiality was guaranteed.

Eleven of the 12 employer organisations approached took part in the survey. Two of the 11 employers who agreed to be surveyed chose not to respond to the four open ended questions (Section 4 of the survey).

3. Findings

In this section we present the analysis of the quantitative and qualitative survey data.

3.1 Perceived level of importance of graduate skills

Employer perceived rankings of environmental awareness is presented in Table 3. Results highlight that the perceived importance of environmental awareness has not significantly shifted since 2001 where it was ranked 14th (Love et al, 2001).

Table 3 Perceived level of importance of graduate skills

Rank	Generic Skill
1	Trust and honesty
2	Teamwork
3	Accepting responsibility
3	Computer literacy
5	Time management
5	Exercising professional judgment
5	Interpersonal skills
5	Leadership capability
9	Numeracy
9	Oral communication
9	Problem solving
9	Written communication
13	Updating professional knowledge
14	Adaptability to changing working environment
15	Academic achievement
15	**Environmental awareness**
17	Practical building knowledge
18	Working autonomously

3.2 Perceived skills of current graduates

Employer perceived rankings of the skills of current graduates, including environmental awareness, are presented in Table 4. Results show that actual graduates' environmental skills are ranked higher (see Table 4) than their perceived importance (see Table 1 above).

Table 4 Perceived skills of current graduates

Rank	Generic Skill
1	Computer literacy
2	Trust and honesty
3	Numeracy
4	Teamwork
5	Academic achievement
6	Exercising professional judgment
6	Interpersonal skills
6	Oral communication
6	**Environmental awareness**
6	Working autonomously
11	Adaptability to changing working environment
12	Leadership capability
12	Written communication
12	Accepting responsibility
15	Time management
16	Updating professional knowledge
17	Problem solving
18	Practical building knowledge

3.3 Perceived sustainability skills of current graduates

Employer perceptions of sustainability skills of current graduates are presented in Table 5. Results show that management and waste issues are ranked highly and are the top 5 sustainability skills.

Table 5 Perceived sustainability skills of current graduates

Rank	Skills associated with sustainable construction	Theme
1	Implication of mismanaging risks	Management
2	How energy impacts and issues affect the construction sector	Energy
2	Awareness of stakeholders associated with a construction project	Management
2	Waste management and waste minimisation	Waste
5	Communicating issues to stakeholders	Management
6	Managing stakeholder concerns	Management
7	Drivers for sustainability within the industry	Management
7	How waste impacts the construction sector	Waste
7	Waste management on site	Waste
10	Key legislation relating to waste	Waste
10	How to evidence sustainable development	Procurement
10	Global and national impacts associated with energy use and production	Energy
13	Global and national water issues	Water
13	Financial benefits of integrating sustainability into procurement	Procurement
15	Ethical, social & cultural requirements of diverse workforce/supply chain	Management
15	Environmental and social risks within the supply chain	Procurement
17	Key legislation relating to water management on site	Water
18	The importance of social impacts associated with construction	Management
18	Business case for sustainable procurement	Procurement
18	Key energy legislation	Energy
18	Managing energy on site	Energy
22	Risk-based approaches to sustainable supply chain management	Procurement
22	How water impacts and affects the construction sector	Water
22	reducing energy use within the workplace	Energy

3.4 Perceived sustainability skills of employees with 10+ years experience

Employer perceptions of sustainability skills of employees with 10+ years industry experience are presented in Table 6. Again, results show that management issues in particular are highly ranked.

Table 6 Perceived sustainability skills of employees with 10+ years experience

Rank	Skills associated with sustainable construction	Theme
1	Implication of mismanaging risks	Management
2	Managing stakeholder concerns	Management
3	Awareness of stakeholders associated with a construction project	Management
3	Financial benefits of integrating sustainability into procurement	procurement
5	Communicating issues to stakeholders	Management
6	How energy impacts and issues affect the construction sector	Energy
7	Drivers for sustainability within the industry	Management
7	How to evidence sustainable development	procurement
7	Key legislation relating to waste	Waste
7	waste management on site	Waste
7	Managing energy on site	Energy
7	reducing energy use within the workplace	Energy
7	Key legislation relating to water management on site	Water
14	Risk-based approaches to sustainable supply chain management	procurement
15	Business case for sustainable procurement	procurement
15	Environmental and social risks within the supply chain	procurement
15	Waste management and waste minimisation	Waste
15	How waste impacts the construction sector	Waste
15	Key energy legislation	Energy
20	How water impacts and affects the construction sector	Water
21	Global and national impacts associated with energy use and production	Energy
22	Ethical, social & cultural requirements of diverse workforce/supply chain	Management
23	Global and national water issues	Water
24	The importance of social impacts associated with construction	Management

3.5 Reponses to the open-ended questions

In response to the question "*Do you want to make any comments on graduates'* sustainability skills?", 5 of the 9 respondents mentioned that they believed that current graduates were more aware than previous graduates of sustainability issues, as illustrated by the following comments:

- Graduates are now more aware of the issues than the older guys…with sustainability skills, the new generation are far more aware than the past generation and this is a good thing; and
- Because it is an emerging area graduates' knowledge is better than predecessors – generally good and better than more experienced colleagues on the whole

While two respondents stated that they expected that graduates should be aware of sustainability, two were of the opinion that graduates did not require a great depth of knowledge in the area, as illustrated by the following comments:

- I would expect graduates to be GENERALLY aware of it [sustainability]; and
- Sustainability – they need only a broad understanding of it.

In response to the question *"What are the current trends in sustainability that you are experiencing in your industry?"*, the most often mentioned trend was the ecological sustainable design (ESD) requirement or green star rating (6 stars) initiative/legislation (5 instances). This was followed by general sustainability issues (4), responding to an increase in consumer demands (3), developing new ways of measuring a building's performance (1) and managing energy and waste during construction (1), as illustrated by the following comments:

- Buildings are becoming Green Star rated – 5-6 stars, and this has turned things around overnight; and
- Clients are requesting greener buildings i.e. ABGR and Green Star rated.

In response to the question *"What kinds of skills will graduates need to meet these trends?",* the skill most mentioned to meet emerging trends was for graduates to have thorough technical knowledge and expertise in sustainability, including knowledge of Australian Building Greenhouse ABGR ratings and AGBC building ratings (3); this was followed by negotiating skills (3) for example, to facilitate agreement on what constitutes innovation; and to manage trade-offs to meet minimum required ratings. Knowledge of local and overseas requirements and future trends in sustainability (2), improved understanding of operating costs lifecycle costing analysis (1), an ability to apply management skills generally and to manage others (2); as well as skills to manage the moral/ethical implications of sustainability (1) were also mentioned.

In response to the question *"What do you think will be the future trends in sustainability for your industry?",* the future trends mentioned by respondents included increased consumer demand for high quality and energy efficient greener buildings (3); more and more onerous requirements to be met, more pressure, and specialized, expertise required (2); adopting carbon neutral approaches; ensuring closer links between design, construction and operational factors; meeting the demand for retrofitting for efficiency; increased pressure on energy reduction during construction; managing environmental aspects and that sustainability will be high on the agenda of any future project.

4. Discussion and conclusions

In this section the findings presented above are used to answer a number of questions:

1. *Have priorities changed given the increased awareness of the need to focus on the environment and on building 'green'?*

The results of this current survey show that for this group of employers the answer is no. In fact the data reveals that they rank environmental awareness slightly lower than the group of employers did in 2001 (n=27).

2. *Is understanding and knowledge of environmental issues considered to be more important now than it was in 2001 and if not, why not?*

Although the results of the quantitative data suggest that this group of employers do not consider environmental awareness to be more important now than it was in 2001, the qualitative data clearly illustrates that they are highly engaged in sustainability, see as critical to the industry and are pleased that current graduates are demonstrating higher skills levels in sustainability awareness than existing employees. However one employer expressed tension in the industry surrounding sustainability and specifically leadership as suggested by the following comment: "still a lot of skeptics (about sustainability) and these people are controlling the finances….contrary to that, we are starting to see a lot of grass roots support – from below the power if you like….".

3. *Do current graduates meet the needs of the industry in terms of their current knowledge and understanding of environmental awareness?*

Both the quantitative and qualitative data show that the employers surveyed believe that current graduate demonstrated an understanding of environmental awareness. Data showed that employer perceived level of importance of environmental awareness (rank = 15) was lower than their perceptions of graduate actual demonstrated skill levels (rank = 6).

4. *Which sustainability skills do employers value in recent construction graduates (first year in industry) compared with construction employees with 10+ yrs experience?*

In both instances the management skill of understanding the implications of mismanaging risks was the most important skill for both recent construction graduates and employees with 10+ yrs experience. Other skills in common at the top end of the scale were awareness of stakeholders associated with construction projects and communicating issues to stakeholders. Where they differ is that the focus for current graduates included more operational-focused skills such as how energy impacts and issues affect the construction sector and waste management and minimisation. Whilst for those with 10+ years experience, issues were the higher-order leadership skills of managing stakeholder concerns and understanding financial benefits of integrating sustainability into procurement.

Issues surrounding the management of risk, waste, stakeholders and energy, as well as the drivers for sustainability legislation were consider core to the skills required of both graduates and employees.

5. *In light of the above findings, what implications do these perceptions of employers have for curriculum development of university construction management programmes?*

The findings from the study reported in this paper reinforce that we cannot ignore the importance and growth of sustainability and sustainable development within the construction sector (Tinkler and Burt 2004). It is imperative that university programmes respond to employer perceptions and continue to ensure that students graduate with requisite sustainability knowledge and skills. Given the importance placed on the design stage for embedding sustainability by employers as demonstrated by the qualitative results of this study, this requires opportunities for students to work in interdisciplinary teams with architects, planners and engineers, where they "embrace the concept of sustainability as a process; one which starts well before construction (in the planning and design stages) and continues long after the construction team have left the site: a process that takes in the design, construction and on-going maintenance of what is being referred to as a 'green' building" (Hayles and Holdsworth, 2005, p 2). In this way built environment students from every discipline can gain an understanding of the different roles other disciplines play in the process and consequently, are educated with a 'whole building' mentality.

There is also a need to ensure that the moral and ethical drivers for sustainability are understood by built environment students, as highlighted by one of the employers surveyed who stated that "[g]raduates have to know the drivers of sustainability and have to know the legislation and [that] there is a moral side to it as well".

In conclusion, this paper shows that whilst employees may not be attaching the level of importance to environmental awareness that we would like see, their comments suggest that sustainability as a whole is high on their agenda and has permeated the everyday life of construction professionals. It is now up to universities, with regard to environmental awareness and sustainability, to continue to educate graduates who exceed the expectations of employers and who become industry leaders implementing sustainable approaches to construction that have yet to be imagined.

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SUSTAINABILITY AND THE STRUGGLE FOR HEGEMONY IN AUSTRALIAN ARCHITECTURAL EDUCATION

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Keywords: architectural education, sustainable design education, ideology, hegemony, curriculum reform

Summary

This paper describes the outcomes of PhD research into ideological barriers to the implementation of sustainable design curricula in Australian architectural education. More specifically I describe ideological positions within the contested fields of architectural education and sustainable development and explain the dimensions of ideological resistance manifest in the values (ethos), structure (eidos) and implementation (praxis) of Australian architectural curricula.

The research has identified strategies of hegemonic struggle which affect the relative dominance of ideologies in Australian architectural education and the positioning of sustainable design curricula within this contested field. I have found that sustainable design curricula are currently marginalised in Australian architecture courses and that this marginalisation has been historically constructed. I have also exposed hegemonic strategies that reproduce such marginalisation within curricula.

1. Introduction

The discipline of architecture has a long history of engagement with environmental issues and environmentalism. Recently there has been rhetorical support from professional organisations for the broader sustainability agenda (eg UIA, 1993; RAIA, 2005; RIBA 2006). Despite this, it appears that architectural education has been slow to integrate the concept of design for sustainability, rather perpetuating the view of sustainable design as being for architecture (Fletcher & Dewbury, 2002). The latter position reinforces the hegemony of professional ideologies of architecture and the vocational intent of architectural education rather than challenging the status quo and educating architects to change the profession so it can better contribute to the ideals of sustainable development Influential advocates of education *for* sustainability suggests that most formal education teaches us how to be unsustainable (Milbrath, 1989; Orr, 1994; Huckle and Sterling, 1996; Sterling, 2001; Fien, 2003; Thomas, 2004; Tilbury & Wortman, 2004; UNESCO, 2005). Can this criticism be levelled at architectural education? Are the dominant ideologies shaping curricula in our architecture schools teaching only how to better replicate an unsustainable status quo? Are the ideologies which have been dominant in shaping architectural curricula at odds with the ideologies of sustainability education? If so how can knowledge of ideology inform curricula reform?

1.1 The Problem of Ideology in Sustainable Design Education

To affect curriculum change it is necessary not only to have a design for a desired state, but also to gain the power to implement it. This assumption demands both an understanding of the power relations that support the status quo and an acceptance of curriculum development as a process of ideological struggle. Hence, efforts to reform architectural education need to be informed by an understanding of the hegemonic struggles which shape architectural curricula. To understand resistance to such reform we must go beyond identifying the problem of integration, and look more closely at the problem of how to gain the power to influence change.

Existing research in the field of sustainable design education has not focussed on such issues. Research in the fields of sustainability education and sustainable design education has commonly stated this problem in terms of integration i.e. how can sustainability be fully integrated into curricula? Conclusions of such Investigations have often identified ideological conflict as a potential barrier to integration, but have left it uninvestigated (Alabaster & Blair, 1996; Thomas *et al*., 1999). Contemporary international studies have not considered curricula as manifestations of a history of ideological struggle (Fletcher & Dewbury, 2002; Fowels *et al*, 2003; Wright, 2003; McDonald, 2004;). Nor have detailed studies of sustainable design education in schools of architecture been conducted in Australia.

This paper presents a summary of the findings of PhD research which has addressed these knowledge gaps by investigating such issues through a critical history of ideas within the contested fields of architectural education and sustainable development. It summarises ideological positions within discourses related to these fields in order to explain documented resistance to the integration of sustainable design curricula in architectural education in Australia.

Using critical discourse analysis I have tested the hypothesis that dominant ideologies shaping architectural education in Australia prohibit rather than support the sustainability agenda. The outcomes of the discourse, content and analyses of curricula support this hypothesis. The following section briefly explains the methodology adopted for this research. The findings which support this conclusion are then presented.

2. Research Methodology

This study focussed on the influence of concepts of ‘sustainability’ and ‘sustainable design’ on discourses in architectural education in general and Australian architectural curricula in particular. The intention of this research was to better understand the power relations and strategies that lead to the dominance and subordination of certain ideas in architectural curricula. Developing an adequate method for investigating ideology in discourse was approached by first addressing the fundamental questions; What is ideology?; How can ideology be identified in architectural education?; and How can ideology in architectural education be understood?

I adopt the view that ideologies are lived systems of values which have a material existence in the practices of institutions (Heywood, 1992). I also consider ideologies to be tacit theories and ideas that shape the language, actions and values that exist within a discourse (Gee, 1990). According to these definitions, identifying ideologies can help explain the unconscious acts and conscious social practices of people and institutions (Marshall, 2000). More specifically, studying ideologies can explain the establishment, maintenance and dynamics of the social relations of power, domination and exploitation within a field as well as forms of resistance and conflict (Foucault, 1984; Fairclogh, 2003).

In summary ideology is subconscious systems of belief which are manifest in the discursive practices of institutions. Because people’s ideology is ‘sub-conscious’, interview and survey methods were not deemed the most appropriate methodology for investigating the dynamics of ideology. Changes in discourse are a more reliable indicator of hegemonic struggle than people’s opinions, particularly over long periods (the total period under consideration in my thesis covered more than 2000 years of ideas in architectural education).

Historical and contemporary analyses of such practices were conducted using a synthesis of the concepts of ‘field’ (Bourdieu, 1985) and ‘discourse’ (Fairclough, 2003; Gee, 1990; Foucault, 1984). A historical discourse analysis (Weiss and Wodak, 2003) was conducted of the handbook descriptions of architectural courses in Sydney over the last thirty years, in addition to a contemporary discourse analysis of courses offered in 2007 by all Australian schools of architecture. This analysis was supported by curriculum mapping to reveal the power relations inherent in architectural curricula. Summarised ideological positions were then presented as ‘story-lines’ and organised in relation to ideological indicators for curricula, namely ethos (values), eidos (structure) and praxis (valid knowledge).

This research method was used to investigate the following questions.

1. Why would sustainable design education be marginalized?
2. What strategies are used to marginalize or promote particular ideals in architectural education?
3. Is sustainable design education marginalized in Australian architectural curricula?
    - If so, how?

The following sections summarise my answers to these questions by relating the influence of the ethos, eidos and praxis of architectural education both historically and contemporarily.

3. Why would sustainable design education be marginalized?

A history of ideas about architectural education shows that concern for nature, materials, comfort and durability have been omnipresent and have from time to time not only been performance parameters for architectural design, but also for the social causes for architecture. Sustainable design is a recent phrase which has come to be associated with concern for reducing the environmental impact of buildings as well as architectural engagement with sustainable development discourses. However, many of the issues associated with the sustainable design agenda, such as climate-responsive design, efficient use of materials and human comfort have been traditional issues for architectural design. In addition, there is widespread rhetorical support for engagement with ‘sustainability’ agendas amongst architecture’s professional organizations. The first question for my research was therefore why would sustainable design education be marginalized? The answer is that there are a number of key differences in ethos, eidos and praxis between traditional architectural concerns and the sustainability agenda.

3.1 Conflicts in Ethos

The sustainable development agenda is not a unified agenda. Contradictory views on development such as ‘no-growth’, ‘pro-growth’ and ‘ecological’ exist within discourses on ‘sustainability’. This has led to perspectives of ‘sustainable development’ as a failed concept (Adams, 2006). These contested ideals within sustainability discourses make it a difficult agenda to implement in the reform of curricula.

Advocates of sustainable development, such as the United Nations, promote a neo-liberal agenda which represents an entrenchment of growth-based economics regarded by many as ecologically unsustainable. Therefore the U.N. agenda of education *for* sustainable development (EfSD) can be hard to distinguish in intent from standard systems of education. This may contribute to the perception of some architectural educators that architectural education already *is* an education for sustainable development. After all, both the United Nations EfSD and 'professional' architectural education are premised on the sustenance of our current economic paradigm. The *change* agendas promoted by 'sustainability' or 'sustainable design' educators may be marginalized by their own lack of definition and therefore their lack of distinction from current practice.

Other grounds for marginalization can be found in the comparison of ideals of architectural education which are fundamental to the civic intentions of sustainable design education. The recurring intent of architectural education is reinforcing the definition of architecture as a discipline which is largely concerned with its spatial-aesthetic agency and of the architect as individual designer. The major problematic for architectural education appears to be learning how to design buildings with meaningful space, form and expression. This is ostensibly framed as vocational education.

The main problematic for sustainable design education on the other hand is to learn how architectural design can facilitate socio-ecological well-being. The main social agency of sustainable design is contributing to the sustenance of socio-ecological systems over time. This requires learning design in terms of civil action, rather than merely a vocation. Further, to this is more expansively engendering the idea that the vocation of education itself is a form of civil action. The emphasis of the sustainable design agenda is not on the individual designer or the embodiment of social ideals in an objectified building. Rather, the focus is on the collective or interdisciplinary *process* of enabling 'building' (both noun and verb) to sustain the natural and social systems with which it is interdependent. 'Sustainability' is therefore an emergent quality which is not immediately aesthetically experienced. The dominance of the ethical-aesthetic value orientation in relation to that of 'sustainability' in contemporary Australian architectural course descriptions is emblematic of these tensions.

Another tension arises because issues of ecological sustainability are also not necessarily immediate to the location of a building but range from local to global. Impacts may also be distant in time, indirectly related to the actual building, and more strongly associated with the supply chain that supported its creation, operation and eventual demolition or reuse. Architectural curricula on the other hand are focused on understanding the impact a building design might have on its immediate surroundings once it is built. The sustainable design agenda seeks to foster global-local '*glocal'* (AIJ, 2005)' life-cycle awareness whereas architectural education traditionally focuses on local impacts of the building once it is built. Students may well learn how to conduct a shadow analysis and to configure a building to its local climate, but rarely learn what sort of building design might contribute to the well-being of a bioregion or water catchment (which may be in other countries and may for example be affected by material manufacturing).

This difference in the physical and temporal scope of consideration is perhaps exacerbated by the shift away from science as the theoretical basis for architecture. This is evident in my analysis of Sydney Schools from 1977 to 2007. Social sciences and systems-sciences such as ecology were influential in non design subjects and prerequisite for design subjects in two of the three Sydney Schools until 1997. However between 1997 and 2007 these knowledges have become structurally disconnected from design subjects. A lack of scientific theory disables student's ability to develop qualities of mind such as ecological literacy which is argued to be fundamental to 'sustainability' education.

In contrast to the sustainable design agenda, the promotion of individualism is evident in the history of ideas that have shaped architectural education. Individualism also finds expression in contemporary architectural education with progression in design subjects almost exclusively culminating in the individual major design project. This is at odds with the perception of the need for interdisciplinary and collective cooperation when dealing with complex 'sustainability' issues. Professional ethics are intended to guide the social conduct of individual architects in these matters. However architectural curricula in Australia do not have a strong history of providing praxis for developing the ethical capabilities required for design collaboration.

There have been times in the past thirty years when design has been described more as a means of social change. However I have found that design education in Australia is predominantly positioned *for* architecture – as a means of reproducing the symbolic field, its precedent ideals and professional niches. Sustainable design education is also *for* architecture but only in so far as the influence of fields of knowledge such as ecology provides opportunities for innovating design methodologies. Sustainable design is more concerned with how architecture can change in order to be a *means of* influencing socio-ecological sustenance and wellbeing. Rather than being primarily *for* architecture this agenda considers design as positioned *for* 'sustainability'. While there is no doubt that sustainability discourses have infiltrated discourses on architectural education, the findings described above establish grounds for conflicts between the dominant ethos in architectural and sustainability agendas respectively. These are summarized in Table 2.

Architectural Education	Sustainable Design Education
The main *problems* for architectural education are creating meaningful space, form and expression and Vocational training;	The main *problems* for sustainable design education are of socio-ecological well-being and Civic action-competence;
The main social *agency* of architectural design is aesthetics;	The main social *agency* of sustainable design is innovation in socio-ecological systems;
Its impacts are considered locally;	Its impacts are considered 'Glocally' and temporally;
Its theory is increasingly based in arts rather than sciences;	Its theory is currently based in sciences rather than arts;
Its over-arching goal is *sustaining* the role of the profession	Its over-arching goal is *changing* the role of the profession

Table 1: Conflicting ethos in architectural and sustainable design education.

The 'ecological' paradigm calls to attention the need to accept change as our survival strategy. Adopting this perspective has the potential to be incredibly empowering for architectural design education because 'design' *is an intention to change.* What to change, for whom, when and how are the ethical questions that, if applied to the ethos of architectural education, would position design as being *for* social and ecological change. Learning to be an agent of change would therefore be *implicit* in design education. The main intention of architectural education is however, to sustain rather than to *change* the profession.

3.2 Conflicting Eidos

The organization of architectural education in Australia reflects its predominant ethos as an education *for* architecture rather than in architecture as a means of survival. Discourse analysis of course handbooks shows courses have overwhelmingly described their disciplinary focus and their professional accreditations. Advocates of sustainable design argue that interdisciplinary curriculum should be fundamental to an education *for* sustainability. However, despite many courses being offered within multi-disciplinary faculties, most design subjects are organized as discipline-specific studios.

Other differences in eidos exist. The sustainable design agenda favors education *as* sustainability, which requires learning through identifying and designing out 'unsustainable' conditions (Table 2 next page). This in turn requires a curriculum that engages with 'real-world' situations and takes advantage of 'service-learning' through community engagement. While it has been observed that structuring curricula around studio design problems provides the capacity for architectural education to be education *as* sustainability, it is evident that studios are neither the major vehicle for engagement with sustainability agendas nor do they provide '*as sustainability'* pedagogy. Instead 'sustainable' design objectives are most commonly taught as an education *about* sustainability i.e. removed from the problem context and delivered in lecture-based subjects. Other aspects of the '*as'* sustainability eidos which are not evident in course or subject descriptions are the use of university campuses and buildings, and their surroundings as '*sustainability*' learning sites, nor are the basis for core design studio projects the adaptive the reuse of buildings. Design studios currently almost always assume a new building.

Architectural Programs must decide that 'sustainability' is a core conviction and therefore, a principle reason *for* the education offered in order to align the eidos of their education with the sustainability education agenda. The commitment of all the staff and students to the exploration of the issues of sustainability in core streams of study is required so a curriculum model for sustainable education can be developed. It will be important to be mindful of both the *process* and *context* of learning and the need for continually evolving content.

3.3 Conflicting Praxis

Synergies exist between architectural and sustainable design in the small-group and progressive assessment within a studio environment. Architectural education and sustainability education share a concern for life-long learning. Discourses in architectural education often make reference to the perception of architecture as a life long pursuit. This perception has also been formalized by requirements for continuing professional development. However, there are differences in terms of transmissive versus transformative teaching styles. This area of conflict is associated with which types of knowledge are enabled by *praxis* (action-reflection-learning) cycles, and also the extent to which 'learner centered' approaches empower students in developing self-knowledge.

Education about sustainability typically introduces content and knowledge about sustainability issues. This approach allows sustainability to be taught through principles, rules, or laws in special courses within a program and does not require any change to standard curriculum models. ***Education for sustainability*** emphasises learning for change. This approach includes learning about social values, critical analysis to identify areas of contemporary practice that require reform, and developing capabilities to affect the reforms. This type of curriculum is predicated on the conviction that aspects of current practice are not sustainable and need changing. It focuses on how to facilitate change without requesting personal change toward sustainable practice from either students or the teaching program. ***Education as sustainability*** emphasises learning as change. In this model the process of actually trying to cease unsustainability and live sustainably becomes the learning activity, and as a result the class-room, the studio, the administration, the campus, the practice, the professional organisations etc should become contributors to sustainable development.

Table 2: Distinctions between EfS curriculum models. (Sterling, 2001)

International research has indeed recorded instances where such conflicts of interest have become manifest in a perceived marginalization of sustainable design curricula. However, the lack of investigation into how such marginalization actually occurs led me to the question, which strategies are used to marginalize or promote particular ideals in architectural education? My answers to this question are now presented.

4. What strategies are used to marginalize or promote particular ideals?

Curricula development is an ideological process involving hegemonic struggle. As such, various strategies are employed to promote and empower certain ideals and forms of knowledge, while diminishing and disempowering others. Through analysis of changes in the interrelated ethos, eidos and praxis of Sydney architecture schools over the last thirty years, and the curriculum mapping and content analysis of contemporary Australian architectural curriculum, I have identified six major hegemonic strategies (Table 3).

Ethos:	– Universalising traditional architectural strategies as ‘sustainable design’ strategies; – Framing ‘sustainability’ concerns in the context of architectural design;
Eidos	– Protecting core subjects by liberalising elective subjects; – Decoupling progression in design from progression in non-design subjects; – Preferential weighting of units of credit;
Praxis:	– Offering ‘stand alone’ subjects without praxis

Table 3: The major hegemonic strategies observed in Australian architectural education.

Over time, the analysis of Sydney architecture schools shows that these strategies have both promoted and discouraged sustainable design education. Identifying these strategies helps to explain changes in the power-relations of different elements of curricula, and provides criteria for investigating the hegemony of ideologies in curricula at a given time. The current position of sustainable design curricula in Australian architecture courses is thus a manifestation of the historic implementation of such strategies. But does this mean that sustainable design education is currently marginalised in Australian architectural curricula? This last research questions was addressed by critically analysing the ethos, eidos and praxis of architecture schools in Australia.

5. Is sustainable design curricula marginalized?

My historical discourse analysis of the fields of sustainability and architectural education has identified grounds for ideological conflict. The review of curriculum changes in Sydney Schools and the contemporary review of Australian architectural curriculum have identified strategies for promoting or subordinating particular ideals. With these insights I have analysed the position of sustainable design in contemporary Australian architectural curricula. I conclude that sustainable design education does indeed currently appear marginalised as a result of the persistence of conflicting ideologies whose dominance is supported by the presence of disempowering hegemonic strategies. I conclude that the sustainable design agenda is currently marginalised by the dominant ethos, eidos and praxis of Australian architectural curricula.

5.1 Marginalised by Ethos

The sustainable design agenda is marginalised by the dominant *ethos* of architectural curricula. Content analysis of handbooks, course descriptions and design subject descriptions shows their explicit and implicit values to be oriented towards ethical and aesthetic concerns rather than concern for sustainable design. The ethical concerns were associated mainly with professional responsibilities to clients, building occupants, the built environment, as well as reflecting social and cultural values. Aesthetic values were associated with such issues as the form, order, space, and tectonics.

Functional aspects of building design and its impact on built environments were also prevalent values. Sustainable design values were among the least prevalent value positions expressed in Program and Course documentation. Where sustainability values were expressed they were positioned as in service to architectural design, rather than as a cause for architectural design.

5.2 Marginalised by Eidos

The predominant structure and organisation of Australian architectural curricula also marginalises those of sustainable design. Sustainable design concerns represent on average, 12% of the total units of credit required for architectural studies. Of these 'sustainability credits', most are allocated to technology related subjects (22%) rather than design studios. Sustainable design also becomes less prevalent as a proportion of units of credit allocated in the last two years of most architectural courses. The average allocation is 14% for the first three years of study and 10% for the final two years of study. These final years are typically the 'professional degree' courses, which gives the impression that sustainable design diminishes in importance as design education becomes more professionally oriented.

By far the most common place for explicit engagement with sustainable design is in elective rather than core subjects (Figure 2). On average 51% of elective stream subjects dealt with aspects of sustainable design. Studio based teaching has been regarded as the main pedagogical vehicle for introducing students to the core values of architecture. The absence of sustainable design from design subjects, and from core subjects in general is therefore likely to contribute to a hidden curriculum which further diminishes the perceived architectural value of such knowledge.

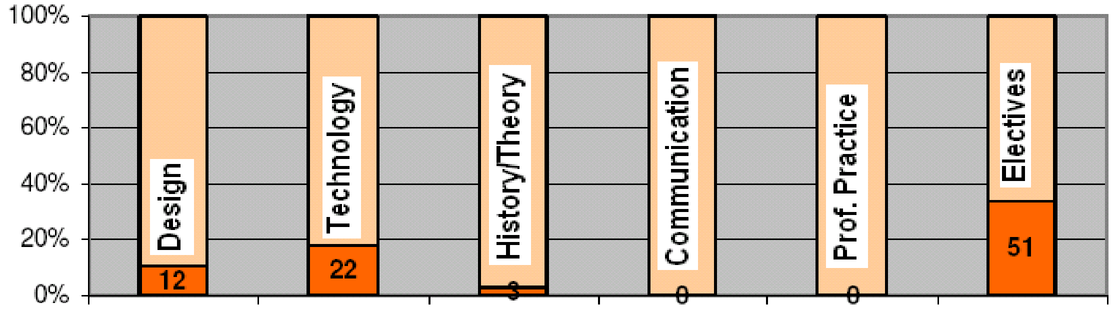

Figure Two: The average % of stream UOC engaged with aspects of sustainable design in Australian architecture programs in 2007.

Sustainable design knowledge is generally not a prerequisite for progression in design subjects. Fifteen of the sixteen architecture schools analysed did not require non-design subjects to have been passed in order to progress in design subjects. This marginalises sustainable design agendas because most of this content is currently presented in non-design subjects. In addition, most courses are not organised in ways that enable progressive reinforcement of sustainable design knowledge. Most courses provide stand alone 'sustainable design' subjects in either design or non-design streams. This represents an *'about* sustainability' approach, which is the least progressive mode of sustainability education.

5.3 Marginalised by Praxis

Praxis is related to pedagogy and the kind of knowledge that is promoted as valid in curricula. Proponents of sustainability education argue that responding to situations of unsustainability is primarily an ethical responsibility. Education should therefore develop ethics that accord with a sustainability agenda, and empower students as citizens who are able to apply their specialised knowledge for social and community benefit. Curricula that facilitate students developing self-knowledge and an image of self as a 'sustainable designer' are therefore necessary. The capacity for contemporary architectural curricula to enable this praxis is already marginalised by the dominant orientations of ethos, and structural limitations of eidos. However, it is further marginalised by the kind of knowledge presented in sustainable design subjects themselves.

A review of the learning objectives of sustainable design-related subjects shows that most subjects aim to impart instrumental knowledge rather than develop self-knowledge. Instrumental knowledge represented approximately 66%, while the development of self-knowledge represented only 34% of 'sustainable design' learning objectives respectively (Figure 3). This creates a bias toward transmissive rather than transformative forms of teaching and learning. Sustainable design learning is therefore not only marginalised by a lack of praxis across the total curriculum, but also from within subjects intended as its primary vehicles.

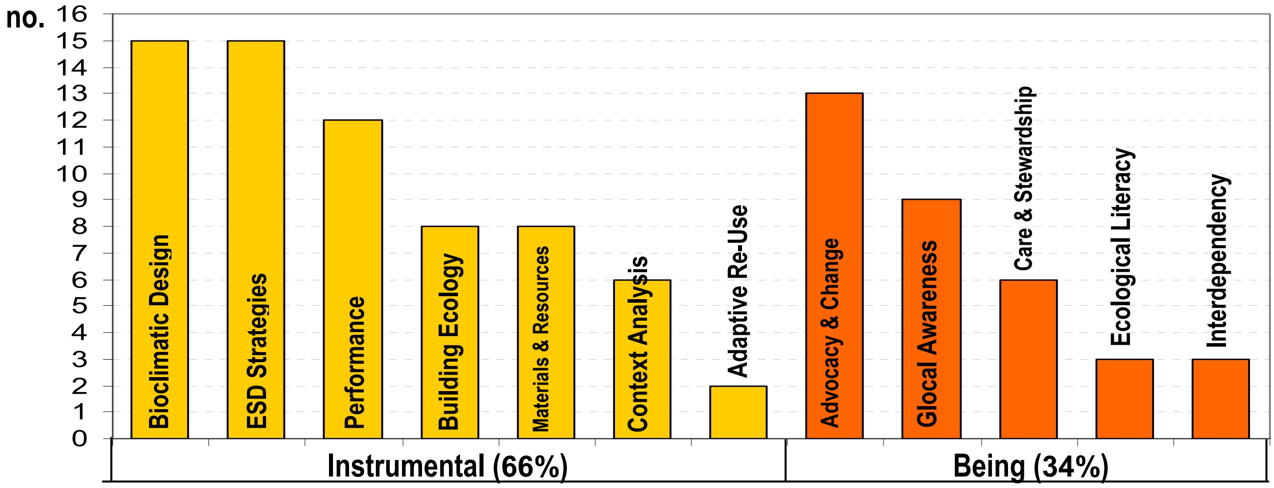

Figure Three: Proportion and incidence of knowledge types in 'sustainability' learning objectives.

Over the past thirty years, changes in curricula ethos, eidos and praxis indicate a drift away from science and towards arts as a fundamental epistemology of architecture in Sydney schools of architecture. Due to the scope of my historical analysis I can not be definitive about whether this drift is evident in other Australian architecture schools. However, I have observed an emphasis on 'design fundamentals' and less emphasis on architectural, environmental and social sciences in contemporary Australian architectural curricula. Because 'sustainable design' is predominantly framed in terms of science and technology, science based epistemologies are essential to theory building. The current bias toward arts based epistemologies therefore aids the marginalisation of sustainable design praxis as it is most commonly defined.

Some schools are beginning to broaden the definition of sustainable design as not only scientific and technical but also as cultural and historical. While these subjects provide new grounds for architectural engagement with sustainability issues, scientific methods are still the predominant ways in which western society analyses and understands our physical relationships with, and effects on the planet. Empowering students in architectural methodologies such as ecologically sustainable design therefore requires *at least* that they learn enough architectural science to be able to communicate with people whose disciplinary focus is scientific. Proponents of sustainable design would call this aspiration the need to develop basic ecological literacy. This learning objective is however, poorly supported by current architectural curricula.

6. Conclusions

These findings describe conflicts of ethos, eidos and praxis between architectural and sustainability education in Australia's schools of architecture. The current marginalisation of sustainable design curriculum is a manifestation of historical and on-going hegemonic struggle between the competing ideals of architecture and sustainability. Furthermore, the dominance of particular ideals is continually influenced by hegemonic strategies which manipulate course ethos, eidos and praxis. I therefore conclude that my hypothesis; *that dominant ideologies shaping architectural education in Australia prohibit, rather than support the sustainability agenda* – is a true interpretation of the current situation.

In the past thirty years awareness and concern for changes in the earth's biocapacity have increased, as have rates of urbanisation. Consequentially so has awareness of building as an influence on social and environmental change.

Despite this, Australian architectural education has remained remarkably unchanged in ethos, eidos and praxis. Emblematic of this stasis is the observation that even learning objectives for sustainable design subjects do not represent a progressive engagement with their own field. *Not only* are most learning objectives constructed instrumentally, but also many represent universalisations of traditional concerns in architectural science such as bio-climatic design, thermal performance and the efficient and appropriate use of materials. Traditional knowledge of how building designs might change in response to climate need to be coupled with for example, new knowledges of how building designs have contributed to climate change and how the human habitat can be designed to adapt to such change.

Even though sustainable development is a contested concept, its various discourses represent *the only major global socio-economic reform agenda.* Indeed, sustainable development is the only truly global conversation on ecological interdependency and social equity in human history. Yet our engagement with 'sustainability' in Australian architectural education continues to be marginalised by ideas which are in some cases at least 2000 years old. Sustainable design education is simply not a core conviction for the majority of our architecture schools.

7. Recommendations

Architectural educators have a responsibility to create curricula that fulfil both the civic and vocational roles of university education and have far more freedom than practitioners to choose their emphasis. History has shown that it is possible to develop curricula which intend to simultaneously be *for* architecture and *for* progressive social change. What is required of educators is *intent*.

A practical first step is to ensure that passing non-design subjects in which sustainable design is currently taught are prerequisite for progression in studio-design streams. A second practical step is to restructure curricula so as to offer '*as* sustainability' education in which sustainable design studios are the core vehicle for investigating and designing out 'unsustainabilities'. In the process students must demonstrate the instrumental knowledge taught in non-design subjects. Thirdly, studio projects should try to foster long term community engagement and implement a continual experiment in rethinking the physical settings for teaching and learning. Students should gain experience in eliminating unsutainabilities in existing buildings, not only the new. Assessment should be informed by monitoring and reflecting on potential and actual contributions to the health of the biosphere and the equity of society.

Taking these first steps would begin to align the *ethos*, *eidos* and *praxis* of architectural studies with the sustainability agenda. And also show students through the tacit experience of their learning, that '*being'* an architect involves being foremost an agent of social change, rather than only perpetuating a image of a design professional who has 'sustainability' as a skill set.

Educators should be mindful that instituting such change is not only a matter of planning integrated curricula. Reform is an ideological struggle. Therefore hegemonic strategies which have historically maringinalised sustainable design such as weighting credit-points, controlling pre-requisites for progression through design subjects, providing or denying reinforcement of certain knowledges, re-naming rather than reforming subjects to universalise or contextualise concepts as 'for' architecture, and protecting the biases of the 'core' course by liberalising elective streams, could also prove effective in its promotion.

The implication of architectural educators failing to engage effectively in the sustainability discourse is that their students will themselves eventually be marginalised. This is because other professions are becoming educated in ways which make useful, meaningful and influential contributions to the sustainability issues facing humanity. I hope that comprehending the limitations of ideology and hegemony in architectural education identified by this research will encourage and assist architectural academics to design appropriate curricula for change. After all, design is our best method of using change as a survival strategy.

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STUDY ON THE TRANSITION AND PROGRESS OF BUILDING ENVIRONMENTAL PERFORMANCE AND HUMAN PERCEPTION IN THE ARCHITECTURAL COMMUNITY IN JAPAN

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Keywords: Environmental Issues, Transition and movement, Perception, Architectural community

Summary

Since the 1990's, environmental issues have been key issues. The general public and architectural community is increasingly concerned those issues year by year, so major movement of environmental strategies and developments have been conducted in the architectural community in Japan. An awareness and perception on environmental issues are expected to be changing in both architectural community and general public. But it is uncertain which direction we are moving to and how much progress we have achieved so far. It will be useful if there is some monitoring and guiding system that will suggest and show the direction and progress on environmental strategies in the building sector.

Reviewing the movement and transitions relating to environmental strategies, especially assessment tools in the architectural community are useful to consider a future trend and direction. It is also important to identify what is a character of the movement, what is being improved and what is a key driver of improvement.

The purpose of this study is to determine progress of building performance relating to assessment tools based on real data, key movements, opinion of key actors in the architectural community, and to provide primary information that supports to consider a future direction and strategies to the architectural community in Japan.

The real data survey covered specific events, environmental statistics data of buildings, leading edge buildings and those applied techniques. The human perception survey covered a series of questionnaires on environmental issues and building performance. The questionnaire surveys were implemented three times in the architectural community in Japan, in 2000, 2004 and 2007 to measure a change of human perception among several years interval.

1. Introduction and Methods

Several surveys have been conducted about real data and human perceptions on environmental issues in the architectural community in Japan. The questionnaire surveys were conducted three times to measure the change in human perception during a few year intervals. The first survey was conducted in 2000 and the second survey was conducted five years later in 2004, and third one in 2007 using the same questionnaire items. Respondents of these surveys were Japanese local governments, building design and engineering firms, construction companies and utilities companies. About 60 to 150 people responded to the questionnaires.

Some of questionnaires contained both current issues and future estimates in order to know future expectations on environmental and building issues.

2.Real data survey

2.1 The trends of specific events and energy consumption

2.1.1 General events and buildings

Fig.1 shows the transition of major events, policies and laws, current expressions, and key words that relate to environment and buildings in Japan from 1970 to the present day. It can be divided into four specific periods based on the social situation as follows:

1955 to 1973: General trend: rapid economical growth period
Building: pollution issues, smog, wind harm, sunlight shading
Large and tall buildings were designed and constructed. Most of them were designed to be mechanically controlled buildings for example; skyscrapers in Tokyo.

1974 to 1988: General trend: period of stable growth,
Building: limitation of resources and chasing improvement efficiency
Energy is one of the critical issues for building design, for example; super energy conservation buildings, passive solar houses.

1989 to 1994: General trend: bubble economy and the collapse of the bubble economy

Building: chasing technological limitation, realization of global environmental issues, for example; Hyper building projects which are over 1000m -3000m height were proposed and Environmental symbiosis houses.

1995- today: General trend: Collapse of the reliance on technological and social systems,
Building: practice and implement of environmental strategies, for example; Natural conditioned buildings, CASBEE assessed buildings.

It is difficult to draw a clear connection between the social situation and building design. However, some buildings indicate that social events influenced the building concept and design, such as energy conservation building around the period of the oil crisis, hyper building projects around the period of the bubble economy, and natural conditioning buildings after Kyoto summit.

2.1.2 Environmental strategies of the Government and Architecture Community

Since the late 1990s, a series of specific events have occurred in both policy and architectural strategies. Some important laws were launched by the government, and an agenda, proposal, and charter relating to the environment and buildings were established by the architectural community. There is a clear transition in both society and the architectural community toward environmental concern.

However, it is still not known whether environmental performance has improved along with strategies.

A more subjective analysis is needed in order to show the social transition and suggest a rough overall trend.

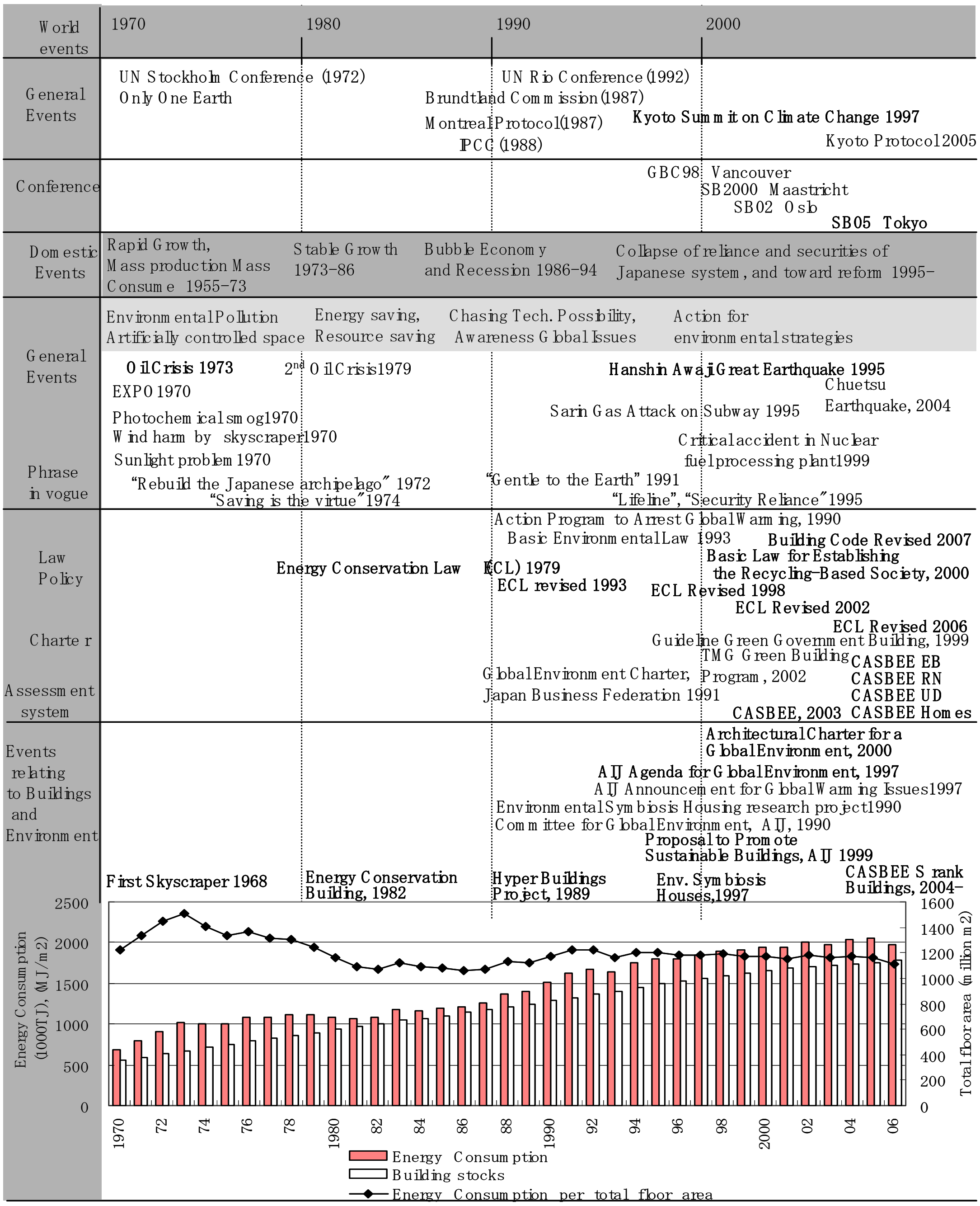


Fig.1.1 Trends of specific events relating to buildings and environment and energy consumption
Energy and building stock data , source: EDMC 2007

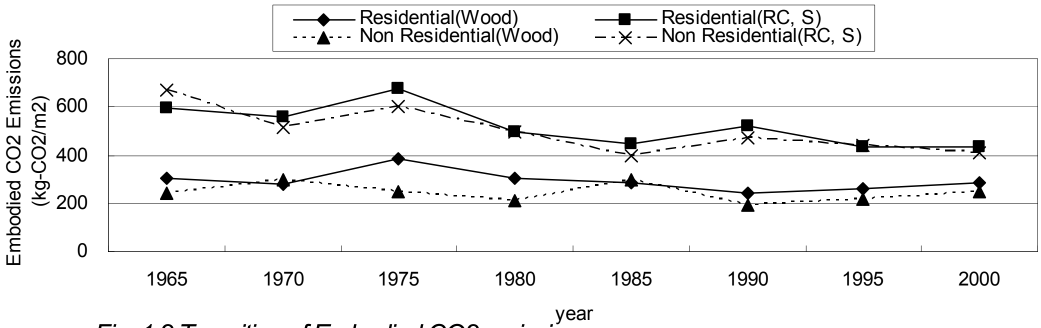


Fig. 1.2 Transition of Embodied CO2 emissions,
Source. Y.Kawazu, Ph.D Thesis, Utsunomiya University,.2008

2.1.3 Stock and energy consumptions

Fig. 1.1 shows the transition of building stocks and operating energy consumption of non-residential buildings, and energy consumption per total floor area. The peak of the energy consumptions was around 1973, and after the oil crisis it began to decrease year by year until it stabilized in the present day.

On the other hand, the trend of energy consumption of buildings as a whole has been increasing year by year and it suggests that energy consumption of buildings has started to decrease around 2006.

Several reasons are considered for this situation. Building stocks and building floor area per person have been increasing and building operating hours of each building have been becoming longer and longer. These trends suggest that there is a gap between the strategies of energy conservation in buildings and the real situation in society.

Fig.1.2 shows that the transition of embodied CO2 emissions of buildings and houses using Input and Output analysis based on I/O tables from 1965 to 2000 in Japan. It suggests that embodied energy and CO2 of RC and S structured buildings improved about 30 % during 35 years. Most of these improvements are brought by industrial sectors that improved efficiency of building material productions and building component productions.

A survey of several environmental data was required, and energy consumption and building stock data were selected to understand the progress in reality. Data availability was also considered. Other data related to environmental issues is difficult to collect or to use to survey the current situation.

2.2 A transition of design strategies and performance of cutting edge Buildings

Several cutting edge buildings were reviewed in order to understand the trend of environmental design strategies. These buildings were selected as case study buildings for the series of events of the Green Building Challenge in 1998, 2000, and 2002. Those were considered the cutting edge buildings in Japan in those days. The design concepts, environmental design strategies and environmental performance of these buildings were reviewed to understand the trend of environmental strategies and their environmental performance.

Table 1 Average performance and introduced design items of Japanese case study buildings

	98		2000		2002	
	Performance score	Desitng items	Performance score	Desitng items	Performance score	Desitng items
Resource Consumption	2.46	10	1.76	11	2.3	9
Environmental Loadings	2.23	3	1.90	3	2.3	2
Indoor Environmental Quality	3.43	4	2.57	4	2.0	3
Longevity,Quality of Service,Service Qu	2.56	2	2.70	3	2.7	2
	98		2000		2002	
actual annual operating energy consumption (GJ/m²/yr)	1.3		1.9		2.3	
actual annual emission related to consumption CO2 (kg/m²/yr)	53.4		93.5		111.2	

Table 1 show that the number of design items, environmental performance score based GBTool, and energy consumption of the case study buildings. The trend shows that energy consumption and CO2 emission per total floor area clearly increased year by year. According to design strategies and the average performance score of "Resource Consumption", energy performance of case study buildings should have improved compared to previous GBC projects.

Despite design strategies and better performance scores, energy consumption of case study buildings has not improved. There are several reasons to explain this situation. It is supposed that operating hours, occupancy and office equipments of office buildings has been changed year by year and these factors affect energy consumption and CO2 emissions trend/. This suggests that it is very important to establish benchmark value and reference building performance based on building types and its detailed conditions.

3. Human Perception Survey

3.1 Methods and questionnaires

The questionnaire survey was conducted to know the human perception on building environmental issues within the architectural community in Japan. The respondents were people in local government, design firms, construction companies, utility companies, etc. It was distributed to 250 people, and answers were obtained from a total of 149 people in 2004, and survey was implemented through Internet by using a web-based questionnaires in 2007. The respondent of the survey in 2007 were 75. This is smaller number of respondent than it was expected. There were technical issues that were accessibility of the system and user friendliness of inputting data on the web-site.

This questionnaire survey prepared several sets of questions that related to the current situation and the near future in order to measure the change and transition. There was also contained another set of questions that were part of questionnaire survey conducted in 2000 and in 2004 in order to measure a change and transition during a few years period from 2000 to 2004 and 2004 to 2007.

The questionnaire survey covered several questions shown in Table 2. Some of questions asked are about the present and future situation and it is expected that the same type of survey will be conducted five or ten years from now. It is expected that this survey would support to compare the differences of perception between past and present, and discuss the future trend.

3.2 Overall issues

3.2.1 Influential Events

Table 3 shows the ranking of most influential events for respondents which relating environmental issues. "Kyoto summit on Climate Change" was ranked first by respondents in 2004 and 2007. "Health issues" and some laws relating to environment were ranked second and third in 2004. "Earth summit", "Oil crisis in 70s" and "Building Code revised" were ranked in 2007. Other events varied based on the ages of the respondents.

Table2 Questionnaire items and respondents

	Question	Respondents
Overall	Priority of Issues Influential events	Local government
Buildings	Building name Negative factor to enhance Green buildings Trend of Energy consumption	Design Firm Construction Company
Design process	Effective tools Environmental design strategies Importance of design strategies Information source	Sub-construction Company Utility Company
Environmental Assessment tools	Awareness of assessment tools Purpose of assessment Environmental criteria weighting Cost and time for assessment Assessment tool user	Others
Env. strategies	Effective strategies: Law, policy and program Research and development	

Table 3. Most influential events based on ages of respondents

Ranking	2004	2007
1	Kyoto Summit on Climate Change	Kyoto Summit on Climate Change
2	Health issues	Earth summit / Oil crisis in 70s
3	Energy Law revised	Building Code revised

3.2.2 Priority of issues

Fig. 2 shows the priority of issues. "Environmental loads" and "Resource consumption" will become more important in the near future, compared to "Economics," which is considered most important today.

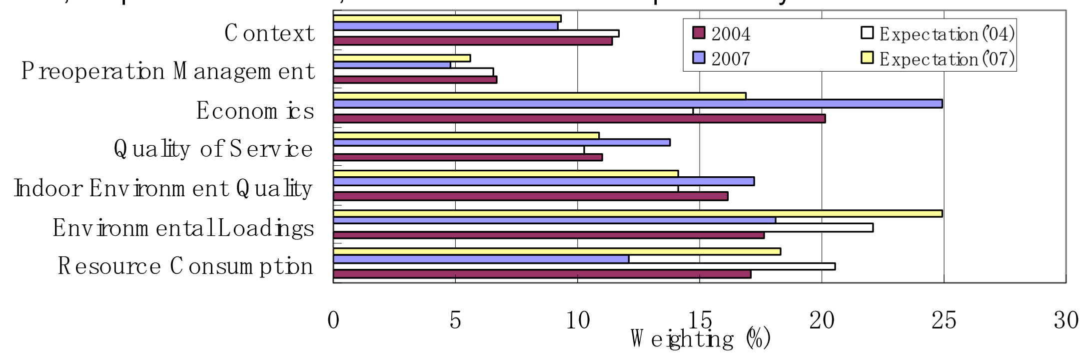


Fig.2 Which environmental criteria is important, today and ten years from now?

3.2.3 Information Source

Fig. 3 shows the popular information source. Professional books and magazines are a popular information source today but many people assess that the Internet will be the most popular source ten years from now.

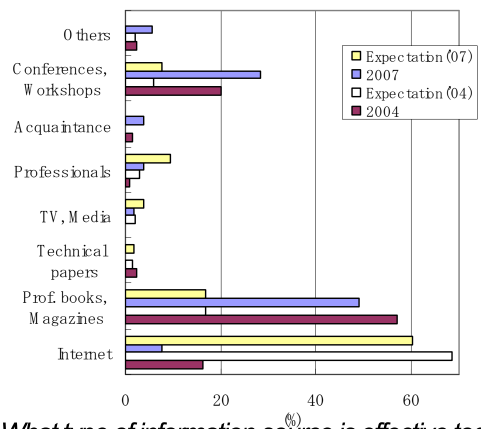


Fig.3 What type of information source is effective today and ten years from now?

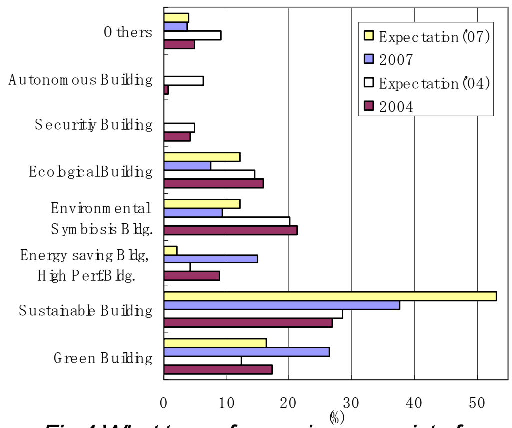


Fig.4 What type of name is appropriate for cutting edge buildings, today and ten years from now?

3.3 Buildings

3.3.1 Building name

Name of "Sustainable Buildings" is supported by many of respondents and expected as future cutting edge building's name. "Green Buildings", "Environmental Symbiosis Buildings" are also popular among the Arch. Community in Japan (Fig.4).

3.4 Design Process

3.4.1 Negative factors

Fig. 5 shows the negative factors in achieving green and sustainable buildings. Increasing initial cost is considered to be a key negative factor to achieving green and sustainable buildings in the present and ten years from now.

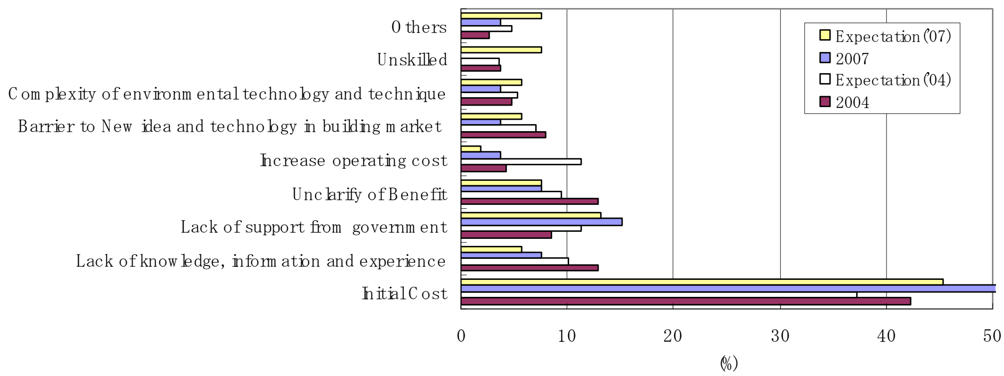


Fig.5 What is a negative factor achieving green, sustainable buildings, today and 10 years from now?

3.4.2 Effective tools for environmental design

Fig. 6 shows the effective tools to supporting environmental design. Energy simulators were thought to be the most effective tools today and environmental assessment tools were supposed to be the most effective as near future tools.

3.4.3 Popularity of environmental design strategies and methods

Fig.7 shows popularity of the environmental design strategies and methods. It shows the difference among 2000, 2004 and 2007. “Recycled material usage” and “Reduce wastes“ were popular in 2000 but their portion are decreased in 2004 and 2007. “The basic law for establishing recycle based society” was introduced in 2000 and many of strategies relating to recycle and reducing wastes were implemented and are achieving results today. Sun-shading, LCA and LCC strategies make up only a small portion in 2000 and 2004 but it is shown that there is an expectation of greater use today. PV and Thermal insulation were supported continually through 2000 to 2007.

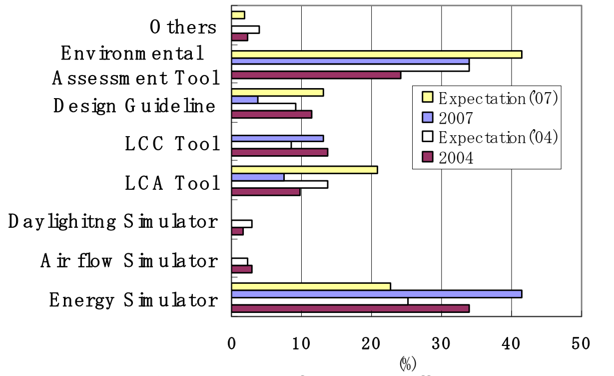


Fig.6 What type of tools are effective to design green buildings today and ten years from now?

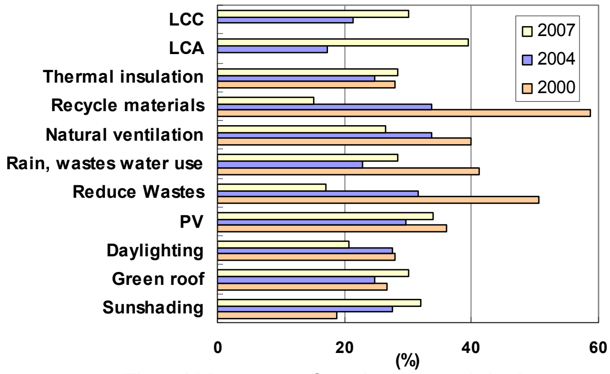


Fig. 7 What type of environmental design are you interested in?

3.5 Environment Assessment

3.5.1 Recognition of assessment tools and purpose of environmental assessment

Fig. 8 and Fig. 9 show the transition of recognition of assessment tools and the purpose of assessment between 2000 and 2004. Around 30 to 40% of respondents knew BREEAM and GBTool in 2000, and more than 50% of respondents knew CASBEE in 2004, and more than 80% knew LEED and CASBEE in 2007. Many of the respondents think the main purpose of environmental assessment is “reducing environmental loads” among 2000, 2004, and 2007, and its ratio increased compare to other purposes.

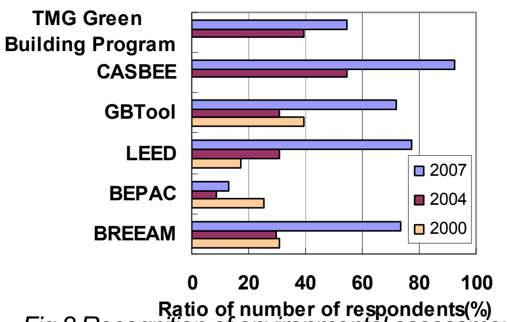


Fig.8 Recognition of environmental assessment tools?

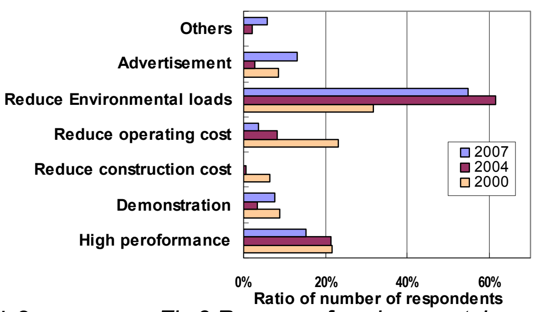
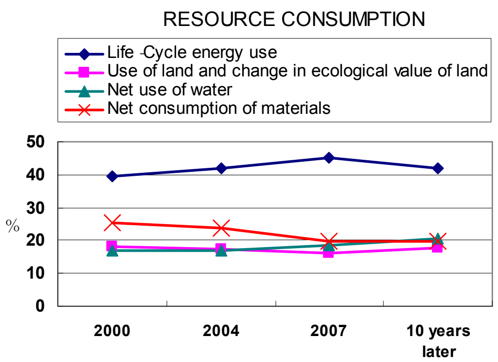
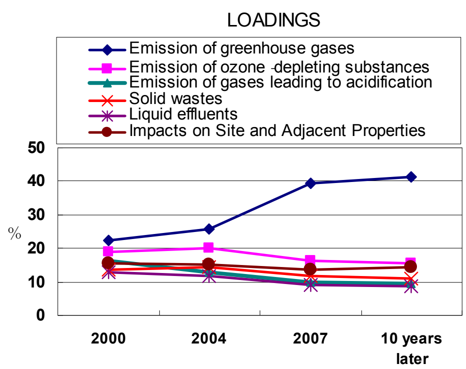


Fig.9 Purpose of environmental assessment?

3.5.2 Weighting of Environment assessment criteria

Fig. 10 shows the transition weighting value about resource consumption, environmental loads, and indoor environment. The differences of weighting value between 2000 and 2004, and ten years from now are small changes. The assessment criteria relating to “Energy,” “GHG,”“Thermal comfort” were weighted higher than other criteria.





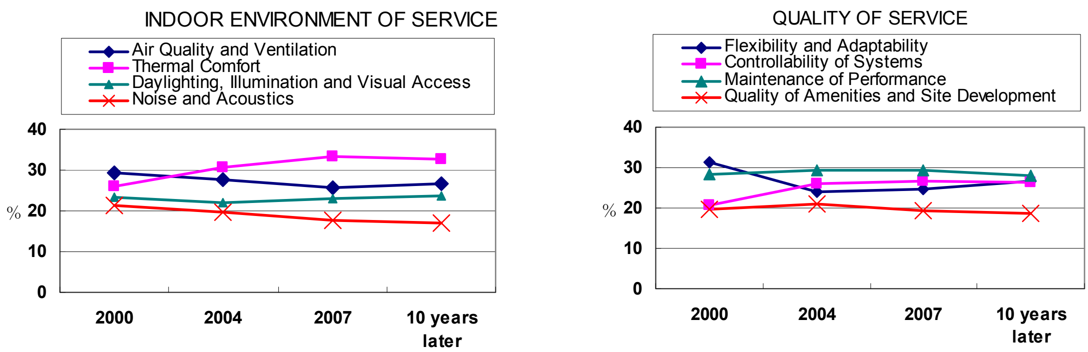


Fig.10 Weighting of environmental assessment criteria

3.6 Environmental strategies

3.6.1 Law, Policy, and R&D

Fig. 11 and Fig. 12 show the effective environmental strategies and R&D. Regulation and taxes are considered effective policies and many people support the R&D related to energy. Energy managements systems, especially, are expected to increase in the near future.

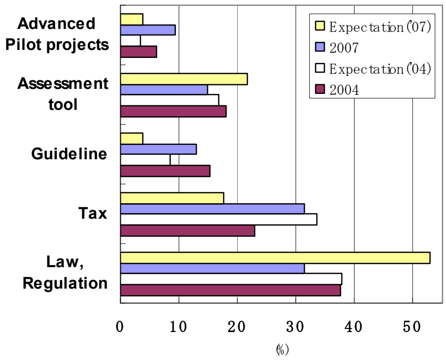


Fig.11 What are the most effective strategies to achieving sustainable buildings?

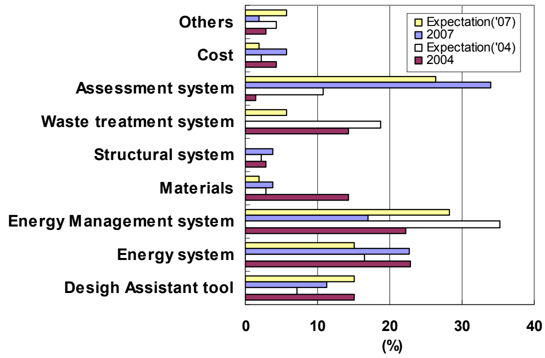


Fig.12 What kind of R&D should be focused on?

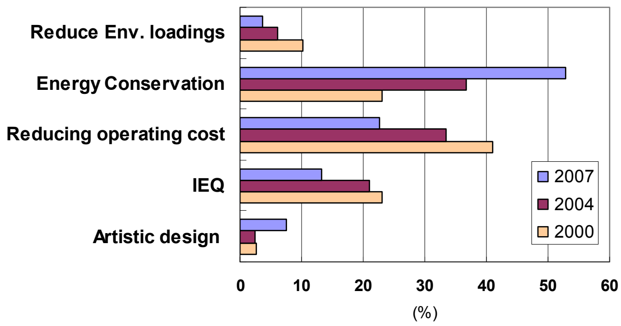


Fig.13 Which design strategies are most popular to invest ?

4. Results

The real data survey and analysis results show some progress and changes between the 1990's and 2004.The data suggests that the environmental performance of leading edge buildings has achieved some progress, and several advanced technologies and green design strategies have been applied year by year.

However, there is a gap between the strategies and reality of energy performance progress that affects the sustainability of society, as energy consumption of buildings stock increases year by year and its trends still continues.

The questionnaire survey results show that the priority of environmental issues and green design strategies have changed between 2000 and 2004. It is supposed that the reason for these changes is that information about environmental issues, experiences of green design strategies, and environmental assessment tools affected key actors in architectural community in Japan.

5. Conclusion and future research

The architectural community has a large responsibility to society through the designing and construction of buildings. It is important to assess the progress and the direction of strategies of the architectural community in order to achieve a sustainable society.

This paper describes an idea and demonstrates a framework to assess the progress and movement in the architectural community. The results suggest that it is possible to assess the movement and progress of environmental strategies by surveying several indicators, events, energy consumption and environmental performance of buildings, and human perception through a questionnaire survey.

It is expected that this framework will be revised and modified into an appropriate one to support the environmental strategies of the architectural community both locally and internationally.

This study is the pilot survey and we are planning to continue conducting this series of surveys both locally and internationally, and present them to the public periodically.

It would be useful if we could conduct the surveys in different countries and regions, and compare technological and cultural aspects to understand what is needed to realize different approaches and solutions while considering each area's climatic and historical backgrounds.

Table 4 show a framework and for future survey. Future works will be expected to describe technological and cultural change and progress, along with the gap between reality and human perception about environmental issues relating to buildings, and these will suggest progress and direction. To map technological change and cultural change, several representative indicators and questionnaire items will be selected to explain the situation appropriately.

Table 4 Framework for further survey

	Overall	Technological Change	Social and Cultural change
(Reality) Data surveys	1) Global issues progress 2) Building community progress	1) Building system progress 2) Energy consumption 3) Building stocks 4) Advance technologies 5) Performance score of cutting edge buildings 4) Design process and tools 5) Affect of assessment tools	1) Weighting on Tech vs Tradition 2) Weighting on Environment, Economy and Social 3) Green movement events 4) Building names 5) Green Design strategies 6) Cost premium 7) Engines and drivers of Change
(Perception) Questionnaire surveys			

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WORKSHOPS IN DUTCH SUSTAINABLE BUILDING DESIGN PRACTICE

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Keywords: workshop, sustainable building, integral design, permanent professional education

Summary

Within the present context of the Dutch Sustainable Building Practice it is hard for the different involved building design disciplines to give a good collective answer for a variety of questions from society especially sustainability. To change this situation a change is necessary: an Integral Approach is needed. This change can not only by 'prescription' of new ways of working by methods, but also by working in the changing situation and adapting / reflecting / learning to this situation.

As traditional methods did not work out adequately a new approach within the building industry is proposed. Integral Design; A "thinking in levels" approach improved the design and decision process by structuring them at different levels of abstraction. The newly developed methodology for structuring and documenting integral design processes enabled verification and reproduction of decisions made during designing. Morphological charts are used to write down the ideas and concepts.

The workshops for multidisciplinary professional design-teams, throughout 2004-2008, showed that integral design provides a suitable methodological foundation for improvement of integrating the activities of a building design team as well as integration of sustainable comfort systems in the conceptual phase of design process. Workshops form part of the permanent professional educational program for BNA (Royal institute of Dutch Architects) members since 2006.

1 Introduction

Preservation of energy resources, occupant comfort and environmental impact limitation are the key issues of modern and sustainable architecture. A major portion of primary energy consumption, about 40 %, is due to create thermal comfort in buildings by heating, cooling, ventilating and lighting. During the last decades, the main focus of research in Building Services was on reduction of energy consumption of buildings. The strong focus on the energy reduction led to situations in which health and comfort are endangered. By using sustainable energy the negative effects of energy use become less important and the focus could be turned to health and comfort again.

The application of sustainable energy systems and components is too complex for integration in the early stages of building design. As a result, sustainable design options are added to the final stages of the design. This results in sub-optimal designs and rejection of the proposals.

The HVAC-industry has identified a need to better integrate comfort and sustainable energy systems in buildings. In 2000, the Royal Institute of Netherlands Architects, BNA, the Dutch Society for Building Services, TVVL, and the Delft University of Technology, TUD participated in a research project called Integral Design. The focus within integral design is on all that is essential to completeness, from all design disciplines nothing essential should be lacking. Since year 2001 'integral approach' has been propagated within Dutch building design practice, through continuously developing 'learning by doing' workshops by the Royal Institute of Dutch Architects (BNA), the Dutch society of consulting engineers (ONRI) and the Technische Universiteit Eindhoven (TU/e). The workshops are a kind of practica or something very similar and are used to structure design actions from different design team members and to evaluate the proposed design method to improve sustainable design.

2 Methodology: Integral Design – Morphological Overviews

The frame for structuring actions of team members is found in 'Integral Design' model, a collection of design tools within a design process matrix. Integral Design is problem oriented and distinguishes, based on functional hierarchy, various abstractions and/or complexity levels during different stages and design activities. This model is used because it allows design to be explicitly approached on different abstraction levels. This aspect is important because of the focus on sustainable comfort systems; changes on the level of sustainable comfort systems automatically have effects on the level of a building as a whole, and vice versa.

In order to confront respective knowledge and viewpoints of design team disciplines morphological overviews, a specific design tool and one of the features of integral design, are used. The main aim of use of morphological overviews (Zwicky and Wilson 1967) is to explore 'field of possibilities', leading to more thoroughly considered solution proposals (Krick, 1967). This method uses a morphological chart where the main task is divided in functions and/or aspects, based on different abstraction levels. Following this initial interpretation of design task by design team, for each of these (sub) functions/aspects a variety of possible solutions can be generated.

By using the morphological overview all disciplines can look into the required completeness: if all necessary functions and aspects are listed. The construction of a morphological overview is like a kind of matrix. On the vertical axis of the matrix the required functions (or sub-functions) and main aspects are given. On the horizontal axis possible solutions for these functions or aspects are given. The purpose of the vertical list is to try to establish those essential aspects that must be incorporated in the product, or essential functions that the design has to fulfill. They should cover all the necessary functions and the main aspects to consider for the product/building to be designed.

3 Experiments: Workshops in 'practice'

To test and analyse what kind of aspects are of influence on knowledge exchange during design processes different workshops series with professionals where initiated. The setting chosen is that of Reflective Practice (Schön 1983). To use human subjects in laboratory experiments to study design theory provide some insight. However, extending results from laboratory experiment to conclusions for the engineering practice is a risk. The effect of Macrocognition describes the differences in cognitive functions performed in natural – versus artificial, laboratory – settings. The real-world setting requires activities in ways that artificial settings can rarely simulate. Schön (1987) has proposed a practicum as a means to 'test' design(ing). Where a practicum is" a virtual world, relatively free of the pressures, distractions, and risks of the real one, to which, nevertheless, it refers (Schön 1987, p.37)". In Schön's practicum a person or a team of persons has to carry out the design. A practicum can asses a design method and the degree to which it fits human cognitive and psychological attributes (Frey and Dym 2006). Crucial is the simulation of the 'typical' design situation. A workshop can be seen as a specific kind of practicum. It is a self-evident way of working for designers that occurs both in practice as during their education. As such a workshop provides a suitable environment for testing the approach. Besides full design team line-up there are a number of other advantages of workshops with regard to standard office situations, while at the same time retaining practice-like situation as much as possible. Workshops make it possible to gather a large number of professionals in a relatively short time, repetition of the same assignment and comparison of different design teams and their results. Never the less the workshops are a virtual world; "contexts for experiment within which practioners can suspend or control some of everyday impediments to rigorous reflection-in-action (Schön 1983 p. 162). Schön refers further to the dilemma of rigor and relevance in professional practice, there is a choice to stay on the high, hard ground ("A high, hard ground were practitioners can make effective use of research-based theory and technique") , or to descend to the swamp ("a swampy lowland where situations are confusing") and engage the most important and challenging problems? (Schön 1983 p. 42).

Together with the Dutch Royal society of architects (BNA) and the Dutch Association of Consulting Engineers (ONRI), since 2005 there were organized 5 series of workshops with experienced professionals from both organisations voluntarily applying to participate. The participants of each discipline were randomly assigned to design teams, which ideally would consist of one architect, one building physics consultant, one building services consultant and one structural engineer. The composition of the design teams is not mentioned for each specific team, but they always existed of at least 3 but mostly 4 different disciplines. Starting with a three day practice-like 'building team' concept, in which all disciplines are present within the design team from the start, the integral design method workshops have evolved to finally a two-day series.

3.1 Three different views (1st workshop series)

The first workshop series was organized in May/June 2005. The series took place during three weeks, consisting of three meetings taking place on the same weekdays.

On the first workshop day the traditional design process is simulated. During traditional design processes the architect is the first one that starts to work on a design assignment. His interpretation of design task is from then on leading during design process. Somewhere along the way other design disciplines are introduced in design process as additional advisers who are confronted with problems that initial client's and architect's ideas created. During the second day all disciplines start working on new design task from the very beginning of the first design session. During this session the disciplines are divided into separate mono disciplinary design teams, within which they individually work on the same design assignment. The reason that they work in teams is to encourage discipline-related cross-pollination in order to get approximately same contributions per discipline in all multidisciplinary design teams, which are to be formed at the start of the second design session. This way variation between different design teams concerning these aspects is kept low. During the second design session new multidisciplinary design teams, different from those of the first day, are again randomly formed. The only used criterion is that none of the participants should be twice put together in the same team. By configuring new design teams each day, the influence of the group forming effect is excluded. The third and final day is used for introduction of the methodical design tools, meaning that morphological overviews are applied during both interpretation and generation activities. The lay-out, the design sessions and formation of design teams are the same as during the second day. The design assignment is different, it is actually varied during all three days, but the type and the size of design tasks are similar. Morphological overviews are used during the third day to structure, as a consequence of the used setting accelerated design processes.

During each meeting two 60-minutes lasting design sessions were observed. The main research aim was to assess the usability of morphological overviews for different design activities of the same design team. The measurements were conducted in four different ways: through direct observations of design teams' activities, by taking photographs of design team's work, through analysis of design teams' produced material and by asking participants to fill in a number of questionnaires.

Table 1 Overview information workshop and analysis workshop series 1

31 May, 7 and 14 June 2005		Utrecht, Kropman	
Workshop series I		**BNA, ONRI, KCBS**	
Type of participants 4 disciplines: Architects (5), Building physics advisers (5), Building services advisers (8), Structural eng. (6)		Number 20 persons 5 teams av. Mark: 7,5 | response: 88%	Arrangement Same teams during whole series, design task the same during 2nd and 3rd day. Last day for 'decision making'.
Days | hours/day 3 | 4	Sessions/day | total 2 | 6	Time/session | total 60min | 6h	
Observations by TU/e students	Arrangement 3 per team (for different aspects)	Using predefined forms (3 types)	Additional photo, questionnaires
PROGRAM [in concept] Day 1: 1 lecture 'methodical design' 2 design session teams (60min) Pause 3 design session teams (60min) Day 2: 1 lecture 'sustainable comfort sys.' 2 design session teams (60min) Pause 3 design session teams (60min) Day 3: 1 lecture 'Kesselring method' 2 client feedback session (60min) Pause 3 design session teams (60min)		AIM Day 1: Introduction of morphological overviews, with the main aim to 'learn' how to use them. Day 2: Use of MO's for interpretation of task and generation of possibilities. Day 3: Use of MO's for selection, through feedback with the client, and for integration activity. Theoretical model of interpreting – generating – selecting – integrating is hereby utilised in order to explore possible use aspects of morphological overviews (MO's).	

Analysis
Positive results: Extensive observations by students provided large variety of data on design process, that can be used to properly evaluate workshops. Working in teams was experienced as positive by the participants, a majority thought that it even led to synergy. Very interesting was the development of participants' perspective towards proposed approach; at the beginning (1st day) almost 1/3 thought of it as not relevant for them, and at the end of 3rd day none of them had negative view on it. It shows the importance of the chosen 'several days' set-up, in which this workshop series can be seen as satisfactory course.
Negative results: Because same 'team interpretation' of design task couldn't be reached, the end results couldn't be compared. Attitude of participants towards workshops was influenced by the fact that researches from TU/e led the whole 3 days. ('course instructor from BNA, ONRI and/or TNO possible in the future?) Design teams changed to frequently during workshop series. 'Kesselring method' was still to much for the participants to comprehend, probably because of the combined feedback with the client. Structural engineers were 'structurally' passive during design process.
Conclusion [to take into account for next workshops]: - Instead of theoretical interpretation–generation–selection–integration activities, use observed interpretation/generation–generation/selection. - Selection as a separate activity has to be more explicitly brought in, in relation to client; combination for Kesselring is too much complicated
Remarks: Although observation by 3 students per group provided various data, there is no 'control measurement' and their presence is a bit overwhelming. The 'client' was not prepared for its role, this was partly the reason why planned feedback didn't work out.

3.2 Single double-checked view (2nd workshop series)

This workshop series was organized in October/November 2005. Based on evaluations from the 1st series, the observation forms were adjusted. Instead of three different, only one type was to be used. Besides, two instead of three students per design team were deployed. These two students had to observe the same team during all three workshop days. Furthermore, instead of TU/e Master students, Architectural Design Management Systems students (ADMS is a bi-annual postgraduate designers' programme at TU/e) were doing the observations. This way both need for decrease of number of observers as the need for control of acquired data was met.

The workshop series' setting concerning design sessions was largely unchanged. The most significant change occurred by itself: since we were dependant on the voluntary application of participants it happened that for this workshop series structural engineers did not apply. Two things were observed, design and communication, both in relation to use of morphological overviews. Besides, the main communication patterns were again registered in 10-minute intervals. Design wise, morphological overviews could be used either for discipline based introduction of new proposals, or for integration of already introduced object design knowledge. Communication wise, morphological overviews could be used either for explanation of design proposals or for archiving.

Table 2 Overview information workshop and analysis workshop series 2

24, 31 October and 7 November 2005		Delft, TNO Bouw	
Workshop series II		**BNA, ONRI, KCBS**	
Type of participants 5 disciplines: Architects (6), Building physics advisers (5), Building services advisers (6), Structural eng. (1), Manager (1)		Number 20 persons 5 teams av. mark: 7,0 / response: 96%	Arrangement Same teams during whole series, design task the same during 2nd and 3rd day. Last day for 'client' feedback.
Days | hours/day 3 | 4	Sessions/day | total 2 | 6	Time/session | total 60min | 6h	
Observations by ADMS students	Arrangement 2 per team	Using predefined form	Additional photo, questionnaires
PROGRAM [in concept] Day 1: 1 lecture 'methodical design' 2 design session teams (60min) Pause 3 design session teams (60min) Day 2: 1 lecture 'sustainable comfort sys.' 2 design session teams (60min) Pause 3 design session teams (60min) Day 3: 1 lecture 'relation with the client' 2 client feedback session (60min) Pause 3 design session teams (60min)		AIM Day 1: Teams were not obliged to work with morphological overviews, main aim was to learn how to use them. Day 2: Results from day 1 used to point out what the advantage is of integral approach. Emphasise also on use of MO's for feedback with the client. Day 3: 'Learning effect' was mainly expected to emerge from interaction with client; transparency of process and design decisions should show the added value.	

Analysis

Positive results:

Although only one manager was involved in workshop, it showed that their contribution within design team setting in conceptual design phase is not relevant (with respect to design content).

Morphological overviews were differently used within different-sized design teams. They were considered helpful in structuring the communication of design teams, especially in more complicated situations. Four-discipline teams used them more for communication purposes than 3-discipline teams. This statement is backed up by the results of the various questionnaires that all participants were given, regardless of discipline or the design team arrangement.

Negative results:

Use of ADMS students didn't produce better observations than last time, when TU/e students observed.

Big differences in experience between participants caused sometimes too big unbalance within design teams; as addition to the absence of structural engineers.

Feedback with client was a step too far, just as previous attempts to introduce 'Kesselring-method' for decision making processes. It seems that 'only' the use of 'morphological overviews', as a basic tool for structuring design process, is more than enough in this short amount of time.

Conclusion [to take into account for next workshops]:

- Introduce only use of morphological overviews, in relation with thinking in abstraction levels.
- Clients need to be 'real' in order to get more commitment from participants.

Remarks:

BNA / ONRI representatives acted as clients.

Workshops were led by TNO representative, this is preferred setting for conduct research because of unobtrusive presence of researches.

Some participants still complained about 'many' student-observers.

3.3 Workshop setting modification (3rd workshop series)

The third workshop series was held in June 2006. Observations during, as well as participants' reactions on the previous two workshop series showed that morphological overviews indeed were useful within the design team and the workshop setting; the next step was to determine the effects of morphological overviews. This meant that we had to move more towards an experimental setting, where quantitative measurements instead of qualitative assessments were possible.

The first consequence was that morphological overviews could not be introduced at the start of workshop series, since this would exclude the possibility of stimulating the traditional building design approach during the workshop series. In order to be able to separately measure the possible effects of morphological overviews, the phased introduction of two changes to traditional approach was needed: 1) design team setting from the very beginning of conceptual design phase, 2) use of morphological overviews.

The second consequence was the design team arrangement. To compare different design processes, not all design teams should work the same way (as was the case during previous workshops). The usual solution would be 'matched design teams', something we oppose because of no resemblance with the practice situation. The solution we came up with was not to observe the same design teams during the whole course of workshop series, but to compare the average results of each workshop day while changing the members of the design teams. This meant different design teams each day, which consisted out of same group of participating designers. The team formation was at random, the only rule was that two designers could be in the same team only once. During previous workshop series we had also compared average results of different workshop days, but at that time we were interested in different activities within same type of design process. This time the focus was on comparison of the same activities within different types of design processes.

This was also the first time that the participants were not satisfied with the workshop. Moreover, they were even disappointed about abrupt ending of the workshop series. They felt that ID-model and morphological overviews, as core of 'ID-methodology', were introduced too late. There was no possibility for a full learning cycle. Therefore, introduction of morphological overviews during the last day was clearly a step back in the workshop development; the participants needed time to adapt and demanded feedback, see table 3.

Table 3 Overview information workshop and analysis workshop series 3

12, 19 and 26 June 2006		Apeldoorn, CODA	
Workshop series III		**BNA, ONRI, KCBS**	
Type of participants 4 disciplines: Architects (7), Building physics advisers (6), Building services advisers (7), Structural eng. (3)		Number 22 persons 6 teams av. mark: 7,3 | response: 98%	Arrangement Random teams that changed each day; clear build-up of program – 1st day traditional, 2nd integral and 3rd incl. method
Days | hours/day 3 | 4	Sessions/day | total 2 | 6	Time/session | total 30-90min | 6h	
Observations by ADMS students	Arrangement 1 per team, (2 teams/day videotaped)	Using predefined forms (2 types, individual and team observat.)	Additional video, photo, questionnaires
PROGRAM [in concept] Day 1: 1 design session architects (60min) CODA building guide tour 2 lecture 'sustainable comfort sys.' 3 design session teams (60min) Day 2: 1 lecture STB 2 design session teams (30min) Pause 3 design session teams (90min) Day 3: 1 lecture 'methodical design' 2 design session teams (30min) Pause 3 design session teams (90min)		AIM Day 1: Traditional approach as reference, to compare with day 2 and 3; also to enhance 'learning effect' Day 2: Design team approach, starting together from 1st session. Different teams and task from day 1. Day 3 Introduction of methodical design 'tool'. (different teams/task). Initially, all disciplines were supposed to work individually during 1st session on day 2 and 3; in order to be able to compare all 3 days. Due to circumstances started with teams.	

Analysis

Positive results:
Set-up of workshop, mainly dictated by 'scientific requirements' is workable. It allows multiple comparison of different processes.
First time that the comments during the workshop from the participants themselves showed that 'learning by doing' indeed is effective.
Enthusiasm is clearly higher than during previous workshops, resulting also in less drop outs. 'By accident' found formula 30/90 minutes for duration of design sessions for one design task proved to be most pleasing.
Constantly changing teams adds to creation of good working atmosphere because people get to know each other better through 'forced contacts'.

Negative results:
Very difficult to observe 1st and 2nd day, because of individual (silent) work.
TNO lecture about 'sustainable comfort systems' was by participants seen as nothing new, no added value.
Usually the 3rd day of workshop is best rated, this time however not. The participants felt that workshop abruptly ended, without feedback on the main theme of the whole series – working with morphological overviews.
Method was actually not assessed, because participants were mainly busy understanding it – partly the same situation as during workshop no.01 (beforehand information does not help either).

Conclusion [to take into account for next workshops]:
- Introduction of 'methodical design' shouldn't happen during the last day: it is too new, participants need time to adapt and demand feedback.
- In current setting the additional sessions are needed.
- Quality of video cameras and preparation of rooms needs to be better.

Remarks:
Video cameras poor quality of sound; teams should also maybe be in separate rooms. Preferably videotape all teams, now only two out of 6 observations per day usable.

3.4 Final workshop setting (4th and 5th workshop series)

The development of the workshop setting was a learning-by-doing process. Instead of starting with a theoretically 'optimal' configuration, workshops were continuously adjusted and improved based on evaluations of participants and analysis of observation results, resulting in the final arrangement as shown in Figure 1. In the current configuration (Figure 1) stepwise changes to the traditional building design process type, in which the architects starts the process and the other designer join in later in the process, are introduced. Starting with the traditional sequential approach during the first two design sessions on day 1, which provide reference values for effectiveness of the method (amount of integral design concepts), the perceived "integral approach" is reached through phased introduction of two major changes: (1) all disciplines start working simultaneously within a design team setting from the very beginning of the conceptual design phase, (2) the integral design model / morphological overviews are applied. The second design setting allows simultaneous involvement of all design disciplines on a design task, aiming to influence the amount of considered design functions/aspects. Additional application of morphological overviews during the third setting demonstrates the effect of transparent structuring of design functions/aspects on the amount of generated (sub) solution proposals. Additionally, the third setting provides the possibility of one full learning cycle regarding the use of morphological overviews. It concerns an individual, rather than collective/team learning cycle, because in order to be able to effectively apply a new approach, one has to first understand it and make it his or her own (Jones, 1992).

Design team arrangement is the crucial element. To be able to compare different types of design processes, while at the same time excluding team development aspects (Tuckman, 1965), the same design teams are not observed during the two workshop days, instead the average results of each design setting of all participating teams are compared. For each setting the arrangement of design team members is changed (although all design teams are composed out of the same group of participating designers). The only rule is that no two designers can be in the same team twice. The focus is on the comparison of the same activities within different types of design processes. The sequence of used design settings is of utmost importance. Reverse or mixed order is not possible because learning effects would not allow for valid comparison of results (Herzog, 1996).

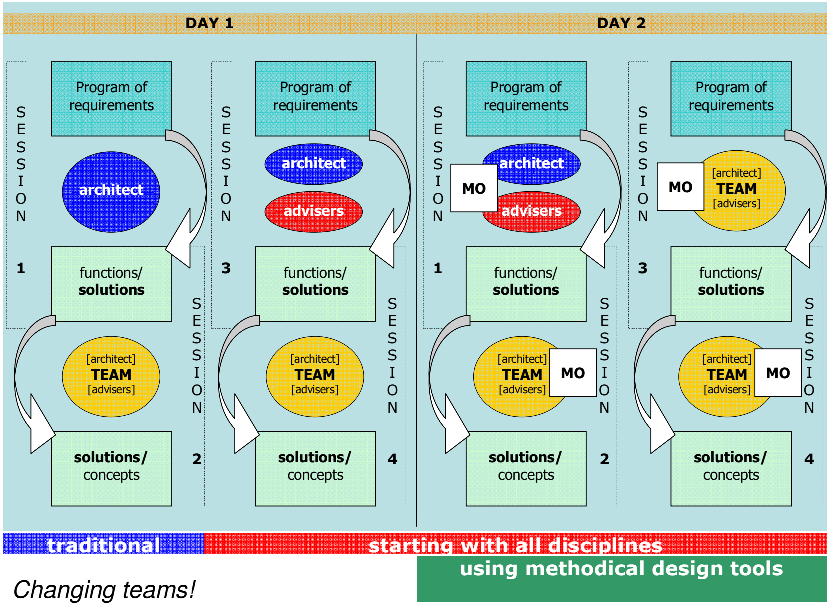

Figure 1 Four different design settings during the final set-up of the two-day 'learning-by-doing" workshop

Table 4 Overview information workshop and analysis workshop series 4

15 and 22 May 2007		Zeist, Buitenplaats Groenoord	
Workshop series IV		**BNA, ONRI, KCBS**	
Type of participants 6 disciplines: Architects (9), Building physics (6), Building services (8), Structural engineers (1), Project leaders (2), Managers (2), Developers (2)		Number 27 persons 7 teams (*) av. mark: 7,0 | response: 96%	Arrangement Two full days, teams and tasks change during noon break. Smooth transition from traditional to integral design.
Days | hours/day 2 | 8	Sessions/day | total 4 | 8	Time/session | total 30/90min | 8h	
Observations by ADMS students	Arrangement 1 per team + video	Using predefined form	Additional video, photo, questionnaires
PROGRAM [in concept] Day 1 1 design session architects (30min) 2 lecture 'sustainable comfort sys.' 3 design session teams (90min) Break 4 design session individual (30min) 5 design session teams (90 min) Day 2 1 lecture 'methodical design' 2 design session individual (30min) 3 design session teams (90min) Break 4 design session teams (30min) Pause 5 design session teams (90 min)		AIM Day 1 Traditional situation in the morning, with variation to it by letting all disciplines individually start working on new design task in afternoon. Day 2 Morning exercise using 'methodical design' approach; starting individually to let everybody 'learn' their own way. In afternoon start on again new task, but this time as a team. This allows comparison of individual/team initial start and interpretation of design task. Results of this set-up should lead to final conclusions for definitive workshop format.	

Analysis

Positive results:
The first major improvement is introduction of an extra experiment (1st during 2nd day). The possibility for an individual learning cycle in working with morphological overviews together with the feedback from organizers is created. With this intervention the main objections from previous workshop, lack of feedback and the abrupt ending of workshop, is removed.
The two-day instead of three-day workshop setting is the second major improvement. The participants get impression that more time is dedicated to the 'main issue' of the workshop, working with morphological overviews.
The transition from 'traditional' to 'integral' design setting proved indeed to be smooth. It also led to insight that working in teams is the main issue.

Negative results:
It remains very difficult to observe the first two experiments, since no structuring tools are given to design teams.
The last experiment / design setting was, even beforehand, seen as needless by the participants. The impossibility of always creating the optimal process during practice, as simulated during the third experiment, and therefore the need of mastering the situations as shown in the last design setting was not (made) obvious to the participants.
Large number of 'non design disciplines' (20%) was not stimulating during design process, partly because of their deviating notion of design concept.

Conclusion [to take into account for next workshops]:
- More emphasis on why the last design setting is so important
- Physical distance between design teams needs to be bigger (sound quality)
- Morphological overviews also as a tool for 'live' observation?

Remarks:
The participants had clear preference for the third design setting – starting individually with MO's, then moving on to team configuration.
Use of microphones satisfactory. However, teams should be further apart.

Table 5 Overview information workshop and analysis workshop series 5

5 and 12 February 2008		Utrecht, Forum 't Zand	
Workshop series V		**BNA, ONRI, KCBS**	
Type of participants 4 disciplines: Architects (5), Building physics advisers (4), Building services advisers (7), Structural engineers (3)		Number 18 persons 5 teams av. mark 7,4 / response 97%	Arrangement Two full days, teams and tasks change during noon break. Smooth transition from traditional to integral design.
Days | hours/day 2 | 8	Sessions/day | total 4 | 8	Time/session | total 30/90min | 8h	
Observations by Video cameras	Arrangement 1 per team	Using -	Additional video, photo, questionnaires
PROGRAM [in concept] Day 1 1 design session architects (30min) 2 lecture 'sustainable comfort sys.' 3 design session teams (90min) Break 4 design session individual (30min) 5 design session teams (90 min) Day 2 1 lecture 'methodical design' 2 design session individual (30min) 3 design session teams (90min) Break 4 design session teams (30min) Pause 5 design session teams (90 min)		AIM Day 1 Traditional situation in the morning, with variation to it by letting all disciplines individually start working on new design task in afternoon. Day 2 Morning exercise using 'methodical design' approach; starting individually to let everybody 'learn' their own way. In afternoon start on again new task, but this time as a team. This allows comparison of individual/team initial start and interpretation of design task. Results of this set-up should lead to final conclusions for definitive workshop format.	

Analysis

Positive results:

The workshop setting proved to be the right one. The overall ratings were never before as high, although the average mark for the workshop was 'only' 7,4. Interestingly, none of the participants mentioned the redundancy of the last experimental / design setting, which was a big issue during the previous workshop series. Seen in retrospective, this might have had to do with the influence of the other disciplines involved during the previous workshop series…

The absence of the (student) observers was not felt during the workshop, it certainly did not result in less good atmosphere. One might even say that the participants acted more freely, even though they were still videotaped.

Negative results:

The main negative result concerned the organisation of the workshop, especially on behalf of ONRI. Apart from TU/e, there were during both days also no other representatives present (from neither BNA, ONRI and TNO).

The ratings for the speakers were below average. However, this negative aspect highlights even more the high ratings for the workshop as a whole.

Because there were no 'live' observations, it s difficult to give a preliminary evaluation without doing the full analysis of data. Even though the results of student observations often proved to be contradictory when fully analysed, their first-hand evaluation did provide a globally accurate first impression.

Conclusion [to take into account for next workshops]:

- This workshop setting can be considered as the final one.
- Even though the quality of sound recordings is better when the teams work in separate rooms, it also creates an experimental atmosphere during the design sessions. This is the reason to use larger rooms where teams can work next to each other in a more informal setting.

Remarks:

Videotaping the sessions is research-wise preferable, even necessary, which makes the live use of morphological overviews for research purposes less important.

4 Results Workshops

During all workshops, following the assignment presentation the design process was observed and no further intervention took place. Observations were conducted in two different ways: (1) noting design teams' activities using observation forms (by students) and the last 2 series the workshop sessions were registered by video cameras because the participants found the student something disturbing their concentration, (2) by taking photographs of design team's work (by researchers, in 10min intervals), (3) the acquired data was analysed together with the material produced by the design teams. The additional resources of information were the questionnaires that participants had to complete after each day session and another questionnaire after a period of approximately six months.

Over the past four years 5 series of workshops have been conducted, these typically include around twenty participants and lasted for two or three days. A total of 107 designers participated in the five workshop series, in which 74% of the designers were present during all days. The average age of the participants, all members of eider BNA or ONRI was 42 and they had on average 12 years of professional experience. Direct at the end of the workshop the participants were asked to fill in a questionnaire in which questions were asked about the importance of the use of Morphological Overviews within the design process and about the concept of the workshops themselves, the results are given in table 6.

Table 6 Overview results questionnaires participants workshop series, rating from 1 to 10.

	series 1	***series 2***	***Series 3***	***series 4***	***series 5***	***Total***
Duration workshop in days	3	3	3	2	2	
Number participants	20	20	22	27	18	107
Percentage returned questionnaires	*88%*	*96%*	*98%*	*96%*	*97%*	*94%*
	rating	rating	rating	rating	rating	rating
Importance daily practice	6,7	7,9	7,0	7,6	7,5	7,3
did the cooperation lead to synergy	8,1	7,3	7,1	7,7	8,2	7,3

MO increases relevant alternatives	6,2	7,3	5,7	7,8	7,9	7,0
MO improves insight other disciplines	7,4	7,4	5,6	7,7	8,5	7,3
MO relevant for own discipline	7,4	7,6	6,4	7,8	8,0	7,4
MO helpfull for communication	6,8	7,6	6,2	7,9	8,1	7,3
MO positive effect design process	7,0	7,4	4,7	7,7	7,7	6,9
MO positive effect final design	6,6	6,2	4,5	7,2	7,5	6,4
Stimulating the use of MO usefull	6,7	7,2	6,4	7,9	8,2	7,3
workshop fit for professional education	9,0	7,6	7,6	8,3	8,9	8,3

5 Discussion and Conclusions

The theoretical basis of the workshops, Integral Design methodology with Morphological Overviews as important design tool for the conceptual phase of the design process was tested in "learning by doing" workshops approach developed throughout 2005-2008 in which professionals from BNA (architects) and ONRI (consultants) participated. The workshops were conducted by KCBS, Knowledge Centre Building and Systems (the cooperation between TNO Bouw Delft (Organization for Applied Scientific Research, Built Environment and Geosciences) and Technische Universiteit Eindhoven). The overview in this paper of the series of workshops prove the positive experiences of the workshops by multidisciplinary professional design-teams, throughout 2005-2008. Most important recommendations and conclusions;

- working on inter-disciplinary knowledge exchange by profession organizations (BNA, ONRI) in collaboration with knowledge / research / education institutions (TU/e, TNO) has to be organized and developed; permanent professional education is a core activity for the future

- workshops are an effective tool to couple practice / research / education; the 'learning by doing'-principle is an effective aspect; the adaptive characteristics have to be developed more extensively; feed-back and evaluation are important tools to use experiences from the past; workshops should be part of the permanent professional education

- design methodology and design tools, for multi-disciplinary design teams, help to structure and develop each others knowledge and are thus a necessary perquisite to develop / effectuate sustainable integral designs

Although the workshop experience of the participants is positive, they find it difficult to implement in practice. When participants were asked for the reason of the difficulties, they mention the already longer existing project setting in which they operate and in which they are the only ones with knowledge about this design tool. The workshops provide only a introduction and a few exercises to work with the design tool, most of the participants need more time to fully implement the basis into their own design process approach. Also the participants find it difficult after the short training sessions of the workshops to really change their traditional approach.

Acknowledgements

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TITLE: "BUDGING BAU' (BUILDING AS USUAL) THE GAIA ECOTECTURE APPROACH"

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Keywords: post occupancy evaluation, timber frame, catalytic projects, ecovillage, vested interests

Introduction and Summary

Context:

The Building Industry is inexorably driven by profit motive and Building as Usual (BAU) is very difficult to change, due to deeply entrenched vested interests which are stubbornly inimical to any reform, perceived to be a threat to those profits. The question is whether the global awareness of grave hazard to human habitat and reforming initiatives can in fact prevail over profit motive and short term-ism ?

The **rationale/significance** of this paper is to give an account of how this small professional practice, (in the context of the GAIA International network) over thirty years can make some progress across a wide spectrum in 'budging BAU' by:

1 . design of **catalytic building projects** ,

2 facilitating **post occupancy evaluation** of that completed work ,

3 collaboration in **eco village** development and **urban planning / zoning** initiatives

4 contributing to **institution building** to counteract the prevailing negative trend

5 activism to assist **governmental fiscal and other instruments** to be devised and applied

6 occasional **teaching**

7 international **think tank** activity in GAIA International.

The **objective** of the paper is to suggest that if these pluridisciplinary efforts are multiplied there is hope for step change in the future of a sustainable building and construction industry.

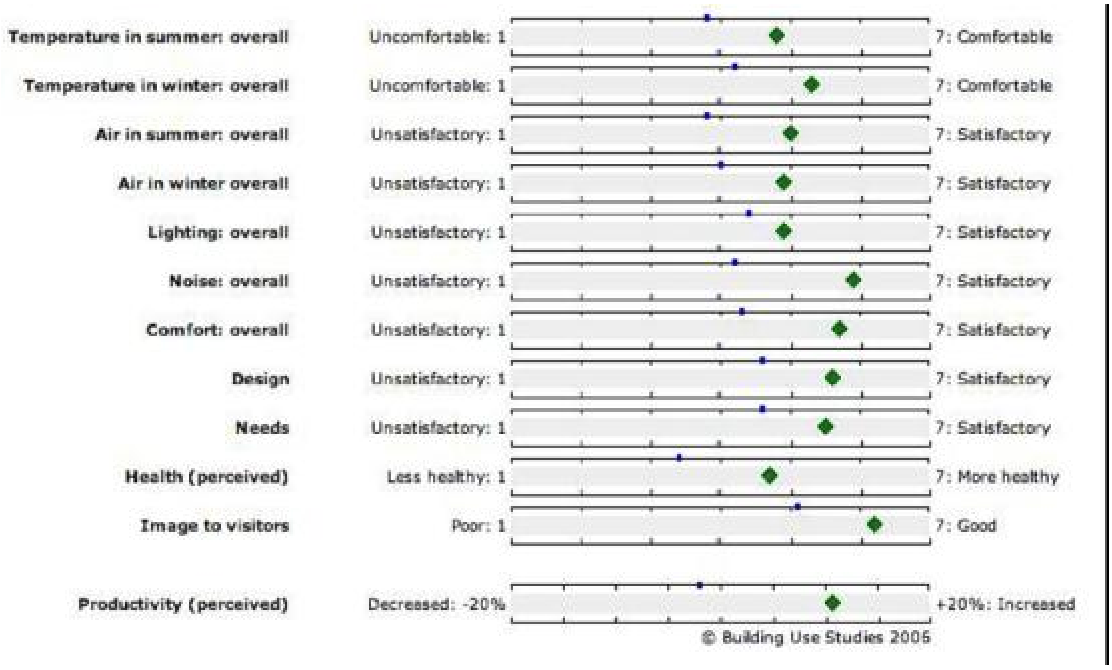
The paper is **organised** around an account of the 7 headings above , leading to **Concluding Comments** with **References** .

Catalytic Project 1 Navan Credit Union; Eco Offices (2005) [1,2,3,4,5]

OBJECTIVE : Post Occupancy Evaluation to learn lessons

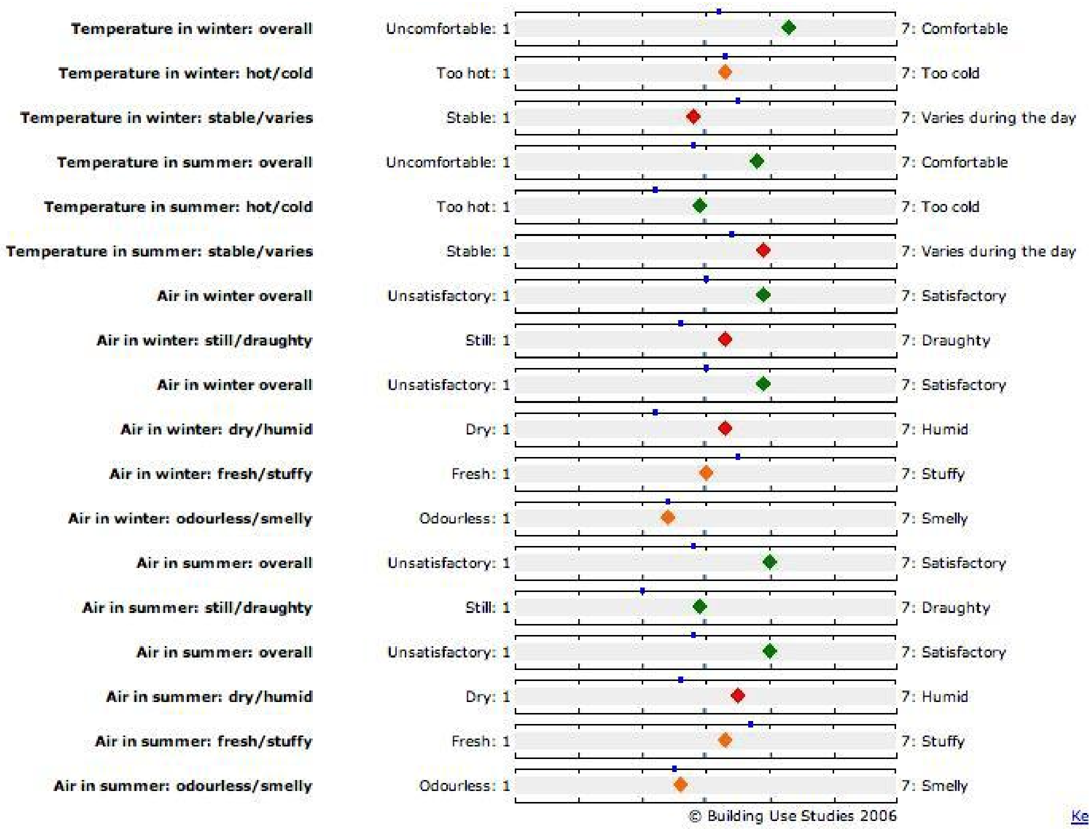
Detailed quantitative and graphic results from are shown below of several years of assessment, and iterative fine tuning, of a completed five storey eco office building, Navan Credit Union: See(www.constructireland.ie/artcles/navan.php) and SB05 proceedings with many passive and low energy design features including:

Blue marks are normative



These results based on independent interviews with the users of the building conducted by Prof George Baird and processed by Adrian Leamon are among the top 5% of all buildings surveyed by the **http://www.usablebuildings.co.uk**

His more detailed analysis indicated perceived shortcomings, again using traffic signal colour codes, as follows on a 'warts n' all basis' : again blue marks are normative:



Lessons learned from these user interviews have lead to fine-tuning and remediation with a view to a follow up interview where it is hoped even better results may be obtained.

ENERGY USE

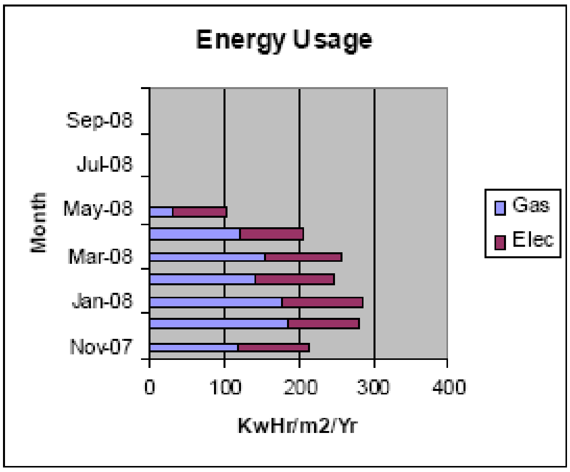


Fig 1. Overall energy monitoring results to Oct 2007 from Nov 2006 expressed as KwHrs / sqM /annum and not normalised: early anomalous results during commission and test phase are notable .

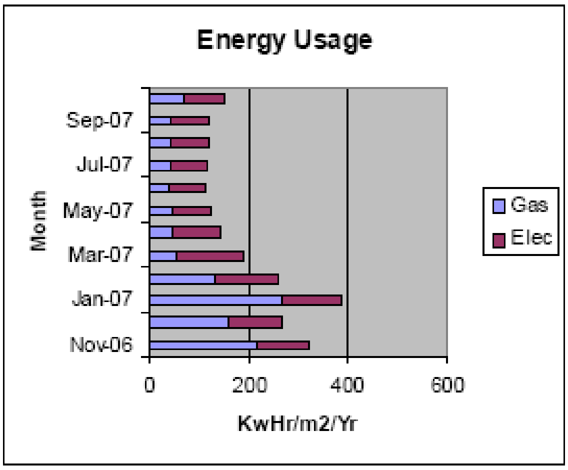


Fig 2) Results from Nov 07 to May 2008 show we are converging on 100 Kwhrs / sq m /annum , a realistic de facto target for best practice office buildings; Although the Winter 07/08 are badly skewed upward by boiler problems (for reasons noted in the text) the winter peak was much less than the previous year (to be updated Sept 2008 before presentation of the paper)

Through a process of elimination energy inefficiencies continue to be eliminated; these include elimination of an air curtain at the main and busy entrance with a generous draught lobby with automatic doors and user behaviour in relation to use of heating ventilation and cooling.

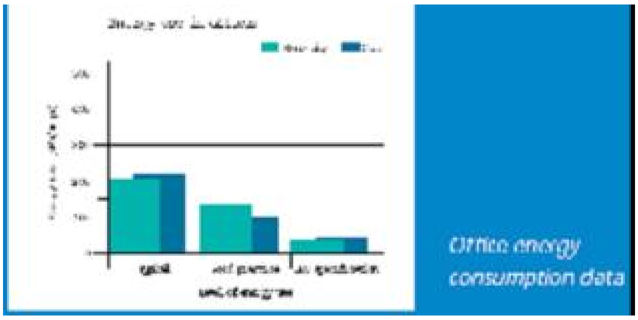


Fig 3 C Typical Good Best Practice

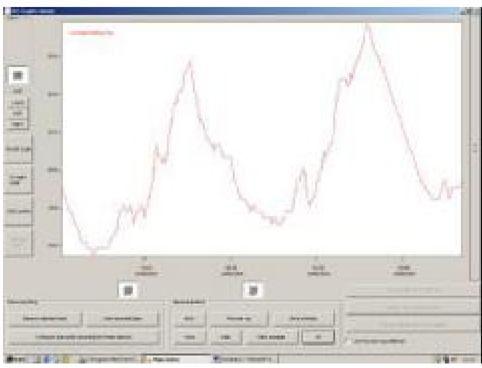
Reference (BRECSU)~ 400 to ~100

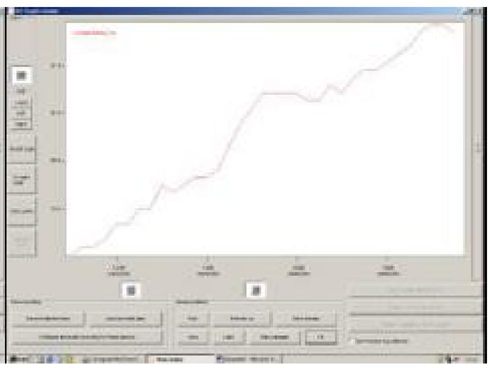
Kwhrs /sq m / annum

VENTILATION Solar Chimney

This simple device (seen centrally above right) at the top of the atrium has proved very successful, especially in fine tuning.
In deep Winter both the 'venturi' and solar chimney are closed down fully . In the shoulder seasons of Spring / Autumn this solar chimney is gradually utilised more or less as required and only in high Summer the Venturi ventilator (see below) is introduced.
From this figure may be seen that velocities of 1 metre per second of free ventilation are achieved in sunlight / naturally in phase with requirement for enhanced ventilation. The consulting engineers have been agreeably surprised by volumes moved.

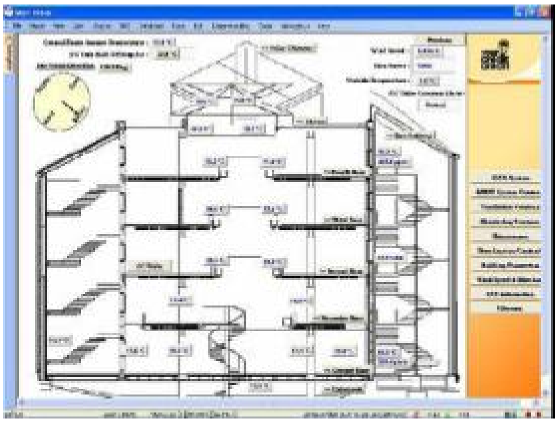
Temperature Control





The commonplace issue here is to control the afternoon 'spike' in office temperature; the left hand shows temperature over two Summer days and the right a daily detail ; it may be seen that auxiliary cooling (gas heat pump) is utilised to delay the natural spike of temperature at 21.25 Deg C until after office hours when it is allowed to climb (when natural ventilation is closed down for security). One of the key issues is staff culture/ behaviour - opening a window is better than turning up cooling.

Conclusion

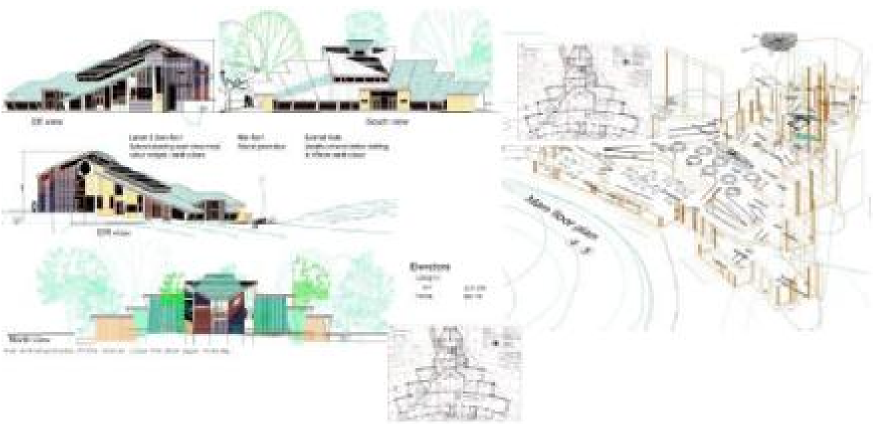


From these results and ongoing work it would appear that 100 KW hrs/Sq M /annum is an achievable target for an office building of this kind at this stage ; ie double the original target which is more appropriate to eco / quasi passive housing. Whereas the atrium design has genuine architectural benefits it contributes to stratification in the building leading to variations during the day ; cold at low level in winter mornings where sedentary workers start their working day . The 'cooling behaviour' of the occupants is cultured by their negative summer experiences of the high thermal mass original building; they are predisposed to the use of auxiliary cooling with inadequate resort to the passive features. The architect would prefer not to install auxiliary cooling at all in this temperate climate. The parallax between design intentions and experienced outcome informs continuing design development in this field.

Catalytic Project 2 Third Level Campus Creche; Dundalk Institute of Technology

OBJECTIVE : Roll forward, on the learning curve of lessons learned from Project No 1

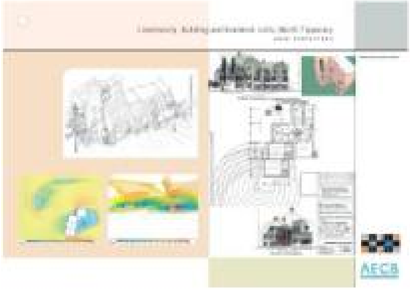
This new design is ready to build on site and awaits funding. Many of the features of the Navan project are reinterpreted here. An essential, point here is form language; an organic building which aims through form, scale, colour, texture, natural light, and ventilation to enhance the earliest years of education of preschool children; the facility itself has a high environmental pedagogical intent re flows of water light waste air etc. In many respectsit brings the thinking of High Scope, into the 21st century.



3 Collaboration in eco village development and urban planning zoning initiatives

OBJECTIVE : The projects are 'budging BAU' by becoming points of reference /precedent for development in Ireland, demonstrating application of principles on macro scale. Two examples will be discussed; The Village Project, Cloughjordan , Tipperary and Laytown Eco Residential Business Zoning.

3.1 The Village Cloughjordanwww.thevillage.ie



One of our principals is a member of the eco village and the Planning Group therein. Infrastructure is complete and roll out of clusters on site is commencing. See www.thevillage.ie We are also designing a community building and some live-work units at the core of the site along with a further Cluster 9 of the development. Infrastructure is now complete and the first roll out of the clusters is just beginning.

3.2 Laytown Eco Residential Business Zoning

This study was undertaken for the landowner of 75 Hectares on the main rail line in the country, on the Belfast /Dublin axis. It resulted in the formal adoption by the Planning Authority of an innovative "Eco Residential Business" zoning. The principles followed were of those of systems theory ; a tolerance of a certain degree of democratic free market 'chaos' while introducing attractors , being an urban civic space and balancing-lake ; one hard edged / urban, one soft-edged, natural.

As an essay in stochastic planning, the out-turn is, as yet, unclear as to how it will affect the market place;as in all 'budging bau' the impulse is sent into the system in the hope that good will come of it of but short of eco fascism one must wait and see how our free society is affected .Three dimensional mixed use live work development is envisaged.

4 /5 Counterculture institutions to BAU with access to Government at Highest Levels.

OBJECTIVE : To proliferate and mainstream eco building ,rather than BAU

In the centre of Dublin a multi faceted sustainability Institution has slowly grown due to the work of a committed team; see www.cultivate.ie . **éasca** has also been founded by the author and others to attempt to shift the sector toward sustainability; the word in Gaelic means 'easy' and the acronym is the Ecological and Sustainable Construction Association. We are subtly engaging vested interests; upstaging those who just 'greenwash' Building As Usual (BAU). See www.easca.ie. **éasca** is often hosted by Cultivate and the offices and staff of **éasca** are shared at Cultivate for synergy and efficiency, in Temple Bar, at the cultural heart of Dublin , the capital city. (Temple Bar itself as an urban quarter has an inspiring history as an urban renewal cell and much of what was learned there is being replicated throughout the city.) **éasca** now has a burgeoning membership with many partners from the sector signing up, to a subscription based on turnover, and assisting the organization to make a difference nationally . The Green Party after a dramatic walk out in negoatiations to form a coalition , managed to secure three Government Ministries: Environment, Heritage and Local Government: Energy and Communications: Food and Horticulture. The synergy between these Ministers and éasca / Cultivate is promising. An advisory committee to the Minister has been formed which sits in his office. A number of initiatives are in hand including a revision of the Building Regulations to effect a 40% improvement in primary energy usage compared with a conventional base case; an escalation to 60% improvement is scheduled to follow . It remains to be seen what possible effect is possible with a majority Government party still very committed overall to BAU, with ministries such as Finance still in the control of that centre right party. The Government have just started addressing the issues, as severe financial penalties are brought to bear under EU and Kyoto measures.

6 Teaching : OBJECTIVE : To communicate with Youth, as the future practitioners and policy makers.

Occasional teaching as guest lecturer allows one to budge BAU by facilitating the new generation of architects and allied professions; it is noticeable how Staff have now become interested; a recent lecture to second year students in Waterford School of Architecture attracted the attendance of the Director and ten staff from several years and a lively discussion followed; one has the sense that things are changing and perhaps a green 'chain reaction' is possible after all ?

7 International think-tank activity in GAIA International [6, 7, 8, 9, 10]

OBJECTIVE : To proliferate and synergise internationally

GAIA International was founded in 1990, standing for "the balance and integration of the built environment with ecosystems for the welfare of all species on the planet". It is a non corporate informal structure of disparate, but like-minded professionals in practice, research, teaching, writing and publishing who by contact from time to time enable and sustain and encourage each others work .It budges BAU in subtle and sometimes overt ways. Several members have contributed significantly to the literature REFS, whereas others teach and practice.

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OPTIMIZED DESIGN OF CONCRETE STRUCTURES FROM THE ENVIRONMENTAL POINT OF VIEW

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Summary

A basic formulation of the optimized design of concrete structures is presented. Deterministic and stochastic optimized design alternatives are shown. The proposed method enables the inclusion into the formulation not only of reliability design according to codes; it is also possible to use fully probabilistic design based on stochastic mechanics. The objective function can be a vector function, which has to be transformed into a scalar function. The environmental aspects of a designed structure such as emissions of CO_2, SO_x or embodied energy are included in the objective function. For transformation from vector to scalar objective function weighting and normalising methods are used. Methods for the solution have been discussed in some other publications (Stepanek, 2006; Stepanek, Plsek, 2007). Two solved design examples are presented.

1. Introduction

There is a current tendency to design new concrete structures and also reconstructions effectively from the viewpoint of minimising the initial cost while preserving serviceability parameters (i.e. Frangopol, 2001, Mróz, 1998). However, this trend in design specialises not only in the execution phase of the construction but also pays attention in recent years to the construction life cycle – MIT conference, 2003.

A key desire of engineers while designing structures has for a long time been to design a structure from such materials whose properties are fully utilised in the structure (conditions of load-bearing capacity) thus causing the structure to fulfil the conditions of applicability (especially in view of cracks and strain). This fact has recently resulted in the origin and construction of a number of composite structures. These structures are formed from different materials, usually combining concrete (utilised in compression areas - its properties may be modified by various additional components) with materials featuring very good properties in tension (steel. glass, carbon and aramid).

A new approach is also manifested in the design of structural materials with programmed physical properties in order to optimally fulfil the functional demands during the predicted activities within an individual structure over the course of its life cycle.

Optimisation of concrete structure design is generally based above all on the following principles (see Stepanek, 2006): optimisation of the technology used when manufacturing concrete components, optimisation of the composition of concrete mixture, optimisation of the shape and reinforcement of structural members, and optimisation of the cost and/or environmental impacts in relation to the life cycle of a concrete structure.

This paper is related to the optimisation of the shape and reinforcement of concrete members by taking into account cost and environmental aspects.

2. Optimised design of concrete structures

To make the design of a structure effective, it is necessary to adopt the method of optimised design. It isn’t really so useful to simply optimise the initial cost. Far more appropriate is to minimize the total cost, i.e. the cost over the life cycle of a construction, and maximize the stiffness of the designed structure at prescribed cross sections. Engineering optimization plays an increasingly important role in structural design. It was carried out at various quality levels from a design update based on a designers opinion to the application of exact mathematical optimisation models. These computational models are usually deterministic with respect to the complexity of the whole design (see IFIP conf., 2003). The optimisation methods and theories of design have significantly developed in the last thirty years.

To find the best possible design of structure or member without a negative effect on the reliability system as a whole, it is necessary to use an optimised method. However, it must be said that a significant amount of the existing optimised methods are specialized in the area of structural design that considers all parameters as being deterministic (DBSO – Deterministic Based Structure Optimisation). The general deficiency of DBSO is the omission of uncertainties while determining loads, material characteristics, responses and the stability of the structure. Elimination of that deficiency enables the combination of design methods based on comprehensive probabilistic accesses and optimised methods. This assessment is called Reliability Based Structure Optimisation (RBSO).

The crucial conceptual problem is, however, the question of how to make provision for stochastic variability, which especially concerns the properties of materials and general loading including environmental and technological effects. Methods of providing for stochastic variability have been well elaborated in simulation reliability models especially – Frangopol, 2001.

2.1 Reliability based optimization - consideration of the randomness of some input variables

The task is defined as follows

a) the target function reaches the extreme

$\{f(\{x\})\} =$ extreme, (1.a)

while keeping the restrictive conditions implicit from

b) the reliability requirements of the designed structure expressed in probabilities

$P_{fj}(\{x\}) \leq P_{fj}^{0}$ $\quad j = 1, ..., np$, (1.b)

and other conditions with the included further terms containing probabilities. These conditions can be expressed in the form of

c) the equalities $\{h(\{x\})\} = \{0_1\}$, (1.c)

d) the inequalities $\{g(\{x\})\} \leq \{0_2\}$, (1.d)

where $\{x\} = \{x_{s1},...,x_{snt}\}^T$ are the design variables, $\{f(\{x\})\} = \{f_1(\{x\}),...,f_t(\{x\})\}^T$ is the vector of the target functions, $f_i(\{x\})$ is the i-th target function, $\{h(\{x\})\}$ is the vector of the restrictive conditions in the form of equations, $\{g(\{x\})\}$ is the vector of the restrictive conditions in the form of inequalities, $P_{fj}(\{x\})$ is the probability of the structure's failure (the j-th condition of the reliability relating to some mode of failure or to applicability in a given locality), P_{fj}^{0} is the permissive probability of the failure determined for the j-th conditions of the reliability, and $\{0_1\}$ and $\{0_2\}$ are zero vectors of the relevant type.

For an established vector of the design variables, the conditions of equilibrium of the solved structure – with the application of discretion of the solved task via an FEM method – can be expressed in the form (1.c), where

$\{h(\{x\})\} = [K(\{x\})]\{\Delta\} - \{F\}$, (2)

$[K(\{x\})]$ is the stiffness matrix of the solved structure, $\{\Delta\}$ is a vector of the nodal parameter of deformation and $\{F\}$ is the loading vector of a structure.

2.2 Deterministic based optimization (DBSO)

The task is defined analogously to the RBSO but the conditions (1.b) are not used and in the relations (1.a), (1.c) and (1.d) the probabilities are not included. For the solution of this task it is possible to apply mathematical programming algorithms and algorithms based on evolution processes too.

3. Optimised design of a concrete cross section

Let's assume an RC cross-section of any shape and reinforcement, which is allowed to contain inner openings and whose perimeter is approximated by closed polygons, placed in a Cartesian ordinate system YxZ. The cross-section is stressed by a set of loading cases $\mathbf{L}_j = (N, M_y, M_z)_j^T$, $1 \leq j \leq N_L$, which represent inner forces (see Fig. 1.a). They are obtained from a previous static calculation on a studied structure in a specified critical cross-section on the axis of a particular bar element. The loading cases are vectors of random quantities with known probability distribution, of which statistical dependences are given by correlation matrix. Design of the cross-section has to minimize the selected objective function and meet all restrictive conditions (constraints), i.e. bear every loading case L_j safely. Cross-section reliability is expressed by the probability of failure $p_{f,j}$, which depends on L_j as well as on cross-section geometric and material parameters and uncertainties.

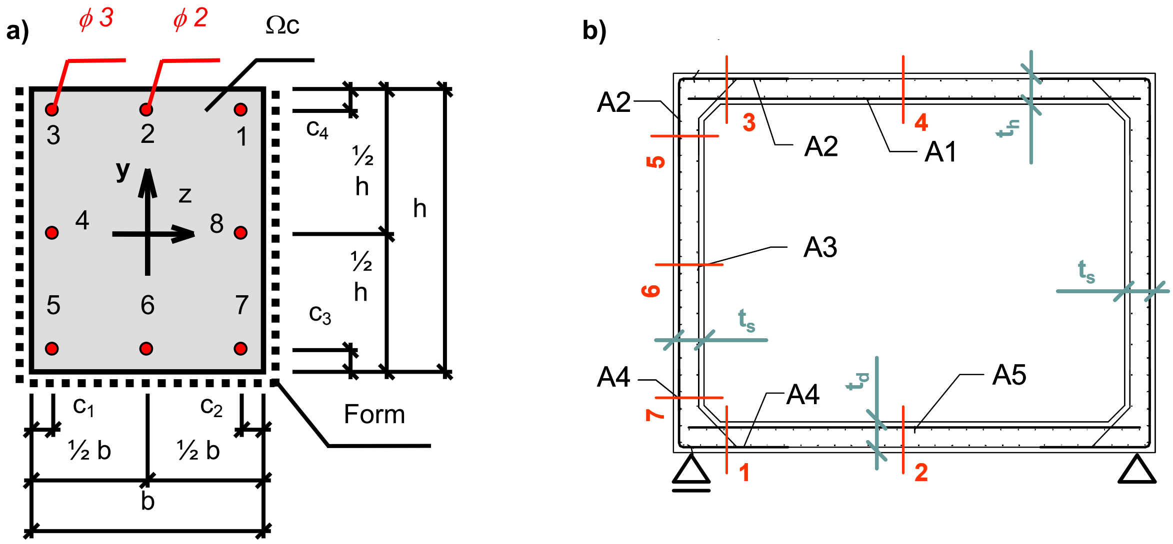

Figure 1 Schemas of solved structures: a) cross section optimization, b) a collector

The vector $\boldsymbol{x}$ of the considered design variables includes characteristic dimensions of a cross-section $\boldsymbol{r}$ (e.g. the width and height of a rectangular cross-section), as well as the set of reinforcement diameters ϕ and strength of concrete f_c and steel f_s, therefore $\boldsymbol{x} = (\boldsymbol{r}, \phi, f_c, f_s)^T$. For simplicity, all variables are taken as continuous.

3.1 Objective function for DBSO and RBSO

For the purpose of DBSO and RBSO comparison, probabilities are omitted in the RSBO objective function and a common simple objective function is defined. Economical and ecological aspects (acquisition costs and CO_2 and SO_2 emissions associated with concrete member formation, respectively) are taken into account. The problem is multicriterial and all the mentioned aspects should be minimised. The method of weighted sums was applied; the problem seems to be monocriterial with regards to the solving algorithm. However, the terms of the objective function have different units and thus can not be directly summed; for that reason they must first be normalized by the chosen reference values:

$$f(\mathbf{x}) = \alpha_p \frac{P(\mathbf{x})}{{}^{\circ}P} + \alpha_{co} \frac{CO_2(\mathbf{x})}{{}^{\circ}CO_2} + \alpha_{so} \frac{SO_2(\mathbf{x})}{{}^{\circ}SO_2}, \qquad (3)$$

$$P = V_c U_p^c + m_s U_p^s + S_f U_p^f, \qquad (4.a)$$

$$CO_2 = V_c U_{CO2}^c + m_s U_{CO2}^s, \qquad (4.b)$$

$$SO_2 = V_c U_{SO2}^c + m_s U_{SO2}^s, \qquad (4.c)$$

where the used symbols mean: P acquisition costs, CO_2 the amount of CO_2 emissions, SO_2 the amount of SO_2 emissions, ${}^0P$ (or ${}^0CO_2$, ${}^0SO_2$) the reference values set by the problem designer, α_P (or α_{CO}, α_{SO}) weights in the objective function for P (or CO_2 and SO_2, respectively), V_c concrete volume, m_s reinforcing steel weight, S_f the form area of a 1m-long beam fragment with a designed cross-section, U^c_P (or U^s_P, U^f_P) the costs of concrete (or steel and form, respectively), U^c_{CO2} the embodied unit amount of CO_2 emissions from concrete production, U^s_{CO2} the embodied unit amount of CO_2 emissions from steel production, U^c_{SO2} the embodied unit amount of SO_2 emissions from concrete, and U^s_{SO2} the embodied unit amount of SO_2 emissions from steel production.

3.2 Specification

Let a simply-supported beam with a constant RC rectangular cross-section be uniformly loaded all along its span l by its self weight *g* and imposed load *q*. The objective is to design all unknown cross-section parameters with the help of the proposed RBSO and DBSO algorithms and to compare the acquired results.

Some of the parameters are given: the strength classes of materials (f_c and f_s), the number of reinforcement bars N_ϕ and their positions in the cross-section (covers c_1 to c_4, see Fig. 5). Reinforcement bar diameters ϕ and cross-section dimensions b and h (width and height, respectively) are left for optimisation.
The calculations are carried out in 5 variants of weighting coefficients α_P, α_{co}, α_{so}, see (3) and 2 variants of cross-section dimensions, which are either optimised or given (fixed).

Given cross-section parameters: Concrete C25/30, steel B490(R), number of reinforcement bars $N_\phi = 8$ and axial covers $c_{1..4} = 40$ mm. Cross-section dimensions: optimised $b, h \in \langle 200, 600 \rangle$ mm or fixed $b = 300$ mm, $h = 500$ mm. Reinforcement bars: corner bars: $\phi_{1,3,5,7} \in \langle 10, 22 \rangle$ mm, inner bars: $\phi_{2,4,6,8} \in \langle 0, 22 \rangle$ mm.
Loading case specifications: Number of loading cases $N_L = 1$. A simply-supported beam is strained the most in the middle of the span by simple bending, so

$$\mathbf{L}_1(\xi) = (0,\ M_y(\xi),\ 0)^T, \tag{5}$$

$$M_y(\xi) = -\frac{1}{8}\left(g(\xi) + q(\xi)\right) l^2, \tag{6}$$

where l is the effective span (8 m), $g(\xi)$ and $q(\xi)$ are random variables with mean values $g^\bullet$ and $q^\bullet$, respectively, obtained from

$$g^\bullet = g_k = b^\bullet\, h^\bullet\, \gamma_{cncr}, \tag{7}$$

$$q^\bullet = q_k, \tag{8}$$

where $b^\bullet$, $h^\bullet$ are design variables b and h, respectively, γ_{cncr} is reinforced concrete unit weight (25 kN/m^3) and q_k the given characteristic value of imposed load (14 kN/m).

Stochastic model parameters are shown in Tab. 1. Each of the random quantities is assumed to be normally distributed without mutual correlations. The mean value of $q(\xi)$ is determined in such a way that the value q_k is its 95% fractile. Multipliers γ_g and γ_q are relevant partial factors for permanent and variable loads in accordance with code EC2 *Design of Concrete Structures,* 1991 [1] ($\gamma_g = 1{,}35$, $\gamma_q = 1{,}5$).

Table 1 Random quantities and their parameters

$\boldsymbol{H}(\xi)$	Random variable	Mean value	Units	γ or σ Type	Value
$\boldsymbol{L}_1(\xi)$	$g(\xi)$	$g^\bullet$	kN/m	γ	0,213
	$q(\xi)$	9,333	kN/m	γ	0,304
$\boldsymbol{D}(\xi)$	$b(\xi), h(\xi)$	$b^\bullet$, $h^\bullet$	mm	γ	0,02
	$f_c(\xi)$	25	MPa	γ	0,12
	$f_{s,1}(\xi)\ldots f_{s,8}(\xi)$	490	MPa	γ	0,06
	$c_1(\xi)\ldots c_4(\xi)$	40	mm	σ	5
	$\phi_1(\xi)\ldots\phi_8(\xi)$	$\phi_1^\bullet \ldots \phi_8^\bullet$	mm	γ	0,05

Objective function parameters: Reference values were derived from a 300 x 500 mm^2 rectangular cross-section reinforced by 8 bars of diameter 22 (maximal allowable reinforcement) ^0P = 1246 CZK (Czech Crowns), $^0CO_2$ = 63.3 kg, $^0SO_2$ = 0.239 kg. Other input parameters for optimization: costs U^c_P = 2343 CZK/m^3, U^s_P ´19 CZK/kg, U^f_P = 400 CZK/m^2 and embodied values U^c_{CO2} = 321kg/m^3, U^s_{CO2} = 767 kg/m^3, U^c_{SO2} = 1.11 kg/m^3, U^s_{SO2} = 3.67 kg/m^3.

Five alternatives of weighting in the objective function were calculated: alt.1: α_P = 1; α_{CO} = 0; α_{SO} =0; alt.2: α_P = 0.75; α_{CO} = 0.125; α_{SO} =0.125; alt.3: α_P = 0.5; α_{CO} = 0,25; α_{SO} =0.25; alt.4: α_P = 0.25; α_{CO} = 0.325; α_{SO} =0325; alt.5: α_P = 0; α_{CO} = 0.5; α_{SO} =0.5.
Other parameters and specifications for concrete section design are taken from standard EC2. Required cross-section reliability is given by minimal Cornell safety index β_{min} = 3.8, which corresponds to the maximal failure probability p_f^{max} =7.2 . 10^{-5}. The number of simulations for p_f estimation is set to $N_S = 100$. $Z(\xi)$ is assumed to be normally distributed.

3.3 Results

Numerical results are listed in Tables 2 and 3. The variant with fixed cross-section dimensions resulted for both DBSO and RBSO in the same results without regard to summation weight changes.

Table 2 Results of DBSO; all variants "b, h = const" always led to the same results shown in the first column; the reliability indexes for DBSO were calculated additionally after termination of the optimisation process

Weights Dimensions		Weights 1-5 Fixed	Weights 1 Optimised	Weights 2 Optimised	Weights 3 Optimised	Weights 4 Optimised	Weights 5 Optimised
$\phi_1 = \phi_3$		10,0	17,1	16,5	22,0	21,9	22,0
$\phi_5 = \phi_7$		22,0	22,0	22,0	22,0	22,0	22,0
ϕ_2	[mm]	0,0	14,8	22,0	15,8	20,6	21,5
$\phi_4 = \phi_8$		7,1	17,3	19,0	20,4	21,7	22,0
ϕ_6		22,0	22,0	22,0	22,0	22,0	22,0
Width b	[mm]	300	254	244	235	228	227
Height h	[mm]	500	424	406	392	381	378
Steel Area	[mm^2]	1376	2244	2516	2753	2967	3024
Concrete Area	[mm^2]	150000	107693	99038	92326	86878	85507
Form Length	[mm]	1300	1102	1056	1020	989	982
Cost of Steel	[czk]	205	335	375	411	443	451
Cost of Concrete	[czk]	351	252	232	216	204	200
Cost of Form	[czk]	520	441	423	408	396	393
Total Cost	[czk]	1077	1028	1030	1035	1042	1044
Amount of CO_2	[kg]	56,433	48,081	46,937	46,213	45,752	45,657
Amount of SO_2	[kg]	0,206	0,18419	0,18241	0,18180	0,18191	0,18204
Target function	[-]	0,877	0,825	0,808	0,788	0,766	0,742
Reliability Index	[-]	4,38	4,51	4,48	4,47	4,43	4,42

Table 3 Results of RBSO, all variants "b, h = const" always led to the same results shown in the first column; the minimal required reliability index was 3,8 (the main restrictive condition of the optimisation)

Weights Dimensions		Weights 1-5 Fixed	Weights 1 Optimised	Weights 2 Optimised	Weights 3 Optimised	Weights 4 Optimised	Weights 5 Optimised
$\phi_1 = \phi_3$		10,0	10,0	10,0	10,0	10,0	10,0
$\phi_5 = \phi_7$		21,5	22,0	22,0	22,0	22,0	22,0
ϕ_2	[mm]	0,0	0,0	0,0	0,0	0,0	0,0
$\phi_4 = \phi_8$		0,0	0,0	6,1	6,3	6,6	0,0
ϕ_6		20,9	22,0	22,0	22,0	22,0	22,0
Width b	[mm]	300	200	200	200	200	200
Height h	[mm]	500	454	446	446	445	454
Steel Area	[mm^2]	1222	1297	1356	1361	1366	1297
Concrete Area	[mm^2]	150000	90752	89201	89105	88991	90752
Form Length	[mm]	1300	1108	1092	1091	1090	1108
Cost of Steel	[czk]	182	194	202	203	204	194
Cost of Concrete	[czk]	351	213	209	209	209	213
Cost of Form	[czk]	520	443	437	436	436	443
Total Cost	[czk]	1054	849	848	848	848	849
Amount of CO_2	[kg]	55,510	36,943	36,800	36,795	36,788	36,943
Amount of SO_2	[kg]	0,202	0,13811	0,13809	0,13810	0,13812	0,13811
Target function	[-]	0,846	0,681	0,655	0,63	0,605	0,581
Reliability Index	[-]	3,8	3,8	3,8	3,8	3,8	3,8

The DBSO amount of steel is always greater than that obtained by RBSO; the amounts of concrete are almost equal in all cases. Modifications of summation weights caused only small changes in the results for

CO_2 and SO_2 emissions. There are substantial differences in the reliability indexes (on average 17% for “optimised dimensions” cases) and total costs (on average 22% for “optimised dimensions” cases).

4. Optimisation of a concrete collector

An optimization of the load bearing concrete structure of a collector was made – Fig. 2. It was required that the structure be designed with normal steel reinforcement, stainless steel reinforcement and GFRP (Glass Fiber Reinforced Polymer) reinforcement. Because of the different mechanical characteristics of reinforcing materials and their costs it was necessary to use optimized design.

The cross section was modeled as a frame structure – in fig. 1.b. The load stages taken into account for design were: dead load (own weight, earth pressure), and traffic live load. Static solution of the structure covers the following load combinations: fully covered up structure, structure covered up on one side, and fully covered up structure with the influence of ground water. The design was created according to code EC2.

From the mathematical point of view a task is a continuous deterministic or stochastic non linear problem of mathematic programming. The solution was carried out using the GAMS system with the Conopt solver according to described theory – Stepanek, 2007. Because of the limited range of this contribution only the DBSO task will be described.

Design parameters were: t_h thickness of top plate, t_d thickness of bottom plate, t_s thickness of walls and amount of reinforcement A_i at designed cross sections of the framed structure – see Fig. 1.b. Design variables are considered as continuous quantities; constraints for thicknesses of plates and walls are t_d, t_h, $t_s \in$ <100, 600> mm, constraints for the diameter of reinforcing bars are <6, 30> mm and the distance between rebars is equal to 100 mm.

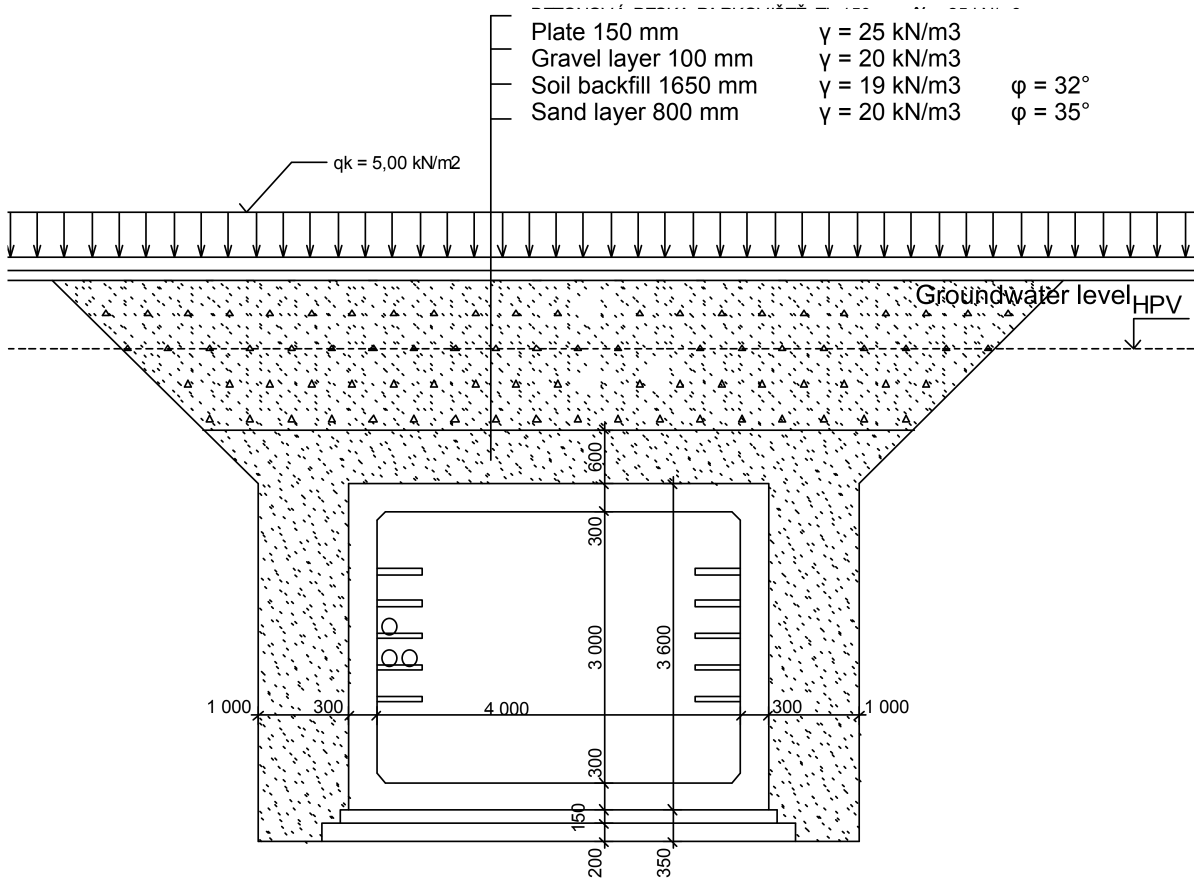

Figure 2 Schematic of the solved load bearing structure of the collector

4.1 Objective function

The target function describes the costs of the execution of a 1 m length structure, the environmental impact expressed in terms of CO_2 and SO_x emissions, embodied energy E and the bending stiffness of some cross sections

$$f(X) = \alpha_P \frac{P(x)}{{}^0P} + \alpha_{CO} \frac{CO_2(x)}{{}^0CO_2} + \alpha_{SO} \frac{SO_2}{{}^0SO_2} + \alpha_E \frac{E}{{}^0E} + \alpha_B \sum_i^7 \beta_i \frac{{}^0B_i}{B_i} \tag{9}$$

where the newly-used symbols mean E energy consumption for 1m length of structure, B_i the bending stiffness of cross section i (i = 1, .., 7 according to Fig. 1.b), ${}^0E$ (or ${}^0B_i$) being reference values for energy (or stiffness) set by the problem designer, and the realization of α_E or α_{Bi} weights in the objective function for energy or bending stiffness, respectively.
Objective function parameters: Reference values were derived for a structure of 1m length with maximal cross section dimensions and a complete structure reinforced with the maximal allowable reinforcement. Input values for those calculations were calculated from tab. 4.

Table 4 Unit costs and environmental impacts

Material	Energy [MJ/kg]	CO_2 [kg CO_2 / kg]	SO_x [g SO_x / kg]	Unit cost	
Concrete C35/45	0,8	0,13	0,5	2385	CZK/m3
Steel rebar	49	3,2	14,6	23,7	CZK/kg
Stainless steel	113	6,7	303,6	200	CZK/kg
GFRP rebar	41,6	1,92	14,66	acc. to diameter	CZK/m'

Constraints: in addition to such defined constraints as intervals of the allowable range of design parameters it is necessary to fulfill reliability constraints according to the ultimate limit states at cross section i defined by EC2 for all described load combinations.

We optimized the collector cross section design using 2 alternatives. The 1st alternative specified as "costs vs. stiffness" was calculated with weighting coefficients $\alpha_B \in$ <0,1>, $\alpha_C = 1 - \alpha_B$, $\alpha_{CO} = \alpha_{SOX} = \alpha_E = 0$. The 2nd alternative "eco-impact vs. stiffness" was calculated with weighting coefficients $\alpha_B \in$ <0,1>, $\alpha_C = 0$ and $\alpha_{CO2} = \alpha_{SOX} = \alpha_E = (1 - \alpha_B)/3$.

4.2 Results

Both alternatives ("costs vs. stiffness" and "eco-impact vs. stiffness") give corresponding (but not identical) results. For this reason and because of limited range of this text only the results of the 1st alternative will be discussed.

From Fig. 3 it follows that the most expensive collector structure design is with stainless steel reinforcement. The costs for a structure with GFRP reinforcement are much lower (about 50% of the stainless steel variant) and the best design from the standpoint of cost optimization is with normal steel reinforcement.

Fig. 3 illustrates the results of parametric optimization studies for some types of weighting (transformation from vector objective function to scalar function). If α_B decreases and other weighting factors increase the change of optimal solution goes through four phases. The difference is with transitional values α_B only – see fig. 3. From $\alpha_B = 1$ to value $\alpha_B = \alpha_{B,Xmax}$ the design variables reach their maximal prescribed values (1st phase). If $\alpha_B \in (\alpha_{B,reinf}\ ;\ \alpha_{B,Xmax})$ decreased, the reinforcing area also decreased and the height of the cross section was maximal and equal to the upper limit of the constraints – 2nd phase. In the 3rd phase for $\alpha_B \in (\alpha_{B,t+reinf}\ ,\ \alpha_{B,reinf})$ the optimization results did not change. If $\alpha_B \leq \alpha_{B,t+reinf}$, the optimization procedure changes the height of the cross section and reinforcement.

From the environmental point of view the worst result is from stainless steel reinforcement, steel reinforcement is better and the best results are obtained from GFRP reinforcement. The difference between steel and GFRP reinforcement from the environmental point of view was approximately 3-5% of the optimal values for stainless steel. Embodied energy and CO_2 emissions for steel (or GFRP) reinforcement are about 50% (or 45%) of those from a stainless steel reinforcement solution. For SOx emissions greater differences were obtained because of the fundamental variance in the embodied emissions.

5. Conclusion

1) It is possible to use the proposed DBSO and RBSO approach in the design of structures. It is possible to include not only reliability criteria according to design codes but also environmental aspects.

2) Materially-optimised structures seem to be environmentally friendly without attempting any explicitly prescribed task to take into account ecological aspects, because material savings cause less pollution.

3) Including the maintenance and repair costs into the objective function will make it possible to use lifetime assessment during the environmental design of structures.

4) From the results of the numerical example, it follows that DBSO, in comparison to RBSO, results in an over-designed cross-section.

5) With the help of RBSO, it is possible to achieve a structural design with a well-proportioned level of failure probability with respect to various failure modes, which is economically advantageous.

6) The objective function has a significant influence on the obtained optimal results. In case of a vector objective function we have to transform this function into a scalar function. Therefore it is necessary to discuss its form and type of weighting. Sometimes it is very useful to do a parametric study for weighting values.

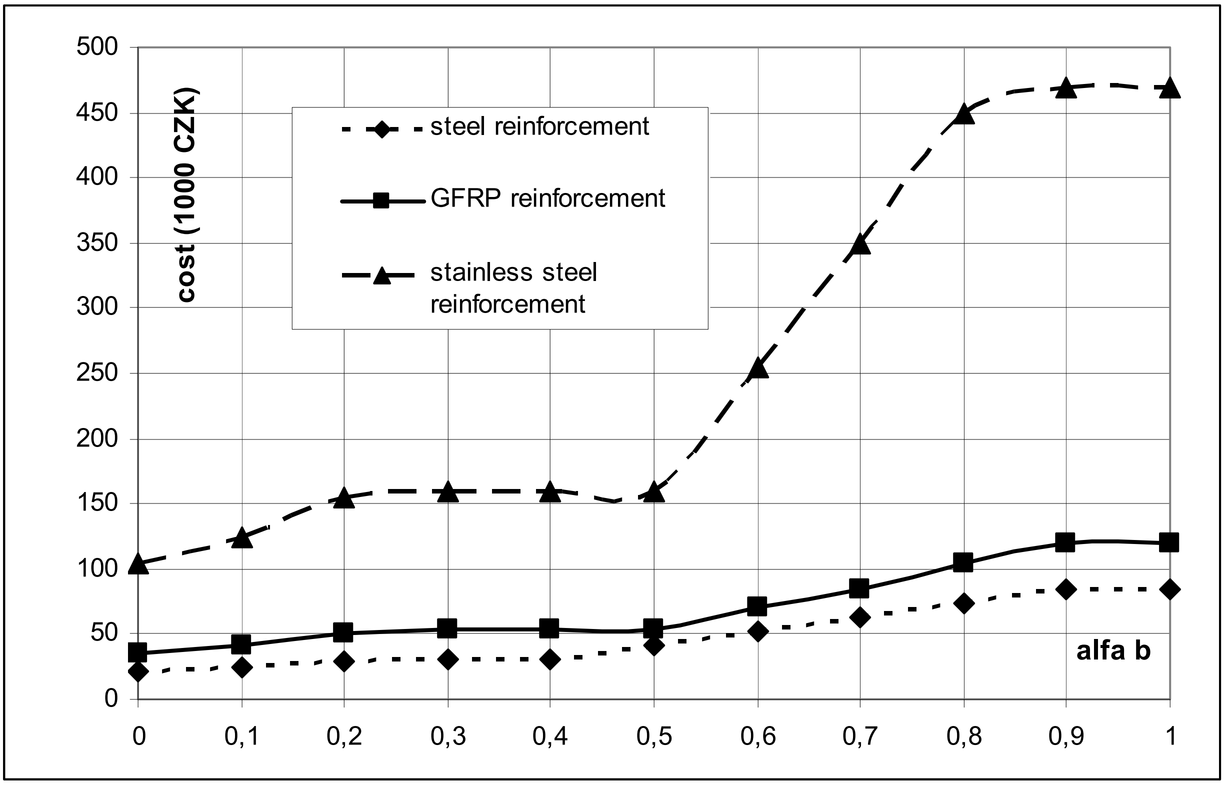

Figure 2 Results for the parametric study of the optimized design of a collector structure

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LIVING SKINS. OPPORTUNITIES, CRITIQUE AND APPROPRIATENESS OF GREEN FAÇADES

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Keywords: living skins, green façades, living wall, green wall, opportunities, critique, appropriateness, framework

Summary

This research argues the current practice of green façades in terms of the accomplishment of a broader range of opportunities they might realize. It analyses existing green façades according to different types, construction systems, and relationships with the immediate context. This reveals there are two major categories of green façades: opaque green façades, and transparent green façades. The research identifies a series of opportunities related to six areas: human comfort; expressive capacity; air & water quality; indoor-outdoor relationship; urban biodiversity; and carbon neutral architecture.

It combines the classification of green façades and the identification of opportunities they offer to develop the Green Façades Framework. This framework enables the critique and evaluation of existing green façades in terms the extent to which they accomplish such opportunities, hence facilitating a determination of their appropriateness to different conditions, solar orientations, and user needs.

The proposed Green Façades Framework is applied to five existing examples of green façades to evaluate their appropriateness to their particular conditions. This application detects the deficiencies of these green façades, enables a deeper critique of their design and reveals the usefulness and limitations of the Framework to improve the current practice of green façades by assisting designers to define more appropriate green façades.

1. Introduction

Architecture today is experiencing an emerging practice in and increasing application of green façades. More architects are experimenting with diverse ways of incorporating greenery into building façades, developing a wide spectrum of systems. Recent examples from Madrid, Spain and Vancouver, Canada reflect the international uptake of this technology [Fig1].

Figure 1 Architecture today is experiencing a boom in green façades around the world. House in Madrid [Spain, 2003]; Aquarium in Vancouver [Canada, 2006]; Prada store basement [Tokyo, 2005].

In this context, leading architects such as Jean Nouvel and Herzog & de Meuron, are utilizing green façades as a natural response to both the current accelerated information society, one which demands a changeable architecture, as well as to carbon neutrality, one which demands an environmentally concious architecture.

Architects are exploring the changeable and expressive capacity of vegetation in the façade, fascinated by its faculty to naturally introduce the notion of time, providing an ephemeral dimension:

"*The ephemeral dimension infers a rapport between architecture and ephemeral elements. Vegetation is one of these and is of course very fleeting, very sensitive and very changeable*" (Nouvel, 2007).

Recent buildings illustrate this statement. The green façade of Nouvel's Quai Branly Museum in Paris [2006], achieves a spectacular explosion of different plant species, emphasizing the thickness and heaviness of 'living walls'. In Tokyo, the green façade of the basement of Herzog & de Meuron's Prada store [2005] uses the same moss-type plant creating different inclinations.

Figure 2 The Green Façades of the Quai Branly Museum in Paris [Nouvel] and the basement of Prada store in Tokyo [Herzog and de Meuron] explore the expressive capacity of green façades.

But, do these green façades realize the full range of opportunities they embody? Although the expression of changeability that occurs naturally through the passing of time is a key aspect of current practice of green façades, this research considers there are many other qualities of green façades that are ignored or underestimated. Looking at these two examples, it seems striking, for instance, to find both green façades respond in such a similar way – attached to opaque walls – to the very different conditions they face: Quai Branly Museum's faces north-west to a main street and the Seine river, while Prada's basement facade faces south-east and north-east to the entrance of the store..

Instead, green façades could and should respond in different manners to different orientations as a means of emphasizing the variability of their surroundings. Green façades could and should show different faces according to the movement of the sun. The opacity or transparency of the walls that they are attached to should play a key role in this sense. Using green facades in this way could significantly reduce the energy demand of buildings, refreshing the façade in summer, allowing for solar energy gain in winter through transparent green façades, or insulating from the cold through opaque green walls. Green façades could also incorporate flexibility and movement in the building envelope, through rotating or sliding systems, allowing users to create their desired relationship with the outdoor space.

Green façades can also act as water storage, reducing runoff, and can even purify grey water generated wtihin the building. In a similar manner, they can purify the air of their surroundings by trapping pollutants such as CO_2. In this sense, green façades can be considered a building material with great potential to contribute to carbon neutral architecture over its life-cycle. Green facades can significantly improve urban biodiversity, especially when situated within the wider green network, enhancing the activity of living organisms. They can even provide space for urban agriculture, acting as cultivated green surfaces, where vegetables can grow.

This research argues that at present green façades are in a rather preliminary stage, given that their design is relatively intuitive and based more on exploring their expressive capacity than on maximizing the breadth of opportunities they can provide. Consequently, designers are often unaware of the larger range of opportunities in green façades. To further this discussion, this research develops and proposes a Green Façades Framework to provide a set of attributes that will assist designers in defining green façades that appropriately satisfy a project's needs.

2. Methodology

The research begins with a preliminary analysis of the current practices of green facades. It classifies them into two major categories: opaque green façades - those attached to an opaque wall, and transparent green façades - those associated to a transparent wall. Within these two categories, five distinct construction types have been identified [Table 1]. The research provides a preliminarily critique of the current practice of green façades by illustrating deficiencies and missed opportunities in their designing and construction process.

The research then, based on related studies, identifies a broader set of opportunities for green façades. These have been condensed into six areas: human comfort, expressive capacity, water & air quality, indoor-outdoor relationship, urban biodiversity, and carbon neutral architecture.

The combination of the two previous findings – the types of green façades on the one hand, and a broader range of opportunities on the other – lays the foundation for development of the Green Façades Framework. This framework enables the critique and evaluation of different types of green façades in terms of the extent to which they accomplish the identified opportunities and helps to determine their appropriateness for different conditions in an effort to improve current practice.

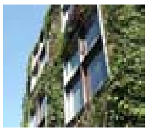
The Green Façades Framework is applied to existing examples of green façades to evaluate their appropriateness to their particular conditions. Five case studies are analysed, corresponding to the previously identified five main types of green façades. The application of the framework reveals its usefulness and limitations in assessing how designers select and define more appropriate types of green façades for specific projects. The research concludes with designs for an opaque and a transparent green façade seeking to fulfill the identified opportunities. Built prototypes of these designs will be monitored in a test room to compare achieved data with related research.

3. Current practice of living skins

The current practice of living skins is situated within the context of a contemporary type of façade that reacts to the stimuli of its immediate environment – in other words, a responsive façade. Green façades represent a natural alternative within this type of façade, they are living skins, changing and reacting naturally to surrounding stimuli.

Within current practice, living skins belong to one of two major categories: those attached to an opaque wall – opaque green façades; and those associated to a transparent wall – transparent green façades. These, in turn, split into five subcategories: greenery climbing through an opaque wall, greenery attached to an opaque wall as a green tapestry, greenery composed of green vertical panels, greenery between two transparent layers and greenery in the external layer and a transparent wall as the internal layer.

Table 1 Types of green façades

	Types of Green Façade	
1 OPAQUE		Greenery climbing through an opaque wall
		Greenery attached to an opaque wall as a green tapestry
		Greenery composed of green vertical panels
2 TRANSPARENT		Greenery between two transparent layers
		Greenery in the external layer and a transparent wall as the internal layer

This analysis detects some preliminary missed opportunitites in green façades, suggesting the need for a deeper study on the opportunities behind green façades.

4. Green Façades Framework

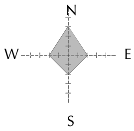
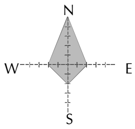
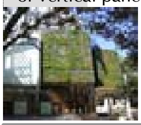
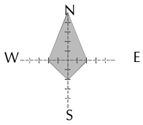
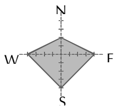
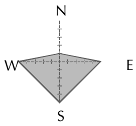
The research identifies six areas of opportunity for green façades: the improvement in *Human Comfort*; the exploration of their *Expressive Capacity;* the influence in *Air & Water Quality;* the enrichment of the *Indoor-Outdoor Relationship*; and the contributions to *Urban Biodiversity* and *Carbon Neutral Architecture*. The combination of the previous analysis – the types of green façades and a broader range of opportunities – lays the foundation for development of the Green Façades Framework.

In order to evaluate the appropriateness of different types of green façades, the framework builds on the available literature on the benefits of greenery to the built environment. Due to the limited literature specifically on green façades, the contribution of green façades to their surrounding environment is assumed to be similar to that of other green surfaces such as trees, grass, parks, or green roofs. Therefore, in analysing the influence of green façades to human comfort conditions, for example, the framework assumes green façades contribute significantly to the reduction of indoor air temperature in the summer by reducing the external air temperature of a west-facing orientation up to 4ºC on a clear August day in Japan; (Hoyano, 1988) and by 5ºC in South Africa (Holm, 1989). This cooling effect could reduce annual cooling energy use by 31%, while windbreak plantings around unprotected homes can reduce annual heating energy use by 15% (McPherson, Nowak et. al., 1993). According to computer simulations, in a warm climate such as Madrid, cooling energy use reduction could reach up to 45% and heating reduction up to 23% (Laurenz, 2005). According to research studies on green roofs, the energy required for space conditioning due to the heat flow through the roof would be reduced by more than 75% (Liu and Baskaran, 2003).

Studies on urban parks suggest that for every 100m2 of vegetation, air temperature is reduced by 1ºC, and that by increasing the ratio of green area to built area by 10% a 0.8ºC reduction is achieved (Dimoudi and Nicolopoulou, 2003). Similarly, Central Park in New York reduces its nearby temperature by 2-5ºC (Rosenzweig, Solecki & Slosberg, 2006), and Shinjuku Gyoen park in Tokyo reduces the urban heat island effect by 2ºC and decreases the temperature in adjacent areas within the range of 80-90m from the boundary. (Honjo, Narita, et. al., 2002). Vegetated courtyards reduce air temperature approximately 4-5ºC (Reynolds, 2002), and vegetated roofs reduce air temperature between 0.5-2ºC (The City of Toronto and Ryerson University, 2005).

The Green Facades Framework, based on these studies, extrapolates data as a series of charts to facilitate the understanding of green facades in relation to identified opportunities. In measuring existing types of green façades, the framework develops an evaluation process which consists of measuring the contribution of each type of green façade based on a scale of values that ranges from the lowest to highest contribution (0-1). This evaluation process proposes different point-scale values depending on the opportunity the framework is evaluating. In addition, some opportunities are more complex to evaluate than others, and requires including more factors in the evaluation process, such as the green façade orientation. This means, for instance, that when evaluating the potential of green façades to influence the comfort temperature and energy demand reduction, the framework proposes a five-point scale of values or percentages, which depends on the orientation of the façade. In this sense, an opaque green façade, where greenery is attached to an opaque wall, performs best with a northern orientation (1) due to the thermal insulation capacity required by north façades. However it does not perform too well for a south-east or western orientation (0.2), since it does not allow solar energy gains. On the contrary, transparent green facades perform best with a south east or western orientation (0.8-1) since they allow solar energy gain, while they perform poorly for a northern orientation, due to their weak insulation capacity. The evaluation of other aspects, such as the influence on acoustics, is much simpler. The framework, based on related studies, measures the green façades attached to opaque walls as contributing to outdoor noise reduction, while the transparent green façades do not contribute at all to this effect. The following Table 2 summarizes one of the charts developed by the framework which shows this evaluation process.

Table 2. Green Façades Framework measuring the contribution of different types of green façades to improve human comfort conditions

	Contribution of green façades to improve human comfort				
Greenery climbing on an opaque wall 	Comfort temperature & reduction in energy d. 	Acoustic Insulation	LOW 0 — HIGH 1	Humidity	LOW 0 — 0.5 — HIGH 1
		Visual Comfort		Psychological benefits	LOW 0 — 0.5 — HIGH 1
Greenery attached to an opaque wall 	Comfort temperature & reduction in energy d. 	Acoustic Insulation	LOW 0 — HIGH 1	Humidity	LOW 0 — 0.5 — HIGH 1
		Visual Comfort		Psychological benefits	LOW 0 — 0.5 — HIGH 1
Greenery composed of vertical panels 		Acoustic Insulation	LOW 0 — HIGH 1	Humidity	LOW 0 — 0.5 — HIGH 1
		Visual Comfort		Psychological benefits	LOW 0 — 0.5 — HIGH 1
Greenery between 2 transparent layers 		Acoustic Insulation		Humidity	LOW 0 — 0.5 — HIGH 1
		Visual Comfort	LOW 0 — HIGH 1	Psychological benefits	LOW 0 — 0.5 — HIGH 1
Greenery external transparent internal 	[illegible]re & [illegible] d. 	Acoustic Insulation		Humidity	LOW 0 — 0.5 — HIGH 1
		Visual Comfort	LOW 0 — HIGH 1	Psychological benefits	LOW 0 — 0.5 — HIGH 1

The evaluation of green facades against the six areas of opportunity reflects crucial differences between the two main categories of green façades –opaque and transparent. For example, transparent green façades are visible from both the outside and the inside, creating opportunities for green façades to enhance the indoor space. They perform much better than the opaque green façades in terms of indoor temperature, reduction in energy demand, indoor visual comfort and psychological benefits. On the contrary, opaque green façades can only partially achieve many of these opportunities, but they provide greater thermal insulation capacity. In addition, some of the attributes are only evaluated for opaque green walls, such as the acoustic influence, and others are only evaluated for transparent green façades, such as the influence on indoor visual comfort.

This framework enables the critique and evaluation of different types of green façades in terms of the extent to which they fulfil identified opportunities, which helps to determine their appropriateness to different conditions in an effort to improve the current practices for building green façades.

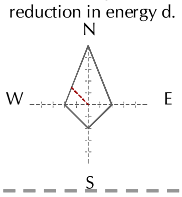
5. Application of the framework

The research applies the green façades framework to existing examples of green façades to evaluate their appropriateness to their particular conditions. Five case studies are selected, corresponding to the previously identified five main types of green façades. The case study selected for a green façade where greenery climbs through an opaque wall is the Rue des Suisses apartment complex designed by Herzog & de Meuron in Paris in 2000. The example selected for the greenery attached to an opaque wall is the Quai Branly Museum designed by Jean Nouvel in Paris in 2006. For a green façade composed of green vertical panels the selected case study is Seedorf House, designed by Manuel Perez in Madrid in 2004. For a green façade between two transparent layers the selected example is the Arts and Human Sciences building by Lacaton & Vassal in Grenoble, France, 1995-2001. Finally, the selected example for a green façade where the external layer is the greenery and the internal layer is the transparent wall is the Gymnastic Pavilion designed by Abalos and Herreros in Madrid in 2002.

By applying the framework to these existing examples, each can be evaluated and critiqued for their suitability within their given context. Table 3 shows an example of how each of the case studies has been evaluated by the framework.

Table 3. Evaluation of the Quai Branly Museum, greenery attached to an opaque wall

Project information	Quai Branly Museum, Paris	Greenery attached to an opaque wall as a green tapestry
Project Quai Branly Museum	**1. Human Comfort**	
Location Quai Branly Street, Paris	Comfort temperature & reduction in energy d. (compass diagram)	
Year 2006	Acoustic ...ation: LOW 0 – HIGH 1	Humidity: LOW 0 – 0.5 – HIGH 1
Architect Jean Nouvel	...l ...ort	Psychological benefits: LOW 0 – 0.5 – HIGH 1
Green Façade orientation North-west	**2. Expressive Capacity**	LOW 0 – HIGH 1
	3. Air and Water Quality	LOW 0 – 0.15 – 0.3 – 0.5 – 0.75 – HIGH 1
	4. Indoor-Outdoor Relationship	LOW 0 – 0.25 – 0.5 – 0.75 – HIGH 1
	5. Urban Biodiversity	LOW 0 – 0.25 – 0.5 – 0.75 – HIGH 1
	6. Carbon Neutral Architecture	LOW 0 – 0.5 – HIGH 1



These evaluations bring together the overall performance of the green façades based on each opportunity. The application of the framework reveals its usefulness and limitations in assessing how designers select and define more appropriate types of green façades for specific projects.

6. Living wall proposal

Subsequent to the case study evaluations, the research proposes two new living wall systems, constructed in collaboration with a local company, MUBI [www.mubi.ca] in order to find local materials to be included in the prototypes. Both an opaque living wall and a transparent living wall are presented.

The first prototype, an opaque living wall, is currently built and installed for monitoring purposes. In order to make it as thin, light, and simple as possible the opaque living wall panel is composed of the following four main layers:

- Moisture and root barrier layer
- Mineral wall which is a rock wool layer
- Felt layer
- Plants which will be inserted in previous layer

These layers form a sandwich in which an irrigation system is embedded. Plants are introduced into the panel through holes in the felt layer, which act as pockets for the vegetation. This provides freedom to select diverse plant species to create an exuberant green wall [Fig 3]. The panel is attached to opaque walls through metallic fasteners.

Figure 3 The design of the two opaque Living wals recently built in Vancouverl

The opaque living wall prototype is based on hydroponics plants, where the nutrients required by plants are introduced within the water of the irrigation system. The prototype living wall will be installed in a test room and monitored in order to achieve more accurate data on its environmental behaviour.

7. Conclusion / Discussion

This research attempts to clarify the definition of appropriate living skins in response to an identified absence of design criteria for the increasing applications of green facades around the world. It presents a larger range of opportunities than those typically considered by designers and forwards the following conclusions:

- **Types of green façades**. The research provides a relevant classification of living skins based on two main categories: opaque and transparent living skins. This classification has been developed by analysing the current practices for building living skins, studying a series of existing examples, and identifying their construction systems.
- **Decisive attributes in green façades**. The research provides a larger spectrum of opportunities to be considered when determining living wall systems. From the all opportunities analyzed, the research focuses on the opportunity to enhance human comfort, specifically in terms of temperature and reduction in energy demand. This is mainly because this opportunity's relationship to passive architecture, in terms of different façade orientations and options for taking advantage of solar energy. At present, the greatest amount of available research and data relates to the influence of vegetation on human comfort conditions.

The research proposes a framework which combines these two findings, one extracted from the current practices of green façades and the other extracted from related research. This enables the evaluation of each type of green façade for particular projects. This is indeed the most relevant contribution of this research: to provide an understanding of why a particular type of living skin, such as opaque, performs better in a north orientation, while other types of living skins, such as transparent façades, function better for south, east and west orientations.

The framework also reveals clear differences between the behaviour of the two main categories: opaque and transparent green façades. It shows that opaque green façades can only partially meet many of the identified attributes. This is mainly due to the fact that opaque green façades only affect one side of the façade, the outside; while transparent green façades affect both the inside and the outside. It also reflects the deficiencies in current practice, namely the enrichment of the indoor and outdoor relationship and the contribution to air and water quality. None of the existing green façades has incorporated any flexible systems nor has the option of retaining rain water or treating grey water been considered.

The research combines the current practice of green façades with current research on green façades, two fields that appear to be limited in their interactions. Current practice seems to be more concerned with exploring the expressive capacity while research seems to be more concerned on exploring the influence on human comfort. This project, by combining both and evaluating them, intends to provide a deeper study of green façades in order to improve their present status. The research proposes living wall systems for each of the two major categories, opaque and transparent. Ongoing will monitor these proposed systems in order to test their behaviour, contrast them with related research, and discover whether the identified opportunities are fulfilled.

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UNFIRED INDUSTRIAL LOAM BRICK BUILDINGS WITH PASSIVE HOUSE STANDARD

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Keywords: Unfired industrial produced loam bricks; Passive House Standard; Pilot building projects

Summary

The target of the Austrian research project LEHM.konkret was to develop a sustainable building solution that takes all three dimensions of sustainability into account. Besides environmental aspects such as the recyclability, energy efficiency in production and use phase of the building, aspects of social sustainability like health and comfort as well as the achievability of the building solution have been considered. By joining forces, partners of industry, science and building practice developed a solution for the Passive House Standard based on unfired, industrially produced and ecologically optimized loam bricks.

Within the research project, two building prototypes were realized with unfired loam bricks: two-storey family houses with the Passive House Standard. One of the challenging steps was to implement a sufficient load bearing use of the unfired loam bricks, which would allow a realization of passive houses with nearly 100 % unfired loam brick walls. The projects were completed in summer 2006. The evaluation results regarding the practicability of the scientific solutions were documented and first experiences of the house owners were collected.

The current challenge is the realization of building projects of a larger scale like the residential house “Orasteig” with 170 apartments, where parts of the project will be constructed with the newly developed building solution.

1 Introduction

The urgent demand for energy efficiency in the building sector is realized by a constantly growing group of stakeholders and policies. Consequently, this energy efficiency includes the improvement of the energy use during the production of the building products as well as the energy use of the building during its use phase. The Passive House Standard is one answer to this requirement regarding the energy efficiency of the building sector.

The traditional and natural building material, unfired loam, with its positive influence on health and comfort, as well as its ecological properties has been rediscovered by many stakeholders. Its excellent life cycle performance due to the low energy consumption during production also has a very positive influence on the life cycle assessment of the concerned building elements. The interest is increasing constantly. Unfortunately, loam constructions in general have been driven out of the industrial building sector and at the moment there are no building systems for industrial loam constructions available on the market. The market is restricted to some small providers of loam products, primarily loam plaster.

The main idea within the project LEHM.konkret was to combine the advantages of the passive house solution with the advantages of the traditional building material, unfired loam. The industrialized production of the traditional building material, unfired loam brick, served the purpose to provide the comfort and safety-guarantee of an industrially produced product.

Within the research project, an unfired and industrial produced loam brick was developed and improved to a satisfying level of quality.

Based on the performance of the newly developed unfired industrially produced loam brick, necessary construction details were developed in order to reach the Passive House Standard as well as consider the special properties of the unfired loam brick.

The most important step was the demonstration of the research results within two building projects. The realization of two building prototypes offered an excellent opportunity to evaluate the practicability of the newly developed construction details and building solutions. The results of the two projects partly confirmed the theoretically developed solutions but also answered some open questions.

2 The Research Project

2.1 Previous Scientific Steps before Realization of the Pilot Building Projects

In order to reach the final target of the research project several new technical solutions had to be found; starting with the optimized performance of the unfired loam brick, and ending with the solutions for the execution procedures and the construction details for the building.

2.1.1 Optimization of the Building Product "Unfired Industrial Loam Brick"

The first step was the improvement of the unfired, industrially produced loam brick that can be used for load bearing masonry in two storey houses, under consideration of some static parameters. Based on an analysis of a conventional unfired loam brick, the main target here was the revision of the material mixture, the brick geometries and the format. The development has been executed with focus on the advanced development of the following properties:

- Compressive strength
- Bending tensile strength
- Thermal capability
- Sound insulation
- Drying properties
- Processing performance
- Ecology, health and hygiene of material mixture

Figure 1: Several tests regarding the strength properties of the unfired loam brick walls have been done

2.1.2 Solutions for Building Execution, Construction Details

Essential for a successful execution of unfired loam constructions is the durable protection against water and intense, long-term moisture during the construction and the use of the building. Different parts of the unfired loam brick walls need a particular treatment during the execution. The research focused on simple solutions that are achievable, effective and allow an efficient integration within the framework of a construction site's conventional operation routine.

The limits, special properties and necessities of the unfired loam brick, which have to be considered, were identified by test results. Of course, the requirements for Passive House Standard, including air tightness, heavy windows and doors, as well as excellent heat insulation and particular HVAC equipment were taken into consideration by the project group. The most challenging and important part of the research activities was the creation of construction details that met, and are meeting the requirements for Passive House Standard under consideration of the limits and special necessities of the unfired loam bricks.

As the intention was to construct buildings with an excellent performance regarding health and comfort, another research target was to define wall systems and indoor materials which respond to the high level of the purely natural building, material unfired loam.

2.1.3 Static Calculations

In its current evolution the unfired loam brick does not have the same strength as fired brick. With static calculations, the limits and possibilities of the load-bearing, unfired loam brick walls were appointed. Recommendations for the building structure have been set and considered during the planning and realization of the pilot building projects.

3 The Pilot Building Projects

3.1 Function and Basic Data of the Pilot Building Projects

The following two pilot building projects that have been realized within the research project are:

3.1.1 Detached Family Home

The two storey house with 118,79 m² living space and 13 kWh/(m²a) was realized with 20 cm load bearing, unfired loam brick walls, 30 cm of mineral wool for the outer walls and 12 cm inner walls of unfired loam bricks. The outer walls have a U value of 0,12 W/m²K.

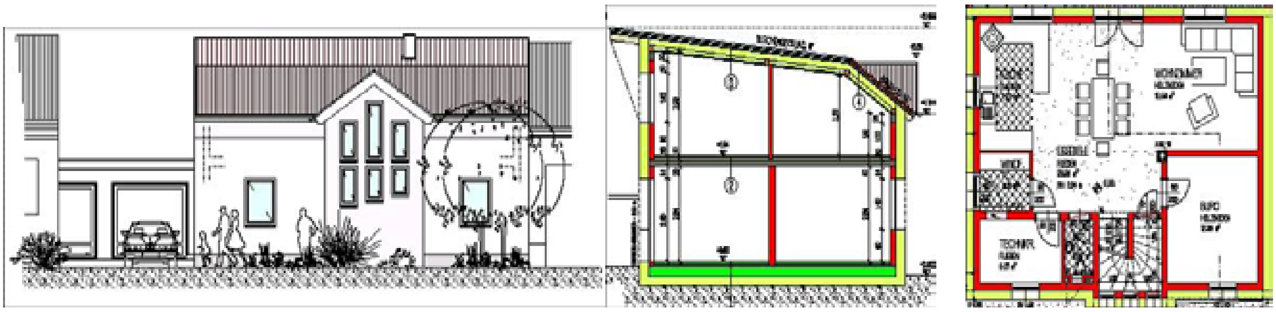

Figure 2: Construction plans for the detached family home. All red marked walls are unfired loam brick walls.

3.1.2 Organic Farm with Integrated Guest Rooms

The house for a farmer and his family with a 290 m² living space is also divided into two stories. The family wanted to provide guests with the opportunity to experience the excellent indoor air quality in rooms which are built only with natural building products. For this reason, two additional guest rooms available for renting are integrated into the project.

4 Construction and Experience

Within both projects many different trial experiences have been collected. In the following section the main conclusions are summarized.

4.1 Protection against Water and Long-Term Moisture

Currently, the unfired loam bricks do not have the same water resistance as fired bricks. They must receive a durable protection against water and long-term moisture during the construction as well as use phase of the building. The unfired bricks were delivered on conventional palettes, which were properly covered to avoid water inside the packages.

4.1.1 The Basis / First layers

During the construction period, the floors can become flooded by melting snow or rain. During the use phase of the building the flooding can occur due to an overflowing bath tub or faulty washing machine. Any contact between the base of the unfired loam brick walls and water on the indoor floors has to be avoided. To guarantee the protection of the wall base, the first one to two layers of the walls have been constructed with fired (water resistant) bricks. Furthermore, the water was lead off in a controlled way, which was ensured within the slope in the floors and water pipes at the lowest point.

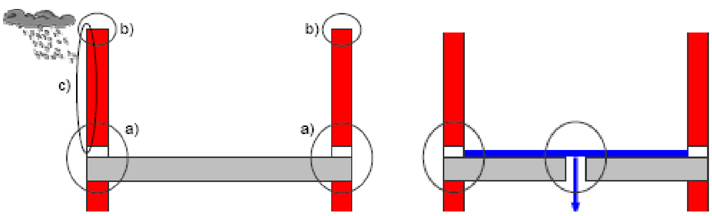

Figure 3: Certain parts of the unfired loam brick walls need durable protection against water and long-term moisture during the construction as well as use phase of the building.

4.1.2 The Top / Final Layer

As the unfired loam bricks have a perforation for technical reasons, it is important to make sure that no rain or snow gets inside the perforation during the construction of the walls. For this reason, during the construction phase, the top layers were covered with a waterproof material that was easily removable.

The supports of the concrete floors got a waterproof leveling course (bituminized felt on a leveling concrete course) which prevents great amounts of water, affected by the concrete flooring, inside the perforation of the top layers.

During the construction phase of the walls, the layer for the sills was covered.

4.1.3 The Wall Surface

During a long lasting rain period, the side of the unfired loam brick walls that were most affected by weather was protected with a waterproof cover. Limited contact of the wall surface with water by rain- or snowfall during the construction period or by water splashed by the user during any other time does not have any significant negative influence on the walls.

4.1.4 Inside the Walls

For the wall parts with water pipes inside, it is recommended to construct those areas with fired bricks or to furnish them with a waterproof sealing coat.

Figure 4: The first two layers were constructed with fired loam bricks. The last layer under the sills and top layers of the walls have been covered with a waterproof material to prevent water inside the brick perforation.

4.2 Attachment of Heavy Doors and Windows with Passive House Standard

The windows and doors with Passive House Standard usually are heavier than conventional windows and doors. An airtight fixing of those kinds of windows and doors was achieved by a leveling concrete course around the wall opening. The heavy windows and doors were only fixed at the fired lintel element (top) and at the concreted sill (bottom). The bearing length of the lintels always had a minimum length of 25 cm inside the wall. The side parts only have been attached with spacer screws (7,5 x 152 mm, each 80 cm). One third of the window frame was positioned to the inside part the insulation level.

Tests with a certain glue and insulation foil confirmed that the insulation foil for airtight connections has the same adhesion quality on unfired loam bricks as on conventional fired bricks.

Figure 5: Fired lintel element, leveling concrete course around wall opening and airtight connection of windows and doors for Passive House Standard.

4.3 Static Strengths and Limits

The specific properties of the unfired loam brick wall regarding strength (f_k = 2,0 N/mm²) and mechanical resistance require for some considerations during the planning and construction phase of the building. For both pilot projects, static calculations have been done to appoint the peak loads and to guarantee the structural resistance of the buildings.

4.3.1 Point Loads

In general, point loads should be avoided. If this is not possible, additional support for point loads could be, for example, integrated columns inside the unfired loam bricks.

4.3.2 Support of Ceilings

Experience regarding peak loads in ceiling supports showed that the particular ceiling, constructed from prefabricated element, affects a high linear distributed load on the inner side of the top brick layer. An optimized load distribution was reached due to a levelling course of concrete on top of walls, which provides an even surface and a solid connection between walls and ceiling. Ecological concrete solutions are already possible with new concrete products without cement. The consideration of the maximum span between the load bearing walls is very important.

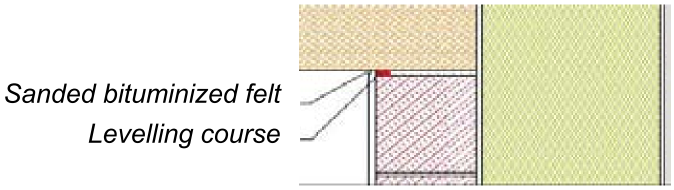

Figure 6: Optimized distribution of the high linear distributed load, affected by the ceiling.

4.3.3 Installation Lines in the Walls

Regarding electrical installations and other works on the wall, horizontal electrical installation lines have been avoided. Exceptions have a maximum depth of 10 % of the wall thickness. Water pipes are mainly led into the floor.

Figure 7: Water pipes are mainly led into the floor. Installation lines in the unfired loam brick walls are not a problem.

4.4 Indoor Air Quality

The inner surface of the walls has the highest influence on the indoor air quality and thereby on the health and comfort of the inhabitants. To make sure that the positive influence of the unfired loam brick walls on the indoor air quality is continued with a plaster material that has the same properties, loam plaster was used for the inner sides of the walls.

It is recommended to do the plasterwork during the months where there is a minimum of 5 °C outside temperature to guarantee conditions for fast drying of the loam plaster. Due to a very tight time schedule on one of the building projects the plasterwork of the family house was done during winter time. Resulting from the low temperature on the outer walls as a result of the very low temperature outside and the air tightness of the building, the ventilation system was used during the drying process to avoid cracks in the loam plaster. When the drying process was finished, and before the inhabitants moved into the house, the filter of the ventilation system was changed.

Figure 8: The loam plaster was executed with two layers and a reinforcement fleece in the first layer to ensure a good adhesion on fired as well as unfired loam bricks. The sorption capacity of the loam has a positive influence on the humidity of the rooms.

4.5 User Experience

Figure 9: Regarding operation costs, indoor temperature, indoor air humidity, the feed-back of the house owners was very positive. A challenging experience was to affix heavy weight onto the walls.

4.5.1 Operation Costs

In general the feedback of the house owners was very positive. The energy consumption responds to the expectations on a Passive House Standard (€ 200, - per year for heating and warm water). During the winter period the house owners of the detached family home had a usage of 15 kg of wood-pellets per week.

4.5.2 Indoor Temperature

The buildings are cold during the summer and warm during the winter season. During the first year the detached family home had no window coverings as protection against the sun. Even considering this circumstance, a slow increase in indoor-temperature was realizable, which started with an outside-temperature of 29 °C.

4.5.3 Indoor air humidity

Regarding the balance of the indoor air humidity, the inhabitants confirmed an observation, which is mentioned very often in connection with unfired loam constructions: due to the excellent sorption ability of the unfired loam, the mirror in the bathroom does not steam up, even after a long hot shower.

The inhabitants also made an interesting observation during winter: the influence of the sorption capacity and, by this, the balance of the indoor air humidity is, of course, limited by available humidity in general, inside or around the building. During the cold season, outside air becomes very dry, having a big impact also on the quality of the indoor air. Another very desirable aspect of the unfired loam is that it can keep a balance in terms of indoor-air humidity, which is providing a very pleasant indoor climate. But of course the unfired loam cannot “create” humidity when there is no moisture available.

4.5.4 Resistance of walls

Up until now, nearly two years after the finalization of the building projects, no cracks have been found in the unfired loam brick walls.

One criticism was the low resistance regarding dowel extraction. This problem was solved with injection dowels at certain spots bearing high loads on the walls. Lower loads were hung using long screws.

5 Current Challenge

Within the next months a large residential project incorporating 170 apartments will be built in Vienna. The cost efficient and government subsidised project won first place in the housing competition and foresees a big variability in floor plans and sizes. Within the project, sustainability in construction works goes hand in hand with high level architectural urban planning.

The building demonstrates excellent technical and ecological performance with an advanced energy standard, and the use of ecological building materials like, for example, unfired loam bricks. The upper two of the four stories will be constructed with unfired loam brick walls. Several feasibility studies have been conducted, and a static calculation has approved the intention.

Figure 10: The results of the research project LEHM.konkret and the experiences due to the pilot building projects will be important for the realization of a large-scale project like “Orasteig” with its requirements regarding the operation routine.

6 Conclusion

The traditional building material, unfired loam, in combination with the well developed and highly sophisticated technology of the Passive House Standard, provides a perfect example for sustainability in construction works.

The unfired loam shows an excellent performance regarding:

- Minimised CO2-emission and minimised emissions of SOx, NOx, OrgC, HF
- Low energy consumption in production
- Recyclability
- Thermal capability due to high mass
- Acoustic protection due to high mass
- Indoor air quality by humidity sorption
- Protection against electromagnetic fields
- Fire safety

During the execution of the walls with unfired loam bricks, the main experiences have been that the processing is very similar to fired bricks. For this reason the efficient training of building labourers is no problem at all. A fast execution was realised with a mortar carriage and the tongue and groove system was experienced as very practicable due to the similarity with conventional brick constructions.

In general, the current result is very satisfying, but for the successful planning and execution of an unfired loam brick building with Passive House Standard, the consideration of certain requirements are needed.

Each unfired loam material mixture has a different properties; some have necessary properties for being a construction material, others not. Nevertheless, there is still a real need for further research activities, especially regarding the compressive strength and the water resistance of the unfired loam brick. Due to the special sorption ability, the air humidity has a very big influence on the strength performance of the unfired loam brick. Also the significant shrinking and swelling of certain loam material mixtures has to be reduced. An improvement regarding those properties is absolutely necessary, and potential for improvement is foreseen.

Standardisation criteria still do not exist apart from some German recommendations of the last century. A harmonised standard will be important for the marketability of this building system.

Also specific training tools for architects and labourers would be very important to maximise the marketability of the building solution.

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protec NET plus, Österreichische Forschungsförderungsgesellschaft mbH; subsidization of the project LEHM.konkret.

Macho Karl Bmst.Ing., AUST-BAU GmbH; construction plans for pilot building projects, construction supervision and execution of construction work.

Raum und Kommunikation; project management and project developer of “Orasteig”.

THERMAL BEHAVIOUR OF A WALL-LINING CONTAINING PHASE CHANGE MATERIALS

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Summary

In temperate climates like UK, buildings constructed with high thermal mass materials have the intrinsic capacity to alleviate the effect of overheating in the summer. Phase change materials (PCMs), which have a high latent heat capacity to volume ratio is a potential effective means to improve the thermal capacity of light-weight or existing buildings. The feasibility of applying PCMs in buildings was investigated through a research and development collaboration between University of Brighton and OMNOVA Wallcoverings (UK) Ltd. The aim was to develop a PCM wall-lining which can reduce energy consumption of buildings, by minimising the use of air-conditioning, and improve the thermal comfort during periods of extreme climate conditions.

This paper reports on the measured experimental findings of the thermal performance of a prototype phase change wall-lining developed and manufactured. Samples of the prototypes were tested using Differential Scanning Calorimeter (DSC) in the laboratory which provided evidence of the projected and actual sensible-latent heat transfer behaviour of the micro-encapsulated PCM. In order to evaluate the thermal performance in actual installed conditions, the prototype wall-linings were subject to a regime of cyclic environmental conditions in a 13.8m^3 chamber. The results were compared with a control chamber that was subject to the same conditions but without the phase change wall-lining. The experiments provided measured data on the effect of different supply air conditions to the charging and discharging behaviour of the wall-lining, the amount of energy stored and the moderation of peak temperatures. These experimental results enabled the evaluation of the effectiveness of the latent heat storage by the PCMs within the wall-lining and are analysed and discussed.

1. Introduction

Research collaboration between University of Brighton and OMNOVA Wallcoverings (UK) Ltd has resulted in a project to develop a thermally interactive wall-lining, utilising OMNOVA's manufacturing technology, that can improve the thermal storage capacity of buildings, reduce overheating and reduce demand for conventional cooling systems. This has been realised by the inclusion of phase change materials in wall-linings.

Phase Change Materials (PCMs) are materials that not only absorb sensible heat as the temperature increases but also absorb latent heat when melting and release the stored heat when freezing, both at an almost constant temperature. PCMs can be used in buildings to significantly improve the thermal mass as they have a much greater ability to store heat than conventional building materials such as concrete. Concrete has a sensible heat storage capacity of 1.0 kJ/kgK, whereas an inorganic phase change material such as calcium chloride hexahydrate can store up to 193 kJ/kg during phase transition. PCMs are able to reduce peak temperatures in buildings by absorbing excess heat during the day and releasing the heat at night when the surrounding temperature is cooler. The storage and release of excess heat results in a narrower temperature band over a diurnal period therefore improves thermal comfort for the occupants.

A significant development in phase change technology is the ability to microencapsulate PCMs. Microencapsulation is the packaging of micron-sized materials (both liquids and solids) in the form of capsules, ranging from less than 1μm to more than 300μm. Microencapsulated PCMs can be used to introduce high thermal storage capacity into conventional building materials. Examples of research developments using microencapsulated PCMs include gypsum plaster (Schossig et al., 2004), concrete (Cabeza et al., 2004), and wallboard (Hummel, 2004); (Khudhair et al., 2003).

An advantage of using a wall-lining containing phase change materials is its direct exposure to heat exchange within the room. Other PCM materials are located deep within the construction of a wall or ceiling and would have less effective heat transfer.

2. Phase Change Wall-lining Development

Initial investigations to incorporate microencapsulated phase change materials into a vinyl wall-lining were successful using microencapsulated phase change materials supplied by BASF. This preliminary phase change wall-lining was tested and the results showed it successfully slowed the temperature rise and reduced peak room temperatures, as reported at SB05 (Dyball, 2005).

To progress the development of a phase change wall-lining to a prototype stage it was desirable to increase the thermal storage capacity of the wall-lining. Outlast Technologies Inc, specialists in the research of phase change materials, was approached to develop microencapsulated phase change materials specially formulated for inclusion in a vinyl wall-lining.

Outlast supplied a range of their microencapsulated PCMs, known as Thermocules®, with different particle sizes for joint development work. Analysis of the Thermocules® determined the larger the particle size the larger the heat storage capacity. Extensive experiments were undertaken to develop a plastisol formulation containing the highest possible loading of the largest Outlast Thermocules, referred to as XXL(2). The resulting formulation was coated out and cured and a vinyl wall-lining containing 46% by weight of microencapsulated phase change materials was produced.

Differential Scanning Calorimeter (DSC) analysis of the lab prepared phase change wall-lining revealed the phase transition temperature has shifted from 24°C phase change temperature of XXL(2) Thermocules) to 23°C. This raised concern that the shell of the Thermocules may have ruptured during processing and the wax core contaminated. If the wax core was contaminated it is likely that after thermal cycling (repeated heat then cool cycles) each phase transition would show a different profile in the DSC graph as the phase change material would be unable to perform in the same manner as the wax composition would have changed. The results, illustrated in Figure 1 showed that repeated heating and cooling of the phase change wall-lining did not affect the phase transition temperatures. The shape of all the peaks remained the same after 22 cycles confirming the Thermocules performance had not been compromised and they were robust enough to withstand the manufacturing process.

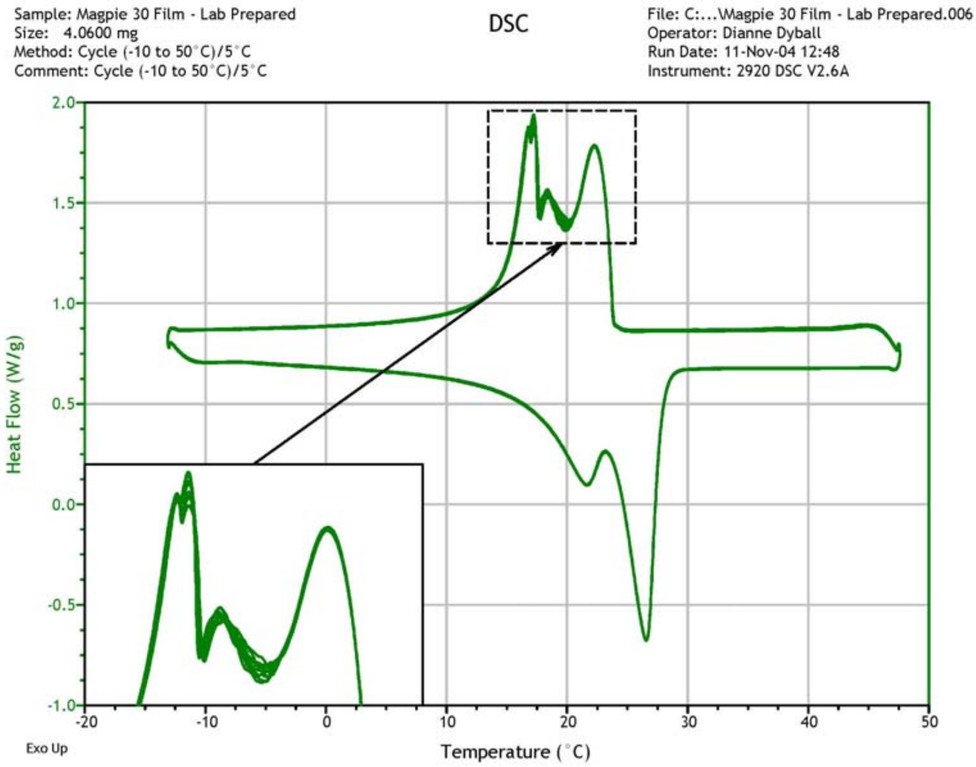

Figure 1 Results of thermal cycling lab prepared phase change wall-lining

A successful pilot scale trial was undertaken and manufactured 50m of 700mm wide, 6mm thick phase change wall-lining. The wall-lining contained 45% by weight of Outlast XXL(2) Thermocules. The thermal performance of the trialled manufactured phase change wall-lining was thermally analysed and the results are shown in figure 2. The DSC results of the manufactured phase change wall-lining show the phase transition temperature is 23°C and the latent heat storage capacity is 87 J/g. This latent heat capacity equates to 503 kJ/m^2.

The graph also includes the DSC results of the Outlast XXL(2) Thermocules used in the phase change wall-lining. This makes it easy to identify any change in the peak profiles and highlight any problems that may have occurred to the microcapsules during manufacture. From the graph in Figure 2 it is clear the melt point has shifted from 24°C to 23°C as occurred in the lab prepared sample. As this is consistent with the inclusion of XXL(2) into vinyl wall-linings there is no need for concern. There is no other significant change to the profiling of the Thermocules within the phase change wall-lining therefore the inclusion was a success.

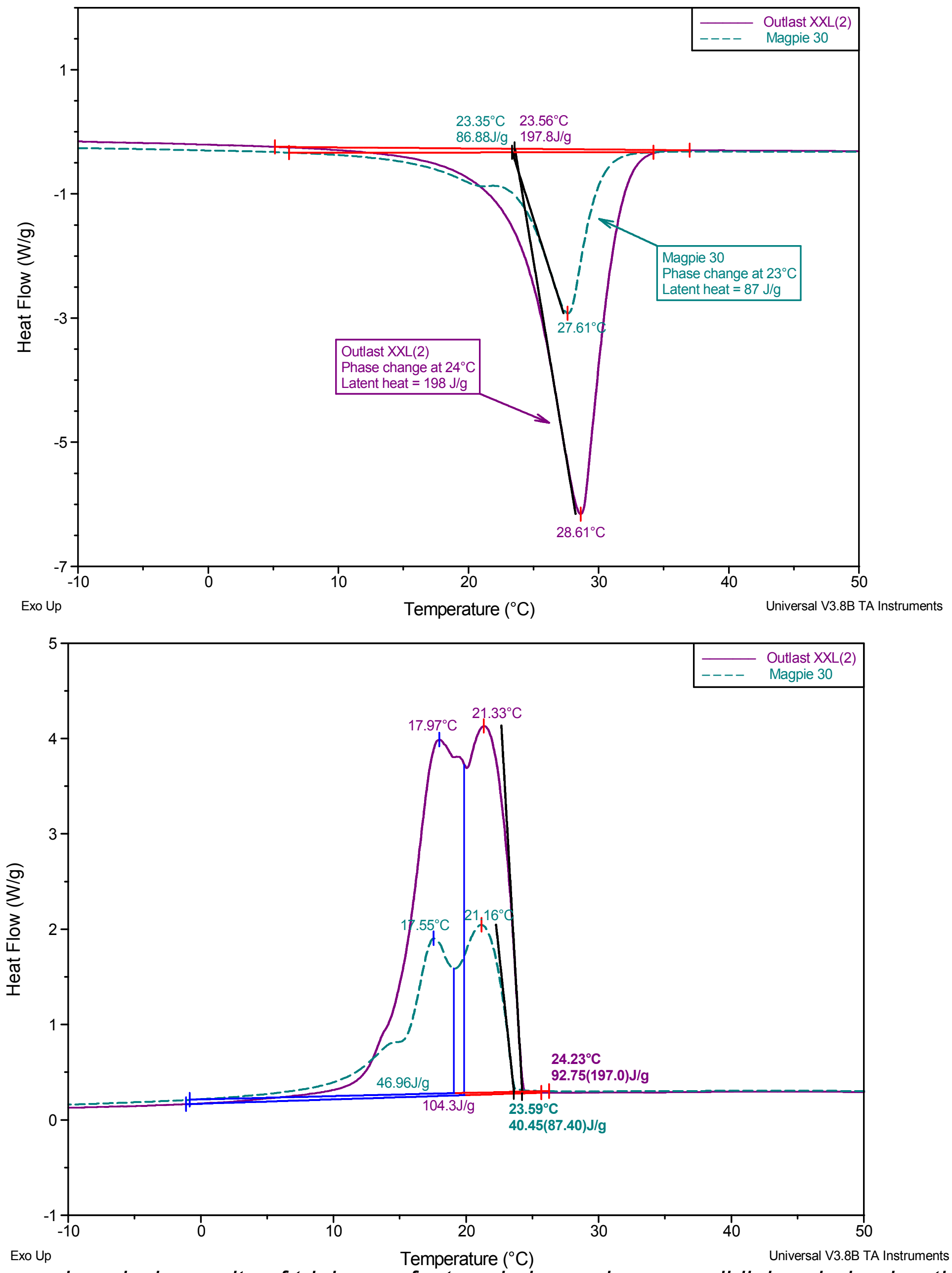

Figure 2 Thermal analysis results of trial manufactured phase change wall-lining during heating cycle (upper) and cooling cycle (lower)

The prototype phase change wall-lining was tested by Gearing Scientific Ltd to determine the conductivity value. The thermal conductivity value of a material is important as it is a measure of the rate at which heat can pass through a material.

The phase change wall-lining was tested using a LaserComp Fox 200 thermal conductivity instrument which conforms to ISO 8301. The tests were conducted at temperature intervals from 20°C to 30°C to ensure before, during and after phase changes were included. The results showed the thermal conductivity value of the prototype phase change wall-lining is 0.12 W/mK.

3.0 Experimental Setup and Measurements

To evaluate the thermal performance of the phase change wall-lining using realistic room conditions two environmental test chambers were proposed. To determine the variables that need to be considered a mathematical model was first developed. A one dimensional finite element heat transfer network through a chamber wall with phase change wall-lining and timber board was then established and simulated to predict the performance. The different elements to be considered for the heat transfer in a chamber with air supply and exhaust are illustrated in Figure 3. The proposed environmental chambers would be used to evaluate the thermal performance of the phase change wall-lining when subjected to different supply air conditions.

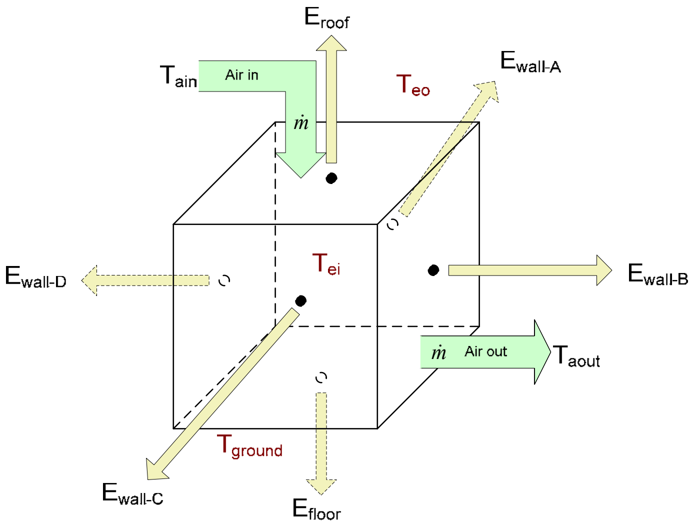

Figure 3 Heat transfer of Environmental Chamber

Two highly insulated, identical chambers, 13.8m^3, were constructed in an open laboratory space that has relatively stable thermal conditions at the University of Brighton, see Figure 4.

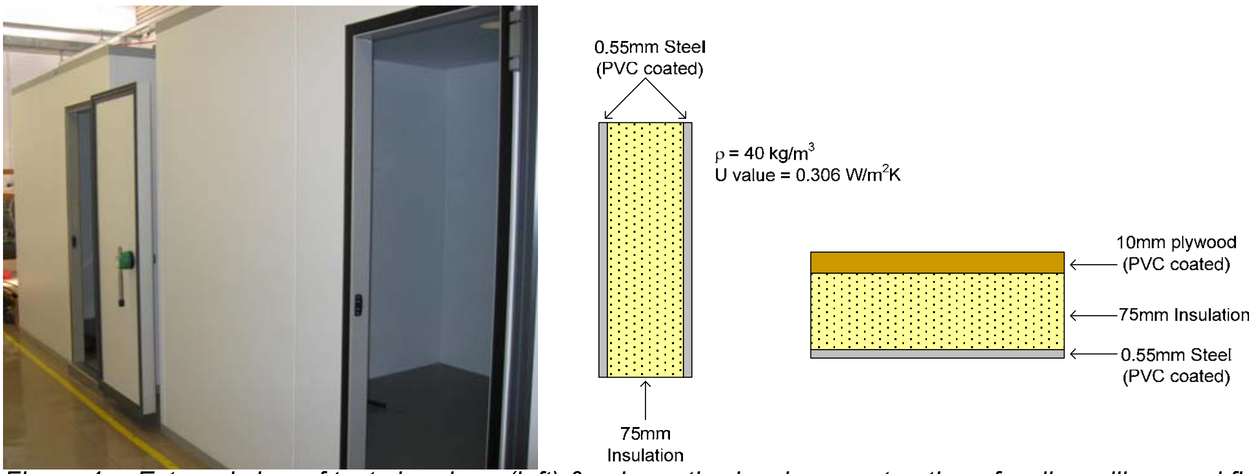

Figure 4 External view of test chambers (left) & schematic showing construction of walls, ceilings and floor (right)

The temperature and air flow inputs to the chambers are set by an Excel programme that operates the air-conditioning system via a programmable logic controller (PLC) in a control panel. The system can operate to provide supply air temperature between 15 - 30°C and air flow of 1.5 – 10 air changes per hour (ach).

The supply temperature is monitored by two air temperature probes, both located in the ductwork prior to air inlet as shown in Figure 5, which feeds back to the PLC and enables the program to adjust the amount of heating or cooling necessary to maintain the temperature set-point.

The test chambers were fitted with extensive surface, air and room temperature sensors which were all connected to a data logger for data acquisition at timed intervals.

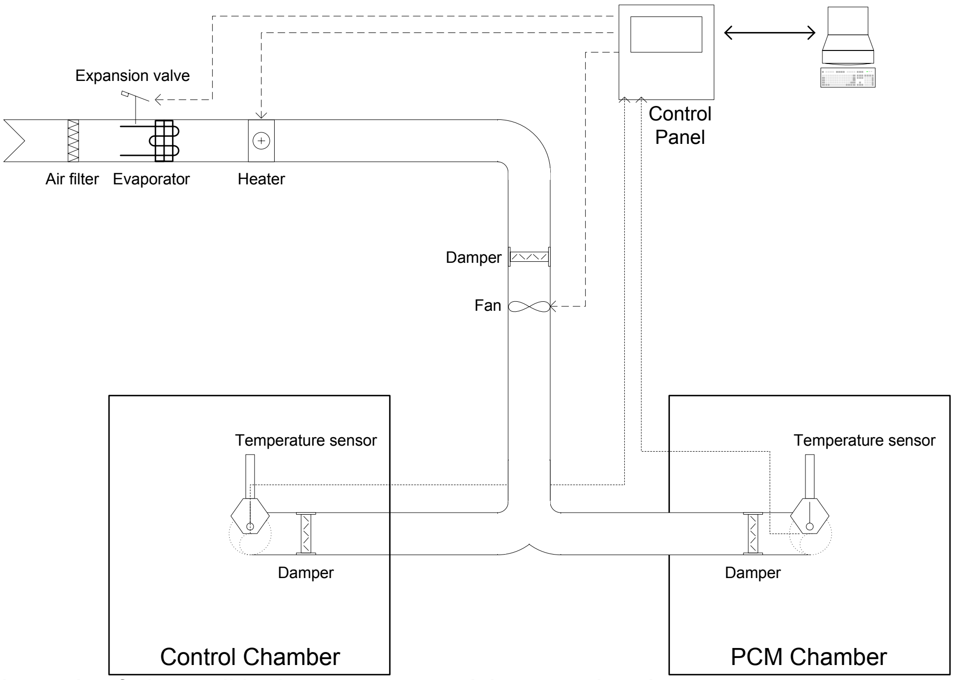

Figure 5 Schematic of air-conditioning system supplying test chambers

The test chambers were heated and subsequently cooled to a fixed temperature. Each experiment used a different air supply rate, which remained constant throughout the duration of the experiment. The experiment continued until steady state conditions were reached.

4.0 Results and Discussion

The aim of the experiments was to evaluate the effect of supply air conditions to the thermal behaviour and storage capability of the phase change wall-lining. Two sets of results are illustrated to demonstrate the charging and discharging behaviour. Figures 6 and 7 show the PCM charging process when air at 30°C was supplied whereas Figures 8 and 9 show the PCM discharging process when the air supply temperature was set at 15°C.

4.1 Heating cycle

The graphs have been divided into 'zones' to represent different stages of the heat transfer process. Figure 6 showing the heating cycle in the Control Chamber has been divided into Zones A, B and S. Zone A is the initial stage when warm air begins entering the chamber. The curve in Zone B shows the effect of sensible heat storage of the chamber walls, which is proportional to the rate of change of temperature. The steady state heat transfer occurs in Zone S where heat contributing to thermal storage gradually diminishes. The charging time (Zone B) is affected by the air change rates; the use of 9 ach reduced the charging time by nearly 50% in comparison with the 3 ach air flow rate.

In Figure 7, heating results for the PCM Chamber, an additional zone has been created. For the PCM Chamber Zone B exhibits the phase change characteristics of the wall-lining where the rate of air temperature increase is reduced in comparison with Figure 6. As the microencapsulated PCM is evenly distributed within the wall-lining, the thermal behaviour is similar to a wall with high thermal capacity that slows the change in temperature, in particular more evidently in the temperature region where phase change occurs. The phase change processes appear to occur mainly between the first 6 to 9 hours. A comparison of the time for the air temperatures to reach a reference temperature of 24°C for the experiments in each test chamber show significant difference from 100, 250 and 880 minutes to 230, 540 and 1740 minutes. Zone C exhibits the sensible heat transfer characteristics similar to Zone B of the Control Chamber (Figure 6) whilst Zone D shows the more gradual temperature rise, due to the additional thermal capacity of the phase change wall-lining, until steady state conditions are reached in Zone S.

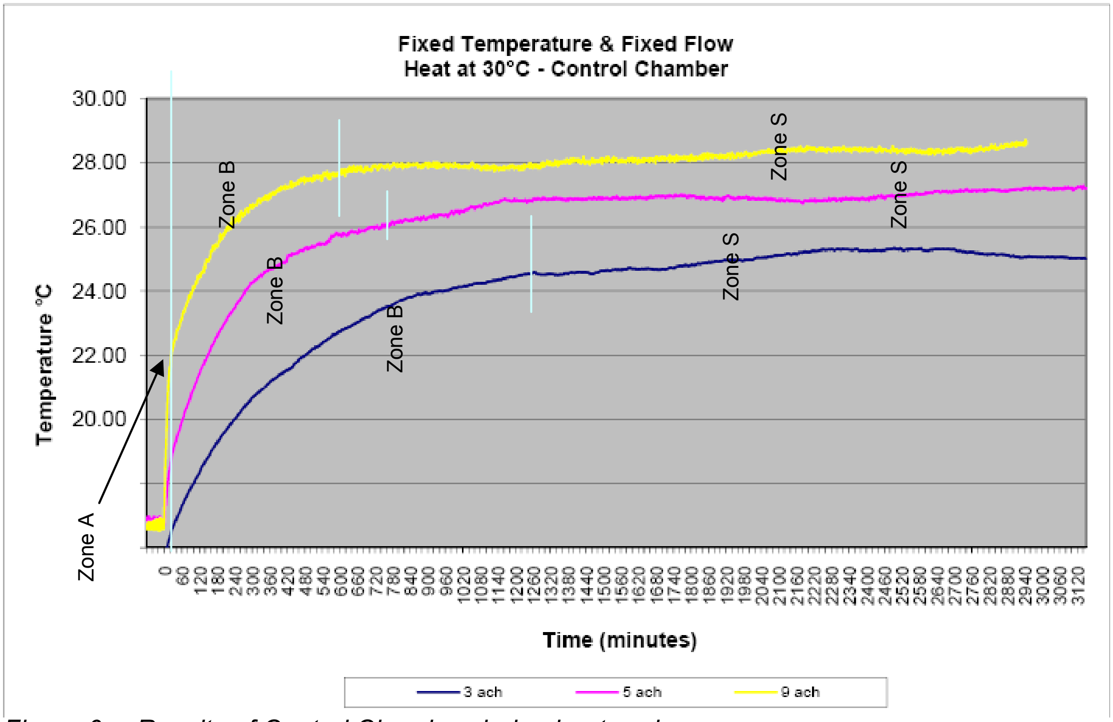

Figure 6 Results of Control Chamber during heat cycle

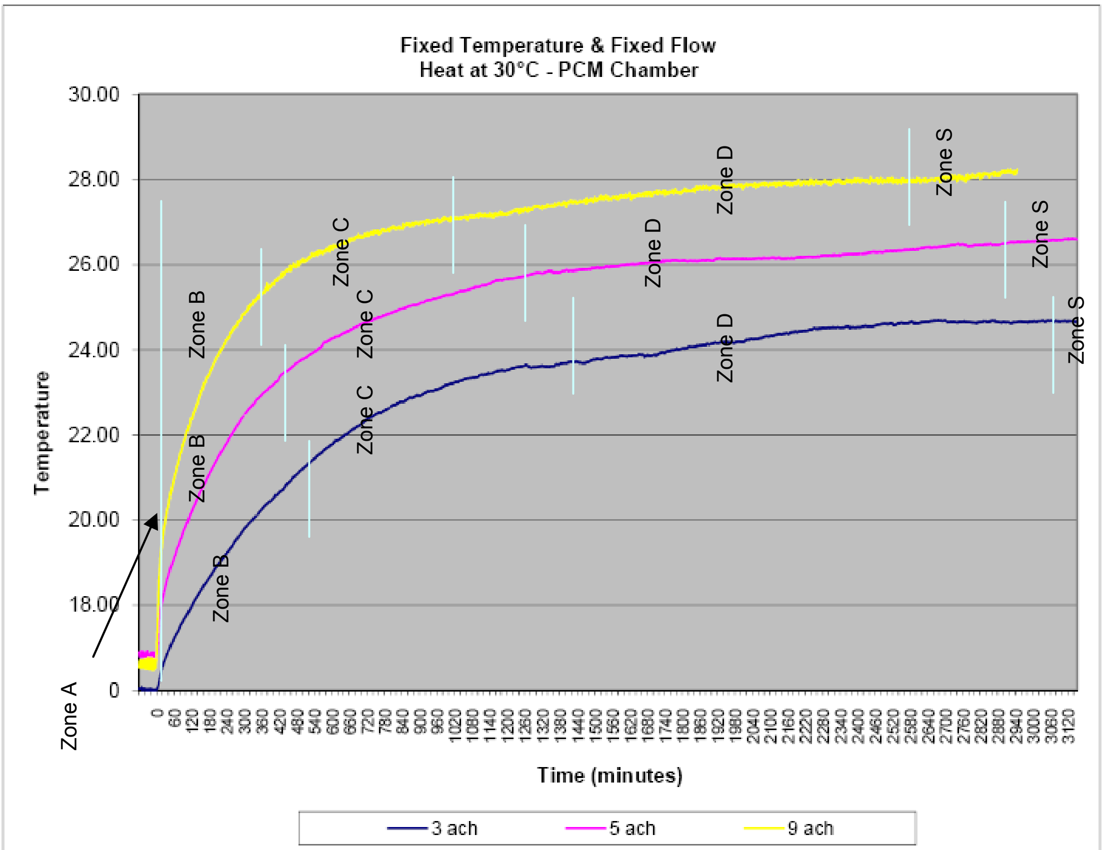

Figure 7 Results of PCM Chamber during heat cycle

4.2 Cooling cycle

For the cooling cycle where the supply air was maintained at 15°C for the three different air change rates in the test chambers the results have also been zoned using the same format as for the heating cycle results.

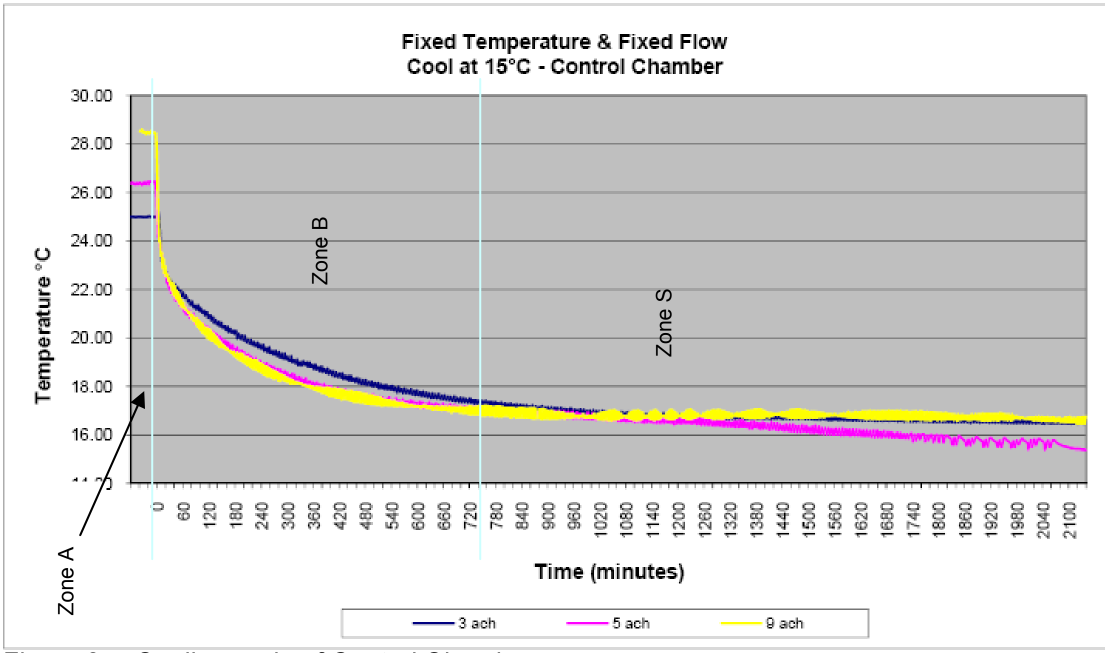

Figure 8 Cooling cycle of Control Chamber

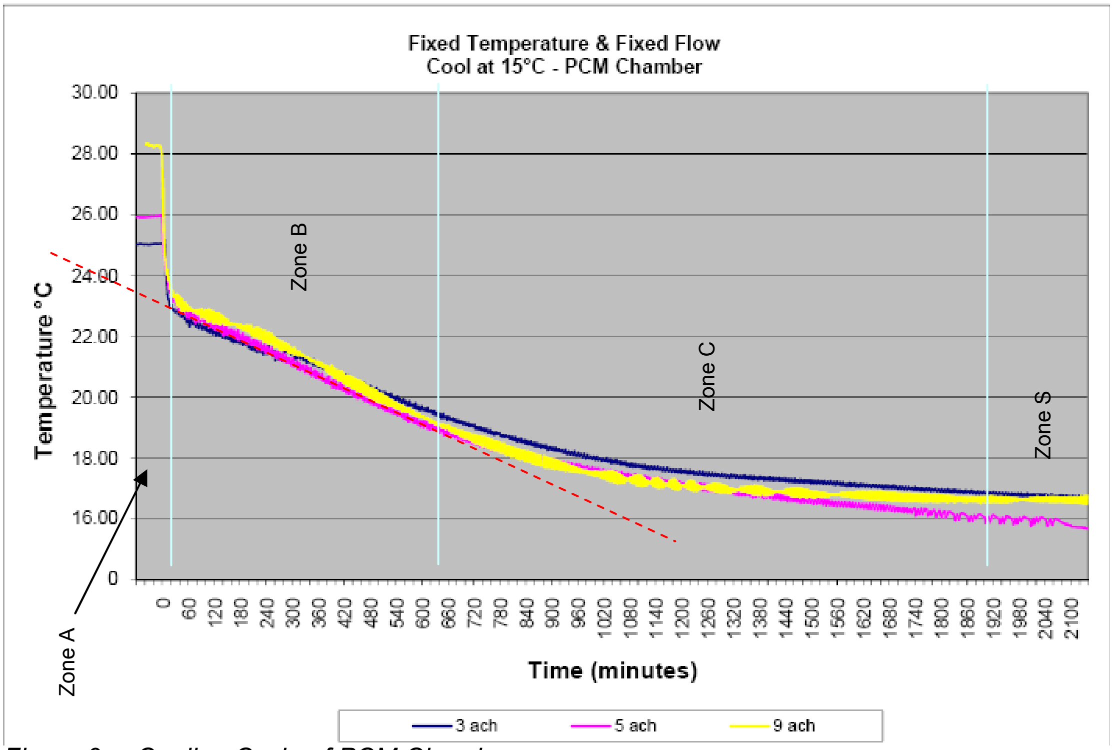

Figure 9 Cooling Cycle of PCM Chamber

The graphs for the cooling cycle in Figures 8 and 9 show the temperature variations are less distinctly separated than those in the heating cycle. This can be attributed not only to the relatively smaller temperature differences between supply air and the external air but also the supply air and the phase change temperatures when the experiments were performed.

Zone A in Figures 8 and 9 show the warm air of the chamber being replaced by the 15°C supply air. The temperature drops quickly as the thermal capacity of air is low. Zone B in the Control Chamber (Figure 8) exhibits the non-linear characteristics of the sensible heat transfer process, therefore illustrating the heat being removed by the chamber wall as the temperature drops. It took about 12 hours to reach steady state.

Zone B in Figure 9 exhibits a linear temperature profile of a constant rate of change of temperature. Such characteristic is in contrast to the results for Zone B of the Control Chamber. It illustrates the rate of change of temperature is maintained by the latent heat released from the PCM in the wall-lining. Zone C shows a non-linear reduction in temperature when most of the PCM in the phase change wall-lining has solidified and the sensible heat transfer process dominates. Zone S again represents the steady state conditions in the chambers.

As the supply air temperature is only 7°C below the phase change temperature, the air change rates do not appear to have significant effects on the temperature during the cooling cycles. This suggests the lower flow rate may be used to save fan energy.

5. Conclusions

This research investigates the potential of applying phase change materials contained within wall-linings to enhance the thermal capacity of buildings. The research has successfully developed and manufactured wall-lining prototypes containing micro-encapsulated phase change materials. The laboratory tests showed the PCM wall-lining has a latent heat capacity of 503 kJ/m^2 with a phase change temperature of 23°C. The dynamic thermal behaviour of the wall-lining as installed in a room has been evaluated using two identical environmental test chambers. Analysis of results for this part of the research is still on-going. Initial comparison of results between the PCM and Control Chambers provided information on the cyclic charging and discharging behaviour of the phase change wall-lining. Future work will focus on establishing the energy stored and detailed performance data to enable the prediction of the daily and seasonal thermal performance with the UK climate.

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ECOBUILDINGS: TOWARDS AN ENERGY-EFFICIENT EUROPEAN BUILDING STOCK BEYOND NATIONAL REQUIREMENTS

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Keywords: energy efficiency, Ecobuildings, retrofit, innovation, EU project, high performance, design guidelines, information tool

Summary

The building sector is at present responsible for more than 40 % of the EU energy consumption. The EU 6FP Ecobuildings concept is expected to be the meeting point of short-term development and demonstration in order to support legislative and regulatory measures for energy efficiency and enhanced use of renewable energy solutions within the building sector, which go beyond the Directive on the Energy Performance of Buildings. The projects aim at a new approach for the design, construction and operation of new and/or refurbished buildings, which is based on the best combination of the double approach: to reduce substantially and, if possible, to avoid the demand for heating, cooling and lighting and to supply the necessary heating, cooling and lighting in the most efficient way and based as much as possible on renewable energy sources and polygeneration.

The results of the four Ecobuildings projects BRITA in PuBs, SARA, DEMOHOUSE and ECO-CULTURE are presented in this paper and shall be discussed during the conference presentation. The main focus is on the BRITA in PuBs project with 8 demonstration buildings and additional project results such as retrofit design guidelines, an electronic database on retrofitting knowledge, a quality control toolbox and many more.

Figure 1 The Berlaymont Building in Brussels; head office of the European Commission. The building was energy retrofitted beyond national requirements – an Ecobuilding.

1. Introduction

Ecobuildings (European Commission, 2004) is an energy demonstration initiative of the European Commission (DG TREN) within the sixth Framework Programme. The definition of the Ecobuildings concept according to the Commission is given in the first paragraph of the abstract. The Ecobuildings projects focus mainly on demonstration but do include also minor parts on research and technical development and on training and dissemination.

Since Ecobuildings deal in comparison with Concerto, another EU Commission initiative, (European Commission, 2005) with single buildings, the concept can be applied at any building and in any country.

Concerto aims to demonstrate the high potential for energy efficiency and high share of renewables which can be achieved through a fully integrated approach in high performing communities. In order to achieve this aim, the Concerto projects will apply highly efficient energy saving measures, to significantly increase the percentage of renewable energy supplies and integrate the self supply of renewable energies and polygeneration into ecobuildings. That means that Concerto might be translated to a combination of Ecobuildings with a common and energy efficient supply system. The concept is therefore mainly applied to new settlements.

Ecobuildings as buildings with an energy performance better than required by the national implementation of the Energy Performance of Buildings Directive (EPBD), include different types of energy efficient buildings such as zero heating energy houses, zero energy houses, passive houses, 3-litre houses, ultra-low energy houses, etc. All those names describe different levels of energy consumption, partly with integrated renewables and partly with defined types of technologies. For example a passive house in the original German definition uses the mechanical ventilation system for space heating as well. Therefore it can abandon an additional hot water heating system, however it relates on a hot air heating system, mostly combined with a heat pump. The 3-litre-house concept on the other hand can be realised with many energy-efficient technologies, yet the primary energy demand for heating, ventilation and domestic hot water (plus cooling if necessary) is limited to the equivalence of 3 litre of heating oil per m² floor area. Figure 2 illustrates the relations between the different terms for energy efficient buildings.

Figure 2 Illustration of the some of the many terms used in the area of energy efficient buildings.

What makes Ecobuildings as concept especially interesting is that it can be applied to all type of buildings: new buildings, existing buildings, single buildings or combined in Concerto projects. Various energy saving technologies at the building envelope and the installation systems can be used and combined with renewable energies. Particularly the application at existing buildings is of importance. Today the heating energy consumption of buildings in Germany is shaped by the existing building stock. 95 % of the heating energy is used for buildings that were erected before 1982, see Figure 3. Other EU Member States have similar figures. Therefore new buildings even with a very low energy demand can influence the total consumption only marginally. The focus has to be on the challenge to reduce the energy consumption of existing buildings.

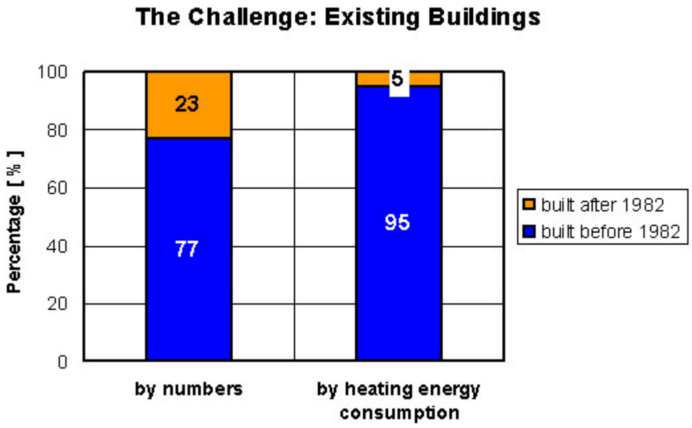


Figure 3 Heating energy consumption in Germany by buildings of different age groups.

2. The 4 Ecobuildings Projects of the 6th Framework Programme

2.1 Similarities and Cooperation

The 4 Ecobuildings projects within the 6FP started under the same call and therefore also roughly at the same time. Their project phase runs from 2004 to 2008. The demonstration projects concentrate on different building types, from new buildings to existing buildings, from large cultural buildings to social housings or public buildings. Also the research work is quite diverse. However besides a general information exchange (mainly via the coordinators) the work plan in all projects foresaw a common dissemination task. Main parts of this task are a website portal for all 4 projects (www.ecobuildings.info), common posters, an Ecobuildings newsletter and a high quality brochure including all demonstration projects. Additionally the project BRITA in PuBs has organised two Common Ecobuildings Symposia in Berlin in November 2005 and Stuttgart in April 2008 with presentations from all projects and many interesting discussions (Kratz, Erhorn, 2005 and Goerres et ali, 2008). Figure 4 shows the actual Ecobuildings poster.

Figure 4 Common poster of all 4 Ecobuildings projects.

2.2 Demohouse

The aim of the project is to develop minimum standards and recommendations in connection to healthy, cost effective, energy efficient and sustainable rehabilitation and to facilitate implementation through the development of a "Decision Support Tool". In 6 participating countries, a pilot project and a reference project was defined. The pilot project is the actual demonstration project, where the recommendations of the investigations and research are implemented. The reference project is a housing complex that has recently been renovated (or which is in the process of renovation) according to the usual local (national) standards. The pilot projects and reference projects are compared in terms of improvement of:

- energy consumption,
- sustainability in general and
- socio-economic aspects.

The demonstration buildings are new or renovated (partly social) housing complexes:

- old urban building in the centre of Bilbao (Spain)
- social housing complex in Budapest (Hungary)
- a development of residential buildings in Attica (Greece)
- suburb housing projects in Copenhagen (Denmark)
- high-rise multi-dwelling houses in Graz (Austria)
- low-rise multi-dwelling houses in Warsaw (Poland)

Besides the demonstration buildings, the project will produce the following results: A common evaluation protocol and a state-of-the-art-in-renovation report.

2.3 ECO-Culture

The ECO-Culture project addresses demonstration of energy efficient technologies integrated into three high-performing cultural ecobuildings:

- the Danish Royal Theatre, Copenhagen (Denmark)
- the Amsterdam Library, Amsterdam (The Netherlands), see figure 5
- the New Opera House, Oslo (Norway).

Figure 5 Photo of the newly erected Ecobuilding Amsterdam Library.

Focus is on investigations, demonstration and testing of the following technologies which have been selected out of the integrated ECO-concepts as being especially innovative and contributing to further development:

- energy storage ("climate belt" with thermoactive slabs, double aquifer)
- heat pump (sea water, ground water)
- advanced demand controlled hybrid ventilation
- building integrated PV systems
- advanced Building Energy Management Systems (BEMS) and benchmarking
- use of environmental friendly concrete for thermal storage in thermoactive slabs.

2.4 SARA

SARA aims to construct sustainable, cost effective, high energy performance, public-access ecobuildings that are immediately replicable at large scale in many locations. The ecobuildings are equipped with advanced sustainable energy technologies integrated by an innovative architectural approach and combined monitoring and building management systems (BMS). SARA involves the demonstration of 7 highly sustainable and replicable public-access buildings in 6 EU Member States and 1 additional country. The key aspects of the project are public-access, innovative yet cost effective and replicable results, consideration of end users and an interdisciplinary team working on various RTD activities. These aspects, applied across various climatic regions produce large scale social, urban and environmental benefits. The project will therefore contribute to future development of European energy policy and legislation that will accelerate market penetration of innovative sustainable technologies. The project includes the following demonstration buildings:

- office and exhibition hall, Sinabelkirchen (Austria)
- primary School, La Tour de Salvagny, (France)
- community centre (refurbishment), Naples, (Italy)
- health centre, Barcelona (Spain)
- supermarket, Ljubljana (Slovenia)

- student service building, Southampton (UK)
- community centre, (refurbishment) Bukara, (Uzbekistan)

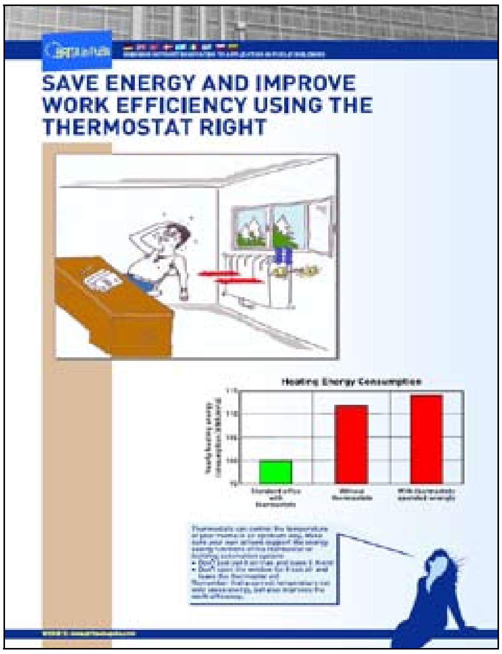
In combination with the demonstration buildings the project works on an instant replicability potential, an integrated BMS and monitoring, shared solutions and interests and technical advice and support.

2.5 BRITA in PuBs

The BRITA in PuBs project (Bringing Retrofit Innovation To Application in Public Buildings) aimed at increasing the market penetration of innovative and effective retrofit solutions to improve energy efficiency and implement renewables, with moderate additional costs.

In the first place, this was realised by the exemplary retrofit of 8 demonstration public buildings in the four participating European regions (North, Central, South, East). By choosing public buildings of different types such as colleges, cultural centres, nursing homes, churches etc. for implementing the measures it is easier to reach groups of differing age and social origin. Public buildings are used as engines to heighten awareness and sensitise society on energy conservation.

Secondly, the research work packages included socio-economic research such as the identification of real project-planning needs and financing strategies, the development of design guidelines, of an internet-based knowledge tool on retrofit measures and case studies and a quality control-tool box to secure a good long-term performance of the building and the systems. The training and dissemination work contains blackboard information sheets, see Figure 6, an Ecobuildings E-learning module, architectural student courses and a facility managers training based on the results of the demonstration projects.



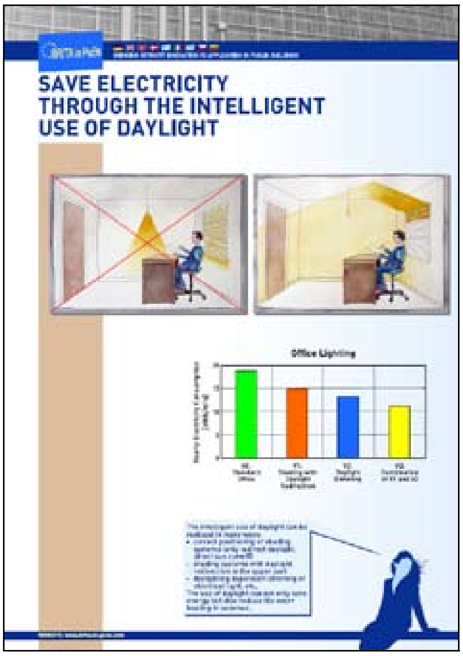


Figure 6 Examples of blackboard information sheets for training energy efficient user behaviour.

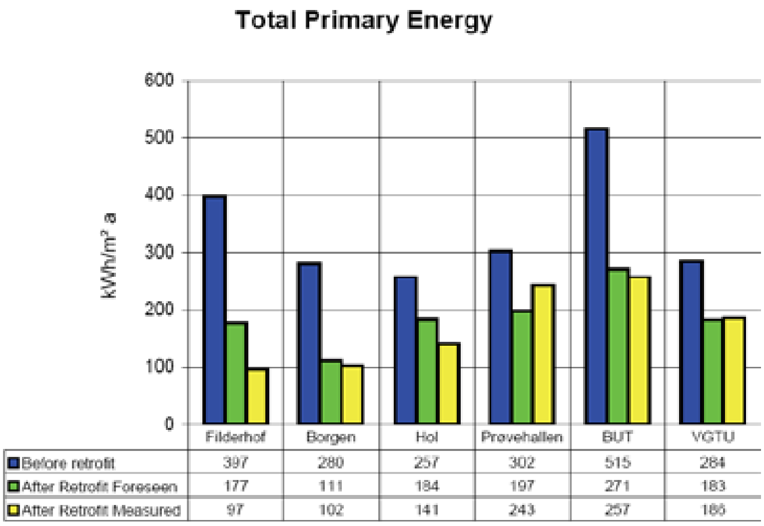
The demonstration buildings are listed in the following:

- nursing home Filderhof, Stuttgart (Germany)
- city college Plymouth (UK)
- community centre Borgen (Norway)
- church Hol (Norway)
- cultural centre Proevehallen, Copenhagen (Denmark)
- Evonymos ecological library, Athens (Greece)
- students centre “Brewery”, Brno (Czech Republic)
- main building of the Vilnius Gediminas University (Lithuania)

The project website (www.brita-in-pubs.eu) contains a building diary with updated information on the status of the demonstration projects. Figure 7 presents an overview of the buildings.

Figure 7 The demonstration buildings in the BRITA in PuBs project after the retrofits.

The general aim of the retrofits at the demonstration buildings was to reduce the primary energy demand for heating, ventilation, cooling and domestic hot water by factor 2 and at the same time to improve the user satisfaction by also factor 2. The latter was analysed by user comfort questionnaires. All buildings were monitored for at least one year. The diagram below compares the primary energy consumption before and after the retrofit for each building. The reduction factors of the buildings range between 1.2 and 4.1 and the average is 2.2 and therefore meets the goal (Citterio et al, 2008).



	Filderhof	Borgen	Hol	Prøvehallen	BUT	VGTU
Before retrofit	397	280	257	302	515	284
After Retrofit Foreseen	177	111	184	197	271	183
After Retrofit Measured	97	102	141	243	257	186

Figure 8 Comparison of the total primary energy consumption before, calculated after and measured after the building retrofits. The results of the Evonymos building are not yet available.

A Life Cycle Assessment of the retrofits has also been made within the project. The analysis showed significant energy and environmental convenience of the accomplished retrofits. In particular the energy and environmental payback times that resulted were very low, with values varying from 0.3 to 2 years. This means that in a relatively small time period the global energy and environmental investments are fully repaid by the obtained benefits. The relatively long useful time of the retrofits therefore produces large energy consumption savings and avoidance of emissions of large quantities of pollutants. It is interesting to note that the largest benefits are generally related to the insulation of the buildings: high efficiency windows, mineral wool and glass wool sheets, in fact, insulation allows great energy savings over a long period with a relatively short life-cycle impact. Even renovation of heating plants and lighting systems produces large benefits. In contracts, the use of renewable energy had lower benefits due to the low productivity of the plants with outputs sometimes lower than expected at the design stage.

The demonstration projects have their own national and international dissemination results, for example the community centre in Borgen had Chinese visitors and the wind generators in Plymouth have been presented in tv footages by both, the BBC and the local commercial television (see project website for the videos).

The project has performed socio-economic research such as an overview report on financial strategies in the different participating countries for the improvement of the energy quality in the existing building stock (Triantis et al., 2006). A detailed analysis of barriers for the energy efficient retrofit of public buildings was also made (Thunshelle et al., 2006).

The partners of BRITA in PuBs have written 14 retrofit design guidelines (see figure 9) with about 4-8 pages each, focusing on specific technologies like innovative insulation, advanced windows, passive solar heating, reduction of overheating, hybrid ventilation, improved daylighting, solar thermal systems, solar heating and cooling, photovoltaic integration and heat pumps or on more general items. The latter deal with the interdisciplinary design approach, energy simulation tools, life cycle assessment and long-term monitoring. The guidelines contain information on why to use the technology, requirements in regulations, current practice, different innovative solutions with their advantages and disadvantages, energy savings and costs, as well as information on maintenance and best practice examples. They are available for download at the project website.

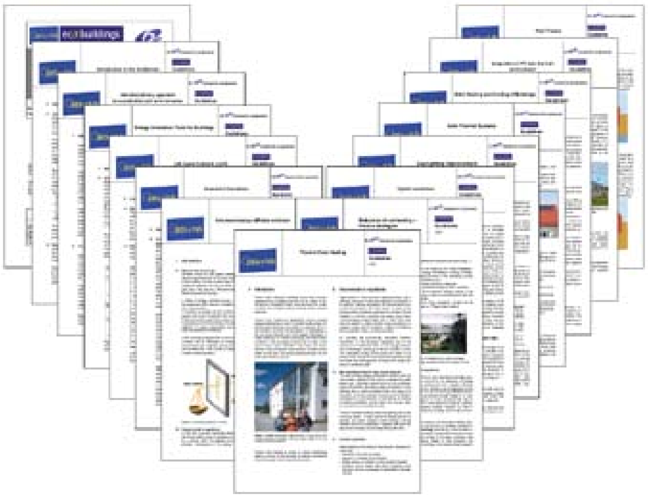


Figure 9 Cover pages of the available retrofit design guidelines (Thunshelle et al., 2008).

An electronic database offers many different types of information for decision-makers of public renovation projects. The BRITA in PuBs information tool BIT (Erhorn-Kluttig et al., 2008) presents in a clearly structured and simple to use way all demonstration buildings from the project plus additional more than 30 educational case study buildings from a just finished IEA project (Erhorn et al., 2003). In a matrix the buildings are opposed to different retrofit strategies starting with the building envelope, over heating and ventilation systems, solar control and cooling systems, lighting systems to renewables and management methods. Figure 10 presents the title page of the BIT tool. The retrofit technologies and the case studies are described in detail in so-called viewers, see Figure 10. For both, the case studies and the retrofit measures, more detailed information is offered as pdf-downloads including the final reports from the demonstration buildings and the retrofit design guidelines.

Figure 10 Title page of the BRITA in PuBs information tool BIT (left) and Retrofit Measure Viewer (here: Lighting Innovations) within the BIT tool.

An additional feature of the information tool is the performance rating tool. Here the user can visually compare the electricity, heating and water consumption of a specific building with the national average for in total 19 different building types.

Another project result is the quality control toolbox. The energy efficiency of buildings should be confirmed in all major stages of a renovation project: planning and design, implementation, use, operating and maintenance. The energy and facility management costs can be optimized by using *BEMS* (Building Energy Management Systems). All major stages of a renovation project are described in the toolbox and put into practice by using new auditing tools e.g. review lists. The review lists are introduced in appendixes.

The demonstration projects and the other project results are documented and illustrated in the BRITA in PuBs brochure. The brochure, with the title page shown in figure 10, can be downloaded from the project website.

Figure 10 Title page of the BRITA in PuBs brochure containing information on the demonstration buidings and all other project results.

3. Conclusions

All four described Ecobuildings projects offer various interesting project results which are now available for use and/or download at the websites. The combination and close link between demonstration projects, socio-economic research and training plus dissemination resulted in a very good transfer of the lessons learned from the demonstration buildings and the combined knowledge of the participating experts to the target audience reaching from public authority decision makers to facility managers, students, building users to the general public. The main conclusion however is that the Ecobuildings concept by the European Commission is a key solution for the major challenge in building energy efficiency: the existing building stock.

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ENERGY CONSERVATION BEHAVIOR AND ENERGY SAVING POTENTIAL OF SINGLE HOUSEHOLDS IN JAPAN

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Keywords: energy consumption, single household, energy saving, energy conservation behavior, house, appliance, lifestyle

Summary

Based on the fact that single households have occupied the largest portion of Japanese households since 2007, and because it was reported that a decrease in the number of household members leads to an increase in energy consumption per individual based on a national scale questionnaire survey, we investigated the energy saving potential of single households in Japan by both measurements and a questionnaire survey. First, measurements on energy consumption of six apartment houses located in the northern part of Japan were conducted in 2005 and 2007. The occupants of these six houses were three university students and three office workers. An energy conservation lifestyle menu was assigned to each house occupant for each season and the energy saving effect of this menu was analyzed. Secondly, a questionnaire survey on the energy conservation behavior of university students was conducted in 2007. From the measurements, it was found that the energy consumptions of the single households varied with different house occupants of students and office workers even though they were single households, as well as with energy sources. The results of the experiments on the energy conservation lifestyle showed that the annual energy consumption and CO_2 emission rate of a house decreased by 2.8 GJ/year and 0.4 t/year, respectively. From the questionnaire survey, the tendency of single households to show preference with regard to energy conservation behavior varied with family types. One approach to address this problem is to provide energy-efficient measures suitable for each family type.

1. Introduction

The first commitment period under the Kyoto Protocol started at last this year (2008). CO_2 emissions still show a tendency to increase in the residential sector of Japan, and efforts should be exerted to reduce such emissions as quickly as possible. According to household projections for Japan, single households are estimated to be the family types sharing the largest part of Japanese households after 2007. It is reported that a decrease in the number of household members leads to an increase in energy consumption per individual based on the national scale questionnaire survey (Inoue et al., 2004). However, detailed surveys on energy consumption focusing on single households have not yet been undertaken. Thus, it is important to clarify the energy characteristics of single households to provide suitable measures for effectively reducing CO_2 emissions. Therefore, the purpose of this study was to determine the energy saving potential of single households in Japan by conducting both measurements and a questionnaire survey. First, measurements on the energy consumption of six apartment houses in Akita Prefecture were conducted in 2005 and 2007. The six occupants of these houses consisted of three university students and three office workers. An energy conservation lifestyle menu was assigned to each house occupant for each season and the energy saving effect of this menu was analyzed and compared with the proposed "CO_2 diet of 1 kg/day per head" from the Japanese Ministry of the Environment. Secondly, a questionnaire survey on energy conservation behavior of university students was conducted in 2007.

2. Measurement of Residential Energy Consumption for Single Households

2.1 Description of Investigated Houses

Table 1 shows a summary description of seven apartment houses. The occupants of the six houses (A01-A06) were single households and those of one reference house (A07) were a family household. All houses were located in the northern part of Honshu Island in Japan (i.e., Tohoku area). The six single occupants consisted of three university students (A01-A03) and three office workers (A04-A06); the measurements on energy consumption of the former and latter occupants were conducted in 2005 and 2007, respectively. The measurement for the occupants of the reference house was performed in the periods 2002-2005 (Genjo et al., 2005). Thermal performances of all investigated houses conformed to the current Japanese residential standard for energy conservation. The total floor areas of four houses varied from 25 to 78 m^2. In addition, the four investigated houses (A01-A04) used only electricity, and the other three houses (A05-A07) used electricity, city gas and kerosene. The occupants of A01-A03 were university students as mentioned above. They do not usually stay at home and lead an irregular lifestyle whether on weekdays or on weekends. The various activities in the houses of these students usually occurred from evening to night. Also, these students tended to dine out and rarely cooked in their house. On the other hand, the occupants of A04-A06 were office workers. They lead a regular lifestyle on weekdays compared with the student single households, although they were not usually at home from 8:00 a.m. to 20:00 p.m. because of work, and they often stayed out at weekends. The occupant of A04 usually stayed with his parents at weekends, and washing and cooking activities were usually done at the family home. In A07 as a reference for a family household, the housewife was usually at home except when she was out for a part-time job three days a week.

2.2 Items and Method of Measurement

The measurement items are shown in Table 2. The consumptions of electricity, gas and kerosene were measured. The consumption of gas was classified into two end-uses (i.e., hot water supply and cooking) using records on gas usage by the occupant. Energy data not measured were compensated by referring to energy bills. Temperature and humidity level in the living room and another room, and outdoors at 1.1 m above the floor surface were also measured. In addition to these measurements, an interview on the usage of appliances and occupants' lifestyle was also conducted.

2.3 Result of Daily Energy Consumption by End-Use

The profiles of daily energy consumption per head by end-use and daily mean temperature of the seven houses for a one-year period are shown in Figure 1. The daily energy consumptions per head of student houses A01-A03 from March 2005 to February 2006 and the office worker houses A04-A06 from March 2007 to February 2008 were compared with that of the family house A07 from March 2004 to February 2005. Energy consumptions were classified into the following seven categories: space heating/cooling, hot water supply, cooking, refrigerator, audio visual/information, housework/sanitation, lighting and others. Calorie conversion was performed for each energy source, that is, 3.6 MJ/kWh for electricity (secondary conversion value), 45.9 MJ/Nm^3 for city gas and 37.3 MJ/L for kerosene.

As seen in Figure 1, daily energy consumption of A01-A06 ranged from 20 to 130 MJ/day and showed large seasonal fluctuations the same as that of the reference family household (A07); in particular, those for A03 and A05 in winter were equal to three times as much as that for other seasons. The daily average indoor temperature of these two houses in winter was about 20ºC and was higher than those of the other houses. The space heating systems for A03 are electric storage heaters with operation at night and those for A05 are a vented kerosene stove and other electric heaters. Not only the type of space heating system but also the area and time of using the space heating system were found to have an effect on the variation of energy consumption. On the other hand, the annual energy consumptions per head of the single households of A02, A03 and A05 were larger than that of the family reference A07, with the exception of A01 and A04 in which the occupants were rarely at home, and that of A06 was the same that of A07.

The energy consumption by end-use of single households revealed two significant characteristics. First, the energy consumption for audio visual/information was much higher in family households. In particular, that of A02 was 16 times as high as that of A07, and those of the other five houses were from two to five times as high as that of A07. Most occupants of the investigated single households in the measurements frequently used TV and PC, making energy consumption for audio visual/information of single households high. Second, that for cooking is said to be much lower in single households than in family households, except for A05 and A06 where the occupants cook for themselves.

Table 1 Description of Investigated Houses

House	Completion	Total floor area[m^2]	Structure	Heat loss coefficient [$W/m^2 \cdot K$]	Normalized leakage area[cm^2/m^2]	Energy sources by end-use				Family member
						Space heating	Space cooling	Hot water supply	Cooking	
A01	2002	26.5	Wooden	1.9	1.7	Electricity	Electricity	Electricity*	Electricity	1
A02	2001	29.0	Wooden	2.2	1.3	Electricity	Electricity	Electricity*	Electricity	1
A03	2002	25.0	Wooden	2.1	N.A.	Electricity	Electricity	Electricity*	Electricity	1
A04	2003	29.0	Wooden	2.5	1.3	Electricity	Electricity	Electricity*	Electricity	1
A05	1999	72.6	Reinforced concrete	1.0	0.5	Kerosene & electricity	Electricity	Gas	Gas	1
A06	1999	72.7	Reinforced concrete	1.0	0.9	Kerosene & electricity	Electricity	Gas	Gas	1
A07	1993	78.3	Reinforced concrete	1.7	1.5	Kerosene & electricity	Electricity	Gas	Gas	4

*late-night electricity use

Table 2 Measurement Items

Item	Method
Electricity	Home energy consumption recording system with recording every one minute
Gas	Digital camera signal data logger with recording every five/one minute
Kerosene	Fine flow rate fuel oil meter and pulse logger with recording every five/two minutes
Temperature and humidity	Small sensor and data logger with recording every ten minutes

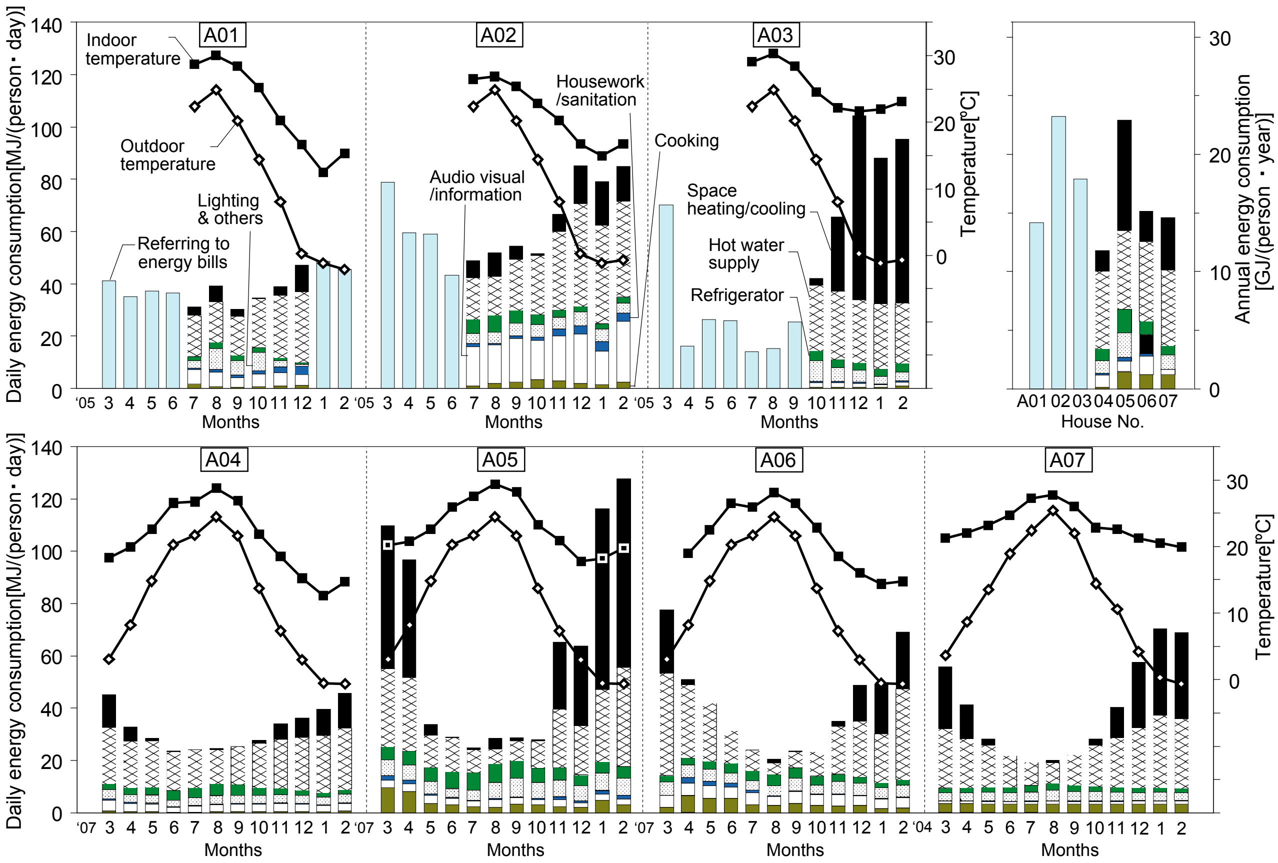

Figure 1 One-year profiles of daily energy consumption per head by end-use and temperature.

3. Questionnaire Survey of Residential Energy Consumption for Student Single Households

3.1 Items and Method of Survey

A questionnaire survey on lifestyle, energy conservation behavior, residential energy consumption in addition to possession of housing equipment and appliances intended for university students of two universities located in the northern part of Honshu Island, Japan (i.e., Tohoku area) was conducted in the summer of 2007. In this survey, both 105 single households and 38 family households of all 143 respondents were investigated. Family numbers ranged from two to seven for the family households. The investigated items are shown in Table 3. A liquid crystal thermometer with a questionnaire sheet was distributed to each student. The students were then requested to set the thermometer in their living rooms and measure the temperature three times a day (i.e., when rising, going home, and going to bed) for one week. Monthly energy consumption from August 2006 to July 2007 was also investigated using utility bills, such as electricity, gas, kerosene and water bills, besides the annual energy consumption was investigated using the questions selected from some choices.

3.2 Result of Monthly Energy Consumption by Energy Source

The profiles of average monthly energy consumption by energy source of 38 single households for a one-year period are shown in Figure 2. These profiles were classified according to three types of energy source: 5 all-electrified houses, 29 houses using electricity and gas, and 4 houses using electricity, gas and kerosene as energy sources. Electricity was used for space heating/cooling, lighting and various electric appliances; on the other hand, gas was used for hot water supply and cooking in all houses except the all-electrified houses. Calorie conversion was performed for each energy source using the questionnaire for the monthly amounts in utility bills, that is, 3.6 MJ/kWh for electricity (secondary conversion value), 45.9 MJ/Nm^3 for city gas, 100.5 MJ/Nm^3 for LPG and 37.3 MJ/L for kerosene. It is noted that there is in fact somewhat a discrepancy between the values of electricity and gas for each month which were based on the utility bills shown in Figure 2 and the actual monthly consumption. In addition, the value of kerosene for each month shown in Figure 2 is different from the actual monthly consumption because of the estimation, which was based on the purchase amount.

As shown in Figure 2, it was found that the profile of monthly energy consumption showed a seasonal fluctuation, and the monthly energy consumption ranged from 0.5 to 1.8 GJ/month. The profile of the houses using electricity and gas showed that the maximum and the minimum of the monthly energy consumption appeared in February and in September, respectively. In fact, the minimum value would appear in August, causing the above-mentioned discrepancy. Thus, it could be said that one of the characteristics of residential energy consumption of student single households is a decrease in monthly

Table 3 Investigated Items of Questionnaire Survey

Building characteristic	House type (detached, apartment), Structure, Story, Completion, Gross floor area
Cooling system	Possession, Cooling period, Cooling time, Set point temperature
Heating system	Type of heating system, Heating period, Heating time, Set point temperature
Ventilation system	Window opening in living room, Type of ventilation system
Hot-water supply system	Energy source, Set point temperature of hot water, Frequency of bath and shower
Cooking system	Energy source, Frequency of cooking
Appliance	Possession and frequency of using appliances, Size and set point temperature of refrigerator, Size and type of TV
Consciousness of environmental problems	Degree of concern about environmental problems, Consideration for energy conservation in daily life, Behavior on resource conservation and reuse
Energy conservation behavior	Degree of action on residential energy conservation behavior
Energy consumption	Energy sources, Annual amount used for electricity, gas and water, Annual purchase amount of kerosene, Monthly amount or rate of electricity, gas and kerosene in utility bills

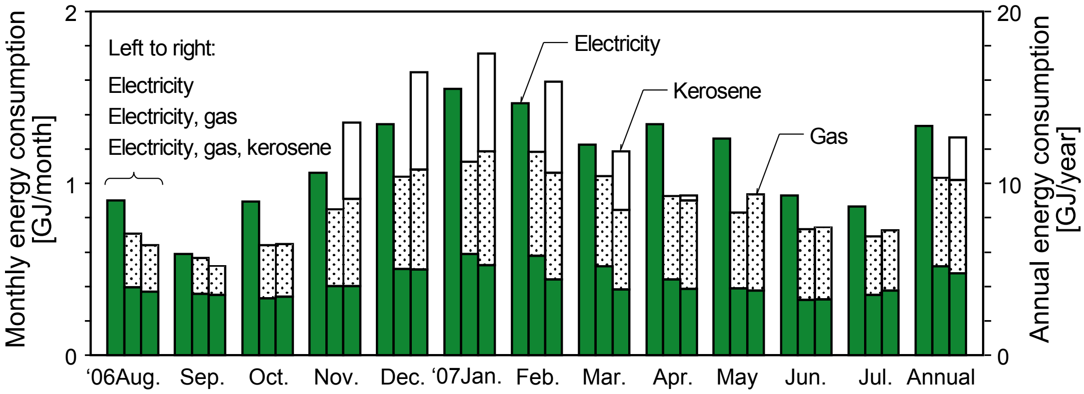

Figure 2 *One-year profile of monthly energy consumption by energy source classified according to the three types of energy source for student single households.*

energy consumption during the summer vacation. The increase in monthly energy consumption during winter is similar to the profiles obtained by the measurement shown in Figure 1.

3.3 Results of Possession and Frequency of Using Appliances

The frequency of using 13 appliances by family type is shown in Figure 3. The frequency of using each appliance was selected from the choices of five levels. The rest of the percentages except for that of "Do not have" in Figure 3 can be defined as the possession rate in this paper. It was found that the appliances of which the possession rate varied from 105 single households to 38 family households were an electric water heater, a video for playing games, a desktop computer, a laptop computer, CD/MD, DVD, an electric toilet seat and a dehumidifier. The possession rates of all these appliances mentioned for family households were found to be higher than those for single households, and those of an electric water heater, a desktop computer, DVD and a dehumidifier were quite particularly higher than those of the other appliances. There was a large difference between single and family households in the percentage of "Used everyday" of a rice cooker, a microwave, a washing machine, and an electric toilet seat, although there was a small difference for a gas water heater, TV, a video for playing games, a desktop computer, a laptop computer, and CD/MD. Based on the results, it can be inferred that single households tend to spend less time for cooking and housework activities than family households.

3.4 Result of Energy Conservation Behavior

Figures 4(a)-(AA) show the degree of action on residential energy conservation behaviors by family type. Whether or not an occupant shows several residential energy conservation behaviors for each appliance was evaluated using five levels. The tendency of preference on energy conservation behaviors varied from 105 single households to 38 family households for several appliances, as well as from contents to contents even if the behaviors were displayed for the same appliance. From a general overview of the results, the behaviors of which the degrees of actions were relatively high (i.e., > 50%) and common for both family type were as follows: 'use water for washing the face, hands and dishes for hot water supply' (washing the face or hand, and cooking) (Figures 4(h)-(j)); 'plug off not in use for a rice cooker' (Figure 4(n)); 'switch off not in use' for TV (Figure 4(q)); 'stop keeping warm', 'lower the set point' and 'close a cover not in use' for an electric toilet seat (Figures 4(x)-(z), and 'turn waste lights off' for lighting (Figure 4(z)). The behaviors of which the degrees of actions were relatively low (i.e., < 20%) and common for both family type were as follows: 'clean an air filter' for space heating/cooling (Figure 4(b)); 'use a microwave for preparation' for induction heating in a cooker/gas kitchen range (Figure 4(l)); 'defrost frozen food by itself' for microwave (Figure 4(o)); and 'plug

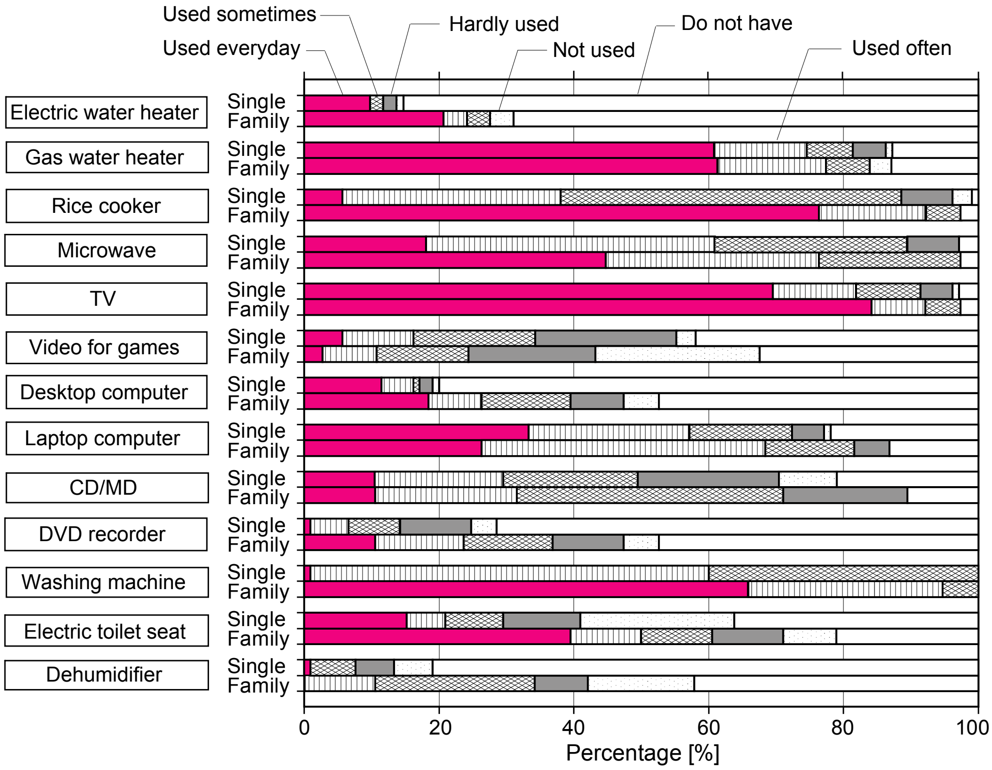

Figure 3 Frequency of using 13 appliances by family type.

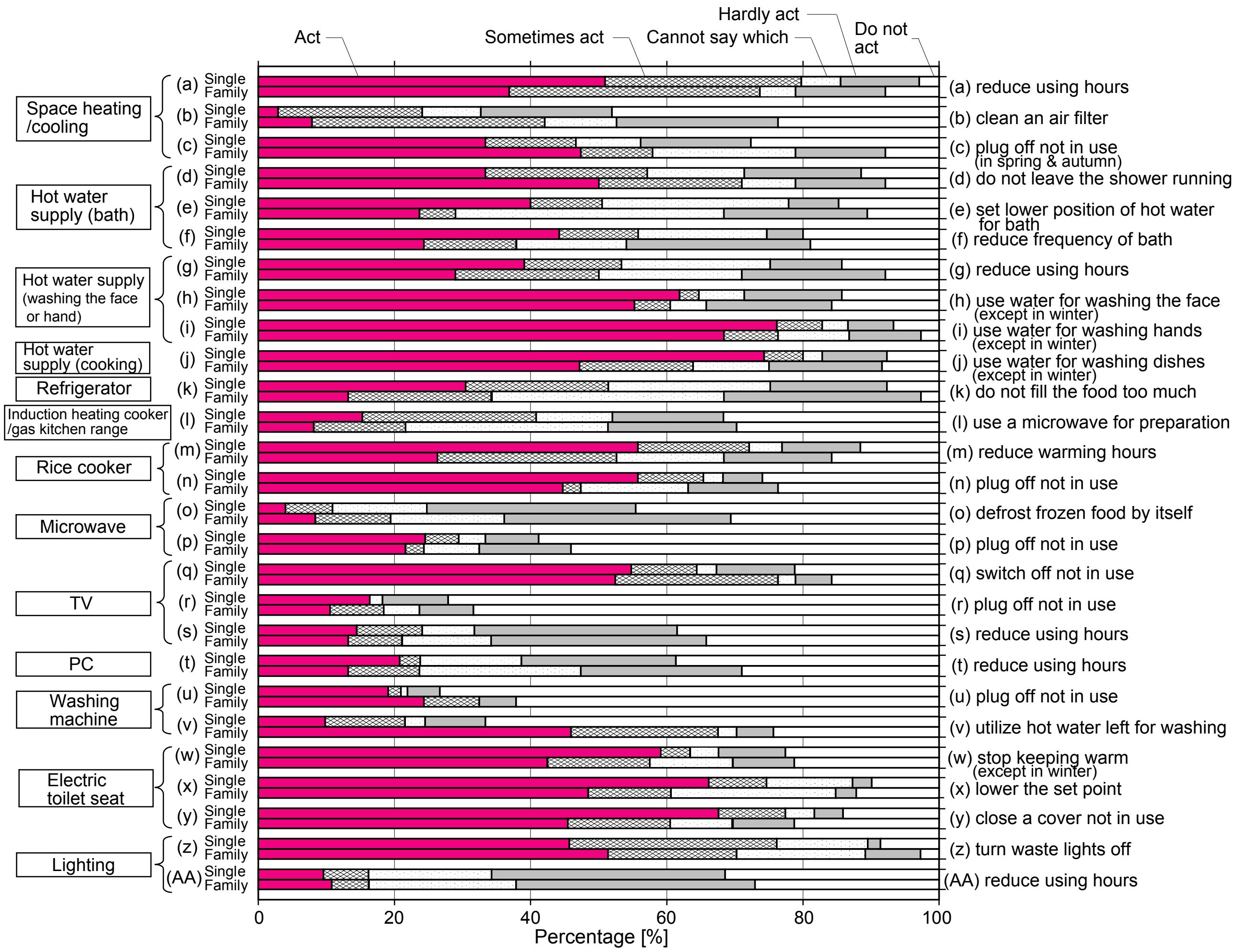

Figure 4 Degree of action on residential energy conservation behaviors by family type.

off not in use' for microwave, TV and washing machine (Figures 4(p), (r) and (u)), 'reduce using hours' for TV, PC and lighting (Figures 4(s), (t) and (AA)). One possible explanation for this result is that the troublesome energy conservation behaviors and the need to reduce using hours of appliances are difficult to act on for both family type. Furthermore, the behaviors of which the degrees of actions were different in each family type were as follows: 'reduce using hours' and 'plug off not in use (in spring & autumn)' for space heating/cooling (Figures 4 (a) and (c)); 'do not leave the shower running', 'set lower position of hot water for bath' and 'reduce frequency of bath' for hot water supply (bath) (Figures 4(d)-(f)); 'reduce using hours' for hot water supply (washing the face or hand) (Figure 4(g)); 'use water in washing dishes (except in winter)' for hot water supply (cooking) (Figure 4(j)); 'do not fill the food too much' for refrigerator (Figure 4(k)); 'reduce warming hours for rice cooker' (Figure 4(m)); 'utilize hot water left for washing' for a washing machine (Figure 4(v)); 'stop keeping warm (except in winter)', 'lower the set point' and 'close a cover not in use' for an electric toilet seat (Figures 4(w)-(y)). Most of the degrees of actions on the energy conservation behaviors mentioned above were found to be higher in single households than in family households, with the exceptions of the behaviors such as 'plug off not in use (in spring & autumn)' for space heating/cooling (Figure 4(c)), 'do not leave the shower running' for hot water supply (bath) (Figure 4(d)) and 'utilize hot water left for washing' for a washing machine (Figure 4(v)). Based on the above-mentioned results, it can be said that the energy-efficient measures to be provided must be suitable for each family type.

4. Comparison of the Annual Energy Consumption of Single Households for the Present Study with the Previous Study

Figure 5 summarizes the annual energy consumption of single households for a previous study and the present study. The figure shows the average annual energy consumption of 129 single households in the Kanto area in Japan based on a national scale questionnaire survey (Inoue et al., 2004). The average annual energy consumptions of six single households (three university students and three office workers) from the measurement and 38 single student households selected as the valid answer from the questionnaire survey on energy consumption are shown in Figure 5. As shown in Figure 5, the annual energy consumption of single households ranged from 10 to 23 GJ/year, probably because of the different house occupants of students and office workers even though they were single households, and the various types of energy sources.

5. Experiment on Energy Conservation Lifestyle

5.1 Contents of Experiment

Experiments on energy conservation lifestyle were conducted for three university students (A01-A03) in two seasons (autumn of 2005 and winter of 2005-2006) and three office workers (A04-A06) in four seasons (spring, summer, autumn, and winter of 2007). An energy conservation lifestyle menu for each season was assigned to each occupant. Energy consumption was analyzed for one week when energy conservation behavior in accordance with the menu was shown. In addition to this experiment, a questionnaire survey regarding the energy conservation lifestyle menu was conducted. The answers of each occupant indicating the degree of action for each energy conservation behavior were any of the following five levels: 1, do not act; 2, slightly act; 3, sometimes act; 4, considerably act; 5: completely act.

5.2 Results of Questionnaire Survey on Energy Conservation Lifestyle Menu and Daily Energy Consumption by End-Use in Winter

The degree of action for each energy conservation lifestyle menu and energy consumption averaged for one week under the energy conservation lifestyle were compared with those averaged for one week (one week before the week for observing the energy conservation lifestyle) under the usual lifestyle for each house. The results of the case on energy consumption for space heating will be discussed here. Table 4 shows the

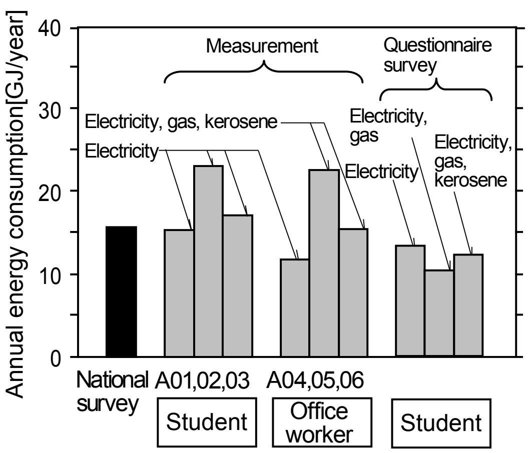

Figure 5 Comparison of annual energy consumption of single households for the present study with the previous study.

degree of action for space heating as part of the results of the questionnaire survey on the energy conservation lifestyle menu in winter. The degree of action for ‘Lower the set point temperature for a main heater’ increased in A01, A03 and A04, and that for ‘Reduction in using hours’ increased in A01, A04 and A05. In addition, that for ‘Control the amount of heat storage for a storage heater’ increased in A03. As shown in Figure 6, the daily average energy consumption for space heating during the energy conservation week of the houses except for A02 and A06 decreased compared with the case during the usual lifestyle week, and that of A03 drastically decreased by 31 MJ/day. Thus, all the houses in which the occupants set the menus for change of set point temperature and use hours showed a reduction in the energy consumption for space heating. On the other hand, the daily energy consumption of A02 under the energy conservation lifestyle increased by 19 MJ/day compared with that under the usual lifestyle, probably because the occupant did not change his lifestyle at all. In addition, two houses (A03 and A05) achieved the target “CO_2 diet of 1 kg/day per head” as proposed by the Japanese Ministry of the Environment from Figure 6.

5.3 Effects of Energy Conservation Lifestyle on Annual Energy Consumption and CO_2 Emission Rate

The annual energy consumptions and CO_2 emission rates of the six houses under the energy conservation lifestyle were estimated from the results of the energy saving effect obtained from the experiment on energy conservation lifestyle in each season. In the estimation of the days for each season, spring, summer, autumn and winter were assigned to May and June, July and August, September and October, and the rest of months, respectively. As mentioned above, the experiments under the energy conservation lifestyle were conducted for three university students (A01-A03) in only two seasons, and the saving effect estimated for each house was not necessarily correct. Note that the data for estimating the energy saving effect of A02 was not the data shown in Figure 6, but that for one week after the energy conservation lifestyle week. Therefore, we concentrated on the annual energy saving effect for three office workers (A04-A06) estimated from the results of the four seasons. As shown in Figure 7, the result of the experiments on energy conservation

Table 4 Degree of Action* for Space Heating from the Results of the Questionnaire Survey on Energy Conservation Lifestyle Menu in Winter

Energy conservation lifestyle menu	A01		A02		A03		A04		A05		A06	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Lower the set point temperature for a main heater	1	5	N.A.	N.A.	3 25℃	5 20℃	1 23℃	2 22℃	5 20℃	5 20℃	4 19℃	4 19℃
Reduce using hours	3	4	N.A.	N.A.	1	1	3	4	2	3	5	5
Clean an air filter	5	5	4	4	1	1	5	5	1	2	1	1
Plug off not in use	N.A.	N.A.	1	1	1	1	Not shown		1	3	1	3
Control the amout of heat storage for a storage heater	Not used		Not used		1	5	Not used		Not used		Not used	

(a) Usual lifestyle, (b) Energy conservation lifestyle

*Degree of action: 1, do not act; 2, slightly act; 3, sometimes act; 4, considerably act; 5, completely act

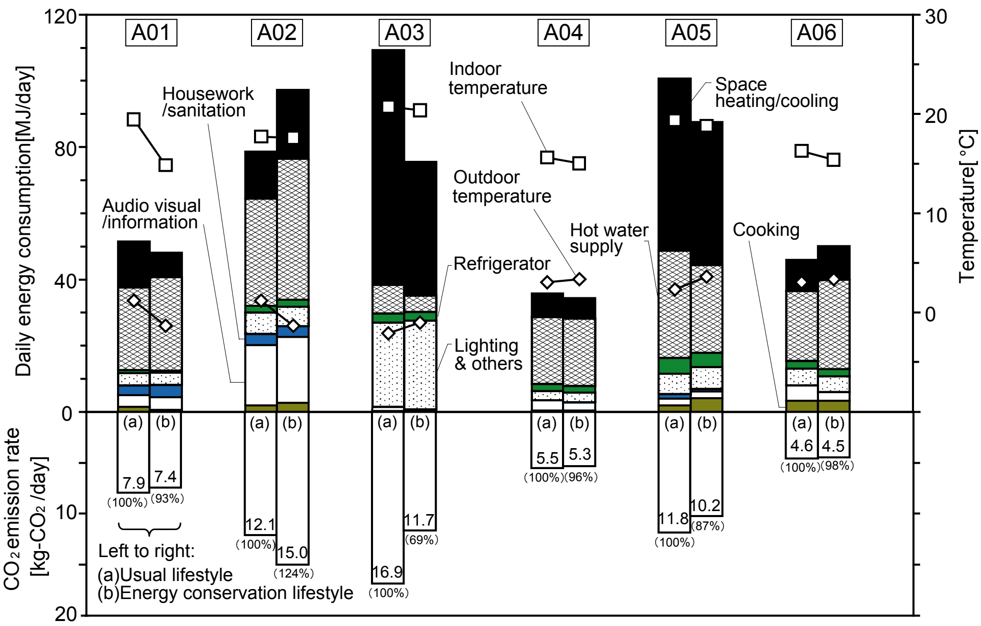

Figure 6 *Daily energy consumption by end-use, CO_2 emission rate and daily average temperature in experiment on energy conservation lifestyle in winter (CO_2 conversion values for estimating CO_2 emission rates are 0.555 kg/kWh for electricity, 2.49 kg/L for kerosene and 2.08 kg/m^3 for city gas).*

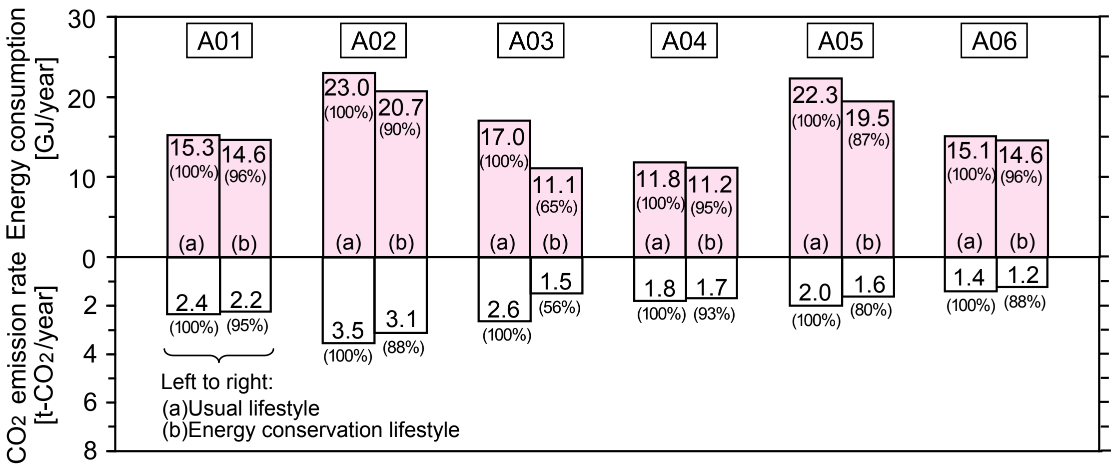

Figure 7 Estimated annual energy consumptions and CO_2 emission rates under the energy conservation lifestyle.

lifestyle proved that the annual energy consumption and CO_2 emission rate of A05 decreased by 2.8 GJ/year and 0.4 t/year, respectively. However, it was also found that the energy conservation lifestyle for one year in the case of the other two houses (A04 and A06) failed to achieve the target “CO_2 diet of 1 kg/day per head” as proposed by the Japanese Ministry of the Environment.

6. Conclusions

From the measurements and questionnaire survey on the residential energy consumption for single households, the following conclusions were drawn:

1) From the measurements, the daily energy consumption of six single households ranged from 20 to 130 MJ/day and showed large seasonal fluctuations the same as that of the reference family household. The differences in energy consumption among the houses were brought about by the winter season.

2) From the measurements, two characteristics of energy consumption of six single households were revealed as follows: Energy consumption for audio visual/information was much higher and that for cooking was much lower than that of the reference family household.

3) From the questionnaire survey, the profile of monthly energy consumption of student single households showed a seasonal fluctuation, and the monthly energy consumption ranged from 0.5 to 1.8 GJ/month. There was a decrease in monthly energy consumption during the summer vacation.

4) From the questionnaire survey on the possession and frequency of using appliances, single households tended to spend less time for cooking and housework activities than family households.

5) The tendency of single households to show preference on energy conservation behavior varied from that of family households. One approach to address this problem is to provide energy-efficient measures suitable for each family type.

6) The annual energy consumption of single households varied from 10 to 23 GJ/year from the results of both measurements and the questionnaire survey. This variation was caused by the different house occupants such as university students and office workers even though all of them were single households, as well as the different energy sources.

7) From the experiment on the energy conservation lifestyle, the annual energy consumption and CO_2 emission rate of a house proved to decrease by 2.8 GJ/year and 0.4 t/year, respectively.

The results of this study highlight the importance of energy-efficient measures suitable for each family type. This information has statistical significance due to the single households that was examined for the purpose of clarifying energy characteristics.

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A GLOBAL REVIEW OF OUTSIDE AIR IN BUILDINGS

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Keywords: outside air, regulations, building, economizer, ventilation, indoor air quality

Summary

A common trade-off in sustainable buildings is between higher outside air rates for improved indoor air quality, and lower outside air rates for improved energy performance. The tension between these two desirable goals is likely to strengthen because on the one hand companies are seeking to attract high-quality employees and provide more productive working environments, and on the other hand the cost of energy is set to increase due to climate change response measures and dwindling resources. This paper presents a global review with the aim of identifying and explaining trends in regulated and desired outside air rates around the world and how building designers have been managing the trade-off between indoor air quality and energy conservation. Based on this review, the paper makes some suggestions about what the future trends might be in Australia.

1. Introduction

Outside air is required in buildings to improve the indoor air quality, and to replace any air that is exhausted from the building. Increased levels of outside air can lead to better occupant comfort and performance, and improved concentration within high intensity work areas. Poor air quality creates discomfort and can be attributable to higher levels of absenteeism. Acceptable levels are regulated around the world, and specified as a legal requirement for any building design. Additionally, there are more and more green building ratings that are incorporating higher levels of outside air in their requirements for a rating. However, with the increasing energy costs and subsequent awareness of sustainability, there is a trade-off in achieving these higher levels of outside air, and the associated increased HVAC energy costs.

This paper presents a number of initiatives available to address the pressure between higher outside air rates and lower energy costs. The goal is to achieve all the benefits from increased outside air, while minimizing the energy costs required doing so. There are additional design tips or 'watch it's' that should be considered within HVAC design, to ensure the effective control and supply of outside air.

2. Background to outside air in buildings

2.1 Historical perspective

Buildings were originally built to incorporate natural ventilation, but with the advent of greater population densities, dust and noise pollution; filtered mechanical ventilation gained in popularity. The removal of natural ventilation as the norm meant that the amount of outside air now had to be regulated, to ensure the air quality within enclosed buildings.

In Australia, originally local state building regulations governed the quantities of outside air, but this was replaced with an Australian standard; AS 1668.2, which was published in 1976, 1980, 1991 and 2002. This Australian Standard sets the minimum outside air requirements for different types of occupancy, and through the Building Code of Australia (BCA) is a legal requirement for any building design.

2.2 Why we need a minimum amount of outside air

Outside air provides for a healthy and comfortable environment. It is not only required for its oxygen content, but also to prevent the build up of contaminants such as CO_2, volatile organic compounds (VOC's) from solvents, paint and synthetic building materials, allergens, micro-organisms and dust. Building occupants may be exposed to a mixture of hundreds or thousands of airborne contaminants, originating from numerous sources, both inside and external to the building (Wargocki et al., 2000).

Different areas within a building require different minimum outside air rates. The same person when in a meeting room requires more outside air than when in a general office space. Historically, this distinction for confined spaces with greater occupancy density is due to body odour, and the close proximity of people. Concentrations of individual contaminants are frequently in the order of one one-thousandth of published occupational exposure limits, but may still be above odour detection thresholds.

During the 1970's energy crisis, the regulations for outside air were decreased due to the energy savings that this created. However, an increased use of synthetics in buildings and a rise in reporting's of 'Sick Building Syndrome' led to the regulations being increased again.

2.3 Why we might want higher levels of outside air

Higher levels of outside air assist in better occupancy comfort and health, provided the source of outside air is not contaminated. Higher outside air rates enable people to be more alert and think more clearly, and are required in areas such as air traffic control booths where concentration levels are critical. Lower levels of outside air can lead to increased discomfort, absenteeism and a decrease in productivity.

There is often a misconception that a reduction in the amount of outside air will lead to increased savings due to the reduced load on the HVAC system to treat the air. However, Milton, et al. (2000) showed by reducing the level of outside air to below comfort levels, the occupant absenteeism rate is more likely to increase, and any savings in energy from the reduced outside air will be overcome by the increased costs for the absent workers. It is important to note that higher outside air rates alone are not the final solution, but are a vital part of Indoor Air Quality (IAQ).

3 Outside air rates around the world

Regulations and building codes have been established around the world to specify the minimum requirements for provision of outside air supply to various building types. The table below shows a selection of these for Australia, UK, USA and Europe, relevant to general office areas. These requirements are dependent upon the room type, climate and application of the specific building, and are all rated in terms of occupancy.

Also shown in the table are the various international requirements for 'Green Building Ratings'. Credits achieved through rating systems like Green Star in Australia, and LEED in USA are becoming a major goal for building designers. Their requirements are more complex than the regulations, ensuring the quality of the indoor air and level of contaminants, rather than just a requirement based on occupancy.

Table 1: Outside air rates around the world

	Regulation / Building Code (*)		Green Building rating	
Australia	BCA / AS1668.2	10 L/s/person	Green Star	Building Air Change Effectiveness must be greater than 95%
UK	BSRIA CIBSE BCO	8-12 L/s/person 10 L/s/person 12-16 L/s/person	BREEAM	12 L/s/person
USA	ASHRAE (STD 62.1)	2001: 10L/s/person 2004: 8.5L/s/person	LEED	1.3 x the ASHRAE requirement

		2007: 8.5L/s/person (**)	(13L/s/person)
Europe	DIN EN 13997	8.5 L/s/person	

* All outside air rates stated are for general office areas.
** Based on an occupancy density of 5 people/100m2.

3.1 Why the rates are different

Internationally, the rates for outside air provision differ slightly as shown in table 1. There are differing views around the world on energy conservation and indoor air quality, and in some climates, hygiene and increased body odour can become more important.

Due to the improved performance of supply systems, filters and maintenance and the increased costs of energy, there is a general movement in the regulations to allow for lower levels of outside air. Building's striving to achieve green building ratings and higher occupant comfort and performance are demanding higher levels of outside air, reflected in the rising green building rating requirements.

4 The implications of higher outside air rates

4.1 Heating/cooling

The schematic of figure 1 shows a typical HVAC circulation system. As exhaust is drawn out of the building, outside air enters the Air Handling Unit (AHU) via a filter, and is mixed with the building's return air to be re-supplied.

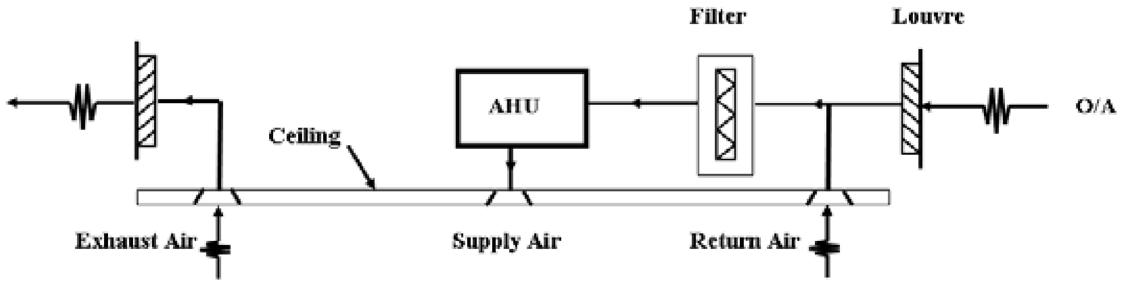

Figure 1 Introduction of Outside air increases the work to Air Handling Unit.

The outside air must be treated before it can enter the building as supply air, and as such requires work from the AHU to match the required conditions of the internal space. In temperate climates where the ambient temperature is close to the room temperature, high outside air rates can be used without penalizing the operating costs too severely. Alternatively, in very hot or very cold climates, higher outside air rates will increase the cooling or heating loads, and hence the energy costs.

4.2 Humidity

In a humid climate, higher outside air rates can significantly increase the latent cooling loads as the increased moisture content within the outside air must be removed by the AHU system. In high humidity regions, outside air should never enter an air-conditioned space un-treated, as it can result in condensation forming on supply diffusers.

4.3 CO_2 Emissions

Without appropriate solutions, increasing the amount of outside air can indirectly create increased CO_2 emissions. The additional load on the HVAC system for the conditioning of outside air requires an increase in energy for the building's plant. This increase in energy use will have a negative impact on the building's level of CO_2 emissions, which needs to be limited.

5 Managing the trade-offs between energy and outside air

Higher outside air rates are beneficial to building comfort, occupant performance and productivity, decreased absenteeism, and overall IAQ. However, the pressures against obtaining these greater rates are the increased load on the HVAC system, and the subsequent increase in energy costs and CO_2 emissions.

There are systems that can be applied to the HVAC system with the potential to reduce these pressures while being able to maintain or increase higher levels of outside air. The following five options detail how the HVAC system can be optimized to gain the benefits of higher outside air, while reducing the costs and emissions.

5.1 Demand-controlled ventilation

HVAC systems are traditionally designed to meet the maximum occupancy levels and loads that a building may experience within its lifetime. To achieve higher outside air rates to meet this criterion would be unnecessary for much of the time. By allowing for air balancing (in accordance with ASHRAE standard 62.1-2004), a building with fluctuating occupancy levels can employ a system that only introduces the amount of outside air required at any time, therefore reducing the pressures on the HVAC system.

Demand-controlled ventilation monitors the amount of CO_2 within the building, and adjusts the amount of outside air entering the system accordingly (Braun et al., 2001). The CO_2 level within the return air stream or conditioned space is monitored before it is recirculated back into the supply, and a signal sent to a controller to adjust the variable intake for outside air. With demand controlled ventilation in place, Brandemuehl and Braun (1999) showed that there is potential to save up to 20% in electrical energy for cooling, while maintaining outside air levels.

For the ventilation to be most effective, it should be installed in conjunction with an economizer system as described in section 5.3.

5.2 Energy recovery technologies

The energy costs for the HVAC system can be reduced if the level of conditioning (temperature and moisture content) required for the outside air is minimised prior to it entering the AHU. There are a number of technologies available to offset the temperature and humidity difference between the outside air and supply air, which take advantage of the conditioned exhaust air leaving the building. To offset the difference, energy may be transferred from the supply air to the exhaust air (cooling), or vice versa (heating).

This energy transfer can be achieved using the following systems.

1. Thermal wheels use an air permeable medium that rotates through the supply and exhaust air streams, facilitating an energy exchange. They can transfer both sensible and latent heat between the streams, by the use of a silica compound within the air permeable layer that also absorbs excess moisture within one stream, and transfers it to the other (Braun et al., 2001). Due to the direct contact between both air streams and the permeable layer, trace amounts of exhaust air can come into contact with supply air, and result in minor contamination. However, a ‘purge’ section can be designed within the wheel which allows excess pollutants to be removed. According to Hamilton (1986), thermal wheels have relatively high heat transfer efficiency, and low energy consumption.

2. An alternative to a thermal wheel is a sensible heat wheel. In climates where high humidity is not as prevalent, a sensible heat wheel can be used to simply transfer the sensible energy (excluding moisture content) from one air stream to another. These systems are identical to thermal wheels, but the air permeable layer will not contain any silica gel or other compound capable of absorbing moisture.

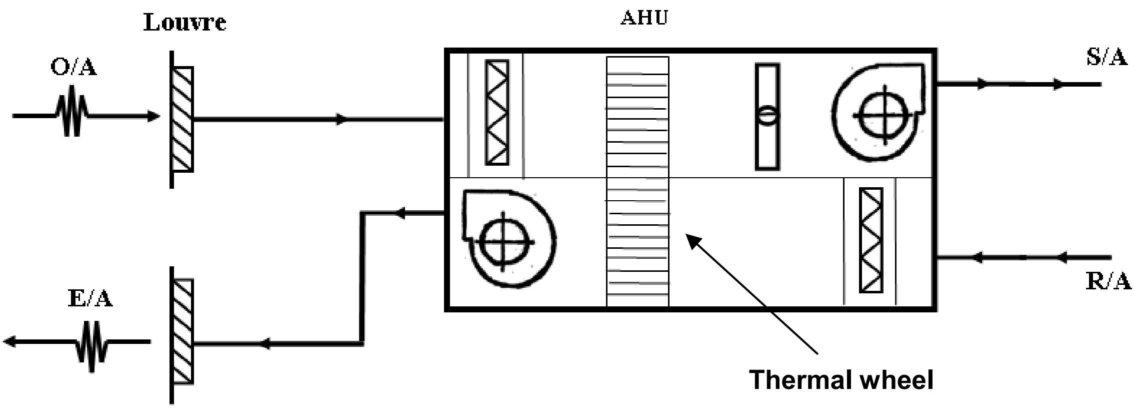

Figure 2 Schematic of thermal/sensible wheel used for heat exchange.

3. A Run-around coil system facilitates the heat transfer from exhaust to supply (and vice versa) by utilising coils with heat transfer fluid, stretching between the outside air intake and exhaust air streams. As there is no direct contact with the heat transfer fluid, this system is only capable of transferring sensible heat and has no possibility of cross contamination. This system has a relatively low heat transfer efficiency compared to thermal wheels (Hamilton, 1986).

5.3 Economizer

Economizer systems take advantage of the changing ambient conditions throughout the day. They are very beneficial in cold and temperate climates, where the ambient outside air temperature can be close to the supply temperature during cooling. In this occurrence, it can be more efficient to increase the supply of outside air to the system, exhausting the warmer return air, and subsequently reducing the HVAC energy costs when it is economic to do so. An economizer circuit monitors the external ambient conditions, and regulates the amount of outside air intake.

How it works:

- As the outside air decreases below the return air temperature, the economizer circuit will direct 100% outside air into the system.
- If the temperature reaches that of the supply air, therefore not requiring any chiller load, then ‘free cooling’ can occur, where 100% unconditioned outside air will enter the supply system.
- When the outside air temperature is below the supply air, the economizer will only direct the amount of outside air into the system, which is required to cool the return air to the correct supply temperature.

Economizer circuits are becoming increasingly popular, with some regulations – eg. those in California, specifying them as mandatory. Brandemuehl & Braun (1991) also distinguish the use of two different types of circuits; ‘Dry bulb’ economizers monitor the ambient dry bulb temperature and fluctuate the outside air intake accordingly, while ‘Enthalpy economizers’ monitor the ambient wet bulb temperature, and increase the outside air supply when lower than the return air.

5.4 Air-change effectiveness

Air change effectiveness (ACE) compares the age of air within the building (time since air molecules have entered), to the age of air that would occur if the air was perfectly mixed (ASHRAE 1997). The greater the level of ACE, the cleaner the air is for occupants to breathe.

Monitoring the air change effectiveness (ACE) will ensure that the supplied outside air is delivered to the building occupants in the most effective way, offsetting the age of internal air.

The ACE within a building is dependent upon the degree of short circuiting that occurs between the supply and return air, and the amount of outside air that enters a system. However, Fisk et al. (1995) showed that simply increasing the amount of outside air to the system will not greatly improve the ACE, due to the lack of mixing between the supply air and internal 'aged' air.

In order to achieve greater ACE within a building, the following options are available to ensure adequate mixing of air:

1. Efficient placement of air diffusers can limit the amount of short circuiting, and ensure that the throw of supply air creates sufficient mixing of internal air. In Australia, Green Star recommends that a well designed ceiling air diffusion system can achieve an ACE of near unity (08-1.2) at design flow rates.

2. Upward displacement systems with high level return air provision can eliminate direct short circuiting, and as such can be more efficient than perfect mixing (Fisk et al., 1995). These systems can ensure adequate movement of internal air, and the removal of 'aged' exhaust air. According to Green Star, displacement ventilation systems typically achieve an ACE greater than 1.2.

5.5 Source control of contaminants

Within a building, air can become contaminated with pollutants that are harmful to the indoor air quality. These contaminants must be exhausted from the internal air and their concentrations reduced to an acceptable level as specified by ASHRAE 129-2004. Outside air is then required to balance out the internal air supply, which may be at levels higher than required to achieve the benefits mentioned previously.

Limiting the amount of contaminated air exhausted from a building will reduce the amount of additional outside air required, and therefore could potentially reduce energy costs for the HVAC system. The exhaust system can be optimised in the following ways:

1. Minimising the direct contaminant sources can be achieved by selecting low emitting products and materials where usually high levels of contamination would occur (eg. paints, adhesives, carpet, furniture). Maintenance of appliances and regular duct cleaning can also minimise these levels.

2. Increased efficiency of exhaust systems, and maximising pollutant removal is possible by localising exhaust points above direct sources of contamination. Kitchen sinks, kettles, stove tops, photocopiers/printers and bathrooms should contain localised exhaust points that can directly remove the contaminants before they can spread around the building. Increasing the pollutant removal efficiency of the exhaust system will assist in achieving a greater ACE (Fisk et al., 1995).

6 Outside air Watch-its

6.1 Outside air intake location

Careful consideration must be given to the location of outside air intakes. Do not locate intakes close to building exhausts, car park discharges, cooling towers, boiler flues or generator flues. Analysis of the contaminant concentrations within the proximity of the intake location should be conducted, along with standard ambient conditions of wind speed and direction that can potentially affect the fan power required to draw in the air.

6.2 Outside air temperature sensors

The ambient conditions of outside air need to be highly accurate to supply information for economizer circuits, and heat recovery systems. Avoid locations of outside air temperature sensors, where the sun or other heat sources may influence the reading.

6.3 Effective control of outside air

Ensure outside air sensors are correctly calibrated and the systems commissioned. Avoid oversized dampers, which may restrict fine adjustments of the outside air intake. Use minimum flow dampers in addition to variable flow opposed blade dampers, with centralised controls to include any economizers or heat recovery systems.

In the case of variable air volume (VAV) systems, it is better to use variable speed outside air fans complete with accurate flow measurement to prevent the outside air reducing as the supply air reduces. By directly controlling the outside air intake as a separate system, the level within the building can be effectively monitored and provided with most efficiency.

7 Conclusions

Increased outside air rates can improve occupant concentration, performance and productivity, and decrease the amount of absenteeism within the workplace. If un-assisted, higher levels of outside air will increase the energy costs associated with the HVAC system. By utilizing the solutions presented in this paper, and by incorporating the effectiveness of air intake and exhaust systems a building can maintain a balance between the higher levels of outside air, and a reduction in HVAC energy costs.

Within Australia, the increased pressure to obtain a Green Star rating by offering increased outside air and air change effectiveness, while minimizing the energy costs is steering building design to include the heat recovery technologies shown in this paper, and to provide better filtration of the outside air to improve its quality.

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Proposal of methodology and optimization tool to achieve safety and energy saving for highly energy consuming building, such as laboratory

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Keywords:• Laboratory, Ventilation, Energy saving, Safety, On-going-commissioning, Fault detection

Summary

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Most of laboratories are highly energy consuming buildings, which contain much exhaust to ensure safety of human body from toxic substances. Air change rate of fresh air intake caused by exhaust for lab facility comes up to 20• 60 air-change/h, compared to office building of only 1• 2 air-change/h to control density of CO_2 . Conventionally, because safety takes precedence, it was allowed that great volume of ventilation consumes much energy, however, recent demand for sustainability strongly requires coping with both proper safety and energy saving. A primary cause, which makes lab exhaust greater, is installation of many spot exhaust devices such as fume hood to prevent human body from suffering chemical exposure. However, codes and regulations require that constant and adequate face velocity to be maintained at sash opening of fume hood for prevention of exposure to toxic substances, it would be a problem if exhaust amount were simply reduced. In recent years, VAV system is introduced for fume hoods which operates together with sash, still, to take diversity factor into system design for energy saving becomes more important. On this paper, we introduce a case where 55% reduction of energy consumption was achieved by introducing VAV and design optimization, compared with conventional system. Furthermore, we propose a methodology targeted to detect fault and optimization by on-going-commissioning. And we also propose the visualizations about fault detection system for end users. The visualizations are friendly tool that end users are able to recognize the trends of possibility of fault before the experts of building energy management analyze the data of energy consumption. This methodology would contribute to energy saving, reduction of CO_2, and improvement of sustainability.

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1. Features of Laboratories: Coexistence of "Safety for human body" with "Energy saving"

When experiments are performed in the laboratories or research facilities, materials are used which are harmful to human body, represented by chemical substances. Therefore, it is necessary to secure the human body against toxic substances. To ensure safety, at the laboratories, mass machine ventilation is performed. That is why laboratories are the buildings where the energy consumption is higher than that of general office buildings. In other words, seeing from a sustainable point of view, coexistence of "Safety for the human body" with "Energy saving" should be important themes. Consequently, both safety at laboratories and energy consumption are mentioned as follows at first.•

••• Safety for the Human body in Laboratories

When experiments are performed in laboratories, there might be many occasions where harmful materials breathed into the body or stuck to the skin or the mucous membrane. Accordingly, to control air quality of places around people in experimental area, special mechanical ventilation devices such as fume hood are introduced in laboratories. Safety for the human body is improved by these systems. About the ventilation by the fume hood, Laws, Codes or Regulations prescribe passage air velocity for the opening area of the sash of fume hood (Face velocity (Figure 1)). The above is a reason why ventilated air volume could not be reduced simply. Table 1 lists Codes and Regulations for face velocity.

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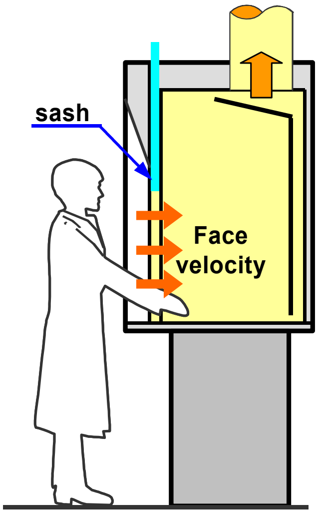

Figure 1• Face Velocity

Table 1• Codes requirements for face velocity

Code	Face velocity
Labor low (Japan)	Min. >• • • • • • • Min. >• • • • • • • Gas• •
• • • • • (Occupational Safety & Health Administration)	Ave. : • • • • • • • • • • • •
• • • • • • • (American Society of Heating, Refrigerating, and Air-Conditioning Engineers)	Ave. • • • • • • • • • • • •
• • • • (American National Standards Institute) • • • • (American Industrial Hygiene Association)	Ave. • • • • • • • • • • • • •
• • • • • (The Scientific Equipment and Furniture Association)	Ave. • • • • • • • • • • • •
• • • • • • (National Fire Protection Association)	Ave. • • • • • • • • • • •

• •• • Energy Consumption in Laboratories

Such as the above-mentioned fume hood, local exhaust facilities and spot ventilation devises perform the forced ventilation, making air flow around people in experimental area. Because a lot of fume hoods are installed in laboratory, there is much amount of energy consumption by air conditioning and ventilation facilities. About air change rate by fresh air intake, laboratories and general office buildings are compared to grasp aspect of energy consumption briefly. Figure 2 shows that fresh air change rate in general office building is around 1• 2AC/h for CO_2 Control, and around 5• 10AC/h for Temperature Control. On the other hands, in laboratories, it amounts to 20• 60AC/h by fume hood In addition, almost all air from Air-Handling-Unit (AHU) is taken form the outdoors, because it is necessary to make up for exhausted air. When the flesh air is taken from outside, it is important to remove the heat load from the air. Therefore energy consumption is huge in laboratories.

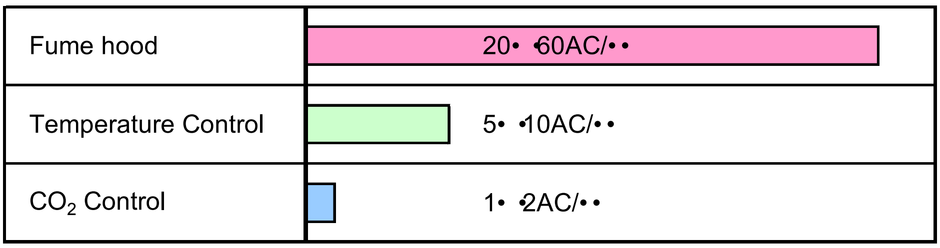

Figure 2• Comparison of Air Change Rate by the difference of the control

•• • Proposed System for Coexistence of the Safety with the Energy Saving from points of sustainability

A fact, that energy is wasted by much quantities of mechanical ventilation, have been accepted, that is to say, safety is made have top priority conventionally. However, recently, it is strongly demanded socially in view of sustainability, that energy saving is necessary to be balanced more while safety is secured fairly In addition, under the circumstance where complexity, advancement and accuracy are required depending on contents of research in recent laboratories, numbers of fume hood installed is increasing, and the operating time becomes irregular. Accordingly, by the operation of the more number of fume hoods, the more outside fresh air to be treated by air conditioning system. As the first step solution, VAV system (Variable Air Volume System) comes to be adopted. The system regulates the air volume matched to the opening area of the sash part of fume hood In the laboratories where a large number of spot ventilation equipments are installed, it is important to design the automatic control systems which function based on "Probability of simultaneous use" for the reduction of building energy consumption. Consequently, in our study, it was examined that design and operation of ventilated air volume does not become superabundant and wasteful. Fume hood is not examined as one piece of article, but it is examined as a part of the whole air conditioning system in the building. Not only the achievement of the energy saving, but also the maximization of the energy consumption efficiency is aimed at.

• •• • **Optimum Design and Operation based on Probability of Simultaneous Use•**

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• •• •• Conventional Independent Exhaust System without Probability of Simultaneous Use•

In Conventional independent exhaust system, constant air volume is exhausted regardless of the opening area of the sash of fume hood. (Figure3) When Fume hood is not in use, indoor air is exhausted from the opening provided at the upper part of the sash. In addition, the exhaust from fume hood is connected to an exhaust fan in a duct system i.e. one-on-one system. (Figure4)

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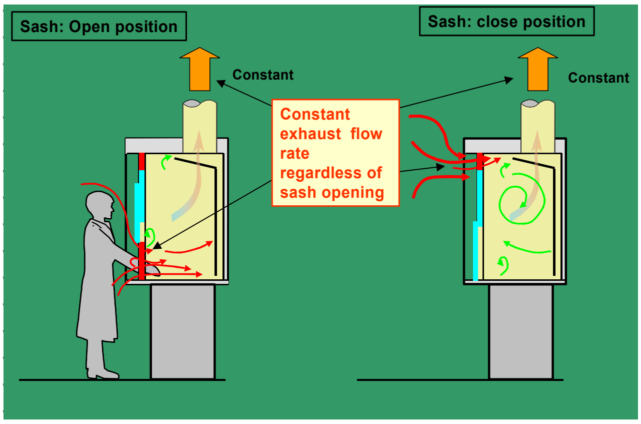

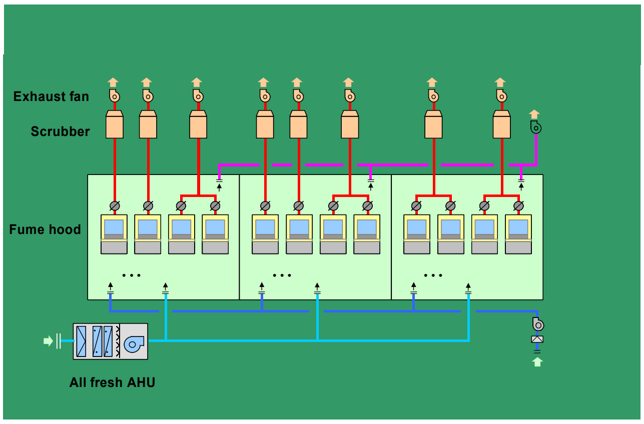

• *Figure 3• Conventional type Fume hood*

Figure 4• Conventional independent exhaust system

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• •• • • Manifold duct + VAV exhaust & supply system•

Because exhaust air volume is regulated by VAV system, controlled based on the opening area of the fume hood's sash, necessary exhaust air volume is set to be properly. (Figure5) In addition, during Standby Mode and Night Mode, exhaust air volume can be changed to perform minimum ventilation. Furthermore, an exhaust fan is not found every fume hood one-on-one, besides manifold duct, which gathers branch air ducts, is installed. As a result, the number of exhaust fans (or, scrubber) is reduced. (Figure6) Because fresh air intake to the laboratories is controlled by VAV system, make-up air volume is minimized.

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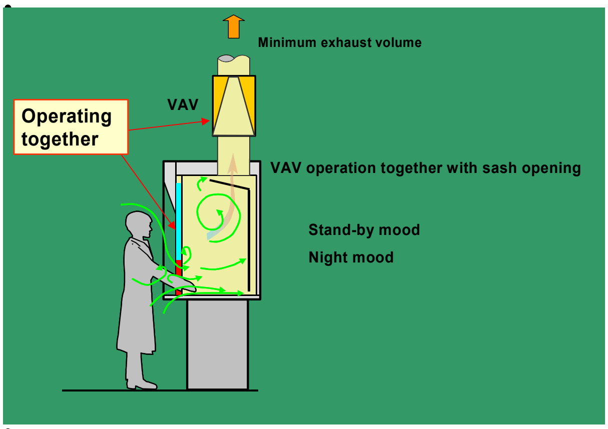

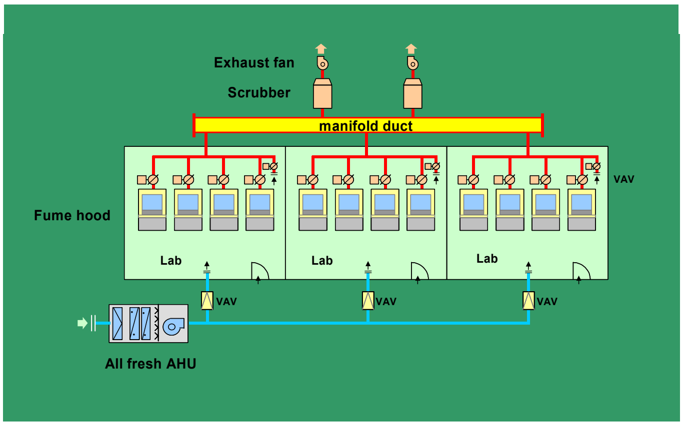

• *Figure 5• VAV exhaust system*
• • • • • • • *Operating with sash*

Figure 6• Manifold duct
• •*VAV exhaust* • •*supply system*

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• •• • • Introduction of demand factor•

Figure7 shows the graph about probability of simultaneous use of fume hoods in lab. Statistical approach for ten Fume hoods was adopted, and demand factor (probability of simultaneous use) was calculated. Concretely, it is binomial distribution that was assumed that parameter (fume hood number) is 10 and demand factor is 10%. In this case, probability that only one of them is used is less than 40%. The simultaneous use more than six of them is not recognized. Accordingly, it is not necessary to make allowances for ability of full ventilation air volume for 100% of fume hoods.•

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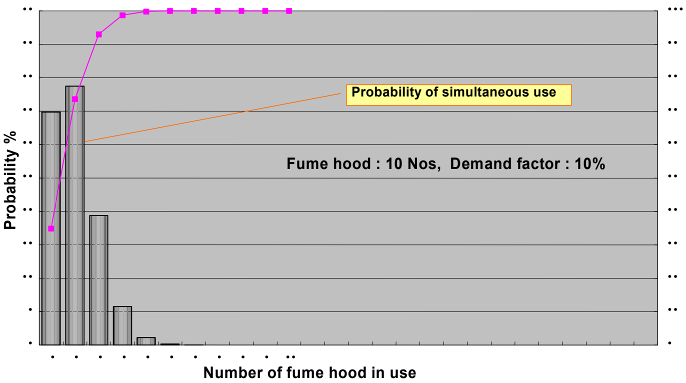
• •• • System Tuning compounded Statistical Method and On-Going-Comissioning (On-Going-Cx) for Accomplishment of the Optimization•

• •• • In case exhaust air volume of laboratory increases, chemical safety improves. On the other hand, energy saving factor deteriorates. Therefore, seeing from the point of view of sustainability, it is important that the most suitable point is found for the both (Chemical Safety and Energy Saving). Figure8 shows this point by a graph. The horizontal axis is Exhaust air volume, and the vertical axis is Performance. The circumstance of the change of Chemical Safety and Energy Saving is made in this graph. In this figure, the point of intersection of each curve is considered to be Optimum Point between Chemical Safety and Energy Saving. The examination result how this Optimum Point is achieved by Commissioning is described in the next clause.



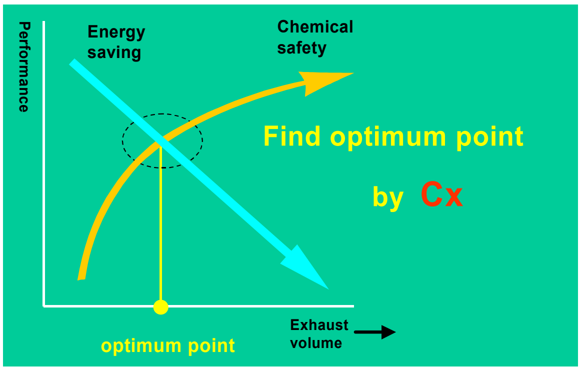
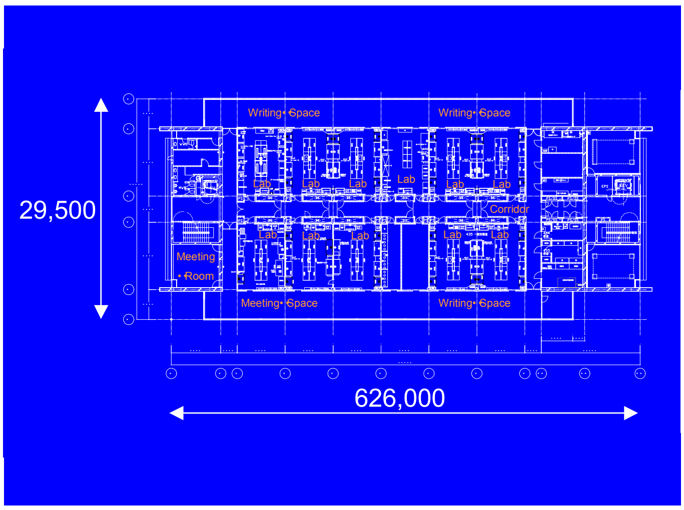


Figure 7• Probability of simultaneous use

Figure 8• • • • • •• • •• •

• •• • A large number of fume hoods are installed in the laboratories. The actual using situation of fume hood was grasped by actual survey. It was aimed that fusion with the system tuning about the air conditioning ventilation facilities of the building. Figure9 shows the plan of the building where actual survey was performed. Figure10 shows monitoring system. Monitoring system was installed in each fume hood, and actual in use situation of fume hoods was recorded. In addition the exhaust air volume by the VAV control system and the fresh air volume to balance the exhaust were also recorded by monitoring system. By this monitoring system, demand factor was found out. Figure11 shows usage of each fume hood. One base exhaust and 17 spot ventilation equipments (Fume hood, Spot Exhaust for Smell) are installed. The simultaneous use of spot ventilation is seven of them at the maximum. A ratio of the number is around 40% of the whole. About fume hood – h, in this graph, it is found that the sash of fume hood was kept in open position.



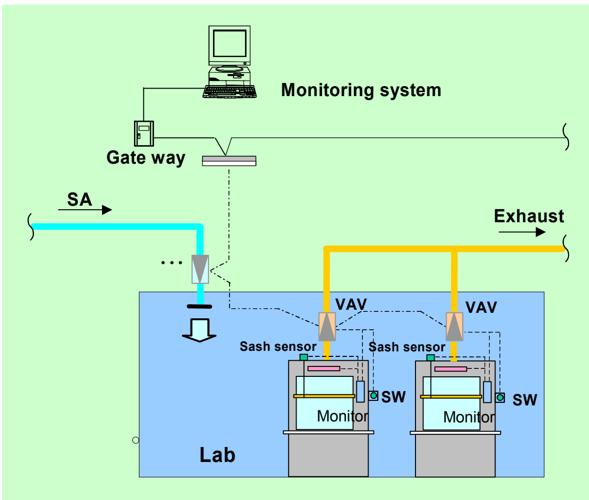


Figure 9• Floor Plan

Figure 10• Verification of diversity factor by monitoring system

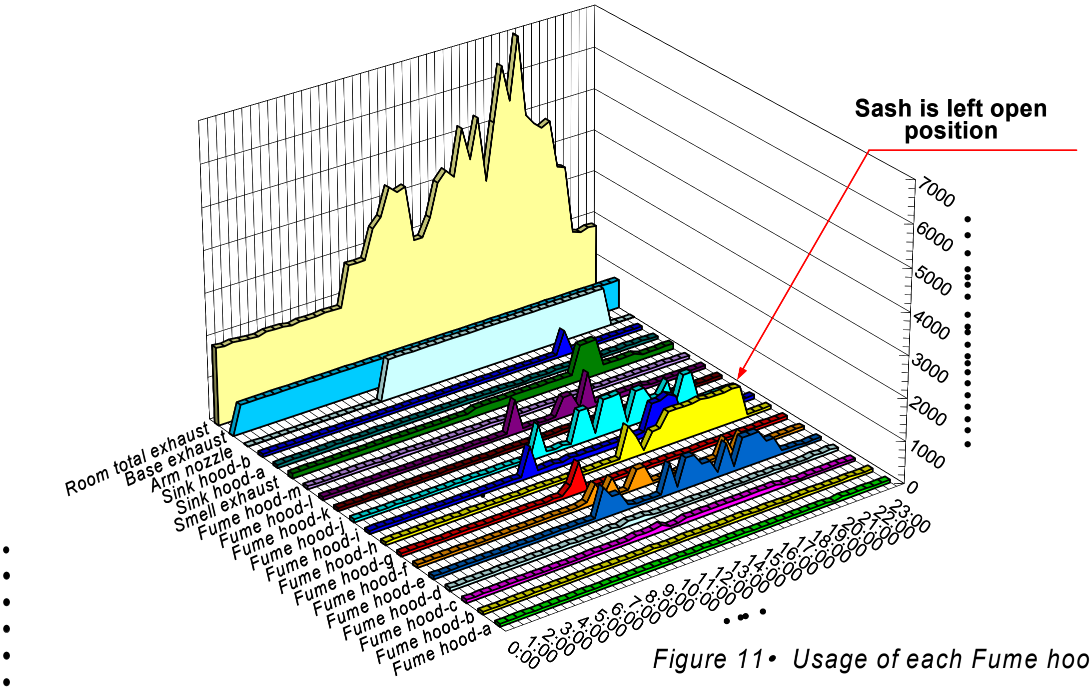


Figure 11• Usage of each Fume hood

• •• • Result of Monitoring•

About above-mentioned system (conventional independent exhaust system / manifold duct + VAV exhaust & supply system), the comparison of the effect for each system was done. Table 2 shows Peak air conditioning load and volume of fresh air intake in each system. Figure 12 and 13 show the trend of demand factor in 24 hours.•

Table 2• Comparison of Peak Load and Fresh Air Intake

No.	system	Peak• Load• •• • • ••		Fresh• Air• Intake •AC• h)
		Cooling	Heating	
1	Conventional• independent• exhaust system	680	528	51(Lab) 25•Lab+Office••
2	Manifold duct + VAV exhaust & supply system	476	364	34(Lab) 17•Lab+Office••
3	Manifold duct + VAV exhaust & supply system• • • Comissioning	305	227	19(Lab) 10•Lab+Office••

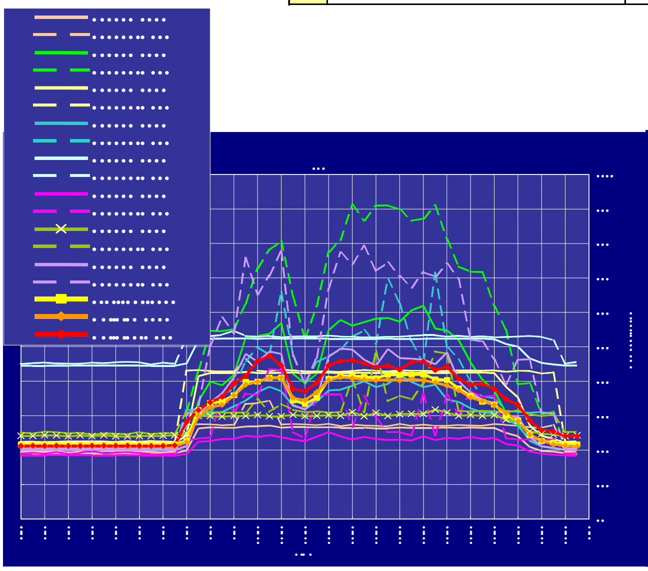


Figure 12• Demand Factor• 1•

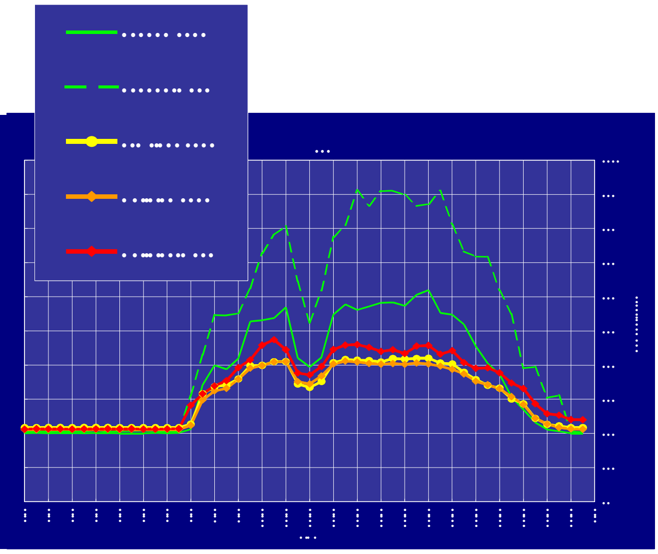


Figure 13• Demand Factor• 2•

About air conditioning and ventilation system, it was put into practice that optimum design and optimum operation based on demand factor which reflects real use frequency of the user. System tuning which combines Statistical Method and On-Going-Cx was put into practice. Figure14 shows a comparison result of the cooling load in each system. The reduction effect by Design phase Cx is 30%. The reduction effect by Construction & Operation phase Cx is 36%. When it was compared with original load by these results, reduction of 55% was accomplished.•

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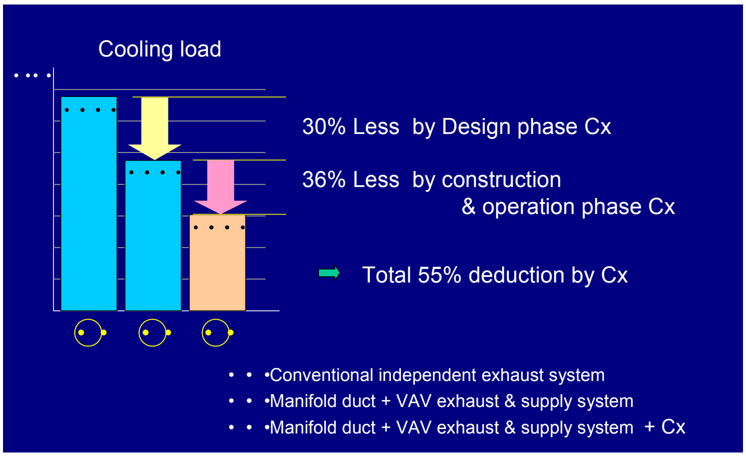

Figure 14• Comparison of Cooling Load

• • •Vision Based on On-Going-Cx

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• •• Proposal of the methodology that aimed at the Fault Detection and the Optimization by On-Going-Cx

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• •• • • Fault Detection System•

For the further improvement of the air conditioning system that leads energy saving, Fault detection systems are studied. The systems make it possible that the coexistence of the energy saving and safety by fault detection system where Building Management System and Building Energy Management System (BEMS) are put into use. About the item to be managed and the method of fault detection, they are divided into two approaches. First one is from indoor environment, second one is from operational condition of the devices (fume hoods).

(1) Approach from indoor environment

This is a fault detection approach where fault is detected by process values of indoor environment. Temperature(degree), relative humidity(• • RH), air pressure deference between rooms(Pa), cleanliness(number of particles/m^3) are nominated items to be monitored. Alert level (upper level / lower level) is settled in building management system. When a process values of the items deviate from alert level, warning is made in real time. Sensors installed for automatic control purpose are utilized for the monitoring purpose mentioned above. It is necessary that the validity of the located place of the sensors to be properly considered. Depending on a case, it is important define method of calculation to obtain a mean value when plural monitoring points are used. About the alarm of the air pressure deference between the rooms, it may arise in two cases. One is air conditioning system trouble, the other is caused by ventilation system for chemical safety. First one to be counter checked by air conditioning system monitoring device. And if the alarm is not arose by air conditioning system, it may considered arose by ventilation system. Second one occurs by ventilation system problem, and also improper user operation. Such as leaving room door open or leaving many fume hood sash open to be considered as example of improper operation.

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(2) Approach from ventilation system itself and operational conditions

Air volume passing in a duct, is monitored by sensors. If it is considered too mach compared with design value, which is based on demand factor, alarm to be made. Besides above, each fume hood has sash opening sensor, then number of fume hoods in operation and opening height of each sash to be monitored for fault detection. This problem is caused by both mechanically and human error. Human error means careless mistake or user's offending against rule, S.O.P (Standard Operating Procedure). For example, in case S.O.P. requests user close a sash of fume hood every time after experimental activities, and if it was not done properly, exhaust air volume would be greater than designed set value. That means excess air is exhausted and energy is wasted, either.

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• •• • • Visualization of Faults for User's easy recognition

With "fault detection" to say here, it means not only finding trouble of the air conditioning and ventilation device, but also finding trouble of the energy consumption (waste of energy). Since behavior of users affect energy consumption directly and seriously, it is thought important to have a user friendly tool complete with visualization that helps researchers in laboratory who use fume hoods realize extraordinary condition immediately by themselves, as well as the operation managers of the building. "Recognizing immediately" leads fast correction of improper usage, and to establish revised S.O.P. Energy saving and chemical safety are not attained until hard ware and soft ware are settled properly. In view of sustainability, especially large

energy consuming facilities such as laboratories, how to improve activities of end user is one of the key issue to be solved.
About visualization, following two categories are listed.
•••The category which identify the condition of the device
- ON or OFF of devise
- Alarms by trouble of devise
- Alarms by unusual number of operating equipments at the same time

•••The category which identify the energy consumption status
- Alarms by monitoring of current energy consumption
  (Alarms when the actual value exceeds the evaluated value)
- Energy consumption of every day, every week, every month
  (Visualization of the data of last year as the comparison value)

Figure15• 17 show the idea of visualization. Figure15 shows the current situation of fume hoods usage. Facility manager is able to be aware of the user's name who causes unusual energy consumption condition. It is necessary to inform user in each occasions, that many number of equipments to operate at the same time, or extraordinary outstanding zone in facility or time of the day. Therefore, to make user pay attention to status of usage and energy saving, visualization is made effectively with the colorful list (ex. orange or red color). Demand factor and number of fume hoods in operation is calculated, on the basis of actual survey value. Time zones with many fume hoods in use are displayed with the calculation results that made use of binominal distribution. Accordingly, prediction warnings are made based on data which were surveyed. If some openings of sash were left open, warning would be made to rectify the situation. These systems are useful for education and prepare guideline or S.O.P for end users. Figure16 shows plan of the building to check the current situation of fume hoods in use. Figure17 shows the list that make people recognize the using situation of fume hoods of the day before. By the accumulation of these data, SOP of management methods will be renewed. And it is possible to change the energy consumption of the building into more effectively

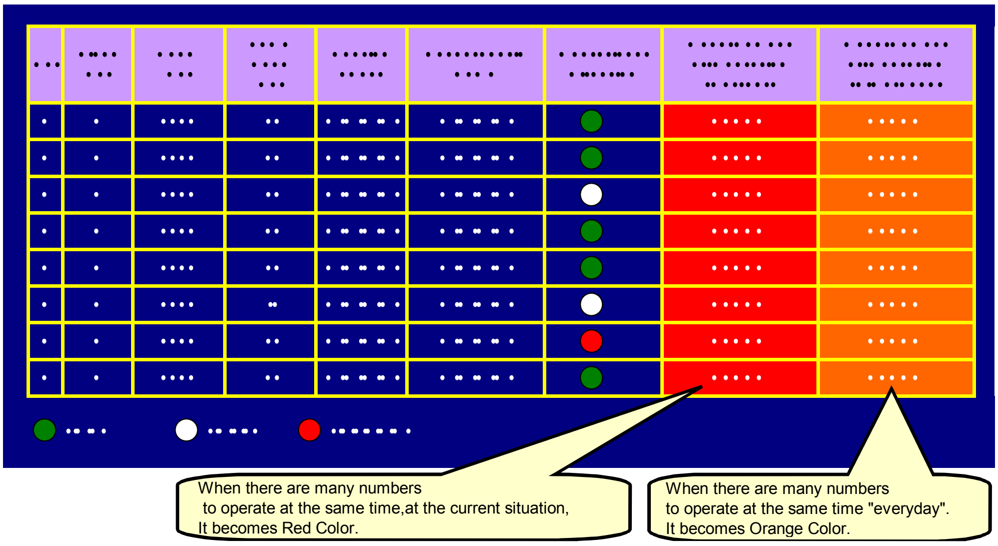

Figure 15• Example of Visualization• 1•

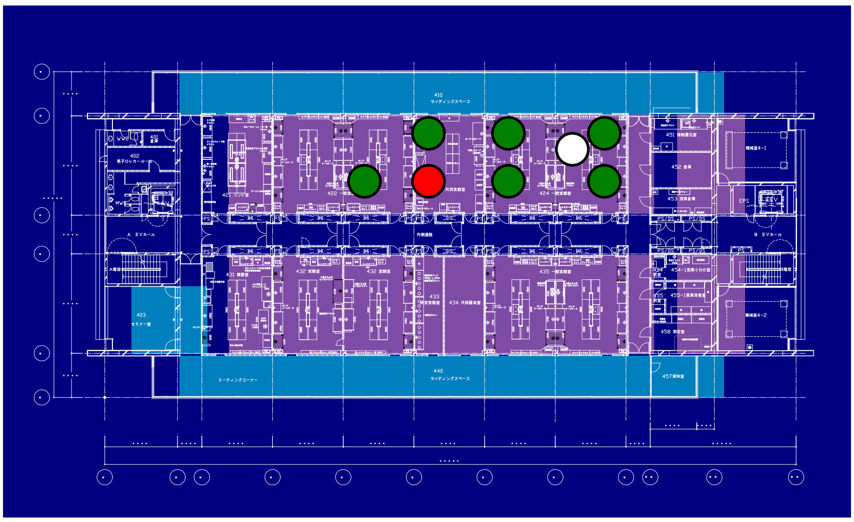

Figure 16• Example of Visualization• 2•

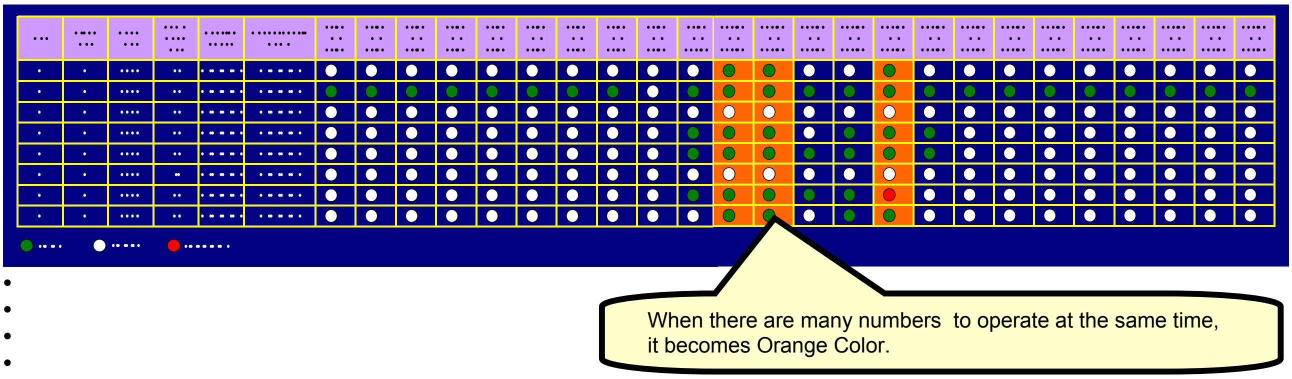

Figure 17• Example of Visualization• 3•

• •• • Conclusion•

On this paper, how to attain coexistence of safety for the human body with energy saving of laboratory for future sustainability was mentioned. Especially, in case of highly energy consuming facilities, it is important to make a careful consideration for both hard ware and soft ware such as users S.O.P. To obtain proper S.O.P., On-Going-Cx is significant. And it is also very important to make facility users prime movers who accomplish energy saving. Visualization tool as a fault detection system that helps user to recognize trouble of energy consumption, was proposed. This system and methodologies are useful for not only laboratories but also factories that require highly energy consuming environment for high productive performance (ex. electric devise, pharmaceutical, food factories). The proposed systems and methodologies may be utilized not only in the large facilities but also small in the others where no facility manager is controlling energy consumption. To make gross energy consumption improvement effective, small facilities improvement is a key issue. In view of the above, it is expected that proposed methodology may contribute to reduction of energy consumption and proper operation.

Reference

Daniel Choinière• "Use of Performance Indices to Facilitate the On-going Commissioning Analysis of Zone Equipment"• Asian Pacific Conference on building Commissioning, October 26, 2007

CONTRIBUTION TO HEATING LOAD REDUCTION IN DOUBLE SKIN ENVELOPE

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Keywords: Double skin envelope, Cavity temperature, Air velocity, Natural ventilation, Energy savings

Summary

The objective of this study is to evaluate the contribution of a double skin envelop for energy saving by natural ventilation in office buildings. A double skin envelop was installed to the east and west façade of the 1st floor in a building which is used as an office facility. Field measurements were conducted to test the performance of the double skin envelope in the winter season. The test was performed on two days that represented a typical clear day and cloudy day respectively.

On the clear sky day, the pattern of temperature variation in the cavity was similar to the intensity of vertical solar irradiance however the temperature variation was not affected by vertical irradiance significantly on the overcast day. The heating load from ventilation could be reduced by heating outdoor air in the cavity. Utilizing the western cavity, the heating load caused by ventilation was reduced by 33.69% on the clear sky day.

1. Introduction

Curtain wall structures covered with glazing are widely used for high-rise buildings since they have some advantage for visual satisfaction and provide an aesthetic exterior. To improve the performance of a glazing curtain wall, double skin envelopes are installed in many buildings. Double skin envelopes provide better thermal insulation and soundproofing than single glazing and they protect the blinds which are installed outdoors to reduce heating load. Energy to preheat outdoor air for ventilation can be reduced. Induced air from outdoors is heated in the cavity of the double skin envelope. In this study, the variation of air temperature in the cavity and air velocity at the inlet and outlet of the cavity were measured to evaluate the performance of double skin envelope for reducing heating load caused by ventilation.

2. Methods

The field measurements were conducted in the building located in Ansan, Korea (Latitude : 37˚ 17', Longitude : 126˚ 49'). The building has three floors and the first and second floors are used for experimental facilities. The third floor is used for offices for researchers and staff. The external appearance of the building and plot plan are shown in Figure 1. The long axis of the building was tilted by 26˚ counterclockwise from the north-south axis as shown in Figure 2.

Figure 1 View of tested building

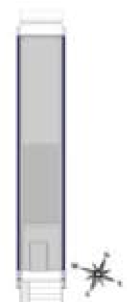

Figure 2 Plot plan

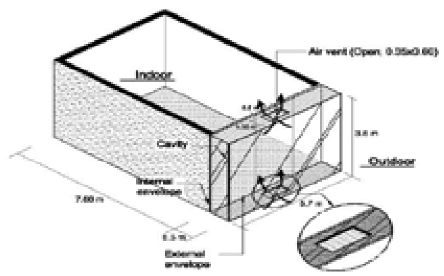

Figure 3 Conceptual description of double skin

Double skin envelopes were installed on the eastern and western façade of the first floor in the building. Glazing is installed both internal and external skins and both sides of the envelope were also covered with glazing to separate them from the adjacent double skin envelope so that the cavity was compartmentalized. The dimension of the double skin envelope is 5.7m (width) by 0.5m (depth) by 3.6m (height) and the conceptual performance of the double skin envelope is shown in Figure 2. Venetian blinds were installed on the outside of the internal skin in the cavity. The blind was set without a tilt angle and its depth was 2.54cm.

The top and bottom of the cavity were covered by transparent plastic panels except for the openings for air inlet and outlet. The dimension of the openings was 0.6m (width) by 0.35m (depth). The air inlet was parted from the ground by 0.3m. Figure 3 shows conceptual description of double skin.

The measurement was conducted in January to evaluate the performance of the double skin envelope for the winter season. Outdoor horizontal and indoor vertical solar irradiance, temperature at the air inlet, outlet and center of the cavity and air velocity at the air inlet and outlet were monitored every one minute.

3. Results

3.1 Solar Irradiance

In this paper, Jan 16th and 17th were selected because they could represent a typical clear sky day and overcast day respectively, and the solar altitude and azimuth of the two days were very similar. On Jan 16th, the maximum solar altitude was 31.72˚ and the solar azimuth varied from -62.88˚ to 62.88˚. On Jan 17th, the maximum altitude was 31.89˚ and the azimuth varied from -63.17˚ to 63.17˚.The variation of solar altitude, horizontal and vertical irradiance on Jan 16th and 17th are shown in Figure 4 and Figure 5 respectively.

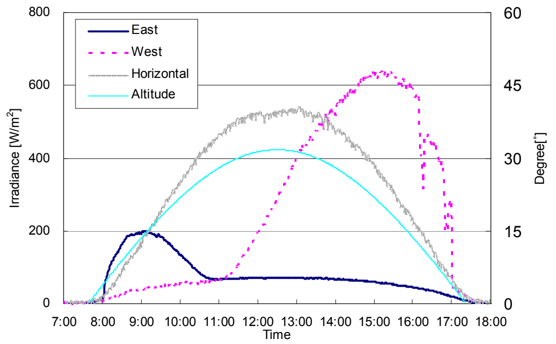

Figure 4 Solar irradiance and altitude on Jan.16th

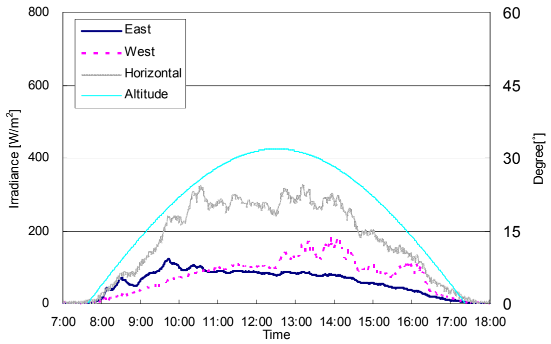

Figure 5 Solar irradiance and altitude on Jan.17th

On the clear sky day, the pattern of outdoor horizontal irradiance was very similar to that of solar altitude and the maximum value of irradiance was 540.12W/m^2 at 13:04 pm. After the sun rose, the vertical irradiance on the eastern envelope increased until 09:06 am up to 199.38 W/m^2. On the western envelope, the vertical irradiance increased radically after 11:00am and its maximum value was 640.84 W/m^2 at 15:17 pm. Since the building was tilted by 26˚ and the azimuth of the sun was -26˚ at 10:50 am

On the overcast day, the outdoor horizontal irradiance increased as the altitude of the sun increased but it was not as intensive as that of the clear sky day. The maximum value was 325.59 W/m^2. Solar altitude was not significant for indoor vertical irradiance. The maximum values of eastern and western irradiance were 122.66 W/m^2 and 184.59 W/m^2 respectively.

3.2 Variation of Temperature and Air Velocity on the Clear Sky Day

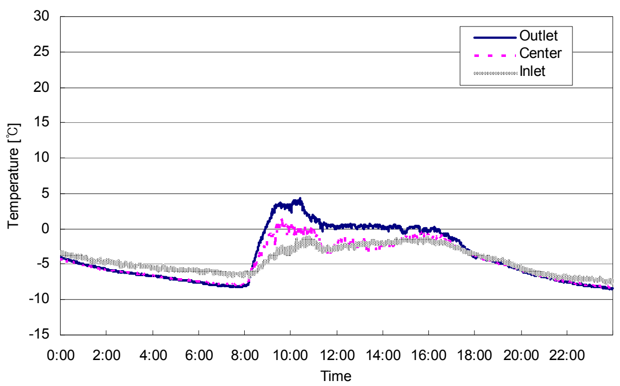

Figure 6 Cavity temperature (East)

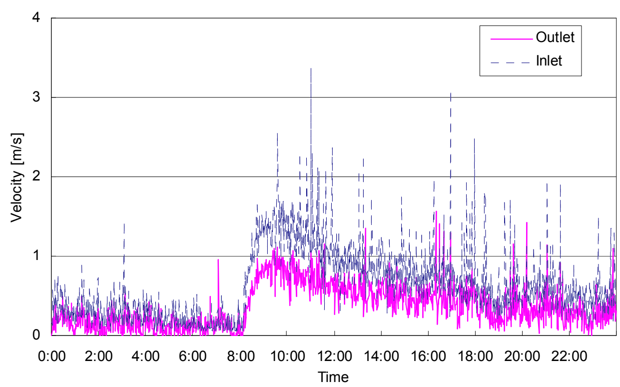

Figure 7 Air velocity at air inlet and outlet (East)

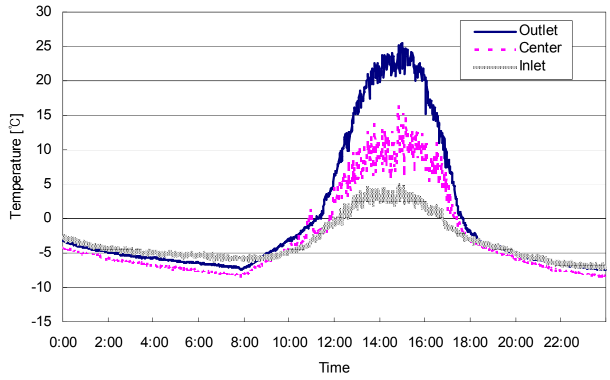

Figure 8 Cavity temperature (West)

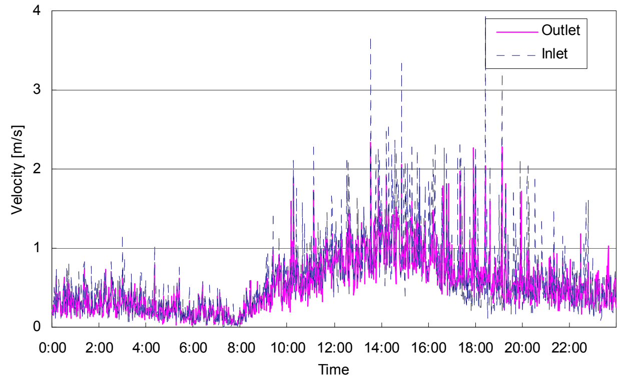

Figure 9 Air velocity at air inlet and outlet (West)

The temperature and air velocity variations on the clear sky day are shown in figure 5 ~ 8. The maximum difference between the air inlet and outlet was 7.61℃ and 22.0℃ in the eastern and western cavity respectively. The pattern of air velocity was similar to that of air temperature in the cavity. Since the temperature difference between the air inlet and outlet generate buoyancy, the greater temperature difference caused the faster air movement. The average air velocity from 09:00 to 18:00 was 0.46 m/s in the eastern cavity and 0.82 m/s in the western cavity.

3.3 Variation of Temperature and Air Velocity on the Overcast Day

Figure 9 ~ 12 show temperature and air velocity on the overcast day. The temperature differences between the air inlet and outlet were not as great as those on the clear sky day. The maximum temperature difference was 5.64℃ in the eastern cavity and 7.23℃ in the western cavity.

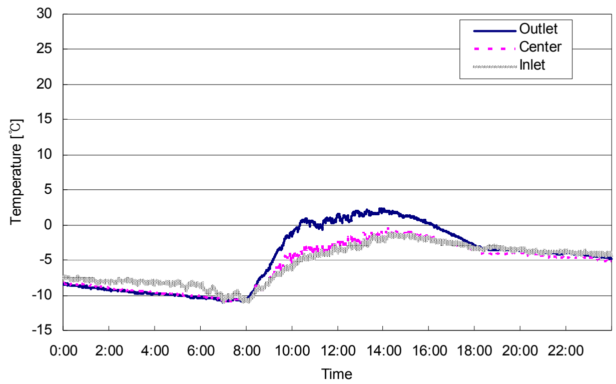

Figure 10 Cavity temperature (East)

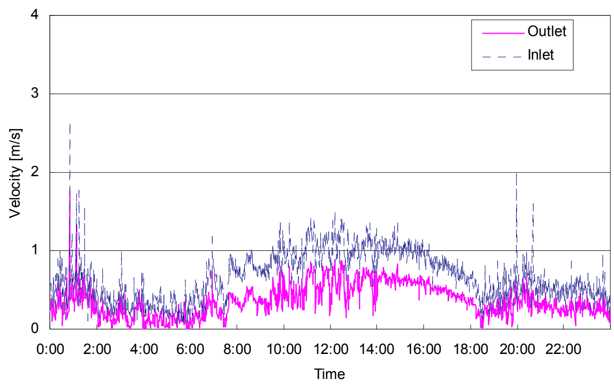

Figure 11 Air velocity at air inlet and outlet (East)

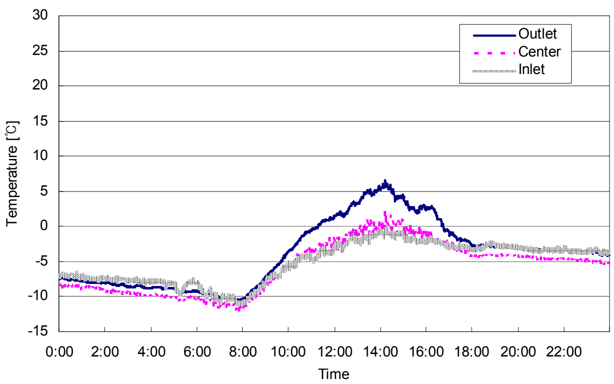

Figure 12 Cavity temperature (West)

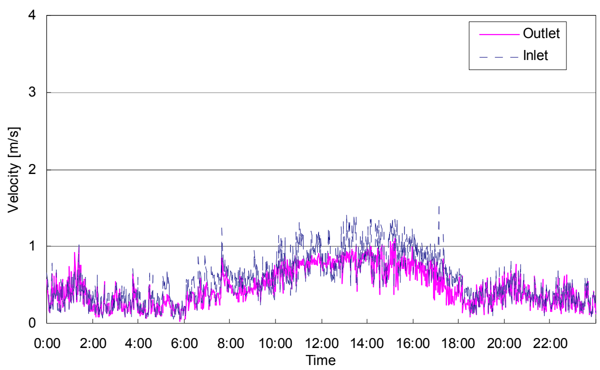

Figure 13 Air velocity at air inlet and outlet (West)

3.4 Reduction of Heating Load

The width and height of the office was the same as those of the double skin envelope and the depth was 7.68 m. The required amount of ventilation was 6,304m^3/h since the ventilation rate for office buildings is regulated at 4 air change rate per hour (ACH) in Korea.

Table 1 Ventilation rate and heating load reduction

	Jan. 16th		Jan. 17th	
	East	West	East	West
Effective amount of ventilation by double skin	4,178m^3	5,198m^3	3,822m^3	4,888m^3
Percent of natural ventilation by double skin	66.28%	82.46%	60.64%	77.55%
Heating load for 4ACH under single skin	203,138KJ	188,237KJ	209,083KJ	207,106KJ
Energy saving by induced ventilation from the cavity	15,025KJ	63,425KJ	14,763KJ	23,451KJ
Heating load reduction under double skin	7.4%	33.69%	7.06%	11.32%

The preheated air in the cavity was considered to be provided to the office. Effective ventilation rate was calculated from the air velocity at the outlet of the cavity. The heating load reduction for ventilation when the double skin envelop was installed was compared with the heating load when the single skin envelope was installed. The reduction of the heating load which was produced by ventilation was shown in Table 1. On the clear sky day, outdoor air of 5,398m^3 was provided to the office by the western cavity and it was 82.46% of required ventilation. In other cases, more than 60% of required ventilation could be provided by the cavity. However, the reduction of the heating load was feeble. In the case of the eastern cavity, the performance on the clear sky day was not definitely distinguished from the performance on the overcast day. It is considered that the cavity was affected by the office since the influence of solar irradiance was relatively weaker than that of the office.

If only sufficiently heated air (warmer than 20℃) was induced to the office to prevent cold draft, the amount of ventilation and heating load reduction would be 1,483m^3 and 34,423KJ when the western cavity was utilized on the clear sky day. In other cases, air temperature in the cavity did not reach 20℃. It is considered that the performance of the double skin envelope for reducing the heating load would be effective when it is applied to a hybrid ventilation system.

4. Conclusions

In this study, field measurements were conducted to evaluate the performance of a double skin envelope in order to reduce the heating load. It appears that the air temperature in the cavity was significantly influenced by vertical irradiance on a clear sky day but on an overcast sky day, the air temperature did not increase as much as that of the clear sky day. The cavity was naturally ventilated because the difference of temperature between the air inlet and outlet generated buoyancy. By utilizing the double skin envelope, the heating load could be reduced. On the clear sky day, 63,425KJ of the heating load was reduced in a day by western cavity and 1,483m^3 of outdoor air which is heated at a temperature warmer than 20℃ could be provided to the office. The performance of the eastern double skin for reducing heating was not significantly influenced by the amount of cloud. A double skin envelope could be effective, therefore, in reducing the heating load when it is applied to hybrid ventilation systems.

Acknowledgement

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ACTIVE HOUSE, AN ALTERNATIVE SUSTAINABLE BUILDING ENVELOPE CONCEPT

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Summary

The present trend in energy efficient sustainable dwellings is the passive house concept. Within the passive house concept every effort is made to minimize the energy use. Substantial savings can be achieved by passive energy systems, especially natural ventilation, summer shading and winter solar heat gain. The development of sustainable buildings is driven by the need to preserve the balance of nature. The ventilation capacity of many of these passive houses is critical. During a three week period different measurements in three of the first passive houses projects in Netherlands were undertaken to define indoor air quality and thermal comfort. Results showed that in some cases ventilation was completely insufficient. Energy saving and sustainability is very important but not at the risk of endangering health of the occupants. This was the starting point for a new approach, which led to an active house concept. By using ground air collectors, labyrinth foundation, muro-causter and hypo-causter, the whole building envelope and construction is thermally activated by natural pre-cooled air in the summer and natural pre-heated air in winter. A first design is presented to illustrate the concept.

1. Introduction

Over the last years average global temperatures have risen. Global warming, caused largely by carbondioxide emissions as a result of energy consumption, shows an increasing effect. Climate change is becoming a major problem. As results of Global Warming [Alley R. et.al. 2007] become more and more prominent, it is necessary to look for new possibilities to save energy and to generate sustainable energy to be used for comfort in the built environment. It is generally recognized that as the existing housing stock is responsible for a large share of the total energy consumption energy savings have to implied to new (re)construction activities. The European Commission reports that the energy demand in households accounts for 25% of the final energy needs in the European Unity. The latest trend on low energy housing is the Passive House. In Germany and Austria more than 5.000 Passive houses have been built and a lot experience was gained. Also in other European countries the passive house concept is promoted, still only a few houses in the other countries have been built. Designing and building of passive houses in a country is not a matter of straight forward following the experience of the already built examples from Germany or Austria. Each country has its own building tradition, architecture, building technologies, climate and culture. Architect and builders are familiar with local construction materials and detailed solutions which were developed to meet the specific building codes and standards of a country (Kaan en de Boer 2006). In France as an example only a few passive houses have been built (Thiers and Peuportier 2008), mainly for experimental purposes and the first attempt to reach the Passive House standard in France has failed (CEPHEUS project in Rennes (Feist et al., 2005)).

The Passive House concept is a relatively low cost method to achieve these energy savings (Storm et.al. 2005). The general definition of a Passive House is that the energy consumption is limited to around maximum 15 kWh/m² for space heating and around maximum total of 120 kWh primary energy/m² for heating, domestic hot water and electrical consumption by electrical equipment and lighting. To meet these criteria, the Passive House concept focuses first and foremost on reducing the energy demand of the building. Analysis of Passive House solutions shows high priority with regard to the performance of the thermal envelope: high insulation of walls, roofs, floors and windows/doors, thermal bridge-free construction and air tightness (Storm et.al 2006). At present in the Netherlands there is the PEP (Promotion of European Passive houses) project, in which ECN (the Energy research Centre Netherlands) and DHV, a Dutch consulting engineering firm, participate. In the Netherlands architect Erik Franke has built the first Passive Houses in the Netherlands according to the 'Passivhaus Projectierungs Paket'(PhPP) (Franke 2005). The

PhPP is a package of tools for architects to help them with the design of passive houses and was developed by the German 'Passivehaus Instituut' in Darmstad. In Germany, the Passiv Haus Institut took the traditional concept of passive solar building as a starting point and developed concepts for very low energy buildings by combining the principles with a very well insulated and air thight building envelope (Kaan & de Boer 2005).

1.1 The Dutch present situation

Though in the Netherlands a number of houses have been built according to PhPP, the actual performance of these houses was not yet thoroughly investigated. The aim of a study at the Technische Universiteit Eindhoven was to investigate if the ventilation levels reached by the installed mechanical ventilation systems in these Dutch passiv houses are sufficient (Balvers et.al. 2008). For the study three project of the Duth architect Erik Franke, a pionier on Passive Houses in the Netherlands, were chosen. Case 1 existed of one of the 12 houses that were built against the inener slope of a river dike. One of the main objectives of this original solar project was to prove that solar houses, designed and based on passive house technology, can compete in the housing market in the Netherlands on price, quality and comfort (IEA 2003). Case 2 and 3 were villas in which the used technology was also based on passive house technology. The study consisted of three methods for collecting data:

- a questionnaire to filled in by the main resident to gather information regarding use and maintenance of the ventilation system
- measurements during a period of 14 to 21 days of air flow, temperature, relative humidity and indicators of air pollution such as carbon dioxide, carbon monoxide and formaldehyde
- a logbook in which the residents kept a logbook to note specific events and changes in behaviour that might have influenced indoor air quality

The results of the measurements are given in table 1. Average airflow in use was in all cases lower than recommended by the Dutch Building Code while the capacity installed is proficient. Some high levels of carbon dioxide were recorded. CO levels in case 2 showed daily peaks around late afternoon and case showed only peaks when there were guest smoking inside the house. For the concentration of formaldehyde both cases and 2 showed distinct almost daily peaks in indoor formaldehyde concentration.

Table 1 Information on Dutch passive houses and measurement results (Balvers et al. 2008)

	Case 1	Case 2	case 3
Town	Sliedrecht	Dalem	Duiven
Type of house	Terraced house	Villa	Villa
Total gross volume m²	512	544	720
Total gross floor area m²	145	155	185
Year of completion	2004	2000	2004
Number of residents	3	3	4
Average U-value construction W/m²K	0,116	0,115	0,122-0,124
Ventilation rate in m³/h ± 2			
Bedroom 1 (2 persons)	18	blocked	13
Bedroom 2	15	23	6,5
Bedroom 3	n/a	n/a	5,5
Bathroom	30/62	20	8
Total air flow	63/110	96	62
Average night time CO2 level(ppm)			
Bedroom 1 (2 persons)	800	750	950
Bedroom 2	800	700	1650
Bedroom 3	n/a	n/a	900

The use and application of mechanical ventilation systems in such low-energy house is the critical aspect for creating an acceptable level of IAQ. The installed mechanical ventilation systems have three different setting of operation;

- level 1, used when no one is home
- level 2, standard operation when there are people at home
- level 3, designed for times of high levels of pollution

The mechanical ventilation system of all houses was by default on setting 1, even when people were at home. The residents of Duiven even turned their ventilation completely down to further reduce energy consumption. This while the functioning of the mechanical ventilation system is essential for maintaining a good IAQ. From this information it is concluded that the residents played an important role in the reached level of IAQ in their own houses.

The building needs to be passive to the external climate change and by good insulation minimize energy exchange with the outside. To reduce the energy use of buildings for heating, besides good insulation, a high level of building air tightness is necessary. Natural ventilation is strongly reduced by these measures and this has to be compensated by additional mechanical ventilation. Due to the required air tightness special attention should be paid to indoor air quality through adequate ventilation. Good ventilation is necessary for a good indoor air quality and to prevent moisture problems.

For good insulated low energy houses the needed heating energy for the ventilation air is around 50 to 65% of the total heat demand (Pottler et.al. 1999). This is the reason that often the ventilation are strongly reduced, some mention valuesas low as a ventilation rate of 0,4(de Boer et.al 2005). There is a competition between energy saving on the one hand and a good indoor air quality on the other hand. Storm et.al (20060 state; "However, since Passive Houses have air tightness, sufficient ventilation must be paid to the actual realization in practice of the required ventilation rate."

As stated by Kenda (2006), modern buildings do not breathe: the quality of air in contemporary architecture has negative consequences for the inhabitant's physical and mental state. Her study focuses on the beneficial integration of architecture and medicine in Renaissance Italy: Sixteenth century pneumatic architecture, especially the examples of hygienico-pneumatic villas. The villas are connected underground by labyrinth caves and wind channels to provide a unique natural ventilation system. The study of Renaissance pneumatic architecture suggests a critique of modern architectural models (Kenda 2006);" *Despite the rhetoric of "functionalism," the most iconic examples of modernist architecture often emphasize the individualistic expression of the architect rather than to promote the actual well-being of the inhabitants. With the recent revival of interest in traditional and environmentally sustainable architectural styles, there is now an opportunity to revive the therapeutic aspects of building well, so fundamental for the art of living well.*" These principles are taken as a basis and translated to modern demands.

2. Methodology; The use of accumulative capacity to save energy

2.1 Active versus passive

As the present passive house concept has some critical aspect related to adequate ventilation, we started to look at other ways for building to utilize the available on-site energy resources in a way that minimizes the need for purchased energy and still maintaining a satisfactory indoor environment.
Besides passive systems with their direct interaction between the building fabric and the environment, which do not produce power and do not need any mechanical devices or significant mechanical energy in order to operate, there are also active systems.
Active systems are designed to utilize the environment to either produce power, or to operate in conjunction with some mechanical devices to utilize renewable energy to provide heating and cooling (Wachenfeldt and Bell 2003). The direct inter-action between the building fabric and the environment in offers many possibilities to reduce the need for additional energy for conditioning in order to achieve the desired comfort and cover the residual demand. It is difficult to categorize the various active systems from true passive systems because they often combine strategies for power generation, passive cooling, passive heating as well as heat storage, heat recovery or avoidance of the various external and internal heat gains (Wachenfeldt and Bell 2003).
A modern variant is the use of the accumulative capacity of concrete constructions to flatten and damp the effect of fast changing outdoor temperatures. One of the first applications of a 'thermolabyrinth' was the 1977 Royal Academy of Music complex in London existing of theatres and music studios by Bill Holdsworth (Holdsworth 2005). Also in Germany there are several project with so called 'Thermo labyrinth' systems built, par example Stadttheater Heilbron and Terminal 1 Hamburg Airport. Recently in Australia there is built Federation Square in Melborne. In this project the outside air is led in a labyrinth under the square and blown into the atrium of the main building (Bellew 2004, AIRAH 2003). By doing this a significant cooling effect was realized.
An interesting modern technology related to the principles of 'thermo labyrinth'systems are earth-air heat exchangers, or ground tubes, or ground-coupled air heat exchangers (De Paepe and Janssens 2003). In the Netherlands only a few of these systems were applied, e.g. the firebrigade stations of Deventer and Soest by the architect Jòn Kristinsson (Kristinsson 2002). In Germany this principle is far more popular and applied in many buildings and passive houses (Pfafferot 1998), mostly with concrete or HDPE tubes as ground collectors.

2.2 Thermal capacitive active ventilation systems

There are ventilation systems which supply air through the concrete ceiling and so use the thermal capacity of the concrete. Of these systems there are different types, such as the ThermoDeck system Barton et al. 2001), or the Energon system (Piggins 1990). Termodeck, developed by two Swedish engineers Mr.Loa

Andersson and Mr E.Isfalt in the 1970s, uses the slab as a means of ducting ventilation through the building through oval or round shaped ducts (hollow-cores) within the concrete structure (Wachenfeldt and Bell 2003). In summer supply air fans at night bring in the cool air into the hollow slabs to cool the building and the warm outside air is cooled in the daytime. It utilizes the hollow cores within pre-cast concrete floor slabs as ventilation ducts to produce an environment which is thermally stable (Barton et al., 2002)
The TermoDeck system relies on heat being exchanged between the air in the core to the concrete of the slab, through the interface which is the surface of the core. Heat is conducted radially through the concrete from this interface until it reaches the surface (top and bottom of the slab) or to where the temperature gradient becomes small—in the horizontal direction between cores. As the temperature difference between the cores is relatively low, the high heat capacity of the concrete means that it is possible to neglect the influence of adjacent cores (Barton et al. 2002), see figure 1.

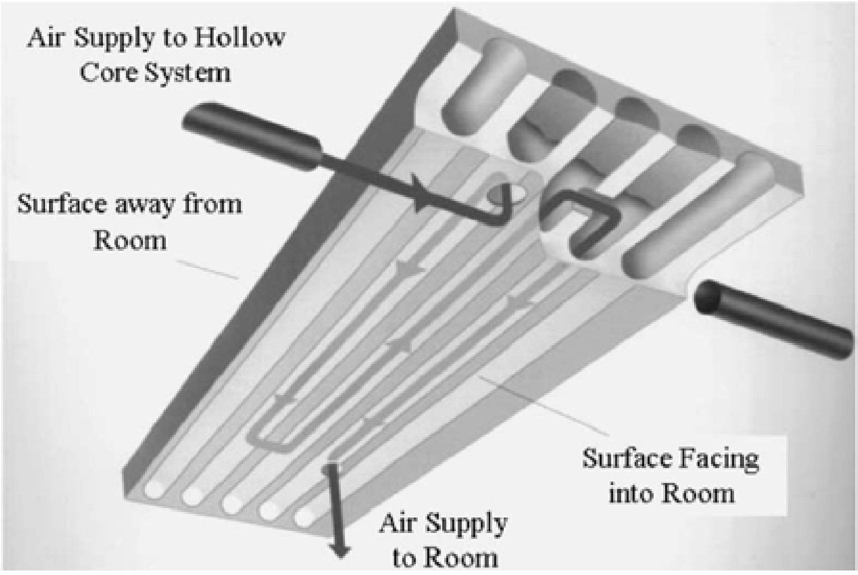

Figure 1 The ThermoDeck system (Barton et al. 2002)

The TermoDeck system employs low air velocities (i.e. approximately 1 m/s) with the result that buildings using this system tend to consume little energy (Barton et al. 2002). For example, the Elizabeth Fry Building consumes very little energy; its average electrical energy consumption for 1997 was only 61 kWh/m2 and its gas consumption was 37 kWh/m2 (Standeven et.al1998), figures which are less than half of the targets values for good practice air conditioned office buildings in the UK (DETR 1998). Typical energy consumption for heating and ventilation for the UK is around 200 kWh/m2./y (Wachenfeldt and Bell 2003). The Elizabeth Fry Building (John Miller and Partners) uses mechanical ventilation with heating and no mechanical cooling at all. Mixed flow ventilation is used throughout the building except the Lecture Theatre where displacement ventilation is used (Wachenfeldt and Bell 2003). The building was monitored for energy consumption and occupant satisfaction by the Professional Organization of Building Examiners (PROBE) team: it was perceived by its occupants to be a particularly comfortable building (Bordass et al. 1999).The PROBE team conclude that of 12 recently constructed buildings in the UK the Elisabeth Fry building had the highest occupant comfort scores and are also recorded the highest comfort scores recorded by the independent survey specialists Building Use Studies (Wachenfeldt and Bell 2003).

In Norway, the TermoDeck system was installed in some buildings in the early 80's. The thermal performance was reported to be good. However, various problems were identified (Wachenfeldt and Bell 2003).:
- Smell and dust from the un-treated concrete ducts.
- The connections between the ducts were not tight, resulting airflow at unwanted places and reduced performance.
- The ventilation systems were often under-sized, resulting in insufficient ventilation airflow to maintain comfort.

Due to these above mentioned problems, since the 1990s , there have been installed few, if any, ThermoDeck systems in Norway (Wachenfeldt and Bell 2003). Most of the TermoDeck systems delivered before this period have been rebuilt in order to increase the airflow rates and avoid especially the problem with concrete dust. The ducts within the concrete structure have therefore been abandoned, and were replaced by regular HVAC duct systems.

A concept to use the accumulation capacity of a building in combination with its envelope is the Lega beam Building System (Toft 1993). Hereby between the outer and inner building walls a concrete core is placed, see figure 2 A and B. In the space between the walls and the concrete core air flows which can also be cooled of heated with a ground-air collector.

In the early nineties the Fraunhofer Institute für Bauphysik studied a similar concept for a hybrid hollow-corefloor-slab-wall-air-collector system with passive discharge to the rooms above and below the slab (Becker 1995, Becker 1997). Figure 2 C presents a scheme of the system, that includes a horizontal hollow-core slab and vertical collectors. The basic repetitious module has a width of twice the core distance. The warmed air enters the slab from the collector through the southern end of one core, is pulled in and pushed through by means of a ventilator, and after discharging heat into the slab's concrete mass it returns to the collector through the southern end of the other core, with a lower temperature than at the collector's outlet (Becker 1995).

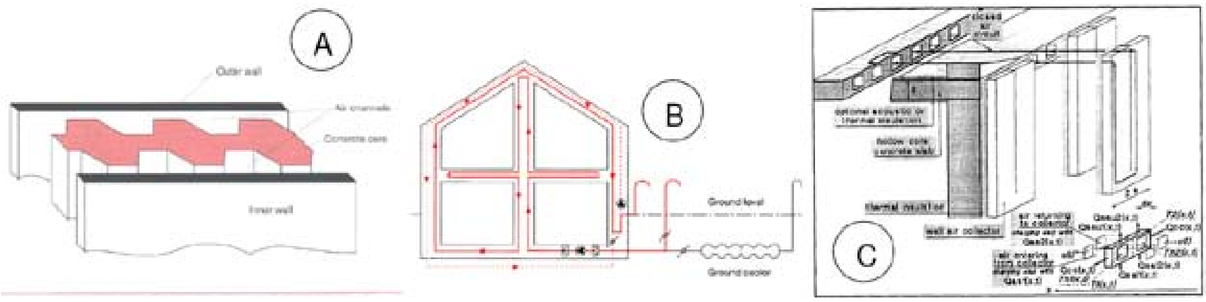

Figure 2 A & B. Legabeam Building Systeem (Toft 1993), 2 C. Scheme of hybrid slab-collector system, basic repetitious module, and basic slab slice (Becker 1995).

In the air ducts in the ground of the ground-air collectors and also in the labyrinth foundation by cooling of supply air, high relative humidity can occur. Often because of this effect air out these air-ground collectors is some what steel and not that suited to supply directly to the rooms. Especially at humid days there is condensation (Koene & Lightart 2001) When there is a long period of high relative humidity of condensation there is no way to avoid bacteria growth.

By these systems there is contact between the fresh outside air and the concrete, something which we think is not optimal, as dust and participles from the concrete can easily absorbed by the air. A system which does not have that drawback is the ConcreteCool system: concrete core cooling with supply air utilizes the high storage capacity of the concrete ceiling with aluminum ducts within the concrete. The supply air flows through the cooling tubes consisting of aluminum with high thermal conductivity.. To improve the heat transfer from the tube to the air, the inner surface was tripled. This system is already used in several German projects (Schröder 2002, Kiefer 2003), see figure 3.

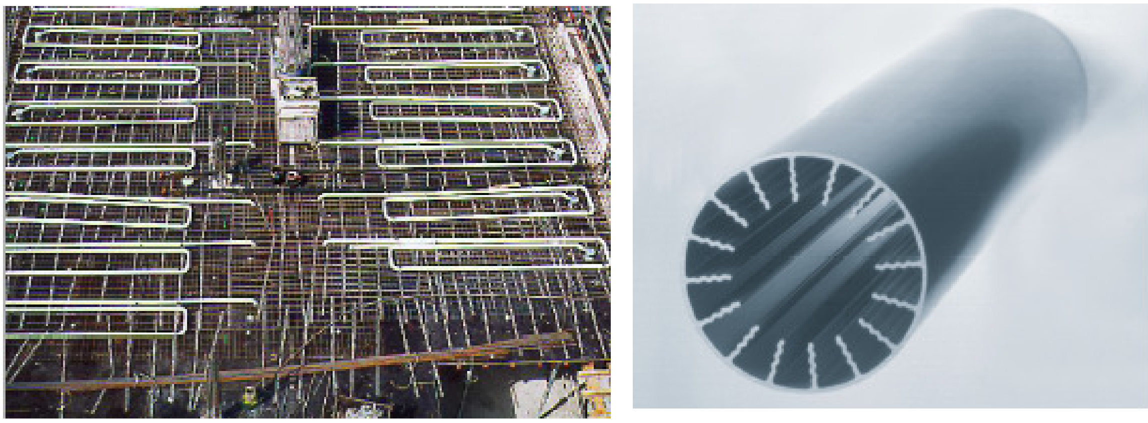

Figure 3 The concrete core activating system ConcreteCool

These systems, in which only air is used to condition the rooms, are based on ideas which can be traced to the Romans, see figure .Sometimes it is good to go back all the way to the beginning, the basis. The basis of conditioning buildings lays with the Greek and Romans. The Greek historian Xenophon mentioned the teaching of the Greek philosopher Socrates (470-399 BC) about the correct orientation of dwellings to have them cool in summer and warm in winter. The Romans pioneered with heating using double hollow floors through whose core the hot fumes of a fire were passed (Florides et.al 2002). They used with their 'hypocaust' and 'murocaust' the materials of the build construction to condition the building with hot air, see figure 4.

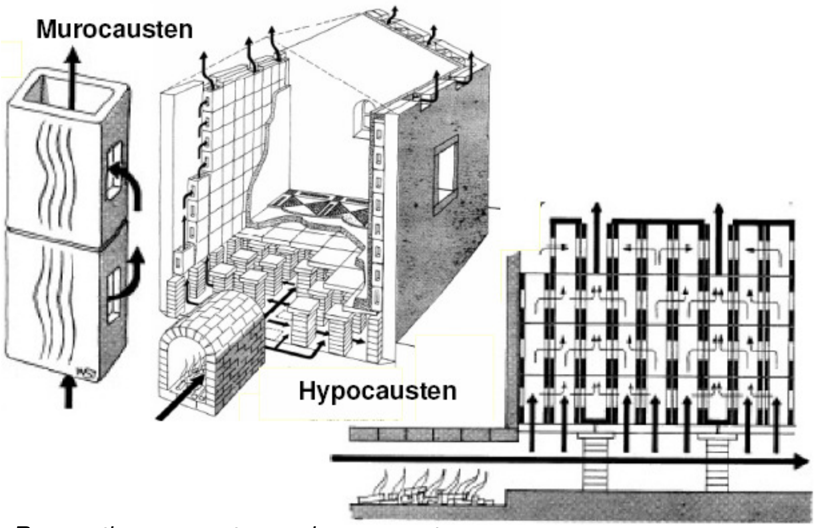

Figure 4 The Roman thermocausten and murocausten system

Since two thousand ears B.C. Mediterrian area has been a place where different architectonic cultures spread. People ruled by Romans assimilated their building techniques and technologies that became one thing with the local ones (Sansone 1999). The basic principles of orientation were known by Romans and they applied them to optimal valuing the effects. The planimetric distribution of the domus and its placing of the rooms was to optimize the influence of the sun rays according to the sun heights and the termic gap between morning and evening temperature. The *domus* often had a complex technological system to carry out what is like a modern centralized heating system. The system is generally called 'hypocaust', that means underground conditioning, in which a particular structure allows hot air to circulate under the floor (Sansone 1999).

BINE Informationsdienst, a service of the Fachinformationszentrum (FIZ) Karlsruhe GmbH and subsidized by the Bundesministerium für Wirtschaft und Technologie (BINE 2006) gives a overview of a few modern principles, of which some already have been applied in projects: Lutzstrassen Apartments in Berlin (Hastings and Mørk 1999) and Gardstens Bostäder aparmentscomplex in Gothenburg (SHINE 2006). These are systems which supply the heat of a thermal suncollector to the floors or walls, see figure 5.

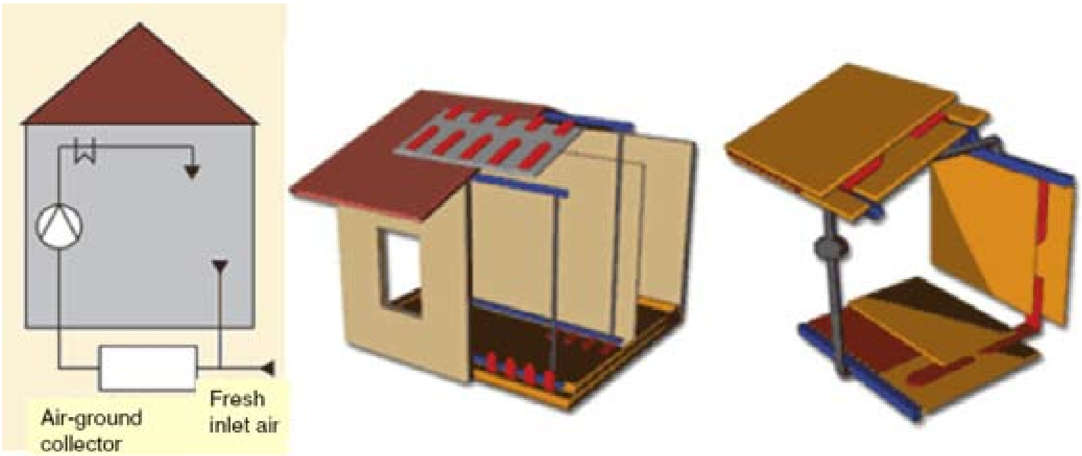

Figure 5 Modern principles of hypocausten and muro cuasten (BINE 2006).

Heat from air collectors can be transferred to mass using the room air, or, as in the Lutzstrassed Apartments in Berlin, warmed air can be blown, using fans, through hollow cores in a massive floor, called a *hypocaust* (Hastings, 1999, pp. 92-95), see figure 6 A.. Architects from the Institute for Building, Environment, and Solar Research designed the building with a closed loop from collectors in the south facade through tubes embedded in the concrete floor, and back to the collector. Discharge is by radiant transfer through the slab. This has the advantage of keeping the indoor air temperature from rising rapidly when the collector is heated by the sun.

In the apartment Block in Gothenburg, Sweden, by Christer Nordstrom ((Hastings and Mørk 1999)) air warmed from rooftop collectors is ducted by mechanical ventilation to a *murocaust* cavity in the external walls, formed by adding an insulated layer outside the existing not insulated masonry wall, see figure 6 B and C.

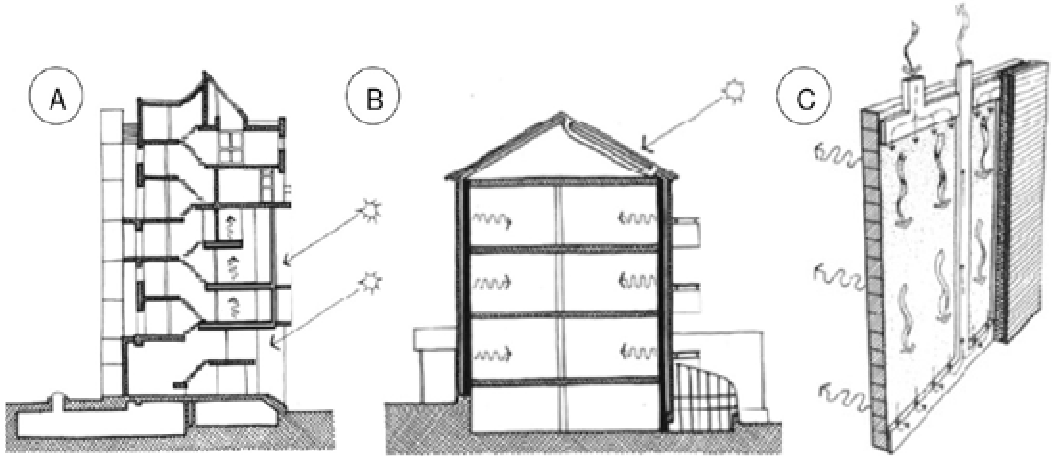

Figure 6 A Hypocaust in the Lutzstrassed Berlin: 6 B and 6 C Murocaust apartment Block in Gothenburg (Hastings and Mørk 1999)

3. Proposed active envelope solution; Active House

To avoid the negative effects of this possible bacteria growth the choice is been made for a separate system with strict moisture barriers by aluminum ducts in the buildings constructions, which carries the air through floors and walls. With a heat exchanger energy is exchanged between supply air and exhaust air, so there is no direct contact between the air directly blown into the rooms and air which went through the air-ground collector and the labyrint foundation. In our proposed system the outside air is let through a ground-air collector and through a labyrinth foundation into the building. There is a separation of the air into one straim used for ventilation and one stream for conditioning. The air for ventilation is supplied into the rooms through a separate floorcooling system. The air for the conditioning is used to cool or heat the total building envelope. The ground with its nearly constant temperature is used as source for cooling or heating for the floors, walls and ceilings. Activating of the buildings'enveloppe by air supplied concrete core can be done with the ConcreteCool systems of e.g. Kiefer in combination of hypocausten and murocausten, see the schematic in figure 7 .

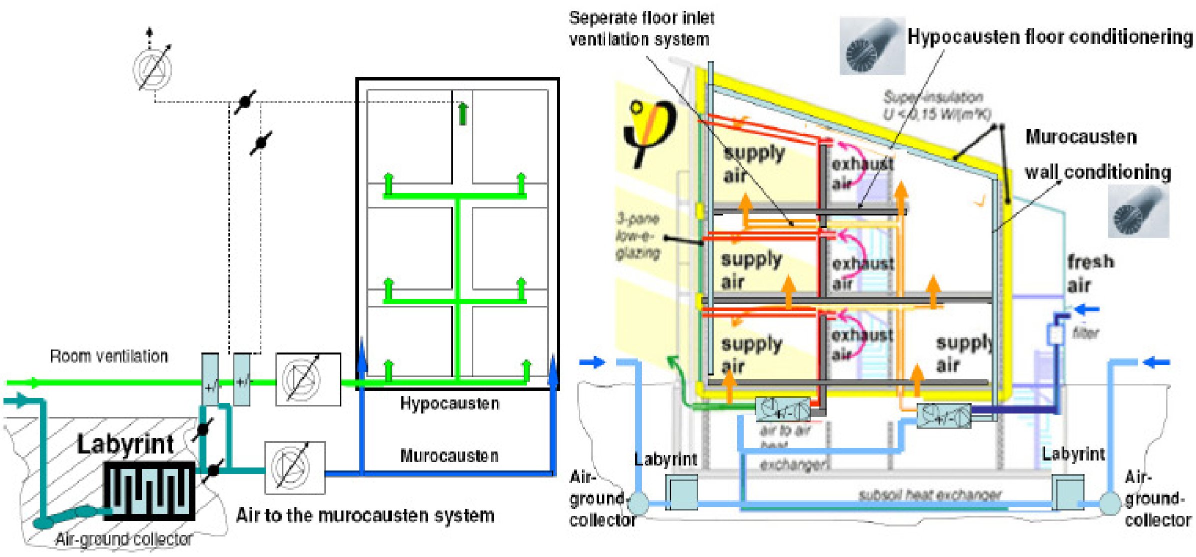

Figure 7 Principe schematic of the hypocausten /murocausten system in combination with air-ground collector and labyrinth foundation collector.

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AN EXPERIMENTAL STUDY OF AIR-TYPE PVT COLLECTOR WITH PERFORMANCE IMPROVEMENTS

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Keywords: roof-integrated PV Thermal collector model, performance comparison, thermal performance, electrical performance, radiant aluminum fin

Summary

The integration of PV modules into building facades or roofs can raise their temperature and thus decrease the power generation of the PV system. The hot air can be extracted from the space between PV modules and the building envelope and can be used as a heat source in buildings. The release of hot air from this space will enhance the performance of the BIPV system as it lowers the temperature of the PV modules. The type of solar collector that utilizes these two factors is known as a PVT (photovoltaic/thermal) solar collector. This paper compares the experimental performance of two different types of air-type PVT collectors that can be integrated into a roof structure: a base case with a 10cm gap for forced ventilation and another type with aluminum fins attached to a PV module to enhance the thermal performance of the module. The experimental results showed that the base case had an overall efficiency rating of 41.9% and the improved unit with aluminum fins showed 49.5% efficiency. For these types of air-type PVT collectors, forced ventilation of the air space improves the electrical performance as well as the thermal performance, and the fins help to improve the overall performance as they work as a radiating plate.

1. Introduction

The high temperature of PV modules reduces the efficiency of a PV system. In particular, BIPV systems appear to be more vulnerable to the PV module temperature, as they are attached to building surfaces. The extraction of heat from the space between building envelope and PV modules will increase the efficiency of the PV systems as it lowers the PV module temperature. It is also possible to utilize the extracted heat as a heat source for buildings. In addition to the improvement of the electrical performance of BIPV systems by the removal of the heat, the thermal collection through heating mediums such as air and water can be achieved with the device known as a photovoltaic-thermal (PVT) combined collector. To enhance the performance of the PVT collectors, it is important to collect higher thermal energy. Several works have sought to increase the air temperature from PVT collectors[1 2 3].

Thus, this study compares the experimental performance of roof-integrated PVT collectors that collect hot air from the space between the roofing surface and PV modules. There are two types of PVT collectors in this study: a prototype of a PVT collector on a sloped roof using PV modules and an improved model with aluminum fins attached to PV modules. Their thermal and electrical performances were analyzed to determine how efficiency is affected by the aluminum fins when these fins are attached to PV modules as a radiant plate.

2. Roof-Integrated PVT

2.1 Experiment Model Design

[1] J.K. Tonui, Y. Tripanagnostopoulos, 2007, Air-cooled PV/T solar collectors with low cost performance improvements, Solar Energy, Vol.81(4), p.498-511

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The roof-integrated, air-type PVT system was designed and built, as shown in Fig. 1. The PV arrays placed on the roof had a 1kWp capacity using eight 125Wp poly-crystalline PV modules. The specifications of the PV modules are shown in Table 1. The system consisted of four arrays, and each array was serially connected 2 modules with a maximum current of 7.04A and a maximum voltage of 34.8V

As shown in Fig. 1, the PV modules were integrated into the roof as building roofing materials while providing an air channel for the collection of solar air. The PV modules were attached onto aluminum profiles into rectangular timber that maintained an open air channel depth of 10cm between the PV modules and the roof surface. Exhaust air pipes that were 10cm in diameter were installed to extract heated air from the space in an effort to cool the PV modules. Fans were installed into each of four air extraction pipes for forced ventilation. The roof maintained a slope of 30°. This roof structure was built according to the required U-value of a building envelope based on Korean building codes.

Table 1 PV module specifications

SUBJECT	SPECIFICATIONS
Maximum power	125W
Maximum voltage	17.8V
Maximum current	7.04A
Shot current	7.66A
Open voltage	21.1V
Module size	670*1505*38mm
Weight	10.5kg
Cell type	6' poly-crystalline silicon

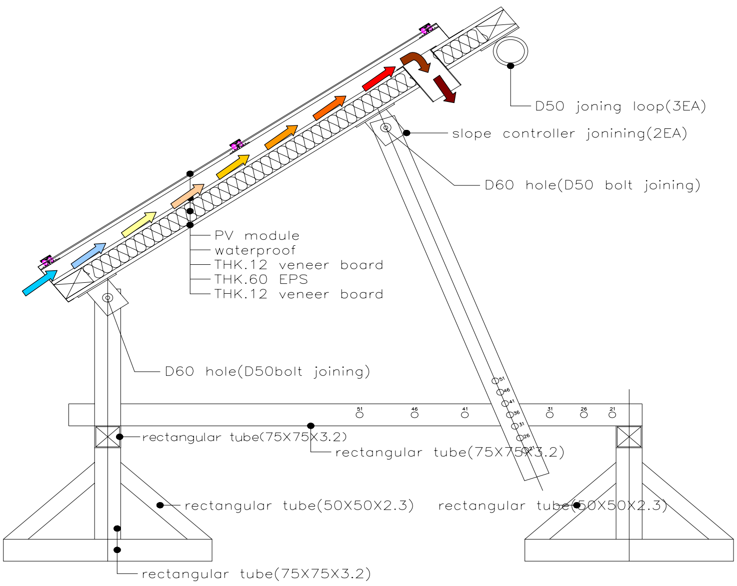


Figure 1 A cross-section of the roof-integrated PVT model

The basic configuration of air-based PVT system maintains an air gap between the building envelope and the PV modules. It uses heated air by fanning without any other special mechanism. However, this air that has been heated to a high temperature is useful in winter as a heat source in buildings. In this study, a new PVT model was proposed to improve the heat transfer through aluminum fins attached to PV modules. The attached fins transfer the heat from the PV modules and radiate it into the surfaces to raise the air temperature. They also raise the air temperature through a convection process in the space. As the attached aluminium fins increase the radiating surface of the PV module, the heat of the PV module releases more thermal energy actively at the achieved air flow. This, however, increases the electrical efficiency of PV systems by lowering the temperature of the PV modules. Cross-sectional views of the models investigated in this study are shown in Fig. 2. The schematic diagrams display a section of the base-type (a) collector, which inserts an air gap of 10 ㎝ between the PV module and the roof surface. Also shown is an improved type (b) that has aluminium fins attached to the back of the PV module. An aluminum plate with a thickness of 0.5mm was used for the fins, and they were attached to the back of a poly-crystalline silicon PV module with thermally conductive adhesive. The height of the fins was 5cm, and they were placed at intervals of 8cm.

a. Base Model b. Improvement Model(aluminum fins attached)

Figure 2 Schematic diagram of roof-integrated air-type PVT collectors

2.2 Experiment Equipment and Methods

The PVT roof model used in the experiment was installed onto the rooftop of the Engineering Building at Kongju National University in Kongju (latitude 36.27N˚, longitude 127.07E˚). Fig. 3 shows photos of the model. Here, the slope of the model roof was 30˚ and it was orientated toward the south.

Several experimental devices were installed to measure the temperature of the PV modules and of the air in the space between the PV modules and the roof surface. Measurements were taken of the electrical power generation of the PV system, and the weather conditions were monitored. Solar radiation on the sloped roof surface and the outdoor air temperature were also measured. For the electrical measurement of the PV systems, electrical load resistors and a power meter were installed. A data acquisition instrument was also connected to record all of the data related to the thermal and electrical performance of the system and the outdoor conditions automatically.

Two different air-type PVT models were tested. The experiment with the base model was carried out during May and June of 2007, whereas that of the improved model was carried out during October and November of 2007. This paper analyzes the performance of the systems for one day in each case on a day with similar solar radiation. A T-type thermocouple was used to measure the temperature of the surface of the PV module and to measure the air temperature of the space. For the measurement of the air flow rate flow, meters were installed in the exhaust pipes. Temperature sensors were also installed to measure the temperature of the exhausted air. The air flow volume can be controlled in the range of 0~1500m^3/h.

Figure 3 Views of the roof-integrated PVT collector

3. Analysis of Experimental Results

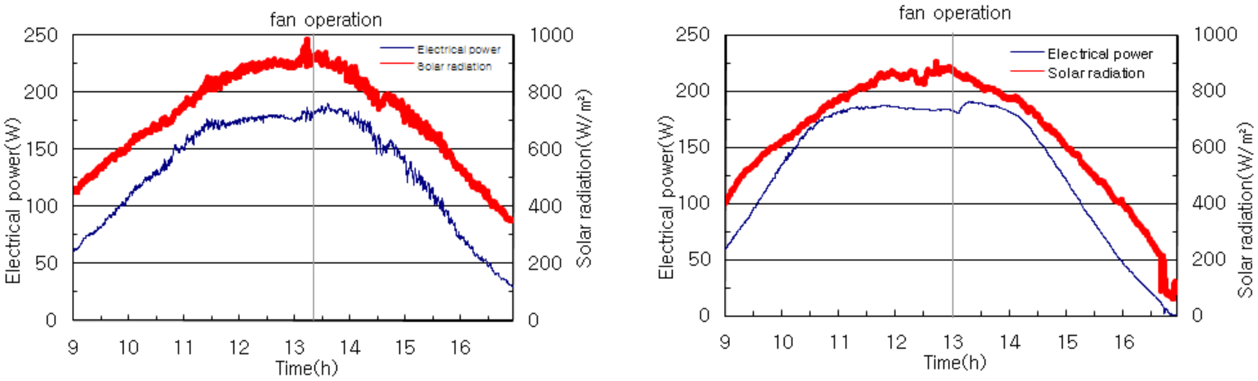
With the results of the outdoor testing of the roof-integrated PVT collectors, the variation of the electrical performance and that of the temperature of the PV module were analyzed. The collection of thermal energy by the PVT collectors via air circulation was also analyzed. The experimental results for the two different types of PVT devices were compared with a focus on the aluminum fins that were attached to the PV modules.

3.1 Electrical Performance

The electrical power generation of both PVT models appeared to be dependent on the amount of solar radiation. The variation in the electrical power generation of the PV system was analyzed to determine the cooling effect of forced ventilation. In order to compare the cooling effects of forced ventilation for both PVT models, the fan installed in the experimental model started at 1: 10 pm. Fig. 4 shows that forced air extraction increased the electricity generation of the PV system in spite of the decrease in the amount of solar radiation. This was clear during the period from 1:10 pm to 2:00 pm for both models.

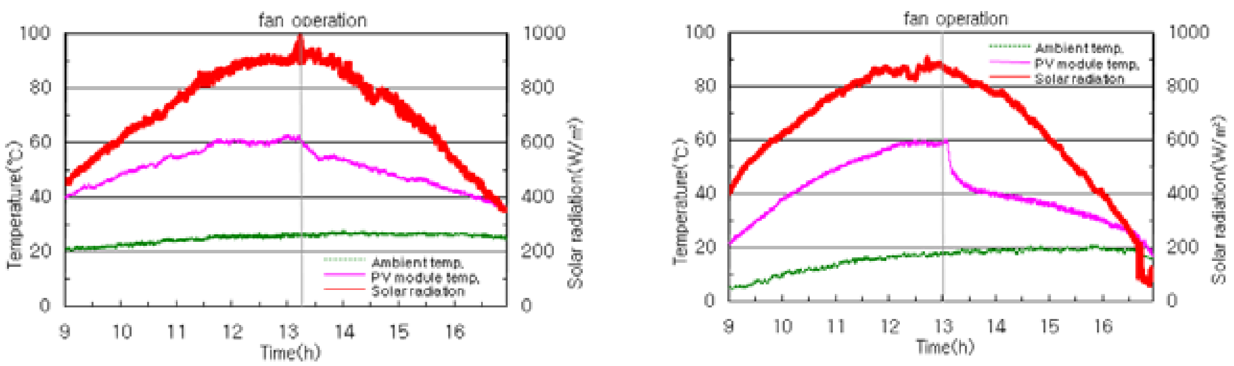
The improved model appeared to perform better than the base model. The electrical efficiency of the improved model changed from 10.3% to 11.4% due to the operation of the fan, whereas the electrical efficiency of the base model increased from 10.1% to 10.6%. These results indicate that the electrical efficiency of air-type PVT models can be improved by forced ventilation in the space between the PV module and the building surfaces. It also shows that the attachment of aluminum fins as a radiating plate contributes to further improvements. The fresh air intake into the air space by the fans decreases the PV module temperature, which helps improve the electrical efficiency.

As shown in Fig. 5, the variation of the PV module temperature indicates that forced ventilation lowered the PV module temperature of the base model and the improved model from 60℃ to 53℃ and from 59℃ to 41℃, respectively, under similar amounts of solar radiation. These temperature changes are related to the variation of the efficiency of the PV system. It was also found that the attachment of radiating fins onto the PV module contributes to a further reduction in the temperature.



a. Base Model b. Improved Model

Figure 4 Electrical power generation of the system in relation to solar radiation



a. Base Model b. Improved Model

Figure 5 Temperature variation of the PV module in relation to solar radiation

3.2 Thermal Performance

The thermal efficiency of the roof-integrated PVT collectors according to the amount of solar radiation is shown in Fig. 6 as calculated with Eq. (1). To calculate the thermal efficiency of the collectors, the measured air temperature of the inlet and outlet and the values for the solar radiation were used with an air flow volume of $150\mathrm{m}^3/\mathrm{h}$.

$Q_1 = A_{pvt}\, G$

$Q_2 = \dot{m}\, C_p\, (T_o - T_i)$

$$\eta_{th} = Q_2/Q_1 = \dot{m}\, C_p\, (T_o - T_i)/\, A_{pvt}\, G \qquad (1)$$

η_{th} : thermal efficiency

A_{pvt} : collector area (㎡)

T_o : collector outlet temperature (℃)

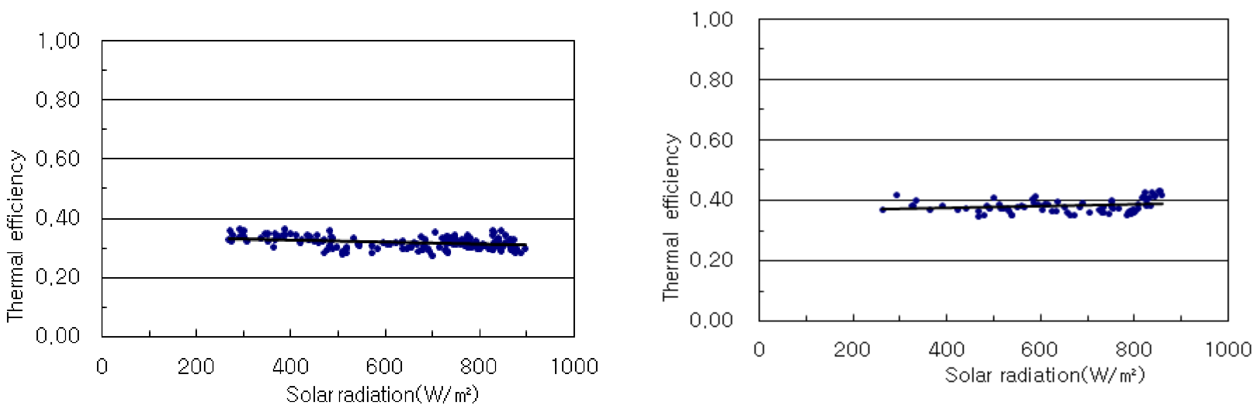
T_i : collector inlet(ambient)temperature (℃)

$\dot{m}$: mass follow rate(㎥/hr)

C_p : specific heat (kJ/㎏℃)

G : solar radiation (W/㎡)

The variation of the thermal efficiency of the roof-integrated PVT collectors is shown in Figs. 6. The average thermal efficiency of the base model was 31.6%, whereas that of the improved model was 38.1%. The thermal efficiency does not change according to variations in the amount of solar radiation, but the thermal efficiency of the improved model is approximately 7% higher than that of the base model. It is believed that the fins that were attached to the improved model contribute to enhance the collection of the thermal energy from the air-type PVT collector and that this is also related to the electrical performance of the PVT collectors: more heat from the PV module with radiating fins is released by aluminum fins that increase the air temperature of the space and lower the temperature of the PV module.



a. Base Model b. Improved Model

Figure 6 Thermal efficiency of the system in relation to solar radiation

4. Conclusions

This study analyzed the thermal and electrical performance of roof-integrated PVT collectors that are able to produce heat and electricity simultaneously. The experimental performance was analyzed for two different models: a base model with an air gap between the PV module and the roof surface and an improved model with aluminum fins attached to the PV module.

The experimental results shows that the electrical efficiency of the base model was improved by 5% as the fans had a cooling effect on the PV module; for the improved model, the efficiency increase was 10 %. The higher improvement is believed to have resulted from the radiating fins, which lowered the PV module temperature. The same pattern of an increase in efficiency applies to the thermal energy from the PVT models: the thermal efficiency of the improved model was 7% higher compared to that of the base model.

The overall efficiencies of air-type roof-integrated PVT collectors investigated in this study were 42.4% for the base model and 49.5% for the improved model due to the operation of the fan. Thus, it can be concluded that additional thermal energy generation of 30 ~ 40% was collected from the PVT collectors compared to a PV system that produces only electricity at an efficiency level of approximately 10%.

In this study, it was confirmed that the thermal and electrical performance of roof-integrated PVT collectors was increased by the attachment of radiating fins to the PV module.

Further studies are required to define a theoretical model for these models and to understand the effect of other factors on their thermal and electrical performances. Various configurations of the air channel when connected to the PV modules could also be studied to improve the thermal performance as well as the electrical performance. Furthermore, the contribution of this type of PVT collector connected to a building heating system could be studied in relation to a decrease of the building energy load.

Acknowledgement

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INTEGRATED TECHNOLOGIES FOR SUSTAINABLE REFURBISHMENT OF OFFICE BUILDINGS

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Keywords: aged office building, refurbishment, integration, decision support, raised floor systems.

Summary

Traditionally, decision making on aged buildings is typically economically driven. This leads to the tendency to either delay refitting for as long as possible, thus causing building conditions to deteriorate, or simply demolish and rebuild with unjust financial burden. For traditional refurbishment, the technologies were typically limited to strip-clean and repartition. Changing operational patterns of business and the demand for better efficiency of office space and improved workplace environment will need more innovative and intelligent approaches to refurbishing office buildings. This paper introduces examples of Australian research projects which provided a more holistic approach to the decision making of refurbishing office space, using appropriate building technologies and products, assessment of residual service life, floor space optimisation and project procurement in order to bring about sustainable outcomes in response to social, environmental and financial implications. Innovative building technologies such as integrated raised floor systems will maximise the utility while promoting productivity improvement. Specific construction procedures including process map, procurement methods, are major issues explored. The paper also discusses the case studies on critical factors that influence some of these building components and key issues for integrated decision support when contemplating the refitting of old office buildings.

1. Introduction

The Australian construction industry has seen a booming market for retrofitting office buildings. The number of office buildings over 30 years of age has reached over 30% on average in Australian capital cities. This increasing stock of aging buildings requires their owners to decide if and when to refit them. It is believed that refitting of office buildings will occupy an increasing proportion of all capital works in the next 20 years. While refurbishment may cost much less than demolition and new construction (Caccavelli and Gugerli 2002), owners and other building stakeholders may have to deal with far more complicated and challenging retrofitting requirements than the traditional approach (Cox 2004).

Retrofitting of office buildings used to be done on ad-hoc basis. Owners, designers and contractors alike were often troubled by the poor building documentation and lack of reference to successful examples. As a result, designers may not foresee all of the potential problems, while the contractors apply huge mark-up for having to deal with the risks. As these professionals begin to get more volume of work, the characteristics of these refurbishment projects and strategies to maximise the opportunities for technological, sustainable and economic solutions become important issues.

Previous research identified the needs for the total consideration of buildings structural assessment and modelling of operating and maintenance costs (Reyers 2001), architectural and engineering designs that may maximise the utility of the existing structure, the need for productivity improvement, reduction of project risks and mitigation (Gray, 1999; Skorupka 2001), and innovative construction management approaches such as new procurement methods, work flow and scheduling and occupational health and safety (Cox 2004). Recycling potential and conformance to codes may be other major issues (Faniran, 1998 and Nigel et al 2001).

This paper introduces examples of Australian research projects which provided a more holistic approach to the decision making of refurbishing office space, using appropriate building technologies and products, assessment of residual service life, floor space optimisation and project procurement in order to bring about sustainable outcomes in response to social, environmental and financial implications. Innovative building technologies such as integrated raised floor systems will maximise the utility while promoting productivity improvement. Specific construction procedures including procurement methods, work flow and scheduling, decanting, and recycling are major issues explored. The paper also discusses the case studies on critical factors that influence some of these building components and key issues for integrated decision support when relifing office buildings.

2. Review of Related Research and Existing Methods

Over the recent years, research efforts have been made to explore the advantages of retrofitting of aged buildings (Allehaux and Tessier 2002; Anderson and Mills 2002; Jones Lang LaSalle 2005). The recent foci and commitment to sustainability encourages retrofitting options. In Europe for example, the retrofitting market has experienced considerable growth over the past 6 years (Caccavelli and Gugerli, 2002), which might be mainly due to the ever changing user requirements, lower cost of retrofitting, and massive energy consumption of old office buildings. In Australia, refurbishment of buildings is expected to form an increasing proportion of the annual capital budget with some estimates being as high as 50% by 2020. This has important implications for sustainability. If the Koyoto targets were to be reached, it is the existing building stock and their efficiencies which must be improved. Waste minimisation and recycling can also form a significant part of the equation, accounting for an estimated 0.5% of GDP.

While the pressure to retrofit existing building is mounting, there remain some major challenges on the refurbishment option as opposed to new build. They include:

- Decisions on political, social, environmental and financial implications of re-life compared to new build (Balaras 2004);
- Feasibility studies assessing the condition of the existing building, the residual service life, and estimating construction costs, modelling of operating & maintenance costs, and the utility and productivity expected from the refurbished building (Reyers 2001; ECI 2003)
- Architectural and engineering design to maximise the utility of the existing structure (Thomas et al 1996).
- Coordinated work scheduling for clients, consultants and contractors in terms of forward capacity and production planning linked with design, procurement and decanting schedules.
- Additional challenges for demolition and waste handling and disposal, potential recycling, occupational health and safety, condition surveys and identification of services etc (Nigel et al 2001).

Availability of historical data and tools for the modelling of different scenarios to allow comparison of the alternatives are other potential barriers. Largely due to the lack of as-built on old buildings, information on the modelling of operating and maintenance costs, the utility and productivity expected from the refurbished building, and the monitoring of building energy performance depending on the alternatives is particularly hard to come by.

Despite these concerns and challenges, the new refitting market is developing due to the sheer volume of work to be done. This phenomenon not only requires immediate attention but also application tools that can help stakeholders making decisions such as:

- Sustainability issues including indoor air quality, energy saving, waste handling, disposal, potential recycling and Occupational Health and Safety (OH&S);
- Conditions of existing buildings and the residual service life;
- Waste management issues and recycling potential;
- Associated risks, costs, time and project delivery patterns and project management processes.

Some earlier research has been conducted in the European countries and America to investigate methodologies and software tools for the assessment of a building's existing structural conditions, energy usage and estimation of costs. For example, TOBUS is an evaluation tool for the assessment of retrofitting needs of office buildings in European countries and for estimating the costs to meet these needs in compliance with sustainability issues such as energy performance and indoor environment (Caccavelli and Gugerli 2002). Office Scorer is a tool developed by the Building Research Establishment (BRE) in the UK in 2002 to systematically compare and test the environmental and economic impacts of different building design concepts for offices. BRE has modelled a number of buildings over a 60 year life and evaluated the economic and environmental impacts of a range of factors including building elements degradation, ventilation and cooling system energy saving (BRE and DTI 2002). EPIQR and MEDIC are software which can provide diagnosis of degradation of existing residential buildings, energy performance and indoor air quality (Flourentzou 2000).

A Facility Energy Decision System was developed by the Pacific Northwest National Laboratory in the US to inform decisions on energy-saving retrofit projects (FEDS 2004). In Australia, the Building Division of the Queensland Department of Public Works developed the Ecologically Sustainable Office-Fitout Guideline as a strategic asset management framework. It covers key aspects of community, energy, material and water in relation to office building fitout works (Queensland Government 2004).

These methodologies and tools provide the global view and focus shift to building's renovation and refurbishment processes. Some enable users make informed decisions in targeted specialty areas. However, most of the tools approached the building refurbishment issue on an ad hoc basis and tend to deal with specific issues within a region. The evaluation results of these tools can be very subjective depending on input and will require substantial as-built information, which is often lacking. Over reliance on computers may render these tools to become inflexible, unadaptable and non-updatable. Therefore, there is an urgent need to develop a more integrated and holistic system that operates in a scientific and procedural manner. In particular, knowledge gaps need to be covered in residual service life, waste management, floor space optimisation, project risk assessment, contractual issues and procurement patterns.

3. Sustainable Refurbishment with Integrated Technologies

To respond to the above challenges and provide a guide for the booming market of office building refurbishment, research projects in applying raised floor technologies and the integrated approach to "re-life" aged office buildings were recently undertaken in Australia. These research projects considered the design and implementation issues of using raised floor systems (RFS) for office space as well as constructability and specific contracting strategies to share risks as well as benefits between building owners, contractors and users. Characteristics of refurbishing projects that impact upon the effective management of the construction process, such as the identification and mitigation of risks, issues of decanting and existing tenants, identification of existing structure and services, work scheduling, occupational health and safety issues for construction personnel and tenants, demolition, waste and recycling, issues of quality and workmanship, cost planning and cost modelling methodologies. The research further explored holistic approaches to dealing with these issues and developed a decision-making support mechanism for assessing the condition of the existing building structure, residual service life and floor space optimisation. A combination of research methodologies were used in these projects, such as Delphi study, Process Integration, Case study and Industry interviews. Extracted information from these processes was presented as decision support tools to guide stakeholders in problem solving and decision making.

A Delphi study was conducted with the assistance of a panel of industry experts to determine the most relevant and important issues of consideration of refitting commercial office buildings. A unique aspect of the Delphi Questionnaire is that the industry experts consider the issues individually, without discussion with other experts (Chan 2001). A total of 48 issues identified by the comprehensive literature study and discussion with industrial partners were incorporated into the Delphi questionnaire. Through four rounds of electronically mailed questionnaire surveys, these experts evaluated, considered and reconsidered the relative importance of these issues presented particularly taking onboard feedback from peer reviews. A total number of 36 critical issues with commonly agreed high ranking were revealed. The six top ranked critical issues are Structural appraisal prior to refurbishment, Purpose of refurbishment, Energy saving potential, Cost analysis for sustainability and building efficiency, Project cost risks, and Building condition assessment.

The 36 critical issues identified were mapped against six major phases of project development for holistic consideration and problem solving. As a result, an integrated project map was developed and linked these critical issues with logic, order of execution, cross-reference, and quality control in mind, along the continuum of project development phases. Based on these issues, a Best Practice Guide was developed to encapsulate relevant problem solving logic and knowledge for decision making. The knowledge and information required for decision making is organised according to (1) the potential causes for this issue, (2) the problems it will bring about, (3) the possible actions that can be taken, and (4) the results from such actions. The top part of the module presents graphical linkage between these elements, depicting the inherent relationships. The bottom part further elaborates "what-to-do" actions of these elements according to the related project development phase. An application example of the Best Practice Guidelines is shown in Figure 5 as a way of dealing with Space Volume Limitation in the Case Study of research on the use of raised floor systems.

In addition to the Best Practice Guide for systematic and consistent approach to guide to building owners, developers and contractors through decision making on potential refitting projects, specific building technologies and systems are also needed to offer alternative fit-out methods, and respond to new office spatial and environmental issues. This concern was addressed in the raised floor project as below.

4. Integrated Office Refurbishment Using Raised Floor System

In addition to structural strengthening, office fitout is another most important task in office building refurbishment. Due to their inherent limitations such as rigid ceiling based HVAC system and wall mounted power, voice and data (PVD) distribution system, traditional office fitout methods cannot support the economical use of resources and provide a sustainable workplace environment on a cost-effective basis (Zhang 2005). Deployment of appropriate construction technologies, innovative building design and flexible facility management patterns needs to be done. As an alternative fitout method and product, Raised Floor System (RFS) has been seen as an integrated pool of technologies to meet the sustainable retrofitting of office buildings. A range of potential benefits of RFS based refit of office space has been identified, using underfloor HVAC system and PVD distribution system (Yang and Zhang 2005). This can be summarized in Figure 1.

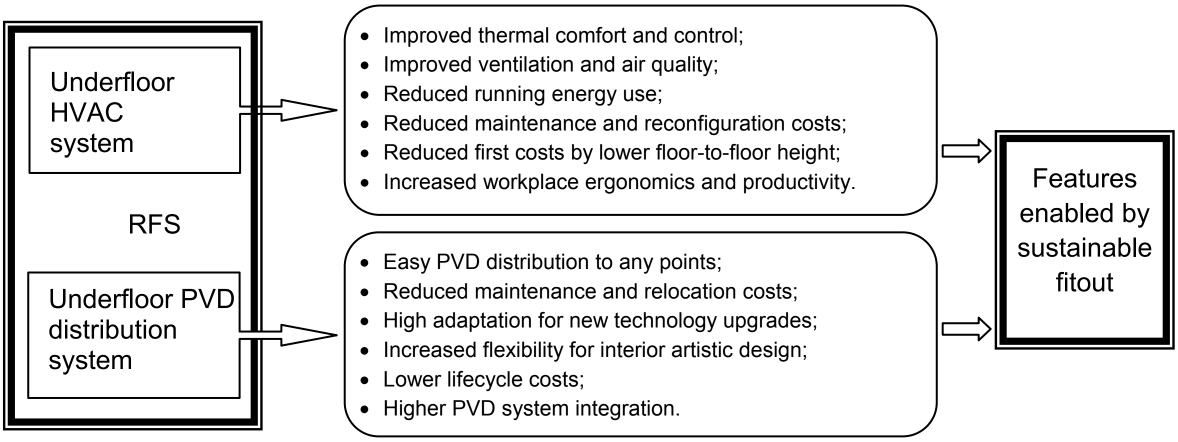

Figure 1 Potential benefits of RFS for office building fitout

A typical RFS consists of structural units, accessories and service units. The structural units, including panels and understructures, provide the basic platform of RFS, supporting loads above. The panels will form the raised floor surface on which office activities are carried out. Understructures supporting these panels create a plenum between the sub-floor and the panels that allows the distribution of building service systems and provides easy access to maintenance. The accessories, such as floor coverings, cable carriers and ramps, are indispensable to many flexible RFS functions, structural integrity, and improvement of workplace environment. The service systems include underfloor HVAC and underfloor Power Voice and Data (PVD) systems, both of which can enhance the versatility of RFS products for office buildings.

5. Case Study – Best Practice Guide for Using RFS

The RFS technology has been explored by many industry practitioners and applied to the refurbishment of a number of green and smart building projects (Zhang 2005). While many merits and potentials have been identified, as with the introduction of many new technologies, some of the earlier applications have experienced problems and encountered barriers preventing more effective implementation. The process maps and best practice guide developed in the re-life of office building project has been adopted to integrate RFS in office building retrofitting.

5.1 Factors Influencing and Problems Associated with the Refurbishment using RFS

Significant influence factors (SIFs) associated with RFS planning has been identified (Zhang 2005). If these factors were not accommodated appropriately, problems in the operation of RFS services might occur. The list of SIFs and Problems are presented in Table 1.

Table 1 SIFs and Problems Associated with RFS Uses in Office Refurbishment

SIFs	Abridged Name (Code)	Problems	Abridged Names (Code)
Structural constraints: *(5SIFs)*	Structural irregularity Space volume limitation Transition difficulties Overhead HVAC influence Structural beam restriction	Major: *(6)*	Uneven air distribution Hot spots Cool air leaking Draught Additional hole drilling Dust
RFS service integration: *(2SIFs)*	Fire safety system accommodation Cables and wires incompatibility	Minor: *(9)*	Uneven raised floor surface Poor panel & wall connectivity Poor floor connectivity Inconvenient underfloor access Noise Breakdown due to holes Panel moving Panel distortion Trip hazards
Industry practitioners' knowledge: *(8SIFs)*	Architects & engineers' incompetency Poor design influence on construction UAD influence on productivity Clients' low familiarity with UAD Contractors' incompetency QS' incompetency Low awareness of RFS Ignorance of RFS implementation		
Cost concerns: *(5SIFs)*	Capital cost obstacle Underestimate of LCC Poor design influence on cost Suspicion of RFS payback ability Ambiguity of fitout responsibility		

Further analysis on the impact of the 20 SIFs on RFS design, construction, operation and maintenance processes highlighted 36 project level critical factors (PLCFs), as shown in Figure 2.

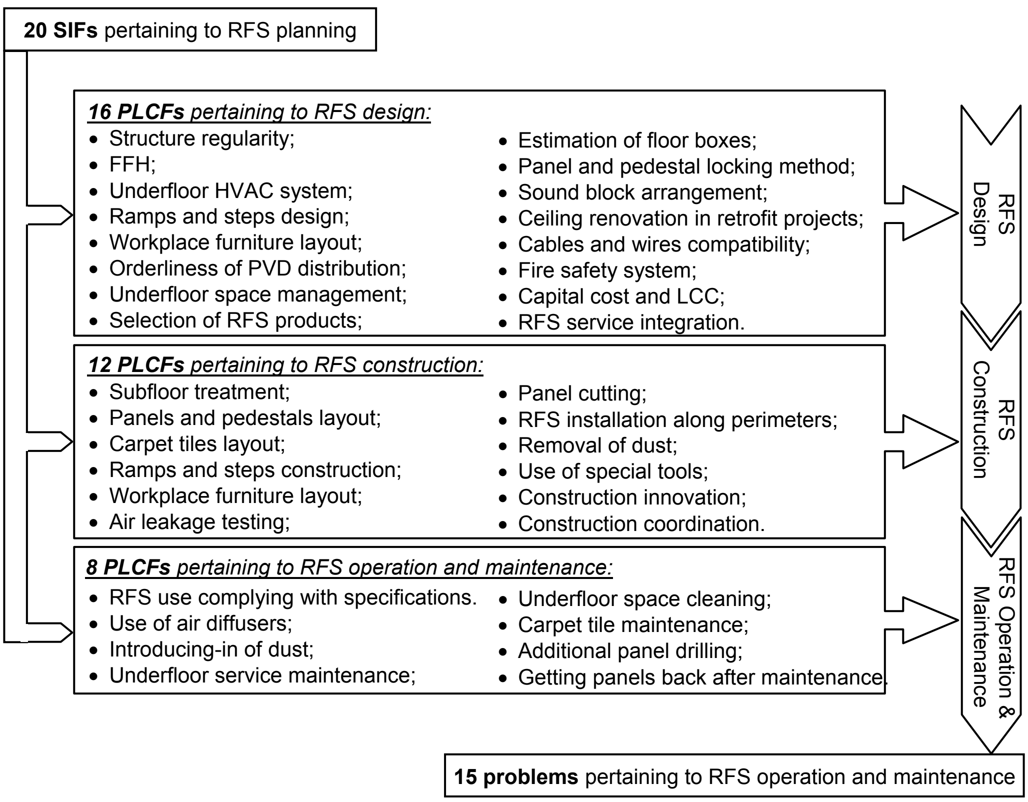

Figure 2 Causality among SIFs, problems and PLCFs in RFS project delivery

5.2 Process Map

With reference to the process map developed by the re-life project, an integrated process map was developed to improve the constructability of RFS in office building refurbishment, as shown in Figure 3. The process map presents a series of interrelated activities for each project stage. The map is hierarchical in nature, in which the lower-level diagrams are sub-elements of the upper-level ones immediately preceding them. Three levels of decomposition are applicable. The first shows the integration of RFS technology in the five stages of the RFS fitout project delivery. The second reflects major RFS constructability functions under each major project stage. Seven constructability functions are also presented at this level. The final level represents specific activities under each constructability function. A total of 37 constructability activities are identified at this level. The evaluation of 20 SIFs and 36 PLCFs is integrated into the process map through 7 activities, as highlighted by the boxes with thick rims.

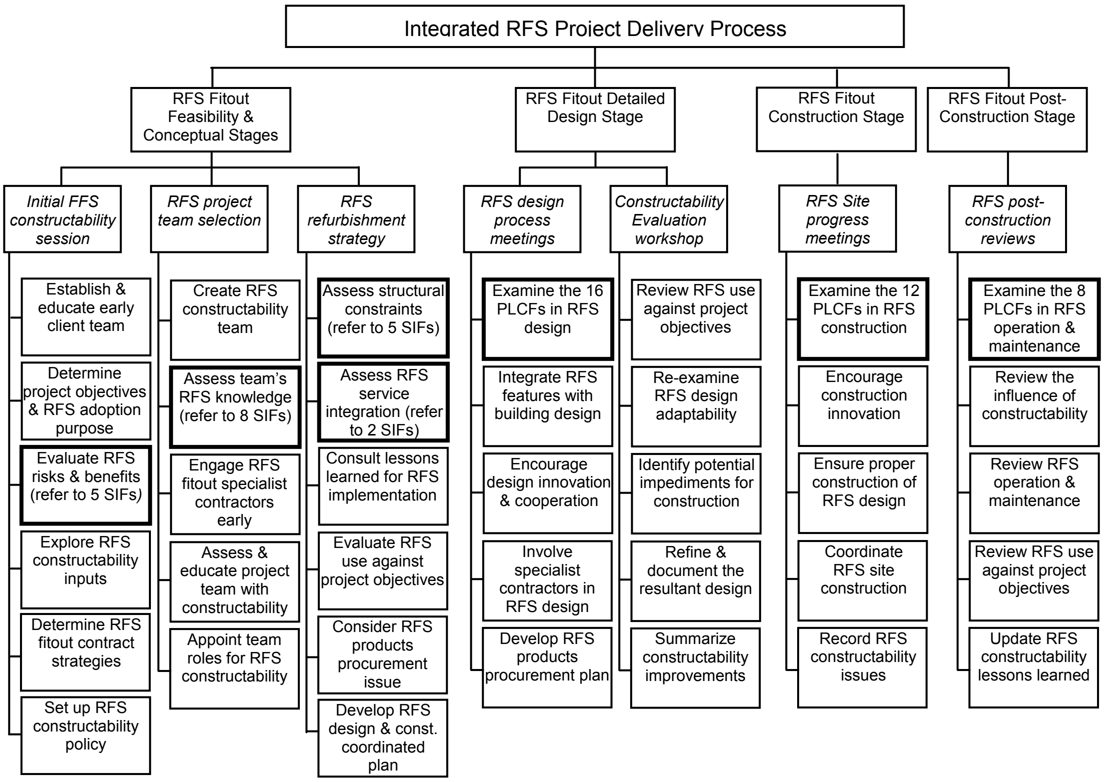

Figure 3 A process map for integrated RFS fitout project delivery process

5.3 Procurement Strategy

As the knowledge contribution of RFS specialist contractor is vital for the refurbishment plan and design, it is important to engage the specialist contractors as early as possible, preferably in the conceptual stage. *Nominated Specialist Contractors*, *Design-Build by Specialist Contractors* and *Design Assistants* are three typical methods allowing early involvement of specialist contractors. However, involvement as design assistants reduces specialist contractors' willingness for knowledge contribution as they have no guarantee to be awarded with the contract. Meanwhile, most specialist contractors have sufficient RFS fitout experience but little design skills, suggesting that they should pass on the construction knowledge to the design team rather than attempting for design. Therefore, *Nominated Specialist Contractors* is often chosen for the fitout work in the refurbishment. Under this scheme, the cooperation and communication in the project team demonstrates that the designers carries out the whole design including RFS fitout with knowledge input from specialist contractors in order to accommodate the SIFs and PLCFs appropriately. As to the contract of the whole refurbishment project, *Construction Management/General Contractor* (CM/GC) is chosen although design and build may also suffice. In comparison, CM/GC can support a non-adversarial relationship between the management contractor and the client, which is essential for improving team cooperation and communication and working for the common project objectives. Accordingly, the *Nominated Specialist Contractors under CM/GC* is believed to be the most preferable procurement strategy for the RFS fitout within the refurbishment of an office building, as shown in Figure 4.

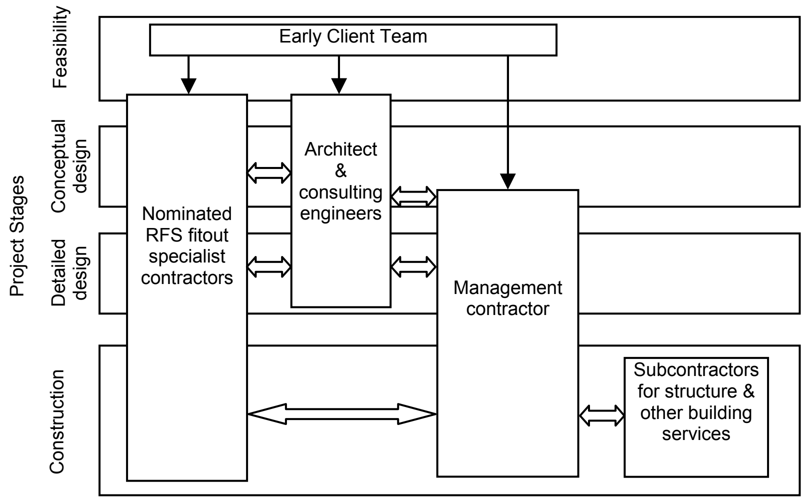

Figure 4 Nominated specialist contractors under CM/GC for RFS fitout project

5.4 Best Practice for Solving Typical Refurbishment Issues

Best practice guide was used to develop problem solving module for solving key issues associated with RFS use in refurbishment projects. A typical problem associated with RFS use in refurbishment project is the limited space volume in old office buildings. Figure 5 presents a problem solving module for space volume limitation. It demonstrates the possible reasons leading to concerns of limited space volume, the possible impacts and the actions to be undertake to accommodate the problem in the whole refurbishment delivery process.

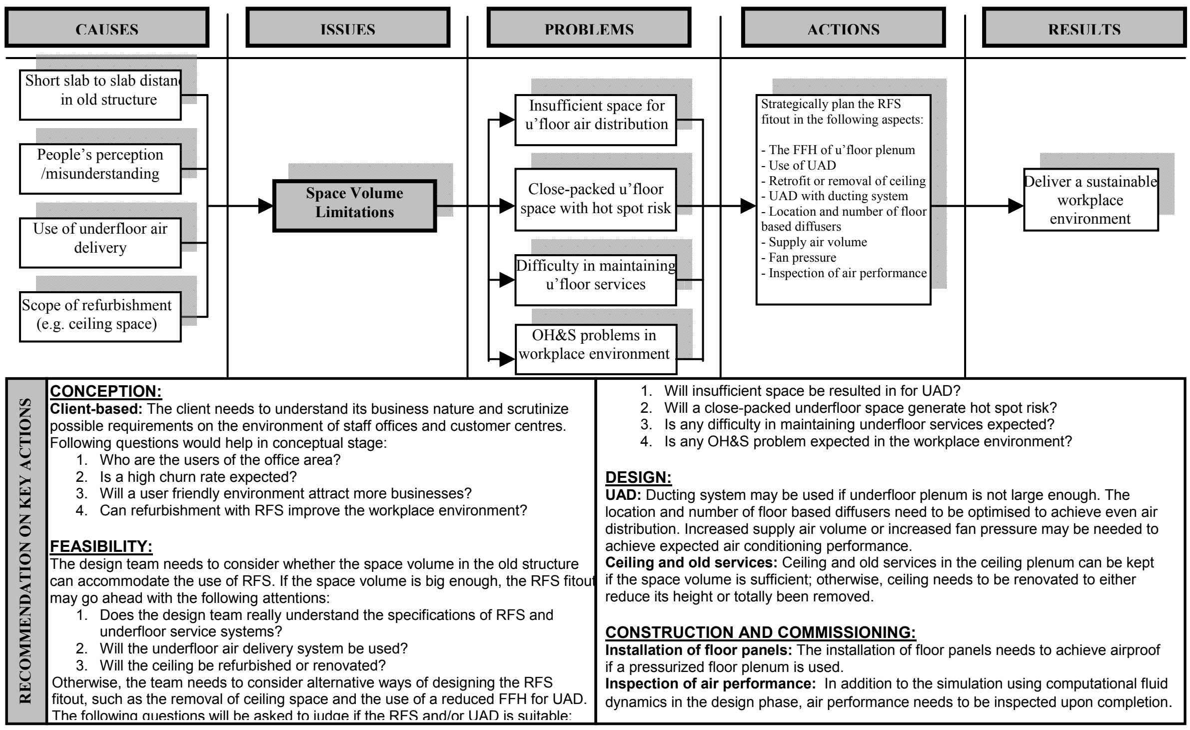

Figure 5 Problem solving module for space volume limitation

6. Conclusions

Construction industry in Australia is experiencing a booming market for office building refurbishment. Integrated methods and technologies can improve the effectiveness of retrofitting and achieve purposes of sustainable building practices. Developing informative guidelines will provide stakeholders of office buildings a valuable tool to make holistic decisions in dealing with complicated issues for refurbish works. Research projects had been undertaken in Australia to develop the decision making guidelines and integrated fit-out systems in order to respond to sustainability challenges.

Critical factors associated with the refurbishment of office buildings were identified through Delphi Studies, which led to the use of project maps and best practice guides to provide problem solving template for issues encountered in office refurbishment process. This was demonstrated through the decision making example of space Volume Limitation. Raise floor systems were used to demonstrate the potential of integrated technologies as part of office building refit. Barriers associated with the implementation of RFS were discussed and then integrated into the consideration of the fitout process. Nominated specialist contractor under construction management was recommended as an appropriate procurement strategy.

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DEVELOPMENT OF BIOCLIMATIC MAPS OF JAPAN FOR APPLICATION OF PASSIVE HEATING AND COOLING DESIGN TECHNIQUES

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Summary

A kind of bioclimatic map gives useful information on design of climate-responsible buildings generally. In Japan, as passive heating/cooling design techniques have attracted the interest more and more to prevent the global warming problems, the authors are developing illustration maps giving good information on passive building design based on the newest and the finest meteorological data of Japan.

In this paper, at the first, indices to indicate natural heating/cooling potentials of local climate are discussed. After calculating values of the indices for all the weather stations over 800, color maps of several indices are illustrated to give passive design information.

Application of passive heating/cooling design techniques should be decided using not only these potential indices but the other indicators which represent heating/cooling requirements for a focused location. Therefore, the other five indices proposed by Watson and Labs (1991) after Givoni (1976) are also considered and an original computer program to calculate these five indices is developed.

Two kinds of indices mentioned above are combined and new indices are proposed. The calculated results of the new indices are shown as illustration maps to give design information from another point of view. Finally, a computer analysis of the proposed indices is conducted to classify regions from a point of view of the passive design techniques. As conclusive design information, a classified map and its brief description are presented.

The authors' methodologies or procedures of climatic analysis may be informative for the other countries or regions excluding Japan.

1. Introduction

1.1 Scope of Development of Bioclimatic Maps of Japan

In order to advance energy conservation and global warming prevention, the residential building code of Japan gives a map divided into seven zones which were classified by an analysis of heating degree-days calculated with the Expanded AMeDAS Weather Data (Architectural Institute of Japan, 2003 and 2005), which are mentioned amply in Subsec.1.2. A “Q-value” which is the heat loss coefficient per a unit floor area of a whole building is clearly defined for each zone in the code. Japanese house builders and architects are familiar with such mapped design information which helps them to plan thermal insulation performance.

All the authors have believed that a climate-responsible housing design, which includes not only the thermal insulation design but design of passive heating/cooling strategies, should be advanced for the sake of energy and global environment conservation. From this point of view, the authors had get an idea that some kinds of bioclimatic maps may be helpful to design the strategies and shared studies related to the development of the bioclimatic maps for application of passive heating/cooling design techniques, alias “passive design maps”. Well-arranged passive design maps are expected to be accepted as important design tools for sustainable buildings.

1.2 Description of AMeDAS and Expanded AMeDAS Weather Data

The most popular dense array system for weather data acquisition in Japan is known as "AMeDAS", which is the abbreviation for the Automated Meteorological Data Acquisition System. The observatories are located in about 840 points all around Japan as shown in Figure 1. This works out to be one observatory every 21 km^2 area on the average. The detail hourly data obtained by and estimated from the AMeDAS were compiled as a DVD named "The Expanded AMeDAS Weather Data DVD", alias "The EA Data DVD". The newest DVD including the data for 20 years since 1981 is published by the Architectural Institute of Japan (2005). One of the authors had worked for the publication during the last decade. The papers by Akasaka et al. (2000) and Matsumoto et al. (2005) are available for getting more information on the EA Data. Table 1 shows all the weather parameters recorded in the EA Data DVD. It can be said that the EA Data have enough quality and quantity to be used as a data source for our study.

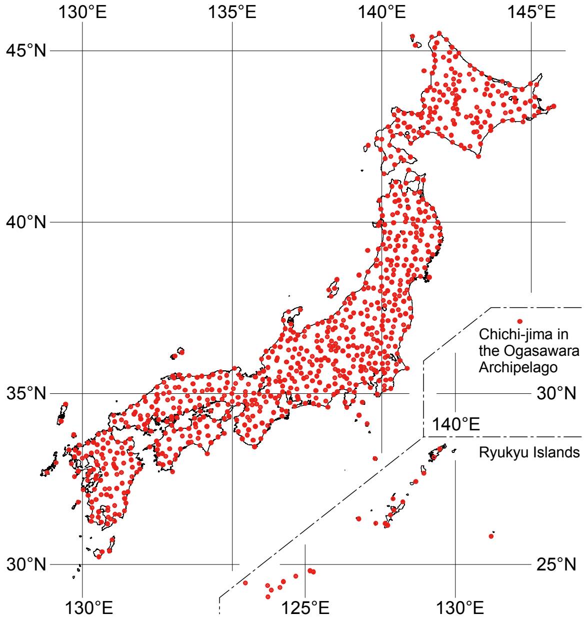

Figure 1 Distribution of the AMeDAS observatories

Table 1 Weather parameters recorded in the Expanded AMeDAS Weather Data DVD

Weather Parameter	Hourly Value Precision / Unit	Additional Statistical Value	Stat. Value Precision / Unit
Air Temperature	0.1 [°C]	Daily Average	0.1 [°C]
Humidity Ratio	0.1 [h/kg']	Daily Average	0.1 [h/kg']
Horizontal Global solar irradiation	0.01 [MJ/(m^2·h)]	Daily Integrated Value	0.1 [MJ/(m^2·d)]
Downward Long-wave Irradiation	0.01 [MJ/(m^2·h)]	Daily Average	0.01 [MJ/(m^2·h)]
Wind Direction	16 directions' index*	*The index when maximum wind speed was recorded for the day*	
Wind Speed	0.1 [m/s]	daily average	0.1 [m/s]
Precipitation Amount	1 [mm]	Daily Integrated Value	1 [mm]
Sunshine Duration	0.1 [h]	Daily Integrated Value	0.1 [h]

* 1: NNE, 2: NE, ... , 16: N, 0: Calm

1.3 Procedure Outline of the Development

In order to obtain several design maps which are comprehensible and useful for general house builders and logically acceptable for the related researchers and specialists, the following steps are taken in this study:

1) Development of suitable indices to explain natural potentials for passive heating/cooling and have clear physical meanings. Two series of indices are considered: The one series is designated as "potential indices"; the other one is "dimensionless indices". After calculating every index for each observatory, a series of color-contour maps of the dimensionless indices is illustrated to obtain passive design information and discussions on utilization capability of the indices;

2) Literature survey and consideration of other indices proposed previously to give different viewpoints. As discussed later, indices by Watson and Labs (1992) after Givoni (1976), which are designated as "strategy requirement indices", are adopted. A computer program to calculate these indices based on the EA Data is also developed.

3) Determination of the final indices named "passive design indices". Each passive design index is multiplied by the related strategy requirement index in order to generate one of the passive design indices. After calculating them, the another maps are illustrated to obtain passive design information which is different from the information obtained by maps of the dimensionless potential indices; and

4) Proposal of a "regional passive design concept map" for the sake to obtain more comprehensive design information as a conclusion. A cluster analysis is applied for the passive design indices to classify regions in which concepts of bioclimatic design strategies are different each other.

Following four sections are described in order of these steps. All the illustration maps shown later are drawn by original software named "ColorMap", which was enclosed with the EA Data DVD and introduced in the paper by Matsumoto et al. (2005).

2. Potential Indices

The indices to indicate several natural potentials which affect to reduce heating and/or cooling energy when they are utilized well by suitable passive design strategies are considered in this section. The Indices are designated as "potential indices" for a brief description.

2.1 Determination of Heating and Cooling Season and Degree-Days

At the beginning, heating and cooling seasons should be defined, because passive techniques can be generally classified into two types: of course, one is techniques for heating season; and the other is those for cooling season. As mentioned below with Figure 2, the authors defined the two seasons for every AMeDAS location by annual daily air temperature profile at the location for each year between 1981 and 2000.

2.1.1 Cooling Season

The day when daily air temperature reaches 22°C at first during a year is considered as the start of cooling season of the year, and the last day when the temperature reaches 22°C is considered as the end of cooling season of the year. The nomenclatures of m_c and n_c are representations of the start day's serial day number and the last day's serial day number, respectively counted from January 1.

2.1.2 Heating Season

The last day before the cooling season for a year when daily air temperature falls 18°C is considered as the end of heating season of the year and represented by n_h. The first day after the cooling season when the air temperature falls 18°C is considered as the start of heating season of the year and represented by m_h. Generally in Japan, the following relation is proved: $1 < n_h < m_c \leq n_c < m_h < 365$ (or 366).

2.1.3 Cooling and Heating Degree-Days

The degree-days indices are used to determine the dimensionless potential indices. The cooling degree-days CDD_{22-22} [K·d] and the heating degree-days HDD_{18-18} [K·d] can be expressed in Equations (1) and (2), respectively. The equations are applied for each AMeDAS location's daily air temperature for every year.

$$\mathrm{CDD}_{22-22} = \sum_{i=m_c}^{n_c} (\theta_{d,i} - 22)\,, \quad (1)$$

$$\mathrm{HDD}_{18-18} = \sum_{i=1}^{n_h} (18 - \theta_{d,i}) + \sum_{i=m_h}^{365\,(\text{or } 366)} (18 - \theta_{d,i}), \quad (2)$$

where $\theta_{d,i}$: Daily average air temperature on i-th day (serial day number through a year), [°C].

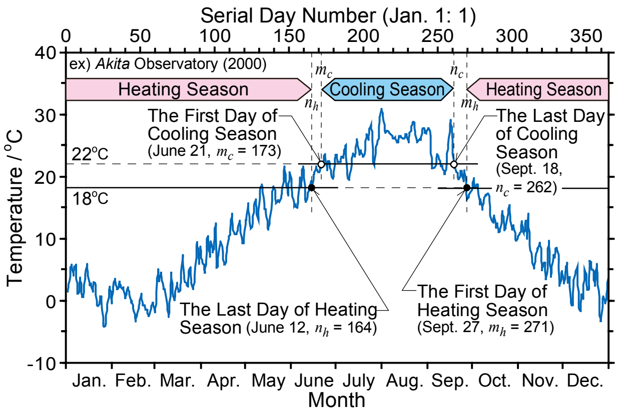

Figure 2 Definitions of heating and cooling seasons for a year

2.2 Considered Natural Potentials and their Indices

Six kinds of potentials are chosen on the bases of a literature survey of related studies and feasibility studies on utilization techniques of natural energy. The related dimensionless indices are also determined as well as basic indices indicating the potentials intermediately. Because every basic potential index has some kind of quantity which is fundamentally quite different each other, it is impossible for them to be compared directly. This is a reason why the dimensionless indices are additionally considered. A key term for eliminating dimensions is the Q-value (Q [W/(m^2·d)]) mentioned in Subsec.1.1, representing the heat loss coefficient per a unit floor area for a whole building.

2.2.1 Passive Solar Heating Potential: $\mathbf{PSP}$ and $\mathbf{PSP'}$

Kodama and Takemasa (1992) introduced the concept of passive solar heating potential, PSP [Wh/(m^2·K·d)], which is expressed in Equation (3). In order to eliminate this complicated dimension, Equation (4) is applied to define a new index $\mathrm{PSP'}$ [-] which is a simple modification of the PSP index. The index $\mathrm{PSP'}$ shows that an effective rate of passive heating by solar gain through south-facing window having a unit area to total space heating loads per a unit floor area. The prime sign is constantly added to show the index has no dimension in this paper.

$$\mathrm{PSP} = \left(\sum_{i=1}^{n_h} I_{s,i} + \sum_{i=m_h}^{365\,(\text{or } 366)} I_{s,i} \right) \Big/ \mathrm{HDD}_{18-18}\,, \quad (3) \qquad \mathrm{PSP}' = \mathrm{PSP}/(24 \cdot 3600 \cdot Q)\,, \quad (4)$$

where $I_{s,i}$: Daily integrated solar irradiation on the south-facing vertical surface for i-th day [J/(m^2·d)].

Because components of the beam and diffuse solar irradiations are not included in the EA Data DVD, Perez et al.'s decomposition method of hourly horizontal global solar irradiation (1992) is applied to calculate $I_{s,i}$.

2.2.2 Cross Ventilation Cooling Potential: $\mathbf{VCP}$ and $\mathbf{VCP'}$

A modified index after Akabayashi et al. (2003) is considered. We assume a typical human body, of which weight and surface area are 70 kg and 1.8 m^2 respectively, wearing clothes thermally equivalent to 0.5 clo and having a metabolic rate of 58.2 W/m^2. A room where the human body is surrounded is also assumed to have the following properties: the room air and mean radiant temperatures are equal to that of the outdoor air; the room air humidity is also the same as that of the outdoor air; the room air is calm and wind speed is

0.3 m/s. This is an image of a room condition without any space cooling and ventilation. We can calculate SET* by using the EA Data for j o'clock of i-th day data and these assumptions. The calculated value is represented as $\theta^*_{r,i,j}$ [°C].

When windows are opened for cross ventilation, thermal comfort may be improved due to indoor air speed increase. We assume that the cross ventilation can be operated in case of $\theta^*_{r,i,j} > 26$°C. Because the wind speed parameter ($v_{6.5}$ [m/s]) in the EA Data DVD is standardized as to indicate values at a height of 6.5 m from the grade line (G.L.) for each observatory, the wind speed is reduced to have value at a height of G.L.+1.5 m by using Equation (4), the reduced wind speed ($v_{1.5}$ [m/s]) can be considered as to be equal to that in the ventilated room. The SET* for this wind speed can be also calculated at j o'clock of i-th day like $\theta^*_{i,j}$ [°C]. It may be happened that $\theta^*_{i,j}$ falls 23°C due to higher wind speed. However, because window opening area is usually adjusted to be suitable for thermal comfort, $\theta^*_{i,j}$ is limited never to fall 23°C. On contrast, it may be also happened that $\theta^*_{i,j}$ exceeds 26°C due to higher outdoor air temperature and/or lack of wind speed. In such case, we assume that the cross ventilation is not operated. Figure 3 illustrates this approach concisely, instead of a little bit complicated description in the above. The indices are expressed in Equations (6)-(9).

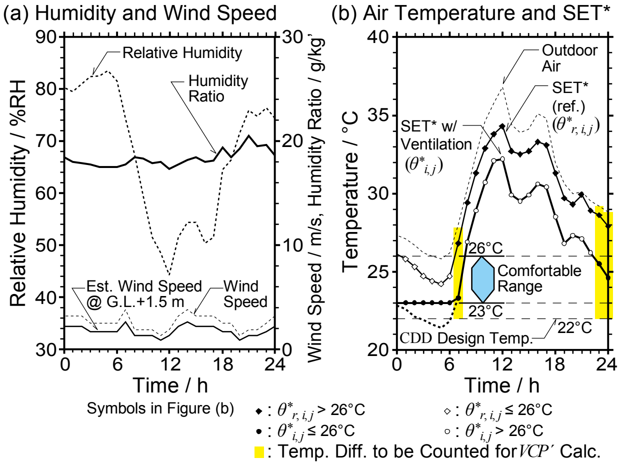

Figure 3 Illustrated explanation of space cooling effect of cross ventilation by the bases on SET calculation*

$$v_{1.5} = (1.5/6.5)^{0.25} v_{6.5}, \tag{5}$$

$$\delta_{c,i} = \begin{cases} 1; \; for\ \theta_{d,i} > 22, \\ 0; \; for\ the\ other\ cases, \end{cases} \tag{6}$$

$$\delta_{v,i,j} = \begin{cases} 1; \; for\ \theta^*_{r,i,j} > 26\ and\ \theta^*_{i,j} \le 26, \\ 0; \; for\ the\ other\ cases, \end{cases} \tag{7}$$

$$\mathrm{VCP} = \sum_{i=m_c}^{n_c} \delta_{c,i} \left\{ \sum_{j=1}^{24} (\theta_{i,j} - 22)\delta_{v,i,j} \right\}, \tag{8}$$

$$\mathrm{VCP}' = \mathrm{VCP}/(24 \cdot \mathrm{CDD}_{22-22}), \tag{9}$$

where $\theta_{i,j}$: hourly air temperature at j o'clock of i-th day, [°C].

2.2.3 Nocturnal Chilled Air Cooling Potential (Night Purge Potential): NCP and NCP′

We assume that the outdoor air temperature not exceeding 28°C can be injected at night time during the cooling season via a mechanical ventilation system performing air exchange of 0.5 ACH and temperature set point during the night time can be setback to be 28°C. When the volumetric heat capacity and ventilation air volume rate per a unit floor are represented as C_a (= 1,206.0)[J/(m^3·K)] and q [m^3/(m^2·h)], respectively, extracted energy at j o'clock of i-th day can be estimated by a term of $C_a q(28 - \theta_{i,j})$ [J/m^2]. Thus, the dimensionless index expressed in Equation (12) can indicate reduction rate of space cooling loads. The term of q is assumed to be 1.2 m^3/(m^2·h) because the average ceiling height of Japanese houses is about 2.4 m.

$$\delta_{n,i,j} = \begin{cases} 1; \; for\ \theta_{i,j} \le 28\ and\ I_{i,j} = 0, \\ 0; \; for\ the\ other\ cases, \end{cases} \tag{10}$$

$$\mathrm{NCP} = \sum_{i=m_c}^{n_c} \delta_{c,i} \left[\sum_{j=1}^{24} (28 - \theta_{i,j})\delta_{n,i,j} \right], \tag{11}$$

$$\mathrm{NCP}' = \frac{C_a \cdot q \cdot \mathrm{NCP}}{(\hat{Q} \cdot \mathrm{CDD}_{22-22})}, \tag{12}$$

where $I_{i,j}$ is horizontal global solar irradiation at j o'clock of i-th day, [J/(m^2·h)], used just for check whether the j o'clock belongs to night time or not, and $\hat{Q}$ is a unit-converted Q-value (= 24·3600·Q), [J/(m^2·K·d)].

2.2.4 Evaporative Cooling Potential: ECP and ECP′

The water to spray building envelops is available naturally due to rich precipitations and groundwater. Thus, evaporative cooling techniques must be useful. We assume that the evaporation occurs due to the humidity ratio difference between a typical envelop surface and the outdoor air and the moisture convection coefficient expressed by Lewis' analogy law. Equations (13) and (14) are expressions of the indices to indicate the potential. The index ECP′ shows an effective reduction rate of space cooling loads as well as the index NCP′.

$$\mathrm{ECP} = \sum_{i=m_c}^{n_c} \delta_{c,i} \left[\sum_{j=1}^{24} \frac{\alpha_c(v_{1.5}) \cdot r(\theta_{i,j})}{C_p(x_{i,j})} \{ \overline{x}(\theta_{i,j}) - x_{i,j} \} \right], \tag{13}$$

$$\mathrm{ECP}' = \mathrm{ECP}/(\hat{Q} \cdot \mathrm{CDD}_{22-22}), \tag{14}$$

where $x_{i,j}$: Humidity ratio of the outdoor air at j o'clock of i-th day, [g/kg'];
$\overline{x}(\theta_{i,j})$: Saturated humidity ratio on the typical envelope with a temperature assumed to be $\theta_{i,j}$, [g/kg'];
$C_p(x_{i,j})$: Isobaric specific heat of the humid outdoor air with $x_{i,j}$ (=1,004.6+1.846·$x_{i,j}$), [J/(kg'·K)]];
$r(\theta_{i,j})$: Specific latent heat of water at a temperature of $\theta_{i,j}$ (=1,996.1+1.846[$\theta_{i,j}$+273.15]), [J/g]; and

$\alpha_c(v_{1.5})$: Convective heat transfer coefficient depended to the neighbor air's speed of $v_{1.5}$, [W/(m^2·K)]. The well-known Jürges' formulae are applied to calculate this value.

2.2.5 Dimensionless Radiant Cooling Potential: **RCP** and **RCP′**

This potential is represented as RCP or RCP′ defined in Equations (15) and (16), respectively. The latter shows an effective reduction rate of space cooling loads.

$$\mathrm{RCP} = \sum_{i=m_c}^{n_c} \delta_{c,i} \sum_{j=1}^{24} \left\{ \left(\sigma_b \left(\theta_{i,j} + 273.15\right)^4 - L_{i,j}^{\downarrow}\right\} \delta_{n,i,j} \right., \quad (15) \qquad \mathrm{RCP}' = \mathrm{RCP}/(24 \cdot Q \cdot \mathrm{CDD}_{22-22}), \quad (16)$$

where σ_b : Stefan-Bolzmann constant (=5.67×10^{-8}), [W/(m^2·K^4)]; and
$L_{i,j}^{\downarrow}$: Downward long-wave (atmospheric) irradiation, [W/m^2].

2.2.6 Dimensionless Geothermal Cooling Potential: **GCP** and **GCP′**

We assume an earth-tube system installed at a depth of 2 m from the grade line and the outdoor air is pre-chilled and ventilated by the system. In order to indicate the performance and an effective reduction rate of cooling loads, the following indices are defined:

$$\mathrm{GCP} = \sum_{i=m_c}^{n_c} \left(\theta_{d,i} - \theta_{g,i}\right) \delta_{c,i}, \quad (17) \qquad \mathrm{GCP}' = 24 \cdot C_a \cdot q \cdot \mathrm{GCP}/\left(\hat{Q} \cdot \mathrm{CDD}_{22-22}\right), \quad (18)$$

where $\theta_{g,i}$ is daily averaged ground temperature for i-th day, [°C].

The ground temperature profile is estimated by finite element analysis program for one-dimensional heat transfer developed by Matsumoto et al. (1999).

2.3 Maps of the Dimensionless Potential Indices

The indices discussed in Subsec.2.2 were calculated for each AMeDAS location and for each year during the period from 1981 to 2000. The same indices for all the 20 years were averaged to get statistically stable information. For samples, the drawn maps of dimensionless potential indices are illustrated in Figure 4.

It is obvious that estimated potentials at a certain location are quite different from those in the other locations and give a lot of information on passive design. Additionally, these maps are nice educational materials for

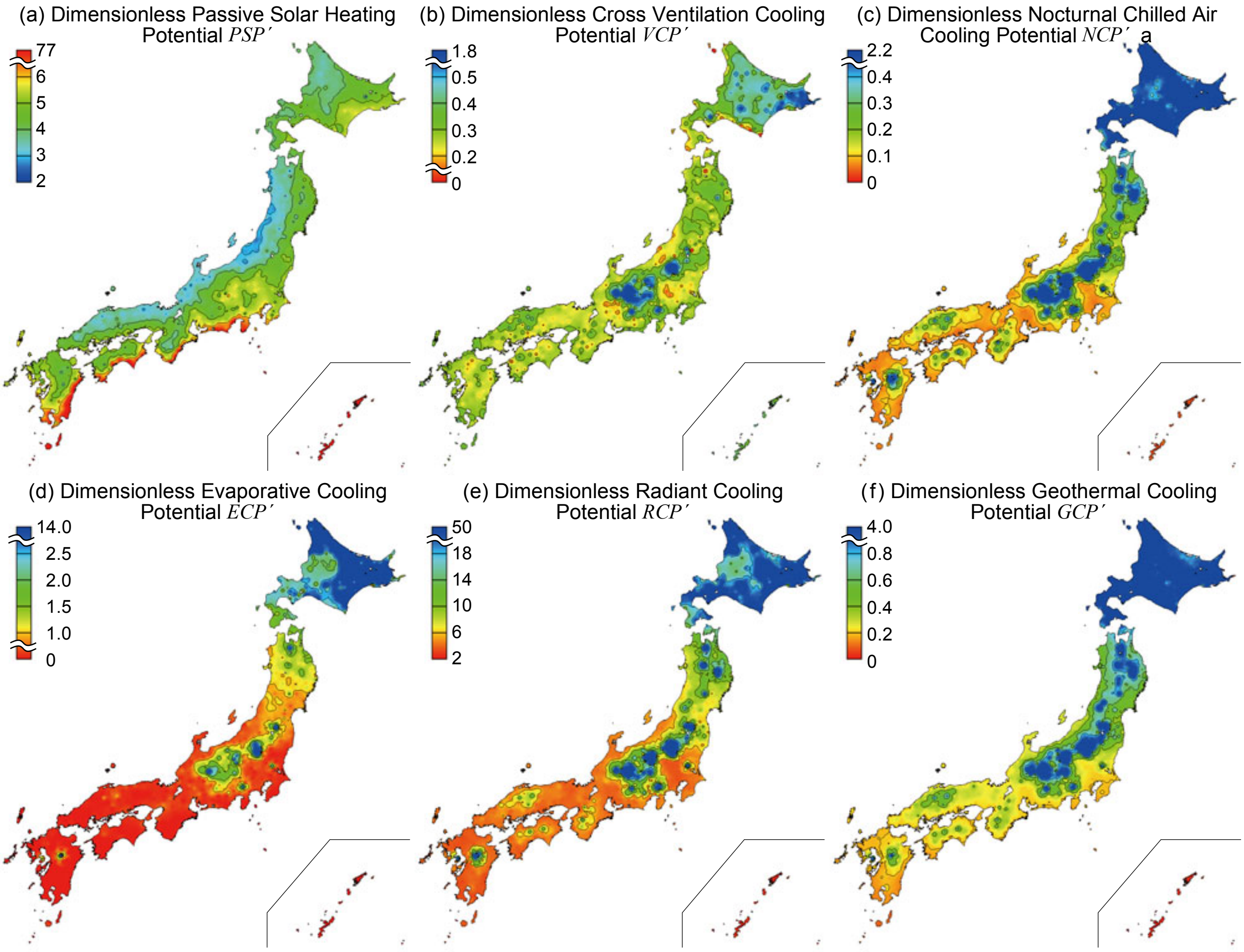

Figure 4 Maps of the dimensionless indices to indicate the passive heating/cooling potentials

us to enlighten house builders, architects and related engineers about reasons why the point of view from bioclimatic design is important to make buildings sustainable.

However, there are two weak points never to forgo in information from these maps: One is a simple point that some indices were explained as indicators of the cooling loads reduction effect but they never vary between 0 and 1 due to their mathematical expressions and there are some singular locations having extreme index value(s); The other is more important point that these potential indices never tell significance or necessity of application of passive heating and/or cooling strategies. For example as shown in Figure 4 (c), distribution of the cooling potential by nocturnal chilled outdoor air NCP' is quite great in Hokkaido, which is Japan's second largest island and the largest, northernmost of its 47 prefectural-level subdivisions, in spite of having little space cooling loads during the very short cooling season. For this reason, some other indices to indicate quantitative requirements of heating and cooling should be expected.

3. Strategy Requirement Indices and Passive Design Indices

3.1 Description of Watson and Labs' method Based on Givoni's Bioclimatic Chart

A literature survey was conducted to get ideas of new indices to indicate requirements of space heating/cooling. The main finding from the survey is that a method proposed by Watson and Labs (1992) is quite suitable for our aim. Their method is based on the famous Givoni's bioclimatic chart (1976), which is a psychrometric chart added boundaries defined by psychrometric parameters as to show 17 zones related to the passive strategies. Using that chart, Watson and Labs proposed to plot outdoor air condition data for a whole year and count plotted frequency for each zone to quantify requirements of several strategies as shown in Figure 5, which also illustrates the authors' original computer program applied their method to the EA Data.

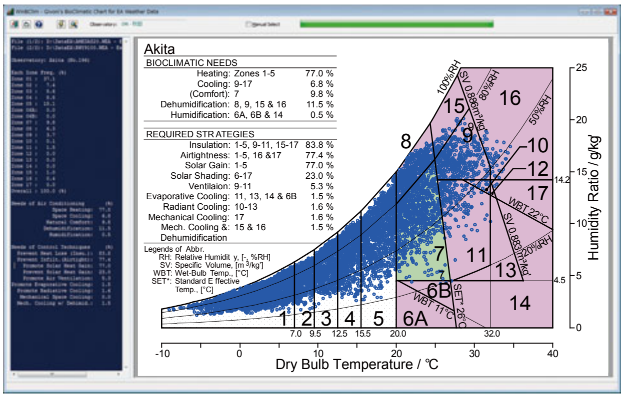

Figure 5 Computer program to analyze strategy requirement

3.2 Definition of the Strategy Requirement Indices

Table 2 includes the explanations of the five indices selected to combine with the potential indices. They are designated as "Strategy Requirement Indices" to tell their differences from the potential indices. These indices are also dimensionless because they are just plotted frequencies of whole year data. Since the EA Data DVD includes quite a lot of data for 20 years (approx. 175,000 hours), all of them are inputted to WinBClim as to get statistically stable values.

Table 2 Summary of three series of indices to get the passive design information

Applied Season	Utilization Strategy	Name of Index Group (Class of Indices)					
		Potential Indices		Strategy Requirement Indices		Passive Design Indices	
		Index Name / *Mathematic Expression*	Abbr.	Index Name / *Defined Zone (see Fig.5)*	Abbr.	Index Name / *Mathematic Expression*	Abbr.
Heating Season	Promote Solar Gain	(Dimensionless) Passive Solar Heating Potential *see Eqs.(3) & (4)*	PSP (PSP')	Solar Gain Requirement Index *Zones 1-5 in Fig.5*	SR	Solar Heat Gain Design Index $SDI = Norm(PSP \times SR)$	SDI
Cooling Season	Promote Cross ventilation	(Dimensionless) Cross Ventilation Cooling Potential *see Eqs.(6)-(9)*	VCP (VCP')	Cross Ventilation Requirement Index *Zones 9-11 in Fig.5*	VR	Cross Ventilation Design Index $VDI = Norm(VCP \times VR)$	VDI
	Promote Cool Air Gain	(Dimensionless) Nocturnal Chilled Air Cooling Potential *see Eqs.(11) & (12)*	NCP (NCP')	Cooling Requirement Index *Zones 9-17 in Fig.5*	CR	Night Purge Design Index $NDI = Norm(NCP \times CR)$	NDI
	Promote Evaporative Cooling	(Dimensionless) Evaporative Cooling Potential *see Eqs.(13) & (14)*	ECP (ECP')	Evaporative Cooling Requirement Index *Zones 11, 13, 14, & 6B in Fig.5*	ER	Evaporative Cooling Design Index $EDI = Norm(ECP \times ER)$	EDI
	Promote Radiant Cooling	(Dimensionless) Radiant Cooling Potential *see Eqs.(15) & (16)*	RCP (RCP')	Radiant Cooling Requirement Index *Zones 10-13 in Fig.5*	RR	Radiant Cooling Design Index $RDI = Norm(RCP \times RR)$	RDI
	promote Cool Air Gain	(Dimensionless) Geothermal Cooling Potential *see Eqs.(17) & (18)*	GCP (GCP')	Cooling Requirement Index *Zones 9-17 in Fig.5*	CR	Geothermal Cooling Design Index $GDI = Norm(GCP \times CR)$	GDI

$Norm(V)$: Function to normalize the variable V with the average and the standard deviation

4. Passive Design Indices

4.1 Definition of Passive Design Indices

Here proposed are the new indices designated as "Passive Design Indices" which are combined indices of the potential indices and the strategy requirement indices. The combination is quite simple as summarized in Table 2. In order to ease a comparison of the indices, each index is normalized by the well-known z-score conversion technique. This idea seems to be a good answer to reinforce one of the weak points mentioned in Subsec.2.3, but their physical meanings may be thinner than those of the dimensionless indices. Nevertheless the indices keep some bioclimatic properties.

4.2 Maps of the Passive Design Indices

Distribution maps of the passive design indices are illustrated as Figure 6. The figures have quite different tendencies from those found in Figure 4. The authors' knowledge on regional distribution of practical building examples designed well with the passive strategies is more coincident with tendencies read from Figure 6 rather than Figure 4. Additionally, it seems that the passive design indices are sensitive to local climate as well as the potential indices and have worth to analyze carefully.

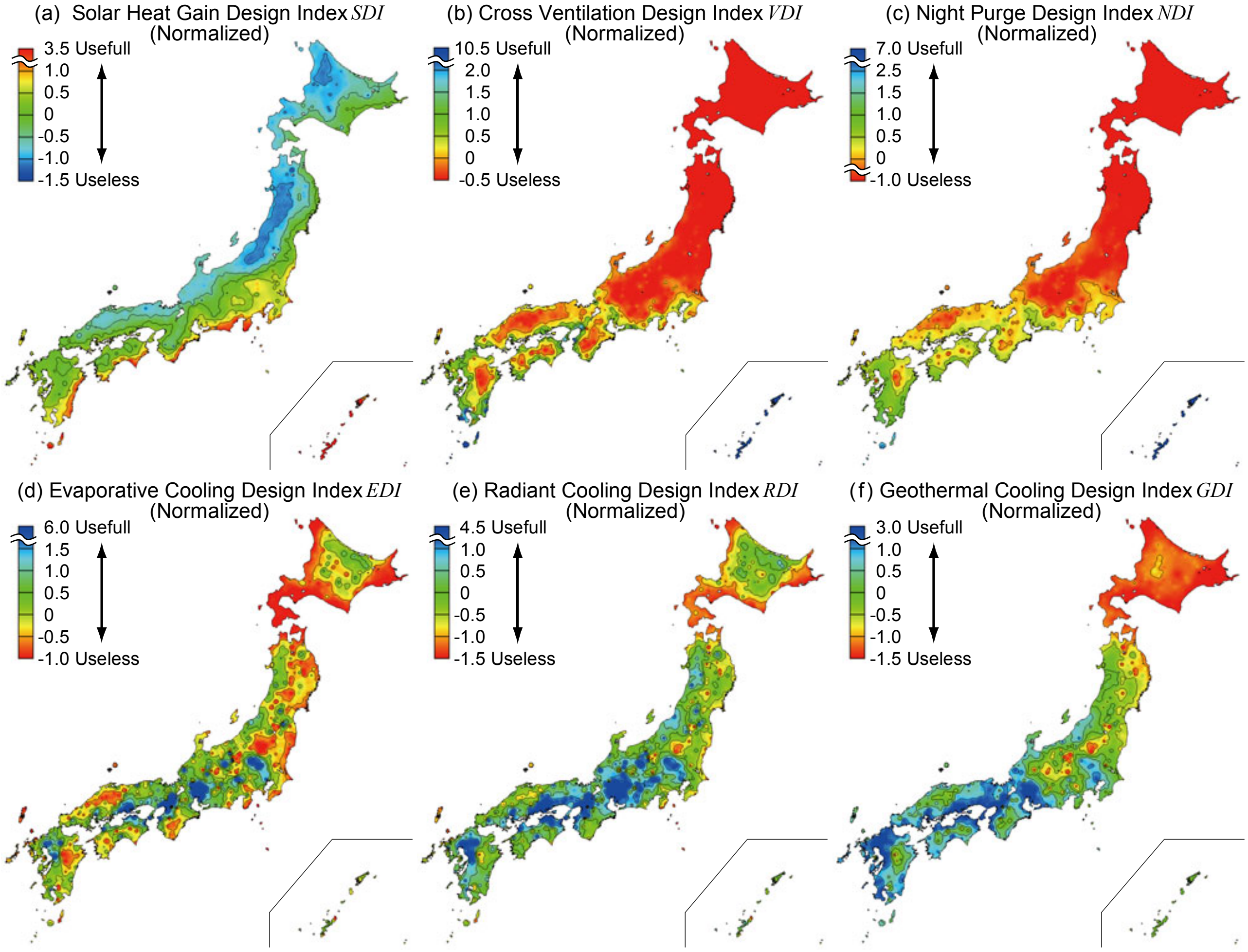

Figure 6 Maps of the passive design indices SDI etc. defined in Table 2

5. Regional Passive Design Concept Map

5.1 Analysis Procedure

A careful reading of Figures 4 and 6 tells that some combinations of passive design techniques are commonly utilized for a certain region and regional design concepts may be classified. A regional concept map with brief description is drawn finally to give comprehensive design information.

In order to find clear regional classification, the k-means cluster analysis method by MacQueen (1967) is applied for the design indices. The analysis program in a commercial statistical software is used.

5.2 The Regional Design Concept Map as an Analysis Result

Figure 7 on the last page is an illustration of the regional concept map based on the analysis. Total number of categorization classes were decided by trial and error to be seven, considering with the interpretation of regions. The authors would like to say Figure 7 is a conclusive fruit of this paper because the illustrated concepts are quite reasonable and informative.

6. Conclusions

The summary of contents and main findings of this paper are itemized as follows:

1) Two different types of indices and the combined indices of them were proposed;
2) The indices were calculated and expressed in the color-contour maps for discussion and practical use. It was clarified that they were useful to obtain design information on passive heating/cooling techniques;

3) A scientific procedure to classify bioclimatic regions was proposed and the procedure was practically applied to conduct a regional passive design concept map. It can be said that the procedure was established well. The established procedure would have a worth to apply for for the other countries or regions.

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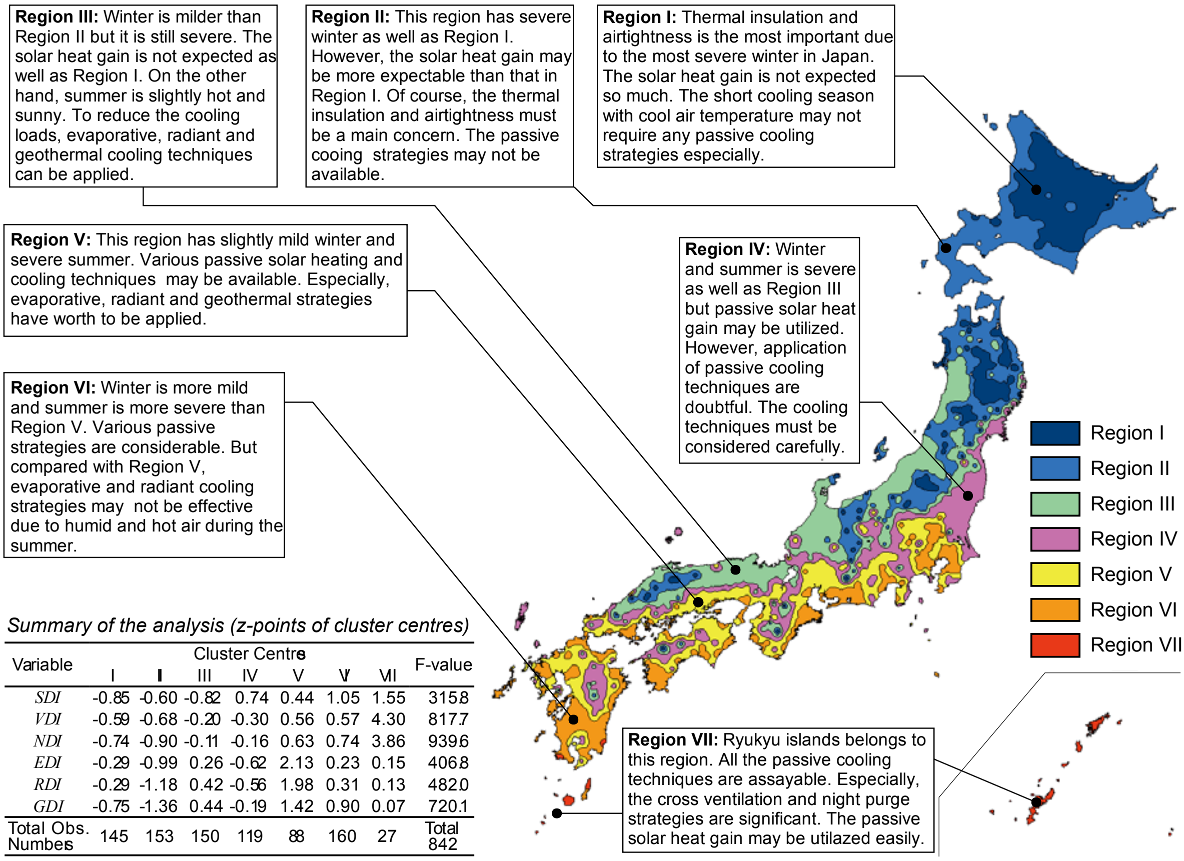

Summary of the analysis (z-points of cluster centres)

Variable	Cluster Centre I	II	III	IV	V	VI	VII	F-value
SDI	-0.85	-0.60	-0.82	0.74	0.44	1.05	1.55	315.8
VDI	-0.59	-0.68	-0.20	-0.30	0.56	0.57	4.30	817.7
NDI	-0.74	-0.90	-0.11	-0.16	0.63	0.74	3.86	939.6
EDI	-0.29	-0.99	0.26	-0.62	2.13	0.23	0.15	406.8
RDI	-0.29	-1.18	0.42	-0.56	1.98	0.31	0.13	482.0
GDI	-0.75	-1.36	0.44	-0.19	1.42	0.90	0.07	720.1
Total Obs. Numbers	145	153	150	119	88	160	27	Total 842

Figure 7 Proposed map of regional passive design concept

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THE ENERGY AND WATER SAVING, AND OTHER BENEFITS, WHEN USING TRANSCRITICAL CARBON DIOXIDE REFRIGERATION FOR BUILDING COOLING AND HEATING

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Keywords: CO_2 emissions, sustainability, energy, water, CO_2 refrigeration, legionella

Summary

A major benefit of transcritical CO_2 refrigeration is the gliding temperature available when cooling the transcritical fluid from the final high temperature at completion of compression to as low a temperature as practicable. This property may be exploited when requiring simultaneous cooling and heating in building air conditioning applications. The CO_2 compressor discharge can usually heat enough water for heating, reheating and hot water purposes thereby obviating the need for a boiler and its fuel supply.

Using USA Department of Energy and Australian Greenhouse Office data for energy consumption in multi-category commercial buildings in the USA and Australia respectively, it is shown that CO_2 cooling reduces energy consumption, combined water consumption at the power stations and cooled office building, and CO_2 greenhouse gas emissions by at least 60%, 60% and 50% respectively in the existing building stock when coupled with a 25% reduction in airflow and a two thirds reduction in lighting energy. Incorporation of energy recovery from exhaust air and economizing cycles will produce additional reductions in all three areas. The absence of cooling towers entirely eliminates the danger of Legionella disease.

1. Introduction

1.1 Data from USA Department of Energy

Westphalen et al (1999) prepared a report dealing with Thermal Distribution, Auxiliary Equipment and Ventilation in the Energy Consumption Characteristics of Commercial Building HVAC systems comprising 3,345 million m^2 of cooled building floor space plus 4,459 million m^2 of heated building floor space. The total annual HVAC primary energy consumption was 4.85 x 10^9 GJ. Primary energy is the calorific energy in the fuel used. See Fig. 1 [Westphalen et al (2001)].

Figure 2 [Westphalen et al (1999)], shows that of the total Parasitic Primary Energy use in HVAC systems, the supply and return air fans consumed 50% of a total of 1.58 x 10^9 GJ i.e. 0.79 x 10^9 GJ. The exhaust fans consumed a further 33% of parasitic primary energy.

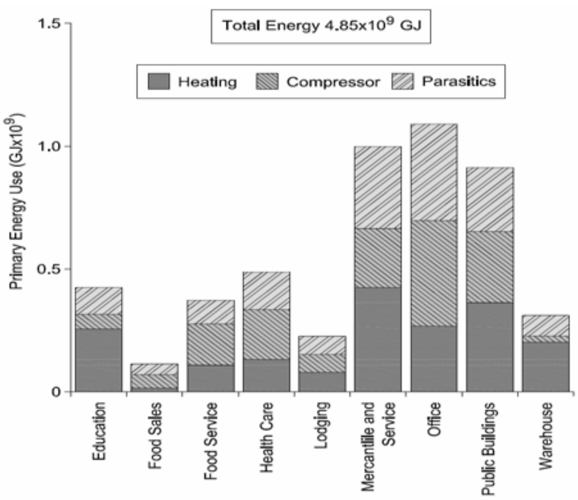


Figure 1 Total HVAC Primary Energy Use by Building Type

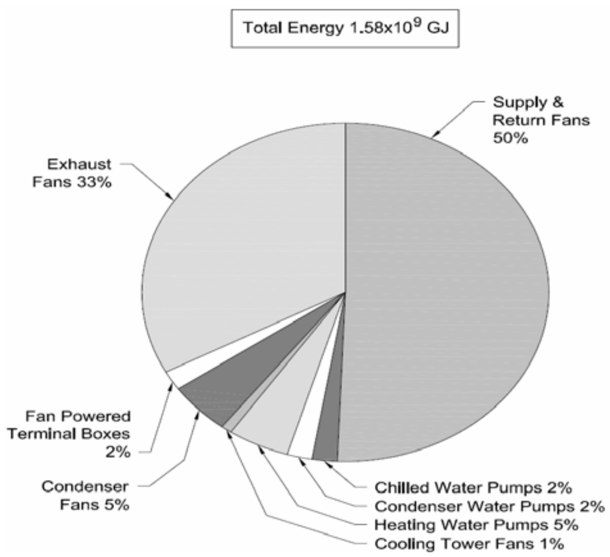


Figure 2 Parasitic Primary Energy use by Type of Equipment

Table 1 shows the equipment seasonal efficiencies over a whole year running. [Westphalen et al (1999)].

Table 1 Equipment Seasonal Efficiencies Coefficients of Performance (COP's)

Equipment	COP		Equipment	COP	
Centrifugal chiller	4.4		PTAC, PTHP	2.49	(2)
Water cooled screw chiller	4.14		Room AC	2.34	(2)
Water cooled recip chiller	3.91		Packaged AC	2.13	(2)
Air cooled screw chiller	3.17	(1)	Heat pump	2.13	(2)
Air cooled recip chiller	2.71	(1)	Absorption chiller	0.98	
(1) Includes impact of condenser fans			(2) Includes impact of condenser and evaporator fans		

1.2 Data from the Australian Greenhouse Office (AGO)

Table 2 shows the primary energy consumption of the Australian commercial building sector by source and quantity determined by Emet Consultants Pty Ltd et al (1999) in a study commissioned by the AGO. The study projected the primary energy consumption on a Business as Usual (BAU) scenario up to 2010.

Table 2 Trends in Energy Consumption and CO_2 Greenhouse Emissions Existing Technologies Future CO_2 Refrigerated Cooling Projected for Sydney

Application		Base Year – 1990				Year 2010			
		Existing		CO_2 in Existing Building		BAU		CO_2 in New Building	
		Energy – PJ pa	CO_2 – kT pa	Energy PJ pa	CO_2 – kT pa	Energy PJ pa	CO_2 – kT pa	Energy PJ pa	CO_2 – kT pa
Air handling		23.5	7017	10.0	2986	43.5	13007	18.5	5535
Cooling		27.4	7854	13.3	3812	50.9	14588	17.6	5044
Pumping		4.2	1248	4.2	1248	7.8	2347	7.8	2347
Total Cooling		**55.1**	**16119**	**27.5**	**8046**	**102.2**	**29942**	**43.9**	**12926**
Heating	Elec	4.3	1298	0	0	8.1	2439	0	0
	Gas	33.2	1970	0	0	69.9	4153	0	0
	Oil	9.1	679	0	0	13.1	984	0	0
	Coal	3.5	312	0	0	2.3	200	0	0
	Wood	0.7	0	0	0	0.2	0	0	0
Total Heating		**50.8**	**4259**	**0**	**0**	**93.6**	**7776**	**0**	**0**
Processes	Elec	2.9	847	2.9	847	5.3	1569	5.3	1569
	Gas	3.9	230	3.9	230	8.3	484	4.7	274
	Oil	1.5	111	1.5	111	2.1	158	0	0
	Coal	1.5	131	1.5	131	0.9	83	0	0
	Wood	0.0	0	0	0	0.0	0	0	0
Total Processes		**9.8**	**1319**	**9.8**	**1309**	**16.6**	**2294**	**10**	**1843**
Other	Elec	12.8	3809	12.8	3809	23.6	7060	23.6	7060
	Oil	0.3	26	0.3	26	0.4	33	0.4	33
Total Other		**13.1**	**3835**	**13.1**	**3835**	**24**	**7093**	**24.0**	**7093**
Lighting		**22.4**	**6694**	**7.4**	**2331**	**52.5**	**15673**	**17.5**	**5224**
TOTALS		**151.2**	**32225**	**57.8**	**15521**	**288.9**	**62779**	**95.4**	**27086**
REDUCTION				**93.4**	**16704**			**193.5**	**35693**
				61.8%	**51.8%**			**67%**	**56.8%**

Source: Emet and Solarch (1999) 1990 Existing and 2010 BAU for AGO

2. Principles of Reduction in Energy Consumption

2.1 Building Heat Load Components and AC Plant and Heating

The heat loads generated in a building are contributed to by heat gains through the building structure and windows, power consumed by office machines, lighting, fresh air leakage into the building, ventilation air, people and so on.

Once the heat load has been determined, an air conditioning plant usually comprising both heating and cooling functions is designed and installed. The compressor heat is rejected to atmosphere via a cooling tower providing cooling water to a condenser or via an air cooled condenser. Chilled and hot water is pumped around to Air Handling Units (AHU's) for cooling and reheating or heating only during Winter. Fans circulate air through ducts and return air fans return air to the AHU's. Exhaust fans remove a quantity of air.

2.2 Reduction in Energy Consumption

To reduce energy consumption in buildings it is necessary to reduce the amount of heat generated during hot weather by all constituent components and ensure that the cooling plant runs at the Most Energy Efficient Operating Point (MEEOP).

The supply and return fans constitute a large energy consumer and add a significant heat load to the system as well. The fan laws state that a 25% reduction in air flow reduces the energy consumption to 0.75^3 i.e. a reduction in energy consumption of $1 – 0.75^3 = 57.8\%$. There is also a corresponding decrease in compressor power requirement equivalent to the fan power reduction divided by the COP.

In existing buildings, a reduction in air flow needs to be compensated for by a lower air temperature which in turn requires a lower chilled water and/or refrigerant evaporating temperature To. A lower To reduces the compressor COP, which would tend to increase compressor specific energy consumption. In new buildings, it would be possible to design ductwork for lower velocities, thereby saving considerable energy.

Initially, the reduction in fan and resulting compressor energy consumption is greater than the increase in compressor energy consumption due to a reduction in the compressor COP. This constitutes an optimization problem identical to that found by Visser (1976) when blast freezing export meat cartons. This shows that it is frequently more energy efficient to select a compressor with a lower COP which needs to handle a much lower heat load. This principle is not widely understood, but universally applicable in cold air chilling and blast freezing systems, including air conditioning cooling.

3. Carbon Dioxide (CO_2) Refrigeration

3.1 Background

CO_2 refrigeration was commonly applied in building cooling until about the mid 1930's after which CFC's became dominant and CO_2 was relegated to the dustbin of history. When the Montreal Protocol outlawed CFC's following the disastrous Ozone Layer Depletion, CFC's were replaced by and large by a new series of chemical refrigerants called HFC's. HFC's have significant Global Warming Potential (GWP), which puts them under increasing pressure in the European Union with a country like Norway applying a Global Warming levy of Euro 79.00/kg of HFC. Other EU countries like Austria, Denmark et al are doing the same. Natural refrigerants like propane, butane, etc. are flammable and not recommended for building air conditioning. The toxic natural refrigerant ammonia is not recommended for building cooling.

The CO_2 properties lend themselves to heat pump applications with tens of thousands of small CO_2 heat pumps being used for water heating in Japan and now also in Europe. The German Motor Vehicle Manufacturer's Association has decided to install CO_2 systems for car air conditioning and heating in all cars by the year 2012. CO_2 is also an ideal refrigerant for the cooling and heating of buildings.

3.2 CO_2 Properties and Performance as a Refrigerant

The properties of CO_2 relevant to this paper are low critical temperature of 31.1^0C, a high volumetric refrigeration capacity due to the high vapour densities and a large pressure differential per degree C. CO_2 is non-toxic, non-flammable and has a GWP = 1. It is a totally natural substance with the average adult human producing about 1 kg/day.

Figure 3 shows the COP of sub critical CO_2 compressor performance as extracted from a CO_2 compressor manufacturer's rating tables. Dorin (2007). Figure 4 shows the COP of transcritical CO_2 compressor performance again from the Dorin (2007) compressor ratings.

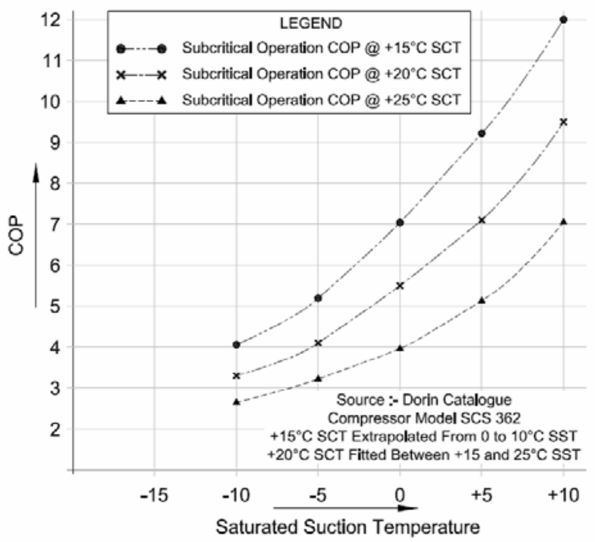


Figure 3 CO_2 Compressor COP Values Variation with Sat Suction and Condensing Temp

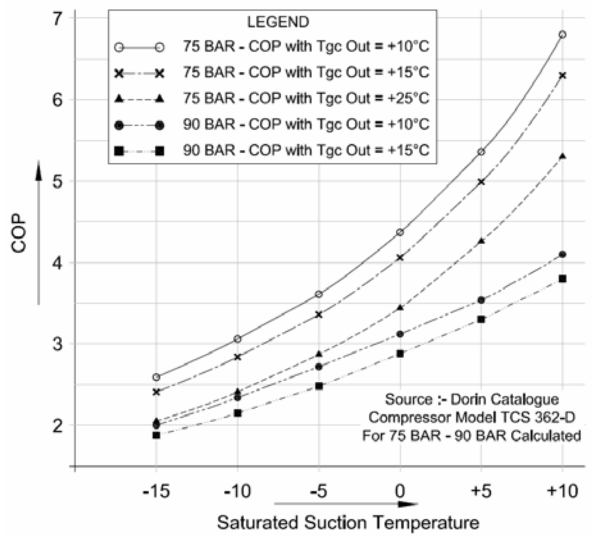


Figure 4 CO_2 Compressor COP Value Variation with Sat Suction Temp, Transcritical Discharge Pressure and Gas Cooler Outlet Temperatures

4. Australian Capital City Ambient Dry and Wet Bulb Temperatures

Dry and Wet Bulb Temperature (DWBT) data was obtained form the Australian Bureau of Meteorology (2008) for all Australian Capital cities except Darwin. See Table 3.

Table 3 Ambient AC Design Dry and Wet Bulb Conditions – Australian Capital Cities 6am – 10pm

City	DB, ^{0}C	WB, ^{0}C
Adelaide	37	22
Brisbane	33	25
Canberra	34	20
Hobart	30	19
Melbourne	35	21
Perth	37	22
Sydney	35	23

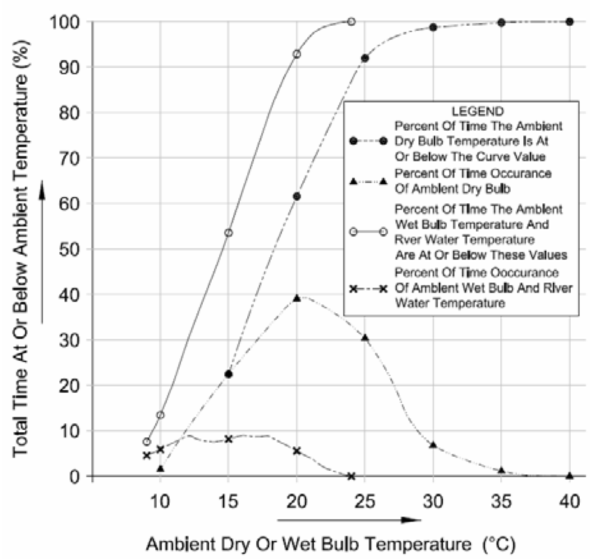


Figure 5 Ambient Dry & Wet Bulb Temperature Profile – Sydney Airport 6am – 10pm

In Figure 5, the ambient DWBT occurrence has been plotted from a total of 199,520 data readings taken at Sydney International Airport between 6am and 10pm for the past 10 years. We have selected a Sydney design condition of +35^{0}C dry bulb, +23^{0}C wet bulb, which are exceeded only 0.2% and 0.3% of the time respectively. After Brisbane, Sydney has the second most humid climate and is Australia's largest city. Sydney was therefore selected as the city for which to project potential energy and water savings to be had from CO_2 refrigerated cooling in both existing and new buildings.

In Table 4, we have evaluated the Seasonally Weighted COP (SWCOP) based on the Sydney climate. An advantage of CO_2 is its high pressure, which allows close temperature approaches between condensing temperature and cooling air or water. The lower the ambient temperature, the higher the COP and the higher the heating load will be in addition to hot water requirements, but the lower the cooling load will be. It has been assumed that on average 25% of the plant capacity would run in transcritical mode to provide heat for all purposes.

Table 4 Evaluation of Weighted COP with Ambient Temp Conditions for 12 Months Running of CO_2 Cooling in Sydney in:

a. Existing Buildings with +5^{0}C Evaporating Temp, Water Chiller Retrofitted to Existing Chilled Water Systems. See Figure 8

Ambient Temp ^{0}C	Sat Cond Temp., ^{0}C Avg	COP from Figs 3 & 4	Refrig load % of full load	% of time from Fig 5	Seasonally Weighted COP
Up to +15	+15	9.2	85	18.3	1.43
16 – 20	+20	7.1	90	31.9	2.04
21 – 25	+25	5.1	95	24.8	1.20
26+trans@75bar,+25^{0}C gas cooler out	–	4.3	100	25	1.07
TOTALS				**100**	**5.74**
b. New Buildings with 10^{0}C pumped CO_2 to Air Handling Units. See Figure 9					
Up to +15	+15	12	85	18.3	1.87
16 – 20	+20	9.5	90	31.9	2.72
21 – 25	+25	7.0	95	24.8	1.65
26+trans@75bar,+25^{0}C gas cooler out	–	5.3	100	25	1.32
TOTALS				**100**	**7.56**

5. Calculation of Energy Savings and Reduction in Global Warming Emissions

In Table 5, the calculated primary energy consumption for CO_2 refrigeration is tabulated. This enables the calculation of the total primary energy consumption of CO_2 refrigerated AC systems as shown in Table 2. The air handling primary energy consumption is reduced by 57.5% due to a 25% reduction in duct air velocity and the lighting primary energy is reduced by two thirds.

Table 5 Calculation of conventional Cooling Capacity, and CO_2 Cooling Capacity and Primary Energy

Year		1990		2010
1. Primary energy consumption conventional cooling, PJ		27.4		50.9
2. Say 30% of primary energy to compressors, PJ		8.22		15.27
3. Average COP of top four from Table 1, 3.66 say		4.0		4.0
4. COP primary energy multiplier (motor losses)		0.85		0.85
5. Effective COP, conventional system		3.4		3.4
6. Cooling capacity, conventional system, PJ (5x2)		**27.95**		**51.92**
7. CO_2 COP form Table 4		5.74		7.56
8. COP multiplier for real power		0.85		0.85
9. Effective COP for CO_2 compressors		4.88		6.43
10. CO_2 System cooling capacity reduction				
10.1 Air handling @ 75% fan speed	4.05		7.5	
10.2 $^2/_3$ reduction in lighting	<u>4.50</u>		<u>10.5</u>	
10.3 Total cooling capacity reduction		**8.55**		**18**
11. CO_2 cooling capacity, PJ (6 – 10.3)	**27.95 – 8.55 =**	**19.40**	**51.92 – 18 =**	**33.92**
12. CO_2 compressor power consumption (11 ÷9)		3.98		5.28
13. CO_2 primary energy consumption (12 ÷ 0.3), PJ		**13.3**		**17.6**

6. Calculation of Water Savings

This is shown in Table 6. It has been assumed that 66% of conventional air conditioning systems are water cooled, whilst water would be applied to air cooled gas coolers in Sydney 10% of the time.

Table 6 Calculation of Water Saving for CO_2 Cooling

a. Water Saving at the Cooled Building. Data from Table 5

	Year	1990			2010		
	Refrigerant	Conv	CO_2		Conv	CO_2	
1	Cooling energy, PJ	27.95	19.4		51.92	33.92	
2	Power consumption, PJ	8.22	3.98		15.27	5.28	
3	Total heat rejection , PJ	36.17	23.38		67.19	39.2	
4	% water cooled	66	10		66	10	
5	Heat rejected to water, PJ	23.87	2.34		44.35	3.92	
6	Water consumption, gigalitres (Gl)	9.95	0.98		18.48	1.63	
7	**Water saved incl 10% bleed, Gl (%)**		**9.87**	**(90.2)**		**18.54**	**(91.2)**
b.	Water Saving at the Power Station. Data from Table 2						
1	Primary electrical energy used, GJ	97.5	50.6		191.7	90.3	
2	Rejected to cooling tower, %	65	65		65	65	
3	Primary energy to evaporative water, GJ	63.4	32.9		124.6	58.7	
4	Total amount of water evaporated, Gl	24.4	13.7		51.9	24.5	
5	**Water saved by CO_2, Gl (%)**		**10.7**	**(43.7)**		**27.4**	**(52.8)**
c.	Total Water Saved Annually by CO_2						
1	Water saved at building, Gl (a. 7.1)		9.9			18.5	
2	Water saved at powerstation, Gl (b 6.1)		10.7			27.4	
3	**Total water saved, Gl**		**20.6**			**46.9**	
4	Conventional water use, Gl (a6 + b5)		34.35			70.3	
5	**Percentage of water saved by CO_2**		**60.0**			**66.7**	

7. Summary of Reductions in Energy and Water Consumptions and Global Warming CO_2 Emissions

This is shown in Table 7 in both quantity and percentages. Table 7 also shows the entire elimination of the legionella disease threat and the total absence of HFC fugitive gas escapes. Note the significant quantities of water saved at the power station, which is commonly not taken into account.

Table 7 Summary of benefits of CO2 Refrigerated Cooling for Air Conditioning with Heat Recovery Coupled with 25% reduction in building airflow and $^{2}/_{3}$ Reduction in Lighting

Year	1990		2010	
Variable and unit	Qty	%	Qty	%
Reduction in energy consumption, PJ (from Table 2)	93.4	61.8	193.5	67
Reduction in resulting emissions, kT (from Table 2)	16704	51.8	35693	56.8
Reduction in water consumption, Gl (from table 6c)	20.6	60	46.9	66.7
Legionella and fugitive HFC escape eliminated	Yes		Yes	

Figure 6 shows the reduction in annual primary energy consumption if the entire Australian Commercial Building stock were refrigerated by CO_2. Figure 7 shows the corresponding reduction in greenhouse gas emissions, which is greater than that which would have been required under the Kyoto Protocol.

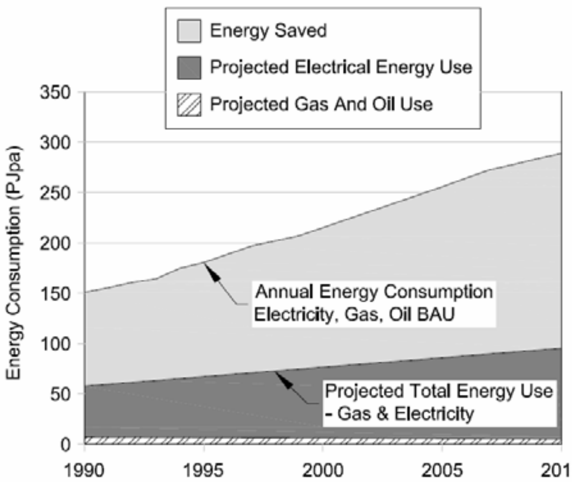


Figure 6 Projected Reduction in Primary Energy Consumption in Australian Commercial Buildings Based on the Sydney Climate

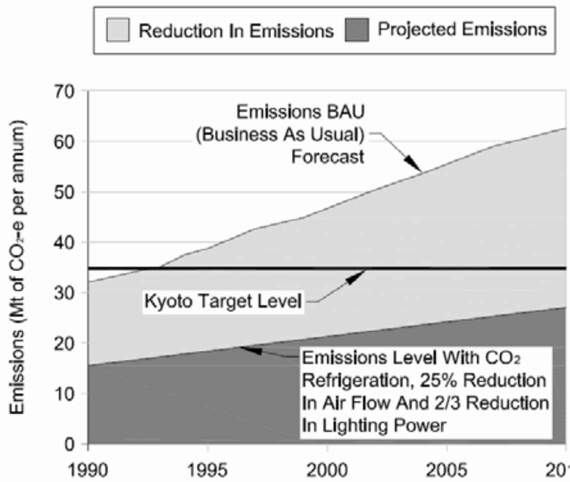
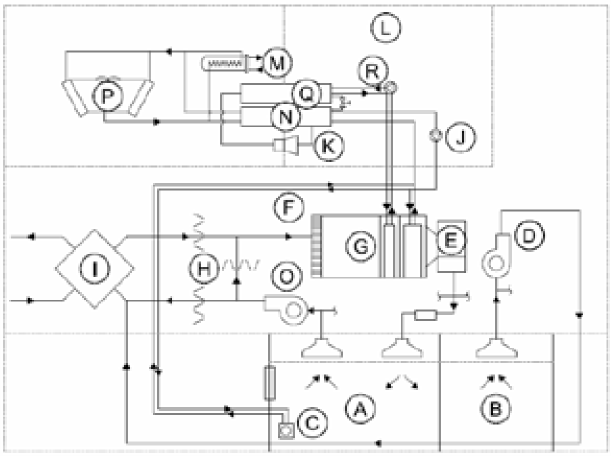


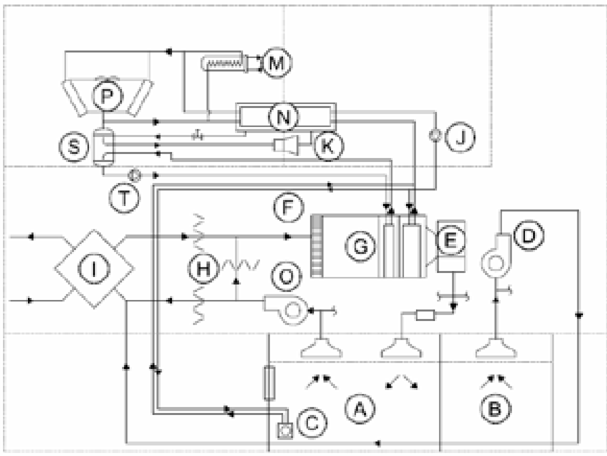
Figure 7 Projected Reduction in CO_2 Emissions in Australian Commercial Buildings Based on Sydney Climate

8. Implementation

8.1 Applied to Existing Buildings (See Figure 8)

In an existing building the chiller set, cooling tower and boiler would be removed. These would be replaced by CO_2 compressors, water chillers, a water cooled gas cooler for heat recovery and air or water cooled gas coolers to remove the balance of the heat. Existing pumps would be used to circulate chilled and hot water through the building to existing air handling units. The supply and return fans would be slowed down to 75% of their current speed and lights would be changed to save two thirds of lighting energy.





COMMON LEGEND

A Office Space	F Air Delivery System	K CO_2 Compressor	P Gas Cooler
B Bathroom	G Central Air Handling Unit	L Cold Water System	Q Evaporator
C Tap Hot Water	H Air Dampers	M River Water Gas Cooling	R Chilled Water Supply & Return
D Central Exhaust Fan	I Air to Air Heat Exchanger	N 2 Stage Water Heater	S CO_2 Suction Separator
E Supply Fan	J Hot Water Pump	O Return Air Fan	T CO_2 Pump

Figure 8 Schematic of a Central System with CO_2 Cooled Water Chiller, Exhaust Air Energy Recovery and Economising Cycle and Two Stage Water Heating

Figure 9 Schematic of a Central System with Direct Pumped CO_2 Evaporators, Exhaust Air Energy Recovery and Economising Cycle and Two Stage Water Heating

8.2 New Buildings (See Figure 9)

A total system would be designed to circulate CO_2 refrigerant or chilled water to air handling units throughout a building. Re-circulated CO_2 would be the most efficient and this would require custom design of the refrigeration systems similar to industrial refrigeration design practices.

All components are available in the market, but the required compressors would be expensive and on a long lead time. The entire system such as ducting and fans, hot water systems, etc would be designed using well established energy efficient design practices.

9. Conclusions

As shown in Table 7, the revival of CO_2 for air conditioning cooling applications has outstanding benefits in terms of reductions in primary energy consumption (62 to 67%), water consumption (60 to 66%) and CO_2 greenhouse gas emissions (52 to 56%) when applied in Sydney. These are all greater than mentioned in the summary. Furthermore, the threat of legionella is entirely eliminated, as are the dangers of HFC fugitive gases with high GWP. There is no other refrigerant, natural or chemical, which can deliver such superior and sustainable results. Greater savings would be possible if economizing cycles and exhaust air energy recovery systems would be implemented as well. Greater reductions would be expected in Adelaide, Hobart, Melbourne and Perth with smaller reductions predicted for Brisbane. Having regard to the outstanding environmental benefits of CO_2 refrigeration evaluated in this paper, it is abundantly clear, that the revival of CO_2 refrigeration for air conditioning cooling is a sustainable process far superior to current practices.

10. Acknowledgement

The writer wishes to thank Dr Anthony Marker, Director of the Australian Greenhouse Office, for making available a copy of the unpublished report entitled *"BASELINE STUDY of GREENHOUSE GAS EMISSIONS from the COMMERCIAL BUILDING SECTOR WITH PROJECTIONS TO YEAR 2010*

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Sustainable building policy evaluation criteria and the application to Japanese policies

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Summary

The building and housing market is now saturated in Japan, and demand for quality is growing in importance. Both the environmental initiatives of the construction sector and the demands of users are key factors. The condition cannot afford to scrap and build houses and building stock any longer. The aim of this document is to help policy makers to evaluate and introduce appropriate policies and strategies in order to achieve sustainability of residential and commercial buildings

Government can give a considerable impulse to sustainable buildings by encouraging these developments. The Japanese government has been trying to facilitate the supply of sustainable buildings by taking various measures. With regard to the evaluation of the "sustainable building policies", the following four criteria are proposed; 1) Environmental effectiveness, 2) Economic efficiency, 3) Technological incentives, and 4) Administrative feasibility.

The author applied these criteria to the recent Japanese sustainable building policies such as performance-based building codes, housing quality assurance system, and new tax systems. The sustainable building policies are classified according to the following five types of policy tool; 1) Regulatory policy, 2) Voluntary policy, 3) Economic policy, 4) Information policy, and 5) Research and Development (R&D) policy.

1. Trends and Actual Condition of Policies

Buildings have a considerable impact on the natural and built environment. In the 1980s, the ideas of energy saving in the building sector were developed according to the increasing social concern and the creation of regulations. The efficient use of energy moved into the forefront, when the mitigation of global warming became an urgent policy object after Rio conference in 1992. According to the statistics by the IEA, the building sector accounts for around 30% of all energy consumption of the OECD countries.

The environmental policy instruments are usually evaluated by the following four principal criteria; 1) Environmental effectiveness, 2) Economic efficiency, 3) Technological incentives, and 4) Administrative feasibility. According to the survey results, the building policy instruments for the energy efficiency objective could be classified as regulatory, voluntary, economic, information-based, technology-based, and comprehensive. Policy examples of the OECD countries including recent Japanese cases are analyzed.

1. Resource Efficiency	(Durability, Waste, Recycle etc.) **Waste Minimization Policy**
2. Energy Efficiency	(Energy saving, CO_2 gas etc.) **Energy Conservation Policy**
3. Pollution Prevention	(Indoor air quality, Noise etc.) **Pollution Prevention Policy**
4. Harmonization	(with Natural and Social environment etc.) **Urban Development Policy**
5. Systemic Approach	(ISO14000's, Urban planning etc.) **Industrial and Urban Policy**

Table 1: Policy Area of Sustainable Building by the OECD Sustainable Building Project

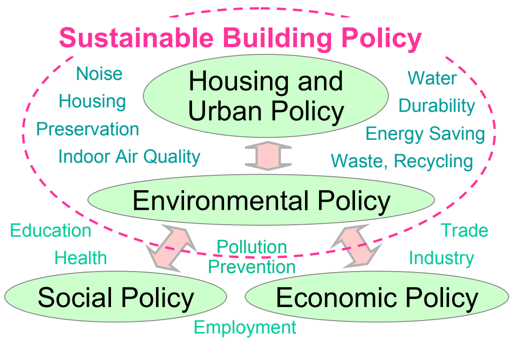

Figure 1: Policy Areas on Sustainability

2. Criteria for Policy Evaluation

The four principal criteria by which energy policy instruments are usually evaluated are as follows.

2.1 Environmental Effectiveness

There is a degree of uncertainty associated with the introduction of all environmental policy measures. This is particularly true when life-cycle and substitution effects are recognized, emphasizing the importance of policy co-ordination. However, some measures provide a greater degree of certainty about the likelihood of the achievement of a given policy objective (e.g. emission reductions, energy use) being realized.

2.2 Economic Efficiency

An economically efficient energy policy instrument is one, which equates the marginal benefits of reducing adverse environmental impacts with the marginal costs of doing so. A measure, which does not equalize marginal cost, will result in relatively higher total costs for meeting a given policy objective.

2.3 Dynamic Technological Incentives

While “static” economic efficiency effects are clearly important, in the longer run, the most important effects of energy policies relate to the incentives that they provide for research, development, innovation, and adoption of environmentally preferable technologies. To be effective such incentives must be predictable and continuous since the research-innovation-diffusion chain is very protracted and there are significant commercial risks involved at all stages.

2.4 Administrative Feasibility

Irrespective of the “ideal” properties of different instruments, they need to be administratively feasible at reasonable cost. While some costs are particular to the instrument itself, the relative feasibility and cost of a given instrument is largely a function of the degree of complementarity, which exists between the policy and the existing institutional and policy framework.

3. Evaluation of Representative Policies

The effects of the different instruments can be reviewed by taking representative policies from each category and assessing their potential advantages and disadvantages relative to the criteria for policy evaluation listed above.

3.1 Regulatory Policy Tools

Specification-based standard

In this case the household or firm is required to introduce particular conservation measures (e.g. energy conservation codes such as mandated levels of loft insulation for new dwellings or technical standards for heating equipment). They are likely to be environmentally effective at the level of the building. They are unlikely to be economically efficient unless there is considerable disaggregation of the standard, but this will tend to result in considerable administrative costs. As such there is usually a trade-off between economic efficiency and administration costs. They do not provide continuous incentives for the development and diffusion of new technologies, even in cases where leading-edge technologies are mandated.

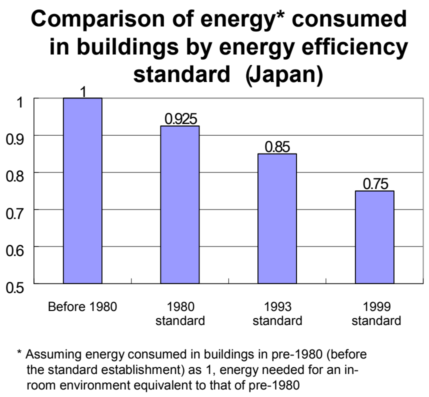

Figure 2: Trends of Japanese energy standard 1

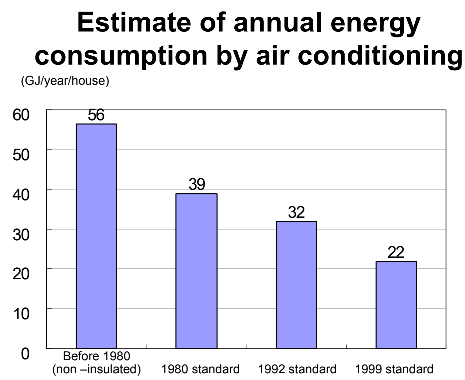

Figure 3: Trends of Japanese energy standard 2

Performance-based standard

These standards are expressed in terms of the actual performance of the appliance (e.g. conversion efficiency) or thermal characteristic (e.g. Heat-loss coefficient, K-values). They give the household or firm flexibility in how it achieves the standard, resulting in greater economic efficiency.

Depending upon how they are elaborated they may also allow for differences in local conditions or building characteristics. In addition, relative to specification -based standards these provide greater incentives for technological change. However they may be more administratively costly since information is required at a more detailed level. They are likely to be environmentally effective at the level of the individual building according to the analysis of the Japanese case and other countries.

Policy example	Environmental effectiveness	Economic efficiency	Technological incentives	Administrative feasibility
Specification-based building standards	**High**	Un-certain	Low	**High**
Performance-based building standards	**High**	**High**	**High**	Middle

Table 2: Regulatory Policy Tools

3.2 Voluntary Policy Tools

Assessing voluntary measures is exceedingly problematic. On the one hand, they are quite recent policy innovations, which complicate assessment. Secondly, they are heterogeneous in nature, containing elements of all of the other tools discussed above. However on the basis of an OECD review of actual experience with voluntary agreements, the following eight points are thought to be key in implementing a voluntary program:

1) Clearly defined targets;
2) Characterization of a business-as-usual scenario;
3) Credible regulatory threats;
4) Credible and reliable monitoring;
5) Third party participation;
6) Individual penalties for non-compliance;
7) Information-oriented provisions; and
8) Provisions for reducing the risk for competition distortions.

These characteristics reveal the close links, which exist between voluntary measures and other instruments, highlighting their role as complements to (rather than substitutes for) other policy measures.

Comparison of per Household Energy Consumption for Particular Uses in European Countries and the U.S. (2001)

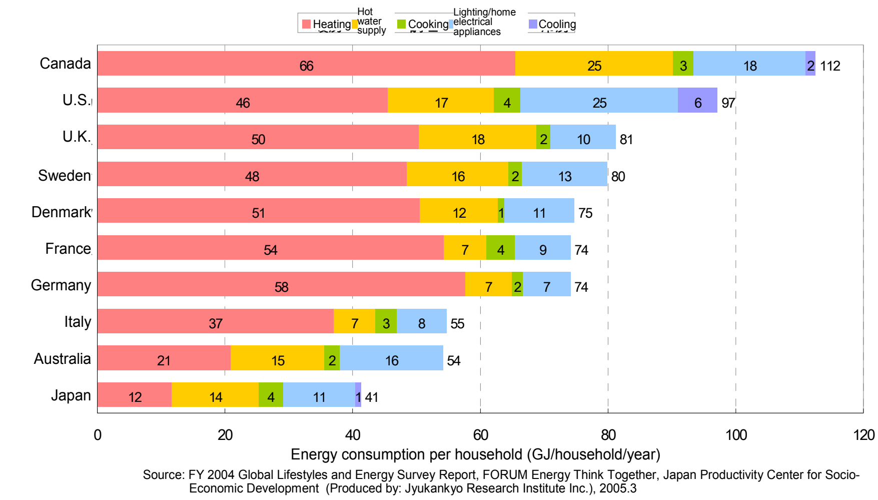

Figure 4: Energy consumption per household

3.3 Economic Policy Tools

Energy Taxes

These are likely to be economically efficient since costs of conservation measures will be equalized. They are also administratively simple, particularly since most energy use is already taxed.

(However, for other environmental objectives such as air pollution emissions where monitoring equipment is required or where damages depend upon location of emission, there is a trade-off between administrative costs and economic efficiency.) They provide continuous incentives for technological change. However, their degree of environmental effectiveness is dependent upon the extent to which household responses to energy price changes can be predicted.

Subsidies/Credit Schemes

In theory these can be economically efficient since costs of conservation measures will be equalized across households and firms if the schemes are implemented in a nondiscretionary manner (e.g. as analogues to universal taxes). However, in practice such measures are usually introduced in a differentiated manner, with access dependent upon household/firm characteristics.

Interestingly, if they are targeted at firms and households that are particularly affected by market failures (information failures, capital market failures, etc…), this differentiation may actually increase efficiency. They are usually relatively administratively burdensome. They can provide continuous incentives for technological development, but they are often targeted more toward increased diffusion of existing technologies. Their degree of environmental effectiveness is very uncertain for the same reasons as taxes, and for the additional reason that take-up may not be predictable. The Japanese case of the Governmental Housing Loan Corporation (GHLC) shows considerable policy effects.

Policy example	Environmental effectiveness	Economic efficiency	Technological incentives	Administrative feasibility
Taxation systems for energy saving	Uncertain	**High**	Middle	Middle
Incentive loans / Subsidy	Uncertain	Middle	Middle	Low

Table 3: Economic Policy Tools

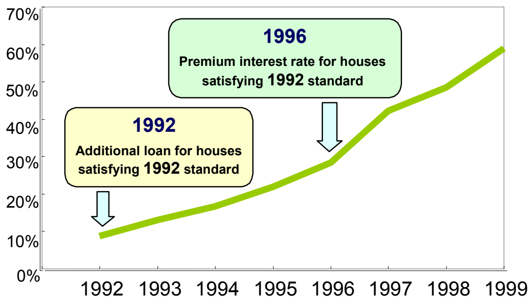

Figure 5: Effectiveness of GHLC Loans Proportion of houses satisfying 1992 standard

3.4 Information Policy Tools

Appliance and Building Labeling

These measures are likely to increase economic efficiency in cases where there are market failures related to information. In general, labeling may be administratively costly for some environmental concerns, but this is less likely to be true for energy use since the data is easily obtainable and can be standardized quite simply. Building labels are likely to be more administratively costly than appliance labeling since information is required at a much more disaggregated level. Depending upon the nature of the label, they may or may not provide incentives for technological change. Building labels have the advantage that they can encourage technological improvements in both the new and existing building stock. Environmental effectiveness is dependent upon the extent of the information-related market failure, and household responsiveness to the information provided. It is also dependent upon whether or not the labels are single-criteria or multi-criteria.

The CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) method developed in

Japan is one of the effective examples of building labeling. This assessment scheme becomes popular in Japan. In the housing sector, the housing performance indication system based on the Housing Quality Assurance Law was established in 2000 and has become popular as well in Japan.

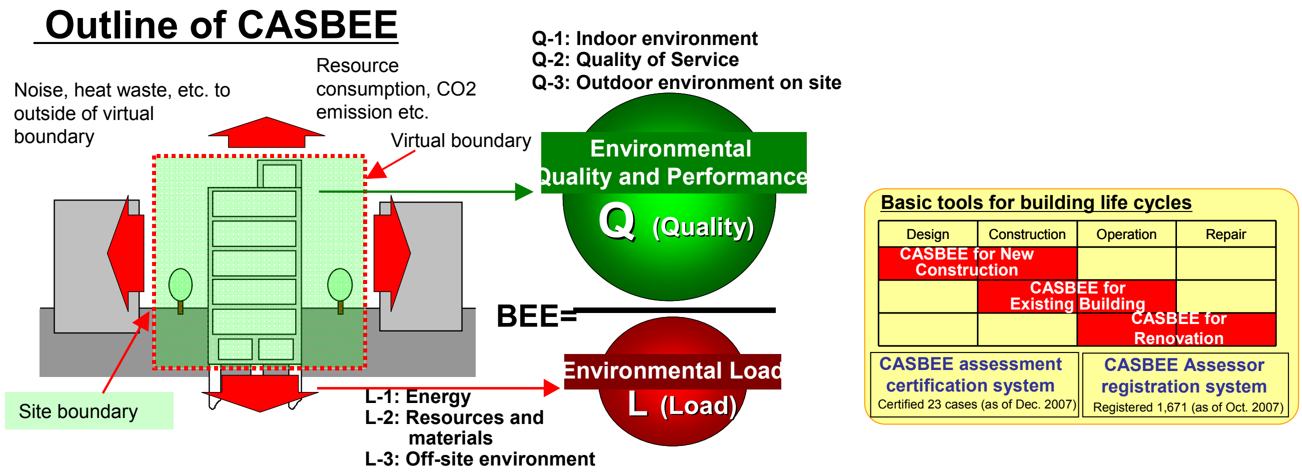

Figure 6: **CASBEE:** Comprehensive Assessment System for Building Environmental Efficiency

Name	BREEAM	LEED	GBTool	CASBEE
Founded	UK	USA	Canada	Japan
Year of implementation	1990 first 2002 latest	1996 draft 2002 latest	1998 first 2002 latest	2002 first 2003 latest
Users	UK, others	USA, Canada	research stage	Japan & other countries
Assess-ment Items	1.Management 2.Health and Well Being 3.Energy 4.Transportation 5.Water Consumption 6.Materials 7.Land Use 8.Ecology 9.Pollution	1.Land Use Plan 2.Water Efficiency 3.Energy & Atmosphere 4.Materials & Resources 5.Quality of Indoor Environment 6.Innovation & Design Process	1.Resource Consumption 2.Environmental Loadings 3.Indoor Environment 4.Service Quality 5.Economics 6.Management before Use 7.Surrounding Environment	Q :Quality and Performance Q1. Indoor Environment Q2. Quality of Service Q3. Outdoor environment on site L :Loadings L1.Energy L2.Resource and Materials L3.Off-site Environment BEE :Efficiency Q/L

Table 4: Comparison of evaluation tools

Dissemination and Diffusion Programs
As with labeling and certification schemes, these are primarily designed to overcome information-related market failures. As such, they tend to have the same advantages and disadvantages. While they are likely to increase rates of adoption for better existing technologies, in general they are less likely to result in continuous incentives for technological change since only specific technologies are usually eligible.

Policy example	Environmental effectiveness	Economic efficiency	Technological incentives	Administrative feasibility
Labeling / rating for energy saving	Uncertain	**High**	Middle	Middle
Information diffusion to consumers	Uncertain	Middle	Low	**High**

Table 5: Information Policy Tools

3.5 Research and Development Policy Tools

Research Programs
These are targeted toward the development of more efficient heating equipment and thermal retention materials. Given the propensity for market failures in the area of research and development, well-designed policies may

increase economic efficiency and provide incentives for technological change. However, it is important that such measures do not require the government to "pick winners", a task for which they are often ill-suited. Environmental effectiveness is very uncertain since there is considerable uncertainty in all stages in research -innovation -commercialization -diffusion chain. Administrative costs will also vary widely, but are likely to be less in cases where the program "piggybacks" on existing technology and innovation policy frameworks.

Policy example	Environmental effectiveness	Economic efficiency	Technological incentives	Administrative feasibility
Research and Development (R&D)	Uncertain	**High**	**High**	Middle

Table 6: R&D Policy Tools

4. Conclusion

Energy policy consists of supply-side and demand-side measures. The largest subject of the demand-side policy is to reduce the amount of energy consumption with securing the efficient use of energy. Recently, the efficient use of energy has become exceeded the frame of an energy policy, and the global warming prevention through an energy efficiency becomes more important policy subject.

In particular, the building sector, which has been behind in advancing energy efficiency, is an important sector, likewise the industrial sector and the transportation sector. The investigation on the sustainable building policy shows that energy policy measures account for approximately half of the environmental measures for a building. The figure below shows the recent trends of the Japanese building energy efficiency in cases of new construction with its improvement.

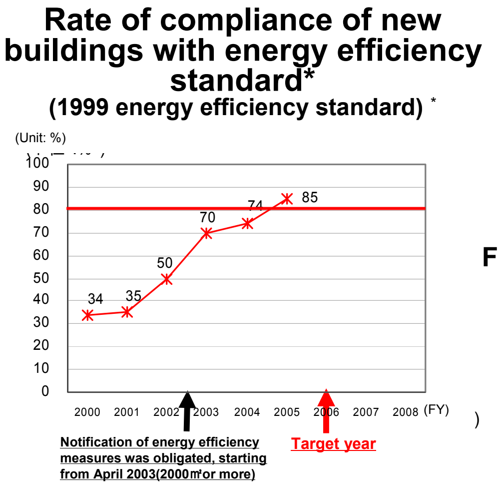

Figure 7: Compliance condition of new buildings with updated energy efficiency standard (2000 – 2005 Japan)

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STANDARDISATION IN THE FIELD OF SUSTAINABILITY OF THE BUILT ENVIRONMENT

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Keywords: sustainable development, buildings, construction assets, general principles, environmental declaration, environmental performance, indicators, international standardisation

Summary

Buildings and civil works are different, by their lifespan, by the numerous transformations people make in, and also, by the fact each building is unique. The impact of construction activities is very important in our present world for people everyday life, for their environment and health. Significant improvements can be quickly expected in building construction and civil works by reducing the environmental impacts, by anticipating and controlling long term costs, by being more concerned about social goals and consequences of a construction.

ISO TC 59/SC17 "sustainability in building construction" got for aim, with a most efficient and humble global approach based on the mutualisation of the expertise of more than 20 countries (North and South), to develop tools, in the form of ISO standards, for their use among construction actors in their economic and own technical activities. Such standards are published or currently being developed in different field:

- general principles and terminology (what the aim? Do we all understand the same things under each same term?)
- sustainability Indicators (proposal for a set of basic indicators)
- environmental declaration of products (based on ISO LCA methods)
- environmental performance of buildings
- and more recently “civil engineering”

The purpose of the proposed presentation is to make a panorama of the standardised tools offer and their dissemination among construction actors all over the world, how they can be experimented and how to get a good feedback for the benefit of all. Finally, the article concludes, at this time, on the level of contribution to sustainable development and the road still to walk.

Introduction

The issue of sustainable development is broad and of global concern, and, as such, involves all communities and interested parties. Both current and future needs define the extent to which economic, environmental and social aspects are considered in a sustainable development process.

The built environment (buildings and civil engineering works) is recognised as a key element in determining quality of life, and contributes to cultural identity and heritage. As such, it is an important factor in the appreciation of the quality of the environment in which society lives and works.

The building and construction sector is highly important for sustainable development because:

- it is a key sector in national economies (more than 1000 milliards Euros (EU 21) for Europe, 10% PIB, 2.3 millions of contractors (of which 97% have less than 20 employees, 7,3% employment in Europe and more than $US 4 trillion dollars and about 110 million workers in the world.) ;
- it has a significant interface with poverty reduction through the basic economic and social services provided in the built environment and the potential opportunities for the poor to be engaged in construction, operation and maintenance;
- it is one of the single largest industrial sectors and, while providing value and employment, it absorbs considerable resources, with consequential impacts on economic and social conditions and the environment (to simplify 40% CO_2 emission, 40% of natural resources, 40% of waste);

- it creates the built environment, which represents a significant share of the economic assets of individuals, organizations and nations, providing societies with their physical and functional environment;
- it has considerable opportunity to show improvement relative to its economic, environmental and social impacts.

Construction activities may or may not take place within a legal and regulatory, or other administrative framework present within a country or region. In either case, aspects of governance are relevant to sustainable development, in addition to those aspects related specifically to building construction. Well established administrative frameworks may contain requirements that can act as drivers and help to move the building and construction sector towards sustainability.

Over their life cycle, construction works absorb considerable resources and contribute to the transformation of areas. As a result, they can have considerable economic consequences, and impacts to the environment and human health.

While the challenge of sustainable development is global, the strategies for addressing sustainability in building construction are essentially local and differ in context and content from region to region. These strategies will reflect the context, the preconditions and the priorities and needs, not only in the built environment, but also in the social environment. This social environment includes social equity, cultural issues, traditions, heritage issues, human health and comfort, social infrastructure and safe and healthy environments.

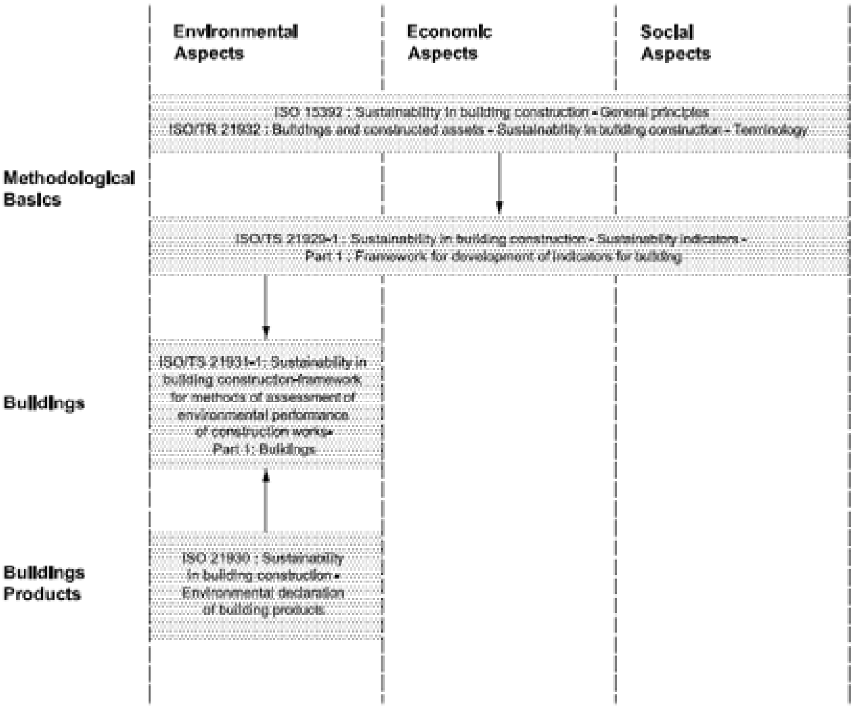


Figure 1 Suite of related international standards for sustainability in buildings construction and construction works

It may, in addition, particularly in developing countries, include poverty reduction, job creation, access to safe, affordable and healthy shelter, and loss of livelihoods.

Applying the principles of sustainability in building construction, including all related processes and activities, requires the direct and responsible involvement of all interested parties. While their legal responsibility and liability is subject to national or regional regulation, individual commitment and responsibility is voluntary.

Nevertheless, this commitment is a basic principle of the application of sustainable development, including application in the building and construction sector.

Applying the concept of sustainability to specific buildings or other construction works includes an holistic approach, bringing together the global concerns and goals of sustainable development and the demands and requirements in terms of product functionality, efficiency and economy. Different target audiences will have a different perspective on these challenges and the preferred solutions.

For all these reasons; ISO TC59/SC17 "sustainability in building construction" tired and succeeded to establish internationally recognized principles for sustainability in building construction and to establish a common basis for communication of the information required. Interested parties, such as product manufacturers and designers will then be able to provide information (by example, from a tool called environmental products declaration [EPD]). Such information can then be communicated internationally and to a wide range of target audiences, extending from policy makers and regulators to manufacturers, building owners and consumers.

The recipients of information can elaborate and interpret information according to their own perspective, reflecting other aspects of decision making, including fields of responsibility or constraints.

The concepts involved in sustainability are highly complex and under constant study. There are no definitive methods for measuring sustainability or confirming its accomplishment. These general principles do not provide a benchmark against which a claim of sustainability can be made. Nevertheless, they may be useful when considering the completeness and validity of claims of, or calls for, sustainability.

The aim of this International Standardisation work is to set out the objectives for sustainability in building construction and from these derives general principles. For the current standardization work, see Figure 1. This work forms now the basis for deriving evaluation criteria and indicators for the assessment of the contribution of buildings to sustainable development, and it enables decision makers to apply the principles in their decision making.

This set of tools does not (and have not to) set the political agendas, or provide priorities related to specific concerns which are established in international agendas, e.g. Agenda 21. However, requirements and targets related to political goals can be related to the identified general principles for sustainability in building construction (see Figure 2 "differences between green and brown agenda").

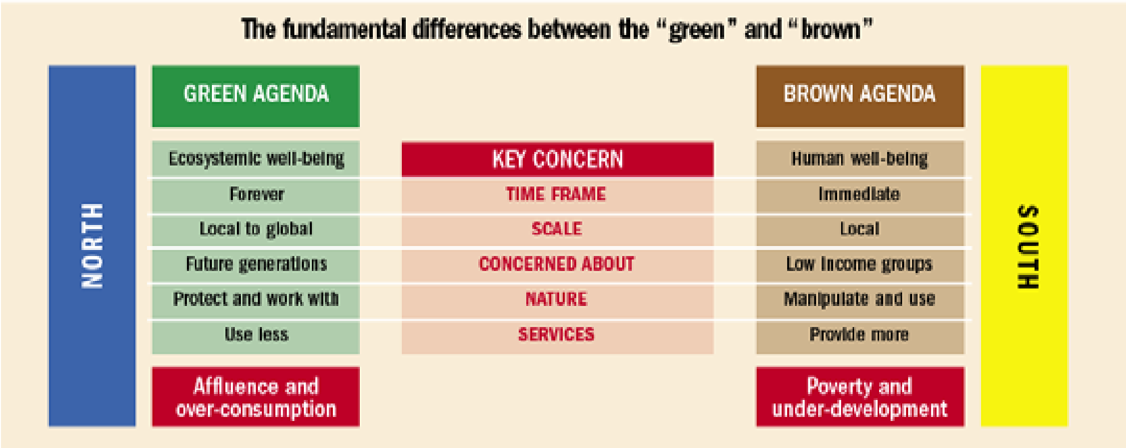


Figure 2 (source : from Ron Watermeyer, Iso Focus June 2007)

2- Overview of the ISO TC59/SC17 work

The purpose of TC59 SC17 is to propose a standardization frame for sustainability in building construction. The objectives of ISO /TC59 /SC17 is focused on the providing of an open forum for all member bodies for the processing, implementation and maintenance of ISO standards relevant to the scope in this SC (see figure 3).

The following objectives are those that the SC has selected as most important:

- assess, identify and meet the market requirements for standards,
- the quality of the standards,
- the standards shall be developed within time schedule laid down in the ISO Directives
- increase the number of participating countries in the SC,
- enlarge the participation to developing countries.

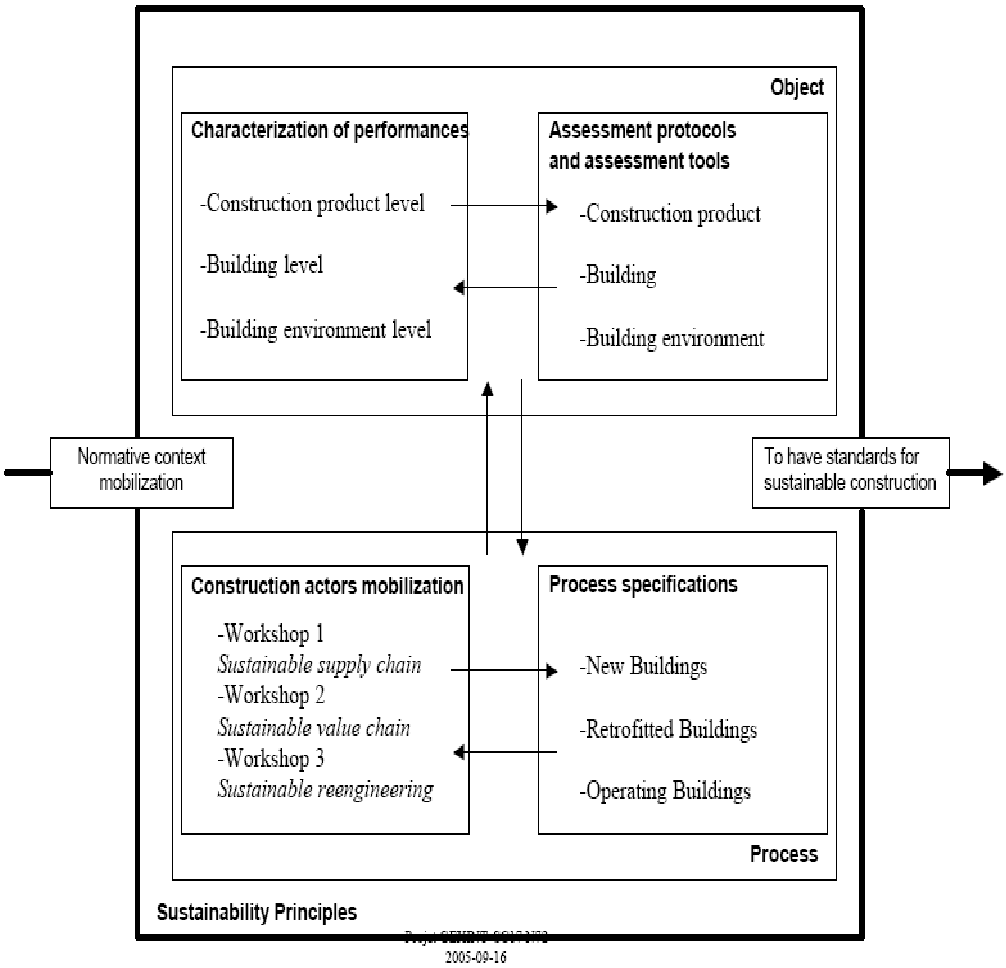


Figure 3 - Thematic and process for ISO TC 59 works

2.1 Organisation and structures

Directly contributing members of ISO TC 59/SC17 are coming from 17 different countries:

> Belgium (IBN), Canada (SCC), Denmark (DS), Finland (SFS), France (AFNOR), Germany (DIN), Italy (UNI), Japan (JISC), Korea Republic of (KATS), The Netherlands (NEN), Norway (SN), Poland (PKN), Spain (AENOR), Sweden (SIS), Switzerland (SNV), United Kingdom (BSI), USA (ANSI).

Some are regsistred as Observer countries and have either welcomed SC17 plenary meetings or WG meeting or have sometimes technically contributed : Australia (SA), Austria (ÖN), Brazil (ABNT), China (SAC), Czech Republic (CNI), Russian Federation (GOST R), Turkey (TSE).

SC17 is also working with some organizations in liaison for their active work in the domain of sustainable building or because they can bring at any time part of their own expertise in a particular domain: ISO/TC 59 SC14 Design life, ISO/TC 59 SC16 Accessibility and usability of the built, ISO/TC 163 Thermal Performance and Energy Use In the Built Environment, ISO/TC 205 Building Environment Design, ISO/TC 207/SC 3 Environmental Labeling.

ISO/TC 207/SC 5 Life Cycle Assessment, Liaison with CEN/BT/WG174 CEN/BT/WG174 Integrated environmental performance of buildings and further CEN/TC 350, Organization for Economic Cooperation and Development (O.E.C.D.), Federation of European Rigid Polyurethane Foam Associations (BING), European Aluminium Association (EAA), European Insulation Manufacturers Association (EURIMA), Council of European Producers of Materials for Construction (CEPMC), Extruded polystyrene Insulation Board Association" (EXIBA), International Federation of Consulting Engineers (FIDIC)

2.2 Five working groups :

WG 1: General Principles and Terminology Convenor – SIS (Sweden)
WG 2: Sustainability Indicators Convenor – SFS (Finland)
WG 3: Environmental Declarations of Building Products Convenor – NSF (Norway)
WG 4: Framework for Assessment of Environmental Performance of Buildings and Constructed Assets Convenor – JISC (Japan)
WG 5: sustainability in civil engineering Convenor : Aenor (Spain)

Table 1 - Working Groups under subcommittee SC17

3- Focus on products – The ISO 21930 standard .Sustainability in building construction — Environmental declaration of building products - Bâtiments et ouvrages construits — Développement durable dans la construction — Déclaration environnementale des produits de construction

3.1 Introduction

Designers of buildings, manufacturers of building products, users of buildings, owners of buildings and others active in the building and construction sector are increasingly demanding information that enables them to make decisions to address environmental impacts of buildings and other construction works.

These demands are currently being addressed only through various national initiatives applying a variety of approaches.

It is essential that there be uniformity in the means of expressing environmental product declarations. This includes having a consistent way of arriving at the declaration that is based on basic life-cycle inventory data and additional information not based on life-cycle assessment (LCA). The user expects non-biased information, which is expected be consistent with the best current practice and understanding over the lifetime of the standard.

According to the set of four International Standards dealing with environmental labelling, (ISO 14020, ISO 14021, ISO 14024 and ISO 14025), environmental labels and declarations are divided into three principal types:

- General principles: ISO 14020;
- Self-declared environmental claims, type II environmental labelling (ISO 14021);
- Principles and procedures of environmental labels and declarations, types I and III environmental labelling (ISO 14024 and ISO 14025).

The purpose of the international standard work was to describe the principles and framework for environmental declaration of building products, including consideration of the reference service life of the building products, seen over a building's life cycle. This work is expected to form the basis for type III environmental declaration programmes leading to type III environmental declarations of building products as described in ISO 14025.

Note EPD is an abbreviation used to represent both the single and plural full form designation of "environmental product declaration", which is intended to be synonymous with the designation "type III environmental declaration". In the practice of developing EPD, programmes or their declarations are referred to by various names such as eco-leaf, eco-profile, environmental declaration of product, environmental product declaration (EPD), and environmental profile.

3.2 Objectives of EPD of building products

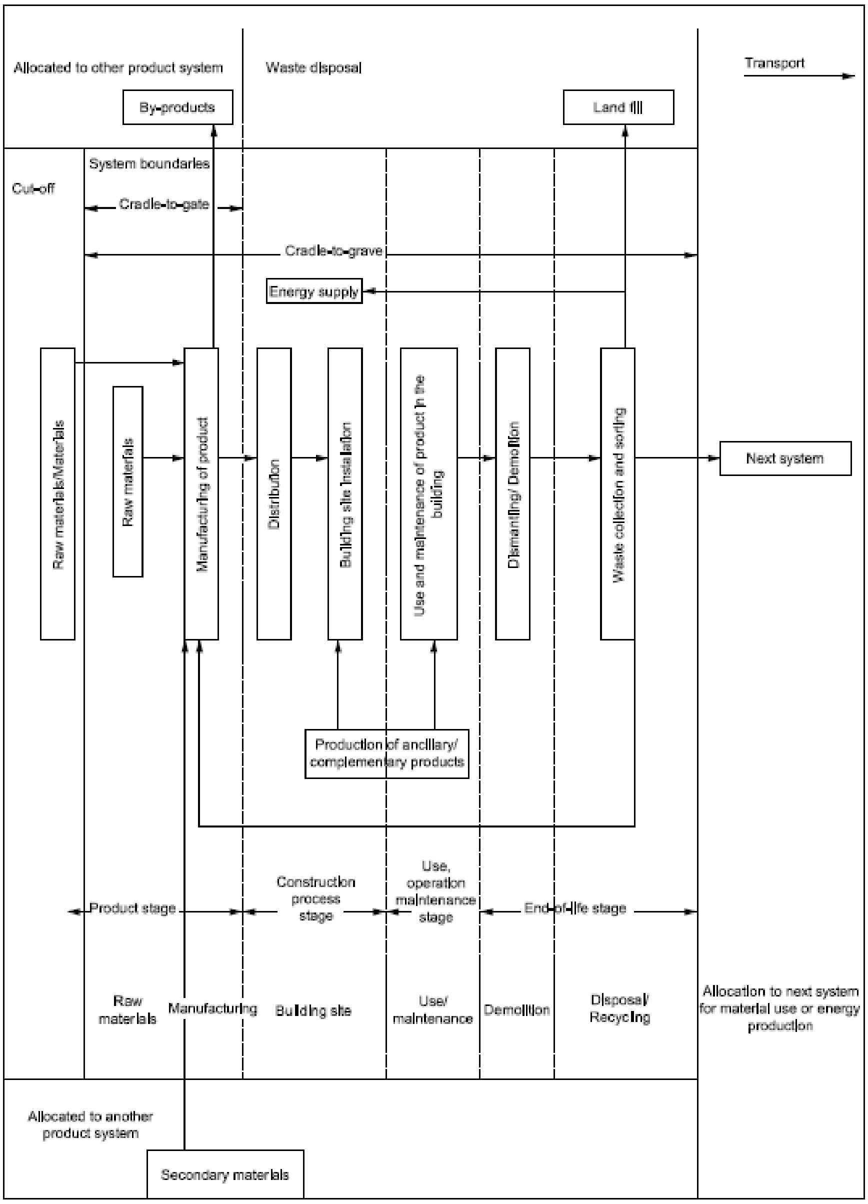


Figure 3 — Example of system boundaries, information modules and life-cycle stages of building products

The overall goal of environmental declarations is to encourage the demand for, and supply of, building products that cause less stress on the environment, through communication of verifiable and accurate information on environmental aspects of those building products that is not misleading, thereby stimulating the potential for market-driven, continuous environmental improvement.

The manufacturer, or group of manufacturers, of the building product is the sole owner of the data and takes liability and responsibility for the EPD of the building product.

The aim is to ensure the transparency of the methodology applied for developing the EPD for building products. The methodology should be consistent, scientifically robust and should ensure that all environmental impacts are completely accounted for without double counting.

In addition to the requirements of the principles and procedures set out in ISO 14025 and ISO 15392 shall apply when considering building products. For this reason, additional specifications and requirements for the EPD of building products were added. Where there are more specific requirements, ISO TC 59/SC17 complemented ISO 14025 for the EPD of building products.

In addition, the environmental declaration principles as described in ISO 14020 apply. The EPD of building products are intended to provide information for planning and assessing buildings. EPD can also be used by other interested parties, such as purchasers, architects, etc., to compare the environmental impacts of building products under certain conditions. EPD are based on LCA, LCI and/or information modules. Relevant environmental aspects that have not been covered by LCA are addressed as additional environmental information;

Environmental information of an EPD covering all life-cycle stages ("*cradle to grave*") is subdivided into at least the four life-cycle stages below. In addition, the stages may be further subdivided; see Figure 3 :

- product stage (including information modules from raw material supply, transport, manufacturing of products and all upstream processes from cradle to gate);
- construction process stage (information modules from transport to the building site and building installation/construction);
- use stage/operation [information module 6 contains information of the impact from the building product during its use and operation (e.g. installed services and appliances)]; use stage/maintenance (information modules 7, 8, 9, and 10 contain information on impacts from maintenance, repair, replacement and refurbishment, including all transport);
- end-of-life stage (information modules from deconstruction, reuse, demolition, recycling and disposal, including all transport).

3.3 The main relevant principles and information provided by an EPD:

3.3.1 Involvement of interested parties

In accordance to the rules set by this standard, the process of developing EPD should include an open, participatory consultation with interested parties and reasonable efforts should be made to achieve a consensus throughout the process. The interested parties for type III environmental declaration programmes may include, but are not limited to, material suppliers, manufacturers, trade associations, purchasers, users, consumers, non-governmental organizations, public agencies and, when relevant, independent parties and certification bodies.

3.3.2 Information modules of building products

An EPD can include all life-cycle stages, such as production, installation into the building, use and maintenance, replacements, demolition, recycling and disposal, the EPD is said to be "*cradle to grave*" and becomes an EPD of building products based on LCA (see ISO series ISO 1404x standards). The material and energy flows for an EPD based on LCA are expressed per functional unit (i.e a functional unit is a quantified performance of a product system for a **building product** for use as a reference unit in an **EPD** based on LCA). .If the information modules considered in a type III environmental declaration do not cover the life cycle, then it shall be stated.

Important: all hazardous and toxic materials and substances shall be included in the inventory (Life cycle inventory) and the cut-off rules do not apply.

3.3.3 Comparability of EPD of building products

Comparison of building products using EPD shall be carried out only at the building level. This comparison requires a scenario and the product category rules (PCR: set of specific rules, requirements and guidelines for developing **type III environmental declarations** for one or more **product categories**) shall describe the rules and requirements for that scenario.

For example, the French standard NF P01-010 is the PCR for all building products. This was a consensual choice of the whole industry.

There are some data quality requirements: the data quality has an influence on the content of an EPD. depending on the goals, the data quality requirements shall be formulated with regard to accuracy, precision, completeness and representativeness.

3.3.4 Reporting

It is an important part of the EPD, allowing it to be publicly communicated and published. The reporting is also used for the verification (by a third party) and the review of the EPD. The ISO 21930 set rules for the project documentation.

3.3.5 Rules for data confidentiality

Product-specific data are very often confidential, because of competitive business issues, intellectual property rights, or similar legal restrictions.

It is not required to make such confidential data publicly available. Normally, the EPD present only data that have been aggregated over the four stages of the life cycle or relevant portions of it and the aggregation obscures the underlying competitive information. Confidential business data provided for the independent verification process can be kept confidential upon request of the body supplying the data and with the approval of the programme operator, in accordance with programme operational rules.

3.3.6 Declaration of environmental aspects

A Environmental impacts expressed in terms of the impact categories of LCIA

- . climate change (greenhouse gases);
- . depletion of the stratospheric ozone layer;
- . acidification of land and water sources;
- . eutrophication;
- . formation of tropospheric ozone (photochemical oxidants).

B Use of resources and renewable primary energy — Data derived from LCI and not assigned to the impact categories of LICIA)

- . depletion of non-renewable energy resources;
- . depletion of non-renewable material resources;
- . use of renewable material resources;
- . use of renewable primary energy;
- . consumption of freshwater.

C Waste to disposal — Data derived from LCA and not assigned to the impact categories of LCIA)

The waste allocated to the building product during its life cycle shall be classified in the EPD as

- . hazardous waste, or
- . non-hazardous waste.

The division between the various categories shall be expressed in percentage terms or as mass per functional or declared unit.

D Emissions to water, soil and to indoor air

Releases to ground- and surface water, as well as emissions to indoor air, shall be declared in accordance with national standards and practice. Information on human health and comfort due to chemical, biological and physical emissions is required for further evaluation on the building level of human health and comfort.

E Additional environmental information

An EPD shall include, where relevant, additional information related to environmental issues, other than the environmental information derived from LCA, LCI or information modules and other than emissions to water and to indoor air. This information shall be separated from the information described in C and D. The manufacturers shall report this information according to the provisions in the PCR document. Such 10 kinds of information can be information on environmental issues, such as :

- impact(s) and potential impact(s) on biodiversity,
- toxicity related to human health, the environment or both, and
- geographical aspects relating to any stages of the life cycle (e.g. a discussion on the relation between the potential environmental impact(s) and the location of the product system)

3.4 Conclusion One

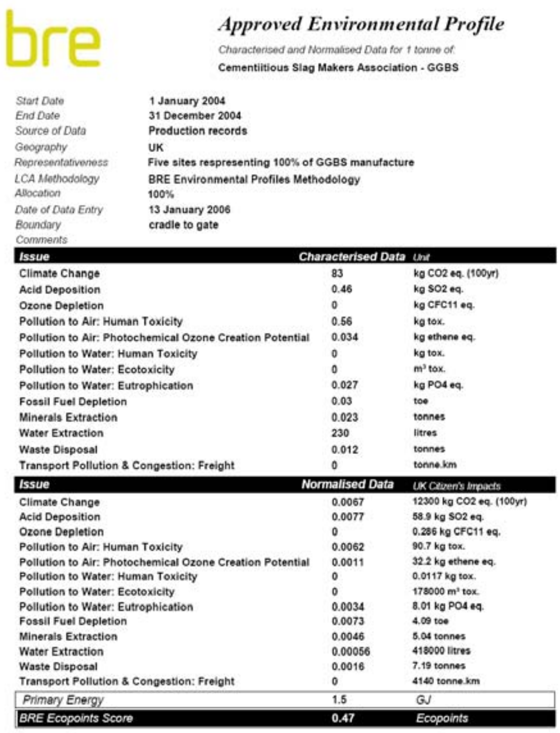
The environmental information on building products is intended mainly for business-to-business communication and its prime purpose is to provide measurable and verifiable input for the assessment of the environmental performance of buildings. However, some EPD may be used in the business-to-consumer marketplace and the user of this International Standard ISO 21930 shall follow the provisions of ISO 14025:2006, Clause 9.

The users are both the information providers and information users, including those setting up type III environmental declaration programmes. Users may include trade associations or other bodies organizing programmes for type III environmental declarations, manufacturers in the manufacturing chain, designers, developers, architects, contractors, facility managers and their clients.

Illustration - Some developments and applications in Europe :

France (CSTB) or UK (BRE) :

Figure 4a- INIES (database for EPDs)



Approved Environmental Profile

Characterised and Normalised Data for 1 tonne of:

Cementitious Slag Makers Association - GGBS

Start Date	1 January 2004
End Date	31 December 2004
Source of Data	Production records
Geography	UK
Representativeness	Five sites respresenting 100% of GGBS manufacture
LCA Methodology	BRE Environmental Profiles Methodology
Allocation	100%
Date of Data Entry	13 January 2006
Boundary	cradle to gate
Comments	

Issue	*Characterised Data*	*Unit*
Climate Change	83	kg CO2 eq. (100yr)
Acid Deposition	0.46	kg SO2 eq.
Ozone Depletion	0	kg CFC11 eq.
Pollution to Air: Human Toxicity	0.56	kg tox.
Pollution to Air: Photochemical Ozone Creation Potential	0.034	kg ethene eq.
Pollution to Water: Human Toxicity	0	kg tox.
Pollution to Water: Ecotoxicity	0	m³ tox.
Pollution to Water: Eutrophication	0.027	kg PO4 eq.
Fossil Fuel Depletion	0.03	toe
Minerals Extraction	0.023	tonnes
Water Extraction	230	litres
Waste Disposal	0.012	tonnes
Transport Pollution & Congestion: Freight	0	tonne.km
Issue	***Normalised Data***	***UK Citizen's Impacts***
Climate Change	0.0067	12300 kg CO2 eq. (100yr)
Acid Deposition	0.0077	58.9 kg SO2 eq.
Ozone Depletion	0	0.286 kg CFC11 eq.
Pollution to Air: Human Toxicity	0.0062	90.7 kg tox.
Pollution to Air: Photochemical Ozone Creation Potential	0.0011	32.2 kg ethene eq.
Pollution to Water: Human Toxicity	0	0.0117 kg tox.
Pollution to Water: Ecotoxicity	0	178000 m³ tox.
Pollution to Water: Eutrophication	0.0034	8.01 kg PO4 eq.
Fossil Fuel Depletion	0.0073	4.09 toe
Minerals Extraction	0.0046	5.04 tonnes
Water Extraction	0.00056	418000 litres
Waste Disposal	0.0016	7.19 tonnes
Transport Pollution & Congestion: Freight	0	4140 tonne.km
Primary Energy	1.5	*GJ*
BRE Ecopoints Score	0.47	*Ecopoints*

Figure 4b- BRE (UK) Environmental profiles

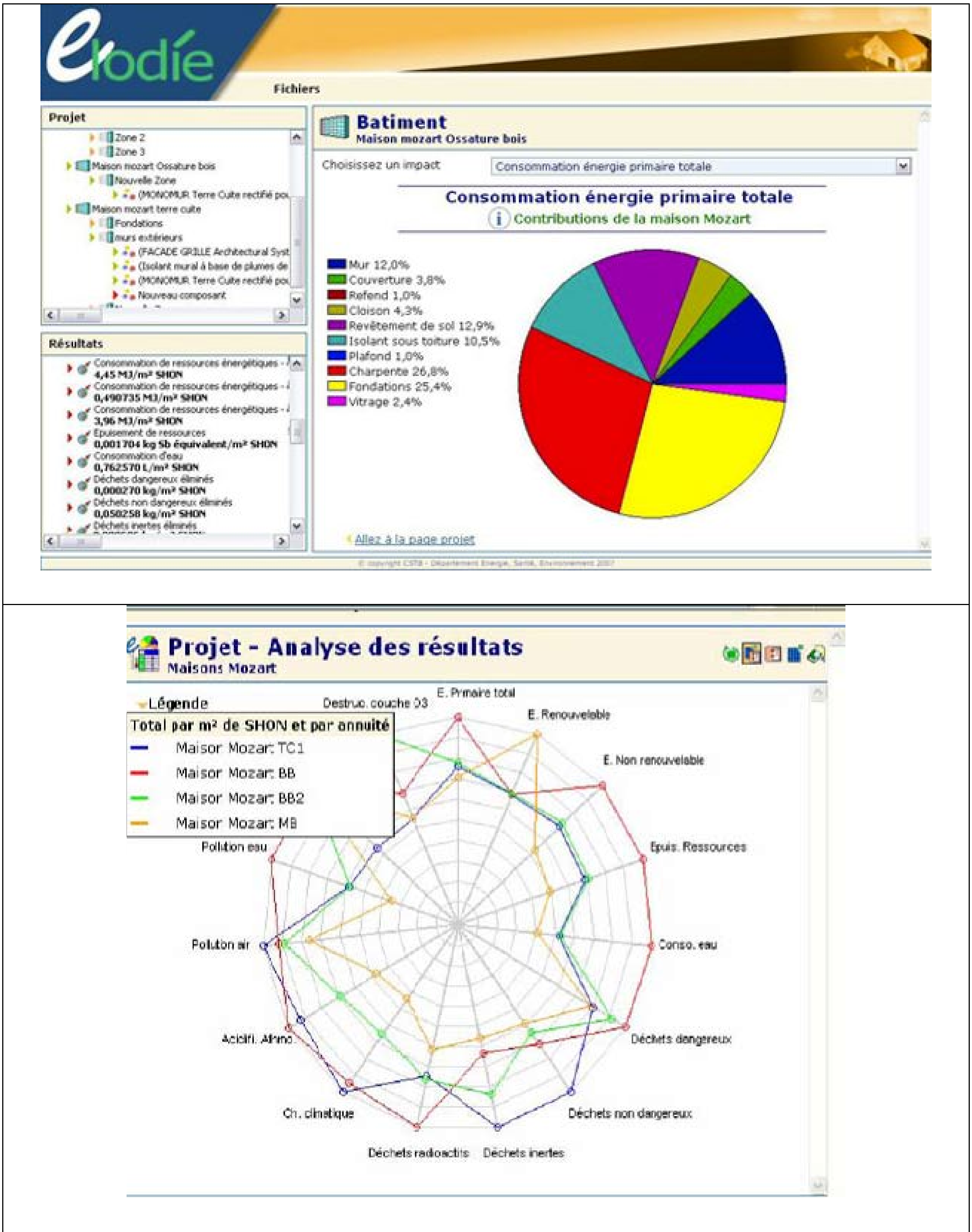


Figure 5 - Elodie (EPD aggregation tool for implementation at building level)

Different verification or third party verification are currently being performed in The Netherlands (MRPI), Germany (AUB) and France (Afnor verification scheme), Sweden (and countries participating in Gednet programme [EPD scheme]), UK 'BRE ecoprofile'.

More than 12 different European countries have set up an EPD-like scheme 5 (in the world: Japan, South Korea, USA, etc.)

In conclusion to the road toward a “green” building construction process, products and materials are part of the basic steps. Priority is given to the production of an objective scientific information (common language) and to its dissemination toward the scientific community (mainly laboratories, LCA experts, etc.). First results are more and more building product production process introducing ‘eco-design’ methods. Second steps should business and consumer oriented in order to make users more environmentally consciencious for their own activity (project, construction, purchasing, etc.). Such tools as Elodie project (CSTB, France) shows the way. That goal shall not be forgotten.

4- Focus on buildings – the ISO TS 21931 : ISO/TS 21931-1, Sustainability in building construction — Framework for methods of assessment for environmental performance of construction works — Part 1: Buildings - *Développement durable dans la construction — Cadre méthodologique pour l'évaluation de la performance environnementale des ouvrages — Partie 1: Bâtiments*

4.1 Introduction

Building construction shall now take into account a more sustainable approach. First steps were made through products EPD (more and more available on the global market) and through different assessment methods that each country tried to develop and implement. There was again a lack of common language in order to make comparable the different assessment methods and, more important, their basic principles. The goal driving the ISO work was to be able to set up a common framework inside which (or from which) the different existing assessment and design methods could benefit to improve, and prepare the next generation of integrated assessment and design tools.

ISO – through TC/59 SC14 (building service life planning) and SC17 and with TC 205 (building indoor environment design) made a great job trying to gather their effort.

4.2 Aim of the work

The aim of this part of ISO/TS 21931 was to define a framework for methods of assessment for the environmental performance of buildings. In order to be able to communicate information to interested parties regarding the potential environmental impact of buildings, in relation to the concept of sustainability, it is important to understand how the buildings themselves perform in this respect and to benchmark their progress towards achieving improved performance.

To this end, assessment methods for environmental performance of buildings have been developed and have been in use worldwide since the early 1990s. These developments have been prompted by

a shift from single performance measures to a more comprehensive set of environmental considerations, a recognition of the benefits of proactive voluntary measures, and the need to meet market demands for information on environmental performance.

Assessment methods for the environmental performance of buildings are the basis for demonstrating and communicating the extent of the proactive commitment of a building’s suppliers toward achieving higher levels of environmental performance. The methods attempt to establish an objective and comprehensive means of simultaneously assessing a broad range of environmental considerations against explicitly declared criteria, and to offer a summary of environmental performance.

Assessment methods for the environmental performance of buildings provide a common and verifiable set of criteria and targets so that building owners striving for higher environmental standards have a means of measuring, evaluating and demonstrating that effort, provide a reference as a common basis by which building owners, design teams, contractors and suppliers, can formulate effective environmental performance improvement strategies, gather and organize detailed information on the building that it can be used to lower operating, financing and insurance costs, lower vacancy rates and increase marketability, and assist the design process by providing a clear declaration of what are considered as the key environmental considerations and their relative importance.

Life-cycle approaches will inevitably play a greater role for setting performance criteria within methods of assessment of overall environmental performance of buildings. However, the collection and maintenance of current data sets for the multitude of systems and elements is not practically achievable at the moment.

Consequently, to achieve the practical goals noted above, assessment methods for the environmental performance of buildings need to refer to a limited number of criteria and seek a balance between rigour and practicality. This means that the deployment of LCA within the methods of assessment of overall environmental performance of buildings must consider the significance of the individual performance criterion within the context of the overall building performance.

Considering all these issues, there was a need to formalize an International Standard that will ensure the quality, and comparability, of assessment methods for the environmental performance of buildings.

The purpose of ISO/TS 21931 is to describe the framework and the principles behind the assessment of the environmental performance of both new and existing buildings, taking into account the various environmental impacts these buildings are likely to have.

The standard identifies and describes issues to be taken into account when using methods for the assessment of environmental performance for new or existing building properties in the design, construction, operation, refurbishment and deconstruction stages.

The building is the object of the assessment defined in this part of ISO/TS 21931, and this encompasses the building itself, the site and the associated facilities on the site. It is recognized that environmental performance is only one of a number of significant factors in a building's overall performance.

This part of ISO/TS 21931 is intended be used in conjunction with, and following the principles set out in, the ISO 14000 (environmental management) series of International Standards.

4.3 Description of the approach

The aim of an assessment of the environmental performance of a building is to examine the ability of the building to contribute to sustainable development with regard to the environmental dimension. It also aims to communicate and/or to improve the building's environmental performance. This can be achieved by supporting the decision-making process in design, construction, transfer, operation, refurbishment and demolition.

An improvement in environmental performance requires the appropriate operation of the building over its lifetime. In existing buildings, this could be enhanced through the use of an environmental policy and the implementation of a management system.

The intended use of the assessment and the life-cycle stages covered by the methods of assessment can be varied by the aim of the assessment.

Buildings can be considered under different angles of view which are not self-exclusive:

- **as an end-use product of itself**.

  A building physically consists of various elements, such as construction materials and components, which are parts of a building and its technical systems. Therefore, a building can be considered as an integrated assembly of component products, which are manufactured, used and disposed of, according to their service life. The manner of assembly is customized having regard to the project-based specific requirements of the building.

  Then, the environmental performance, which relates to the characteristics of the building as an assembly of elemental products, is subject to systematic maintenance management of the component products during their service lifetime.

  The environmental performance that relates to the characteristics of a building as an assembly of component products has relevance to the issues described in ISO 21930. Environmental product declarations (EPD) may be utilized in the assessment of buildings as established on the basis of agreed product category rules (PCR) according to ISO 14025.

- **as supports for active processes**

  According to systemic analysis, a building can be considered as supporting an active process. Through its operation during the utilization stage, a building provides a number of services to its users as well as conditions appropriate for living, working, studying, provision of health-care, leisure activities, etc. The provision of these services involves input and output flows to make this process function. It can also be considered as an active process when, combined with other buildings or industrial equipment, it performs, for example, as part of an ecosystem (when pollution or waste from another building or equipment can be used as resources).

  Therefore, the environmental performance of the building relates to the quality of services to users as well as to relevant conditions that a building generates when perceived as an active process. As an active process and in order to function, the building is provided with energy, water and various resources. Under these circumstances, a building yields the services for which it was intended and flows are incurred, including atmospheric emissions, wastewater and other waste. In addition to this, a building is linked to infrastructures both upstream and downstream, which also require energy, water and transportation energy and which generate wastes. These processes also have input and output flows.

  Consequently, the environmental performance of a building relates to input and output flows that a building generates as a process.

- **as places of activity**

  A building can also be considered as a place of activity, such as place to live and work, where it makes an effective contribution to the creation and the life of the urban context.

Therefore, the environmental performance of the building relates to the comfort and health of its users, such as occupants, site workers, maintenance staffs and neighbours and interested parties, over the building's life cycle.

4.4 Basic principles of the approach

4.4.1 Relevance to local context

The environmental performance of a building depends on the characteristics of the climatic, social, economic and cultural context of the nation and region where the building is located.

For comparison purposes between countries or regions, transparency is required and, as far as possible, standardized calculation methods shall be used. The standards underlines that the characteristics and relevance of local contexts make possible the co-existence of regional and national methods for the assessment of the environmental performance of buildings, providing that the methods are within the framework given in this part of ISO/TS 21931.

4.4.2 Framework for assessment of environmental performance

Any assessment method built to follow the standardized framework shall involve the following elements:

intended use of the method ;

- definition of the system boundary ;
- statement of assumptions ;
- structured list of issues for environmental assessment ;
- means of quantifying the environmental performance of a building ;
- sources of information (generic and specific database, etc.) ;
- evaluation and interpretation ;
- reporting of results of assessment and communication format

4.4.3 Intended use of method

The intended use of the methods of assessing the environmental performance of a building shall be clearly stated.

The intended use may encompass:

- design of a new building,
- assessment of an existing building,
- improvement of operation,
- design for modernization, and
- design for deconstruction and disposal.

The environmental performance of a building should be assessed in operational activities, including new construction, refurbishment or retrofit.

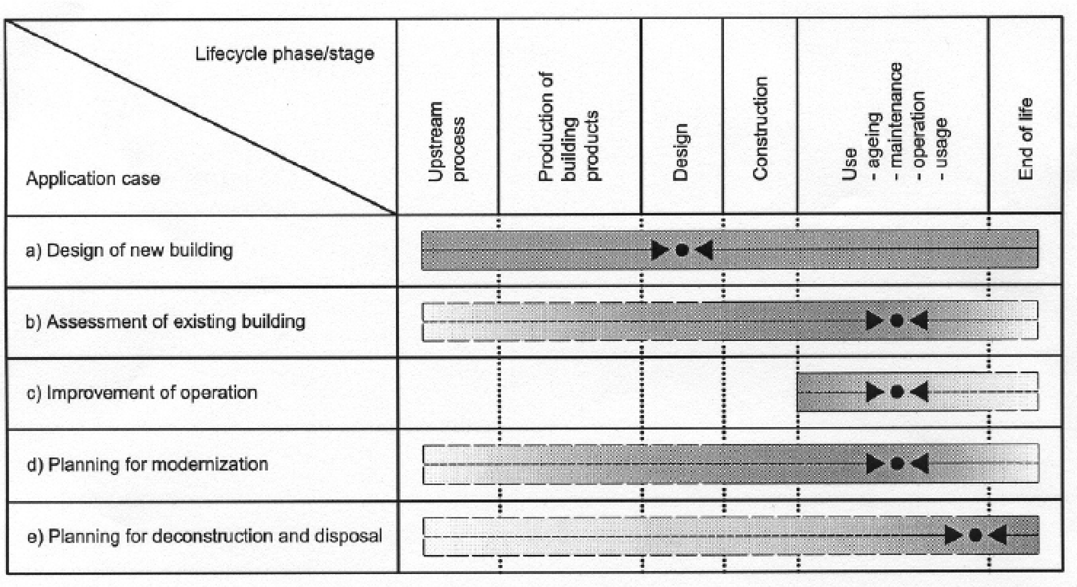


Figure 6 — Relationship between application cases and life-cycle stage

4.4.4 System boundary

The system boundaries are determined by the intended use of the methods of assessment, by the intended users and beneficiaries of the method, by the intended stages of the building life cycle to which the methods are applied, and by the assumptions underlying an assessment.

4.4.5 Statement of assumptions

A particular attention is paid toward two specific cases. Indeed, critical assumptions have to be made concerning the scope and context of the environmental performance assessment of buildings:

- Newly built or refurbished buildings
- Existing buildings

4.4.6 Structured list of issues for environmental assessment

Environmental issues of concern related to		**Additional (where relevant)**
environmental impacts of buildings climate change; destruction of the ozone layer. and destruction of non-renewable resources; formation of pollutants; formation of photochemical oxidants; acidification of land and water sources; eutrophication.	**environmental aspects** a) **energy and mass flow during life cycle**: 1) material use, differentiated into • depletion of non-renewable material resources, • use of renewable material resource, and • use of substances classified as hazardous or toxic according to national or international regulation; 2) primary energy use, differentiated into • depletion of non-renewable primary energy, and • use of renewable primary energy; 3) water use; 4) land use; 5) waste production, differentiated into reuse/recycling or energy recovery, and waste production for disposal. b) **local impacts** 1) on soil, 2) on ground water, 3) of noise, and 4) of odours. And : wind damage by the microclimate around building, including tunnel effect; load on local infrastructure; sun shading and glare on the property in question and any neighbouring property.	**aspects of building performance usefulin assessing environmental aspects in view of the entire life cycle** (to be integrated into the technical description for this purpose): • accessibility; • adaptability; • durability; • deconstructability; • recyclability; • maintainability; • safety. NOTE The environmental performance of a building utilizes outputs from various sources, including the LCA. Issues dealing with energy and material flow could have relevance for the inventory-oriented and/or impact-oriented results of an analysis of the energy and mass flows within a building's life cycle, including an examination of risks for the environment.
Issues of concern related to building management Additionally, where relevant: limitation of waste production; recovery of waste; reduction of nuisances; reduction of pollution; pollution control; water saving; wastewater treatment; maintenance; rehabilitation of the environment to promote biodiversity; environmental emergency management.	**Issues of concern related to indoor environment** (influence the comfort and health of the users and occupants.) where relevant: indoor air quality; quality of ventilation; hygrothermal conditions (air temperature and humidity); noise and acoustics; glare, access to daylight and exterior views; quality of light; odour conditions; quality of water; intensity of electromagnetic fields; radon concentration; hazardous substances; existence of unwanted micro-organisms, e.g. black mould.	**optional, issues**: relevance to the environmental issues of concern that the interested parties have to take into consideration in the decision making; effective communication of the result of assessment among interested parties who have various concerns; expected use of the result of the assessment; compliance with local regulations; relevance to significant environmental aspects of building in the local context; traceability, transparency and verifiability of process of assessment; technical feasibility of assessment; avoidance of double-counting when assessing the env^{tal} performance.

All issues shall be fully described, including their calculation and evaluation rules. In addition, the process involved in the selection of optional issues by the designer of the assessment method of the environmental performance shall be explicitly documented as reference information accessible to all interested parties.

4.5 Methods for quantification of environmental performance

4.5.1 General

The measurement of the environmental performance of a building requires indicators for the environmental criteria selected by the designer of an assessment method. Indicators may be either qualitative or quantitative.

Methods for quantification of environmental performance are composed of

a) a methodology for measuring the environmental performance by specific criteria, and

b) a methodology for aggregating the results of environmental performance measurement from multiple criteria.

4.5.2 Principles

- Data quality
- Transparency
- Traceability
- Assessing qualitative information
- Functional unit
  - The functional unit of a building may include information on the following:
  - type and use of building (offices, factories, public housing, etc.);
  - occupancy (period and pattern of use);
  - floor area and volume;
  - expected service life;
  - adaptability.
- Reference level
- Weighting

  The relative importance of criteria for environmental performance could necessitate the use of a weighting system for aggregation. The weighting system will vary depending on national, regional or local contexts and conditions and should provide a method for addressing such variances. If a weighting system is used, a method for addressing such variances shall be provided, justified and documented. The underlying data of the method shall also be documented. The weighting factors shall appear explicitly in the assessment method documentation.
- Aggregating results of measurement of environmental performance by multiple criteria.

  The environmental performance relating to a specific category of environmental issue of concern may be aggregated from multiple indicators. Aggregation methodologies may incorporate the use equivalency factors, which comply with generally accepted scientific or engineering principles, or weighting. Weighting should only be used if no such equivalency factors are available. The method used to aggregate the results of measurement of environmental performance by multiple criteria shall be consistent. Where ordinal data is used, it shall be stated whether there is a difference in the distance of the ranks.

4.6 Sources of information

The sources of information used in the assessment shall be clearly indicated in the assessment method documentation and shall be accessible to the interested parties of the assessment.

4.7 Evaluation and interpretation

A particular attention is paid to the possible choice for a “singe score” evaluation which is not necessarily relevant depending the use of the assessment.

4.8 Reporting of assessment results and report format

5 Conclusion Two – involving actors in the dissemination and the appropriation of standardized based assessment tools

When considering the figure below, the span of use of ISO 21931-1, very soon followed by another part including civil engineering approach, is very large. It is hoped, from the industry and building owners they will benefit quickly from this framework. A challenge could be launched "test and measure"- like with the help of SB organisation to make a learningful significant feedback from efforts of the construction community to improve, through the use of this framework, its global practices. Surely, impacts on the economic and social activity could come quickly.

Intended users of the assessment information	Intended stage			
	Strategic planning and Schematic design	Detailed design and construction	Operation including repair and maintenance	Deconstruction
Clients Designers Constructors Suppliers Governmental Agencies	**Methods of assessment of environmental-conscious design** Comparison of possible design alternatives Assessment against stated target values Communication between client and designers			
Owners Facility managers Building managers and operators Occupants Developers Real estate brokers Investors Governmental agencies		**Methods of assessment for rating existing building from environmental aspect** Communication between interested parties for investment to existing building		
Owners Designers Building managers and operators Occupants Governmental agencies			**Methods of assessment for environmental oriented operation** Communication between interested parties for building operation Continuous improvement of operation	

Figure 7— Interests of intended users of assessment information and intended life-cycle stages

Overview

The ISO Technical Specification **ISO/TS 21929-1** - **Sustainability in building construction — Sustainability indicators —** Part 1: **Framework for the development of indicators for buildings /** *Développement durable dans la construction — Indicateurs de développement durable — Partie 1: Cadre pour le développement d'indicateurs pour le bâtiment*

ISO/TS 21929 defines a framework for sustainability indicators for buildings based on the premise that sustainable construction achieves the required technical performance of the construction with the minimum of environmental impact. At the same time, sustainable construction encourages economic, social and cultural improvement at a local, regional and global level.
Indicators are figures or other measures that enable information on a complex phenomenon like environmental impact to be simplified into a form that is relatively easy to use and understand.
The three main functions of indicators are quantification, simplification and communication. Changes over time and the development of changes in relation to stated objectives can be monitored with the help of indicators. One of the important functions of an indicator with reference to decision-making is its potential to show a trend.

Indicators should be objective and the results should be repeatable.
When developing and selecting indicators, the starting point is the identification of the main users and user needs. Sustainability indicators for construction works are needed by a number of interested parties in the building and construction sector. Indicators are needed in decision-making by investors and owners of real

estate; occupiers and users of buildings; planners, developers and designers; manufacturers of products; contractors; facility managers and real estate agents; public bodies (housing, building, traffic, environment). The building and construction sector needs sustainability indicators both for its own decision-making within design, production and management as well as for indicating the economic, environmental or social impact of products and processes to the public and to clients.

The aim of this part of ISO/TS 21929 is to define the process that shall be followed when addressing the economic, environmental and social impacts of a building using a common framework and a set of indicators.

This part of ISO/TS 2192

- adapts general sustainability principles for buildings;
- includes a framework for the assessment of economic, environmental and social impacts of buildings;
- shows indicators as examples;
- shows how to use sustainability indicators with regard to buildings and shows the process of using
- sustainability indicators;
- supports the process of choosing indicators;
- supports the development of assessment tools;
- defines the conformity with this specification

This document is under revision both to consider integration of civil engineering aspects and to take into account the publishing of ISO 15392.

5- ISO 15392 Sustainability in building construction — General principles - Développement durable dans la construction — Principes généraux

5.1 Introduction

This International Standard, approved at unanimity in the very beginning of 2008, identifies and establishes general principles for sustainability in building construction. It is based on the concept of sustainable development as it applies to the life cycle of buildings and other construction works, from their inception to the end of life. Its application is dedicated to buildings and other construction works individually and collectively, as well as to the materials, products, services and processes related to the life cycle of buildings and other construction works.

Thus, it should be underlined that this standard provides neither levels (benchmarks) that can serve as the basis for sustainability claims,or the basis for assessment of organizations or other stakeholders. From the whole participants in this work, it would have been very uneasy to pretend to have written the only criteria for sustainable development. This standard is therefore written for an active experimental use.

Several notes explain the philosophy of the work:

- the principles established are intended to be applied broadly in the context of buildings and other construction works. Specific applications are the subject of other related international standards.

- buildings and other construction works are designed to meet numerous requirements, expressed and established in national and international standards or regulations. None of these requirements is replaced or changed by this international standard.

- sustainability aspects relative to organizations are sent back to future ISO 26000 (social responsibility).

5.2 Definitions

It is also relevant to focus interest on the definition of “sustainability” given is article 3.20:

sustainability

state in which components of the ecosystem and their functions are maintained for the present and future generations

NOTE 1 Sustainability is the goal of **sustainable development** (3.21) and can result from the application of the concept of sustainable development.

NOTE 2 In building construction, it relates to how the attributes of the activities, **products** (3.17) or services used in the **construction work** (3.7), or the use of the **construction works** (3.8), contribute to the maintenance of ecosystem components and functions for future generations.

NOTE 3 While the challenge of sustainability is global, the strategies for sustainability in building construction are local and differ in context and content from region to region.

NOTE 4 “Components of the ecosystem” includes plants and animals, as well as humans and their physical environment. For humans, this includes a balancing of key elements of human needs: the economic, environmental, social and cultural conditions for societies’ existence.

Finally, this document proposes the application of sustainability to building construction needs to reflect the context in terms of goals, priorities, preconditions, possibilities and constraints (such as poverty, accessibility and access to services). And, following the basis of the work philosophy of the SC17, it does not provide the prioritization, but recognizes that an application will balance the aspects according to overarching goals of development targets.

5.3 Structure of the document – Objectives and principles

For sustainability in building construction, the **objectives** and **principles** should be considered in their entirety, without regard to the prioritization of aspects. The extent, to which these objectives and principles can properly be addressed, also depends on the scope and the scale of the project. The significance and magnitude of impacts also may depend on and change with the life cycle stage under consideration.

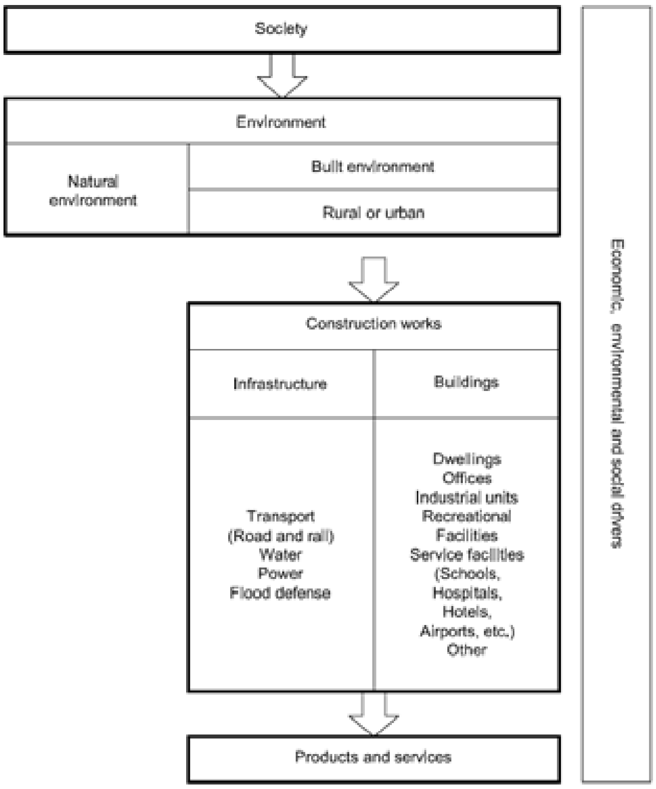


Figure 8 - Requirements posed to the built environment, its parts and related drivers

5.3.1 Objectives

Whilst applying the concept of sustainability to buildings and other construction works, and at the same time promoting sustainable development, the objectives are:

improvement of the construction sector and the built environment;

NOTE 1 Sectors interacting with and supporting the construction sector are to be addressed by the objectives where relevant, e.g. real estate sector, financial and insurance sector, transportation, etc.

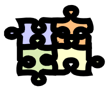
reduction of adverse impacts while improving value, where impacts as well as value may be judged against any combination of the three primary aspects of sustainability;

NOTE 2 “Value” embraces performance, but is conceptually broader and is not intended to refer solely to “economic value”.

- stimulation of a pro-active approach;
- stimulation of innovation;
- decoupling of economic growth from increasing adverse impacts on the environment and/or society;
- reconciliation of contradictory interests or requirements arising from short-term and long-term planning or decision making.

5.3.2 Principles

The principles applied to reach the objectives are, without indication of importance and in alphabetical order: continual improvement, equity, global thinking and local action, holistic approach, involvement of interested parties and long term consideration, precaution and risk, responsibility, transparency.

9 principles	**global**	**local**
	(Global thinking and local action) *the consideration of the global consequences of local actions taking account of local and regional concerns, to ensure that:* a) when acting locally, the regional and global relevance and consequences are considered; b) when establishing and applying global strategies, the local implications, relevance, demands and resources are considered.	
Involvement of interested parties	*the taking into account of the contribution and requirements of interested parties relative to their respective areas of responsibility, and the timing of their involvement.* ☞Due to the nature of the building and construction sector and its products, a wide range of stakeholders has interest in this industrial sector and its outputs. These stakeholders may demonstrate significant differences in their appreciation and understanding of the building sector. Such differences explain the multiplicity of views that exist in the interpretation of sustainable development in the context of building and construction, particularly in terms of scope, content, level of detail, priorities, etc.	
Long term consideration	*the taking into account of the short-, medium- and long-term implications in decision making. As a minimum, it includes the following:* *a) performance over time (as the ability of fulfilling a defined level of function throughout the use phase);* *b) life cycle thinking (i.e. considering the consequences of a choice made in one stage of the life cycle, on the other stages);* *c) legacy – the consideration of the impacts that are handed down as a result of development. The legacy may extend well beyond the physical boundaries of the development.* ☞ The legacy can be physical (e.g. the buildings and infrastructure), environmental (e.g. environmental benefit or damage), social (e.g. cultural heritage, skills, capacity building) or economic (e.g. employment, economic growth).	
Precaution and risk	*the avoidance of risks by applying the precautionary principle, or considering the most unfavourable impacts through risk management.* - Precaution (avoidance of risks): The precautionary principle aims to avoid risks – it sets concerns of future generations as the basis for the analysis of risk potentials. ☞ Adoption of new technologies or new products should include a precautionary perspective without unduly compromising innovation. - Risk management (management of identified risks): Risk management is a set of coordinated activities including risk assessment, risk treatment, risk acceptance and risk communication.	
Transparency	*the presentation of information in a manner that is open, comprehensive and understandable and, like the underlying data, traceable, with verifiable credibility.* ☞ For sustainability of buildings and other construction works, transparency relates to information about products as well as decision-making processes. For that purpose, an appropriate review and verification route of relevant documentation may need to be established.	
Responsibility	*the moral responsibility for, rather than legal or financial consequences of, actions carried out by individuals or groups of individuals. The development of local skills and institutional capacity supports the sustainability of construction works.*	

Continual improvement *the improvement of all aspects of sustainability related to the built environment including the buildings and other construction works over time.* It includes the performance of construction works as well as processes, and addresses means of assessment, verification, monitoring and communication.	**Holistic (Systemic) approach** *the inclusion of all relevant and related aspects of sustainability when considering and assessing sustainability aspects of buildings and other construction works.* A holistic approach ad dresses all aspects of sustainability over the life cycle of the building or other construction works.	**Equity** *the balanced and objective consideration of intergenerational, interregional and intra-societal ethics, including environmental protection, economic efficiency and social needs.*

Illustration: a French view of "9 principles" applied to works and construction process :

Continuous improvement
Equity

	WORKS	PROCESS
Interested parties	Allow the progress of the foreseen activities at an acceptable price.	Build while taking into account all the interactors.
Long term	Allow an adaptation in order to face changes over time.	Plan over the whole life cycle of the built work.
Precaution	Contribute to the operation of the system at all the other spatial scales.	Minimize the negative impacts of the work and bring the corrective elements.
Transparency	Assist the users in their use practices.	Be ready to justify the choices which have been made.
Responsibility	Give responsibilities to the users so as to assume the good use of the works.	Assume the good use of the resources (including production means)

6- Difficulties and further standardisation works

Common language construction, as anyone knows since temps immémoriaux, is one of the most difficult exercise for standardisation experts. Lot of reasons for this : technical backgrounds, business views, regulatory background, cultural issues, etc.

It can be now acknowledged that the success of SC17 standardisation work, after some years of "try-to-know-each-others-meetings", comes from the will of each participants to bring the best of their knowledge and practices (experimental or building works/.production) to raise a bet : go toward a better world, more sustainable. The spirit of G.H. Bruntlandt probably.

New stages are to be crossed over, among which:

- integrating civil engineering : products, works, probably with another complementary approach linked to land management (anotherr level for sustainability).

- succeeded revision and getting more completeness for the building approach and the sustainability indicators setting up?

- involving more participation from South countries and welcoming UNEP as a full contributor, if possible.

- getting feedback from the existing and new experience from each actors and building up this expertise.

The ultimate goal is the SC17 work be brought to the whole users for their practical benefit, from the laboratory and manufacturer to the contractors and final clients.

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MAJOR CHALLENGES IN ACHIEVING SUSTAINABLE BUILDINGS IN NORWAY

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Keywords: Funding, statistics, regulations, sustainable, building, planning, construction, operation

Summary

Norway's climatic conditions, low electricity prices, high standard of living and a relatively large building construction industry has resulted in a very high energy consumption per capita. The paper focuses on three major challenges concerning how to achieve more sustainable buildings, and describes the most important governmental policy instruments used to meet these challenges. The three major challenges are:

Planning.

Holistic planning and design are important. Sustainable building materials, building framing, site criteria, solar angle utilization etc. must be given high priority.

Construction

Good construction workmanship. Due to high construction activity construction periods have shortened and there is a shortage of labour, especially skilled labour. This has caused a massive import of foreign labour which has led to challenges regarding language and differences in building traditions etc.

Operation

Good operation implies effective energy monitoring systems and energy management etc. The Ensuring skilled maintenance staff is crucial.

Building regulations, EU building directives and Enova's funding programs are the main governmental instruments used in meeting these challenges. The paper presents a general view of how these instruments make an impact on planning, construction and operation. In particular, the paper describes Enova's programs, energy statistics and the impact these programs have on the above challenges.

1. Norwegian conditions

Number of degree days in Norway varies from 3442 to 7160, dependent on latitude and topography. The huge variation in the amount of energy required, is also due to the proximity to the Gulf Stream, as well as the length of the country (1200 miles from south to north). Due to the northern latitude (from 58 to 71 degrees), the solar angle during the summer season is low and this makes air conditioning units a normal solution especially in non-public/non-residential buildings.

Traditionally the use of electricity for heating in buildings in Norway exceeds 30 % of total electricity consumption pr. year. The main reason for this is that Norway historically has had access to cheap electricity due to a big national hydro-power industry. A mountainous country and precipitation conditions are the main reasons for this.

2. Three major Policy Instruments

The building sector represents 40% of the Norwegian overall energy consumption. Thus, the building sector can contribute to considerable reductions in CO2 emissions through more energy-efficient and sustainable buildings.

The authorities' initiatives to reduce energy consumption in buildings include stricter regulations and control requirements, an energy marking system and the establishment of Enova.

2.1 Directive 2002/91/EC – Norway adapts to EU Regulations

The Directive on Energy Performance of Buildings (Directive 2002/91/EC) of the European Parliament and of the Council of 16 December 2002 pertaining to the energy performance of buildings, states that the Member States must apply minimum requirements concerning the energy performance of new and existing buildings, ensure the certification of their energy performance and require the regular inspection of boilers and air conditioning systems in buildings.

The Building Energy Directive is designed to provide information to the purchaser or lessee about the building's energy performance. There are great expectations of this new directive.

The introduction of the Building Energy Directive in Norway is planned to be during 2008.

2.2 Technical Regulations – Public Authority Regulation

The Norwegian Government (public authority) regulates the building sector through national building codes. The building regulations are being revised every 10th year from 1987, thus the latest revision is from 2007(TEK 07). The latest revision lists detailed requirements for the design and properties of the climate shield and also functional demands for technical installations (lighting, heating and ventilation). It also describes two separate methods used to calculate maximum allowed energy consumption in new buildings. These methods are an Initiative Method and an Energy Framework Method. Both of these methods are supplemented by minimum requirements that must not be exceeded, regardless of the applied method.

2.2.1 Initiative method.

The initiative method has specific requirements for maximum energy requirements in building sections and technical installations. Exemption from one or several of the energy initiatives is permitted, provided that the compensatory initiative does not lead to an increased use of energy.

2.2.2 Energy framework method

This method sets requirements for the building's maximum energy requirements (net requirement). The limits are differentiated according to building category. The building regulations have stipulated ambitious energy framework requirements. The set requirement for office buildings, for example is 165 kWh/square metre, year.

The latest revision of the Norwegian Building Codes also stipulates a requirement that heating shall be provided by another energy source than electricity, provided this does not lead to extra costs beyond the building's lifecycle.

All buildings' energy requirements shall be documented at the planning stage via energy and effect budgets.

2.3 Enova - a Public Authority Policy Instrument

Enova SF is the government's most important environment-related project and the annual allocation to Enova is approx 250 million Euro. Enova provides support to projects that involve increases in energy efficiency or projects in which local and environmentally-friendly forms of energy are used. Enova is responsible for increasing the efficiency of energy consumption and for increasing the production of environmentally sound electricity and heat (renewable energy). Enova currently supports major projects within industry, domestic use, technology, remote heating, wind energy and construction.

Enova SF enters into goal-oriented contracts with property owners, construction firms and contractors in Norway. This is to ensure that the goals for a reduction in energy consumption and the transfer to renewable forms of energy are quantified in terms of kWh per year and that this goal is clearly stated in the agreement.

The energy figures must be verifiable. If the goals are not reached, Enova has the right to reduce the amount of financial support. When the project is completed, the recipient must provide a final report that specifies the actual, completed initiatives and the results achieved in the form of energy accounting. The final report shall also include a set of audited project accounts.

When Enova enters into a contract with an operator for energy-effective construction projects, the project is followed up by Enova's operating agent throughout all phases up to the completion and final commission.

The progress of a project supported by Enova may be thus:

The building owner holds an introductory meeting with Enova, along with an external advisor.

The building owner surveys the buildings, energy consumption and the potential for energy reduction.

The building owner applies to Enova for support in accordance with the funding programs.

Enova processes the application and issues a letter of acceptance.

Both the building owner and Enova sign the letter of acceptance.

The building owner is responsible for the completion of the project – this takes normally from 3 to 5 years.

The results are documented at the building object level and sent to Enova via a database. Statistics are collected and collated annually by Enova on the basis of the data from the database.

Table 1 Owner structure for buildings in Enova's statistics 2007.

Building owner	Heated floor space	Number of buildings	Average floor space
	m2		m2
State	3 551 990	405	8 770
County (public)	947 460	149	6 359
Municipality	3 209 426	937	3 425
Commercial	5 676 681	910	6 238
TOTAL	13 385 557	2 401	5 575

Enova's support is paid out after the initiatives are implemented, up to 4 times per year.

The level of support corresponds at the present to 0.08 Euro/kWh. This is a popular system for large, established companies. Both private and public building owners can apply for support.

All projects are followed up by Enovas own staff and operating agents.

Table 2 Buildings reported to Enova's statistics in 2006 and 2007. Decrease in energy consumption.

Building category	Number of buildings	Specific energy consumption Corrections made for temperature and location		Energy consumption decrease
		kWh/m2		%
		2006	2007	
TOTAL	1810	285	279	-2,3 %
Block of flats	40	227	246	8,5 %

Industry	98	333	319	-4,3 %
Storehouse	23	490	443	-9,6 %
Office	236	247	234	-5,3 %
Commercial building	370	426	428	0,3 %
Expedition building	43	330	319	-3,4 %
Garage	8	342	334	-2,2 %
Hotel	73	244	245	0,7 %
Motel	13	236	235	-0,1 %
Restaurant	8	299	297	-0,7 %
School	516	185	179	-2,9 %
University	41	315	282	-10,5 %
Laboratory	9	563	531	-5,7 %
Museums and library	6	237	237	0,1 %
Sports centre	45	275	261	-5,1 %
Culture building	16	267	237	-11,0 %
Church	79	279	284	1,9 %
Hospitals	45	328	317	-3,2 %
Nursing home	103	263	255	-3,1 %
Health care centre	10	214	212	-0,8 %
Prison	8	377	302	-19,9 %
Emergency centre	7	427	415	-2,8 %

Almost 50 000 companies exist within the building and construction industry. It is a notoriously difficult industry to influence. The public authorities expect solid results from Enova's cooperation with the market and there are great hopes that Enova can help and persuade the industry to increase their overall energy awareness.

Enova has since 2001 entered into approx. 500 contracts with major operators in the construction industry - these contracts represent approx. 20% of total business enterprises. Enova is a successful enterprise, exemplified by its large budget framework.

3 Planning Phase: What kind of Issues Influence Planning?

Holistic planning and design are of vital importance. Sustainable building materials, building framing, site criteria, solar angle utilization etc. must be given high priority. The consequences of wrong/poor choices at this particular phase are complex and costly, if they are to be rectified later.

3.1 Norwegian Building Regulations regarding Planning

The new building regulations of 2007 affect almost 10% of Norway's workplaces and the entire construction industry. New commercial buildings are directly affected by the regulations. The regulations are designed to have a major impact on the planning of new buildings. After the previous amendment to the Norwegian building regulations in 1997, national approval systems were introduced for both planners and contractors with self-control on both project planning and practical sides. An important experience has been that the system of self-control has led to construction of buildings of a considerably lower energy standard than that contained in the national building regulations as a minimum standard, with a consequent increase in energy consumption. This is evident, from among other sources, Enova's energy statistics. The introduction of an independent, third-party building control body is now under consideration.

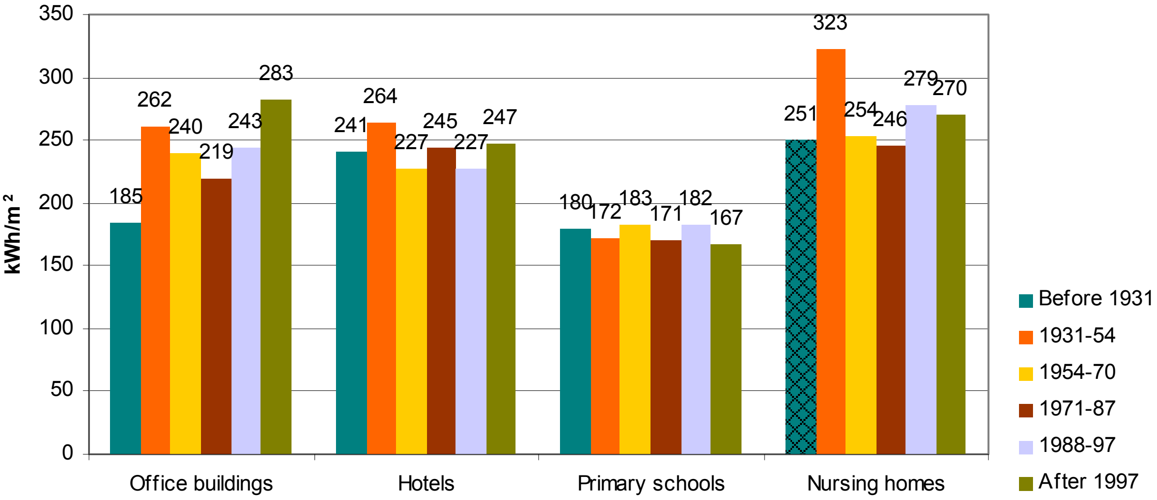

Figure 1 Specific energy consumption in 2006 by construction year for 4 of the largest building type groups (Corrections made for temperature and location). From Enova energy statistics 2006.

3.2 The Directive on the Energy Performance of Buildings in relation to Planning

The Building Energy Directive applies to buildings that are sold or leased and the directive thus has no direct influence on the planning of buildings.

The aim of the authorities, via the introduction of the directive, is to encourage builders, architects, consultants and real estate agents to plan for increased energy efficiency. The construction industry is sensitive to changes in the market and it is thus of vital importance that the energy marking system leads to an increased awareness concerning a building's energy qualities, such that buildings with a 'sound' energy label are especially sought-after and consequently easier to sell at higher market prices. It is feasible that property owners and contractors wish to offer the market a higher energy classification than the minimum standard contained within the Norwegian building regulations.

The organization and implementation of the energy marking system is of vital importance to avoid indifference to the system (which may be due to a lack of faith in the marking itself, lack of influence on the buildings' end users, i.e. no consequence of a 'lower class' mark). If the energy marking system does not succeed in becoming an important parameter in the evaluation of the qualities of a building, the mark will have little influence on the planning of new buildings.

3.3 Enova and the Planning Phase

Enova's goal is to influence operators, to encourage them to make demands for energy efficiency in the early phases of building projects. To be able to influence this phase, Enova has entered into project agreements with the operators that have the greatest influence at the early stage of construction projects. There are mainly major construction firms, property owners and larger contractors. The goal is to persuade these operators to demand stricter and verifiable energy requirements for new buildings.

A main consideration when entering into an agreement with Enova concerning energy-effective buildings is that the building owner is obliged to exceed the minimum requirements of the building regulations, in regard to energy consumption, in order that the project shall qualify for support from Enova. It is therefore required that the building project goes even further than the specific initiatives in the building regulations. In practice this will often lead to investment in on-demand control systems for technical installations.

Enova supports projects that set ambitious energy goals. The reference point is defined as "current practices" for annual energy consumption in a corresponding building category. "Current practices" is as defined in Enova's annual energy consumption statistics.

4 Construction Phase – the Issues that Influence the Construction Industry.

The construction industry is large, fragmented and has problems with language and cultural issues. Approx. 10% of all employment in Norway is within the construction industry and it is the second largest industry in the country. Approx. 50 000 companies are registered and 97% of these have less than 20 employees. It is a considerable challenge for the authorities to raise the quality of the construction industry and to influence a large number of these companies to cooperate with their plans.

The construction industry in Norway experiences the same high conjunctures as other industries and enterprises and there is constant competition for the supply of necessary labour. The solution for the building industry has been to import labour from the former eastern European countries, mainly Poland. Available figures from the authorities show that there are currently approx. 10-15 000 registered foreign workers within the construction industry, in the Oslo area alone. This type of situation in the labour market produces even greater challenges in the form of communication issues, work routines, professional performance and knowledge and an understanding of the importance of finer details in construction projects. One of the unintentional aspects of this situation is the risk for increased amount of energy used in building projects.

4.1 Building Regulations regarding Construction Phase - They are Not Respected!

A relatively high number of non-skilled workers, tight project deadlines and budgets contribute to (both intentional and unintentional) undesirable methods of construction that have long-term negative consequences for the energy consumption of buildings. Enova experiences that negligence occurs in both insulation and weather protection.

In order to compensate for cost excesses in the planning and building phases, simpler and less effective technical systems are installed. Energy-saving initiatives (regarded as costly) are omitted, as budgets have a tendency to “balloon”. The reason for this is that costs of future energy consumption are charged the lessees and many operators wish to build as cheaply as possible and sell at maximum profit. This is a situation that is not merely restricted to Norway. The purchaser/lessee thus receives a “cheap” building, however the operational costs of lighting, heating, ventilation and cooling are considerable in comparison with those actually attainable via modern technology.

The authorities have indicated that they will introduce more stringent regulations regarding the control of building sites. This type of control is controversial as the construction industry claims that it already has adequate measures in place. The authorities wish to prevent unscrupulous operators and will therefore introduce stricter controls for construction sites.

4.2 The Directive on Energy Performance on Buildings related to Construction

The Building Energy Directive applies to buildings that are sold or leased and so has no direct influence on the construction phase; however, the Building Energy Directive will motivate the industry to supply better products.

In the construction industry guarantee and compensation cases are significant areas of conflicts. Thus, increase in the level of skills, attitude training and control are important issues. In order that the Building Energy Directive will become known within the industry, a good deal of effort will be applied to information and training within the industry. The public authority policy instrument will actively contribute to construction industry organisations putting the Building Energy Directive on the agenda and informing their members. The Building Energy Directive’s influence on the construction phase is, as for the planning stage, dependent on the consequences of a ‘lower’ energy classification. If faith and interest in the energy classification mark is weak, then buildings will not be influenced by it. It is hoped that the energy classification will lead to better construction of buildings, better follow-up on site and less negligence.

4.3 Enova regarding Construction Phase – a Successful Policy Instrument!

Enova supports the major property owners, administrators and contractor companies that build more energy-effective buildings. Support is provided to contractors that build on their own behalf, or on behalf of others, that can document a high level of competence, major building programs and clear and ambitious goals. Enova has signed contracts with Norway’s largest private and public building firms, administrators and contractor companies. This is a successful program that has contributed to heightened competition and good results.

Through a contract with Enova, the project is secured against changes made as the project progresses. Enova has regular follow-up meetings concerning each project, from the point in time the support is allocated, via the planning and construction phases.

Enova’s support represents approx. 10% of the extra costs involved in incorporating energy effective solutions. Enova’s most important effect is however that the concept of energy-related, effective solutions becomes firmly embedded in the senior management of the property owners and/or construction companies and this seems to contribute to maintaining focus and status throughout the project period. Another important factor is that Enova’s support is reduced or withdrawn completely, if the operators fail to implement the energy-saving solutions that form the basis for the contract with Enova.

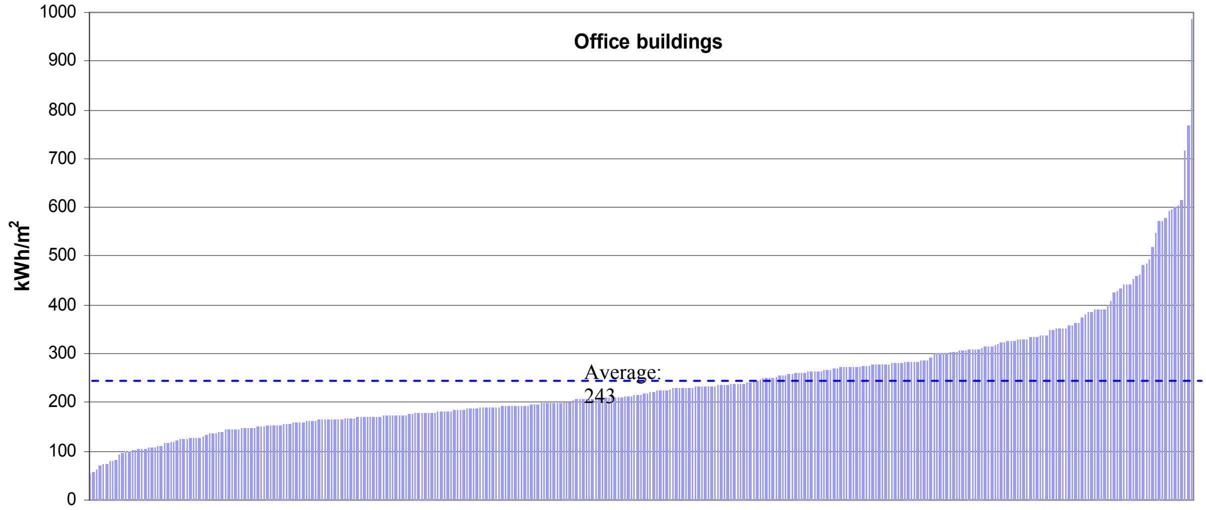

Figure 2 Enova's energy statistics. Specific energy consumption for 343 office buildings in 2006.

5 Operational Phase – a very Large and Complicated Market

Enova experiences that the phase from completion of projects and handover of finished buildings until the building has settled into a normal operational phase, is disproportionately long. Good operation necessarily involves energy monitoring systems and energy management etc. The reasons for this can be defined as follows:

Time constraints on operators during the handover phase.

The lack of coordination between the interface of technical professions and control systems. leads to the control systems functioning less than optimally, on handover.

The absence of operational personnel and lessees participating in the final phase of construction.

Lack of proper training of operational personnel in programming and use of control systems for technical installations.

Inadequate focus on the operational phase by planners, project managers and operational personnel.

Inadequate focus on follow-up. Delayed responses to rectifications and defects on handover often lead to unstable operations during the first year.

In order to change this trend it is of principal importance that greater focus is placed on the final phase of construction projects, such that the coordination of operation periods, temperatures, air flow and necessary training is carried out much more effectively. The construction industry has a great deal to learn in this respect, for example, from the Norwegian oil industry's methods and strict requirements concerning the handover of installations.

Table 3: Average heated floor area per "unit" for office buildings and primary schools in 2007, corrections made for temperature and location.

Building category	Number of buildings	Unit	Heated floor area [m2/unit]				Energy consumption [kWh/unit]			
			Average	Min	-	Max	Average	Min	-	Max
Office	10	Employee	40	10	-	71	9 030	3 007	-	20 084
Elementary schools	63	Employee	19	8	-	86	3 284	901	-	15 589

The division of technical infrastructure and systems, in combination with an on-demand control of lighting, heating, ventilation and cooling will lead to an energy-effective operation of installations.

One of the main premises of effective operations is, of course that the responsible operative personnel have been given adequate training in the use and controls of installations before the buildings are commissioned. The presence of skilled maintenance staff is crucial.

5.1 Building Regulations concerning Operational Phase

The building regulations' requirements are designed to influence energy-effective operations via the construction of buildings.

5.2 Building Energy Directive concerning Operational Phase

The Building Energy Directive is designed to influence customers that purchase or lease a building, to demand the most effective energy solutions.

2.1 million dwellings and 120 000 commercial buildings in Norway are to be given a classification 'mark' that is to be valid for a maximum of 10 years. This means that the certification must be renewed many times during the building's lifecycle. The energy classification will thus be an incentive to improve the building's energy properties during the operative phase. Just how much this will actually be the case, depends on how the energy classification influences the sale price of buildings.

If the market only will be based on the calculated normalized values and not the actual operating energy consumption, the energy classification mark will not have any influence on the effective use of the building's existing installations. The Norwegian Parliament will probably make the conclusions through a new Act during 2008.

5.3 Enova concerning Operational Phase

Enova's survey of several larger office buildings built after 1997 shows that energy consumption has been up to 20% higher than estimated during the first two or three years of operation. After the operations personnel have been given the necessary knowledge and training in the control of their 'own' buildings and technical installations, consumption has gradually become normalized.

In contrast to building regulations (TEK07) and the building energy directive, Enova stimulates operators to use more effective operative measures by optimising the use of the building's existing installations (for example, the adjustment of technical systems to the actual usage times of buildings). One premise for receiving financial support from Enova is that an energy consumption control system is set up to monitor the consumption of various types of energy relative to the outside temperature. The energy monitoring is carried out via registration of the collective net energy consumption per week and the values are measured against the average outside temperature for the same period. In buildings with several lessees, Enova encourages operators to meter the energy used at the actual place of consumption. This means that all lessees in an office building, shopping centre etc. is able to document their energy consumption each week. Via analysis of the collected data in these systems, it has become apparent that new buildings have unusually high energy consumption in the first and second year of operation, in comparison to the designed and estimated energy consumption.

Table 4 Share of buildings with Building Energy Management System

Building category	Building Energy Management System (Share of heated floor space, %)
Nursing homes	48 %
Office	45 %
Hospital	42 %
School	41 %
Commercial building	40 %
Sport centre	35 %
Expedition building	35 %
Industry	29 %
Hotel	26 %
Storehouse	18 %
Church	4 %
University	2 %

Enova supports the establishment of energy management and investments in initiatives. Energy reductions and conversion to new and environmentally-friendly heating systems is also supported. Great emphasis is placed on the reduction of the energy requirements and ensuring that the discharges of CO_2 are kept to a minimum. Norway's largest energy source for heating is electricity, followed by oil. Enova works purposefully towards the replacement of electricity and oil with remote heating, bio-energy and heat pumps. In addition, operators are stimulated to reduce heating demands to a minimum via effective climate shields, high-efficiency heat exchangers and automation systems that ensure that lighting, heating and ventilation systems are only in operation when there are persons present in the buildings.

6 Summary and Conclusions

Building regulations, EU building directives and Enova's funding programs are the main governmental instruments used in meeting the national challenges. On the basis of 7 years' experience with Enova and cooperation with the building industry, the following recommendations and conclusions are made:

There has been a very limited demand in the market for effective energy consumption in buildings, energy prices have been at a low level, combined with a surplus of electricity and fossil energy.

Enovas impression is that the building regulations are not followed especially in private office and hotel buildings in the period of 1997-2007. This is despite stricter requirements and a high level of expertise in the industry.

Despite good profitability and low additional costs for energy-effective solutions, these will not be implemented without stronger future involvement of public authorities.

During the last few years, new office buildings often have had a significant increased energy requirements compared to older buildings.

Enova has established a considerable amount of contacts within the construction industry, both within existing commercial operators and decision makers in the new building sector. Results have been comprehensive and significant.

At present time Enova's contribution to the reduction of energy use in Norway makes 8 % of the domestic stationary energy consumption.

Enova's support regime complements regulatory measures and has been a success that other countries can draw valuable experience from.

Table 5 Enova and regulatory measures' influence on energy in the building industry:

Buildings lifecycle	Building regulations	EU-directive	Enova
Planning phase	Expected great impact	Expected medium impact	Possible impact
Construction phase	Expected impact	Possible impact	Great impact
Operative phase	Indirect impact	Expected great impact	Great impact

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NEW TRENDS IN SUSTAINABLE EDUCATION DESIGN

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Keywords: schools, education, sustainable design, Green Star, learning outcomes, curriculum integration

Summary

The focus in educational design is shifting from cost effectiveness, space efficiency and energy savings to 'fitness for purpose'. More attention is being paid to the qualities of the space and their ability to support the role of the teacher and to improve conditions and comfort for the learner. Many of these more tangible qualities can be categorised as Indoor Environment Qualities (IEQ). IEQ is a cornerstone of holistic sustainable design. If a structure must be erected then it should be designed to fulfill its role as well as possible. It should be economic in operation and environmental impact whilst maintaining high levels of comfort and function.

A shift in focus from financial to environmental is symptomatic of an increasing awareness in society of the issues in and around climate change. Educational institutions are taking the opportunity to lead by example and to provide education for the next generation in a more responsible manner. The design industry is responding with a more dynamic and integrated approach to design.

Sustainable Built Environments (SBE) is a unique environmental design consultancy firm consisting of both engineers and architects. Sustainable design opportunities must be pursued beyond the traditional boundaries that exist between the design disciplines. With a mix of disciplines working in collaborative teams, SBE can promote a more holistic approach to sustainable design. Some of SBE's current thinking on Educational design and some recent projects are discussed in this paper.

1. IEQ and learning outcomes

There have been several reports published over recent years linking improvements in Indoor Environment Quality (IEQ) to increases in productivity and learning outcomes. The Heschong Mahone Group (2003) has published a series of papers suggesting that in their studies increased levels of daylighting and ventilation have lead to improved child development and learning. Questions remain about the rigour of the analysis. The number of variables that would need to be isolated to determine with empirical certainty the proportion of influence of each IEQ enhancement is beyond comprehension. However, the report found across a significant sample that performance (learning outcomes) did appear to be improved in spaces with good daylighting and ventilation compared to a base case without.

A recent office renovation was completed at 500 Collins Street in Melbourne Australia. It was the first refurbished tall city office building in Australia to receive a 5 star Green Star Office rating in October 2006. There was a particular focus in the renovation on improvements to IEQ, including ventilation and thermal comfort. The owners of the building, Kador, commissioned a Post Occupancy Review (POE) of the renovation in terms of workplace productivity. The research was conducted by the firm 'Business Outlook and Evaluation' on two building tenants; law firm Oakley Thompson and stockbrokers Lonsec. The study involved staff surveys, examination of sick leave records, typing tests and billable hours ratios. Carbon dioxide and carbon monoxide levels, along with temperature and relative humidity, were also measured.

The results of the POE suggested

- average sick days per employee per month were reduced by 39%
- sick leave costs reduced by 44%
- speed and accuracy of typing increased
- lawyers' billing ratios increased, even as average hours declined

A similar study was commissioned to evaluate the contributions of enhanced IEQ to increases in staff productivity at the City of Melbourne's recently constructed 6 star office building, known as Council House 2 (CH2). The authors of the POE. Paevere P and Brown S (2008), claim that after one year of operation the City of Melbourne's staff productivity has improved by 10%, resulting in a cost saving of over $2 million in reduced sick days. In the report the author states "In terms of IEQ impacts on productivity, it is concluded that improved thermal comfort and air quality are likely to have had an enhancing effect on productivity perceptions."

It is generally accepted that IEQ initiatives such as improved thermal comfort, access to fresh air, daylighting without glare, eye relief and good acoustics can and do contribute to a person's sense of comfort within a building. If a person is comfortable they are likely to be least hindered or distracted by their surrounds when attempting to concentrate on a task and so should have a better chance to be productive in an office or to learn in a classroom.

2. Pedagogy and learning outcomes

Changes in teaching styles are leading to changes in classroom layouts and space requirements. The desire for spaces for large group, small team and individual working has taken classroom design away from the traditional cellular model of the past.

There are instances where changes to pedagogy and improvements IEQ can be complimentary. A series of well connected spaces can be easier to condition with cross flow ventilation. It can be easier to provide even levels of daylighting if there are fewer obstructions. Access to views and the potential for eye relief can be enhanced when spaces are opened up.

However, there are times when pedagogy and IEQ may be at odds. A pedagogical requirement for a large central space connected without walls to adjacent smaller spaces can present acoustic problems with a potentially detrimental effect on IEQ. Equally, the increasing demand for 'infinite flexibility' in the reconfiguration of spaces and the conversion of corridors into mode 2 learning spaces presents a serious challenge for design teams attempting to cater for all manner of unforeseen uses. The challenge for design teams will be to create buildings and spaces that accommodate and support both pedagogy and IEQ without wasteful over servicing and excessive energy use.

3. Ventilation and fresh air

Access to fresh air is an important consideration for classrooms. Much of Australia's climate is relatively benign and traditional classroom design has relied on openable windows as a primary source of ventilation. However, even in this benign climate there are times when ambient conditions will be unfavorable for open windows. In such cases windows are likely to remain closed and access to fresh air limited. Compounding this problem is the demand for high volumes of fresh air to a typically densely occupied classroom. According to AS 1668-2-1991 'Ventilation' a classroom requires 10l/sec/person of fresh air as a minimum (12 l/sec/person for students under 14). Given a classroom may conceivably accommodate 30 students or more the volumes of fresh air required begin to tally. Without a continual supply of fresh air CO2 levels will rise and a classroom will begin to feel stuffy. This is likely to hinder learning outcomes. The Green Star Office design tool V3 developed by the Green Building Council of Australia suggests that where CO2 levels can be monitored they should be maintained within a range of 640 ppm to 800ppm for optimum comfort.

A classroom should not be sealed up and unventilated in order to ride out periods of unfavorable ambient condition. Instead, good educational design should ensure students have access to guaranteed increased rates of fresh air throughout the year. The Education version of the Green Star design tool mentioned above awards projects with points for achieving guaranteed levels of fresh air provision at 50, 100 and 150% increases over the minimum stipulated in the Ventilation standard. Where passive ventilation measures are insufficient to guarantee these fresh air rates all year a back up ducted ventilation system becomes necessary. This is known as a hybrid ventilation approach.

Ducted ventilation offers some advantages over purely natural. Ducted ventilation allows fresh air rates to be controlled and maintained in adverse conditions. A ducted ventilation system can introduce untreated outside air into a space at a greater range of temperatures than an openable window. For example, 14° air striking a person from an adjacent window may be uncomfortable whereas 14°C air delivered up high into a space can mix with (and be diluted by) the existing air before it strikes a person.

Ducted ventilation also enables fresh air to be filtered, tempered and modulated. A ducted system can avoid the acoustic problems associated with openable windows and finally it can permit secure and automated night purging of a building.

4. Comfort with less energy

Some would say that providing air conditioning for children sends them a poor message and gives them unsustainable expectations. Others would argue that providing good levels of comfort will help improve learning outcomes and that if energy is required to do so then it is energy well spent.

Both schools of thought need not be contradictory. Good thermal comfort does not necessarily require traditional energy intensive air conditioning.

A perception of thermal comfort is influenced by several factors:

- Air temperature,
- Radiant temperature of adjacent surfaces,
- Relative air velocity,
- Humidity,
- Activity levels, and
- Clothing.

By careful attention to building design and local climate response many passive opportunities can be harnessed to target these contributors to thermal comfort without consuming energy.

Examples of passive comfort contributors:

- By orientating and shading a building in the appropriate manner the impact of unwanted heat from the sun can be reduced.
- Effective insulation and the use of improved glazing in a space can reduce the number of surfaces that may radiate cold into a space on a cold day (or heat on a hot day). At the same time having exposed thermal mass within a space can help absorb heat in summer (effectively radiating 'coolth') and improving comfort.
- Permitting sun to radiate into a space in winter can provide warmth and a sense of comfort, even if the air temperature is lower than normal.
- Having good levels of air movement can allow the skin to cool itself with the evaporative effect, permitting higher than normal air temperatures to be perceived as comfortable.

By tackling these contributors to thermal comfort the reliance on a controlled air temperature can be reduced. An indoor air temperature range of 20-26°C can be perceived as an acceptable and comfortable based on this approach.

When air temperatures threaten to fall outside an accepted range tempering may be required. Tempering can be provided by low energy means such as labyrinths, solar air heater, night sky cooling and flushing a building at night with cool outside air to recharge internal thermal mass.

If low energy tempering systems prove incapable of maintaining comfort throughout the year low energy active systems should be explored. These might include evaporative cooling, low energy radiant heating and cooling systems (such as hydronic heating and chilled beams).

By making the energy consuming active component the last in the list of comfort control measures a project stands a better chance of providing comfort with less energy.

5. Other current trends

5.1 Curriculum integration

By making systems visible and their function apparent students can begin to learn about sustainability issues. With appropriate metering and monitoring systems students are offered the opportunity to link cause with effect and action with consumption (or saving). The availability of detailed and easy to comprehend building user guides and metered data will allow teachers to introduce the building and its ongoing operation into the curriculum. The building can become an aid to teaching, a 3D textbook.

This enterprise has two important consequences. As well as teaching students about sustainability it also makes it clear to both students and parents that the educational institution values the issue of sustainability.

5.2 Materials

Concerns about Volatile Organic Compounds (VOCs) arising from off gassing of materials and finishes has encouraged an industry of low VOC alternatives for applications ranging from paints to sealants, adhesives, finishes and furniture.

Concern over the origin of materials and their environmental impact is also rising. The specification of timber from sustainably managed forests is a case in point. The independently monitored standard of the international Forest Stewardship Council (FSC) has become the accepted indicator of a stick of timber's sustainability status.

Third party certification of the environmental credentials of a material or product will make environmentally responsible specification an easier and more certain task in the future.

5.3 Controls

There has been some call for designs to move away from complicated engineering systems and automated controls back to good passive design, basic active systems and manual control. This approach works particularly well in classrooms where the occupants are permanent, as in a primary school. In such cases the students are able to take ownership of the classroom and are able to closely monitor and manage the operation of systems such as opening and closing windows, blinds, fans, lights etc. Students can take charge of comfort within the classroom and become champions of their local environment.

In secondary and tertiary instructions where a classroom's occupancy is transitory the same approach can be problematic. A lack of ownership of the space will mean occupants are less likely to take the time and trouble to learn about the space and operate it to its full potential. Automated systems (with manual overrides) can help ensure systems are not left on when the room is unoccupied.

The ability to take some control of the local environment grants the user an increased perception of comfort and a level of satisfaction that is worth pursuing. A balance needs to be struck between automation and manual operation. The best solution might combine automated control with temporary manual override of systems such as lighting, ventilation and comfort.

5.4 Transport

The combined impact of children’s transport to and from school has the potential to be greater than the operation of the classroom itself. Schools should seek to encourage the use of public transport and to discourage use of the car. Alternatives such as walking and cycling should be encouraged by enhancing connections to adjacent paths and routes as well as by providing adequate storage and change facilities.

5.5 Community Use

By making Educational Facilities available for use out of hours by others the need for additional community facilities may be displaced. It is better that one building is used for longer hours than two intermittently. Interestingly, this increased use may alter the servicing solution so opportunities for integrated community use are best considered during the design phase

6.0 Future trends

6.1 Design tools

In the past, sustainable design may have been evaluated using different methods of measurement with varying levels of rigour and to different standards. With the advent of widely accepted design evaluation methods, such as the Green Star suite of tools, agreed benchmarks have been established.

The Green Star tool requires the design assessment to take into account a set of protocols for the standardisation of variables (such as times of occupancy, clothing, activity, internal gains and green house gas emission coefficients etc). With this approach it is possible to compare one design’s predicted environmental performance with another on a fair and even basis.

Using agreed protocols and pre-set variables will limit the accuracy of the predicted performance of a building. For example the hours of occupancy must be standardised to an agreed set of days (and times). For the Green Star Education tool this equates to Monday to Friday for the entire year. However, in a Victorian school it is usual for a school to be closed during January. Because of this the predicted performance from the Green Star tool may vary from actual.

Calls for design assessments that are closer to actual performance misunderstand the value of a common assessment method that permits fair benchmarking and relative comparison. With fair benchmarking comes the added incentive of recognition both national and international.

6.2 Carbon Neutral and Autonomy

A Carbon Neutral school may become a reality. To succeed the primary focus must be on reducing the school’s demand for energy. After all passive measures are incorporated and sources of free energy adopted (such as the solar air heater, labyrinth and thermal mass examples listed above), efficient active systems should be explored and only after that should on site generation be contemplated.

Subscribing to the purchase of accredited Green Power might be a more practical alternative to on site generation in many instances. However, the benefits of onsite generation are social as well as environmental. With a properly metered and monitored Photo Voltaic (PV) array students can observe the passage of the sun and the impact on generation capacity through the day and the seasons. If supply and demand can be tracked simultaneously on a visual display then students have the opportunity to learn valuable lessons about cause and effect and the consequence of actions.

SBE’s recent educational work has concentrated on providing classrooms with good levels of comfort and reduced energy consumption. After introducing a suite of passive and efficient active systems (including evaporative cooling) on a recent Victorian school project it became apparent that lighting and heating were the two remaining areas of significant energy consumption. Sourcing environmentally free heat (from solar hot air collectors for example) became an initiative worth pursuing as a result. Investments in lighting efficiency were also explored, including more efficient luminaires, time and motion sensing and switching and daylight dimming.

With the above building operating comfortably and with a reduced energy demand it became conceivable that it could be provided with a degree of autonomy (in terms of energy demand). The project explored the opportunity to match the base building load with an appropriately sized Photo Voltaic (PV) array. It was proposed the PV array be linked to the grid as an insurance against occasional peak loads or intermittent spikes of demand. At the time of authoring this paper the project was in budget review. Suffice to say that without access to additional funding the likelihood to installing a PV array is low.

In December 2007 England's Schools Secretary Ed Balls announced 200 new Educational projects, costing £110m over three years. Each will include using greener technologies such as wind turbines, solar power and biomass boilers. Under the ‘Children's Plan’, there is a target for all new school buildings to be carbon neutral by 2016.

On 8 May 2007 the Australian Government announced a $150 million extension to the Photovoltaic Rebate Program over 5 years, bringing the Government's total investment in photovoltaic rebates to $201.8 million.

6.3 Outcomes

If a child learns at their optimum in a comfortable classroom and in the process about how to live in a sustainably responsible manner then a school or classroom could be said to have delivered a very worthwhile outcome.

The ultimate Holy Grail for educational design would be the ability to link investments in improved IEQ to improved learning outcomes in a measured and empirical manner. If a value could be placed on learning outcomes then justifying the initial investments in improved IEQ would be a matter of course.

7.0 Conclusion

Sustainable design is an interesting and evolving field. There appears to be many new and innovative approaches to servicing buildings and enhancing comfort and productivity while using less energy. However, the most cost effective design influences are also the oldest. The importance of good passive design has been rediscovered. SBE's founding director, David Oppenheim, himself a recognised pioneer of solar design in Australia, would have said that we were on the right track if we were adopting the lessons of our ancestors and applying in his words 'nanna' technology'.

8.0 Some examples of recent work

SBE has a large portfolio of educational work in design and under construction at present. We have explored many of the ideas discussed above in some of the following examples.

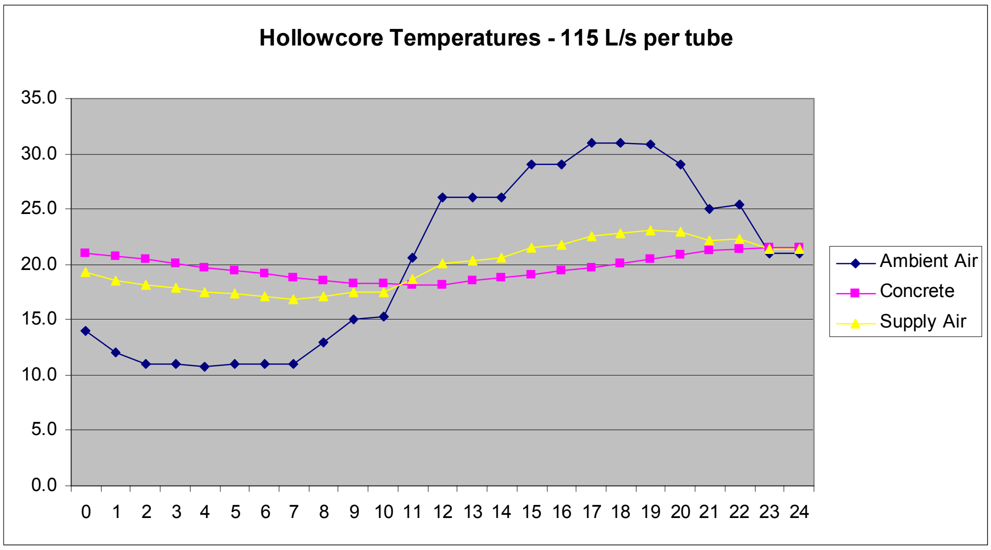
8.1 Dandenong Education Precinct (DEP)

Then DEP project involved the design of a 200 student self contained teaching building that could be replicated a number of times to cater for the growth of an Education Precinct over a number of years. Each teaching building is known as a 'Schools within Schools' (SWIS) and has two storeys with classrooms and staff offices opening off a central studio like space.

The Architects, Hayball Leonard Stent, have deployed the latest thinking on Pedagogy in the building's design. The mix of open and semi enclosed spaces enables activities of different sizes to take place in a range of locations and configurations. Instead of having one teacher and 30 students there are six teachers and 200 students working in flexible group arrangements.

The open planning will present acoustic challenges and these will be addressed with a series of acoustic panels on walls and ceiling as well as absorbent partitions and furniture.

This building has achieved a guaranteed 50% improvement on fresh air rates and a daylight factor of 2.5 for over 60% of the floor plate. Thermal comfort has been achieved by a combination of good passive solar design and orientation, good shading, increased levels of insulation, improved glazing, free cooling from the active use of thermal mass (hollowcore) and evaporative cooling. With evaporative cooling the building will be able to maintain comfort for up to 90% of the occupied hours in February, the hottest part of the school year. Night purging recharges the building's internal thermal mass with coolth in summer.



Free Summer Cooling. This option utilises the "Hollow-core" floor slab, planned for the first floor of the SWIS building, to pre-condition the ventilation air. Fresh air is drawn through tubes cast into the Hollow-core slab by an auxiliary fan and delivered to the air distribution system: in summer this process will cool the air and warm the slab. At night, cool air is drawn through the slab to "re-charge it ready for the next day.

The building has a predicted energy consumption of 397 MJ/m2/annum or 77 kg/CO_2-e/m2/annum, which equates to 5 points in the energy calculator for the new Australian Green Star Environmental design assessment tool for Educational Facilities. The building is targeting an overall star rating of 4 stars (Australian Best Practice).

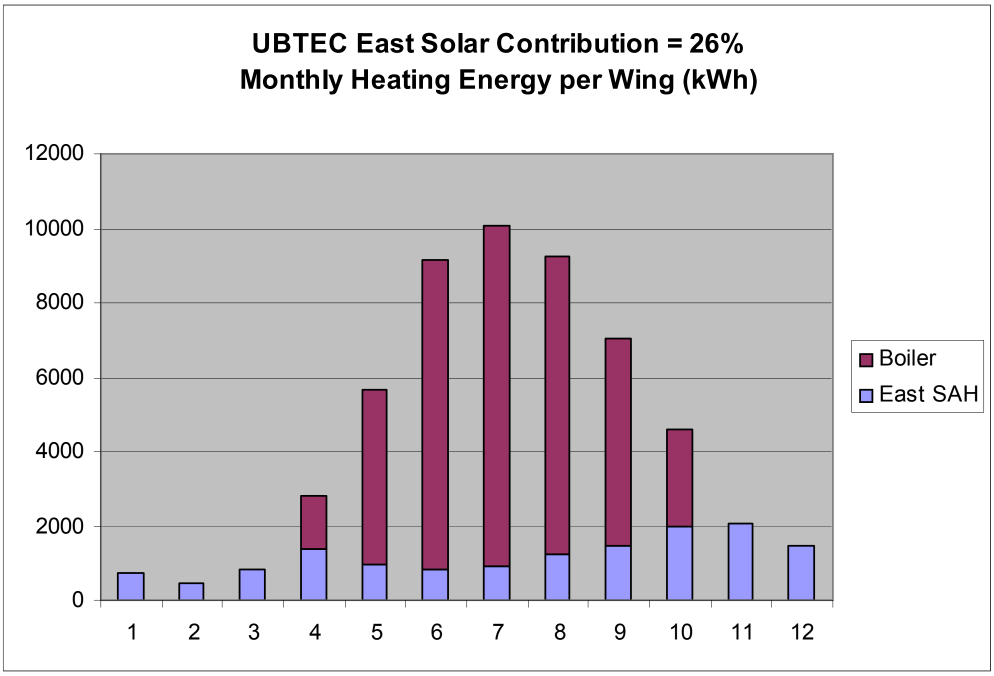
SWIS. *Image courtesy of Hayball Leonard Stent Architects.*

8.2 University of Ballarat Technical Education Centre (UBTEC)

The University of Ballarat Technical Education Centre (UBTEC) is aiming for a 5 star Green Star Education rating. The building will cater for the general education of first year apprentices. The building will have designated classrooms as well as centralised shared spaces for informal learning, computing and socialising.

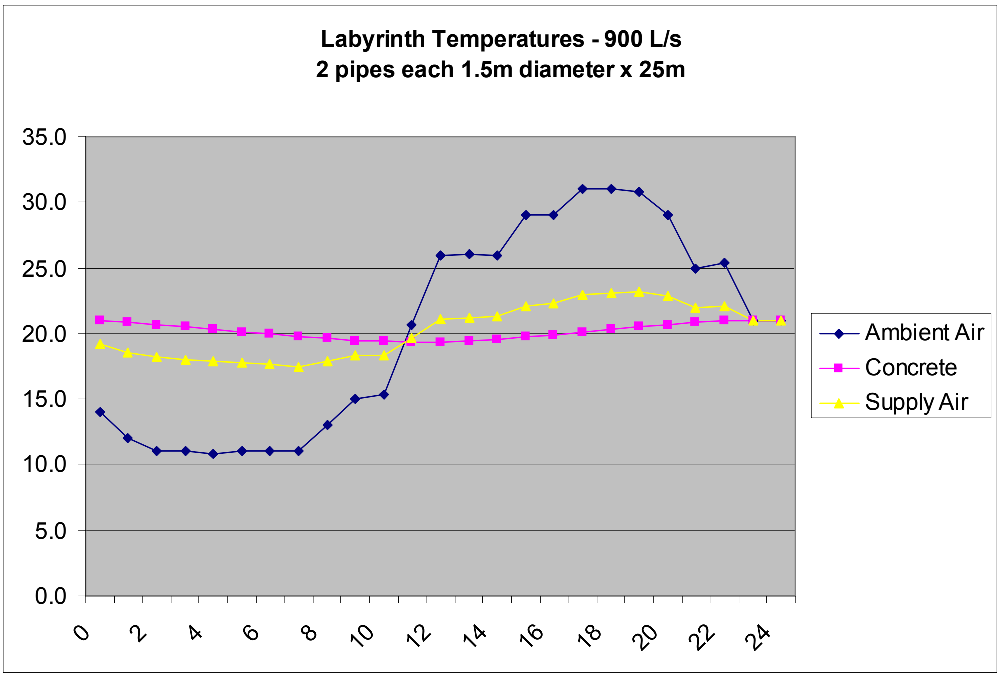
A fundamental influence on the design of this building was the desire to guarantee consistent levels of fresh air and thermal comfort. The building will deliver a guaranteed 50% improvement on fresh air rates compared to the relevant Australian Standard and will achieve Predicted Mean Vote (PMV- Accepted measure of comfort) of +/-1, which is the design target for a high grade city office tower.

The building features a ducted ventilation system linked to a thermal labyrinth and solar air heaters. The labyrinth tempers the fresh air supply in summer and the solar air heaters in winter. The solar air heaters facing east are designed to assist with morning warm up and it is anticipated they will satisfy 26% of the annual heating demand of the building.



This graph shows the expected contribution of the East facing Solar Air Heater (SAH) to building heating loads. The model allows for a number of cloudy days per month and only counts the contribution if there is a load to offset. i.e. During summer there is available solar energy that cannot be used.

The labyrinth under the building is designed to help temper ventilation air in summer before it is delivered into the building. It is anticipated the labyrinth will reduce ambient temperatures by 5-7°C on a 32°C day.



Free Summer Cooling. This model shows the impact of the labyrinth as proposed. At 4pm, outside air is cooled from 29°C to 22°C. The velocity of air through the concrete pipe is approximately 0.25 m/s, thus taking 100 seconds to pass through the full length.

The building is open over two floors and achieves a daylight factor of 2.5 to over 60% of the useable floor area.

The high levels of daylighting, fresh air and thermal comfort achieved will compliment the flexible teaching and learning models being adopted in this building.

This building will feature a series of metered and monitored systems connected to a visual display to teach occupants about the building's operational and the energy and water savings being achieved during operation. The surrounding landscaping features a purpose designed 'wetland' that will help detain and filter peak stormwater flows thus reducing the impact on the local stormwater infrastructure and ensuring that stormwater leaving the site has been filtered and cleaned to an acceptable level.

The building has a predicted energy consumption of 151 MJ/m2/annum or 48 kg/CO_2-e/m2/annum, which equates to 5 points in the energy calculator for the new Australian Green Star Environmental design assessment tool for Educational Facilities. The building is targeting an overall star rating of 5 stars (Australian Excellence).

UBTEC. Image courtesy of the Architects Gray Puksand. Note the large solar air heaters on the end façades.

8.3 Environmental Design Standards.

SBE recently authored new Environmental Design Standards for the Victorian Department of Education in Australia (now called the Department of Educational and Early Childhood Development – DEECD). These new standards incorporate measureable environmental performance requirements. They will provide the Department with the opportunity to mandate a level of environmental performance that can be benchmarked against national and international best practice.

The department has taken into consideration the recent focus on learning outcomes. They will use their new design standards to mandate environmental design initiatives that will improve access to fresh air, thermal comfort and daylighting and in so doing will lead to improved learning outcomes.

The new Design Standards are designed to interface with the Australian Green Star Education tool, and will reference its various calculators and benchmarks where useful. In this way the DEECD Standards will adopt the accepted industry jargon and will maintain currency as the Green Building Council of Australia have undertaken to keep the suite of Green Star tools updated.

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Redevelopment of Public Rental Housing Estates in Hong Kong

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Summary

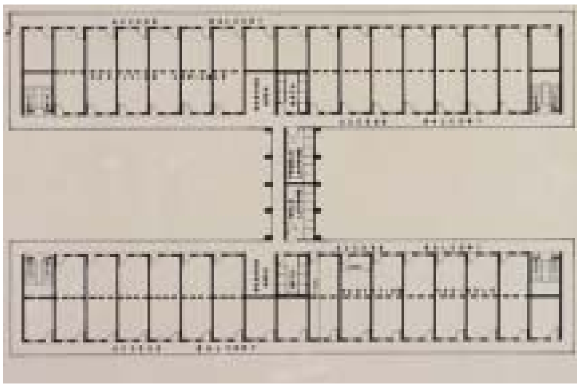
In response to the growth of economy and increased housing demand, the Hong Kong Government prepared the 'Long Term Housing Strategy' (LTHS) to review the housing policies in 1987. One of the key policies under the LTHS was to establish a Comprehensive Redevelopment Programme (CRP). The target of CRP was for the Hong Kong Housing Authority (HA) to redevelop 57 public rental housing estates built before 1973. After 21 years of redevelopment, the CRP has achieved its objectives of improving the living environment of the residents. However, it also exerted a heavy drain on land, manpower and financial resources. As such, the Government recognized that in future, redevelopment should be undertaken only when necessary to replace housing blocks which were no longer safe or economic to maintain. This principle was reinforced by the HA in 2005. Safety and cost-effectiveness are the major considerations in determining the sustainability of existing public rental housing estates. To ascertain the condition of the estates, the HA will conduct comprehensive structural appraisals for estates which are over 40 years old where there are often soaring maintenance and repair costs. For estates which remain structurally sound but require functional improvements, appropriate works will be arranged so that no further major structural strengthening will be necessary for at least 15 years. This paper will examine the impact of CRP on public housing development since 1988 and highlight the future plans for sustainability of public housing in Hong Kong.

1. INTRODUCTION

Comprehensive redevelopment of old public rental housing estates contributes significantly to urban renewal in Hong Kong. It marks the era of success in providing self-contained public rental flats, as well as improving the living environment of millions of residents.

Shek Kip Mei Fire in 1953

Public housing initially emerged in the form of transit housing, i.e. the resettlement estates following the disastrous fire at Shek Kip Mei in the Christmas Eve of 1953 when over 53,000 people were left homeless overnight. The old resettlement estates were the 7-storey Mark I & II blocks with communal toilet facilities between two linear blocks.



Typical Floor Plan of Mark I Block

Mark I blocks in Shek Kip Mei Estate

With the influx of immigrants from Mainland China, the demand for public housing increased throughout the 1950's and 1960's and these transit housing gradually turned into a form of permanent housing. A total of 240 Mark I & II blocks in 12 estates were built during the period. By 1970's public housing blocks have evolved from Mark I & II to Mark VI. In 1972, the Government announced the Ten-year Housing Programme with a view to providing permanent self-contained flats in a reasonable environment by building new public housing estates and redeveloped the non self-contained Mark I & II blocks.

Mark VI blocks in Lam Tin Estate

In April 1973, the new Hong Kong Housing Authority (HA) was established by the Government to develop and implement the public housing policies and programme. The HA is responsible for all aspect of public housing developments including the public rental estates, Home Ownership Scheme (HOS) flats for sale, flatted factories and ancillary commercial and other non-domestic facilities. To implement public housing development, the Housing Department (HD) was formed to act as the executive arm of the HA.

In 1980, about 45% of Hong Kong's population lived in public housing estates. The HA initiated a review of the structural condition of its housing stock, which indicated growing maintenance problems with the old estates. The first survey in March 1984 showed that approximately half of the buildings inspected at that time were likely to require significant repair work. As a further follow-up action, a more intensive structural coring survey was conducted which recommended the HA to demolish 26 structurally unfit blocks. To enable such large-scale demolition to proceed, an ***Extended Redevelopment Programme (ERP)*** was developed, giving priority to rehousing the affected residents in the same district wherever possible within 3-year period. This required the urgent acquisition of supplementary public housing sites in addition to offering residents priority status to purchase their own flats through the Home Ownership Scheme (HOS), where available without affecting the programme of redeveloping the Mark I & II blocks.

2. COMPREHENSIVE REDEVELOPMENT PROGRAMME (CRP)

In 1988, the **CRP** was drawn up after the announcement of the Long Term Housing Strategy (LTHS) in April 1987. It recommended that redevelopment should be extended to clear all older public housing stocks including all Mark I to VI Estates and Former Government Low Cost Housing Estates.

2.1 Objectives of CRP

The objectives of redeveloping the old public rental housing stocks include:

- To improve the living conditions and liveability of the public housing estates.
- To optimise the development potential of the individual housing sites.
- To implement comprehensive social and environmental improvements.
- To stimulate revitalisation of the larger community.

Priorities for redevelopment are determined largely by the availability of reception estates, structural conditions, age and build-back potential of the old estate.

Reprovisioning of social welfare, school, transport and commercial facilities are all carefully planned to avoid creating serious disruption to the local community.

Tsui Ping Estate (Before)

Tsui Ping Estate (After)

In view of the massive scale of the CRP involving clearance of over 560 domestic blocks affecting 240,000 households and 630,000 persons, it has to be executed by phases from 1988 to 2009. The redevelopment programme is being reviewed periodically to suit the changing circumstances. A 5-year Rolling Programme is announced at the beginning of each financial year to keep the public informed of the planned redevelopment operations over the period. The following Table 1 shows the progress of the CRP since 1988. The whole Programme will be completed by 2009 with only 7 blocks or 5,410 flats remain to be cleared as at March 2008.

Table 1. Progress of Comprehensive Redevelopment Programme (CRP) (as at 31.3.2008)

Redevelopment Programme[Note 1:]	Year	No. of Blocks Cleared	No. of Flats Cleared	No. of Persons Affected[Note 2]
Completed CRP	1988 - 97	326	138,340	391,710
	1997/98	33	14,810	37,200
	1998/99	35	15,490	35,620
	1999/00	17	5,870	14,680
	2000/01	49	13,590	36,180
	2001/02	55	32,360	66,880
	2002/03	9	4,510	11,760
	2003/04	7	5,170	9,930
	2004/05	4	490	1,000
	2006/07	15	2,170	3,750
	2007/08	9	5,480	13,970
Sub-total for completed CRP		***559***	***238,280***	***622,680***
Remaining CRP[Note 3]	2008/09	(7)	(5,410)	(8,840)
Total for CRP		***566***	***243,690***	***631,520***

Note 1 : Based on Completion Report of CRP, HD.
Note 2 : Figures excluding residents already moved out before the target evacuation date.
Note 3 : (No.) of blocks, flats and persons not yet cleared.

2.2 Process of Redevelopment

Redevelopment of a large estate operates in cycles. A reception site must be identified, wherever possible, in the nearby area or within the estate due for redevelopment to rehouse tenants affected by the first phase of the redevelopment scheme. Once the affected tenants are rehoused to the new blocks, the old buildings will be demolished and the vacant site will be used for building reception flats for the subsequent phase. This process continues until completion of the whole redevelopment scheme. Some large estates take more than twenty years to complete the whole redevelopment process.

The redeveloped estates are planned to be self-contained with basic necessities such as retail and social welfare facilities, local open space, primary schools, car parks and Public Transport Interchange etc. During the redevelopment process, views and expectations of the local residents and District Councils are seriously considered and taken into account, wherever appropriate, by the HA. As such, tenants moving in the new redeveloped estates can enjoy a better quality of living and healthier environment.

The ensuing paragraphs highlight the HA's established policies to assist the removal of domestic and commercial tenants.

2.3 Arrangement for Domestic Tenants

In order to minimize disturbances, the HA gives sufficient notification to the affected tenants through annual announcement of the 5-Year Rolling Programme and formal notification of about 18-24 months prior to the target evacuation date. Tenants are offered designated rehousing within the same district as far as practicable. Their preferences for other districts will also be considered if resources are available. Face-to-face interviews with tenants to identify individual problems are conducted after formal notification. CRP tenants are given priority to purchase Home Ownership Scheme (HOS) flats. Financial assistance in the form of Domestic Removal Allowance is payable to assist tenants to meet part of the removal cost as well as decoration expenses.

Briefing of redevelopment arrangement to tenants

2.4 Arrangement for Commercial Tenants

Commercial tenants will have their existing rent levels frozen upon formal notification which is about 18-24 months prior to the target evacuation date. They are granted an ex-gratia allowance as compensation for disruption of their established business. In addition, they are allowed to participate in restricted tender exercises so as to acquire alternative non-domestic premises in other public housing estates to continue their business. A three-month rent-free period in the newly acquired premise is also granted. For those who relinquish their opportunities to take part in the restricted tender exercises, a lump sum payment in lieu is paid.

2.5 Community Support and Involvement

Service teams led by professional social workers are set up to provide community services required by the affected tenants. The HA will line up representatives from other government departments, Non Government Organizations and volunteers to form an 'Elderly Removal Working Group' to assist the needy elderly in their removal. Special cases will be referred to the Social Welfare Department for provision of counselling service or other assistances required by the affected tenants.

Volunteers assisting elderly removal

Liaison meetings with District Council members, Mutual Aid Committees, local leaders and concern groups are regularly held from time to time with a view to consult and inform them of the redevelopment arrangement for domestic and non-domestic tenants for each CRP operations.

2.6 Achievements of the CRP

After 20 years of redevelopment, the CRP has achieved its objectives of clearing all the oldest public rental housing estates in Hong Kong. It also enables large families to split into smaller units and rehoused within the same locality. Family ties and relationship with neighbours can be maintained.

The quality of public housing has also improved significantly through redevelopment. The newly redeveloped estates are all self-contained with adequate local open space, car parking spaces, commercial, social welfare and community facilities. Tenants enjoy higher standard and better quality of living environment.

New Public Rental Housing Estate

2.7 Problems of CRP

In 1998, the 'White Paper on Long Term Housing Strategy in Hong Kong' ('the 1998 Strategy'), recognized that the large-scale CRP has exerted a heavy drain on land, manpower and financial resources. As shown in Table 2 below, about 30% of the new public rental flats were allocated to the CRP affected tenants during the first decade of the Programme. This arrangement had greatly reduced the allocation opportunities to other needy categories like waiting list applicants.

Table 2. Allocation of HA's Public Rental Flats (by percentage)[1]

Year	Rehousing Category				
	Waiting List	Clearance[2]	CRP	others categories[3]	Total
1987/88	38%	26%	23%	13%	100%
1988/89	38%	15%	26%	21%	100%
1989/90	43%	16%	32%	9%	100%
1990/91	35%	25%	30%	10%	100%
1991/92	38%	21%	33%	8%	100%
1992/93	44%	15%	28%	13%	100%
1993/94	43%	14%	33%	10%	100%
1994/95	38%	25%	20%	17%	100%
1995/96	39%	13%	29%	19%	100%
1996/97	31%	20%	31%	18%	100%
1997/98	38%	15%	29%	18%	100%
1998/99	58%	6%	14%	22%	100%
1999/00	49%	4%	32%	15%	100%
2000/01	50%	1%	38%	11%	100%
2001/02	65%	2%	15%	18%	100%
2002/03	66%	0%	11%	23%	100%
2003/04	71%	0%	1%	28%	100%
2004/05	67%	1%	3%	29%	100%
2005/06	65%	1%	5%	29%	100%
2006/07	66%	1%	5%	28%	100%
Overall Average	49%	11%	22%	15%	100%

Notes:
1. Figures exclude applicants joining the Rent Allowance for Elderly Scheme and Buy or Rent Option Scheme.
2. **Clearance** includes clearance from Squatter Areas / Temporary Housing Areas / Cottage Areas, Interim Housing / Temporary Housing Areas trawling and Urban Renewal Authority.
3. **Other Categories** include 'emergency', 'compassionate', 'junior civil servants and pensioners', and 'transfer and relief of overcrowding'.

Source: Housing in Figures, HA

Financial costs involved in redevelopment are high. It is estimated that about HK$49.3 billion was spent on the construction of reception estates for the CRP between 1987 and early 2007. The additional costs in granting ex-gratia allowances, management and maintenances are not included.

The actual housing stocks after redevelopment has reduced by about 30% due to larger flat size. More land is required for the provision of sufficient local open space, free standing schools, commercial and car park buildings and public transport interchange within the estates.

3. SUSTAINABLE FUTURE OF PUBLIC HOUSING STOCKS

After extensive consultation, the 1998 Strategy has set out the strategy for redeveloping aged public rental housing estates after completion of the CRP. It states that in future, redevelopment will be carried out as required having regard to the actual conditions of individual estates rather than by types of estates or blocks. Clearance will be undertaken only when the estate is structurally unsafe or has become uneconomic to maintain. Following the completion of the CRP, the need for another large-scale clearance of a certain class of old estates is no longer necessary. The need for clearance should hence be considered on an estate or block basis only.

To ensure a safe, comfortable and sustainable living environment for public housing residents and in light of the principles set out in the 1998 Strategy, the HA adopted a new strategy in 2005 for sustaining the existing public rental housing estates. It will be driven primarily by safety and cost-effectiveness considerations, alongside the existing maintenance regime.

4. THE NEW STRATEGY

Under the HA's regular maintenance programmes, the public rental housing stock is kept in good repair through regular inspection and prompt maintenance. Whilst all blocks are structurally safe, the building conditions are deteriorating at varying degrees as a result of ageing and other factors. This has given rise to persistent and multi-faceted problems concerning the upkeep of public rental housing estates. To face the challenge arising from ageing of the public housing stock, it becomes imperative for the HA to devise a holistic and systematic approach to ensure the structural safety of old housing blocks on one hand, and to clear aged estates on the other.

To ascertain the building conditions of individual estates, the HA has commenced a comprehensive structural investigation of ageing estates. The ensuing paragraphs set out the approach of this strategy.

4.1 Comprehensive Structural Appraisal for Aged Estates

In general, comprehensive structural appraisal will be carried out for public rental housing estates around aged 40 or above which are often associated with soaring maintenance and repair costs. Flexibility will be exercised to extend the investigation scheme to other estates taking into account the actual building conditions.

The detailed appraisal aims to determine the material strength and rate of deterioration of the structural elements of a building, focusing on major aspects such as concrete strength, extent of spalling and cracks and corrosion of steel reinforcement bars etc. The findings will facilitate consideration and planning of the necessary follow-up actions such as monitoring, repair, or clearance. If certain blocks or estates were found to be structurally unsafe, demolition would be recommended. For other blocks or estates which remain structurally safe but require improvement works to enhance the structural capacity, appropriate works such as structural strengthening, recasting or normal concrete repair will be arranged so that no major structural strengthening work will be necessary for at least 15 years. Another detailed structural appraisal will be carried out near the end of the 15-year period with a view to mapping out the way forward for a particular estate.

4.2 Financial Appraisal

The expenses on maintenance and improvement works for old buildings will increase with age. While it may be technically feasible to extend the serviceable lifespan of the rental blocks through various upgrading works, the associated costs may at certain point in time outweigh the benefits, thus making it uneconomic to retain the buildings. Hence, in considering whether to undertake repair works for aged estates, a financial appraisal will be carried out to determine the financial viability of the proposal. Demolition may be considered if the cost-benefit analysis suggests that the aged buildings or estates are beyond economic repair.

4.3 Investigation Programme

At present, there are a total of ten public rental housing estates of age 40 or above have been selected for comprehensive structural investigation starting from September 2005, with completion targeted for 2008. Investigation of eight estates have been completed, of which two are considered less cost effective for retaining and are proposed to be cleared. The remaining six estates will be retained and refurbished to enhance their living environment. After completing the current structural investigation in 2008, HA intends to extend the investigation programme to cover another 32 old public rental housing estates which will reach the age of 40 in ten years time. Nonetheless, the actual progress will be subject to the complexities of building conditions of each estate, residents' co-operation, availability of resources and logistical considerations such as availability of vacant flats for on-site testing.

5. CONCLUSION

CRP has greatly improved the living conditions of many public rental housing tenants in the past 20 years. It has also allowed those better-off affected tenants to have priority in purchasing HOS flats which in turn free up the rental flats to those in need. However it is a huge commitment from Government in terms of land, finance and manpower resources. As the oldest blocks have all been redeveloped, it is time to consider whether this commitment should be continued indefinitely.

In view of the 1998 Strategy, Government has decided that redevelopment should only take place when the housing blocks are no longer safe or economic to maintain. In future, comprehensive structural and financial appraisals for old estates will become the key elements of sustainable public rental housing development in Hong Kong.

Existing Public Rental Housing Estate

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TITLE: ENVIRONMENT, HEALTH, AND SUSTAINABLE BUILDING ; PROPOSAL FROM THE HEALTH & WELFARE FACILITY DESIGN

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Keywords: health, environment, sustainability, medicine, economy, nursing, hybrid, will

Summary

Living in the sustainable building should be a good system for both human health and the global environment preservation. That is, it sets the way of living, which approaches zero piece of energy and zero emissions plan newly to the building. Then, it wants to make to master the building and to live become good for the global environment and the health of the human being. When thinking like this, it is suggestive that the sustainable building depends on the environment, the area, the tradition and the climate. It is necessary to influence once again each other and to learn the inventing characteristic according to the green engineering with the present-day material. If unsolvable only by the search for the moral and the building ethics, it is important as the new duty to the building to do the application of the environmental performance evaluation and the addition of the design specification. And the sustainable environment economic system must be immediately arranged. As the follow-up, it is necessary to service the sustainable hospital building where extreme weather, too, can be supported and to do enough health care. It should make“ will to the health” the important theme of the human being.

1. The way that is good for both of the earth and the human being health

1.1 Thinking of Building in the viewpoint of the positive healthy environment making

Living in the sustainable building should be a good system for both human health and the global environment preservation. When there are not comfortable house and health, the human being cannot live. The medicine has continued suggesting a precious matter to make a healthy house. The hospital building, which is the space of the medical care, can show the role in the sustainable times. The hospital building space raises the self-healing power of the patient as the healing-up space. The patient goes to the recovery of the health by own power and appropriate measures of the cooperation of the medical team. When adding a sustainable viewpoint to the health and the welfare, the preservation of the living environment and the cooperation of the wonderful society, which realizes the last-ability of the health in the area, are born. It is understood that there is no clear line between health and unhealthiness; and the value of health is always actually felt, and the maintainable approach is important. It is possible to make a common goal create good healthy environment in the various view of the world. Moreover, the medical facility is well recognized in the value of the health, and is one of them, which need the service of the environment. The value of the health is made wonderful; a value of the time is made very important by the people work at the hospital and at the welfare facility. When thinking of the global environment and the viewpoint of the life of the human being, it is the thing that the health is the most important.

1.2 Clinical Path Based Design

The great health can be brought to both of the global environment and the human being if the scenario and the critical path of the global environment recovery can be created. If the new technical development is necessary, it should accomplish with the path to this “health”. As well as a building, broad cooperation is necessary to accomplish to do this.

The clinical path that a medical team develops in a hospital is the tool, which made a care process the chart by a kind of the disease. And that is prepared for both medical team and patient. “When? Who? What kind of symptom? What medical care has done? How does health care? ” A person, Action, Time are pursued and checked. In case of design, “Where? What equipment used? How safety space prepared? What environment is it?”; the way of the design based on the clinical path should be proposed to complement a place, medical equipment and space more. The clinical path, which the medical team creates at the hospital, is a scenario to the health; for the patient, the field of activities, which is the space of the spiral up revives with the recovery; for the medical team, the safety tool is made, which is incorporated a element in the time into the procedure and the space of the medical care. And the people engaged in medical facilities are well informed of the value of health from various angles. There is a space where the mind and the body are relieved. The space where security to the recovery with a psychological aspect is designed, and the safe space, which make up for a handy cap of physical movement of the patient, is prepared. Appropriate medical apparatus and equipment are arranged in a room of right area for the staff. The system, which checks the medical practice of the staff appropriately and makes an action safe, is arranged. As for the clinical path, a good partnership is shown. The design team does a" hearing" every each department; when reviewing the arrangement of the medical equipment and the furniture in the room space, it is necessary for a element in the place to be added to the clinical path, and for the space to be simulated; it is believed that this way is concluded as the common condition which does the safe and appropriate design. This way is named “clinical path based design” and has been proposed. It should appear that the space, which is the result of this action, is “clinical path space”.

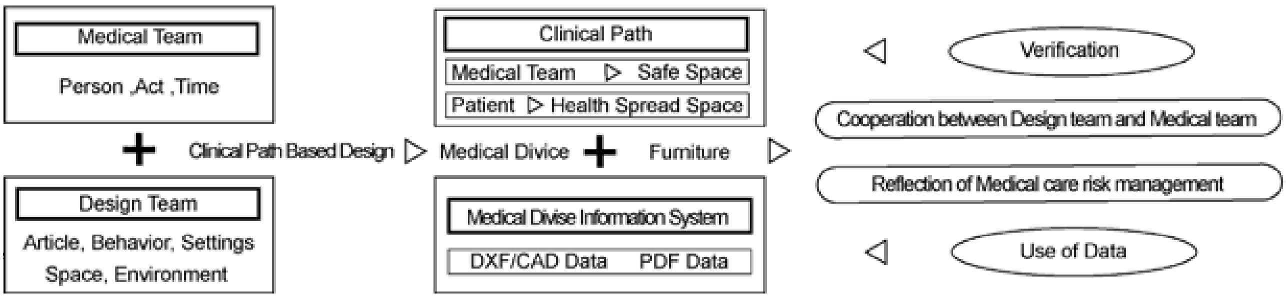

Figure 1 Clinical Path Based Design

The clinical path based design proceeds with the reviewing for each hospital department to become appropriate for the medical care, with the cooperation between the medical team and the design team; introducing a medical equipment information system, the electric capacitance, plumbing equipment, the appropriate kind of medical care gas, which are eligible for the equipment, are accurately chosen. Operation space and the necessary maintenance space are simulated and designed. Here, all at once it is a very important thing for the medical team to make improvement factor, check list and the result by the medical care risk management reflect to the appropriate and necessary space. The clinical path based design should be carried out by the cooperation. At this point, in order to effectively use limited space to the full, both teams should clarify the problems, identify the solutions, exercise ingenuity and run a simulation by Clinical path. Then, after complete of the hospital building, the medical team checks effectively by the actual medical practice. Then, to feed back so as to improve, to clear indication of problems for new plan is important. These things will make also good meeting and treats for patients by Clinical path. There is cooperation between Supply, Processing and Distribution (SPD) and the Hospital logistics in the supply of a wide range of medical equipment such as the pharmaceutical to the patient. Moreover, a bar code is shared and medical equipment information is taken out from the medical care information, the safe check of the medical practice should be done, and it is possible to build the system which supports a medical staff, too, at the same time. There is a big additional value of the medical care of the article management, which can connect safely. It is necessary for the disposal of the hospital waste to be stuck a bar code in the same way and to be made the strict management with trace ability. The clinical path based design let the medical care environment making of Health & welfare facility add the element of the flow of the time; it takes a way of catching in the static space at the facility as the more dynamic one.

1.3 To the viewpoint of the global environment life from the nursing

The healing properties can be more improved if medical ward is in the comfortable environment like the home. Environment at the patients room is requested to be in the nearly atmosphere of the daily life as much as possible. However, there is a problem that the 24-hour control system at the sickroom itself is sometimes bad influence in health. However, there is not a meaning that the environment, which the room at the house of the able-bodied person needs, is the same as the sickroom. As for 24-hour's being managed in the place of the general life except the hospital, the health cannot be maintained is obvious. Nevertheless, it cannot help thinking that there is a defect caused in the air-conditioning system that has not consideration for the global warming prevention through the 24-hour in the building management, and for the freedom of control for resident himself. The system that the resident can participate in his own indoor air quality environment will have to be made. Like the nursing, by the new home economics, the resident arranges a living environment by himself and then, has to create the viewpoint to watch and see it continuously. Sustainable home economics is necessary and should call it just “global environment home economics”. It creates the new home health maintenance life style which also care the state of climate include extreme weather, the global warming prevention and consideration of an earthquake, a tsunami, a fire and a flood occurring. Also, it becomes the way of living to feel simple “will to the health” and to feel a natural environment and also to defend a body against the forces of nature. Therefore, it becomes very important to feed back from the medical ward and the welfare facility environment kept with the nursing science, and to think of the viewpoint of the room environment suitable for the able-bodied person. At a glance, by the freedom of consumption economy and the waste, there is no limitation for citizens to live in their own room space. Therefore, the facility equipment needs the function to forward the energy saving and to stop the running with note sound by checking energy loss appropriately, and also needs the feature which can not do the setting of surplus warm environment. To set the good environmental efficiency of the building for every kind according to the condition of the user, citizen, the health, the age, the climate and the other and to live are valid from viewpoint of the health care. Moreover, every building environment isn't the same according to the location condition with the scale, the spatial arrangement and the kind. Therefore, all buildings should express their own environmental efficiency and doing their best. The comfortable indoor environment 24-hour automatically managed seems to be a space station but is suitable for the healing-up environment at medical ward of some kind. However, the able-bodied person desires to notice the sun, a wind and light; it symbioses with the nature like the yachtsman to look for the wind just like on the ocean and to handle a sail, and will find the viewpoint which lives in the severe global environment. To improve a global environment, the way of human being's living prepares for the new environment, and the moral of the life should be made tough one. It is necessary to control the healthy indoor environment liberally, to maintain the healthy condition to feel nature, and to adapt the life style to the new global environment little by little and to spend, too. It should create a healthy living environment by the cooperation of the industry-university-government. Then, it is necessary to service the sustainable hospital building where the natural disaster of the sudden extreme weather and the earthquake, the tsunami, the fire, the thunderbolt and so on, too, can be supported as the follow-up and to do enough health care. At the facilities, the environment that the health always spreads safely to both of the citizen and the staff should be planned, and arranged inside and outside.

2. The new global environment and building

2.1 Skeleton infill

The picture and the sculpture were independent of the whole building as the former art; and the building has developed a new method of construction, material and a technology and has won liberty in the space. But it welcomed a wide range of chemicals material and surplus artificial environment to the personally opened “Skeleton” again; please let it not become the insalubrious existence, which cannot be controlled as a result. It should be strict from the point of view of the health and the energy consumption about the material, the industrial products that creates a building. Moreover, with the challenge, the preservation of the global environment and the sustainable society of the human being, it should advance towards the direction, which creates the environment, which is good for the health of both human being and the global environment preservation. It gives the “Skeleton” a long-lived structure in 100, 200 years and it plans life cycle cost down and life cycle carbon dioxide down; and “Infill” creates living space by the choice of the best environmental performance at any point in time. The mechanism that the update of a wide range of electric facilities, mechanical and plumbing equipment, too, can be easily supported is required. In the Health & welfare facility, the “Skeleton Infill” can realize the mechanisms, which can renewal medical equipment and building equipment efficiently by the durable period.

2.2 Invisible Environment

2.2.1 Air

The sky is high infinitely because of its transparency; capacity of atmospheric air cannot see the picture by sense. How does the heat budget of the atmosphere in the earth become among the space? Even if a simple equation is supposed to be found, the tactics that the building can be immediately utilized for in the validity isn't found. It is likely to have to think the heat exhaust to the atmosphere to be the limited one. The transparent air pollution like the sick-house syndrome, too, is behind in the cause grasping; the exhaust heat, too, cannot be recognized by sense. The approach, which changes a way of spending unnecessary thermal environment, is necessary. There is important and beautiful thing that is invisible to the eye. It is necessary for human being to make the mechanism, which becomes the life to be zero piece of energy and zero emissions plan, without noticing the finiteness of the global environment and resources by living in the building.

2.2.2 Glass

At the tradition wooden building in Japan, it hung a roof on the structure of the beam with the pillar and it was putting in a simple fittings. The scenery of the nature could be gotten by a natural garden view, through the adjustment band of the thermal environment of the deep eaves, from void picture window of the beam with the pillar. In the summer, fittings were opened largely or removed; deep eaves shaded sunlight; seasonal southeast wind was through so as to be pleasantly and cools off; this is the device. Mud wall range spread but there was a small device, which introduced the consideration of the ventilation in the summer, and of the rays of the sun in the winter as expected in the district where had the need preventing coldness in the winter.

The glass seems whether or not to have left this scenery and to be useful for the coldness in the winter as the transparent wall. The transparency of the glass is beautiful but has changed the traditional way of living by planning house, by control with the fittings, and has changed the study of the essence of the thermal environment roughly. Without noticing the loss of the energy by the transparency, it is reaching global environment times.

2.3 Building on Earth

To create the building which can try to live in the earth healthily is needed. The influence is immeasurable because the building leads a way of living, and the way and the space of the life are in the indivisible relation. The sturdy life to feel a natural environment and to live personally is better than the artificial environment by viewpoint of the energy consumption. Super hi-rise skyscraper penetrating cloud aims at the sky; it has been isolated from the external environment in the creating artificial environment; and it seems to be in the world of the hazard of the space station of the air tightness and the exclusiveness. The technology, which lives in the sky, influences the technology, which lives in the ground just as it is. The dwelling in the earth would take on an aspect which heads for the space station, even if ground dwelling made aim at the sky environment about creating artificial environment in the mechanism that the sky and the ground were the same. As for the global environment, the ability to process the loss of the energy and a heat emission by it is noticed to be limited. As for creating the indoor environment and the thermal environment without interest in the climate around is noticed to beggar a human being at the same time. Without combining the characteristic of the kind of the building to the health of the resident, and to the climate of the area, and moreover to the sense of the climate with the design policy of the indoor environment by the scale, a living environment and a global environment are aggravated. Earth doesn't waste yet as Moon and Mars. The given artificial environment mechanism beggars a human being in the unconsciousness to the environmental destruction. It was liberated from the living to feel nature in the rain, the wind, the thunderbolt, the sun and the moon; but once the extreme weather occurred, a terrible loss got to occur. The building associates with the nature well and creates the mechanism as it finds its own comfortableness in it; and it is the maximum thing for the building to cultivate the feeling and the moral of the living people, and to form these in it. The economy changed the direction for the pleasure, and improved the heat-coldness, which was formerly thought ordinarily, by the development and the introduction of the facility equipment; but it is necessary to reduce this aim; that is simple and moreover big study into the building. Green engineering is added to the building culture and the greatest result is the directionality of the research, the exploration and the popularization to approach zero piece of energy. That is, it sets the way of living, which approaches zero piece of energy and zero emissions plan newly to the building. Then, it wants to make to master the building, and to live become good for the global environment and the health of the human being.

3. Plan to Building and Health

3.1 The way of keeping a moral by observing the rules

To spend quietly and delightfully with the earth should be wonderful. It is good and healthy for human being to change the mechanism of the building to notice the finiteness of the earth if not wakening. It is not merely design style of the building group, and it becomes necessary to propose socially as the way of living. When referring to the car, which is the symbolical existence of mass production machine, it is impossible to sell if not passing to setting exhaust regulation; it is necessary to specify building environmental efficiency evaluation such as passive, active, insulation design and various tries by all means. Also, the building is not only the one for the person to live in the wide sense. Even the power plant, the factory, the cleaning factory, the ironworks, the drainage treatment plant and the industrial waste processing plant with machine and mechanical equipment should set environmental performance value strictly, and also should be expected in the safest sustainability to support life as the building. To set high goal value and to achieve it continue to be the wisdom of the human race. To spend the daily life and to think the moral from the individual and the area as same as the earth level can be created with the efforts at the sustainable building. It is very important to lead to the good technical development become valid healthily, to make the environment economic active and to maintain a network. And it is necessary to release the environmental efficiency that has approach as the richness of the global environment home economics, told each other; also it is necessary for the citizen, lives at the building and in the earth, to execute the new direction discovered personally. Also, it is necessary to disclose about the energy consumption and the discharge data after completion, and to feed back into the new plan easy. To build gets the perfect opportunity, which reaches some new global environment times with the social big goal, and is not the expression of the merely building group. It is necessary to display whether or not to live safe like the house structure investigation after the big earthquake occurrence. To display a signal in blue, yellow or red about the environmental performance at the existence building and to forward improvement are urgent necessities too. The factory and the power plant with bad efficiency are an object too.

3.2 Environment Economy

For the life cycle cost and the carbon dioxide reduction, for making the specification which is strong in the fire for protecting, for indoor thermal environment to extreme weather and for adopting the seismic isolator which can show sustainability in the earthquake, if the initial cost increases, environment economy should be created and the society should conquer the problem and make it realize. The investment should be able to be collected easily in making a restoration cost zero boundlessly with the disaster, and in getting longer operating life at the building. Specifically, for the hospital building, this technology and the investment is necessary by all means for the disaster medical treatment. The risk is too large if the direction of an economic activity doesn't agree even if the solution by sustainable building can be presented. The building doesn't automatically give all environments, which the person lives in; but it generates even the show of the way of living to become consciously aware of the global environment, and the responsibility of the explanation to the living person. It is bad for our health not to head for the solved direction quickly, though there is a solved beginning. “Will” is necessary to become healthy, and has to arrange a mechanism and an organization so that all become healthy. It is the mechanism, which can point out health in the pursuing of comfortableness. Consumption economy does not advance in the technique of the building good for health and the direction of healthy technical introduction; but it is not because personal awareness and morals are insufficient. The environment economy, which cooperates with the environmental efficiency evaluation, should be necessary. The life force of the human race with excessive vitality and trying to advance always beyond its own limit, tries to accomplish the choice of the best in the pile of the level of the individual from limitless; however, it isn't possible to think that it grasps the volume of the global environment. The match of the choice of the technology, which is appropriate to ride over the global environment crisis, the mechanism of the environment economy and the life of the building, which nourishes a moral and ethics, is indispensable.

3.3 Hybrid

A good hybrid for environment and health is effective when thinking passive solar is supplemented with active solar as a hybrid. It is thought that to take the rich mechanism of the indoor environment at the tradition house once more with the good material of the low-cost, light-weight and safe environmental performance, too, is the hybrid of the wide sense. The mechanism at the house in the warm district and one in the cold district coexist globally; this has been a global hybrid, and will continue to be. This is also thought to be one of hybrid systems that super hi-rise building and the high, middle, low-rise building, the house and the tradition house make a city with scale, the technique and the environmental engineering, which suited the kind of the building. The mechanism of the propagation of the building culture repeated a hybrid condition and fusing; the buildings become the world heritage is telling it. The global society has won the viewpoint where to see a result at the building all over the world beyond the culture and the tradition in today; it is possible even to find the traditional technique which doesn't propagate to Japan yet. The viewpoint is needed to understand beautiful building not by a form but by an effort of the living environment to the climate. This is the compilation of a tens-of-thousands-of year of human being and an activity at a house. The essential existence value in a dwelling and at a building is there; to take the explored result how it lived in the area environment once more is very valid. It is possible to find the direction, which is not a rebellion against the global environment; not to utilize the thousands-of year accumulation of the area design is wasteful.

4. Sustainability

4.1 Sustainable Building

The healthy environment design by continuous efforts should be the newest theme if buildings in the world search for a new design, a molding, the green engineering and the theme at the house. More specifically, if a collage of a geometric tradition and a traditional building is a study of the building design, it doesn't show essence in the building and dwelling, which is in the symbiosis with the natural environment. The transparent fascinating space should do the device of the ventilation, solar shading, solar radiation and so on, and should improve an environmental performance; and it is necessary to propagate and to become popular. The building in the world can be responded to each other by having a tough will and a sense, with which human being lives in the global environment. The traditional architecture in Japan has been telling a sense to spend a climate of an island in a Temperate Zone in East Asia with a culture. A lot of buildings that is reorganizing search for the house of the culture and the climate by a technology in today can be seen. Life style with zero piece of energy should have an influence on the nowadays building once again now. It attempts to think of the dwelling by the sense at the traditional architecture in Japan, the culture of the world, and the technology, the technical innovation today. The most famous Katsura Imperial Villa made a high floor type because of Katsuragawa-river flood, avoiding moisture in the summer, and repeated enlarging along with the setting of a pond and a garden in the horizontal direction; and also it says that that villa created so as to the wind goes through, to use solar radiation, and to form elegant site plan according to the arrangement with the tour garden. There are an art culture that supports the garden appreciation in noon and the moon viewing in night. In a measure to a flood, it is possible to admire the traditional house in Thailand for the sense, which floats by a buoyant force of bamboos to be put under the floor. High floor can be far seen at the traditional house in the Switzerland shore of a lake, too. As for the ventilation, in today, the tower of the wind of Pakistan that takes the wind of the sky extremely becomes reference. It became difficult in cities in Japan for the wind to be gotten from the horizontal direction; a sense to be taken from a vertical direction harmonizes with a new lifestyle and a form of a house at a narrow site successfully. The room becomes bright because a natural light flows when combining with the skylight, which is often used in

Northern Europe countries in today. There is ground beam structure of the traditional wooden house in Iraq and a measure to the earthquake, which is realized as the quake absorbing structure by new technology. Insulation in roof-top greening like a flowering grasses which had grown in a former roofing with thatch is recommended in today; otherwise to prevent the garret temperature rise with the solar reflective paint is useful to make cool roof that reduce heat flux from roofs to the atmosphere too. The ondoor of Korea becomes a hint of a floor heater and insulation at an outer wall. The sense and the culture in the world each place can be reorganized by the technology in today in this way, too. It is valid to a change of an environment.

Today, we become conscious of seeing an appearance of the blue planet, the earth which rises from the moon of the gray which gotten good reception by the orbiting satellite in the moon and to feel an arrival in the global environment times in the world together. The world agrees about a conservation of the global environment. In this time, the living strategy becomes sustainable building displayed the environmental efficiency with the global environment home economics. There, a living operation manual, then an explanation of how to live with the environment symbiosis is necessary. In addition, as for it, it should be equipped with the preparing checklist in the mechanism to prevent a building from energy loss. It is also necessary the simple rule of global environment preservation for an individual to be permitted common with a company, an area, a nation and the world.

4.2 Sustainable Hospital Building

Sustainable hospital is further follow-up of the environment, which the sustainable building creates and the sustainable hospital building should be equipped with an information power and vitality to do health care and environmental management by discovering a new problem. Because it is simultaneously not only medical care space but also building space, the hospital building reflects efforts of the medical health care directly. The medicine has woken up patient's natural healing power by locating the hospital construction to the good environment place from at first. It is thought that the environment of the patient is not only as "to cure" but also as "to heal". It is a valuable modern problem in the hospital in city that takes "to heal" into construction; because it becomes difficult to choose the geographical convenience that an environmental condition has well. "To heal" has been made the big theme of design for hospital building with neighboring environment. In the clinical path based design, as for the space of the patient, it experiences that the health rises in the spiral with the expanse in the field of activities from a flower of the vase with vital principle, from a healed picture, from the light, the wind and the nature overflowed at the window, from the rooftop green, from the suitable healed interior and exterior design, to daily life. Then, these are the environments of the disease healing-up, which the hospital building creates; at the same time, it should utilize to practice at the very least in the place of the usual life and to keep health. A space of the medical team is safe one by the clinical path based design, reviewing an operation of the medical care facilities, equipment, and patient and staff.

Figure 2 Niigata City General Hospital, Niigata pref.Japan.2007
New generation Hospital Building toward the 21st century. The establishment of functionality and the amenity as the acute period hospital. The making of trusted hospital strong in the disaster, the change of the future can be flexibly supported. Environmental symbiosis and harmony with a new town.

However, it wants to emphasize that a characteristic at the hospital in today, which is different from the other kind of building, is a positive health being united with the environmental development. In any case, there are tough “will” of medical staff that has opened new healthy environment and a high sense of ethics and they are repeating a discussion on the occasion of utilization of a high technique. The development of medical equipment is the extremely good example that high- technology is utilized for the health promotion. Then, various invisible matters have been treated. It is the big characteristic that the environmental infection control based on a clean to dirty airflow, an aerial pure degree and clean room classifications management every zone has been developed and united with air conditioning facilities. The air and the glass are very important to create artificial environment at the hospital; it is mentioned that this is the special consideration to the powerless patient. And the environment “to heal" is demanded; simply because it is the space that entrusts the position to advanced technology. A flower of the vase changes carbon dioxide into vast amounts of oxygen. It is impossible to do planting trees and green in city in any case if not depending on a special way. The environment at the hospital building should be created with the small bloom and planting. To do the health care of the citizen in the vicinity in city is demanded, not in the vast natural environment. It is necessary to release information of the building environmental efficiency equipped with such advanced technology, too.

*Figure 3 Ogachi Central Hospital, Akita pref.Japan.2005.
Green hospital built in the heavy snowfall area, The promotion of the planting, the rooftop planting, Harmony with neighboring environment, The measures are taken against a winter seasonal hard wind, an snowfall, an icicle, a snowdrift and a condensation. The design got close to by inhabitants and a patient.*

Moreover the matter sustainable hospital building should prepare for is following things; skeleton infill system which can update medical equipment at any time; daily environmental information and health information network; the system to appeal a caution to the health care and the environmental destruction to the wide area around; a function that the last-ability of the medical care activity can be shown at the time of the disaster. As a countermeasure against the disaster, it is necessary to be equipped with the energy independent system, the duplication of the lifeline, to stockpile water, food and fuel. The number of the casualties that occurs around, the kind and the quantity of the medicine, which needs for first aid should be understood as pre-disaster. These medicines are always secured as an inventory in a hospital physical distribution; this system plan as one of the lifelines at the hospital is the new goal of the cooperation with the hospital logistics. It is the installation of the quake absorbing structure to the earthquake, the lightening arrester to the electric trunk line to the thunderbolt. The hospital building should be fire-resisting construction. At the same time, to the fire, the fireproofing woods, which prevent the spread from surrounding area, is valid with the planting trees, too. It becomes necessary to improve insulation, water tight and air leakage efficiency, as the countermeasure to the extreme weather such as heat wave, the bitter cold and the extraordinarily large typhoon, and to prevent a rapid change in the room temperature from taking place. It is also important to prepare for terrorism, accident, human damage and drug-related damage, and to bolster security, and to plan a first aid isolation room, and to cooperate with other organization.

5. Will to the Health

There are wide ranges of ways in sustainable building according to the area, the culture, the climate and the technology but they need each environmental efficiency disclosure. It is possible to suppose that it gives a new value to the building, it gives the citizen a relief and safety and it attempts to improve a global environment. This is the new presentation for the new relationship between the human being and the earth. To spend while conscious of this thing is the forward movement of the sense of values of the new human being. It is the new step to grasp relation with the nature again like the human being who lived in the vast nature. The human being is powerless with keeping thermal environment personally by the health care in the closed living environment isolated from the outside world; as a result, it has despoiled the ability and the liberty of the citizen to notice environment and to introduce a natural environment to the thermal one. At the acute-care patients room of the disease healing-up, this way is sometimes very valid but in the daily life of the able-bodied person, it has been possible to advance on the direction of the large energy consumption.

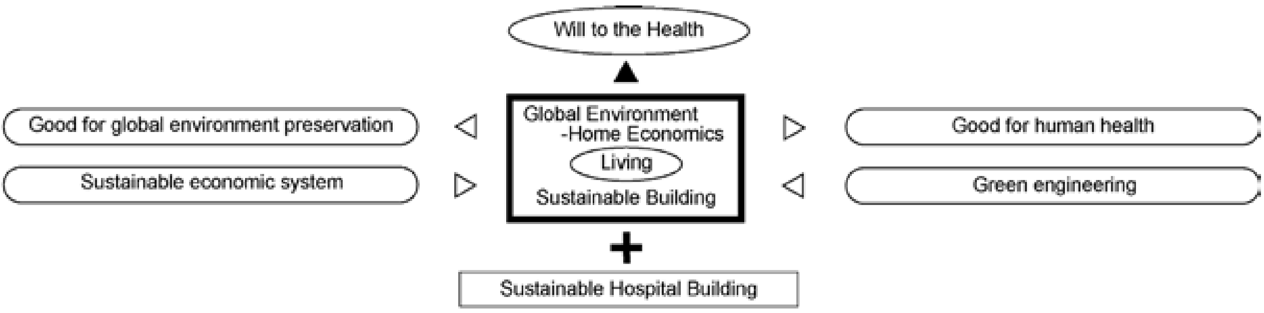

Figure 4 Will to the Health and Sustainable Building

Then, now, the maximum what forming in the building is to expand the comfortable range of the human being, to create the mechanism to the life style to notice environment in the outside world by the skin with the energy consumption as little as possible. The people who try to regain their health are desperate notice environment and are cultivating the self-healing power. It is important for the healthy people to embody the role actively from the near place to the environmental engineering development for the maintenance of the health and to create the sustainable society. The medical equipment which used the most advanced scientific technology has been utilized for the health recovery, but the human being know and use alternative medicine as the living custom too; it is the way which continues to be healthy before becoming an ill. In the same way, it should use the way of maximum of utilizing natural energy to set comfortable indoor environment, not the way that the energy consumption by the development of the scientific technology is big. When it heads for the direction, which reduces energy consumption by the "will to the health" as much as possible, as for the way of sustainable living united with the global environment home economics, the expected living quality becomes wonderful and important. It improves the passive performance of the building as much as possible, and complements it by the active performance; the environment economy for the environmental performance improvement and a wide range of environmental green engineering become necessary. Moreover, not only the way of the living by sustainable building and the show of the living manual to citizen, but also the creation of the new lifestyle and the forward movement of the value of the health become important. It is necessary to make up environment that keeps being healthy before man gets sick. Speaking of the earth, it became clear to worsen the global natural environment state severely by the activity of the human being in city. This is prime task that the sustainable building takes action to rescue and to make it become popular, in the situation that the human being may have robbed even the healing properties of the earth's own. The citizen is sensitive to the sign of the climate change, which is happening in world each place; to continue to build a building with much energy consumption so far goes against the building ethics and the moral. To build is not the expression of the building group and must make agree with the social big goal. The building should aim at the most advanced environment equipment, which can do the maintenance of the health of the human being and the global environment. The building had begun to make order in being disordered from the natural place. The order in the new global environment times must be the disclosure of the building environmental efficiency and search for it together by cooperation.

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AN OVERVIEW OF THE *EFFECTIVE SUNLIGHT DURATION* IN BEIJING'S HIGH-RISE AND HIGH-DENSITY RESIDENTIAL BLOCKS

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Keywords: effective sunlight duration (ESD), high-rise and high-density residential blocks, duration of sunlight, sunlighting performance

Summary

Optimum Sunlighting distribution to individual dwelling in high-rise and high-density residential blocks has many difficulties from both internal and external factors. In Beijing, in order to buffer the conflict between optimum sunlight indoors and economical land use in high-rise and high-density residential blocks, a new concept of the Effective sunlight Duration (ESD) as a criterion is introduced into the calculation and assessment of sunlighting performance for dwellings. This paper is to provide an overview onto the concept of ESD in terms of the specifications of urban development of Beijing city, thereby it brings up to a possible balance between optimum sunlight use and economical land use in the future plans of high-rise and high-density residential areas.

1. Introduction: Sunlight Duration

In the development of sustainable urbanization, maximal possible duration of sunlight indoors is taken into substantial consideration in modern dwellings. It is one of the most important measurement units of sunlighting performance. Internationally, the calculation and assessment of sunlight duration indoors are achieved by evaluating the matters to do with the penetration of sunlight on a specific day of year, which is usually selected from the dark months of year. In fact, the selection of the day varies from region to region because of geographical differences and climate diversity. In some countries, the 8th of February as the standard date of assessing duration of sunlight indoors has been in popularity(Grandjean & Gilgen, 1976), whereas the Winter Solstice and the Greater Cold—two alternative standard dates in China are applied(Standard for daylighting design of buildings, 2001).

The need, on the other hand, to achieve equally maximum duration of sunlight indoors for individual dwelling is difficulty approached in high-rise and high-density residential blocks owing to the complexity of spatial layouts and configuration of buildings, especially for the residences in low-levels. In majority of countries, to obtain a balance between optimum duration of sunlight indoors and economical land use, an acceptable minimal duration of sunlight on the standard date is permitted in practice. For example, In Berlin, two hours of sunlight possible on 21st February for at least one room of the dwelling (Grandjean & Gilgen, 1976). The approach is also utilized in China.

Beijing city (Lat39.9056, Long116.3914), located in the climate of Cool Temperate, suffers the prolonged winter period. Hence, the significance of maximizing duration of sunlight indoors is more apparent. Even though the selection of the standard date for the calculation of sunlight duration stipulated in Building Code of PRC is from either the Winter Solstice or the Greater Cold, both the two days as the simultaneous standard dates are utilized in Beijing, so as to maximize the use of sunlight. As far as minimal duration of sunlight indoors is considered, one-hour duration of sunlight in the Winter Solstice and two-hour in the Greater Cold are mandatory.

After the mid 1980s, however, the fact that a vast of high-rise and high-density residential blocks were built to meet the increasing needs for residences in Beijing (Sit, 1995) brought up the conflict on capturing as much as possible sunlight and maximal land use. In a number of residential areas, even minimal duration of sunlight was difficult to reach. In this circumstance, the new concept of the Effective Sunlight Duration in later 90s was introduced into the system of the calculation and assessment of sunlighting performance for residential blocks. This paper is to provide an overview onto the concept of ESD applied in Beijing, thereby it provides potential to balance optimum sunlight use and economical land use in the future plans of high-rise and high-density residential areas.

2. Scope

A number of researches into energy conservation and health issues integrated solar radiation have been done and put into practical applications. Indeed, the most important factor to the completion of these activities is sunlight access. However, in high-rise and high-density residential blocks, the lack of sunlight is a major issue in many regions with finite land use. Therefore, the study scope, in this article, is primarily to describe the concept of ESD as a criterion in the assessment systems of sunlighting performance to balance sunlight accessibility in high-rise residential and high-density blocks. The article will answer the following questions:

What is meant the Effective Sunlight Duration?

Why is the concept of ESD utilized in the assessment of sunlighting performance, especially in the circumstances of current urban development of Beijing high-rise residential blocks?

What are the advantages of ESD, compared to conflicts of maximal duration of sunlight in reality?

How is the calculation of ESD achieved?

It is remarkable, on the other hand, that the achievement of ESD in dwellings may induce positive effects on the increase of energy efficiency and human health from solar radiation. However, the original application of ESD is to ensure as much as possible sunlight indoors, while using land reasonably. Effects on other aspects are not considered. The limitation of researches results now in the impossibility that the contents of ESD related to energy rationalization and human health are presented in this article, but deeper insight into the ESD applications will be written in other papers. For this reason, the article will only discuss the concept of ESD and relevant reasons of its emergence in Beijing.

3. Understandings of ESD

3.1 What is the Effective Sunlight Duration?

The Effective sunlight duration is an assessed criterion of sunlighting performance for dwellings applied in Beijing. Different to prevalent assessment methods considering much more in the quantitative, qualitative or heat-radiation factors of sun's ray, which penetrates into the space, the concentration of ESD is at the consideration of sunlit periods irradiating onto sun-accessible façades or window areas of dwellings. The dominance of the criterion is in ensuring that residents have opportunities to obtain as much as possible continuous solar-time throughout the year, even on severe days of the year.

The key of ESD is the domain to regulate so-called 'effectiveness' of sunlight duration. In the concept of ESD, effectiveness is always linked to solar time rather than solar energy-content or illumination. The confines between effectiveness and ineffectiveness of sunlight duration are clearly delimited when the concept of ESD is proposed by Beijing Municipal Commission of Urban Planning(Design Code for Beijing Residential Buildings, 1994), namely, more than or equal to 30 minutes duration of sunlight is considered as a unit of ESD; conversely, less than 30 minutes duration of sunlight is considered as ineffective sunlight duration.

Taking fully actual time of sunrise and sunset on the standard date of Beijing into consideration, the calculation of ESD is implemented within a specific period of 8am to 4pm, so that the precision and effectiveness of results can be orthodox. In accordance with National Code, two ESD units in the Winter Solstice and four ESD units in the Greater Cold as minimal standards are accepted(Measuring-point: on the window wall), whereas the following different number of rooms in term of different types of dwellings must attain minimal standards:

one room of 1-bedroom dwelling without north-facing room;

one room of 2 or 3 bedrooms dwelling with one north-facing room;

two rooms of 4 bedrooms dwelling with one north-facing room;

three rooms of 5 bedrooms dwelling with one north-facing room.

In the process of design, as many as possible units of ESD on the standard dates should be highlighted with reasonable land use.

3.2 Contexts of Emergence of ESD Concept

Even though the concept of ESD is only utilized several years, its introduction into the assessment systems of sunlighting performance is inevitable. Discussing the emergence of ESD concept, the following contexts that sunlight assessment systems have been in popularity in current circumstances of Beijing urbanization have to be mentioned here:

High-rise and high-density residential constructions as a major type of dwellings in Beijing is immensely developing than any periods in the past because of the increase of population, the limitation of land for residence and the incentive-policy for real estate industry.

According to Beijing Fifth Census Statistics by the year of 2000(Department of Beijing Population Statistics, 2005), total number of population was reached to 13,569,000 with the average population density of 821 persons/ k ㎡, which is approximate 1/4 total population of Australia, whereas its total area of available urban land has only 16,807.8 k ㎡(Beijing Municipal Statistical Bureau, 2002). Such a huge number of population increase and finite land use have already exceeded the national planned target. Increasing the population density by building higher with more living area per unit of building land becomes an obvious solution for improving the average living situation and for accommodating more people.

Beijing as a long-historical city, on the other hand, has constraints on urban development, especially in the historical building blocks of inner area. The inner area of Beijing embodies invaluable architectural heritages. The perseverance of these heritages is significant for city sustainable development. In this circumstance, small number parts of inner area have potential to build new accommodations and heights of the buildings should be strictly controlled to avoid the intrusion into the profile and skyline of the low-rise traditional core of the Ming and Qing Dynasty preservation of the Forbidden City. Besides, to economize residential land use, cutting down the invasion of building land into the good vegetable land in the suburban districts, is vital for Beijing sustainable development. Therefore, constructing the high-rise and high density residential blocks in the vicinity of inner city become a means for reducing the disturbance to inner old city and the use of agricultural land.

In addition, the incentive-policy for real estate industry is another important factor to boost the development of high-rise and high-density resident blocks. Since the year of 1988 when the housing reforms was launched nationwide, new private housing provided by developers has mushroomed in Beijing(Sit, 1995). In the finite residential land, building high-rise and high-density residential blocks becomes a prior way for developers to obtain maximum profits by selling as much as possible living units. Remarkably, official preference for building higher and raising density standards(Laurence & Wu, 2005) impels that most of developers build massive high-rise and high-density residential blocks. Hence, based on the influence of above factors, high-rise and high-density residential blocks are increasingly dominant on the market of Beijing housing. At the moment, the problems of high-rise and high-density residential blocks are apparent. Less sunlight is one of the most serious issues in current environment.

The standards of relevant residential environments qualities should be improved to meet the demands that people desire to live in more sustainable and comfortable residential communities. To achieve higher objectives, the Chinese government has made a clear commitment to increase the standard of living for its population after the housing reforms. On those new objectives, improving environmental quality within and surrounding neighborhoods is an important aspect, including increasing the standards on sunlight access and duration of sunlight (Jia & Hugentobler, et al, 2002).

In the past, the Greater Cold as the standard date of assessing sunlighting performance was widely applied nationwide. One-hour minimum duration of sunlight was the only criterion to assess sunlighting performance in the dwellings. With the increase of living standards, people have more demands on receiving as much as possible sunlight. As a result, the governments increase the standards of sunlight assessment: two-hour minimum duration of sunlight on the Greater Cold. In addition, a new standard date of the Winter Solstice is the alternative. On the day, one-hour duration of sunlight is the minimum standard. Each city can choose either one as the standard date of assessing sunlighting performance in terms of local climate conditions.

Apart from the increase of standards of assessing sunlighting performance, the rapid increase of awareness that people have right to obtain sufficient sunlight in their dwellings is another factor to compel the improvement of the standards. To buffer the conflicts between residents' desires of hoping to obtain as much as possible sunlight and efficient land use, parts of city, especially in large city like Beijing, Shanghai, have applied both the Greater Cold and the Winter Solstice as the standard dates to assess sunlighting performance.

In current Beijing urbanization, the considerations on the closed relationships between sunlight and residents' health—both physical and psychological influences are taken into. As we know, sun's radiation falls into three ranges after it penetrates into earth surface: the long-wave, the medium-wave and the short-wave(Lynes, 1968). All the waves have influences on humans. The long-wave is a type of heat-radiation, which embodies around 98% of energy of the sun's rays. It has significant effects on warming the walls and the space, so as to make for a health indoor micro-climate. The medium-wave, visible rays, provides the visible spectrum around us. It has psychological effects on humans. Obtaining optimum medium-wave makes people feel fine. On the contrary, without sunlight, people may suffer sun-related healthy problems, such as Seasonal affective disorders(Hawkins, 1992) The short-wave belongs to a type of the ultraviolet radiation (UV). Its effects on human life are positive. It can kill germs in the air and the longer short-wave irradiating has beneficial chemico-biological effects on the human body(Pjrek & Winkler, et al, 2004). Based on the irreplaceable benefits from the sun's ray, it is very important to permit as much as possible sunlight into the dwellings.

In retrospection above, massive constructions of high-rise and high-density residential blocks, the improvement of living standards and healthy considerations promote together the development of sunlight assessment systems in current Beijing urbanization. Assessing sunlighting performance has become an indispensable part of design process of residential blocks. However, the traditional approach of assessing sunlight performance—the calculation of duration of sunlight, has its weaknesses in practical applications for high-rise and high-density residential blocks. It is difficult to approach one-hour minimum duration of sunlight on the Winter Solstice or two-hour minimum duration of sunlight on the Greater Cold because of sunlight inaccessibility formed by tight layouts of the high-rise and high-density residential blocks. To achieve current standards of sunlight indoors under finite land use is impossible for dwellings in Beijing. Thus, the concept of ESD as a new criterion is introduced into current sunlight assessment systems.

3.3 Merits of ESD against Disadvantages of Traditional Approaches

The concept of ESD as a new criterion in the assessment systems of sunlighting performance has its merits in reality. Compared with the application of duration of sunlight in the traditional assessment systems, the concept of ESD has overlaps, but there is an important difference—the criterion of defining the length of time that sun's ray irradiates on the sun-accessible facades or windows areas of dwellings. Based on this difference between them, the concept of ESD has obvious advantages over the traditional approaches.

The application of ESD in current residential construction market of Beijing is more feasible. National minimum standards on the assessment of sunlighing performance are one hour duration of sunlight on the Winter Solstice or two hours duration of sunlight for dwellings. Considering climate zones and location of Beijing, however, to achieve the minimum standards has problems in current Beijing urbanization. Building the massive high-rise and high-density residential blocks in Beijing for meeting housing needs has to reduce sunlight accessibility. When the high-rise and high density residential blocks were rapidly built from 1995 (Sit, 1995), in order to meet traditional standards of sunlight assessment, the developers have had to decrease the density of building blocks. However, the negative effects were that economical land use could not be achieved and benefits of developers were reduced. As a result, some of developers retracted the planned investment on the constructions of high-rise and high-density residential blocks, seriously hindering the development of Beijing urbanization. In this circumstance, introducing the concept of ESD into the existing sunlight assessment systems buffers the conflicts. Even though, to a certain extent, the application of ESD diminishes the national standards of sunlight assessment for dwellings, its feasibility in current development of Beijing urbanization is beneficial and marketable.

In addition, the application of ESD for the assessment of sunlighting performance of high-rise and high-density residential blocks is more reasonable. In conventional approaches, the calculation of sunlighting performance is based on a long continuous sunlit period. On the Greater Cold, two hours duration of sunlight is required, which means that there are two continuous hours sunlit time irradiating on the sun-accessible façades and windows from 8am to 4am; or one hour duration of sunlight must be achieved on the Winter Solstice. In fact, only southern facades have full accessibility to the eight hours. The eastern and western facades can only obtain four hours sunlight—8am to 12am on the eastern facades and 12am to 4pm on the western facades. In the dwellings design of high-rise and high-density residential buildings, the Tower-shape building is widely used in current Beijing. Its characteristics are economical land use and more living units per floor. In the meantime, numbers of living units facing eastern or western orientation have to be placed. Those units have actually four hours sunlight accessibility. Hence, in the high-rise and high-density residential blocks that buildings are constructed close to each other, those living units have difficulties to achieve two hours duration of sunlight on the Greater Cold and one hour duration of sunlight on the Winter Solstice because of self-shading and external obstruction.

In the concept of ESD, however, the sunlit period that is defined as the effective sunlight is shortened. It seems to reduce the standards of assessing sunlighting performance, but its reasonability in the construction of high-rise and high-density residential blocks is prominent. Among the close buildings, the small space only permits limited sunlight to irradiate onto the buildings. Especially for those living in low-level, the accessibility of sunlight is very finite. Compared to residences in the medium or high levels, which can obtain the sunlight from both top and the space among buildings, they have only sunlight access via the space among buildings. Besides, for the living units facing east or west, it is extremely difficult to achieve the traditional standards. Providing that traditional standards should be achieved in the high-rise and high-density residential blocks, the height and density of the buildings have to be decreased a lot; thereby the usability of land should be reduced. In this circumstance, the application of ESD introduced into the assessment system of sunlighting performance is likely to balance optimum land use and sunlight access in current Beijing built environment.

3.4 Sunlight Simulation Program- Sunshine2002

The sophistication of current computer programs makes possible to evaluate and refine the building design before its construction by the realistic modeling, and functionally linking to energy consumption or lighting performance to permit rigorous analysis in quantitative and qualitative format. Some of software programs have functions to calculate and assess the illumination level and heat-energy of sunlight integrating the building, but the software programs with the function of calculating and assessing sunlight duration on a day of the year have not been developed widely. Nowadays, most of software programs have been likely to calculate and assess the sunlighting performance at one time-point, which means that the transient performance of sunlight can be measured, but the calculation and assessment of duration of sunlight cannot be achieved. In order to measure and evaluate duration of sunlight on a specific day, the traditional manual methods have to be used, such as the Horizontoscope.

However, in the high-rise and high-density residential blocks, the complexity and diversity of the buildings bring up many problems on the process of manual calculation of sunlight duration. Time-consuming, inefficiency and inaccuracy are the major obstacles. To solve these problems, CAAD Research Center of Department of Architecture, TsingHua University developed the software of Sunshine96 in later 90s, which was developed on the basis of the software of AutoCAD R14 For Windows 95/98 Windows NT(Wang & Zhang, 2003). This program has an evident difference on the calculation of sunlighting performance compared to other sunlight-relevant programs. It has capability to calculate and assess the performance of sunlight within a specific period of time on a day. Initial considerations of applying the program are to calculate and assess duration of sunlight rather than that of ESD. Hence, on the basis of traditional standards of duration of sunlight, the calculation and assessment of ESD units can not achieved. Under the current residential construction market that high-rise and high-density residential blocks take up the majority of share, the software of Sunshine96 is not capable as the tool of calculating and assessing the sunlighting performance.

To meet new demands for the calculation of ESD units, the software of Sunshine2002, one updated version of Sunshine96, was developed in 2001, which has two key features on the calculation of sunlighting performance: a new mode of calculation for ESD units and a high-efficiency sub-program for the calculation of sunlighting performance of the high-rise and high-rise residential blocks(Wang & Zhang, 2003). Its advantages are obvious in current Beijing urbanization. Accurate and quick calculation of ESD units not only ensures optimum sunlight use for each dwelling, but also economizes residential land use. For designers, on the other hand, this program provides the possibility to refine their projects in conceptual phase, integrating sunlighting performance. In order to achieve the objectives of improving people living environment, Beijing Municipal Commission of Urban Planning suggests(Zhang, 2005) that all the design of residential blocks should involve the calculation and assessment of ESD by Sunshine2002.

4. Discussion and Conclusions

This paper introduces the concept of the Effective sunlight duration as a criterion of assessing sunlighting performance applied in Beijing. Its emergence has the inevitability in current Beijing urbanization. Rapid increase of population and finite residential land induce the massive constructions of high-rise and high-density residential blocks, whereas a negative effect caused by enhancing the density of buildings is sunlight inaccessibility. The utilization of traditional assessment systems of sunlighting performance has been not suitable in current environment. By the application of ESD into the assessment systems of sunlighting performance, the objectives of optimum sunlight use and economical land use can be achieved. However, the concept of ESD is only applied into Beijing residential market for several years. Its effectiveness and reliability should be examined in future utilization.

In addition, ESD concept is developed on the specific conditions of Beijing. Its feasibility to be applied in other regions should be examines. Beijing city with huge population and limited land use has to construct massive high-rise and high-density residential blocks. The new criterion has its marketability. For other regions with less population and plenty of land use, as much as possible duration of sunlight for dwellings can easily be achieved. In this circumstance, the concept of ESD does not need to be one criterion of assessing sunlighting performance.

For those regions similar to Beijing situations, On the other hand, the concept of ESD has potential to be utilized as a criterion to balance optimum land use and sunlight access, but 30 minutes as the unit of ESD may need to be redefined in terms of local climate conditions and geographical features. Beijing, located in the zone of cool temperate, suffer certain long winter. 30 minutes sunlight duration is the minimum standard for warming walls and indoors. However, in some regions, 30 minutes sunlight duration as a standard may be insufficient or too much, therefore how long can be defined as an ESD unit in different regions may be different.

The initial utilization of ESD as a criterion in the assessment system of sunlighting performance for Beijing high-rise and high-density residential blocks is to economize the finite resources of land and meet the sunlighting needs for dwellings as well. More possibly, interlinking the concept of ESD with energy rationalization and human health, more reasonable sunlight use in the high-rise and high-density residential blocks can be achieved. It is one of possibilities to realize the low-energy consumption and create a healthy and comfortable living environment in high-rise and high-density residential areas.

In a word, this research on the concept of the Effective sunlight duration as a criterion of assessing sunlighting performance applied in Beijing is to provide a possible balance between optimum sunlight use and economical land use in the future plans of high-rise and high-density residential areas. It is hoped that the work presented would be of interest to designers of residential blocks and others working with the calculation and assessment of sunlighting performance.

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SICK BRICKS

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Summary

Using brick or not using it is not only a moral issue but also a logical one. To clarify the subject, we should answer two important questions: whether we like our children work in brick kiln? If we know to what extent our life is affected by these kilns whether the "sound judgment" allows us to use brick. All brick kilns employ the women, children and aliens have entered the country illegally as workers. Unfair situation of women and children who are working in brick kilns in Middle East specially Iran, Iraq and Afghanistan. All brick kilns employ the women, children and aliens have entered the country illegally as workers. The highest wage for making 1000 bricks is 20000 Rials (2$) and each family with five members makes 3000-4000 bricks daily which means 6$ for five persons in a day in the best condition.

1- A majority of workers are women and children who because of hard physical working have no chance or ability to enjoy education and learning and usually wear male clothes to hide their sex for protecting themselves from sexual abuse.
2-This kind of work brings no technical skill for workers and there is no chance for their development in the future.
3-For supplying the required soil, we have to destroy the high-quality soil layers and this leads to destructive influences on environment.
4-By excavating the earth, some ditches and pits will be formed that generally are used as places for cumulating rubbish and constructional wastes that provides accommodations for addicted persons and offenders.
5- Low quality, intense reduction of the quality of the yield due to the lack of skill
6- Seasonal unemployment due to direct relation to construction ratio
Hypothesis:
Whether the brick based system of construction in Iran has been a proper one in last century?

Introduction

Figure1,Traditional brick kiln

Figure2, girls at work

By entering the industrial brick to Iran, there was a great need to the force work and consequently, constructional workers. This caused that the villagers move from villages to the cities. They preferred constructional work, which was seasonal but had a higher wage to the agricultural work which was permanent but had a lower wage. The job vacancy was filled and supplying the work force became more than demanding work force. Thus , living situation of workers not only was not improved but also it reached to the lowest level (theory of classical economy) and the rate of unemployment was increased .Fertile lands were destroyed and agricultural products was intensely decreased and Iran changed to the one of the most major importers of the wheat. City's population became more than village population and therefore the number of consumers became more than producers. So industrial brick which was the sound of progress in Iran, changes into Achilles' heel.

Figure3, women as the main victim of brick kilns

Brick kiln or Petri dish

Brick kilns, not only because of their hard work conditions but also for their impact on social and economical system should be closed down. A majority of workers are women and children who because of hard physical working have no chance or ability to enjoy education and learning. This kind of work brings no technical skill for workers and there is no chance for their development in the future. For supplying the required soil, we have to destroy the high-quality soil layers and this leads to destructive influences on environment. By excavating the earth, some ditches and pits will be formed that generally are used as places for cumulating rubbish and constructional wastes that provides accommodations for addicted persons and offenders. Since these kilns consume fuel five to ten folds of the usual kilns in Europe and their fossil fuel is including gas and gas oil, they cause increase of greenhouse gases, earth temperature, and finished price of brick. So the government has to give subsidy for fuel and the factories in order to decrease production cost, try to reduce workers' wage and the standards of workplace. The factors such as age and sex of workers (women and children) , minimum wage , lack of standard workplace and workshops for quality control and careful supervision , high rate of demand for brick in the market etc. ……. cause lowering the quality of produced bricks . Low quality of brick leads to occurring cracks during the process of production , transportation and laying as well as less adhesion of brick to mortar, less compression strength etc. …..which in turn lead to increase of maintenance costs and decrease in the rate of construction operations.

Figure4, A woman dresses like men working in brick kiln

One of the most important problems of construction field in which brick technology is used, is its dependence on unskilled force and workers .This is not an advantage but during the recent 100 years it has been the most important problem of this system because the countries including Iran , Iraq and Afghanistan are developing and need construction so there is high demand for blue-collars and the young workforces prefer to be engaged in hard manual labors which don't need any proficiency and skill. The following cases are among the problems of this system:
1-Lack of exporting 2- demolishing of skills 3- Intense reduction of the quality of the yield due to the lack of skill 4- low quality 5-Seasonal unemployment
7-Because of war in Afghanistan, during the recent 30 years, and worse circumstances in Iraq, a majority of population of these countries have immigrated to Iran. Most of them engage in constructional works and since the place of their work is not a certain place so prosecuting them is not possible. On the other hand their home is often the place of their work and this leads to severe increase of insecurity in the construction sites. Every day we can read in the newspapers the news about the murder, rape or rubbery committed in a semi-finished building by Afghani subjects. Villagers, Afghans have instituted the primary core of marginalization in the metropolitan cities including Mashhad, Tehran and province of Sistan and Balouchestan . These persons, who have no identity card and suffer from worse economical situation, can not dwell in the legal suburb of cities. To legalize their residence , these people get marry with poor Iranian so that they can get permit for residence .Thus we encounter with problems such as supplying drinking

water, electricity, lack of educational facilities, waste disposal , prevalence of infectious and contagious diseases, drug abuse, prostitution and so on.. Lacking congruous politics in different executive systems such as municipality , Water and Electric department , Gas , Natural Sources , law enforcement forces, etc.…causes contradictory treatments to be governed over them .One organ provides urban services for them , the other puts them under pressure to evacuate their house .On the other hand , municipality , to prevent from human disastrous events in these marginal districts , render services including disposal of the wastes , supply of water , electric and gas .This leads to contradiction in this matter . The problems such as living outside the suburb of Mashhad , lack of educational facilities , absence of family supervision , drug abuse, etc lead to social and terrible problems . Because of problems such as; outside the vicinities, lack of educational facility, lack of family supervision; difficulties including prostitution, corruption, drug abuse, buying and selling children, rape and … will be resulted

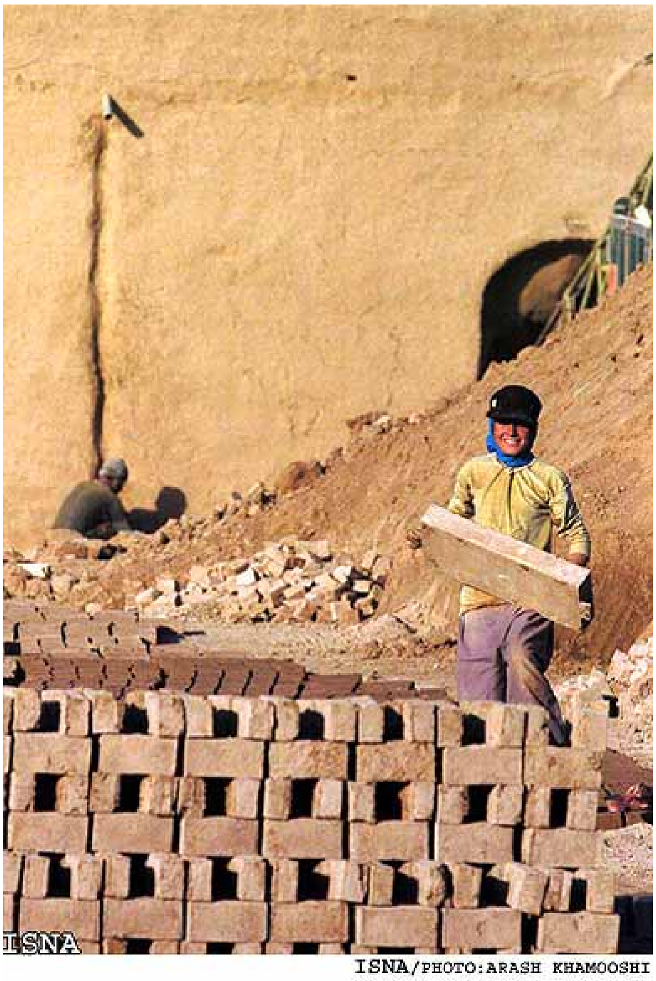

Figure5,An Afghans girl works in brick kiln

Undoing the relation between brick and crime

In 2004, one terrible criminal was committed by one of hut dwellers of south of Tehran. Such terrible criminal shocked all people of Iran .The case was that a boy called *Beize*, an adolescent with 15 years old , kidnapped 29 children during 3 years .He tortured them and after raping them , burned the corpses of his victims in the brick making furnaces .

In 1993, during one night, Mashhad city became the stage of a street fighting. Many banks were fired , many stores were plundered and offices were demolished and many garrison and the Police stations were occupied .After subsidizing commotion , and doing investigation ,the government declared that the origin of commotion were the estates which were formed illegally and as the municipality says confidentially, our enemy (in Mashhad and throughout Iran) is not America, not the opponents residing abroad and not the people who are counter-revolutionists but they are marginal dwellers.

If there is not police, we can not imagine what situation there will be for marginal dwellers .Indeed we are imprisoned inside our homes and automobiles but the marginal dwellers are free to go everywhere and so no law can control them .Among 2.5 million

Figure6, children live and work in very unhealthy and unsafe situation

When villagers migrated to the cities, they began to construct new houses outside the city; it caused the problem of marginalization which accompanied with social abnormalities. Increasing use of brick in buildings located in the margins of the cities caused a texture required to be reconstructed .Due to the characteristics of brick, the houses were not considered as the temporary ones but they were entirely like the urban houses. They could be used as the permanent dwelling so the people didn't attempt to improve their life conditions .According to the official statistics, there are 600000 city margin dwellers in Mashhad.
With respect to the culture of construction in the country, brick benefits from high potential in designing and construction so it can be said that the people participation in the process of designing is somehow acceptable; but in Iran people participation in construction process has no result except wasting resources or nonstandard implementation, and … "people participation" is often used as an excuse for the government to neglect its liabilities.

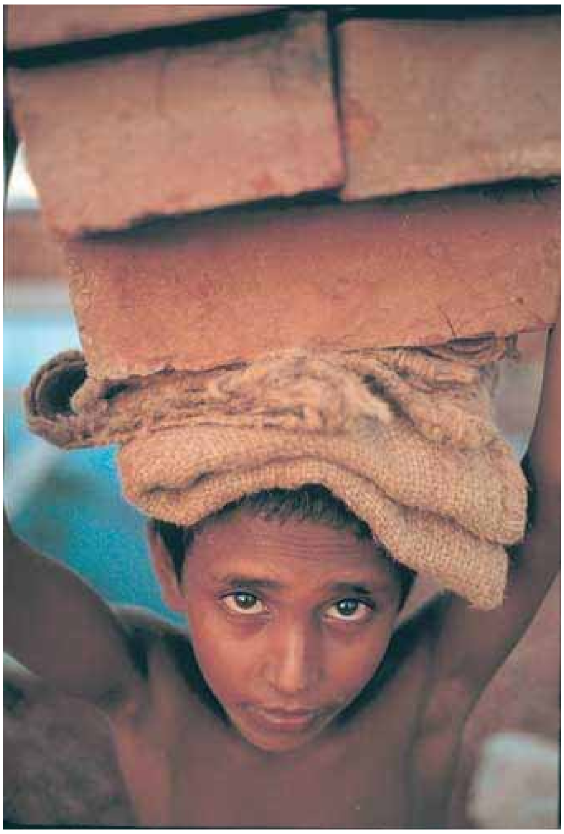

Figure7, Another Great Expectation!

Architect or *Brickitect*

It is important to change the passive architect's role to an active and effective one in order to manage the system of construction effectively, today's selection of materials are just based upon their price, color, texture and availability but it should be based on wider range of factors
Nowadays beauty is not only based on economic, environment and classic theory but also it should be considered on its micro and macro effects in every aspects and scale. Now the question is whether the existence of beautiful building could underlie the creation of beautiful city and whether the existence of beautiful city might underlie the creation of beautiful country, even if the answer would be yes, it is surely not, now one may ask whether the beauty have its classic
Definitions and if we could sacrifice ecological and systematic beauty because of creating visual beauty!
We as architects by selecting each material for buildings create economic potential for that industry and for the same reason we promote these industries, of course if we could entitle them "industry", and therefore we should ponder in their effects in micro and macro scale in all aspects until avoiding unintentionally providing the brick kiln with fuel!

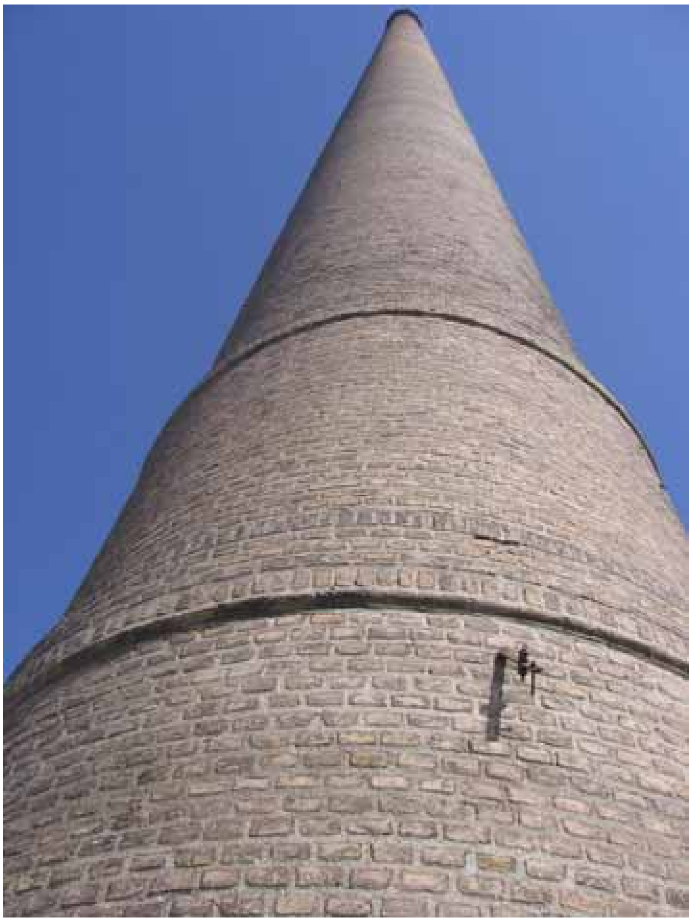

Figure 8, traditional brick kiln's tower

Consuming or devouring the fossil fuel

The entire industry sector in iran consumes approximately 21% of energy in quantities which means 15% in value that means 3.7 billion dollar. Brick industry use more than 5.4% of this amount consisting of 7000 thousand active and major brick kilns which they produce 50 million tones brick annually and nearly they burn 4 billion liters of oil. Fuel consumption in Iran's brick kilns based on theirs technology and oldness is about 1000-2000 Kcal/Kg which in comparison to international standard norms 400-600 Kcal/Kg is reluctantly high.

Table 1, comparison of fuel consumption in Brick industries

Country	Fuel consumption, MJ/Kg
Belgium	1.94
Germany	1.73
Denmark	2.16
Spain	2.14
France	2.29
Greek	2.1
Italy	2.11
Ireland	2.15
Netherlands	2.45
Portugal	2.55
England	2.70
Iran	6

Figure 9, bricks are dying under sun

Brick or terminator

Deficiencies of using brick based system of construction in building

Façade:

Heavy weight of façade because of the necessity of furnishing on brick due to low quality
Fragile cohesion of brick wall and furnishing stone
Inefficient isolation
Conducting of humidity
Potential danger in earthquake
Collapsing the stone furnishing onto the street due to weight and low cohesion
Using incongruous materials
Heaviness of structure
Low quality of welding, steel, and cement
Over design the structure due to inherit unpredictable process of brick based system
Lacking of unity between structure, floor and wall
Complexity and plurality of details
Lacking skillful worker in welding
Lacking proper welding machine
Lacking knowledge of welding
Inefficient design of joints
Designing the structure as definite
Neglecting the standard distance of two building
Lack of knowledge and expert for isolation

Lack of proper technology and materials due to sanction
Localization of isolation resulting to inappropriate and unscientific product
Increasing the whole weight due to exploiting inappropriate materials
Decreasing useful surface of building
Dependency to foreign market
Increasing the total cost of building but not very effective reduce in energy loss

Figure10, Bam earthquake killed 40000

Figure11,Bam earthquake killed 40000, fragility of Brick-based building

Figure12, Bam earthquake killed 40000, Bricks are falling down

Waste including broken brick
Increasing the cost because of necessity of additional furnishing for façade
Increasing the weight of structure
Necessity of financial aid to reduce the price
Creating seasonal work
Increasing the potential for non productive work

Standard bricks or brick's standards

Selecting brick for building cause to promoting this so-called industry to a wider range of economy possibilities and this would increase the number of brick kiln which would be resulted to more economic and socio-cultural problems. Being standard in traditional point of view does not necessarily means being standard in production process, quality of work place, quality in work force and last but not least in its aftereffects in micro and macro scale

Figure 13, low-tech modern brick kiln

Who is the decision-maker?
As we know that any recommendation that any recommendation associated with using brick for buildings creates motivation and strong economical potential to establish more brick plants and this ultimately leads to more social, economical and cultural complexities. So the best solution is to "prevention" in this way the target group is building sector including architects, civil engineers, contractors and decision makers who can decrease demand for brick effectively so I propose establishing "*Archanalysis*" which performs comparative study about complexities of the cities in the Middle East and analyzes the changes in these regions and provides solutions in the field of brick usage for architects and encourages them to use other construction systems that use more modern technologies and form small construction sites. In these solutions other systems are substituted, the systems which consider technical and productive services, export of services and training specialist forces so that single-product economy based on oil can be discarded. In this way we can control demand of brick by making building sector aware of the importance of their decision and help them to promote much sustainable system of construction.

Conclusion

Architectural problems are extremely complex, multilayer and nonlinear. It's impossible to solve them with linear equations, however, one of the property of these systems are their butterfly effect rules, with exerting a little force the system would be influenced dramatically, so to analyzes the very systems we should search to find these critical points so that to achieve a great extent of results with the minimum change in the whole system. In Iran, because a lot of things but due to some excuses such as national pride, nostalgia, Islamic architecture, identity. We try to use brick as much as possible. It means more dependency to brick-base system and industry and always with this nostalgia we celebrate our triumph while, destroying from inside, exactly, like Trojan myth. What we called triumph and reputation which should serve us with honor in the world was nothing but destroying brutal dreadful enemy that called Brick so I propose the theory of "Brick is Crime" as bellow:

Brick based system of construction in last century in Iran was the worst with the most undesirable aftereffect on environment, society, economy, culture, in macro and micro scale thus it can be said that brick is the Trojan horse of contemporary Iran's architecture.

Figure 14, children are the innocent victims of brick kiln's battle field

PROGRAMMING OF BASE BUILDING SIZE IN SUPPORT OF OPEN EDUCATION ELEMENTARY SCHOOLS IN TAIWAN – A KNOWLEDGE MANAGEMENT APPROACH

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Keywords: open building, open education, elementary school, building size, building programming

Summary

A School's educational pedagogy needs to be supported by its buildings. To better support Taiwan's elementary schools of Open Education, a space program based on Open Building that can accommodate the desired Infill changes was proposed in the past. Though the defined Infill capacity of the program has been demonstrated to be effective in terms of education support and building management, its effectiveness is still bounded by the physical structure of the Base Building. Therefore, how to program the physical size of the Base Building that allows the defined Infill capacity to be brought into play effectively becomes one of the critical aspects of the total effectiveness of the space program. Based on Knowledge Management theory on realizing better value of current knowledge objects and knowledge to create better effectiveness and returns, this paper reviews and evaluates past school building size related research and investigation results, sets the program goal to be users needs fulfillment, and proposes a size program of the Base Building that can accommodates the defined Infill capacity mentioned above. By providing a space program that integrates the size of the Base Building with the most desired capacity of the Infill, an Open Education elementary school in Taiwan can be better supported by its buildings.

1. Introduction

A school's buildings need to support the educational pedagogy of the school. In 1996, the first public elementary school based on Open Education pedagogy formally enrolled students in Taiwan (Shiue 2003). Since then, this type of elementary school has become the predominate type for new public elementary schools in Taiwan. Comparing to traditional teaching practice of "Lecturing", Open Education encourages students to learn in many different ways, modes, and/or groupings freely. Teaching/learning practice can be many forms other than traditional "Lecturing" and the role of a teacher is not lecturing but learning facilitating. In responding to the space needs of the educational practices of Open Education, a "Clustered Classrooms and a Multipurpose Space" method was devised to program and design the needed teaching and learning space (Fig. 1). However, this method has an inherent critical drawback, i.e. it may lose its support to Open Education due to enrollment changes (Wang 2005).

To a school, one critical issue of administration is to maintain the school's educational practices when the number of students enrolled changes. The number of classrooms needed and the assignment of classrooms to each grade, division, or department are affected not only by the total enrollment of the school but also by the enrollment total of each grade, division, or department. To be sustainable, a school's buildings need to support the school's administration to maintain its educational practices. Therefore, how to accommodate the enrollment changes and facilitate school buildings to support the pedagogy of Open Education becomes a part of the sustainable issues in school building programming and design for an Open Education public elementary school.

To resolve above said drawback of the "Clustered Classrooms and a Multipurpose Space" method and to make an Open Education public elementary school in Taiwan more sustainable, Wang (2005) took Open Building approach and proposed that an Open Education public elementary school can be better supported if a cluster unit of the "Clustered Classrooms and a Multipurpose Space" can accommodate Infill possibility of three and four classes. However, according to Open Building, the proposed three and four classes Infill capacity is still bounded by the physical size of the Base Building since the Base Building's size will be fixed once it is built. Therefore, programming the size of the Base Building of a cluster unit of the "Clustered Classrooms and a Multipurpose Space" that is neither insufficient nor a waste to support the two different Infill becomes a necessary endeavor to the sustainability and success of an Open Education public elementary school's buildings in support of Open Education. Based on Knowledge Management theory, this paper reviews and evaluates past school building size related research and investigation results and proposes a Base Building size of a cluster unit that can accommodates the defined Infill capacity mentioned above. By providing a space program that integrates the size of the Base Building with the desired capacity of the Infill, an Open Education public elementary school in Taiwan can be better supported by its buildings.

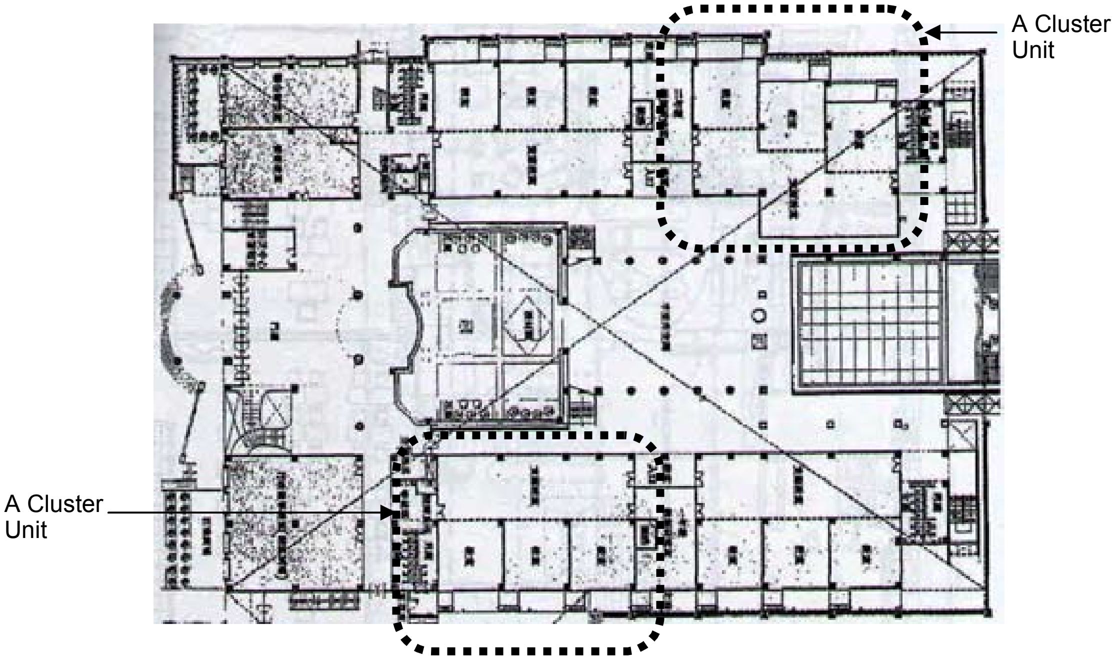

Figure 1 An Example of "Clustered Classrooms and a Multipurpose Space" Design

2. Base Building of Open Building

Open Building responds to the changes of building uses and functions (Kendall 1999). Open Building separates a building into two levels: the Base Building level and the Infill level to provide built-in capacity for changes of uses and functions and to reduce environmental impacts caused by construction for changes.

For an Open Education public elementary school, though the built-in capacity of the Infill of a cluster unit of the "Clustered Classrooms and a Multipurpose Space" has been proposed to comprise only three-class and four-class variations (Wang 2005), the Base Building of the cluster unit, once built, will be fixed in size with very limited potential for changes. Hence, in terms of sustainability of resources, the size of the Base Building of a cluster unit should provide satisfactory space for both three-class and four-class situations without causing inconvenience due to insufficient space and waste due to excessive space. For a cluster unit, the size effect of Base Building in terms of sustainability is shown in Fig. 2.

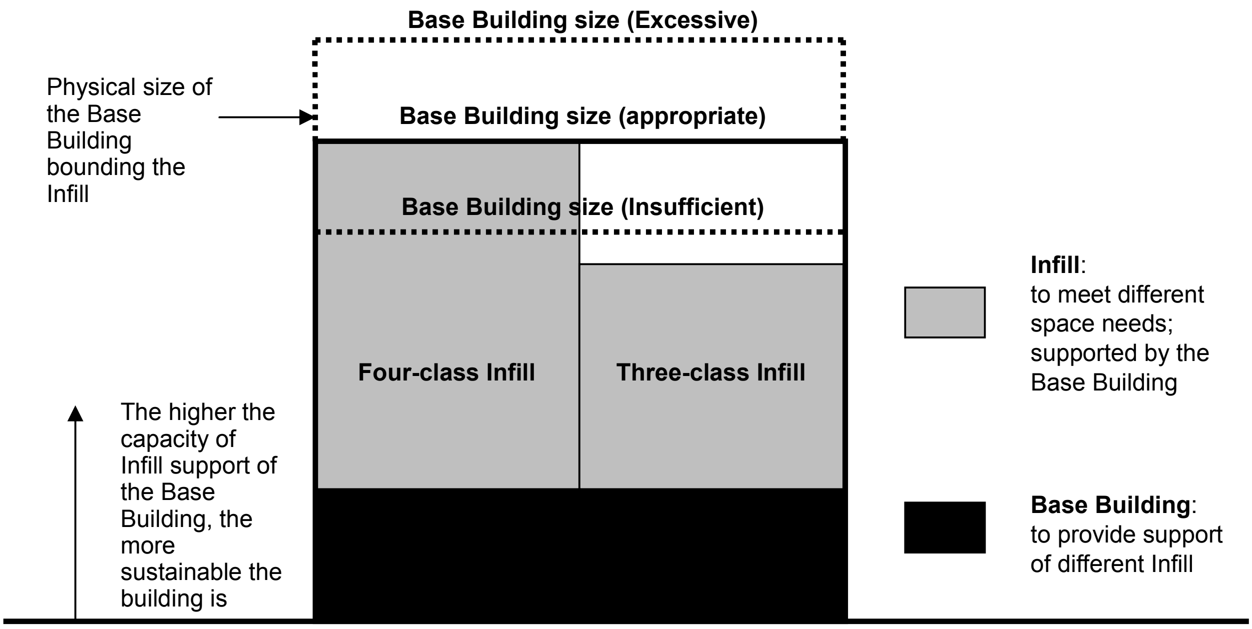

Figure 2 Base Building Size Effect in Terms of Sustainability

3. Knowledge Management

In recent years, in order to improve competitiveness and succeed, knowledge management has become an important tool for individuals, organizations, and nations. The main objective of knowledge management is to realize the best value of knowledge objects and knowledge to create maximum effectiveness and returns (Wiig 1997). Knowledge management has two levels: the object level and the management level. The object level deals with the knowledge item, element, unit or data to be managed and the management level is the management activity itself. To be effective, knowledge management needs to preset its management goals.

Basically, the management level of knowledge management is a cyclic and dynamic process. It can be divided into four stages: Review, Conceptualize, Reflect, and Act (Wiig et al. 1997, Wielinga et al. 1997). Review examines what knowledge objects and knowledge exist and what has been achieved. The outcome of the Review stage is the evaluation results, which provides the foundation for the Conceptualize stage. Based on the evaluation results of the Review stage, the Conceptualize stage constructs a conceptual framework tailored to the preset knowledge management goals and tries to create the most possible value out of existing knowledge objects and achieved knowledge. Following the Conceptualize stage, the Reflect stage is to set up a plan for improvement. This plan for improvement needs also to satisfy the preset management goals. The Act stage is the execution of the plan for improvement. It implements plans set up in the Reflect stage and creates a new state of knowledge objects and knowledge.

A model of the management process adapted from Wielinga et al. (1997) and Wiig et al. (1997) is depicted in Fig. 3. This model shows the sequential relationship of the four activities of the knowledge management process, the position of the outcome of each of the four activities and the cyclic and dynamic nature of the process.

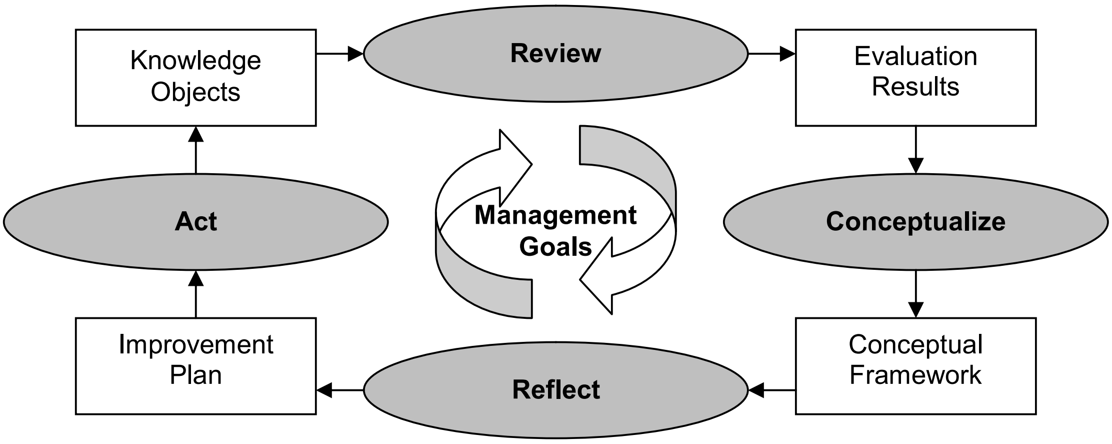

Figure 3 Knowledge Management Process Model

4. Management Goals and Review

Since the size of the Base Building of a cluster unit of the "Clustered Classrooms and a Multipurpose Space" of an Open Education public elementary school should provide satisfactory space for both three-class and four-class Infill without causing inconvenience due to insufficient space and waste due to excessive space, this research sets the management goal of programming the Base Building size of a cluster unit of the "Clustered Classrooms and a Multipurpose Space" to providing enough space as perceived by students and teachers. The reason is straightforward. Students and teachers are the real users of the teaching and learning space. Their perception of the size of the teaching and learning space to daily educational practices is the most direct and first-handed and should be taken into account seriously in building programming and design.

In the past, there were some standards and studies regarding the classroom size of elementary schools (Ministry of Education 1981, Kao 1992, Huang et al. 1998, Lo 2000). However, most of these standards and studies were for non-Open Education schools and the focuses of these standards and studies were either on investigation of existing classroom sizes or providing standards for school administration to use without sound reasoning and further explanations. Table 1 shows the data and results of these standards and studies.

Table 1 Data and Results on Classroom Size Standards and Studies

Sources	Educational Pedagogy Based	Average Classroom Size (unit: m^2/student)	Remarks
Ministry of Education (1981)	Non-Open Education	1.26	Minimum Required Standard
Kao (1992)	Non-Open Education	1.57, 1.48	Investigation Existing (each for one school)
Huang et al. (1998)	Non-Open Education	2.39	Investigation Existing (112 "old" schools)
Huang et al. (1998)	Non-Open Education	2.76	Investigation Existing (11 "new" schools)
Huang et al. (1998)	Open Education	2.04 (for classroom area) 2.11 (for multipurpose area)	Investigation Existing (four schools)
Lo (2000)	Non-Open Education	2.50	Suggested Standard

Furthermore, there was a research showed the results of a study of space adequacy of general classroom as perceived by students and teachers (Chen et al. 2005). Though this study was not on space adequacy of a cluster unit of the "Clustered Classrooms and a Multipurpose Space" of an Open Education public elementary school as perceived by students and teachers, nevertheless, from the points of view of Knowledge Management, the results of this study plus the data and results shown in Table 1 are the existing knowledge objects and knowledge on the subject under research and need to be explored and evaluated to realize the best value of these knowledge objects and knowledge to create maximum effectiveness and returns.

The results of Chen et al. (2005) are:

1. For school type I (the number of students per class is equal to or over 19), about 58% students of schools with classroom size below type I suggested 1.92 m^2 per student expressed their dissatisfactions about the classroom space.
2. For school type II (the number of students per class is less than or equal to 18), about 57% students of schools with classroom size above type II suggested 2.50 m^2 per student expressed their satisfactions about the classroom space and 60% students of schools with classroom size above twice of the type II suggested 2.50 m^2 per student (i.e. 5.00 m^2 per student) expressed their satisfactions about the classroom space.
3. For teachers, the highest satisfaction occurred at schools with classroom sizes in the range of 1.92-3.84 m^2 per student. The less satisfaction of schools with classroom sizes over 3.84 m^2 per student may due to the increased difficulty and tasks in classroom management and administration to teachers.

Based on above and Table 1, the following evaluation results can be concluded:

1. The classroom size of non-Open Education elementary schools seems to be bigger for newer schools. However, the size of classroom still varies among newer schools. Some are smaller and some are bigger.
2. From Huang et al. (1998) and Fig. 1, for Open Education school building based on "Clustered Classrooms and a Multipurpose Space", the size of a cluster unit of the "Clustered Classrooms and a Multipurpose Space" is about twice the size of the classroom area of this unit.
3. For students, though smaller classroom size is perceived as less satisfactory and bigger classroom size is perceived as more satisfactory, it does not necessarily mean that if the classroom size gets bigger and bigger, it will be perceived as more and more satisfactory accordingly. Actually, from the results of school type II, the percentages of students satisfied with their classroom sizes show no significant difference between schools with classroom size above type II suggested 2.50 m^2 per student and schools with classroom size above twice of the type II suggested 2.50 m^2 per student (i.e. 5.00 m^2 per student). Therefore, it seems that, once the classroom size reaches a certain level, it will not change students' perception about the space adequacy significantly as it grows. Therefore, it can be

conservatively concluded that if the classroom size is over 2.50 m^2 per student, students will perceive the space as satisfactory.

4. For teachers, it seems that the classroom sizes of 1.92-3.84 m^2 per student is the most appropriate. Classroom size that is bigger than 3.84 m^2 per student is not so satisfactory to teachers.

5. Conceptualize and Reflect

Since the knowledge management goal of this study is set to providing enough space as perceived by students and teachers, therefore, the classroom size should be perceived as satisfactory by both the students and teachers. Based on above evaluation results, it can be reasonably concluded that if the classroom size is located in the range of 2.50 m^2 per student (lower-bound perceived by students) to 3.84 m^2 per student (upper-bound perceived by teachers) should satisfy both the students and teachers at the same time the most. With this information in hand, the Base Building size of a cluster unit of the "Clustered Classrooms and a Multipurpose Space" of an Open Education public elementary school that can accommodate Infill possibility of three and four classes can be programmed as follows:

1. If the number of students per class is set to 30, then a cluster unit of the "Clustered Classrooms and a Multipurpose Space" that can accommodate Infill capacity of three and four classes needs to provide satisfactory space as perceived by 61 (the minimum number of students for three classes) to 120 students and their teachers.
2. If 3.84 m^2 per student is the upper-bound classroom space perceived as satisfactory by teachers, then 3.84 m^2 per student times 61 students equals to 234.24 m^2.
3. If 2.50 m^2 per student is the lower-bound classroom space perceived as satisfactory by students, then 2.50 m^2 per student times 120 students equals to 300 m^2.
4. Since 234.24 m^2 is smaller than 300 m^2, it is more appropriate to chose 300 m^2 as the programmed size for the classroom area of a cluster unit of the "Clustered Classrooms and a Multipurpose Space". The reason can be explained by fig. 4.

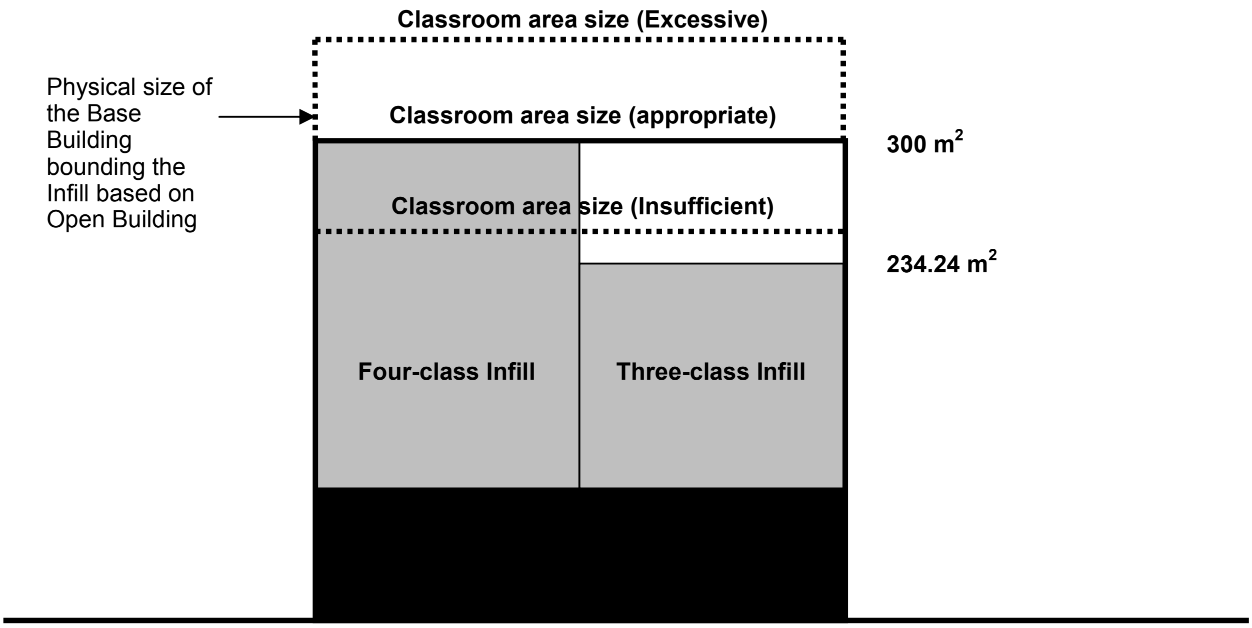

Figure 4 Selections of the Programmed Classroom Area Size of a Cluster Unit

5. Since the size of a cluster unit of the "Clustered Classrooms and a Multipurpose Space" is about twice the size of the classroom area of this unit, the Base Building size of a cluster unit of the "Clustered Classrooms and a Multipurpose Space" can be programmed as 600 m^2 to provide satisfactory space as perceived by students and teachers of three and four classes with 30 students per class.
6. For the number of students per class other than 30, the same procedure 1 to 5 above can be applied to reach the programmed Base Building size of a cluster unit of the "Clustered Classrooms and a Multipurpose Space" for that number of students per class.

6. Conclusion

To an Open Education public elementary school based on the "Clustered Classrooms and a Multipurpose Space" method, the support of its buildings to Open Education needs to be secured as much as possible. Based on Open Building, the programming and design method of "Clustered Classrooms and a Multipurpose Space" can be improved to secure its support to Open Education when student enrollment changes by providing an Infill capacity of three and four classes per cluster unit and by programming a satisfactory Base Building size of a cluster unit as perceived by students and teachers. For an Open Education public elementary school with 30 students per class, the Base Building size of a cluster unit of the "Clustered Classrooms and a Multipurpose Space" is suggested to be 600 m^2 by this research . Though this research is not direct on space adequacy of the Base Building size of a cluster unit as perceived by students and teachers, based on Knowledge Management, the results of this research is valuable for it is concluded by realizing the best value of current knowledge objects and knowledge on classroom size to create the maximum effectiveness and returns of these knowledge objects and knowledge.

Combining with the three and four classes Infill capacity, the proposed Base Building size of a cluster unit is a step further towards sustainability of an Open Education public elementary school based on the "Clustered Classrooms and a Multipurpose Space" method in Taiwan. It takes building sustainability beyond the physical structure and construction of a building itself and integrates the sustainability of educational practices and school's administration in support of education. However, this proposal is still just an advanced step in pursuing sustainability of school buildings. There are other issues need to be studied to better support Open Education such as how to program and design the subsystems of the cluster unit and what the Infill system could be. In addition, the result of this study is based on Knowledge Management, it needs to be implemented and studied to create new knowledge objects to deepen our knowledge on school buildings in support of education and to bring our knowledge on Base Building size in support of Open Education public element schools to the next state.

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SEROEPIDEMIOLOGIC STUDY OF VECTOR-BORNE DISEASES AT THE ARCHILIFE SYMBIOSPHERE I CENTER (ASIC) IN FULONG VILLAGE, TAIWAN

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Keywords: seroepidemiologic, vector-borne, disease, Archilife Symbiosphere I Center, Taiwan

Summary
The GB + Symbiosis = SB has been declared by Archilife Research Foundation (Taiwan) at the SB05 Tokyo. We symbiosis with not only green buildings but also green environment that has been discussed as an important issue previously. With global warming, emerging and reemerging infectious diseases are becoming more serious. To understand the risk and prevalence of vector-borne diseases in a symbiotic environment, rodent serums were analyzed for scrub typhus infection. This study retrospectively analyzed rodent serum collected from January 2005 to December 2007 in the main airports and seaports in Taiwan. By using an enzyme-link immunosorbent assay (ELISA), the sero-prevalence rates of scrub typhus in rodents were found to be 9.48%, 16.41%, and 18.08% in 2005, 2006, and 2007, respectively. Sites with the highest sero-prevalence rates were Su-Ao harbor (northern Taiwan), Mai-Liao harbor (centeral Taiwan), Kaohsiung airport (southern Taiwan), Hualien harbor (eastern Taiwan), and Shuei-tou harbor (an island separate from Taiwan). The Archilife Symbiosphere I Center (ASIC), located in Fulong Village, is near Keelong harbor, Ba-Dou-Zih fishing port, and Su-Ao harbor. The sero-prevalence rate of scrub typhus from 2006 to 2007, however, was 3.12% near ASIC in FuLong Village. This preliminary serologic data from wild rats points out the potential risk from ectoparasites on wild animals in Fulong Village. It will be important to conduct further research that focuses on the management of symbiotic resources and elimination of invading rodents in the local environment.

1. Introduction
There is a scientific consensus that the global climate is changing, with rising surface temperatures sea levels, melting ice and snow, and increasing climate variability. These changes are expected to have substantial impacts on human health, such as vector-bone infectious diseases. Scrub typhus is a mite-borne infectious disease caused by *Orientia tsutsugamushi* (Tamura et al. 1995). This disease distributed throughout the Asian Pacific rim and is endemic in South Korea, China, Taiwan, Japan, Pakistan, India, Thailand, Malaysia, and northern Australia (Fan et al. 1987, Currie et al. 1993, Yi et al. 1993, Strickman et al. 1994, Chang 1995, Horinouchi et al. 1997). Approximately one million cases occur each year, and more than a billion people are at risk worldwide (Rosenberg 1997, Watt et al. 2000). Taiwan has been endemic for scrub typhus for many decades (Ho 1998, Lee et al. 2006, Wang et al. 2007). The major trombiculid mite of this disease in Taiwan is *Leptotrombidium deliense*. Humans may get sick and have a characteristic skin lesion, known as an eschar, when they enter these areas or are bitten by infected mites. In past studies, scrub typhus was mostly focused on islands apart from Taiwan, such as Kinmen, Lanyu, and Green Island. Surveillance data of scrub typhus from northern Taiwan is limited. Rodents play a key role in the epidemiology of scrub typhus because they serve as maintenance hosts for the vector mites (Philip 1980). Many animals that serve as hosts for chiggers have been implicated as the

natural reservoirs of scrub typhus, such as *Apodemus agrarius*, *Microtus fortis*, *Rattus flavipectus, R. norvegicus, R. rattus, Suncus murinus*, and bats (Jo et al. 1990, Ree 1990, Ree et al. 1991, Lee and Lee 1992, Wang et al. 2004). A serologic survey in rodents performed in 1986-1987 by Lee and others recorded the seropositive rates of the house mouse (5%), *A. agrarius* (58.9%), and *Microtus* spp. (77.7%) (Lee et al. 1989). In Taiwan, higher seropositive rates were also recorded in *Rattus flavipectus* (89.0%), *R. norvegicus* (46.0%), *R. rattus* (80.0%), and *Suncus murinus* (24.0%) in Kinmen County from 1999 to 2000 (Wang et al. 2004).

The Archilife Symbiosphere I Center (ASIC) has semi-open construction. The center has a number of novel designs, including a vertical planting system, dry toilets, a residual food composting system, and a biological greywater recycling system (Su et al. 2002). People living or farming there face many kinds of arthropods, such as mosquitoes, flies, beetles, moths, fleas, mites, ticks, lice, and predator spiders (Tsai 2003). Except for the assault of mosquitoes bites, ectoparasites of small animals are the major vectors (Tsai 2002, Tsai et al. 2005). Moreover, many wild rodents from the local environment are found to be infected by fleas, mites and ticks. With the increase of vegetation and ecological activities, people will be harmed by these small arthropods unless attention is paid to the problem. In this study, we evaluated sero-prevalence rates of scrub typhus in rodents mainly from airports and seaports around Taiwan. The sero-prevalence of scrub typhus in rodents near ASIC was also calculated.

2. Materials and Methods

2.1 Ectoparasites collection and DNA extraction

From January 2005 to December 2007, serums were collected from wild rodents in 13 locations, including airports and seaports around Taiwan (Table 1): Keelong harbor, Ba-Dou-Zih fishing port, Taoyuan airport, and Su-Ao harbor in northern Taiwan; Taichung harbor, and Mai-Liao harbor in central Taiwan; Pingtung fishing port, Kaohsiung seaport, and Kaohsiung airport in southern Taiwan; Hualien harbor in eastern Taiwan; Shuei-tou harbor, Liao-luo bay, and Fu-wo harbor on islands apart from Taiwan. From January 2006 to December 2007, serums were collected from wild rodents at Fulong Village in Taiwan.

2.2 Enzyme-link Immunosorbent Assay (ELISA)

Enzyme-link immunosorbent assays were modified from our previous study (Shu et al. 2002). The whole cell antigen was replaced by a 56-kDa recombinant antigen. Positive and negative samples were randomly confirmed by immumofluorescence assay (IFA).

3. Results

Between 2005 and 2007, a total of 1,494 rodents were collected (Table 1). By using ELISA, sero-prevalence rates of scrub typhus in rodents were found to be 9.48%, 16.41%, and 18.08% in 2005, 2006, and 2007, respectively. Sites with the highest sero-prevalence rates were Su-Ao harbor (northern Taiwan), Mai-Liao harbor (central Taiwan), Kaohsiung airport (southern Taiwan), Hualien harbor (eastern Taiwan), and Shuei-tou harbor (a island apart from Taiwan (Table 1). The number of positive rodents was recorded monthly, in particular during June and July 2006 (Figure 1). The dynamics of sero-prevalence rates shows an increase in positive rates from 2005 to 2007 (Figure 2). The sero-prevalence rate of scrub typhus from 2006 to 2007 in ASIC was 3.12% (Table 2).

Table 1 Serological diagnosis of *O. tsutsugamushi* infection in wild rodents in Taiwan

		Positive rate % (No. positive/No. collection)		
Sites of Taiwan	Locations	2005	2006	2007
Northern	Keelong harbor	2.38 (1/42)	26.32 (10/38)	0 (0/28)
	Ba-Dou-Zih fishing port	13.64 (3/22)	4.00 (1/25)	0 (0/0)
	Taoyuan airport	0 (0/31)	1.41 (1/71)	1.23 (1/81)
	Su-Ao harbor	13.16 (5/38)	5.13 (2/39)	25.53 (12/51)
Central	Taichung harbor	10.26 (4/39)	5.00 (2/40)	3.23 (1/31)
	Mai-Liao harbor	9.18 (9/98)	7.69 (5/65)	6.67 (3/45)
Southern	Pingtung fishing port	7.14 (2/28)	12.50 (2/16)	0 (0/0)
	Kaohsiung seaport	9.33 (7/75)	18.18 (10/55)	19.12 (13/68)
	Kaohsiung airport	3.77 (2/53)	6.25 (2/32)	57.14 (8/14)
Eastern	Hualien harbor	0 (0/9)	33.33 (2/6)	0 (0/15)
Apart Islands	Shuei-tou harbor	23.81 (5/21)	52.46 (32/61)	62.22 (28/45)
	Liao-luo bay	20.75 (11/53)	33.33 (12/36)	29.73 (11/37)
	Fu-wo harbor	5.56 (1/18)	13.04 (6/46)	9.09 (2/22)
Total		9.48 (50/527)	16.41 (87/530)	18.08 (79/437)

Table 2 Serological diagnosis of *O. tsutsugamushi* infection in rodents around the Archilife Symbiosphere I Center (ASIC), located in northern Taiwan (2006-2007)

Locations	Rodent spp.	No.	No. positive	Positive rate (%)
Long-Long riverside	*R. norvegicus*	4	1	25.00
Planting area	*R. norvegicus*	2	1	50.00
	S. murinus	1	0	0
Fu-Long rail station	*R. ratus*	2	0	0
Lunch box Store	*R. norvegicus*	14	1	7.14
	S. murinus	4	0	0
Long-Long mountain corridor	*R. norvegicus*	4	0	0
	S. murinus	1	0	0
Total		32	3	9.38

4. Discussion

This is the first detection of scrub typhus in wild rodents by serological study in northern Taiwan. The seropositive rate in rodent collected around ASIC is observed. Recently, mite-borne rickettsioses have been diagnosed in local residents from the local hospital (data unpublished). Higher peaks of mite index and scrub typhus cases reported consistently appealed in May to July and November to January in different locations in Taiwan (Wang et al. 2004, Lee et al. 2006). During these seasons, the weather is suitable for outdoor activities. With the increase in ecological activities, infectious diseases such as scrub typhus have raised concerns regarding vector-borne diseases on grasslands. This preliminary study of vector-borne diseases points out the potential risk from ectoparasites on wild animals in Fulong Village. When performing activities or farming in that ecosystem, people should be alerted to the possibility of bites by mites. Reducing the risk of infection by the application of repellents to skin and clothes, avoiding contact with overgrown grass and brush, and wearing long pants, long sleeves, and long socks should be advised as well (Lee et al. 2006). It will be important to conduct further research that focuses on the immune-response activated by these pathogens in local residents. It will be important to conduct further research that focuses on the management of symbiotic resources and elimination of invading rodents in the local environment.

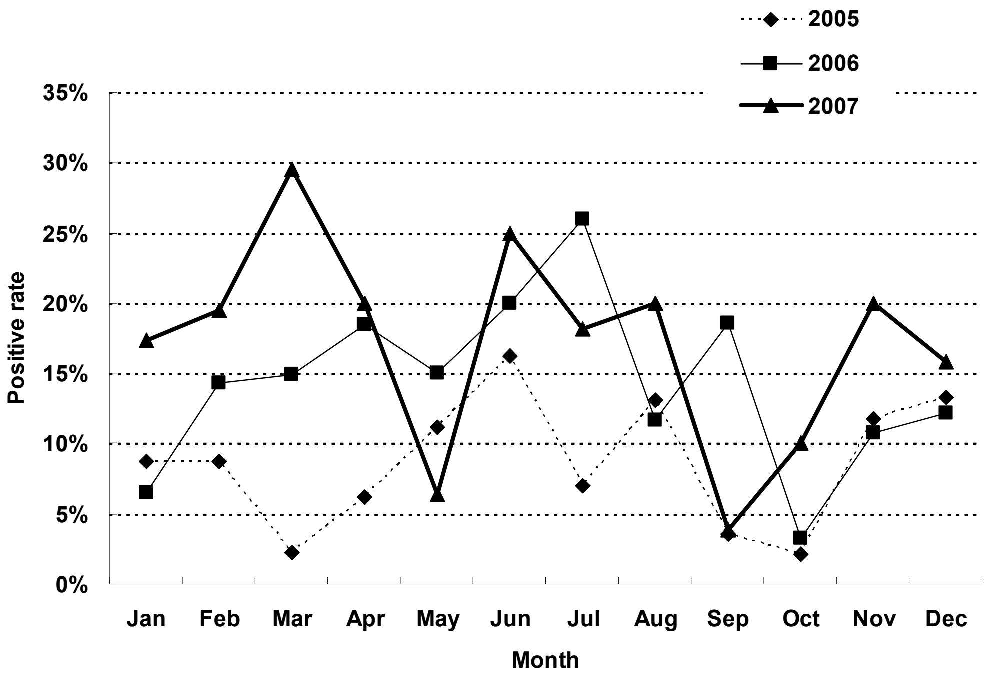

Figure 1 Sero-positive number of *Orientia tsutsugamushi* infection in wild rodents in Taiwan (2005-2007)

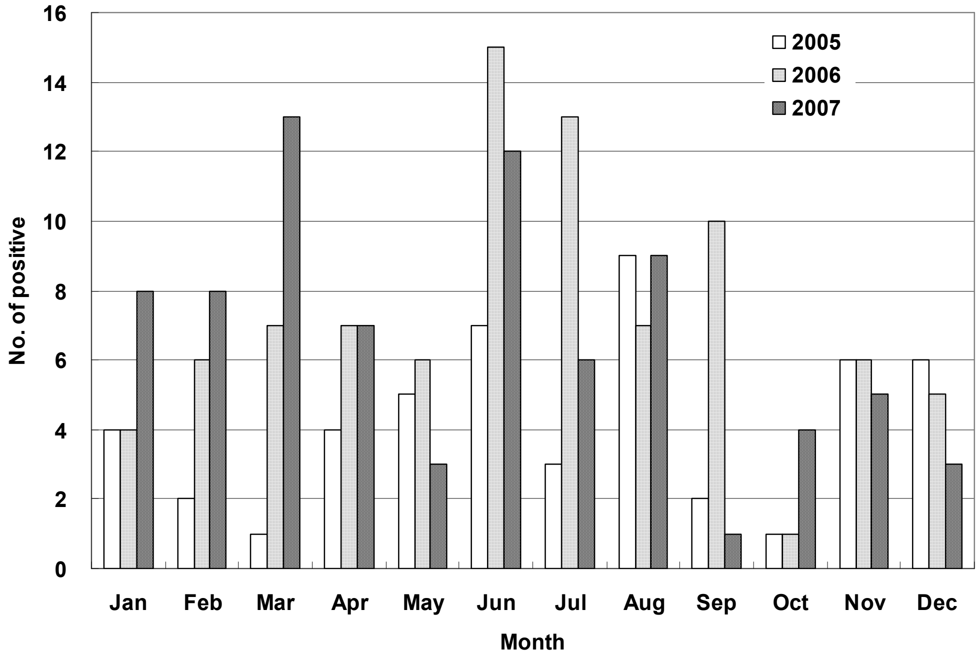

Figure 2 Sero-positive rate of *Orientia tsutsugamushi* infection in wild rodents in Taiwan (2005-2007)

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TEN YEARS OF SUSTAINABLE CONSTRUCTION – PERSPECTIVES FROM A NORTH CONSTRUCTION MANAGER AND A SOUTH ARCHITECT POINT OF VIEW

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Keywords: sustainable construction, conferences, differences, North and South perspectives

Summary

This paper is about, from a North and South different perspective, how the international focus of sustainable construction issues has changed over the past ten years. The north part is a review from four different international and regional sustainable building conferences between 1998 and 2007,mostly based of the first author's notes from the conferences, especially from the plenary sessions and discussions. The reviewed conferences are GBC98 in Vancouver, Canada 1998, SB02 in Oslo, Norway 2002, SB05 in Tokyo, Japan 2005 and the regional conference SB07 in Malmö, Sweden 2007. The south part is based on literature reviews, research findings and reference buildings from Mozambique and Tanzania reflecting sustainability. The perspectives presented in the paper are those of construction project and environmental manager from northern Europe and from architects in southern Africa with an interest in sustainable construction. The findings of the paper shows that focus of sustainable construction matters has changed from almost solely environmental aspects to a more broad and transparent complexity of sustainability, including ecological-, economic- social- esthetical- and cultural aspects. It also reflects regional and national differences and some shifting views of focus about sustainability in the construction sector during the past ten years.

1. Introduction

Sustainable development is a subject that has been of increasing interest by the global community the last two decades. The construction sector has adapted this by introducing the concept of sustainable construction. However, the adaptation depends of the level of the sustainability view, global, national, regional or individual level. It also depends of the cultural and social context of the actual society. For example many of the modern buildings and settlements in developing countries reflect an uncritical reception of modern European buildings form without taking into consideration the special climatic and social conditions of the home country. The aim is to make some reflexions of these differences from a North and South perspective through engineers and architects eyes respectively.

The first section, the North perspective, is about how the international (read North) focus of sustainable construction issues has changed over the last ten years by a review from four different international and regional sustainable building conferences between 1998 and 2007. This section is mostly based of the first author's notes from the conferences, especially from the plenary sessions and discussions, but some contributions are also considered and selected from breakout sessions and from the proceedings. The reviewed conferences are GBC98 in Vancouver, Canada 1998, SB02 in Oslo, Norway 2002, SB05 in Tokyo, Japan 2005 and the regional conference SB07 in Malmö, Sweden 2007. The reviewing perspective is a engineer by a project and environmental manager.

The architecture in Mozambique and Tanzania, like in many other developing countries, shows little concern for the local environment and climate. The South perspective exams the contribution architects have made towards sustainable architectural practice for the last ten years in Mozambique and Tanzania. Key information is derived from literature review, existing documents, observation, interviews and experience. The section focuses mainly on the analysis of traditional and modern/contemporary architecture in Mozambique and Tanzania with the aim of understanding the attempts that architects have made in the search for sustainable architecture in the tropical countries. This perspective is by architects with southern Africa matter of sustainable construction

2. The North Perspective

2.1 GBC98, Vancouver, Canada

The aim of the Green Building Challenge Conference in Vancouver, Canada, 1998, was to benchmark Green Buildings with different design and assessment tools of current and next generation. Many design and assessment methods were presented by the participated designers and researchers, e.g. among others: GBC98 Tool (international), Athena (Canada), BEES (USA), HK-BEAM (Hong Kong), C2000 (Canada), BREEAM (UK), EcoQuantuum (The Nederlands), Home Scheme (New Zeeland), Ekoprofil (Norway), LEED (USA), Green Building Adviser (USA), CAAD (Germany), Building Stock Model (Germany) etc. The keys of most of these tools were to minimize energy demand during construction and operation, to optimize energy use integrated with renewable energy and to maximize living and working quality for occupants. To ensure the data quality of the inputs was the most frequent issue about to use these tools. Other comments of the tools regarding usefulness was too much information, too much criteria, too many choices and too little time to assess. Two examples of contributions were:

- A test of different assessment tools (Boonstra et al 1998) on the same building showing the output data was too differentiated to be comparable between the methods and an optimization of data not a goal for most tools. Most of the tested tools were developed for specialized consultants and not for actors in the market
- The introducing of the international GBC98 Tool (Cole and Larsson 1998) developed to assess different buildings in different countries with the same tool.

The general conclusions of the assessment methods were about to recognize differences between the tools and the sites of assessments and differences between local and global conditions. But it was important on the other hand to maintain the big picture by the methods

The conference was mainly a presentation of pros and cons of “second generation” tools where the design methods were looking forward and the assessment methods were looking backwards. The main opinion of the future was to develop more LCA-based methods or applications. Absence of methods or tools that covered the construction process was obvious. Most of the methods and the contributions were about Green Buildings and environmental issues, only a very few regarded the whole triple bottom line of sustainability, balancing economy and social development with ecological considerations.

2.2 SB02, Oslo, Norway

The introducing theme of SB02 in Oslo, Norway, was about the -02 World Summit and issues of economic growth, natural resources, environmental impacts, social and cultural development. It was about the challenge of sustainability with prioritized key issues as:

1. Objectives of sustainable development – find reordering of global priorities
2. Sustainability – realize the closed system of earth, the spaceship view
3. Eco-efficiency – Factor 4 is a minimum, Factor 10 is a vision
4. Ratification of the Kyoto Protocol

The knowledge has to shift from a deductive view to a holistic view. The technologic knowledge is dominated over the socio-related. It has to be an integrated design process. The Building Industry is rather proactive than active and the feedback from the performance stage is very low. The solution has to be in small steps with ISO 14001 significant environmental aspects. It is important with affordable living in a market driven environment.

Presentations were made of assessment and design tools that were developed by Europe and North America countries. Some of them were already evaluated and commercial available as national applications as LEED in USA and BREAM in UK. The methods were environmental oriented with most focus on energy savings. It occurred frequently a lot of confusing interpretation of the terms sustainable construction, sustainable building, environmental sustainable building and green building. One effort of explaining the differences between these terms was by CIB´s Agenda 21 of Sustainable Construction. New parts of the world were introduced by the Developing Countries Agenda 21 (du Plessis 2002) with South Africa and Brazil in the frontline. There was also a couple of construction process oriented contributions from Australia, Finland and South Africa. Discussions of indicators of sustainable construction was made e.g. by the CRISP project (Häkkinen et al 2002)

This conference focused mainly on environmental issues as material productivity, CO2 emissions and assessment tools and methods. But some awareness of the rest of the triple bottom line of sustainability was addressed. Two agendas of sustainability in the constructions sector were presented, one general by CIB and one concerning the developing countries. The latter stated a definition of sustainable construction including the triple bottom line and the necessity of a holistic view. New countries as Brazil and South Africa contributed with thoughts about more socio-economics and management focus. Still, the mainstream research community was focused on solely environmental issues.

2.3 SB05, Tokyo, Japan

The latest world conference about sustainable buildings, SB05, was held in Tokyo, Japan, 2005. The introducing theme was about the importance of reducing CO2 emissions, to reduce environmental loads, about eco-efficiency through Factor 4 and Factor 10. Some new approaches were made as Life Cycle Value and Management of Environmental Ethics i.e. sharing common vision and ideas. New issues about ethics, the global aspect and city development were discussed. The conclusion was that sustainability in construction in general was initiated and has become to gain acceptance but it is still a very long way to go. Concerning the broad spectra of sustainability in different economies and regions of the world follows a few examples of contributed presentations and papers:

- Procurement procedures were discussed by Brophy and Lewis (2005) as barriers to sustainable development and sustainable construction. They found the building projects within their study were procured, the scope of sustainability was lacking. The design teams in the study indicated that client commitment, design team commitment, motivation and expertise as the features that most contributed to the achievement of the project targets
- Sustainable – affordable habitat for the rural poor in developing economies by Nair et al, 2005, is depending on socio-cultural, economic, technologic and environmental factors including strategies and policies
- Sustainable construction contains environmental, economic and social values (Yin and Cheng 2005) where local dimensions are significant. Sustainable construction is a long term objective. It should be in account of an early stage of a facility development. This with a management approach and with a focus on procurement methods.

This conference contained more practical issues as procurement procedures, valuating of assessment methods and social housing issues regarding all triple bottom line values. More of management approach was assigned. Again, the mainstream contributions were focused on environmental issues as energy savings and material productivity.

2.4 SB07, Malmö, Sweden

Before the next world conference in Melbourne, Australia, SB08, there were some regional conferences during 2007. One was held in Malmö Sweden as SB07 Malmö or Sustainable City Development -07. The key issue was to demonstrate good examples of sustainable buildings and sustainable development of a city. The concept of Passive Houses and the importance of local sustainable development were highlighted plus the UK housing agenda – the Green Paper. Some lessons were learned, as S-house in Austria – a factor 10 example, but sustainability in the real mainstream project is still invisible. An ethical commitment is essential. From a plenary discussion of how to make sustainability more attractive there were some summarised keywords as liveability, make it easy, initiative, motivate, transparent, local context, lifecycle value and participation.
Following conclusions was made:

- Sustainability not enough – it is necessary to regenerate.
- Reduce consumption – changes in values and lifestyle is also necessary
- A holistic triple bottom view.

Some good practice of green buildings in Scandinavia was demonstrated as progress in sustainability, but the arguments of sustainability contained only environmental issues. Mainstream project is still in the very beginning to adapt a sustainability view.

3 The South Perspective

The history shows that even the greatest monuments and largest civil and religious buildings, the ancient builders designed in harmony with nature (Barr-Kumar 2003). Buildings were designed and oriented to take advantages of prevailing winds, to block excessive solar radiation for the case of tropics and in other climates to face the warming rays of the sun. Tanzania and Mozambique, like many other developing countries, has abundant natural resources like water, sun, and natural building materials. However, the development of Dar es Salaam and Maputo, the major urban centers in these two countries, does not utilize these abundant resources. The emerging architectural development of these countries has to consider more appropriate architecture techniques in order to contribute to the sustainable use of the available natural resources. This can be achieved by considering micro climate, culture, and the economy of the country and the specific geographical area within the country which the building will be located (Yimprayoon 2005). However, the level of environmental sustainability awareness in the construction industry in Tanzania and Mozambique is very low and government environmental policies are yet to be implemented. Awareness about the use of climatic principles of architecture (Tombazis 2005) and their utility in achieving sustainable architecture has to be increased.

3.1 The Colonial Heritage: a Paradigm of Environmentally Sustainable Architecture

Before the German colonial period in Tanzania most buildings were of typical Swahili–Islamic style that featured simple regular plans utilizing mangrove poles for construction. Swahili–Islamic architecture was characterized by the use of an interior courtyard and a deep covered front veranda. Materials used were wooden sticks, mangrove poles, coral hardcore, and clay soil. The German regime adapted traditional construction techniques in an innovative and sophisticated way giving the colonial architecture of Tanzania a unique character and quality.

The "old Boma" built during the German colonial period is an example of architectural environmental sustainability. The Germans used thick coral hardcore, poles and limestone walls of about 600mm to protect interiors from heat gain and also act as noise barrier. The materials and construction technology used were locally available. Windows were mainly placed on the north and south side to allow cross ventilation since air conditioning was not available. The courtyard design was also adopted from traditional Swahili architecture of Dar es Salaam. The use of a courtyard was important to facilitate air flow through a chimney effect. White colour was an essential part of colonial buildings and was used mainly to reflect solar heat.

The German colonialists learned and adopted local building techniques to suit their own purposes. From the pre-colonial and colonial architecture there are clearly lessons to be learned in order to achieve sustainable architecture for Tanzania. The optimal cross ventilation of spaces, shading against sunshine by walls and other shading devices are things that can still be employed in today's architecture (La Roche 2005). Pre-colonial and early colonial architecture is highly instructive.

3.2 Last Ten Years Development

Since the colonial era Tanzania has invested funds to improve its infrastructure, particularly in the area of transportation, urban planning and public buildings (Lauber, 2005). However, most buildings in Dar es Salaam and Maputo in Mozambique show a minimum concern for the micro–climate, economy, and social cultural conditions of the country. In general, in these last ten years we have seen a gradual disappearance of traditional architectural forms as a result of importing the European, American and Asian technology without taking into consideration the special climatic and social condition of the home country. Some cities of these countries such as; Maputo, Beira, Nampula and Nacala in Mozambique; Dar es Salaam, Mwanza, Arusha in Tanzania, did start to construct some buildings using glass materials. These buildings have many air-conditioners which expend a lot of energy for cooling. The extra energy so used would be better used somewhere else.

Some examples:

- The Kilimanjaro (Kempinski) Hotel, facing Dar es Salaam's harbor, was renovated in 2005. The hotel has a perfect orientation for sun protection; east–west, with the long façade facing north–south. During renovation operable windows on the south and north façade were replaced by fixed glass panels, which necessitates the use of an air conditioning system all the time. This increases energy expenditure for maintaining a comfortable temperature in the building, and prevents any use of the cool breezes from the ocean and the south–east monsoon winds.

- A few blocks southwest from the Kilimanjaro Hotel is the PPF (Parastatal Pension Fund) tower in downtown Dar es Salaam. It was designed in 1996 and features glass facades that are completely exposed towards to the east and west ensuring the PPF tower heats up all day because it must absorb the maximum daily dose of the intense equatorial sun. This leads to a high level of energy consumption for cooling the building.

During the same period, a number of recently built houses, residential and institutional, present different design solutions corresponding to specific local conditions. This is evidence of climatically appropriate architecture. These buildings are well-oriented with optimal natural cross-ventilation of spaces and protection against direct sunshine offered by walls; benefits easy to achieve using local material. Some of these buildings can be seen in Maputo and Dar es Salaam, e.g.:

- A new Central Library at Eduardo Mondlane University, Maputo. The building incorporates the most important aspects of sustainability. The design has been conducted in a very participative way and focus was placed on the need to find innovative architectural and engineering solutions. Local conditions were regarded important and such effort was made to take them into account.

- The offices of The World Bank and Swedish Embassy are other examples of sustainable architecture in Maputo.

- The American Embassy in Dar es Salaam where it is good relationship between natural and artificial situation. It is possible to see the application of Sustainable Construction knowledge.

Both countries have other public and private buildings where this knowledge has been applied.

3.3 Influence from the North

Instead of applying and modifying proven design and construction techniques developed in Southern Africa to meet Southern African conditions, the building industry has become fixated on importing the latest technological developments and new construction techniques from the North with little reflection on their suitability for local conditions. This new phase of building design completely ignores traditional and early colonial architecture. In many ways the building industry reflects larger patterns of economic, political, and social interaction between Southern Africa and the North, where Northern ideas and practices serve as the benchmark to be adopted. In the building industry this has meant the disappearance of efforts to achieve sustainable architecture and its replacement with buildings that use high rates of energy in their daily operation and imported materials for their construction.

3.4 Awareness of Sustainable Architecture

The construction industry by large should be responsible for converting the natural environment into a built environment without destroying its natural state. However, in Tanzania and Mozambique, awareness of environmentally sustainable architecture is very low. In order to make an impact, the basic principles of sustainable architecture will have to be known to all members of the building team - including the client, architect, consultants, contractors, building product manufacturers, and building users. There is a need to change the way in Southern Africa to build and use the buildings from an architecture based on low quality replication of Northern designs to more innovative use of traditional low technology. It is a matter of low energy use designs to achieve greater long term sustainability of the region's natural resources, the economic viability of the client's building and to ensure greater comfort to the buildings users.

3.5 Lack of Architectural Research and Communication

Research in the field of architecture provides an opportunity to link new knowledge with design. It is therefore a fundamental aspect of the architectural profession (Emmitt 1996). It provides scientific knowledge, useful for resolving architectural problems. However, the research element in Tanzanian and Mozambican architecture is not given the importance it deserves in order to promote a positive development of the profession towards sustainable development.

4 Conclusions

Many developing countries in the Southern hemisphere do not apply the knowledge of Sustainable Construction due to many reasons. As a result of this situation, many of the modern buildings and settlements in these countries, in the last ten years, reflect an uncritical reception of modern European buildings forms without taking into consideration the special climatic and social conditions of the home country. The examples from the pre-colonial and early colonial era when mechanical air conditioning did not exist and the use of local materials showing the structures that made use of materials, cross ventilation, colours, and orientation toward/away from the sun that kept occupants comfortable with minimal energy inputs, even under the intense equatorial sun. In comparing this earlier period to modern day architecture in Southern Africa we can see that the principals that underpinned the early sustainable architecture have been forgotten. However, this knowledge has gradually started to be applied and it is making it possible to see some buildings on the basis of this knowledge. The principal of making buildings to fit their environment, climate and culture, rather than aping the architectural styles of developed countries is the key for making sustainable architecture to be achieved in Tanzania and Mozambique.

The economic development that occurs in the North and the South perspective, especially in non-developed countries, in the last decade, is made up of great utilization of the production of energy from the fossil resources. The finite nature of this natural resource, and the environmental impact of its production and consumption, makes these countries to rethink their development plans. New strategies must be found to maintain the current standards of life in developed societies and to help aspiring new developed countries to reach higher standard of life. This has to be developed without compromising the new technology, not only for the benefit of the environment, but also in level of economic and social development.

With a look backwards from the Rio summit in the beginning of the nineties, there has been a long time for the construction sector in the industrial countries to adapt the whole concept of sustainability including the triple bottom line . The research community of sustainable building has moved its focus slowly from solely environmental issues and assessment methods through questions as energy savings and material productivity to a holistic view of sustainable buildings including the triple bottoms. What about the mainstream project and its involved stakeholders as clients, project management team and end users? Where are the process thinking and management aspects of sustainability? The objective is to reach a resource productive factor of Factor 10 or Factor 20 in one generation but the first generation is soon at halftime and we have barely just started. It is time to prioritize the objectives to make it easy to get information how to do and make rules or opportunities to promote the mainstream construction project towards sustainability . It is obvious that a general global agenda of sustainable construction has to be complemented with specific conditions of the actual site, of the specific project or facility, of the ability or knowledge of the design and management team and of course regional and local conditions of the triple bottom lines of sustainability. It is a matter of fact a question of knowledge transfers from bottom-up and top-down perspectives locally adapted, despite if the site is located in a Northern Artic mountain area or in a Southern tropical urban area.

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SUSTAINABLE CONSTRUCTION MANAGEMENT AT A PROJECT LEVEL: A MODIFIED ENVIRONMENTAL MANAGEMENT SYSTEM STRUCTURE

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Keywords: sustainable construction, project management, knowledge transfer, quality, stakeholder,

Summary

The management of a construction project in a sustainable way should focus on the entire process from an early design stage towards the final product, and on the benefits and negative impacts that are to be expected during the life of the facility. The research presented here argues that there is a difference between sustainable building and sustainable construction, where the first considers the final product and the latter considers the way to the final product, i.e. the process. To manage such a process, in a sustainable way, there is a need of some kind of management system or tool from the perspective of process owner and the management of the project. To link sustainability with quality and environmental aspects is one way to systemise this process. Common and useful structures are the international standard of the environmental management system ISO 14001 and the international quality management system ISO 9001. This linkage could be achieved by using a sustainability evaluation model, STURE, where the construction project stakeholder's different demands are considered alongside the quality and environmental aspects. The result is a suggestion of a combined system/tool of how to manage the process of a construction project's sustainability, environmental and quality aspects towards a sustainable building.

1. Introduction

At present, actors within the construction sector in Sweden are endeavouring to develop a more effective process than hitherto available for achieving a combination of high quality, economic advantage and sustainable construction management. The management team of a sustainable construction project should focus on the entire process from an early design stage towards the final product, on the benefits and negative impacts regarding the triple bottom lines of sustainability that are to be expected during the life of the final product, i.e. the facility. There are relatively few examples of good practice regarding sustainability in mainstream construction. It seems that clients and project managers face barriers to implement sustainable construction. Williams and Dair (2005) found at least 12 barriers to implementation. The most common were lack of consideration of sustainable measures, real and perceived costs and inadequate expertise and powers.

A common misunderstanding in the construction sector is that sustainable buildings are more expensive in investment cost than 'normal' mainstream buildings. A survey by the World Business Council for Sustainable Development (WBCSD 2008) investigated the difference in investment between a normal building and a certified sustainable building. The result indicated that sustainability concerns should be about 17% more expensive in investment cost. Other sources indicate up to +15% (Lützkendorf 2005). Kats *et al,* 2003, and Matheissen and Morris, 2007, found that a green building is cost effective, no additional cost compared to normal buildings is necessary and the total benefits over the life cycle are over ten times the average initial investment required to design and construct a green building. It seems that the stakeholders to the project, i.e. clients and building professionals, are not well enough informed about the basic linkage between construction and sustainability. It is important to clarify the difference between sustainable building and sustainable construction, where the first considers the final product and the latter considers the way to the final product, i.e. the process. To manage such a process, in a sustainable way, there is a need for some kind of management system or tool from the perspective of the process owner and the management team of the project. To link sustainability with quality and environmental aspects is one way of systemising this process. Common and useful structures are the international standard of the environmental management system ISO 14001[1] and the international quality management system ISO 9001[2]. This linkage could be achieved by using a sustainability evaluation model, STURE (Persson and Olander 2004; and Persson et. al. 2005), offering a triple bottom line perspective where the construction project stakeholder's different demands are considered alongside quality and environmental aspects.

2. Sustainability as Sustainable Building and Sustainable Construction (Product and Process)

Views of sustainability are quite different with shifting focus of content from a regional/national level to the individual level and from different nations/regions to different cultures and societies. The terms sustainable building, sustainable construction, green building and so forth are interpreted quite differently by involved stakeholders depending of education, age, cultural background etc. (Cole and Lorch 2003). It also seems to be quite confusing where differences between the terms, especially between sustainable construction and sustainable building, are concerned. If sustainable building considers the final product, i.e. the building, then sustainable construction is about the whole process towards the final product and during the product's lifetime. The process includes the stages of pre-design, design, procurement, construction, operation, maintenance, refurbishment, re-construction, demolition and recycling. Construction itself could imply everything between site-specific activities to the creation of human settlements. Sustainability on the other hand should imply a holistic view; the whole is more than the sum of its parts with relationships and interactions between humans, society, the biosphere, economy and the state of technology (Plessis 2007).
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Sustainability in construction has been defined by Agenda 21 for Sustainable Construction (CIB 1999). There is a present standardization process through Agenda 21 known as ISO FDIS 1532:2008 "Sustainability in Building Construction – General Principles". Sustainable buildings, as cited by Trinius and Sjöström (2008), "…provide the required performance with minimum adverse environmental impact, while encouraging improvements in economic, social and cultural aspects at local, regional and global levels"

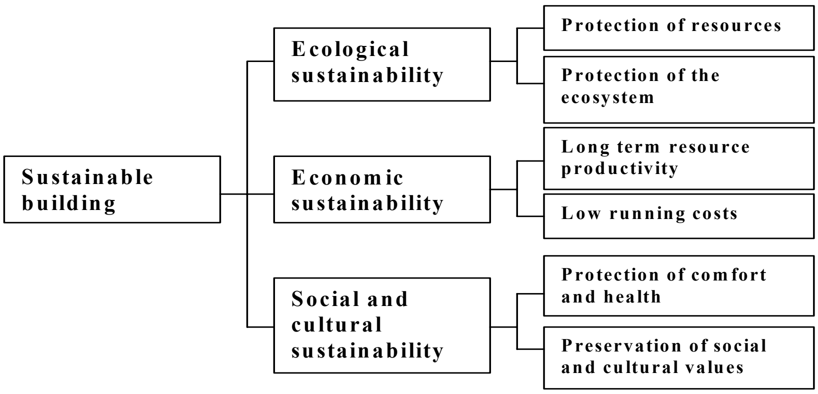

Figure 1 Sustainable building (Kohler 1999)

A sustainable building could also be defined as "buildings that contribute to sustainable development" (Lützkendorf 2005) or as described in *Figure 1* (Kohler 1999). The right column defines the performance objectives of a sustainable building regarding the principles of the triple bottom line of sustainability; ecological, economic and social/cultural development having equal importance (Pope et al 2004). O'Connor (2006) argues for a fourth part or 'sphere' to be involved in sustainability: The political sphere that acts as a rule and regulation setter of, and between, the other three.

Sustainable construction can be interpreted in many different ways. It covers a broad and complex interaction between involved stakeholders, aesthetic issues, material interactions and functionality. To find a definition of this process in terms of sustainable building over its life cycle is one of a few clarifying terms in regard to sustainable construction made by CIB, UNEP and the research institutions CSIR and CIDB of

[1] ISO 14001, 2004: Environmental management systems – Requirements with guidance for use. *ISO 14001:2004*

[2] ISO 9001, 2000: Quality management systems – Requirements *ISO 9001:2000*

South Africa in their Agenda 21 for Sustainable Construction in Developing Countries (UNEP et al 2002, Plessis 2007):
"… principles of sustainable development are applied to the comprehensive construction cycle, from the extraction and beneficiation of raw materials, trough the planning, design and construction of buildings and infrastructure, until their final deconstruction and management of the resultant waste. It is a holistic process aiming to restore and maintain harmony between the natural and built environments, while creating settlements that affirm human dignity and encourage economic equity."

This supports the triple bottom line philosophy mentioned above and should also be applicable in a country anywhere in the world despite its level of industrial development.

3. Project, Knowledge and Sustainability Management Linkage through STURE

As sustainability issues increase total complexity in a construction project, the ability and the knowledge of the project management team has to be deeper and broader. This increasing complexness is visualised by Hacking and Guthrie (2008), who compared the assessment methods of traditional environmental impact assessment (EIA) with a sustainability assessment, *Figure 2.* This requires it to be a more strategic and holistic way of dealing with these issues on the part of the project management team.

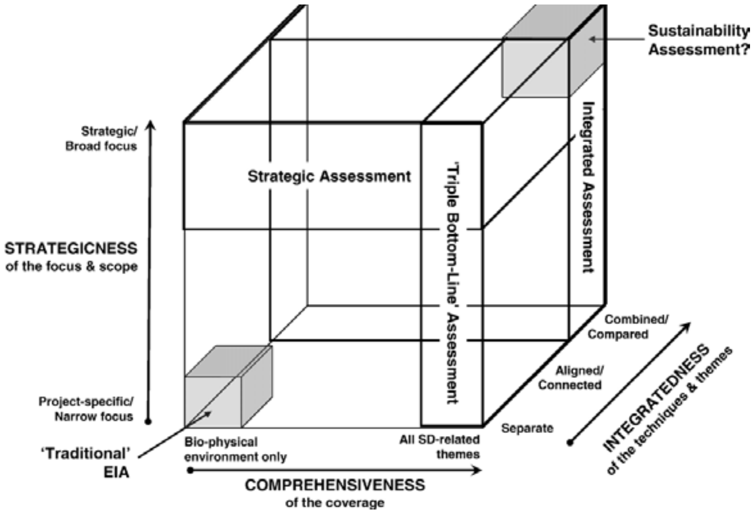

Figure 2 The complexity of assessment methods (Hacking and Guthrie 2008)

The low degree of transfer of experience gained within the construction process to those participating in it has been noted frequently, a weakness that reflects a lack of a natural forum for the distribution of information. There is a need for some system for reporting experience gained in such a way that those engaged in the chain of tasks to be performed can access the knowledge and experience of others, both during a project and afterwards. If no such transfer of knowledge and experience takes place, there is the risk of the firm failing to take advantage of what has been learned and of it making the same mistakes again.

The assembly of information relevant to a project is part of the requirements of the managerial system generally, as expressed in the set of international standards ISO 9001:2000 and ISO 14001:2004, which are common used in the construction sector. The complexity of the construction process means, however, that special measures are called for if the collection of relevant information, including the experience that has been gained and made available to those in need of it, is to function properly. The continual public debate regarding what takes place within the construction sector is considered by many to reflect flaws in the quality assurance system and the lack of a well-functioning system for collecting and distributing knowledge. There is good reason behind the construction sector's endeavour to identify ways in which the functioning of these two systems can be improved.

In temporary organizations, such as those in construction, knowledge of a specific project and the use of routine checklists often play a central role. Knowledge and information often need to be handed on to the next actor in a sort of relay race. It can be difficult at times for the craftsman to understand from explicit sources how a particular step in the construction process is to be carried out to satisfy the demands for sustainable construction. Tacit knowledge can play a major role under such circumstances, meaning doing what one is accustomed to do, without studying drawings or written materials. The willingness to work in this way (i.e. figure things out on the spot) can be a positive trait, especially when no drawings or descriptions of the exact procedures to carry out are available. Yet, it can lead to insufficient precision and result in quality, environmental and sustainability requirements not being met (Persson 2006).

A case study performed at an SME in Sweden serves as an example to illustrate possible ways of coping with problems during the production stage when new systems are tried, e.g. managing sustainability issues. The overall aim of the study was to analyze how knowledge and experience can best be made available continually to those in need of it, with a system being designed to serve these ends as effectively as possible. A specific objective of the study was to investigate how a particular construction company deals with the knowledge potentially available to it and how the organizational work of the company supports its knowledge management efforts (Persson 2006).

Nonconformity as defined in terms of ISO 9000 should represent an ideal point of departure for learning and for the transfer of knowledge (Persson 2006). Nonconformity in terms of ISO 9000 can be noted in managerial reviews, which concern primarily matters of documentation, routines and procedures of a general nature. One reason why it may be difficult in a business organization to deal adequately with both major problems as well as lesser problems is that there is much greater profit for a firm in using most of the limited resources it has for business of major importance than in concentrating on overcoming weaknesses in areas of little financial importance. Managerial reviews should be concerned in part with questions of the quality and environmental management system. Another possible reason for the limited attention of nonconformities and not being documented can have to do with the working culture in the construction sector. Instead, it is a conversational culture in which the social network and people's discussions with each other are regarded as the major ways of spreading knowledge and information, although this is a matter that was not investigated systematically (Gluch 2005).

The protocols of the management reviews make note of significant matters of experience taken up in the meetings for sharing experience (Persson 2006). Certain comments by customers are also contained in these protocols. There appears to be a lack of effort in the protocols, however, in combining and integrating the information from different sources taken up in the meetings.

In order to bridge the gap between project management routines supported by ISO9001 and ISO1400, the knowledge transfer as described above and 'the new and unknown' sustainability management the authors propose to link these issues by using a sustainability evaluation model as the Stakeholder Urban Evaluation Model (STURE) – see *Figure 3* (Persson and Olander 2004, Persson, Olander and Landin 2005). In this decision model the stakeholder's different demands are considered alongside the quality and environmental aspects.

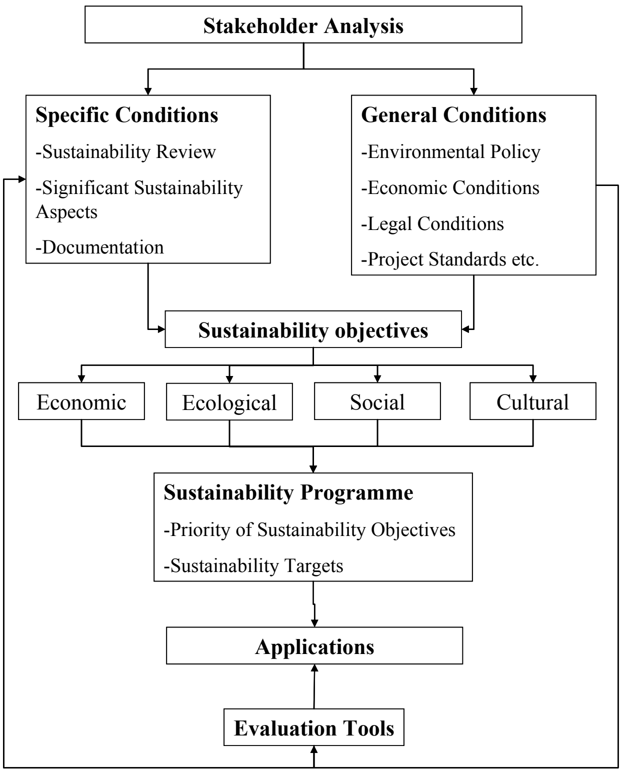

Figure 3 *The STURE model (Persson and Olander 2004; and Persson et. al. 2005)*

The principle of STURE comprises four steps: *stakeholder analysis*, *specific conditions* for the actual application, *general conditions* that need to be addressed and the *sustainability programme.* This last step acts as a synthesis of the other three steps. This concept corresponds to the environmental management standard of ISO 14001 with the distinction of exchanging all terms defined with the prefix or suffix of 'environmental' to the triple bottom line definition of the term 'sustainability'. STURE could be described as an objectives-led integrated assessment (*Figure 4*) applied at the project level, but it also could be the prototype of a sustainable assessment method suggested by Pope et al (2004).

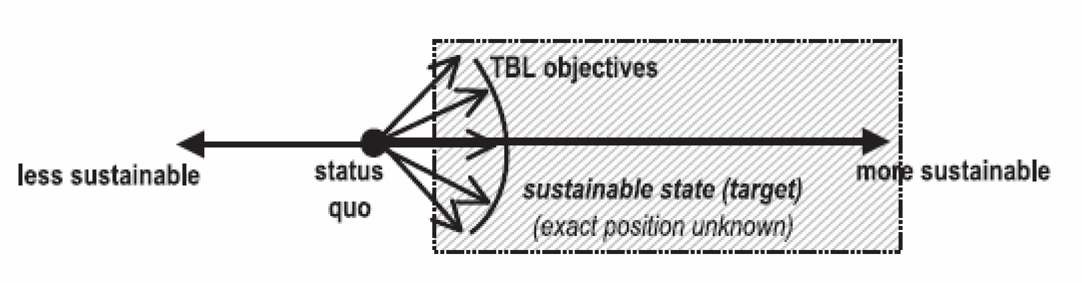

Figure 4 An objectives-led integrated assessment approach to sustainability assessment (Pope et al 2006).

4. Stakeholder Concerns

It seems that information between the involved stakeholders in a construction project is one essential and missing part, especially regarding complex relationships and interactions related to sustainability issues. The communication of sustainable issues can be the difference between a successful project and a failure. In order to obtain acceptance to construct a facility from its various stakeholders, it is often a requirement to communicate the triple bottom line impact that the facility brings. Communication should thus be seen as an essential part of project manager's efforts to manage stakeholder interests with respect to the purpose of the project and to the impacts of the sustainability that it brings. If the project management team, through communication, can create a working dialogue, it may be easier to pinpoint the real conflicts in a project and eliminate false conflicts and misunderstandings, thus reaching acceptance for the project (De Laval 1999). In other words it is essential to know who the stakeholders are and their needs and concerns in relation to the purpose of the project. In the construction sector, stakeholders include a wide range of entities that directly or indirectly can provide support or resistance to the accomplishment of project objectives (Walker 2000). Karlsen (2002) argues that there are at least four reasons for performing a stakeholder management process. First, to be acquainted with the project's stakeholders; second, to ensure the balance between contribution and reward in the relationship with stakeholders; third, to plan and define how to manage stakeholder concerns; and last, to set a base for deciding which stakeholders are to be involved in determining the project goals and the measurement of success. Stakeholders can be divided into internal and external (Gibson 2000). The external stakeholders are those affected by the project in a significant way, but not directly involved in execution of the project (such as neighbours, the community, the general public, as well as trade and industry)

Often, both proponent and opponents to a construction project argue their case from a perspective of sustainable development, which means that it is important for the project management team to clearly and openly evaluate all possible options to obtain the project purpose with respect to the relevant sustainable issues from the perspective of the project stakeholders. It is thus relevant for a construction project manager to have tools and methods to combine the goals and purpose of the project with the concerns and needs of various stakeholders divided into the triple bottom line aspects of sustainable construction.

5. Conclusions

As argued before, the broad spectra of sustainability increase the complexity of the number of decisions the project team has to make during the process of a construction project. Information is circulating in the companies, but the companies lack any system for transforming this into knowledge needed to move the process towards sustainable construction. When it concerns to involve the stakeholders in the process, internal and external, there is a need for a combined method/tool for the project management team in relation to the process of the project's sustainability, environmental and quality aspects towards a sustainable building. Using the model of STURE, the team could make a structure of sustainability, environmental and quality issues linked to the project and to the demands of the stakeholders alongside the technical solutions. This may not guarantee the all best solutions regarding sustainability, as shown in *Figure 3*, but it could reveal the best path towards a sustainable building from the specific project's conditions, the project team and the client's ability to deal with the subject and demands from the users and other involved stakeholders. However, we have seen that this area is important in a larger context and we have been inspired by ongoing research in other countries and research groups which confirms this research direction as valid.

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3RS PRINCIPLES ON THE IMPROVEMENT OF EXISTING BUILDINGS

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Keywords: life cycle assessment, building performance, 3Rs

Summary

There is a connection between buildings usage conditions and environmental performance. It is admitted that most efficient ones consume less resources over time. Those which are assessed as inefficient tend to be replaced, disposing used resources and consuming new ones. The worsening in performance indicates that a building life cycle is coming to an end, even if some of its components and systems are still in good usage condition. It is possible to intervene to extend its life and prevent its demolition, before performance is mainly unfavorable and maintenance becomes impracticable. This can be done by adapting it to current needs and new regulations on accessibility, safety, health and energy efficiency, but it depends of appropriate assessment tools. Among the approaches on sustainability, one that can serve as a reference for decisions is 3Rs (recycle, reuse and reduce), widely used in environmental education initiatives. This paper discusses the applicability of reduced consumption, reuse of products and recycling of materials principles for the assessment of building components and systems in order to optimize its performance and increase its life cycle. Its goal is to propose a simple tool, easy to understand and in public domain, which may contribute to spread concepts of sustainability among different stakeholders and minimize the impact of demolition, refurbishment and construction on the environment.

1. Introduction

A significant part of the existing built space was made without taking environmental issues into account. The assessment of the environmental performance of these buildings based on current tools can lead to a very poor result. In this case, would it be appropriate to substitute these buildings for others, more adequate to current needs and with better environmental performance (even though this would generate demolition residue and consume new resources)? Or would it be better to extend its life cycle through the recovery of its performance?

The life cycle of a building has a significant relation to its conditions of use: while the physical and functional performance is adequate, it can still be useful. Significant buildings, of recognized cultural value, can have quite a long life. Common ones, made to cater to very specific needs of a certain moment, tend to have a short life: declining performance indicates the approach of the end of its life cycle.

Comparative analysis between an existing building and a new one, based on their life cycles, can bring answers in terms of the best alternative: refurbishment, up to a certain deadline; substitution, after that. The problem is that the instruments for assessment are not yet developed enough for their use on a large scale, the databases are incomplete and the methodologies are not yet consolidated to assess existing buildings. This kind of analysis, then, does not occur and the decisions as to demolish or to recover are taken without proper criteria, not considering impacts on the environment.

The Federal University of Santa Catarina, a governmental higher education and research institution in the south of Brazil, illustrates the dilemma of the discussion of the management of the built environment. It is an institution that is growing to facilitate access to higher education and to promote changes in the living conditions of the population. A significant part of its buildings were done in the eighties and already present a decline in performance. This case must be seen in the perspective that education, research and government institutions should lead the search for sustainability through the exemplification and application of the Best practices, according to the Agenda 21 for Sustainable Construction in Developing Countries (CIB, 2002).

Even if in the current state of the art it is not possible to measure with precision the effects of decisions, the urgency of the environmental issue makes it necessary that the parts involved seek to minimize impacts. Any initiative that seeks to reduce the use of new resources or the best use of resources already employed or yet the possibility of recycling the resources that have no further use can contribute to the reduction of the weight of construction, reform and demolition activities on the environment. Thus, it may be possible to apply the 3 R's approach (reduce, reuse and recycle), that are used in environmental education and waste management as a guide for decisions on built space.

Objectives

This study has as its objective to verify the applicability of 3Rs principles, reduce, reuse and recycle, in the assessment of parts, building systems and buildings for the management of built space.

Procedures

The article is divided in five titles that correspond to the stages of the study. The introduction presents the research problem, the objective of the study and the methodological procedures adopted. The theoretical basis builds a framework based on the literature on: sustainability assessment; life cycle and performance, and; 3Rs approach. The proposition formulates an instrument for the analysis of built space, building systems and components. The application exemplifies the use of the instrument in practice, taking as a reference buildings made for the Federal University of Santa Catarina, UFSC. Finally, the conclusions evaluate the results, the attainment of the objective of the study and points out some paths for the sequence of the research.

2. Theoretical basis

The theoretical framework of this study is formed by approaches to the environmental issue and management of built space, with a quick discussion of: sustainability and assessment systems; life cycle and performance of buildings, and; on the 3Rs as a principle for the reduction of residues.

Sustainability assessment

Sustainability is a condition where the necessities of the present are met without compromising the possibilities of future generations meeting their own necessities. The Agenda 21 highlights the importance of the refinement of production through technologies and processes that use resources more efficiently, doing more with less (CIB, 2002). Attaining sustainability implies stabilizing, or reducing, environmental loads. This load is a function of three factors: population, consumption capacity and technology. Due to the impossibility of reducing population or consumption (that tends to increase through the improvement of the population's living conditions), sustainability can only be obtained through radical changes in the technologies employed today to generate wealth, so that the conditions to provide what is essential to all exist (HART, 1997).

A sustainable building seeks to maximize the operational efficiency while minimizing its environmental impacts (GBC, 2008; ACE, 2001). A way of demonstrating the environmental adequacy of a building is through certification, with the voluntary adoption of performance criteria and standards. Certification seeks to attain the performance standards voluntarily. Most existing buildings were constructed before the establishment of environmental performance criteria, which makes a favorable evaluation more difficult. However these criteria can guide interventions for improvement.

Environmental performance certification systems, such as BREEAM, LEED and CASBEE, converge in the sense that they take into account the consumption of natural resources, which corresponds to around 40% of the weight of the assessment. In the other aspects they vary according to concerns and regional aspects that make it difficult to use in a indiscriminate way. The prescriptive characteristic of the assessment, as a check list, does not necessarily guarantee the best performance. In truth, there is the risk that buildings are evaluated more for their equipment than by their global environmental performance. That is why there is a tendency to seek quantitative evaluation systems that take into account the buildings life cycle. It is a transition from the 'green building' approach, where its environmental performance is qualified, to a 'sustainable building' approach where the impacts of the production process are quantified, from its use until its demolition (SILVA, 2007).

Life cycle and performance

Life cycle analysis, LCA, is a tool used to quantify the environmental emissions or impacts throughout the life of a product, system or process. In the case of buildings, this approach ranges from the extraction of raw materials for the production of components until demolition and residue disposal. However the complexity of construction, that demands and infinity of processes and materials, and regional specifics, makes it difficult to establish the limits of analysis, to form a consistent database and to define the impacts in order to allow the understanding of information. Several authors (SILVA, 2007; KAWASE, 2005; ACE, 2001) recognize the difficulty of its use in civil construction, which restricts the analysis to a few theoretical exercises or very specialized applications. From the practical point of view, its limited application permits a comparison of alternative solutions. However, there is no way to present a number that expresses the environmental impact of a building from 'cradle to grave' nor is it possible to determine a more sustainable alternative between refurbishing or substituting an existing building (LUETZKENDORF, 2005).

One must take into account that the performance of a building does not maintain itself unaltered throughout its life cycle. Over time the building's components and systems suffer wear which affects their conditions of use to the point of total wear or ruin. Performance can be recovered by maintenance interventions. These interventions must be made before the component or system goes from 'good stand' to 'partial outworn', so that the edifice's performance can be preserved and great and costly renovation interventions avoided (KESKKYLA, 2005).

Another aspect to be considered is that the performance of the buildings also varies according to the activities that occur there: more intense use tends to be more sustainable. If the buildings are not used, if their spaces become unused, there is no way to assess them positively from the environmental point of view, even though no negative impacts and effects are perceived (ELLE, 2005). This, initiatives to improve the use of existing spaces can reduce the demand for the expansion of built space and for the consumption of new materials; in other words, intensifying the use minimizes consumption.

3Rs Principles

Sustainable development demands a reduction in consumption of natural resources and a reduction of the environmental load (HART, 1997). The lack of concern with practices directed to the efficient use of materials in construction results in the excessive use of natural resources and in the generation of large quantities of waste that are rarely recycled. Data indicates that approximately 40% of all waste globally are originated in the construction and demolition activities. In general, construction waste have a lot of volume, are heavy and not suitable for incineration or composting (NITIVATTANON, 2007; JOHN et al, 2001).

The approach of reducing waste, reusing artifacts and recycling resources is frequently called 3 Rs. Reduce means the option of using materials or objects taking care to minimize waste and the amount of residue. Reuse involves the repetitive use of items or parts that still have useable aspects. Recycle means the use of the residues themselves as a resource. The ease of comprehension of these principles makes the 3Rs a powerful environmental education tool for the reduction of residues in human activities. The application of these principles can lead to a fuller use of the materials in their life cycle (MoE, 2005). For its implementation, some governmental initiatives have been taken forward, especially in Asia, such as the creation in 2006 of the 3Rs KNOWLEDGE HUB (www.3rkh.net) intended to produce, systemize and disseminate knowledge.

The 3Rs principles are not applicable only to the management of waste. In truth, these principles tend to modify the standard of behavior when they demand a reduction in consumption. This induces the individual and society to think of their needs and expectations. The search for satisfaction can give way to a more responsible attitude that does not depend on the acquisition of another artifact. We know that just by minimizing the consumption of natural resources we can manage to reduce the environmental load. We must admit with urgency that faced with the environmental crisis, and for the possibility of survival of future generations, we must change (UNEP, 2007; MMA, 2005; MANZINI 1998; HART 1997).

3. Proposition

The way in which the 3Rs principles are presented is not for free: first we must seek to reduce consumption, then reuse what is already available and only then recycle, when there is no more possibility of use. This sequence permits a parallel with the life cycle of industrial products, the extraction of materials for their manufacture, from their use until their disposal and final discarding of residues. Buildings can be seen in the perspective of this cycle: first, the use of resources for construction, that must be minimized by design initiatives; after, the maintenance activities, that assure the continuity of its use and the full use of the resources employed, and; at the end, the demolition, when there are no more conditions for use and when the recycling of materials should occur.

The perspective of the 3Rs as a life cycle approach allows that other more complex readings be made. For our analysis, buildings can be broken down into several levels: by their materials, their components, their building systems and even their spaces of use. Each one of these entities can be seen as a resource in its repetitive life cycle (of creation, use and discarding) and can always be submitted to questioning as to: hoe to reduce, how to reuse and how to recycle. This leads to thought on the use of resources employed in the construction, maintenance and demolition phases. Table 1 presents possible meanings for the 3Rs in relation to resources, in every level.

Resource and level	approach	meaning
Edifice Level 1	1. reduce	Reduce the demand for built space
	2. reuse	Use intensively built space
	3. recycle	Attribute new uses to built space
Environment Level 0.1	1. reduce	Reduce the space occupied by the environment
	2. reuse	Use intensively the available environment
	3. recycle	Attribute new use to the unused environment
Building system Level 0.01	1. reduce	Reduce the demand n the building system
	2. reuse	Make better use of the installed capacity
	3. recycle	Susbstitute components and recycle
Component Level 0.001	1. reduce	Reduce the quantity of parts and material
	2. reuse	Make use of the component
	3. recycle	Substitute the component and recycle
Materials (and energy) level 0.0001	1. reduce	Reduce the consumption of materials
	2. reuse	Use materails intensively
	3. recycle	Attribute new uses to the material

Table 1 – possible meanings of reduce, reutilize and recycle by resource.

These different meanings for the 3Rs share a common goal of smaller consumption, better efficiency and the possibility of recycling. Despite it may present conflicting answers, in many cases, such as in the substitution of the components of a system which implies in discarding in order to achieve better efficiency, the 3 Rs can be useful as a guiding principle for less impacting practices, and therefore more sustainable ones.

4. Experimental use

The use of the 3Rs principles can be exemplified in buildings made for the Federal University of Santa Catarina, UFSC, in the city of Florianopolis, in the south of Brazil. It is a built area of over 300.000 square meters, to house educational activities, research and extension. The standardized buildings that characterize the environment of the main campus were built for the most part in the 70's and 80's. They are classroom blocks, laboratories or administration in three pavements that organize themselves around a connecting block, where the vertical circulation and sanitary installations are concentrated. The constructive technology is conventional in reinforced concrete, panels in ceramic blocks with no revetment, fibrocement roof and aluminum windows. These austere buildings are in a good state of conservation despite few maintenance initiatives, which demonstrates the quality of its construction.

In terms of performance however, these buildings do not meet current regulations concerning accessibility, security, cleanliness and energy efficiency: there are no adequate bathrooms and elevators or access ramps for people in wheelchairs, there is a lack of alternative routes for emergency escape and the natural lighting and ventilation are hampered by inadequate solutions of sun shades on the building facades. In the same way the buildings do not meet current needs in a satisfactory manner: the infrastructure for information technology and communications was implemented later in an improvised fashion, the configuration of the space makes it difficult to adopt renewed approaches to teaching and learning and the austerity of the buildings is not recognized as value in an environment that is naturally marked by diversity and by youth and for a desire for social ascendance through education. For the future, these buildings will have to be adapted to changes in climactic conditions.

Despite the growing involvement of society in the discussion of environmental issues, even in a higher education institution like UFSC, management decisions of physical space still consider that constructions, building systems and entirely new components have better performance and a longer useful life ahead of them. Difficulties inherent to the reconditioning process are pointed out to justify demolition and disposal. This logic of the new does not consider the possibility of reducing, reusing and recycling. In the case of the UFSC, it also does not consider that a good portion of the components of the building systems of the buildings are in full useful life and still perform as foreseen in their design. Foundations, structure, cover, seals and door beams, as well as significant parts of the building installations can represent around 2/3 of the total cost of the building. This value can be recovered with investments towards meeting current legislation and new necessities. It is doing more with less. In this context the 3Rs can be adopted as a simple instrument for analysis and decision-making. Figures 2a, 2b and 2c exemplify the application in a standard UFSC building. In 2a the effects of reducing energy consumption are dealt with; in 2b, the effects of reutilizing the illumination system, through the intensification of its use, and; in 2c, the recycling of the building, through the alteration of its use.

resource	item	initiative	principle	effect
building	Class block			Intensify the use of the building
environment	Class room			Intensify the use of the environment
System	Lighting			Diminish demand
Part	lamp			Reduce the number of lamps
material	energy	Improve performance	reduce	Diminish energy consumption

Figure 2a: effects of performance improvement - reduce energy.

resource	item	initiative	principle	effect
Building	Class block			Intensify use of the building
Environment	Class room			Intensify use of the environment
System	Lighting	Improve performance	Reuse	Intensify use of the existing system
Part	Lamp			Intensify use of lamps
material	Energy			Intensify use of installed capacity

Figure 2b: effects of performance improvement - reuse lighting.

resource	item	Initiative	principle	Effect
Building	Class block	Improve performance	Recycle	Alter use of the building
Environment	Class room			Alter use of the environment
System	Lighting			Intensify use of an existing system
Part	Lamp			Intensify use of lamps
material	Energy			Intensify use of capacity

Figure 2c: effects of performance improvement – recycle building.

There are numerous actions that can lead to an improvement in performance. Just an example: in 2a, a reduction in the consumption of energy can be obtained through changes in the covering of walls and ceiling (recycle); in 2b reutilizing the lighting system can be obtained through the intensive use of the environment (reuse), and; in 2c recycling an building can be a result of the use of unused environments (reduce). What is interesting to observe is that the better use of a resource positively affects the use of the others; the improvement in the performance of a resource affects the performance of the entire building.

In deciding between demolishing or renovating, be it a system or an building, an institution like the UFSC must take into account that in the case of demolition the existing resources that are at an inferior level are no longer fully used. In the case of renovation, on the contrary, the resources at a superior level become better employed. Thus, in the perspective of a better use of resources, one can have as a principle that it is better to renovate than to demolish. Renovating permits a reduction in the consumption of new resources, reusing those already consumed and recycling the conditions of use of the existing one.

5. CONCLUSIONS

The example of application at the UFSC permits that we infer that on any scale from a bolt to a building it is possible to question the possibility of reducing, reusing and recycling the components, the building systems and the spaces of the buildings. The 3Rs is a tool that permits a rapid assessment of any item, from the simplest to the most complex. The focus on the intensive use of resources induces a concern with the maintenance of the performance of the building so as to prolong its useful life.

The great advantage of applying the 3Rs as a principle in the management of physical space is its simplicity and ease of comprehension; both the layman in thinking about his needs as the specialist proposing solutions to complex problems can base their decisions. Despite that in some cases it may seem difficult to find the answers on how to reduce, how to reutilize and how to recycle, the approach points clearly in the direction of more sustainable practices.

As a principle, in the perspective of the use of resources, better use of what already exists is more favorable than disposal and the consumption of new resources. Thus, before building a new building, one must seek to make better use of the current supply of buildings with the recuperation of their performance and the extension of their useful life. Perhaps the most sustainable building is the one we avoid building.

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A CONCEPTUAL MODEL FOR ANALYZING LIFE-CYCLE COST OF RESIDENTIAL WINDOWS IN TURKEY

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Keywords: Life-cycle cost analysis, process modeling, residential windows, Turkey

Summary

This paper is the third one reporting an on-going research within an ITU funded research project which aims to develop a dynamic model supporting life-cycle decision-making in the selection of energy and cost efficient window systems for residential buildings in Turkey. HiPerWin life-cycle cost analysis process model which is a sub function of the HiPerWin process model is presented by using IDEF0 function modeling method in detail. In IDEF0 method the functions describing the conceptual model are illustrated with a graphical representation of a set of components that are presented with hierarchical parent – child diagrams. HiPerWin IDEF0 model is composed of a series of diagrams that hierarchically indicate increasing levels of functions and their interfaces in detail. Inputs, outputs, controls and mechanisms of each function are expressed. The shortages and difficulties which are faced by the users in life-cycle cost analysis in Turkey are also introduced.

1. Introduction

1. 1. Research Project

Windows are the most complex and interesting elements in residential design and owners are often confused about how to decide the most efficient window for their residence since there are many complex issues that are difficult to balance. This decision is important in terms of creating a more sustainable built environment, which provides a healthy indoor air quality for occupants and increases energy and cost efficiency. Understanding the energy and associated cost implications of different window systems will help the owners or contractors to make the best decision for their particular case, whether it is a new building or a window replacement. Although up-to-date, reliable and accurate, time and cost data can be provided from various sources such as manufactures, contractors, and research institutions, time and cost data regarding the residential window systems are not well-organised in Turkey.

Recently, a research project has been initiated to develop a dynamic model to design and select energy and cost efficient windows for residential buildings, namely “High Performance Window Design and Selection Model for Residential Buildings in Different Climatic Regions of Turkey (HiPerWin)”. The model aims to assist the owners, designers, manufacturers, vendors and contractors to provide their understanding about the potential and performance implications of the new window products in different climatic regions of Turkey. The challenge is to attain a basic source which supports the user to provide the energy and cost data required for the decision making in the design and selection of the residential window systems (Tavil et.al., 2006 and 2007).

The ultimate objective is to develop a relational database (RDB) which comprises the whole data and processes data into information regarding the window systems and helps the comparison of the alternatives. Therefore query parameters are presented for helping the users to define the built environment and housing unit characteristics of their own case to find out the appropriate window alternatives by comparing their total annual heating/cooling energy consumption and associated capital and ownership costs at the end of the research project. The HiPerWin model will accomplish the user to select the most energy and cost efficient window system for their own case by considering the issues which have influence on the residential window performance.

In this paper, after discussing the HiPerWin process model briefly, HiPerWin life-cycle cost analysis process model is presented by using IDEF0 function modelling method. The shortages and difficulties which are faced by the users are also introduced.

1.2. Life-Cycle Cost

There have been considerable research and development carried out in the field of life-cycle cost (LCC) in the US, Canada, Australia and EU member countries. The literature on life cycle costing is mostly conceptual in nature, the potential benefits of LCC and the technical issues regarding the application of the approach receive most of the attention in the literature. There is a considerable body of literature relating sustainability assessments on a life cycle basis and, in particular, to one of the main assessment methods – Life Cycle Assessment (Davis Langston, 2007).

The LCC concept was initially applied by the US Department of Defence. Since then a large number of documents, guidelines, standards and reports are available. For instance ISO 15686-5: Building and constructed assets – service life planning (draft), ASTM E917-05 Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems, The Norwegian Standard, NS 3454: Life cycle cost for building and civil engineering work – principles and classification, Task Group 4: Life cycle costs in construction, Procurement guide 07: Whole-life costing and cost management, The Green Book by HM Treasury in UK.

ISO 15686-5 draft defines life-cycle cost as the total cost of a building or its components throughout its life, including the costs of planning, design, acquisition, operations, maintenance and disposal, less any residual value. The National Institute of Standards and Technology (NIST) Handbook defines life-cycle cost as "the total discounted dollar cost of owning, operating, maintaining, and disposing of a building or a building system" over a period of time (Fuller & Petersen, 1995). Furthermore in ISO 15686-5 draft life-cycle costing is defined as a technique which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors both in terms of initial capital costs and future operational and asset replacement costs. (Davis Langdon, 2006). This technique is measured over the asset's "effective" life, generally considered as its economic and or operating life (Langston, 2005).

The LCC technique is especially useful when the project alternatives which fulfil the same performance requirements, but differ with respect to the capital and operating costs, have to be compared in order to select the one that maximizes net savings. For example, LCC analysis will help to determine whether the incorporation of a high-performance HVAC or glazing system, which may increase the initial cost but results in dramatically reduced operating and maintenance costs, is cost-effective or not (Fuller, 2007).

Based on these studies, in this paper, LCC technique is selected to make the comparative assessment of different window systems. This technique helps to find out the most appropriate choices among proposed window systems which satisfy the performance requirements related with energy and cost efficiency in different climatic regions. In that point, realistic evaluation of present value becomes significant by considering multi-criteria which affect window system.

2. HiPerWin Process Model

Since the issues affecting the window performance are complicated and include complex relationships, the functions/activities; inputs/outputs; the issues that control the functions; internal/external mechanisms used for implementing the functions and the interrelationships among the functions within the context of the project are explained by using "IDEF0 (Integrated Definition for Function Modelling) method" (see Figure 1) (web link 1). In IDEF0 method the functions describing the conceptual model are illustrated with a graphical representation of a set of components that are presented with hierarchical parent – child diagrams. HiPerWin IDEF0 model is composed of a series of diagrams that hierarchically indicate increasing levels of functions and their interfaces in detail.

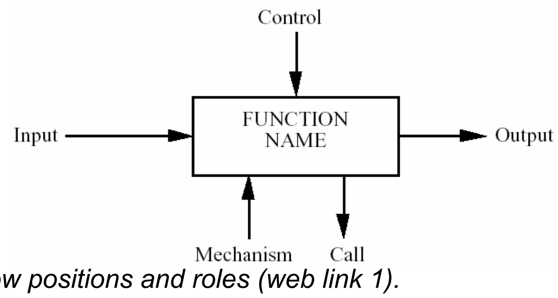

Figure 1 IDEF0 method arrow positions and roles (web link 1).

The top level (A0) diagram of the HiPerWin IDEF0 model consists of six main functions which are briefly described below (see Figure 2):

1. Determining the Outdoor Environment – The impact of windows on building energy use can considerably vary with the location because of the climatic differences. The analysis has been performed for three different climatic regions of Turkey.

2. Describing the Built Environment – Estimating the energy consumption of a building with various window alternatives is possible with the determination of an appropriate set of values for the parameters associated with outdoor environment and built environment. The parameters attributed to the built environment are considered on the basis of a building settlement, a single building block, a housing unit as a thermal zone and a functional building element. All the constraints such as local regulations, limitations and statistical data related with the cities are taken into account as the control issues used for modelling the building settlements for the parametric study.

3. Designing a Typical Residential Block – Every building involves a set of unique features and requiring customized solutions. Therefore, the reference building blocks are designed to represent the scale and

occupancy patterns of a Turkish single-family resident in general. Orientation of the building, position of the building among other buildings, building shape factor (rectangular and square plan shape) and building dimension are the built environment parameters used in designing the typical buildings in the project. Four basic 5 storey high residential building block types with different plan shapes of 100 m^2 each are designed and seven residential building types are generated for the standard representations by orienting the buildings to different orientations.

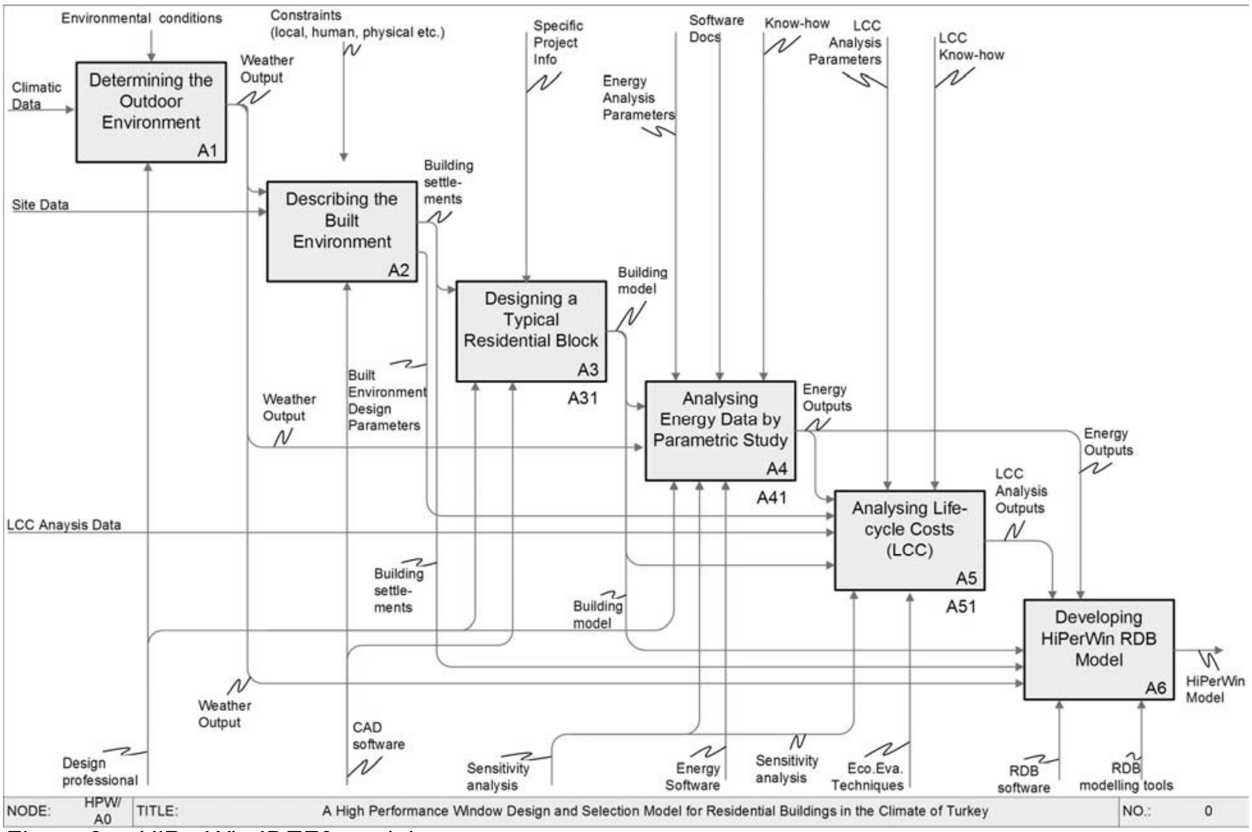

Figure 2 HiPerWin IDEF0 model.

4. Analysing Energy Data by Parametric Study – In accordance with having many parameters such as climate, building type, orientation, window area, shading devices and window components, a comprehensive parametric study is required for preparing the energy consumption and associated cost data of each case for the model. Obtaining the actual energy consumption in a specific climate, for a specific period, for specific environmental conditions and for a specific building and occupants' lifestyle in accordance with control actions is a complex phenomenon in analysing the energy and cost efficiency of a window system. Hence Energy Plus software, which is a powerful and comprehensive simulation tool, has been used to develop standard representations of buildings (i.e. building model), involving geometrical and semantic properties.

5. Analysing Life-Cycle Costs (LCC) – A5 level diagram which comprises the HiPerWin LCC analysis approach which is the major topic of this paper is given in Figure 3. The parent boxes are detailed with child diagrams at the next lower level until all of the relevant detail of the whole viewpoint can be adequately exposed. A sub-function of the A5 parent diagram is decomposed by the child boxes in A54 diagram.

6. Developing HiPerWin Relational Database (RDB) Model – A dynamic model is required for keeping records and facilitating the comparison of the available window alternatives by providing self-representation of each case. Query parameters related with the characteristics of the built environment and housing unit options are presented in order to specify the particular cases. The model has to dynamically realize this self-representation via computational applications. For reaching the ultimate objective, a RDB is required to be developed for helping the users to select energy and cost efficient window systems for a particular case. RDB will be used to store and retrieve up-to-date, reliable, timely and the most accurate life-cycle cost and technical information as the results of the all possible cases.

3. HiPerWin Life-Cycle Cost Process Model

LCC methodology is an iterative process in general. From inception to disposal at each stage, decision and procurement processes, the calculation of LCC should be refined to provide increasing certainty of the total LCC of the project. The ultimate goal for carrying out LCC calculations is to aid decision-making in (Davis Langton, 2006):

- assessing and controlling the costs and identifying the cost significant items
- producing the selection of work and expenditure planning profiles.

In this paper, the conceptual model of the HiPerWin LCC analysis process is given in detail by using IDEF0 method. HiPerWin LCC analysis essentially takes into account of post-construction, i.e. operating phase of a building production process. The objective is to arrive at an analysis plan and the profiles in service period of a window component depending on the owners' purchase and replacement decision which can be considered as a key factor in a sustainable building design.

As seen in Figure 3, functions of the HiPerWin LCC analysis process model can be addressed as follows:

1. Planning the HiPerWin LCC analysis,
2. Determining HiPerWin LCC analysis requirements,
3. Grouping window alternatives and
4. Performing HiPerWin LCC analysis.

3.1. Planning the HiPerWin LCC analysis

The first function of the HiPerWin LCC process model is planning the LCC analysis in order to determine the objectives and constraints for developing the plan that will be followed throughout the analysis. A work breakdown structure (WBS) is generated to determine the tasks which have to be performed during LCC analysis and thereafter the WBS is used to classify cost breakdown structure (CBS). Window components (frame types, glazing, thickness of the gap and infill gas material options etc.) to be included in life-cycle costing are also determined. Available resources and the building model are the major inputs of the planning function. The building model consists of built environment data, outdoor environment and climatic data. Planning function is controlled by user requirements and guided by LCC methodologies and know-how. While numerous information technology tools are available on-the-shelf, expertise and advisory are the indispensable mechanisms of the LCC analysis.

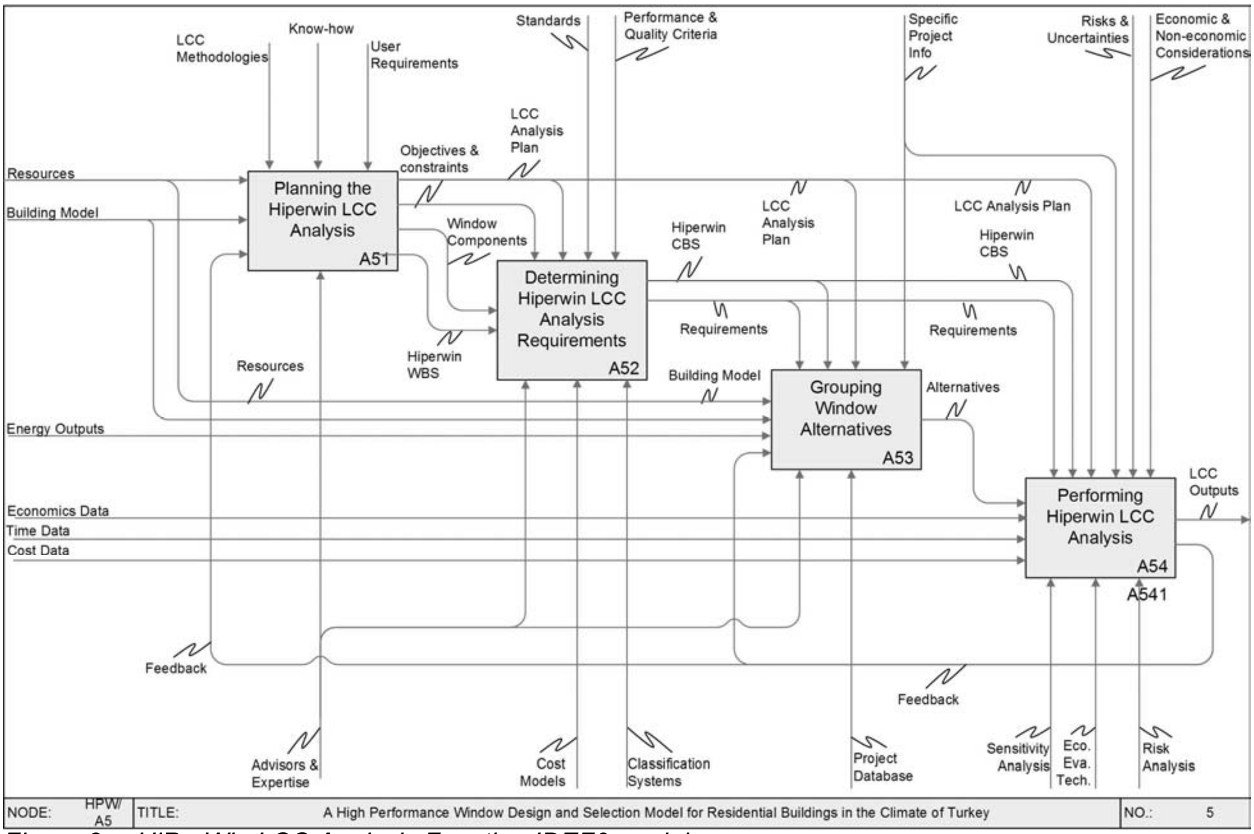

Figure 3 HiPerWin LCC Analysis Function IDEF0 model

3.2. Determining HiPerWin LCC analysis requirements

The outputs of the planning function are used as the inputs of the second function in which HiPerWin LCC analysis requirements are determined. The objective of the LCC analysis requirement determination is basically as follows (Davis Langton, 2006):

- available LCC analysis approaches and techniques,
- current information technology tools,
- data requirements,
- cost calculating and estimating methods and techniques,
- risk and sensitivity analysis requirements.

Not only the purchase or owning costs but also a number of costs including operating, maintaining and disposing costs as well as the benefits occurring throughout the life-cycle of the window alternatives which are crucial for the performance prediction of windows are considered as the life-cycle cost issues.

One of the main outputs of the function is HiPerWin cost breakdown structure (CBS) in which cost data can be classified are essential in the life-cycle cost analysis. HiPerWin CBS can be summarized as follows:

- Capital Costs
  - Purchase Cost: It consists of the construction costs of each window component (glazing unit, frame etc.) as well as the professional fees of the designer and engineer.
  - Installation Cost: Material, labour, equipment, fixtures and fittings costs arising from the fitting out of window components including overhead and profit rate.
  - Finance Cost: It consists of non-construction costs of purchase phase such as interest, cost of money, rates, insurance costs, fees and local taxes etc.
- Operating Costs
  - Ownership Cost: Regular or periodical operating costs, such as cleaning, security, waste management, facilities management, etc.
  - Maintenance Cost: Annual or periodical repair and maintenance costs, such as periodic replacement or planned renovation costs.
  - Selling or Disposing Cost: Salvage value of replaced window components which will be used as second hand.
  - Energy Consumption Cost: Annual or periodical energy consumption costs.

Requirement determination function is controlled by the standards (such as ISO 15686-5 draft), performance and quality criteria and finally LCC analysis plan developed in the planning function. Available cost models and classification systems (such as Uniclass, Uniformat II etc.) can be used as the mechanisms as well as advisory and expertise in order to determine HiPerWin CBS.

3.3. Grouping window alternatives

Outputs of the requirement determination function are used to group window components to be used in life-cycle cost calculations. Recent technological advances in window systems offer many alternatives in the energy and cost efficient window design. In the context of the research project, a set of glazing unit alternatives with various glass types, coatings, thickness of the gap and infill gas are obtained from one of the leading glass company in Turkey. The window dimensions are defined according to window to wall ratio (WWR) of 45%, 30% and 15% representing large, moderate and small area windows, respectively. Timber, aluminium and PVC frames are the frame options considered in the project. Both interior and exterior shading devices are taken into account in the window system combinations. Annual heating and cooling energy consumption of each housing unit having various properties with the combination of these different window components is calculated with a whole building simulation program, EnergyPlus Software. Window alternatives in the evaluation can be increased by adding new window parameters such as advanced glazing types, composite frame types or different shading types, etc.

3.4. Performing HiPerWin LCC analysis

Performing HiPerWin LCC analysis is the last function of the upper level decomposition. HiPerWin CBS which is one of the outputs of determining analysis requirements function and the LCC analysis plan are used as the main inputs of this function. LCC analysis reports and tables are the outputs of the implementation function. Economics and time data are used to convert cost to a common base. Cost data is used to identify the cost of each window alternative of each particular housing unit. Sensitivity analysis, such as Monte-Carlo simulation, can be used to evaluate the effects of a parameter on the value of another one. As investment decisions often made under uncertainty and risk, different methods such as Delphi technique or operations research method can be employed in dealing with uncertainties and in preventing from the effects of the possible variations. Although these methods are out of the context of this paper which mainly covers the interactions of the LCC analysis functions, the effects of uncertainty and risks will be taken into account during the implementation phase. LCC analysis output tables and documents are used as feedback signals to select new alternatives and/or to refine existing alternatives or to take corrective actions in the LCC analysis plan.

Since the ultimate objective is to develop a relational database, cost issues related to window components have to be integrated in the “conceptual model”. For this aim, HiPerWin LCC analysis function is decomposed by the child boxes in A54 diagram at the next lower level until all of the relevant detail of the whole viewpoint can be adequately exposed (See Figure 4). HiPerWin “information model” will be carried out by using IDEF1X “Integration Definition for Information Modeling” method after completing “function model” mentioned above. Up-to-date, consistent, reliable time and cost issues are the two major data class used in the calculation of LCC. In LCC calculations cost data is classified by using CBS, while time data is taken into account in terms of analysis period and service life of window components in concern. The data is provided mainly from manufacturers, contractors and research institutions. There is a lack of structured data collection mechanism in Turkey where real time and cost data are stored; hence the data have been collected from the current local market individually.

3.4.1. Identifying Cost of Each Alternative

The capital and operating unit costs of window systems used in each housing unit are determined. The sub-costs within capital and operating unit costs are classified and expressed in HiPerWin CBS to satisfy the specific requirements of the window system alternatives. The capital unit cost includes purchase, installation and finance costs, while operating unit cost includes ownership, maintenance and energy consumption costs and salvage value if applicable.

The unit cost identification of each option is carried out under the control of specific project information. Square and rectangular shaped 7 residential block types consisting 100 m2 housing units are considered in the project. Each block is 5-storey high, faces different orientations and has 2 or 4 housing units at one floor. The capital costs of each window option are calculated according to 3 different WWRs of each housing unit. In the calculation of the unit capital cost of a window system, all components such as window frame, window ledge and hardware (casement, sash, hinges, handle etc.), double glazing, window sill, sealant, gaskets and weather strips are taken into account. The unit prices of the material and the installation are obtained by having an average of the offers of four Turkish leading vendors. Window areas of each façade are multiplied by the unit capital cost acquired from the market search. Overhead and taxes are included in the unit costs; however design and engineering costs are not demanded by the contractors. Total price is calculated by considering the purchase of the windows for cash. In case of monthly payments 1% interest is added for the finance cost.

Operating costs are the costs arising from the regular and periodical operations which have to be incurred by the occupant after the installation of the window systems. Ownership, maintenance and energy consumption costs and salvage value are the basic items in the procedure of calculating the operating cost of the window systems. Periodical cleaning and security costs are included in the ownership costs for each housing unit. Maintenance costs are the replacement costs of windows at the end of their service life. The salvage value is added to operating costs depending on window frame material, for instance PVC is not a recyclable material while timber and aluminium frames can be reused.

Heating systems with natural gas and wall-mounted split air conditioner are assumed to be used in each housing unit in heating and cooling periods of each climatic region. Heating and cooling energy demands are simulated for housing units with different window systems, facing various orientations and having different shading strategies in different climatic regions with the help of EnergyPlus software. Heating energy costs are determined by multiplying the current natural gas unit price in KWh with annual, monthly or peak day heating energy demands of the housing unit in concern. The heating system efficiency factor (HEFF) is taken as 0.8. Natural gas unit price used in housing and commercial buildings in Turkey is announced as 0.569220 YKr/m3 which is equivalent to 0.0535 YTL/KWh (Web Link 2) for March 2008. However, the valid current price on the invoice, which is 18-20% above the nominal unit price, is determined by adding taxes and the other factors. Additionally, cooling energy costs are determined by multiplying the current electricity unit price in KWh with annual, monthly or peak day cooling energy demands of the housing unit in concern. Electricity unit price used in housing in Turkey is announced as 0.121050 YTL/KWh while the valid current electricity unit price is 0.19 YTL/KWh by adding taxes and the other factors.

3.4.2. Grouping Cost of Each Alternative

The costs determined for each option must be grouped by year over a number of years equal to economic service life of the window systems. Determining the life of window systems and the analysis period in years are crucial in grouping the cost of each alternative. The life of window systems and their components can be described in different ways such as design life, working life, service life, economic life, useful life and technological life. The estimated number of years during which a window system will perform its functions required is the useful life of it. It is a well-known fact that there are significant differences between the useful or service life of window components and the design life which is introduced by the manufacturers depending on different materials used in window systems. A database in which cost and time data of window components are stored is necessary in acquiring historical and realistic data.

On the other hand, the analysis period is the period of time, over which the life cycle cost is to be analysed. The length of analysis period is dependent on the users' preference and the life of the product. In addition, the analysis period should not be too long, since the discounting factor applied in the analysis tends to make the future costs less significant and besides, the risks and uncertainties in the future cannot be effectively defined based on the existing data. Window systems can be handled as "repairable or replaceable with some more efforts" along with the "assumed working lives of works and construction products" table of EOTA (EOTA 1999). Thus, analysis period is assumed as 25 years regarding the service life of window systems and time requirements.

3.4.3. Converting Cost to a Common Base

The costs of alternatives must be converted to a common base using a discounted cash flow method which incorporates interest rates and inflation in order to account for different operations taking place during the analysis period. The present value of future cost of window system can be calculated by using the factors and indices, especially those related to operational energy costs. However there is a lack of national source of factors and indices that will be used in LCC analysis in Turkey. Therefore it is assumed that a nominal discount rate can be determined by using long-term Treasury bond rates averaged over 12 months as described in Federal Energy Management and Planning Programs of Department of Energy in the USA (Fuller & Rushing, 2006). The nominal Treasury bond rate, i.e. market rate is converted to a real discount rate by subtracting the long-term average rate of inflation from nominal rate to correspond with the constant-dollar analysis approach. The nominal discount rate, i.e. Treasury bond rates averaged over 12 months is 16.25%, long-term average rate of inflation is 8.39%, and therefore real discount rate is approximately 8%.

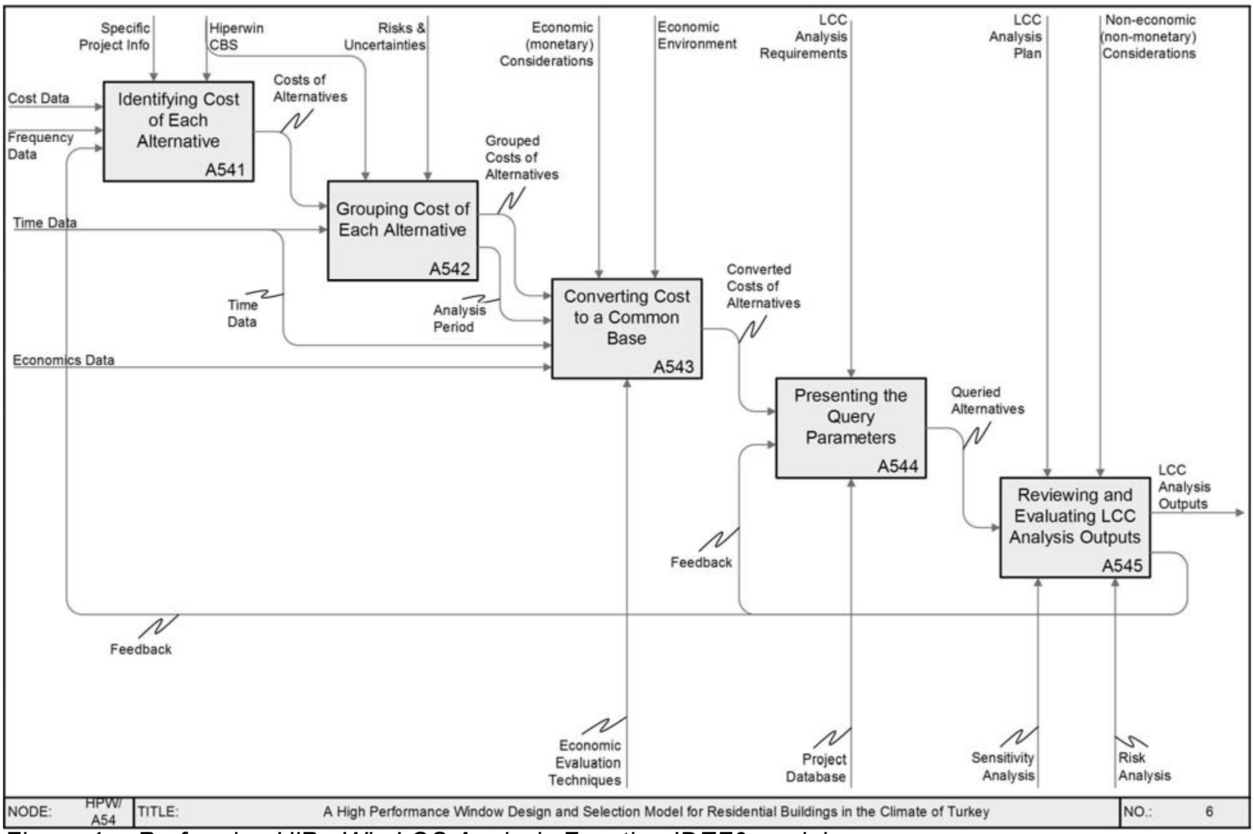

Figure 4 Performing HiPerWin LCC Analysis Function IDEF0 model.

3.4.4. Presenting the Query Parameters

The key items of the built environment and housing unit characteristics which are described at the top level of HiPerWin process model are transformed into query parameters. Query parameters are necessary for helping the users to specify their own case to find out the appropriate window alternatives by comparing their total annual heating/cooling energy consumption and related initial and operating costs. Those are defined for three climatic regions, twenty housing unit types, three window areas and windows with/without shading strategies. They are presented for directing the user to retrieve the appropriate alternatives through the database. The query parameters and LCC analysis requirements are integrated at this function.

3.4.5. Evaluating and Reviewing LCC Analysis Outputs

The energy consumption and cost data of the alternatives are evaluated in order to facilitate the user to select the appropriate window system alternative. Various evaluations and outputs will be presented for different users such as designer, owner, contractor, vendor, etc. Energy consumption, cost information and life cycle cost of the window alternatives for specific cases will be attained by the guidance of the query parameters. The results of the appropriate window systems for the particular case will be listed in order. Comments, explanations and suggestions in the context of the whole process will be made and the user will be able to access the technical specifications of the proposed alternatives. If the user does not satisfied with the energy consumption and cost of the options, he/she can specify another case by changing the query parameters in the design process.

Conclusion

HiPerWin model aims to assist the owners, designers, manufacturers, vendors and contractors to provide their understanding about the potential and performance implications of the new window products in different climatic regions of Turkey. The challenge is to attain a basic source which provides the required energy and cost data for the decision making in the design and selection of the residential window systems. Cost issues are evaluated by LCC analysis. The paper explains the HiPerWin LCC process model for residential window systems in detail which covers planning the LCC analysis, determining LCC analysis requirements, grouping window alternatives and performing LCC analysis.

HiPerWin "information model" will be carried out by using IDEF1X "Integration Definition for Information Modelling" method after completing "function model" mentioned above. For improving the conceptual model information modelling is a significant phase in developing the relational database which is the ultimate objective of this research. Although HiPerWin process analysis comprises the post-construction phase, the model will be utilized at design, construction and operating phases of the building production process. The model can be employed window system selection both in new and retrofitted buildings. Appropriate window systems will be selected among the alternatives by the designer, contractor and owner during the design, construction and operation process, respectively. While the designer can use all the query parameters such as orientation, block type, window area, shading strategy and all window components for the decision making in schematic design and design development phases, the owner only can use the parameters related with the window components and shading strategies for retrofitting. Besides, the vendors can guide their customers and the manufactures can provide feedbacks from the users and develop their products.

Making the energy and cost efficient window system selection prevalent will contribute to the national economy by enabling the usage of the limited resources which supports the sustainable design on country base. Since there is a lack of source which can be used in LCC calculations of the window systems in Turkey, the implementation of the model will serve as a basis of such a source.

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CAN ARCHITECTURE REALLY EDUCATE PEOPLE FOR SUSTAINABILITY?

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Summary

People interact with architecture not only by living, working or learning in it, but also through indirect messages that architecture represents via its design process, built form, functions, and patterns of use and maintenance. To educate people for sustainability, architecture should be recognised as a tool or medium that encourages people to live more sustainably. The paper presents three scenarios for architecture to promote constructive attitudes towards sustainability. First, are the positive first-hand experiences of a healthy human environment that sustainable architecture could provide to people who have occupied or visited such buildings. Second, is the fact people could learn about the effects of unsustainable design on the environment and society and the benefits of sustainable design from second-hand experience, such as verbal communication, publications and other media. Finally, involving people in sustainable architectural design processes could educate them to look at their environment, create a sense of belonging, and to take part in improving its conditions. Via these three aspects, people will gain positive experiences of sustainable design. They will learn how to interact with their environments and extend their perceptions about appropriate design, which could also lead to more demand for sustainable design in the future.

1. Introduction

This paper is based on research undertaken as part of an investigation into the relationship between sustainable architecture and sustainable education. The research aims are to discover how architecture can possibly be used as a learning tool for sustainable education and stimulate change of attitudes and behaviours towards sustainability. This paper focuses on the first stage of the investigation of the issues. It primarily illustrates a broad framework of the relationship and potentialities of using architecture as an educational tool for sustainability. The framework and possibilities presented in the paper are fundamental and need to be clarified before moving to the other stages, such as further exploration of how people reform their attitudes and behaviours when influenced by sustainable buildings, or making policy to promote the use of architecture as a tool for the change, or putting such the policy into practice.

2. Architecture as a Tool for Education

People interact with architecture in many ways. They commonly use it for living, working and other related human activities, such as storing goods and operating machinery. Many people also visit renowned architecture because of its aesthetic, cultural, or performance reputation, and often all three. Thus people visit the Pompidou Centre in Paris to see the aesthetic created out of the exposed structure and services (aesthetic and performance) and because of its importance as a gallery and for the outside performance activities that happen around it (cultural). People also read about architecture and the relationships buildings have with their contexts, such as their cultural and historical backgrounds, social and economic constraints, as well as any unique or interesting characteristics. Moreover, architecture has always conveyed social and symbolic messages, being the embodiment of the specific ideas and expectations of its designers, clients, and users (Voordt and Wegen, 2005). Several professions are currently involved in architectural design and construction processes, including architects, engineers, project managers, contractors, and builders.. Roles and responsibilities are varied depending on the profession and conditions of the project. Although in most contemporary architecture the people involved with the design and construction process are usually not the same group of people who use the building, in some cases, such as self-built projects, they are, and often in the past in the context of vernacular architecture, future users directly participated in design and construction. Despite the varied roles and actions of each individual being, all people are involved with architecture in some way and experience architecture most of the time.

When interacting with architecture, people have a chance to experience its creation through perceiving the skills and knowledge that led to the design and construction of the building. This experience of the underlying skills and knowledge is often shared between those visiting or using the building and also transferred from one group of participants to other individuals, groups and even the general public. Transfer frequently occurs among people in the same social institutions, such as the same family, the same community, and the same profession. In a family the shared architectural experience can come from looking at photographs taken on holiday by one of the family members. This discussion would be very different from the same building being written up in an architectural journal, but both are passing on experience about a building to people who have never seen it before. Based on the idea of socialisation, which is a process of teaching and learning where every individual and social institution represents the teacher and all members of the society are the learners (Scotter et al., 1979: 119), architecture is undoubtedly able to be a tool and medium to educate and connect people in society. People learn how to create architecture, to use it efficiently, and to maintain it properly. In terms of the natural environment, they can extend their understanding about the relationship between their actions, architecture, and ecology, and consequently develop their attitudes and actions towards better relationships. The process of learning from architecture was described by David Orr (1993; 1994) as 'architecture as pedagogy'. Although people can to some extent always learn from architecture, the capability of architecture to educate people depends on the quality of the architecture, effectiveness of the communication, and method of using architecture as an educational tool.

3. Sustainable Architecture and an Educational Tool for Sustainability

Since the late 20th century, sustainability has become an international concern in many professions, including education and architecture. The important role of education in elaboration of paths to create a more sustainable world became widely known after the promotion of education and public awareness in Chapter 36 of Agenda 21 (UNCED, 1992). The aim of education for sustainability is not only an enhancement of knowledge and concern about the issue, but also involves change in attitudes and promotion of responsible and sustainable behaviours. In the architectural field, concern that buildings are responsible for their impact on the natural environment and quality of life has gradually been accepted and has led to many responses to the issue, such as professional responsibility, assessment methods, and/or other design strategies (e.g. UIA, 1993; Barnett and Browning, 1995; European Commission et al., 1999; Edwards, 1999; Gauzin-Muller, 2002; Sassi, 2006). Furthermore, linking to the idea of education for sustainability, architecture can be used as a tool or medium that encourages people to live more sustainably.

To create sustainability, actions for sustainability are first required. Based on the model of responsible environmental behaviour suggested by Hines, Hungerford, and Tomera (1986-87, as cited in Hungerford & Volk, 1990) and developed by many educationalists (e.g. Hwang, Kim and Jeng, 2000; Kollmuss and Agyeman, 2002; Pruneau et al., 2006), to strengthen actions for sustainability, both internal and external factors should be determined. The internal factor or intention to act is influenced by knowledge of issues, knowledge of action strategies, action skills, and personality factors, including attitudes, locus of control, and personal responsibility. The external influences or situational factors encompass economic constraints, social pressures, and opportunities to participate and choose different actions.

According to the model, to support sustainable actions, architecture could and should encourage individual intention to act and provide an appropriate situation for sustainable practices. A framework of connections between sustainable architecture and responsive sustainable behaviours is presented in figure 1. In terms of external factors, sustainable design is one of the physical results of social demand for sustainable practices. It primarily originates from concerns for environmental and social issues and the number of sustainable design projects can increase only when more people request them. Political, social, and cultural factors in society and the architectural community form the main influences behind the creation of sustainable architecture. Meanwhile, sustainable architecture can also be part of suitable situational factors, as it usually provides opportunities to act in more sustainable ways. For example, a passive solar design strategy, such as maximizing natural lighting and natural ventilation, gives people the chance to use solar energy and hence form a connection with the natural environment. It leads to less demand for artificial lighting, smaller mechanical space conditioning systems, and consequently reduction of energy consumption to operate such a system. In terms of personal intention, there are three scenarios for architecture to promote constructive attitudes towards sustainability, these being direct experiences from sustainable design, indirect experiences of sustainable design and related issues from the architectural media, and participation in the design and construction process.

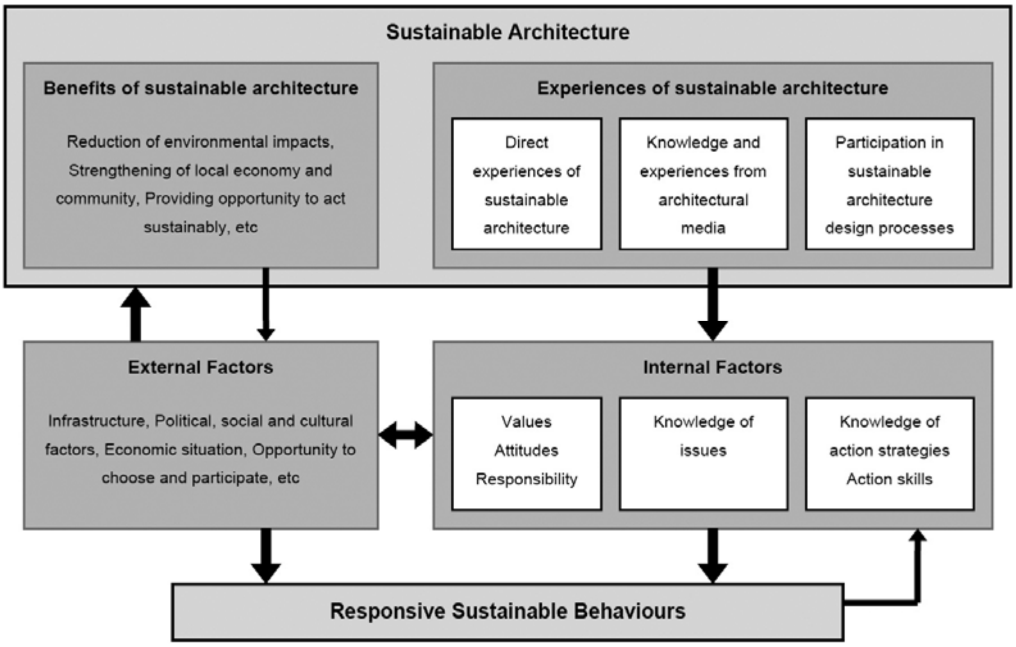

Figure 1 Relationships between sustainable architecture and responsive sustainable behaviours.

3.1 Direct Experiences of Sustainable Design

A healthy environment has emerged as an apparent catalyst for sustainable design and construction. To create a healthy environment, appropriate lighting design, air quality, acoustic conditions, thermal and physical comfort, and safety of use and maintenance have become basic issues for sustainable architecture. Although some issues may be not a direct threat to life, they are concerned with the satisfaction users have with architecture and its conditions and deal with the long-term health of the occupant and passers-by (Williamson, Radford, and Bennetts, 2003: 91). Design based on these issues normally prevents building related illness and responds positively to user needs. Since sustainable design usually maximises natural lighting and ventilation and often provides the occupant an opportunity to do at least some activities outside the building, it promotes natural stimulation that provides a counterbalance to artificial stimulants (Edwards, 2005: 144-145). Natural light, pleasing views, comfortable environments and an opportunity for personal control of light and ventilation also assist in reducing stress, enhance productivity, and improve the quality of work performance (Heschong Mahone Group, 1999; Boyce, 2004; Davis, 2005; Edwards 2005).

Besides providing a healthy environment, sustainable architecture commonly comprises design strategies that aim to reduce environmental impacts. Once occupants have encountered design solutions that provide a high quality of health and comfort and design solutions that are better for the natural environment, they usually feel good about the architecture and may be willing to change their attitudes and behaviours. For example, the occupants of Kingsmead Primary School in Cheshire report that they have a positive attitude to their school that was designed to demonstrate the virtues of low energy design and renewable energy use without jeopardising health (TSO, 2006: 12-19). Basically, the school was designed to make the best use of daylight and adapt to change. It also incorporated several sustainable strategies, such as selection of timber for portal frames from a claimed sustainable source, collecting rainwater for flushing the toilets and urinals, a solar collector to preheat hot water, and electricity generation by photovoltaic cells. The occupants were satisfied with the overall comfort of a building that responds to users' needs. The design intention and how the building is supposed to work and be used is clearly communicated to the occupants. The daylight quality is good enough to encourage users to keep the lights off and blinds up, and the design, as revealed in a post occupancy survey conveys a pleasing image to visitors and lifts perceived productivity at work (TSO, 2006: 19). As a result, the staff and students are overwhelmingly proud of their school and its environmental credentials. This self-esteem consequently influences and changes attitudes and behaviours of staff, pupils and parents. Accordingly, the positive first-hand experience that sustainable architecture could provide to people who have occupied or visited it is the primary encouragement that reinforces positive attitudes to sustainable practices. The experience leads to recognition of the benefits of sustainable architecture and higher demands for such architecture.

In addition, experience of using and maintaining sustainable architecture can form a tool to learn about the relationship between natural and human-created systems. The users can learn about building systems and the use of energy and natural resources to operate them. They can also monitor the building performance.

Several educational buildings, for example, Roy Lee Walker Elementary School in Texas (SHW Group, 2001; Furger, 2004), Sidwell Friends School in Washington DC (AIA, 2007; Sidwell Friends School, n.d.), and the Adam Joseph Lewis Center at Oberlin College in Ohio (Janda and Meier, 2005), have installed equipment and set up their educational lessons or programs to allow students or the community to study the building system operation, monitor the building functions, and measure the health quality of the facility.

3.2 Knowledge about Sustainable Design from the Media

Besides direct experience from actual activities, people could learn about the effects of unsustainable design on the environment and society and the benefits of sustainable design from second-hand experience, such as verbal communication, publications and other media. Since the 1990s, many conferences have been based on themes related to sustainable design (e.g. Passive and Low Energy Architecture Conferences, International Conference on Urban Regeneration and Sustainability, Greenbuild International Conference and Expo, and World Sustainable Building Conferences). These conferences provide a chance for architecture related professions to transfer ideas, knowledge, and experiences about and for sustainability. Moreover, there are now a significant number of architectural publications that deal with models of sustainable practices and/or the process of their creation. Many authors have illustrated environmental problems and the roles of architects and architecture, as well as presenting cases studies (e.g. Vale and Vale, 1991; Steele, 1997; Gauzin-Muller, 2002; Sassi, 2006; Hyde et al., 2007). Some focus on guidelines for architectural practice (e.g. Barnett and Browning, 1995; European Commission et al., 1999; Roaf, Horsley and Gupta; 2004; Kwok and Grodzik, 2007). While some provide the history of green design (e.g. Farmer, 1996; Steele, 2005) some employ the tactics of criticism (e.g. Guy and Farmer, 2001; Williamson et al., 2003; Moe, 2007). In addition, recent films like *Blue Vinyl* (2002), *The End of Suburbia: Oil Depletion and the Collapse of the American Dream* (2004), *Power Shift: Energy + Sustainability* (2004), and *An Inconvenient Truth* (2006) have aroused concerns about environmental impacts and have stressed the importance of change towards sustainable attitudes and habits, which architecture is also able to support.

Despite various sources of sustainable design solutions, knowledge related to sustainable practices still needs to be researched, developed, and frequently updated. The lack of suitable information often deludes architects and clients into inappropriate decisions. Regulations, directives, and standards related to environmental issues have to be promoted not only to the architectural profession but also to the public. The development of appropriate technology and building systems, which affect design decision making, should be publicised. For example, improvements in the appearance of photovoltaic cells offer a variety of choice in transparency, colour, and patterns, and give new application possibilities and potential for architectural integration (e.g. Hermannsdorfer and Rub, 2005). This may encourage more people to accept such a technology. Other established building systems and appliances, such as energy-efficiency appliances, compact fluorescents, low-flush and composting toilets, waterless urinals, and greywater recycling systems, provide wider opportunities to reduce the use of energy and resources, environmental impacts, and operating cost. Knowledge about the effects of building materials and components on human health and environments also influences the choices made by clients and designers. Because of more concern for environmental issues and higher demand for sustainable architecture, information about environmentally friendly products and systems is becoming increasingly available. However, because the green agenda has created a marketing opportunity, often many manufacturers and distributors do not present all the information about the environmental effects of their products but only present some dimensions that relate to sustainable issues (Woolley, 2000: 44-45; Williamson et al., 2003: 10-12). Clients and designers have to be careful about their selection and society should also require fundamental changes in the way the industry operates.

Accordingly, information about sustainable design should be obtained alongside experiences of sustainable design. This will enhance perception and appreciation and ensure accuracy of the information. Often the proposed vision, based on information and calculations undertaken during the design process is different from the actual results (e.g. Janda and Meier, 2005; TSO, 2006). Some building elements, such as sunscreens and building performance monitoring systems, may not be installed according to the design and specification, because of financial constraints, meaning energy consumption is often higher than expected. Higher than expected energy use occurs for other reasons. These might be problems with an installed system, longer-than-expected use hours, and installation and use of additional appliances. Because of this, appraisal and post-occupancy information is an essential way to improve building performance and provide lessons for future projects.

In addition, information and experiences about sustainable design must be provided in various forms, both quantitative and qualitative. While quantitative data are useful for research professionals and scientists, qualitative information is usually suitable for members of the general public who have little experience in integration of quantitative performance data. Moreover, information and experiences should come from various sources, such as designers, clients, builders and users. This is useful to promote sustainability and its practices to a wider range of people and potentially reduce any bias caused by dominant data sources.

Although general ideas of sustainable design could be applied in different situations, it is also necessary to mention the specific contexts of the practices. This helps people, particularly those who do not have first-hand experience, to understand the situation and facilitate the possibilities for applying some of the design concepts elsewhere. Since building systems, materials, and modes of construction that work properly in one place may be not suitable for others, the contextual data will help people who receive such information compare design solutions with their local conditions and apply them rationally.

Apart from information associated with architecture, information about related fields and local conditions, such as a geography and topography, climate conditions, available resources, and local culture, should be publicised. Such knowledge provides a broad view of sustainable issues and encourages comprehension about the relationships between architecture and other fields. It is a fact that design does not solve all problems (McDonough, 1996: 409), so sustainability can only be achieved by simultaneous moves to this goal in every field. The knowledge of related fields enhances the vision of how architecture can support other sustainable practices and, on other hand, how other practices can support sustainable architecture.

3.3 Participation in Sustainable Design Processes

Sustainable design requires expanded interdisciplinary collaboration and a greater focus on process (McLennan, 2004). Encouragement towards involvement in the sustainable architectural design process not only improves design quality, but also plays an important part in educating participants. The process explores the importance of values in addressing and resolving issues related to human and built environments, connects them to the local situation and everyday experiences of learners, and engages people in critical reflection of current lifestyle and actions. Through the process, stakeholders gain knowledge, experience participatory skills, and gradually develop sustainable attitudes.

Because each individual has a limited experience, besides self observation and personal experiences, both first and second hand, sharing ideas, problems, purposes, and visions can increase perception about issues and knowledge about how to solve the problems. Building professionals, including architects, engineers, specialists, developers, and builders, can always learn from each other. They can learn to understand the work and responsibilities of others, to have respect for what each person does, and to work collaboratively. Meanwhile, through the participatory process, building professionals can share their technical knowledge and experiences with the future users, so they can use architecture efficiently and maintain it properly. At the Hockerton Housing Project, for example, the architects of the project, Brenda and Robert Vale, worked closely with other project members who were also the future residents, such as David Leigh, an independent water design specialist, and Nick Martin, an experienced builder of low-energy buildings who acted as project manager (Hockerton Housing Project, 2001). Via the collaborative design process and self-build approach, all project members shared experiences and learned together from the project. Most of the local labour and contractors who were employed for more specialist work, such as plastering and brickwork, also enjoyed the innovative aspects of the construction and gained experience. The project also developed good relationships with many of its suppliers who were providing environmentally friendly building materials. They were keen to be associated with the project, as it helps in the promotion of the environmental aspects of their products. Since this first collaboration the residents from Hockerton have gone on to design and build two more houses on the site using the same sustainability principles and also offer a design advice service to others. This is a good example of skill being learned collectively and passed on. The Hockerton Housing Project also changed the attitudes of those who lived near it and who had watched it develop over the years. The group has just gained planning approval to put up a wind generator in the local village which will be big enough to supply all the village electricity needs and to export a surplus to the grid. This was done at the request of the village residents who are paying for the wind generator. These are the same village residents who opposed the original very much smaller wind generator that the Hockerton Housing Project wanted to install just after the houses were finished. This shows how real projects with real people trying to live sustainbly can change attitudes over time.

Although builder professionals may be the experts in design and construction, as Wates and Knevitt (1987: 115) noted, only users are experts in their lifestyle and relationships. Users can provide noteworthy information about a place, including experiences gained from using the place in many different conditions, and awareness of issues, living patterns and user preferences, which is essential for any analysis prior to design. They can also give details of how local architecture is being used and maintained and participate in evaluation of success and failure of the old and new built environments. Moreover, all participants can share their knowledge of other projects they have participated in or know about. From this they can gain motivation and learn how others overcame obstacles and then apply this knowledge to their situation. Sharing experiences and knowledge also increases people's awareness of responsibility for decision making (Sanoff, 1990).

Via design and planning processes, stakeholders can practice their citizenship skills, including communication, group facilitation and civic engagement. These skills can reduce misunderstandings and conflicts as well as create a sense of community. As suggested by Maser, Beaton, and Smith (1998: 31), good communication means *"respect for both listener and speaker, because one must first listen to understand and then speak to be understood."* To be a good communicator, each person should respect the other in sharing knowledge and ideas to create better understanding and better solutions for their community. The more chances to participate and practice citizenship skills, the greater the possibility of overcoming communication barriers, including lack of common experience or frame of reference, difference of culture and approaches, and inability to transfer experiences from one situation to another (Maser et al., 1998). Participants can also learn together to create an agreement and develop consensual problem-solving. Moreover, achievement and knowledge of past successes can give participants confidence to establish new projects and can help to encourage more people to become involved in such activities (ORTEE, 1994).

As Sanoff commented (2000: 26), typically, people tend to be motivated by self-interest and short-term vision. They are willing to be involved in solving problems when the problems directly affect them. Without valid reasons for driving themselves to act towards sustainability, it is hard for them to change attitudes, values, and actions. Participation in a design process gives stakeholders some sense of ownership and some degree of control (e.g. Alexander et al., 1975; Sanoff, 2000; Hubner et al., 2005) and fosters concerns about design issues and the environment. Consequently, people may recognise that they will be affected by environmental issues and problems of non-sustainability and that they should take part in solving these.

4. Conclusion

In conclusion, architecture, particularly sustainable architecture, can be used as a positive learning tool for sustainability. Constructive experiences of sustainable design can educate people about sustainability and sustainable practices, make them aware, and move them to behave responsibly and sustainably. The people who experience sustainable architecture will learn how to interact appropriately with their environments and extend their perceptions of appropriate design. Based on the framework of the relationship between sustainable architecture and responsive sustainable behaviours (figure 1) the three scenarios for experiencing sustainable architecture, (direct experiences, learning about sustainability issues through the media, and participation in sustainable design processes), act as incentives that encourage people's desire to live more sustainably. In reality, these scenarios can happen simultaneously and support each other to enhance responsible sustainable behaviours. First-hand experience, which is mainly related to the development of sustainable attitudes, can be recognised as a source of knowledge for actions, particularly about how to use and maintain architecture and the built environment. Although secondary information primarily plays a key role in enhancing knowledge of sustainable design and related green issues, this information can be related to action strategies and reinforce concerns about personal responsibility and action. Participating in the sustainable design process is fundamentally related to action skills. During a process of sharing information and visions, discussion, and integrating ideas, both experiences and secondary information are usually used. Such information and experiences in participation also contribute to the improvement of personal attitudes towards sustainability.

In addition, via these scenarios, people who gain positive experiences of sustainable design could also lead the demand for more sustainable design in the future. Conversely, to promote responsive sustainable behaviours in this way, it is essential there be many more sustainable buildings for people to experience. There needs to be a considerable number of examples of sustainable architecture of diverse project types, in many places, and in different conditions. The greater the number of sustainable buildings, the more people can be involved with experience of them. For this to happen it needs bodies like public clients and possibly enlightened developers to come forward and commission many more sustainable buildings. In addition, to advance the idea of sustainable architecture as an educational tool for sustainability also requires more detailed research to find out how attitudes and behaviours do change via the experience of sustainable architecture and how such a change affects the demand for sustainable architecture. This task should be a long term project between architectural, educational, and other fields. The participation of multi-stakeholders and professions in creating sustainable architecture and developing the use of sustainable architecture as a sustainable educational tool is also part of enhancement of responsible social attitudes and sustainable culture. These become one of many external factors influencing responsive sustainable behaviours. The resulting cause-and-effect cycle will lead to higher demand for sustainable architecture and make sustainable architecture a true educational tool for sustainable education.

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A SUSTAINABLE INDEX FOR CONSTRUCTION WORKS IN SPAIN

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Summary

Since the Brundtland Report was published, and despite of its ambiguity in the definition of the aims of sustainability, initiatives of all kinds related to sustainable development have increased in every sector of human activity, public or private.

Spain, along with the rest of the countries integrated into the European Union, is deeply committed to the promotion of policies aiming at a greater balance among economic, social and environmental aspects. Nevertheless, despite all the efforts already undertaken in our country in this respect, the results so far, according to the report 'Sustainability in Spain 2006' published by the Observatory of Sustainability in Spain, dependent on the Ministry of Environment, are insufficient, and consequently, a Spanish Strategy of Sustainable Development in accordance with the recently approved European Union Revised Strategy for a Sustainable Development is very much needed. Even more, the last report from the OSE, 'Sustainability in Spain 2007', points out a moderate advance towards more sustainable practices, particularly regarding economic aspects, but still deficient regarding territorial, environmental and social aspects.

During the past years, the convergence of the Spanish economy towards the EU has caused great environmental costs, territorial imbalance and social inequality that must be corrected for better sustainability of our development. The building sector, one of the most important of our economy, but also a great consumer of territory, energy and transport, must contribute to correct this situation by consolidating and increasing the initiatives towards sustainability.

1. Background

In concordance with the hope of reconciling the environment and economic development that gave way to the concept of sustainability, the term should be understood as a specific philosophy -an *ecosophy*, in Guattari´s words-- as a response to our ecological registries. In accordance with this train of thought, partial sustainability does not make sense, and the sum of its parts does not provide us with a sustainable society. Sustainability is a concept based on balancing different aspects, whose results have been defined as solidarity.

Moreover, the imprecise definition of sustainability has arisen numerous critiques, while transforming the concept of sustainability into a type of *symbolic capital* with the added risk of becoming an empty label for the consumer market.

However, maybe it is now more necessary than ever for this new sensibility provided by sustainability to propose a balance between the economic, social and environmental. This affirmation, made in a general sense, is not less realistic for the construction sector, along with all of the sub-sectors it influences; it plays a key role in the Spanish economy and thus for the sustainable development of our society, while also being the one with the largest environmental impact.

As we all know, the construction sector extracts more raw materials than any other production sector, and the creation and operation of the space created (including the energy used in construction processing and transporting materials and products) supposes at least 50% of Europe's energy consumption. Its impact on the land is also evident, keeping in mind that 80% of the inhabitants live in urban areas. To this we must add the high volume of waste from construction, use, maintenance and demolition, all generated by the buildings; this volume continues to increase and this implies serious difficulties for their reuse and/or recycling.

The commitment to a more sustainable development requires the adaptation of all agents implied in construction, going beyond the mere superficial adoption of a series of concepts, techniques and mechanisms "supposedly sustainable." The change must work on a deeper level and affect the method of planning, projecting and constructing. It is also necessary to surpass the current excessive dispersion and join forces, not just sum up the existing forces, but respond to a broader expansion based on this previously mentioned balance between the economic, social and environmental.

2. Spanish Context

In April, 2002, the European Union ratified the Kyoto protocol which gave way to the adoption of measures, programs and both joint and separate guidelines for each country to reach the aims assumed in the protocol. More specifically, the EU committed to a reduction of 8% of its total, but understanding the needs and characteristics of the different countries integrated, the assigned reductions or increases allowed for each country are different. For Spain, a 15% increase of emissions was forecasted.

This same year, the Directive on the Energy Performance of Buildings (Directive 2002/91/EC), which the member states had to incorporate into their national legislation before January 2006, guarantees that the building standards include guidelines on insulation, orientation, energy and hot water consumption. This directive also establishes the obligation to carry out periodic inspections of boilers and air conditioning systems, and to include an energy performance certificate in all newly constructed and existing buildings, with some exceptions. In Spain the European directive's requisites have been incorporated into the Building Technical Code, approved in 17 March, 2006.

If we take a close look at the panorama of activities relative to sustainability in construction in Spain, we see an excessive atomism in terms of the initiatives taken, which results in an unnecessary multiplication -even reiteration- of the efforts instead of a convergence of them towards a common aim. To this we must add that, besides that they all respond to the interests of the specific activity in question, they fundamentally focus on the economic and environmental aspect of sustainability, practically leaving out its social aspect.

However, at this time, as the European Union has recognised, the emphasis should be the development of reliable sustainability indicators, with special attention to social indicators.

Expected impact:

The creation of a reliable index of sustainability indicators for Spain will set, on a permanent basis, a common reference for the assessment of the construction sector sustainability, in the improvement of which all parties involved will be welcome to participate.

At a later stage, and following the Spanish index, it is possible to initiate the same project in other countries of the EU, in order to get a series of national indexes that will allow a comparative base for the assessment of sustainability in the European construction sector and the implementation of measures towards its accomplishment.

3. Aims

3.1. Definition

In accord with that previously stated, and as a response to the current state of affairs, the aim of this research project is to develop an index of sustainability indicators for Spain that should:

- Be representative of and applicable to the complete sector
- Transcend the construction sector's different sub-sector's partial interests, along with those of the different agents implicated in the building process
- Be flexible enough to absorb possible future changes

3.2. Operative principles

For this point we have focused on establishing the main characterising operational principles for the complete index development process, and for the index itself, and keeping in mind the general situation described, the following are essential:

- Focus on the balance between social, economic and environmental factors
- Take the complete life cycle as a reference, both in terms of materials and processes
- Consider the set of agents that intervene in the building process
- Conceptual robustness as a consequence of applying the general principles of sustainable construction

3.3. Developmental framework

To achieve the defined aims, it seems logical and suitable to establish the same guidelines for this project as those used by the National Construction Programme included in the previous *Plan Nacional de Investigación Científica, Desarrollo e Innovación Tecnológica* 2004-2007 [Spain's 2004-2007 National Scientific, Development and Technological Innovation Research], created by the *Comisión Interministerial de Ciencia y Tecnología* [Inter-Ministry Commission on Science and Technology]. The Programme aims to '*configure sustainable construction that contributes to a harmonious growth of our society and that establishes the bases for a better future for the generations to come'.* This aim establishes three key thematic priorities: (1) Materials and products for construction, (2) Technologies, systems and constructive processes, and (3) Evaluative and management systems in construction.

As we can see, the National Construction Programme establishes a broad framework of possibilities for the construction sector and its different sub-sectors to propose initiatives to improve their sustainability and constitute the operational bases in the future.

It is also important to introduce and maintain the European reference, among other things, as a response to the different initiatives of the European Commission for creating a European Research and Innovation Area (ERIA).

4. Methodology

In order to achieve the previously defined aims, we first need a comprehensive analysis of the different phases of construction, always from the perspective of the life cycle, with the aim of being able to establish the most adequate indicators to evaluate the sector's sustainability, but also with the aim of suggesting changes or modifications that can improve its sustainability.

Parallely, and given that construction is integrated by not only a set of processes, but also a wide range of agents of all sorts with their own, sometimes contradictory interests, it is necessary to gather the information on each one of them in order to create an index of indicators that properly represent the sector's complete reality.

In accordance with this general train of thought, we can define the following developmental phases:

- **Phase 1:**
  Collecting and selecting data.

  Stage 1
  Collect documentation on the agents involved in construction (annual reports, publications, articles…).

  An approach to the creation of a construction sustainability index in Spain through indicators for agents intervening in the building process first requires that the indicators be identified. For this, we have started from those agents included in the *Ley de Ordenación de la Edificación* (LOE) [Building Regulation Law] to which others have been added to, not included in the LOE, even though of great importance to the process.

Table 1 Building Agents

Included in the LOE	Not included in the LOE
Developer	Governments (central, regional and local)
Planner/Designer	Credit Agencies
Builder	Insurance Companies
Project Manager	Real Estate Agents
Foreman	Utility Companies (energy, telephone, internet...)
Quality Control Entities	Universities and Research Centres
Product Suppliers	Training Centres (Work Foundations, Professional Training Institutes, etc.)
Proprietors and Users	Standards Entities
	Operators, installers, maintenance…

The final aim of this stage is to create a list of agents linked to the building process, defining the activity and legal framework in which it is developed, besides the responsibilities and obligations for this process.

A legal bibliography has been started from the information collected with periodic updates.

Stage 2
Definition and limits of the different phases and construction processes for future analysis.

Parallely, and keeping in mind that the final aim is to determine the influence of each of these agents in the building process, with the aim of establishing a weight for elaborating the index, we must also organize each of the agents into production or activity sectors, but also according to the construction process phases in which they intervene.

Each of these phases includes a series of operations that are used to identify the different agents implicated. Moreover, the possible appearance of a single agent relative to the various phases may be indicative of their greater or lesser incidence in the process.

The aim of this stage is to configure a comprehensive table linking phases and agents. A list of associations, research institutes, etc. was also created to group the different agents implicated in the construction process in order to contact these entities and obtain updated information on each of the areas of activity.

- **Phase 2**
  Data processing.

  The data collected from the previous phase, which can be presented through annual activity reports, specialized sector publications, conferences, articles, news, etc., are then processed in order to extract a true representation of each activity to create the proposed index.

Conclusions from Phase 1 and 2:

Organising the building agents in tables according to their legal framework and by the responsibility their activity derives, along with a table linking phases and agents, or a list of associations, were initially posed as a necessary tool for the research. However, in practice they constitute a complete map of the sector, which is key to understanding its complete complex performance.

Phases 1 and 2 have laid the foundation to what could be a complete, comprehensive database of the sector, designed for clarity and capable of being periodically updated.

- **Phase 3**
  Selecting the indicators by processes, sectors and agents.

  The currently available indicators relative to the construction sector in Spain will be associated, on the one hand, by their corresponding application phase, and on the other, by the agents implicated in it.

The aim is to identify and organise the numerous indicators currently used in the construction sector, and which have supposedly been chosen for being useful, representative and feasible. Then, they will be selected in accordance with this project's aims. Once the final list of indicators is set, a descriptive file for each one of them will be created to define the application framework of the indicator.

After having finished this phase, a critique-informative conference would be organized with a small number of experts. The researchers will explain the origin and development of the project to the group members, and present the available results for discussion and critical review.

Conclusion of Phase 3:

Phase 3, which was currently in progress when writing this paper, has become especially difficult, mainly in terms of collecting data for the indicators used in Spain, and then the selection of those to be used in the index. This is why we have decided to use some of the leading companies and entities as references: FCC, Ferrovial, the Basque Country's Government and ITEC. It is also necessary to adapt indicators that attempt to measure the same parameters, but are formulated differently.

However, once having finished this phase, the currently used indicators in construction will be greatly clarified, making it possible to add others which are deemed equally necessary.

- **Phase 4**
  Establish the priorities and importance (weighting criteria) of each factor. Development of a mathematical model (application) to manage data.

  The aim of this phase, once the index's indicators are selected, is to establish whether it requires a mathematical model as a function of its characteristics, or a battery of indicators with the appropriate application level allocated.

  Having done this, the most suitable weighting criteria will be set and if necessary, the corresponding mathematical model.

- **Phase 5**
  Reviewing the Index. Corrections. Definitive Proposal.

  The aim of this phase is to review the index. Once a series of preliminary tests are performed, and before proposing the definitive index, it will be submitted to external testing from experts, after which another critical review will be held.

Previsions for the conclusion of Phases 4 and 5:

Given the possible importance of the development of an index, not only for the Construction sector in general, but for its different sub-sectors, we are preparing to participate in Spain's upcoming Congreso Nacional del Medio Ambiente (CONAMA) [National Environmental Convention], as well as taking other actions to disseminate the project's results.

- **Phase 6**
  Parallel initiation of the same project in other EU countries.

  The aim in this phase is to start the same project parallelly in other European Countries (United Kingdom, France, Germany, Italy and Portugal), with the aim of obtaining a series of national indexes that make up a solid comparative base to evaluate the sustainability of construction in Europe and implement measures for achieving it.

5. Conclusions

- Even after having organised critical sessions with experts throughout the development of this project, it seems necessary to establish a more direct collaboration with the different agents and sub-sectors that make up the construction sector in Spain. The aim is to update the information obtained from each one of them, their implication in the process, and a joint effort to adapt and improve the proposed index according to the needs and function of these sub-sectors.

- Moreover, there is an obvious need to constitute a permanent platform to manage the database created during the development and periodic updating of the index. This platform would constitute an open dialogue within the sector, with the same integrating character that marks the index. This way, the platform can articulate the relationships with those EU countries that have started or will start the creation of indexes similar to our own.

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SUSTAINABLE CONSTRUCTION AND HIGH ARCHITECTURAL QUALITY – A CONTRADICTION?

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Keywords: Total Quality, brick, sustainable, passive-house, demonstration, architecture, assessment

Summary

The feedback from designers and architects on several demonstration projects for sustainable construction in Austria was not as positive as could have been expected, the criticism focused on the esthetical and architectural quality of the projects. As a reaction to this situation a new systematic approach was developed to ensure a highest possible level of technical and sustainability quality but going in parallel at the same time with good and modern architecture. Main elements of this procedural approach are the involvement of well-known independent organizations, e.g. architects federations or the like, an architectural competition to guarantee a broad participation of young and ambitious architects and last but not least the involvement of an interdisciplinary team of experts who accompany the planning architects throughout the whole design process. This procedural concept was applied to a newly developed residential area in Innsbruck in The Tyrol.

1. Introduction

Very often one can hear: buildings designed to reach a maximum level of sustainability are probably modern, healthy, ecological, and future oriented, but they are not beautiful or they are even ugly, they show disappointing architectural and esthetical quality. Is that true? And even more important: is that a must? What can be done to avoid this situation?

2. Some Examples of Older Sustainable Building Demonstration Projects in Austria

Since about 7 years the Total Quality (TQ) tool is now in use in Austria. This TQ tool is the national implementation of the Green Building Challenge framework. Very recently the TQ tool has been amalgamated with two other Austrian rating systems, the so-called “Oekopass” of the Institute for Building Biology and the “klima:aktiv” model of the Ministry for Environment and will in the future be called TQB.

The association of Austrian clay brick and roof tile producers (VOEZ) has initiated several brick projects, which were evaluated and certified with the TQ assessment tool. All these projects had very good results in the TQ assessment, and one of these projects – the SOL4 office building in Moedling near Vienna – even reached the highest result of all projects which were assessed with TQ so far.

Figure 1 Project Apartment Buildings Telfs Puite in The Tyrol

2.1 Project "Apartment Buildings Telfs Puite" in The Tyrol

This project is part of a big residential development area in the second biggest city in The Tyrol. Two apartment blocks with 30 flats were designed as brick passive houses with a brick cavity wall construction (U-value 0,15 W/m^{2}K) for the external walls. The heating energy requirement of these two buildings is 14 kWh/m^{2}a. The heating is mainly provided by the controlled ventilation system, but there are also small dimensioned radiators in the apartments for the personal comfort of the users. Warm water is produced by solar collectors. The buildings were assessed with TQ, the rating was 3,78 (out of maximum 5 points – this was the best rating for a residential building so far)

2.2 Project "Semi-detached Houses Hamoder" in Linz / Upper Austria

12 double-houses were built in a very scenic but noisy place on the outskirts of Linz, the capital of Upper Austria. Again a brick cavity wall with external rendering was the solution for external walls (U-value 0,15 W/m^{2}K). The heating energy requirement of these houses is between 12 and 14 kWh/m^{2}a. The heating is mainly provided by the controlled ventilation system in combination with small heat pumps. Warm water is produced by solar collectors. The buildings were assessed with TQ, the rating was 3,38 points.

Figure 2 Project semi-detached houses Hamoder in Linz

2.3 Project "Residential Building Wienerberg City" in Vienna

A big apartment block with 99 flats was built on the grounds of the old Wienerberger factories on the southern outskirts of Vienna. Of the 9 floors 7 are built in concrete frame construction with clay block infill masonry, thermal insulation and different facades (metal, rendering and clay panels), in the two top floors the external walls are monolithic clay block masonry with external thermal insulation compound system. The average U-value of the external walls is 0,14 W/m^{2}K, the heating energy requirement of the building is 15 kWh/m^{2}a. The building has a controlled ventilation system; the small heating requirement is covered by district heating and distributed via the ventilation system. There are also solar collectors for warm water. The building was also assessed with TQ, the result was 3,44 points.

Figure 3 Project residential building Wienerberg City in Vienna

2.4 Project "Office Building SOL4" in Moedling / Lower Austria

The first office building with passive house standard in Austria was built in Moedling, a small town south of Vienna. The external walls are made with clay block masonry and external thermal insulation (mineral foam boards). In big parts of the façade photovoltaic panels replace the rendering. The average U-value of the external walls is 0,12 W/m^2K, the heating energy requirement of the building is 10 kWh/m^2a. The building has a controlled ventilation system with heat recovery; the small heating requirement is provided by two heat pumps. There are also solar collectors for warm water. Electricity is provided by the photovoltaic system. The building was also assessed with TQ, the result was 4,21 points – this was the best result of all buildings which were assessed so far.

Figure 4 Project SOL4 in Moedling

Although all these projects reached excellent results in the Total Quality assessment, which is in principle an assessment of the sustainability of the building, and although the buildings include the most modern elements of heating and ventilation equipment, the resonance from leading designers and architects, especially the young and committed architects, was not very positive. There feedback was that these buildings are probably very innovative and future oriented concerning the technical performance but they do not satisfy high esthetical architectural requirements.

3. Development of a New Procedural Approach for Demonstration Projects

3.1 First Step: Selection of Partners

The situation described above lead to an intensive and deep going process to develop a new approach for demonstration projects which can guarantee that both the technical and ecological requirements and also the esthetical architectural requirements can be met at the same time. The first and most important strategic step was the selection of professional partners with high reputation and here in the first instance the involvement of a well known architectural organization. It was decided to choose an organization which is active in The Tyrol, because this part of Austria is quite open for innovative architecture and new approaches and secondly because we found a very competent and cooperative partner in Innsbruck, the capital of The Tyrol from the sector of the project developers who was willing to make such a project together with us.

The selected architectural organization is called "architektur und tirol (aut)", which plays an influential role in the architecture in The Tyrol. Most of the young and committed architects are members of this organization and regularly participate in the meetings and events organized by "aut". One interesting example what type of events "aut" organizes was an exhibition about the work of the famous South-American architect Eladio Dieste a few years ago.

The selected project developer was "Wohnungseigentum (WE)", one of the biggest project developers in the sector of residential building in this part of Austria. WE is a developer with very high reputation and was already our partner for the above mentioned demonstration project in Telfs.

3.2 Second Step: Architectural Competition

The next important step in the process was the development of a two step architectural competition. Besides the intention to demonstrate exemplary sustainability, lowest energy consumption (passive house standard), high esthetic quality and modern technical equipment it was also a target of the competition to show the possibilities of bricks and clay blocks in their various product types in an innovative way. The idea was that by means of a competition many young and ambitious architects can be motivated to deal with this traditional but sometimes a bit out fashioned construction material and to develop new ideas what can be done with this material, how it can be used to create modern architecture. For this purpose the brick industry offered a special price for the best and most creative ideas for the use of clay products.

The other important criteria for the competition were:

- Economic situation in the construction phase and in the usage phase: the project must meet the requirements of the subsidy regulations in The Tyrol
- Acoustic performance: there is high noise load at the site due to a motorway and a railway which pas by very close
- Energy performance: the project must fulfill the criteria for passive house standard
- Sustainability: the project will be assessed with TQB and should reach a high ranking

It was decided to organize the competition in two steps. In the first open phase all local architects from The Tyrol were invited to send in their project proposals. In this first stage 25 architects forwarded project proposals, which were treated anonymously. The high ranking jury consisting of representatives of the city of Innsbruck, the project developer WE, well-known architects and engineers selected the best 7 projects. In the second phase those seven architects and their teams were invited to rework and detail their proposals based on the comments and recommendations of the jury. During the whole process an interdisciplinary team of experts and also a team from the brick and roof tile industry was available to support the participating architects concerning all relevant sustainability aspects, concerning building physics (thermal performance, acoustic performance) and concerning the use and possible limitations of the use of clay products. By doing so it was guaranteed that the target to get an optimal result integrating technical and esthetical aspects and the innovative use of clay products could be reached.

In the second round the jury selected one winner project and awarded two projects with a second price. The special price of the brick industry was split between three projects, the winner of the architectural price also received the first price of the brick industry, and two other projects were awarded with a second and a third price. The appraisal of the jury for the winner project is very interesting, it says:

- The project fulfills the requirements of a human design and construction and takes into account the needs of the future users
- The structured and membered but at the same time interconnected structure correlates ideally with the use of bricks
- And creates a livable and communication friendly environment with courtyards for the future users
- Additionally the planning allows to realize the individual parts in esthetically different brick variations also with visible facades in parts of the buildings

The winning team is Dipl.-Ing. Andreas Scharner and Dipl.-Ing. Peter Wurnig from Vienna who also have an office in Innsbruck.

4. The Winning Project by Architects Scharner and Wurnig

4.1 Architectural Concept

The basic idea of the architects is a vertically compressed garden city. Important aspects for the architectural design are:

- The creation of an individual living feeling through individual terraces and gardens
- Small units with maximum 20 apartments each, situated around courtyards
- A generous and attractive transition from public to private areas by means of light-flooded staircases and connecting bridges and openings in the building structure
- The membered structure of the buildings allows for the development of an individual living feeling and supports the neighbourship

4.2 Structure and Orientation

The membered structure is grouped around courtyards which open to the south; in north direction to the street the courtyards are closed through the buildings themselves. Alongside the railway on the north side of the site the buildings are higher (ground floor + 3) to protect the courtyards against the noise. The openings between the buildings are closed with glass sound-proof walls and in the openings facing clay brick masonry is used to absorb the noise. Most of the flats have a clear south orientation. Shading interaction between the buildings is avoided by the arrangement of the buildings on the site.

As a result of the structured arrangement of the six buildings the site density is exceptionally high.

Figure 5 Project Sieglanger by architects Scharner and Wurnig – ground floor level

Altogether there are 83 flats with 2, 3, 4 or 5 living rooms and net areas between 39 and 121 m^2. The total net area is 6658 m^2. Some of the flats are maisonettes on two levels. Approximately two thirds of the flats have a south orientation, one third is east-west oriented. Half of the flat have a private garden or a roof terrace.

4.3 Concept for the Green Areas

Green areas are an essential part of the architectural concept. The open structure provides the possibility to have a garden landscape in between the individual buildings, which consists of courtyards, groups of trees, playgrounds and private gardens. Further on the garden landscape is also brought to a vertical dimension by means of the terraces which form sort of “hanging gardens”.

4.4 Facades and Materials

As already said it was an essential target of the project to use clay materials as far as possible. Therefore the greatest parts of the external and internal walls are made with clay block masonry; the external walls have an external thermal insulation compound system with rendering. In parts of the façade in public areas cavity wall construction will be used with facing brickwork with a thin semi-transparent coating.

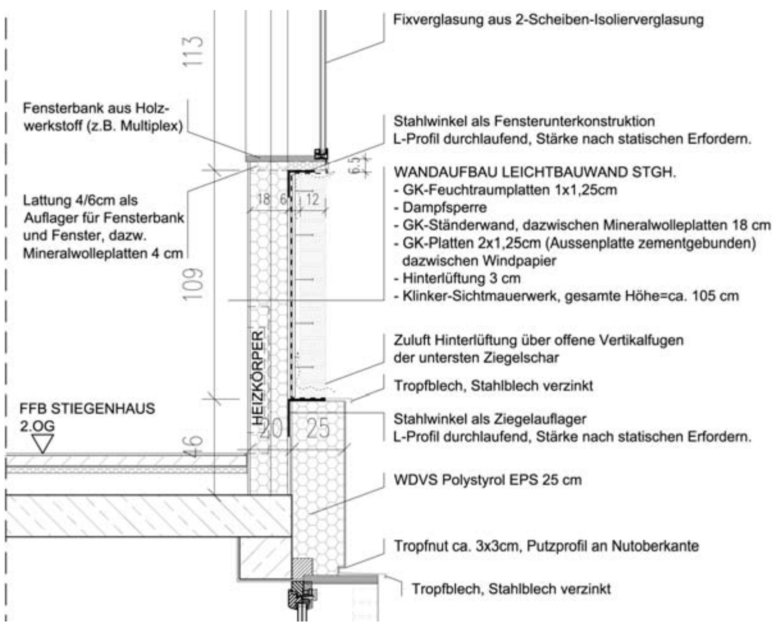

Figure 6 Project Sieglanger by architects Scharner and Wurnig – facade section

4.5 Energy Concept

The whole residential area will fulfill passive house standard which means a heating energy requirement of less than 15 kWh/m^{2}a. In detail the following is foreseen:

- A controlled ventilation system with heat recovery
- Warm air collectors to pre-heat the air for the ventilation system
- Solar collectors for the warm water production.

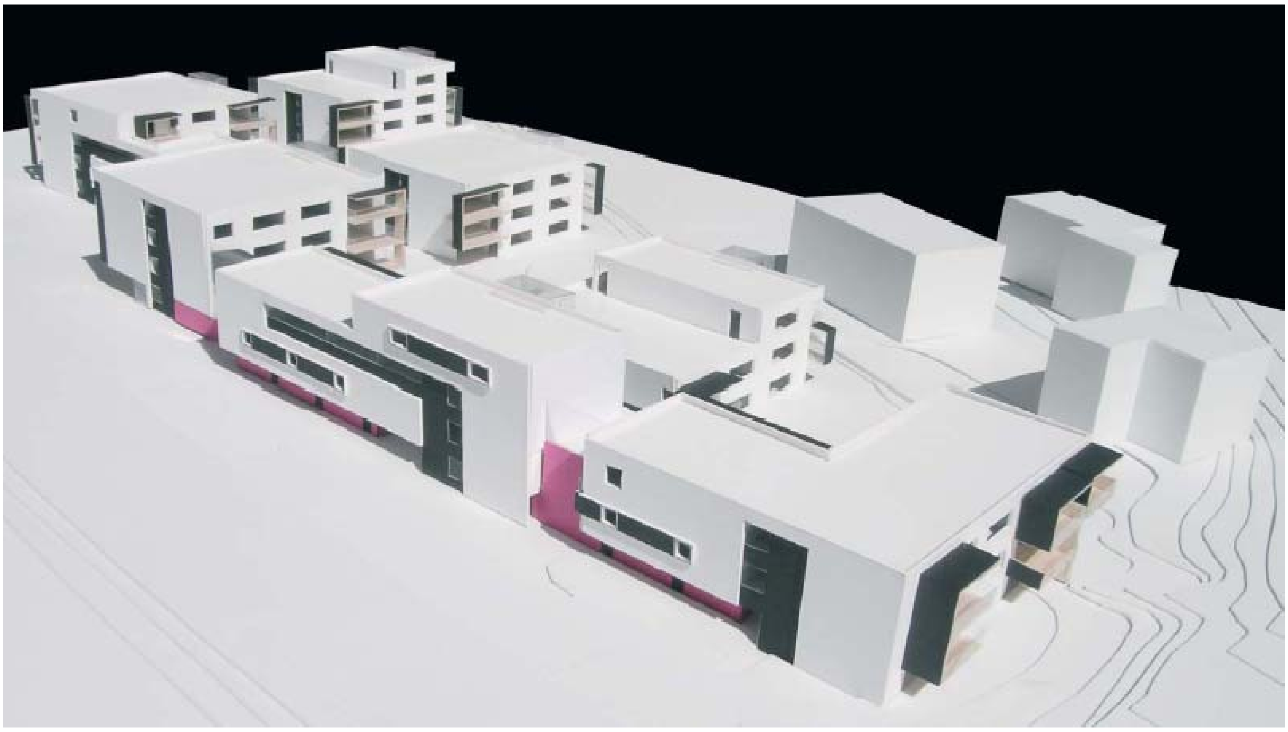

Figure 7 Project Sieglanger by architects Scharner and Wurnig – model photo

5. Current status of the project

Originally it was planned that the project should start in 2007. Due to unforeseen problems with the local building authorities of the city of Innsbruck the start of construction has been delayed until now. Most probably the work will now start very soon and should be concluded until summer 2009.

6. Conclusion

The national implementation of the Green Building Challenge framework, the so-called Total Quality tool has proven to be a valid and easy to apply instrument for the assessment and certification of buildings concerning their sustainability. The Austrian clay brick and roof tile industry has contributed to the development of the TQ tool and its further improvement by applying it to several demonstration projects in both the sector of residential buildings and the sector of office buildings. The feedback from designers and architects was not as positive as could have been expected, the criticism focused on a lack of esthetical and architectural quality of the projects. As a reaction to that a new systematic approach was developed to ensure that a highest possible level of technical and sustainability quality can be reached but going in parallel at the same time with good and modern architecture. Main elements of this procedural approach are the involvement of well-known independent organizations, e.g. architects federations or the like, who accompany the planning process. Another important element is the architectural competition to guarantee a broad participation of young and ambitious architects. Last but not least it proved to be important for the result to have an interdisciplinary team of experts who can accompany the planning architects throughout the whole design process.

This new procedural concept was applied to a residential area in Innsbruck in The Tyrol. Due to unforeseen circumstances we can state for the time being that the planning process is going on very satisfactorily and that the project seems to be very ambitious and will most probably fulfill all the high expectations. Unfortunately it is not possible yet to report about the final result, because construction work will only start in spring 2008 due to a delay caused by troubles with the local building authorities.

EFFECT OF FLY ASH ON PROPERTIES OF CEMENT AND LIME BASED COMPOSITES

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Summary

Fly ash as waste material, that is characteristic by latent hydraulic properties, can substitute certain amount of Portland cement in the composition of cement based composites. However, it can be used as partial aggregate replacement as well. In concrete production, around 90% of all energy consumed is used to obtain cement, which is also a major source of CO_2 emissions. On this account, partial replacement of cement binder with the recycled waste materials is profitable from ecological as well as from economical point of view. Fly ash can also be used as partial replacement of lime. Due to its pozzolanic activity, it can significantly improve particularly the mechanical properties of lime renders where it can be used instead of cement for that purpose. In this paper, basic mechanical and hygric properties of cement and lime based composite materials containing fly ash as partial cement or lime replacement are studied and comparison with materials without any admixture is done.

1. Introduction

Nowadays we are standing behind lack of natural raw materials and our lifestyle brings the pollution and greenhouse effect. On that score is tendency of maximal recycling of all types of wastes and reducing their disposal. The greenhouse effect, discovered by Joseph Fourier in 1824 and first investigated quantitatively by Svante Arrhenius in 1896, causes that the Earth's average surface temperature is warmer than it would be without it. A recent warming of the Earth's lower atmosphere is believed to be the result of an enhanced greenhouse effect due to increased concentrations of greenhouse gases in the atmosphere.

The combustion methods, production of cement and lime for example, are presently considered as significant source of greenhouse gases, especially of carbon dioxide. From the basic calculations we can obtain the amount of CO_2 production. For example, in lime manufacture, from 1,500 kg calcium carbonate according reaction it is produced nearly 38.10^3 m^3 CO_2. Within the production of 1 t of Portland cement, 1 t of CO_2 is evolved in the atmosphere. Each day we emit huge amount of combustion gases together with solid wastes that are formed during incineration processes. These solid wastes can be generally divided into three basic groups: under-furnace grate slag materials, solid wastes from electro-filters (ash materials) and fly ashes from sleeve and catalytic filters. These fly ashes differ in grain size distribution, composition and amount of heavy metals, and many other parameters. Among them, the toxicity is from the point of view of their utilization at the top of the interests. Depending upon the source and makeup of the coal being burned, the components of the fly ash produced vary considerably, but all fly ash includes substantial amounts of silica (silicon dioxide, SiO_2), both amorphous and crystalline, and lime (calcium oxide, CaO). Toxic fly ashes are contaminated with toxic organic compounds, especially with polychlorinated dibenzo-p-dioxines, benzofurans and biphenyls phenols (POP compounds – persistent organic pollutants).

These highly toxic fly ashes should be detoxified by safe technologies because the current practice of landfilling these materials is quite provisional from an environmental point of view. Presently, no effectual legislative limits on the content of toxic POP compounds in the solid wastes from municipal waste incinerators are valid. The legislative process that assessed the limits of the toxicity of fly ash materials was in EU finished in 2007 (EU regulation No. 850/2004, No. 1195/2006, No. 172/2007). On the other hand most of ashes from electro-filters are according to current legislative harmless because of low content of polychlorinated dibenzo-p-dioxines and benzofurans. Electro-filters enable fractional separation of fly ashes with respect to particles size. It can be used for the optimization of composition in the study of fly ashes recycling from the point of view of optimal properties of solidified products for building purposes. Under-furnace grate slag materials represent majority part of solid waste produced in incinerators. However, the amount of solid waste is highly dependent on the type of burnt material. It is possible to say that approximately one weighted third of the total amount of burnt waste will come out of incinerators in form of solid waste. In case of meeting European Union requirements on landfilling reduction to 35% in 2020, the amount of recycled solid waste will be 500 kt per year. It is absolutely evident that successful economical solution of recycling of these waste materials is highly actual topic. Therefore, development of new advanced building materials having higher utility quality is necessary in the sense of the sustainable progress of building industry. However, not only the final advanced properties of materials should be considered. Also the energy and natural materials consumption should be taken into account. Hence, the secondary raw materials (i.e. waste materials) will find widespread use in building materials production.

The application of fly ashes in building industry is oriented first of all into the production of building materials, such as cement, concrete, artificial light aggregates, bricks and ceramics (Jian-Hua (2006), Coelho (2006)). Also, their application in grouting mortar and cast floor layers is possible. Fly ashes from municipal waste incinerators can be applied in a similar way, using all the experience gained at power and heating plant fly ashes. However, their chemical, mineralogical and granulometric composition and the toxicity remainders have to be taken into account. Fly ashes, as waste materials, are characteristic by latent hydraulic properties and hence they can substitute certain amount of Portland cement, in the composition of cement based composites and concretes, or some quantity of lime in lime based composites. However, they can be used also as partial aggregate replacement. Partial replacement of inorganic binders in composite materials with the recycled waste materials is profitable from both ecological and economical points of view.

In this paper, basic mechanical and hygric properties of cement and lime based composite materials containing fly ash as partial cement or lime replacement are studied and comparison with materials without any admixture is done.

2. Tested materials

The sustainable progress brings demands for development of new, advanced building materials having higher utility quality and durability. On this account, we tested commonly used inorganic binders, cement and lime, combined with pozzolana active fly ash, a waste material. The amount of fly ash as a binder replacement was taken as a maximum to give a material with good rheological behaviour. Fine-grained cement mixtures without and with fly ash addition, denoted as FGC and FGCF, respectively, and two lime based composite materials without and with fly ash addition, VO and VOF, respectively, were prepared. Table 1 presents the exact composition of the studied mixtures.

Table 1 Composition of tested mixtures

Type of mixture	Amount (kg)				
	Lime	Cement	Sand 0/2mm	Fly ash	Water
VO	4.80	-	14.40	-	4.80
VOF	4.00	-	14.40	0.80	4.20
FGC	-	4.20	16.70	-	2.50
FGCF	-	3.40	16.80	0.80	2.50

Both inorganic binding materials were of the Czech origin, cement CEM I 42.5R was manufactured in Hranice and lime CL 90 was produced by limekiln “Čertovy schody”. In the tested mixtures, fly ash from Dětmarovice, CZ, with granularity 0-0,7 mm with the content of 29 mass% of SiO_2 and 15 mass% of Al_2O_3 was added. Fly ash was a very fine grained product of powder coal combustion with different chemical, physical, mineralogical, morphological and technological properties; it meant it was a highly heterogeneous material. The reason why fly ash could be used as partial replacement of major binders was that it had pozzolanic properties, reacted with calcium hydroxide at common temperatures (about 20°C) and formed hydrated calcium silicates and aluminates. The products of pozzolanic reaction had porous character. The specific surface measurements using gas adsorption method (Keppert et al. (2007)) showed for cement binder 365 m^2/kg, lime binder 11 100 m^2/kg and fly ash 250 m^2/kg. Sand 0/2 mm fraction was delivered by Heidelberg Cement Group, Brněnské písky Inc., affiliate Bratčice, normalized according to EN 196-1.

Tested mixtures were prepared using laboratory mixing machine with forced rotation for 3 minutes and then compacted using vibrating machine. Each mixture was cast into standard prism forms, with dimension 100 x 100 x 100 mm and 40 x 40 x 160 mm. After two days all prisms were taken out of forms and then cured for 28 days in high relative humidity environment. The specimens were then cut to required sizes depending on the method of investigation.

3. Experimental methods

As fundamental physical material characteristics, bulk density, matrix density, and open porosity were determined. Bulk density was measured using gravimetric method. Matrix density was obtained using Pycnomatic ATC, automatic helium pycnometer with fully integrated temperature control with precision of ± 0.01 °C and real multi volume density analyzer. The samples for the basic material parameters determination were cut from cubic prisms with the size of 40 x 40 x 40 mm and their dimensions were 40 x 40 x 20 mm.

Investigation of mechanical parameters was carried out according to the Czech-European technical standard (ČSN EN 196-1(2005)). The compressive and flexural strengths were determined as the most important mechanical parameters for composite materials. For each measurement standard prisms 40 x 40 x 160 mm were tested with DSM 2500 hydraulic testing device, Inova Praha. The flexural strength was measured using standard three-point bending test. The compressive strength was determined using the same test device on the remainders of the specimens after bending test. The measurements were done after 28 days of hardening period.

The measurement of water vapour transport parameters was based on the method proposed by Roels et al. (2004). Firstly, cylindrical samples with the size of 95 mm in diameter and 20 mm in height were cut from the standard prism 100 x 100 x 100 mm and water-vapour-proof insulated with epoxy resin to ensure one dimensional water vapour transport. The measurement was carried out in steady state under isothermal conditions. It was based on one-dimensional water vapour diffusion and consisted in measuring the water vapour diffusion flux through the specimen and partial water vapour pressure in the air under and above specific specimen surface. The measured samples were sealed into the cups containing burnt $CaCl_2$ (0% relative humidity), then they were placed in a controlled climatic chamber at 25±0.5°C and 45% relative humidity. The sealed cups with samples were weighed periodically. The steady state values of mass gain were utilized for the determination of water vapour transport properties.

Liquid water transport in the sorptivity concept was analyzed using one-dimensional free imbibition experiment (Kumaran (1994)). Specimens sizes of 40 x 40 x 20 mm were cut from standard prisms and then water-vapour-proof insulated with epoxy resin on four lateral sides, and after that dried in an vacuum oven at 110°C. After cooling the face side of each sample was immersed 1-2 mm into water on top of a saturated sponge. The sample mass was measured continuously. The water absorption coefficient was then calculated from the linear part of the cumulative mass of water vs. the square-root-of-time function (Krischer (1963)). Then, the apparent moisture diffusivity was calculated from the vacuum saturation moisture content and water absorption coefficient.

The sorption isotherm presents the dependence between the water content in the porous matrix and the relative humidity in the system. The shape and position of sorption isotherm depends on the type of porous body of tested materials. The water adsorption and desorption in a porous material are based on van der Waals forces between the surface of the porous matrix and water molecules. The dry material mass increases after a contact with moist air because of gradual bonding of water molecules from the air to the pore walls, in the case of adsorption. Desorption is reversed physical phenomenon, the initial state is capillary saturated sample. At the moment of achieving the equilibrium state between the water vapour pressure in the moist material and in the surrounding air the process of adsoprtion/desorption is stopped. Tested samples were cut in the required size of 40 x 40 x 10 mm. In the adsorption isotherm measurement the dry samples were placed into climatic chamber at 25°C and relative humidity was increased into given values after samples reached equilibrium. In the case of desorption isotherm the wet samples were placed into the desiccators with different salt solutions to simulate different values of relative humidity. The experiment was performed parallel in all desiccators in thermostatic chamber at 25 °C. The mass of samples was measured in specified periods of time until steady state value of mass was achieved. Then, the moisture content was calculated for each relative humidity state and the sorption isotherm for each tested material was plotted.

4. Results and discussion

Basic properties of all tested materials are summarized in Table 2. Each result represents the average of five measured values. The measurements of all parameters took place in controlled climatic conditions at 25±2°C and 30±5% relative humidity. Dry material was taken as the initial state for most of the experiments.

Table 2 Basic properties of tested mixtures

Type of mixture	Bulk density (kg m^{-3})	Density (kg m^{-3})	Porosity (%)
VO	1 650	2 605	36.70
VOF	2 005	2 345	22.50
FGC	2 122	2 611	18.70
FGCF	2 066	2 544	18.80

The open porosity was found not to be distinctly affected by the fly ash addition in the case of cement based composite material, bulk density decreased by about 3% and open porosity increased by about 0.5%, but these differences could be disregarded because of the measuring error range which could be estimated as 1%. On the other hand, due to pozzolanic reaction of fly ash the open porosity of lime based composite material decreased very significantly. This is, though, not a positive outcome, because we need the lime based materials to have a high porosity, which guarantees fast water vapour transport, thus its fast removal from load bearing structure.

The survey of mechanical properties of studied mortars after 28 days of hardening is presented in Table 3. Each result represents the average value of six values of compressive strength measurement.

Table 3 Mechanical properties of tested mixtures

Type of mixture	Compressive strength (MPa)
VO	0.4
VOF	0.8
FGC	50.5
FGCF	56.0

The measured values show that usage of pozzolana active fly ash led to about 10% increase of compressive strength in comparison with the basic cement mixture. In case of lime composite material with fly ash addition the compressive strength reached two times higher value than for pure lime mixture which was caused by hydraulic products formation due to chemical reaction between binder and fly ash.

The calculated average values of water vapour transport parameters are presented in Table 4, each result represents the average value from five measurements.

Table 4 Water vapour transport parameters of tested mixtures

Type of mixture	Diffusion coefficient of water vapour (m^2s^{-1})	Water vapour diffusion resistance factor (-)
	0-45% RH	0-45% RH
VO	2.9E-6	9.0
VOF	4.7E-7	50
FGC	4.2E-7	55
FGCF	4.6E-7	51

In the case of fine grain cement composite with fly ash addition the measured values of water vapour diffusion resistance factor were similar to those of the basic FGC material. The differences were on the edge of the error range of the measuring method. For the studied lime based materials the water vapour transport parameters were very different. Lime mixture with fly ash addition had nearly six times higher water vapour diffusion resistance factor than the reference lime mortar as a result of calcium silicates formation in lime matrix. From the practical point of view, the obtained value of water vapour diffusion parameter of lime based material with fly ash addition may be considered as a negative finding (as already anticipated and pointed out in the analysis of porosity measurement) because water vapour can not be easily transported out of the load bearing structure.

The liquid water transport parameters of all tested materials are presented in Table 5; each result represents the average value from three measurements.

Table 5 Liquid water transport parameters of tested mixtures

Type of mixture	Water absorption coefficient ($kg\ m^{-2}s^{-1/2}$)	Saturation moisture content ($kg\ m^{-3}$)	Apparent moisture diffusivity (m^2s^{-1})
VO	2.30E-1	359	4.10E-7
VOF	1.20E-1	224	2.87E-7
FGC	1.10E-2	186	3.50E-9
FGCF	1.80E-2	187	9.20E-9

The values of water absorption coefficient of cement mixture with fly ash addition increased almost two times compared to the basic cement mixture FGC. Thus, the apparent moisture diffusivity visibly increased due to fly ash addition. However, the values of moisture diffusivity of both materials remained relatively low. An opposite trend of about the same magnitude was observed in the case of lime based composite mixtures. For a lime mortar the reduction of liquid moisture transport into material structure is a very positive feature.

The results in Figs. 1a, b show the sorption isotherms of all tested materials.

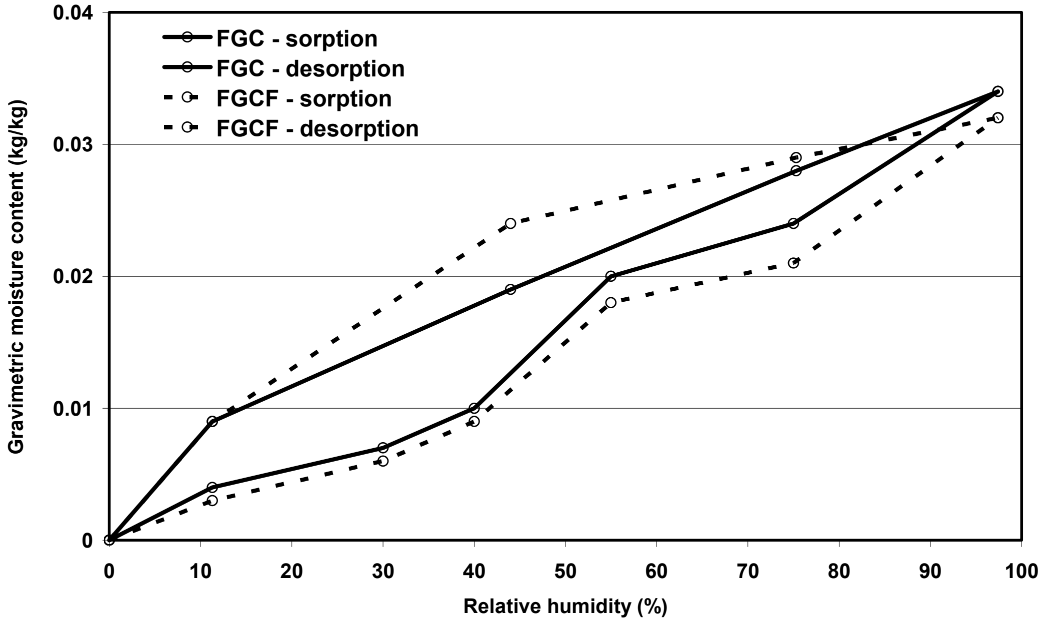

Figure 1a Sorption isotherm of cement based materials.

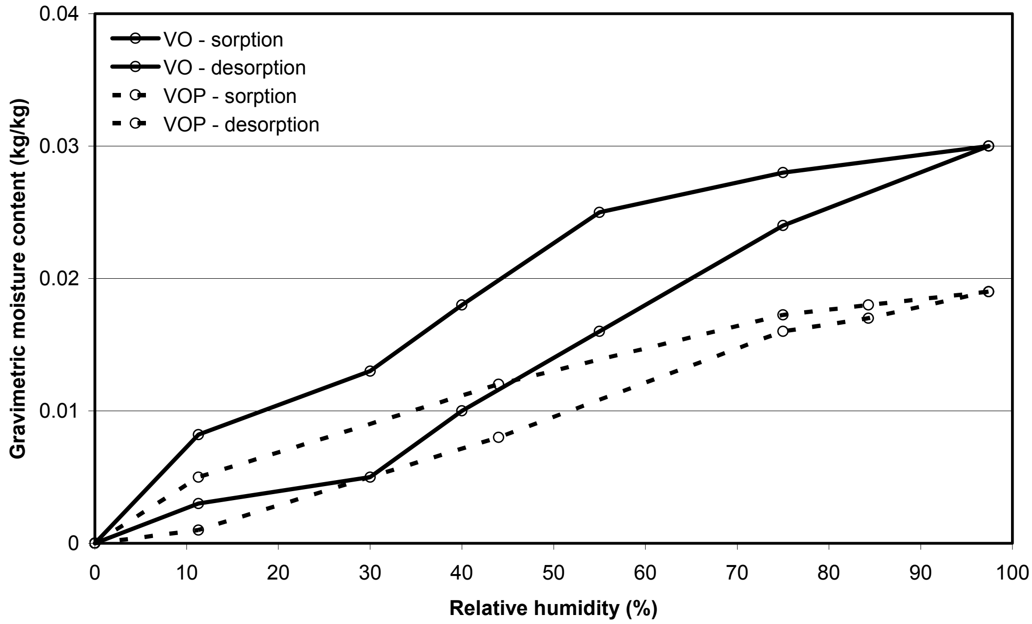

Figure 1b Sorption isotherm of lime based materials.

The sorption isotherms of all tested materials exhibited relatively low hygroscopicity and low hysteresis. The effect of fly ash on the water vapour sorption capability was important for lime based composites where the maximum hygroscopic moisture content decreased by about one third as compared to the reference lime mortar. This seems to be a consequence of the lower porosity of lime mortar with fly ash. Water vapour sorption of cement based composites was found basically unaffected by fly ash.

5. Conclusions

The results presented in this paper have shown that fly ash can be effectively used as environmental-friendly replacement of a part of common inorganic binders, which production presents a significant source of greenhouse gases, in composite materials applied in building industry. The use of fly ash as partial replacement of cement resulted in an about 10% increase of compressive strength of the analyzed fine-grain concrete. The water and water vapour transport parameters were higher than in reference concrete but the increase was not so high that it could harm the water protection ability of the concrete in a significant way. The application of fly ash as a binder in lime mortar led to more pronounced effects on hygric properties, in particular. The fly ash addition to lime binder had the most important influence on water vapour transport which was reduced almost six times. This finding has to be taken into account in further considerations concerning the application of the mortar; its higher strength compared to the reference lime mortar indicates that it should be used as walling mortar rather than plastering mortar.

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A STUDY ON THE ADAPTATION AND UTILIZATION OF SBTOOL IN TAIWAN

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Keywords: SBTOOL, Sustainable Building, Building Performance Assessment.

Summary

An international collaborative effort called the Green Building Challenge (GBC) is developing a building environmental assessment tool that exposes and addresses controversial aspects of building performance based on harmonized criteria and indicators. This research will use SBTOOL which has been developed by GBC to assess Taiwan buildings located north and south of the Tropic of Cancer, analyze and discuss the difference in terms of sustainable development.

1. Purpose

Sustainable development needs explicit consideration in context of time and space, and a holistic n-Bottom line (nBL) approach. The International Initiative for Sustainable Built Environment (iiSBE), following the standards formulated by the International Standardization Organization like ISO14025 and ISO21930, developed an SBTOOL. The previous research in 2005 analyzed the operations of GBTOOL in the assessment of Taiwan cases and discussed the difference in the performance results between local weights established by experts and GBTOOL's default weights. See Figure 1. This research now applies SBTOOL to assess two building cases located in the north and south regions of Taiwan, with the purpose of finding out the key regional factors influencing operating, applying and processing the results of SBTOOL. This study also hopes to provide references for relevant researches at home and abroad.

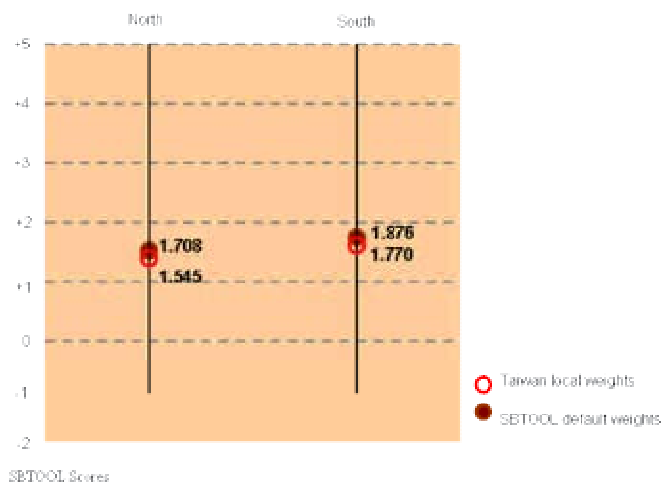


Figure 1. Assessment results of GBTOOL cases in previous research

2. Overview of Taiwan Region

2.1 Geographical and climate Conditions of Taiwan

Located in a subtropical zone, Taiwan as a whole has a high-temperature and high-humidity climate. Taiwan is a long and narrow island along north-south direction with the Tropic of Cancer at 23.5 degrees north latitude passing through it. See map below. The climate in the area north to the Tropic of Cancer is subtropical, and that in south is more tropical and warm. Therefore, Taiwan plays an indicative role in terms of environment. In Taiwan's present residential building environment, existing buildings account for 97% and new buildings only 3%. Urban areas are narrow and densely populated, without large hinterlands for use, so the buildings there develop towards high-rise/high density forms whereas, buildings in countryside towns or mountain areas are of low density, without limitations of space. The goal of sustainable development is more easily reached in countryside towns and mountain areas.

2.2 Development of Green Building Evaluation in Taiwan

To get a full knowledge of the environmental performance and quality of buildings in Taiwan, the Taiwan Architecture and Building Research Institute (ABRI), Ministry of the Interior developed a Green Building Evaluation (EEWH) in 1999 and added two more indicators in 2003. Now there are nine indicators in EEWH for green building assessment: biodiversity, greenery, soil water content, daily energy saving, CO_2 emission reduction, waste reduction, indoor environment, water resource, and sewage and garbage improvement. Each assessment item is scored using its respective assessing formula as well as its weight coefficient, and scores are rated into the following ranks: qualified rank(12<=RS<26) bronze rank(26<=RS<34), silver rank(34<=RS<42), gold rank(42<=RS<53)and diamond rank(53<=RS). According to statistics released by the Chinese Architecture & Building Centre (CABC), among new buildings built up during the period from 2004 to 2008, 223 cases have acquired Green Building Labels, and 1072 cases have gained Candidate Green Building certificates. The distribution of green buildings among building types is shown in the chart below.

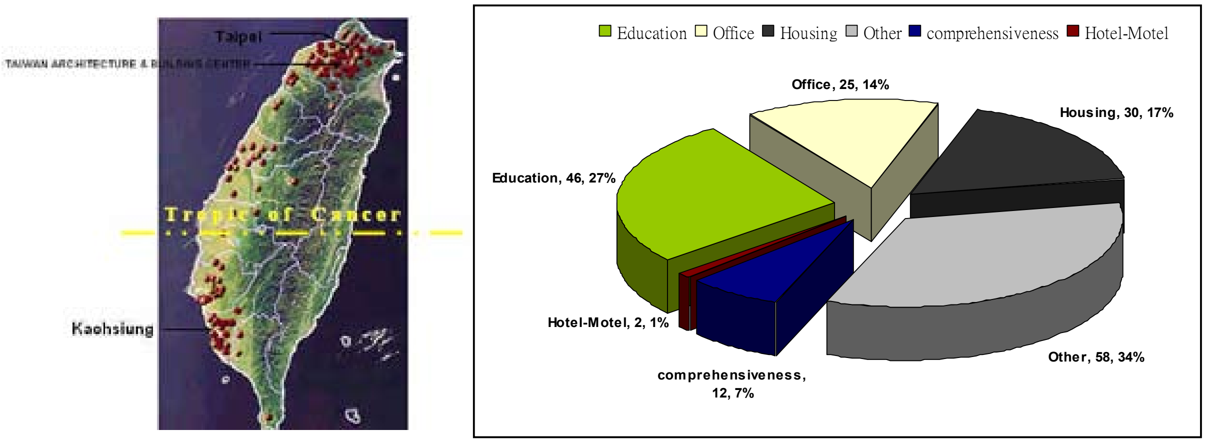


Figure 2. (Right) User-Type Distribution of Green Buildings in Taiwan as of 2006.
(Left) Map of Taiwan.
Source：TAIWAN ARCHITECTURE & BUILDING CENTER

3. Background of Cases and Descriptions of Their Performance Results

3.1 Background of Cases

3.1.1 Taiwan North case: an apartment building located in an urban area of Taipei city, completed and opened in October of 2005, with 5 floors under ground and 14 floors above ground. The building has an annual average temperature of 20°C, annual average precipitation of 2325.2 cm, and annual average 1381 hours of sunshine.

3.1.2 Taiwan South case: a high-rise residential building located in an urban area of Kaohsiung city, completed and opened in April of 2005, with 3 floors under ground and 27 floors above ground. This building has an annual average temperature is 25.1°C, the annual average precipitation is 1720.2 cm, and the annual average sunshine hours is 2075.4.

3.2 Scores of Cases under Taiwan EEWH

3.2.1 Taiwan North case: This case gained a label verifying it passed seven Green Building Evaluation indicators including greenery, soil water content, Energy conservation, CO_2 emission reduction, indoor environment quality, water resource, sewage and garbage improvement. Refer to Table 2.

3.2.2 Taiwan South case: This case gained a label verifying it passed five indicators of Green Building Evaluation indicators including greenery, soil water content, Energy conservation, water resource, sewage and garbage improvement. Refer to Table 3.

Table 2 Scores of North Case under Taiwan EEWH

Assessment indicators	Designed value in this case	Criteria	Assessment results
Greenery	TCO_2c = 126901.68	TCO2c = 118800 TCO2>TCO2c	2.3
Soil water content	λ = 0.45	$λ_C$ = 0.44 $λ>λ_C$	2.0
Energy conservation	EEV = 0.6	0.80 EEV<=0.80	4.2
CO_2 emission reduction	CCO_2 = 0.81	0.82 CCO_2<=0.8	2.4
Indoor environment quality	IE = 62.4	0.04 IE>=60	2.4
Water conservation	WI = 4.0	4.0 WI>=2.0	4.0
Sewage and garbage	Gi = 10.0	10.0 Gi>=10.0	2.0
Comprehensive score = 18.4 (qualified rank)			

Table 3 Scores of South Case under Taiwan EEWH

Assessment indicators	Designed value in this case	Criteria	Assessment results
Greenery	TCO_2c = 526740	TCO_2c = 277985.7 TCO_2>TCO_2c	5.8
Soil water content	λ = 0.41	$λ_C$ = 0.32 $λ>λ_C$	2.3
Energy conservation	EEV = 0.79 EAC = 0.8 EL = 0.76	0.80 EEV<=0.80	4.2
Water conservation	WI = 5.5	4.0 WI>=2.0	1.7
Sewage and garbage	Gi = 10.0	10.0 Gi>=10.0	2.0
Comprehensive score = 21.6 (qualified rank)			

3.3 Assessment Results of Cases under SBTOOL

The assessment parameters of SBTOOL are grouped into 3 levels; there are 7 assessment parameters at the first level, 29 parameters at the second level and 120 parameters at the third level. The assessment using SBTOOL is carried out using basic data and weights inputted by the third-party authorities and professional design teams. SBTOOL is suitable to handle new and existing buildings, or a mixture of both new and existing buildings. SBTOOL permits assessments to be carried out at four distinct stages of the life-cycle of a building and provides the users/operators with the comprehensive average value of calculated results at each phase thereby allowing the users to have a complete understanding of the conditions of this building.

This research carries out assessment of two building cases on the basis of the default weights of SBTOOL as established by international experts, considering only the design phases of the life-cycle of the two buildings.

3.3.1 Performance results of Taiwan North case: The comprehensive weighted score is 1.5. Among the assessment indicators of SBTOOL, the Energy and Resource Consumption got the highest score of 2.2, the Social And Economic Aspects comes next, getting 2.0, followed successively by the Environmental Loadings, Site Selection, Project Planning and Development, Indoor Environmental Quality, Cultural and Perceptual Aspects, and the Service Quality came last with the lowest score of 0.3. Refer to Table 4.

3.3.2 Performance results of Taiwan South case: The comprehensive weighted score is 1.3. Among the assessment indicators of SBTOOL, the Cultural and Perceptual Aspects got the highest score, 2.0, both the Energy and Resource Consumption and the Environmental Loadings had the score of 1.9, followed successively by the Social and Economic aspects, Site Selection, Project Planning and Development, Service Quality and finally, Indoor Environmental Quality. Refer to Table 5.

Table 4 Score Rating of Taiwan North Case Using SBTOOL

Indicators	Design target scores	Assessment Scores
Site Selection, Project Planning and Development	3.3	1.8
Energy and Resource Consumption	2.3	2.2
Environmental Loadings	3.6	1.9
Indoor Environmental Quality	3.3	1.2
Service Quality	2.9	0.3
Social and Economic aspects	3.1	2.0
Cultural and Perceptual Aspects	4.3	1.0
Comprehensive score	**3.1**	**1.5**

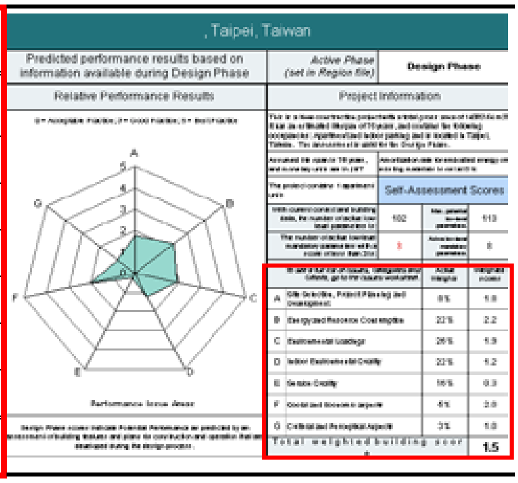
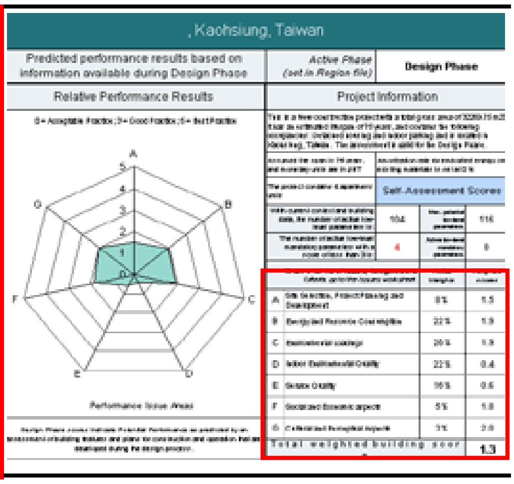


Table 5 Score Rating of Taiwan South Case Using SBTOOL

Indicators	Design target scores	Assessment Scores
Site Selection, Project Planning and Development	3.2	1.5
Energy and Resource Consumption	2.2	1.9
Environmental Loadings	3.2	1.9
Indoor Environmental Quality	2.6	0.4
Service Quality	2.6	0.6
Social and Economic aspects	2.4	1.8
Cultural and Perceptual Aspects	4.3	2.0
Comprehensive score	**2.8**	**1.3**



4. Comprehensive Comparison and Analysis

4.1 Analysis of Operation results of SBTOOL in Cases

After assessment on cases using SBTOOL, it is discovered that since the North case is located in urban area and especially in a political administration district, so the development of its site is controlled by strict legislative decrees, therefore, each of its assessment indicators got a higher score than the South case. The South case is also located in urban area, but a general residential district with more households, therefore, the scores of the Energy and Resource Consumption, Energy and Resource Consumption, and the Cultural and Perceptual Aspects are obviously higher than those of the North case. Refer to Figure 3.

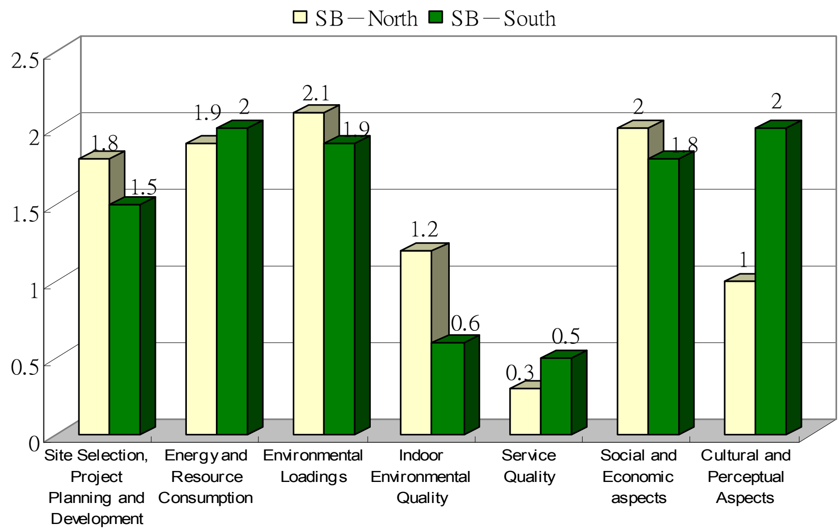


Figure 3. Comparison between Performance results of Taiwan North and South Cases under SBTOOL

4.2 Comparison between SBTOOL and Taiwan EEWH

Compared with Taiwan EEWH, the assessment indicators of SBTOOL put more emphasis on the Service Quality, Social and Economic Aspects, Cultural and Perceptual Aspects, reflecting its orientation in the transformation from green building to sustainable building and emphasizing long-term social and economic development. Refer to Table 6.

Table 6 Comparison between Assessment Results of Two Building Cases

SBTOOL Indicators	Self-Assessment Scores		Taiwan EEWH Indicators	Assessment Scores	
	North	South		North	South
Site Selection, Project Planning and Development	1.8	1.5	Green	2.3	5.8
Energy and Resource Consumption	2.2	1.9	Energy conservation	4.2	4.2
Environmental Loadings	1.9	1.9	Soil water content	2.0	2.3
			CD$_2$ Emission Reduction	2.4	-
			Water conservation Sewage and garbage	4.0 2.0	1.7 2.0
Indoor Environmental Quality	1.2	0.4	Indoor Environment Quality	2.4	-
Service Quality	0.3	0.6	—		
Social and Economic aspects	2.0	1.8	—		
Cultural and Perceptual Aspects	1.0	2.0	—		
Score	**1.5**	**1.3**	**Score**	**18.4**	**21.6**

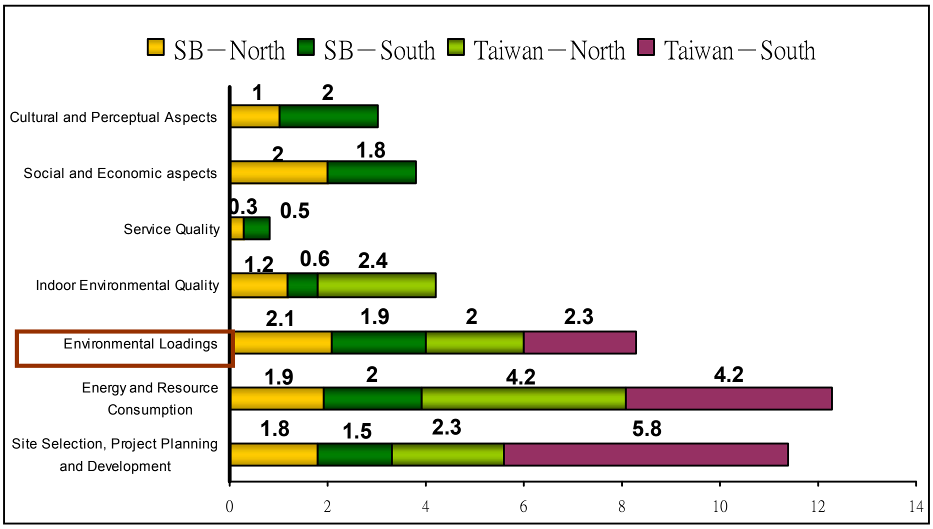


Fig 4a. Environment Loadings using SBTOOL and EEEW

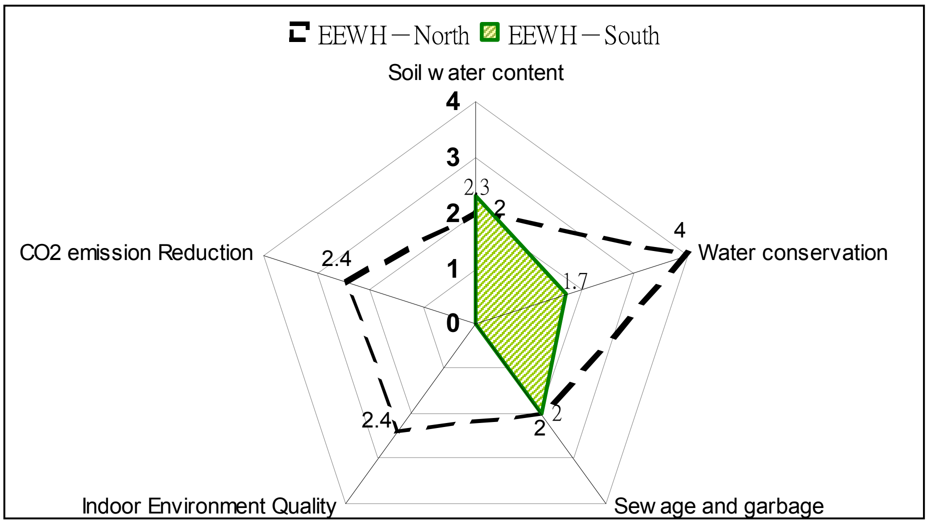


Figure 4b. Score Analysis using Taiwan EEWH

The Environmental Loadings category of SBTOOL covers the assessment indicators of Soil water content, Carbon Dioxide Emission Reduction, Water conservation, and Sewage and Garbage of Taiwan EEWH. Refer to Figure 4a. In the assessment using Taiwan EEWH, all assessment parameters of Environmental Loadings have been taken in account, showing its emphasis on this category. Refer to Figure 4b.

5. Conclusions

This research used SBTOOL as the measuring platform for sustainable buildings in Taiwan region as well as on the comparison with the Taiwan Green Building Evaluation and Labeling System EEWH:

- Assessed using SBTOOL, the North case got a score of 1.5 and the South case got 1.3, both belonging to the Bronze rank; whereas, assessed using Taiwan Green Building Evaluation and Labeling System, the score of the North case is 18.4 and the score of the South case is 21.6, both belonging to the Qualified rank. It shows that the assessment results obtained under SBTOOL are slightly higher than those under Taiwan EEWH. Refer to Figure 5.

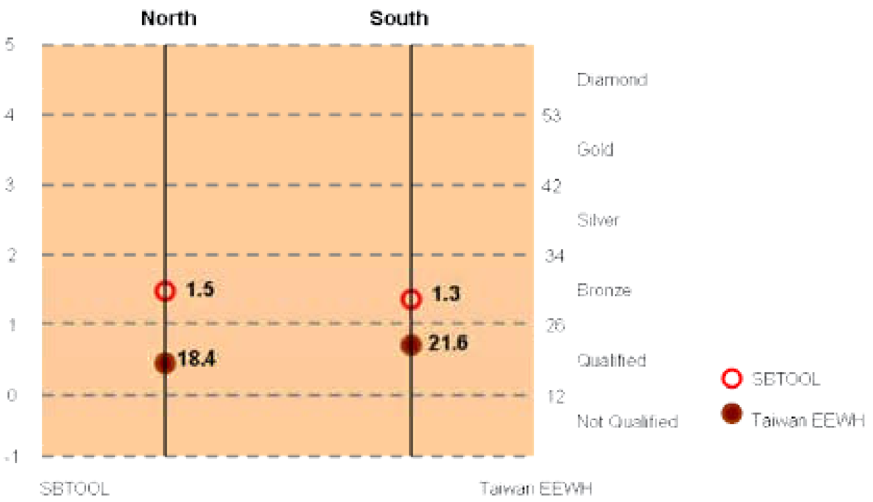


Figure 5. Score Analysis using SBTOOL and Taiwan EEWH

- The comparison between the performance results of the cases in the research and those in the previous research reveals that although the scores obtained using SBTOOL and Taiwan EEWH are different, the calculated results were subjected to the correction using regional expert weights.
- Looking more closely into the score of each assessment item indicates that the environmental loadings in SBTOOL has an influence on the scores of the South case, namely slightly lower than those of the North case. This is because Carbon Dioxide Emission Reduction and Indoor Environment Quality indicators have not been assessed in Taiwan EEWH, showing that the South case did not put more attention to CO2 Emission Reduction and Indoor Environment Quality.

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SUSTAINABLE ARCHITECTURE: ARCHITECTURE AS SUSTAINABILITY

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Keywords: Sustainable architecture, Sustainable Schools, Sustainable education, Definition of sustainable architecture, Sustainable about sustainability, Sustainable for sustainability, Sustainable as sustainability

Summary

Recently, for some people the idea of sustainable design has become the basic criterion of architectural design. Frequently, however, many buildings that are claimed as sustainable are only so in terms of the design. All these talk *about* sustainability, only using sustainable techniques without concern for the results or consequences or, worse, the word 'sustainable' or 'sustainability' is attached to an ordinary building. To improve the world so as to become close to sustainable conditions, architecture should be designed *for* sustainability, using sustainable ideas and techniques as the basic design criteria. With the support of a sustainable milieu, including sustainable behaviour and management as well as sustainable political and social conditions, architecture could be part of sustainability or be sustainability. This idea of architecture *as* sustainability shows the interrelationships of people and the non natural environment, of which architecture is a part, and emphasises the aims of development that are not for 'external' goals to achieve sustainability but for architecture for own sake that is sustainability.

1. Introduction

This paper is based on research undertaken as part of an investigation into sustainable schools and the connections between sustainable architecture and sustainable education. It is based on an interdisciplinary approach that suggests all forms of sustainable practice could and should support each other in the creation of sustainability. As a result, study of sustainable practices in the educational field helps to an understanding and enhancement of the meanings of sustainable architecture.

Sustainable architecture and sustainable education share many similarities. For example they both originated from environmental concerns and the promotion of interrelationships between human beings and nature. While sustainable education is mainly developed from preceding practices, like nature study, outdoor education, conservation education, and environmental education that began to be used broadly in the mid 1960s (Palmer, 1998), sustainable architecture has also evolved from earlier practices, such as green architecture, ecological design, and other familiar ideas and practices (Farmer 1996; Ryn and Cowan, 1996; Wine 2000; Steele, 2005). The main influence that has driven the development of sustainable architecture and sustainable education is the environmental movement in the 1960s and 70s, which can be traced through literature, such as *Silent Spring* (1962), *Design with Nature* (1969), and *Limits to Growth* (1972), and environmental events, such as the first Earth Day in 1970, the UN conference on the Human Environment, Stockholm, Sweden, in 1972, and the UNESCO First Inter-government Conference on Environmental Education, Tbilisi, USSR in 1977. In the 1980s, environmental consciousness was revived again as a result of a movement in favour of sustainability as part of what Beder (1996) called the second wave of environmentalism. This involved governments, economists and business people in the promotion of sustainable development. The term 'sustainable development', which was internationally promoted by the WCED report, *Our Common Future* (1987), and the United Nations Conference on Environment and Development (UNCED) in 1992, has led to adaptation of the term 'sustainable' to modify educational and architectural practices. Since then, in the architectural field, sustainably-modified terms, such as sustainable design (Crosbie, 1994; Mendler and Odell, 2000; McLennan, 2004), sustainable buildings (Barnett and Browning, 1995; Maiellaro, 2001), sustainable architecture (Edwards, 1996; Steele, 1997; Gauzin-Muller, 2002; Guy and Moore, 2005), have been used in a similar way to environmental-related texts, such as green and ecological architecture, while in the educational field the terms related to sustainability and sustainable development concepts, such as sustainable education (Sterling, 2001), sustainability education (Shallcross, O'Loan and Hui, 2000), education for sustainability (Huckle and Sterling, 1996; Federico, C. M., et al., 2002), and education for sustainable development (ESD) (UNESCO, 2004), have been used in a similar way and in parallel with environmental education.[1]

In terms of the definition, one of the most definitive models of environmental education is that proposed by Lucus in 1972.[2] It refers to education *in* the environment, *about* the environment, and *for* the environment (Lucus 1979; Linke, 1980). While education *in* the environment is characterised by the use of a particular pedagogic technique that takes place in the environment, education *about* the environment is characterised by the content, focusing on information concerning the environment. In contrast, education *for* the environment is focused on the aims of education to assist preservation or improvement of the environment. As Fensham (1978) observed in the UNESCO/UNEP definition of environmental education, education *in* the environment or *about* the environment is, however, not environmental education. Only education *for* the environment, or any combination which includes a *for* component can be classified as environmental education (Linke, 1980). In the same way, sustainable education can be categorised as education *about*, *for*, and *as* sustainability. While education *about* sustainability focuses on the content and education *for* sustainability places emphasis on the purpose, this being similar to what Gough (1987) called education *with* environment, education *as* sustainability proposes a characteristic of education that enables education to be understood both as an integrated process and as an element of a whole process of creating sustainability (Foster, 2001; Sterling, 2001). Although sustainable education encompasses education *about*, *for* and *as* sustainability, educational activities that are part of sustainable education need to aim at least at being education *for* sustainability, rather than just education *about* sustainability.

The definition of environmental education and sustainable education provide a lesson for revisiting the definition of sustainable architecture. Using a similar approach, sustainable architecture can be categorised into three types, namely architecture *about* sustainability, architecture *for* sustainability, and architecture *as* sustainability. These three possibilities are presented here as being separate, but in practice they may be merged or dominated by each other according to the focus of the approach.

2. Architecture about Sustainability

The most common form of sustainable architecture is architecture that is *about* sustainability. It embraces every building and built environment that contains sustainable components or provides information concerning sustainability. This information is varied ranging from building components, such as building materials and systems, to sustainable design tools and techniques, such as environmental impact assessment (EIA), life cycle assessment (LCA), and building evaluation systems (e.g. LEED and BREEAM), to general relationships between the built environment and environmental and social issues, such as addressing environmental concerns and social benefits in planning policies or architectural programming.

Architecture *about* sustainability usually comprises sustainable elements or sustainable strategies. While the elements encompass sustainable products, materials, and technical devices, the strategies include sustainable approaches in site selection and development, transport impacts, building configuration and orientation, selection of products and materials, energy conservation, use of renewable energy, water conservation, air quality, human comfort, operation and maintenance, renovation, and demolition. Because of differences of project conditions, each project cannot accommodate all sustainable elements and strategies, but select some that support each other and that are likely to respond to the particular approach. The diversity of implementation can be classified in various ways, for example, the three images of sustainable architecture, namely, natural, cultural and technical (Williamson, Radford and Bennetts, 2003: Chapter 2), the six competing logics of sustainable architecture (Guy and Farmer, 2000; 2001), and the ten shades of green architecture (Buchanan, 2005).

Architecture *about* sustainability, however, may not always lead to sustainability. Since many buildings that are claimed as sustainable are only so in terms of applying specific design elements and strategies, without

[1] In the architectural field, although a few authors have pointed out the difference between sustainable architecture and green architecture (e.g. Hengrasmee, 2005; Kwok, and Grondzik, 2007), most authors recognise that the terms are used interchangeably. Meanwhile, in the educational field, many authors (e.g. Jickling and Spork, 1998; Stables, 2001; McKeown and Hopkins, 2003) have discussed the conflicting relationship between environmental education and other educational terms related to sustainability and sustainable development concepts, such as education for sustainable development (ESD). Although priorities and foci are varied depending on definitions and interpretations of concepts of sustainability and sustainable development, as McKeown and Hopkins (2003) have stated, the terms have similarities and can be complementary.

[2] Arthur M. Lucas first introduced this concept of environmental education in his 1972 dissertation, which was then revised and published in 1979.

concern for situational appropriateness and whole-life consequences, their actual results may not create positive effects on society and the environment. For example, timber products may be specified in the design, based on the idea that timber is a natural and renewable resource, but the products may come from unsustainable harvesting and production processes, they may be transported from overseas manufactures, or are traded unfairly. The decision to use timber may thus lead to deforestation, higher energy consumption in transport, or other social problems caused by unjustifiable manufacturing and trading. Meanwhile, setting up renewable energy production systems, such as solar panels, and applying other energy conservation strategies, such as addition of insulation and enhancement of natural light and ventilation, does not guarantee that the building will be efficient and totally rely on renewable energy sources. Without being conscious of the need to reduce energy consumption, the users may carelessly use energy and have too many appliances, so the building consumes a lot of energy and still requires considerable energy from non-renewable sources to satisfy the rising demand.

In addition, because the sustainable agenda is marketable, discourse of architecture *about* sustainability can be just greenwash (Williamson et al., 2003: 10-12). Some clients and architectural firms use sustainable design strategies mainly for creating a marketing opportunity for their products and services, but do very little to create sustainable solutions. These companies often use sustainable design strategies to show their visions or inspiration, but ignore the appropriateness for local conditions and long-term effects after trading. They mainly place their focus on financial profits and selling rates of their products and services. Moreover, they rarely provide adequate information about the products and design solutions or suggest alternatives for the buyers or users to make fully informed decisions. Based on such data, the consumers are therefore deceived into choosing only the products and services they provide. These selling strategies often create negative outcomes for the environment and also create a misleading public understanding of sustainable design and sustainability. In fact, use of sustainable design for selling and marketing strategies is not always wrong. With concern for the whole-life effects and local situation, this method can help to promote sustainable design and enlighten clients, developers, and designers to come forward and commission many more sustainable buildings.

Recently, the number of buildings representing architecture *about* sustainability has increased. Many buildings are labelled as sustainable architecture and increasingly project descriptions mention the words, ‘sustainable’ or ‘sustainability’. This represents an increase in the general concern about sustainable issues and sustainable design. Nevertheless, as mentioned earlier architecture *about* sustainability, particularly as a term bolted onto the pre-existing unsustainable agenda (Willis, 2000; McLennan, 2004), may not necessarily lead to sustainability. To improve the world to be close to a sustainable condition, it is essential to focus on the overall results as well as the intention of the creation.

3. Architecture for Sustainability

Unlike architecture *about* sustainability that focuses on sustainable components and techniques, architecture *for* sustainability is centred on the purpose of architectural creation. Architecture *for* sustainability usually uses sustainability as the objective of the project and uses sustainable techniques as the basic design criteria. Since stakeholders’ objectives are frequently interconnected and conflict between objectives is common (Williamson et al., 2003: 65), when using sustainability as an objective, the particular definition of sustainability should be identified. The definitions may vary but are generally considered in terms of the level of sustainability from an anthropocentric or ‘weak sustainability’ to a non-anthropocentric or ‘strong sustainability’ (Turner, 1993; Bosselmann, 2002: 89-92). For ‘weak sustainability’, which equates to a type of economic sustainability, to achieve the sustainable condition, a balance of three issues – ecology, economy and society – is required. On the other hand, the ‘strong sustainability’ model, which equates to what some call ecological sustainability, is concerned with ecology as the overarching system. In this approach, every action affects others and ecological issues are the most important.

The diversity of sustainability definitions and approaches results in various means to achieve them. For instance, based on the ‘strong sustainability’ approach, architecture should be in harmony with nature, designed within limits of ecological footprints, and ensure the stability and integrity of local and global biodiversity. Examples related to this approach are autonomous house and self-sufficient community design (e.g. Vale and Vale, 1975; 2000; Hockerton Housing Project, 2001; Tlholego Development Project, 2001). Based on the ‘weak sustainability’ concept, architecture should be the result of compromise solutions between ecological, social and economic benefits. Several projects based on the techno-rational and policy-oriented approach (e.g. Catherine, 1997; Ray-Jones, 2000; Broto, 2003) are relevant examples of this category. It is quite clear that ‘strong sustainability’ implementation allows the world to reach a more sustainable situation than the ‘weak sustainability’ approach. In contrast, because of the difficulties of applying the sustainability concept, ‘weak sustainability’ practices are more popular.

Although architecture *for* sustainability obviously shows an intention to create sustainability, it is crucial to consider the process of implementation from objective statements to actual results. Architecture *for* sustainability with inadequate knowledge and skills and inappropriate strategies may lead to unsustainable conditions. Stakeholders should have knowledge about basic environmental concepts, environmental regulations, life cycle assessment and other sustainable design methodologies, and the environmental performance of built environment components and systems (Martin, 2001). If they do not have enough knowledge, they should learn constantly from their own experiences and through information from publications and other media, and can also ask for advice from experts or other people who have more knowledge or experiences. The stakeholders should also obtain skills that facilitate the creation of sustainable architecture, including the ability to understand the circumstances of the community, communication and collaboration skills, and adaptation skills (Maser, Beaton, and Smith, 1998). Furthermore, design tools and techniques should be appropriately selected and accommodated in every phase of architectural design. For instance, as Hyde et al (2007) suggested, setting goals, environmental briefs, specifying principles, checklists, and design phase rating and benchmarking systems are useful during pre-design and schematic design, while monitoring, surveys of building in use, operational phase rating and benchmarking systems are practical strategies for the post-occupation phase.

In addition, since objectives can be changed at every part of design process, to create architecture that is mainly *for* sustainability it is important to examine the purpose of projects frequently. This will help to ensure that sustainability is a main purpose and does not get shifted to be a sub-objective under other purposes, such as to complete a checklist or create more profit, which may limit the visions of development or even misguide the process so projects become unsustainable architecture.

4. Architecture as Sustainability

In contrast to architecture *about* and *for* sustainability, which are both characterized by components and goals, architecture *as* sustainability is characterized by its process. It is defined as a transformative architectural process towards sustainability and as a part of an entire process that leads to sustainability. Architecture *as* sustainability encompasses processes from pre-design, design, construction, operation, renovation, and demolition, to creation of new projects. The processes are considered as a cyclical and dynamic system that is connective, contextual, inclusive, integrative, and that extends the boundaries of care and concern to the social, environmental, non-human and future dimensions. To deal with a complex and vital system, whole systems thinking or the holistic approach is required (Vale and Vale, 1991; McLennan, 2004; Hyde et al. 2007). This mode of thinking indicates that all things are interconnected and the interrelationship of the parts forms the whole. Since building is basically an open system that relies on the import of energy and resources from the environment, sustainable architecture commonly aims to create 'more closed' and 'less open' systems in buildings (Williamson et al., 2003: 82-84). Similar to what Guy and Farmer (2001) have labelled eco-centric logic, sustainable architecture based on this approach tends to draw directly on analogies with ecological systems as living, efficient, self-reliant, closed, and cyclical processes, which oppose the linear, inefficient, dependant and open systems of conventional buildings. Furthermore, related to time-linked dimensions, contemporary sustainable architecture can shape patterns of subsequent projects. While knowledge and skills from one project will contribute to design and construction procedures of future projects, sustainable conditions that the project provides, such as healthy environments and positive attitudes towards sustainable practices (e.g. self-esteem and self-reliance), enhance constructive circumstances for other existing and forthcoming projects.

As an element of the whole process of sustainability, architecture *as* sustainability participates in the process of change from the less sustainable condition to the more sustainable situation, or so-called 'weak' to 'strong' sustainability. Sustainable architecture is thus a subsystem of a whole system of sustainable practices. It overlaps and interconnects with other subsystems, such as the building industry, education, economy, politics and society. Fundamentally, sustainable architecture reduces environmental impacts and improves quality of life. It also imparts positive environmental conditions for other sustainable practices to occur in such buildings. Meanwhile, to create and sustain the conditions, sustainable architecture demands collaboration with sustainable practices in other disciplines (McLennan, 2004). As the list of issues of concern is expanded, it requires participation of various people with specific knowledge in the process. Architects, engineers, specialists, developers, project managers, builders, and users can share their knowledge and expertise to solve problems and create sustainable conditions. Sustainable approaches in local politics frequently lead to policies that demand and support sustainable practices, including sustainable architecture and planning. Innovations in the building industry towards sustainability, such as eco-label materials and products, environmental regulations, as well as environmental design and operational directives and standards, can guide sustainable practices and reinforce participation of various stakeholders in the process. To maintain appropriate conditions, sustainable architecture requires constant sustainable management and users that behave sustainably. Moreover, continual study, research and development in architectural and other green related fields assists in enhancing the quality of sustainable architecture, as well as promoting attitudes to and understanding of the importance and impact of sustainable design.

It appears that architecture *as* sustainability, which can be simply described as a process of continual development, shares a similar characteristic in its continual and cyclical process with other practices, such as an on-going process of educational action and research (e.g. Robottom, 1987; OECD, 1995; Sterling, 2001) and community development (e.g. ORTEE, 1994; Maser, 1997;). The resemblance shows the inherent shared quality of sustainable practices and ensures the possibility of developing architecture *as* sustainability, so that architecture becomes an integrated part of sustainable systems.

In addition, architecture *as* sustainability evokes a shift in approach from the traditional viewpoint that considers architecture as an end product of design and construction and sustainability as a goal that will be achieved some day to the new model that recognises architecture as a whole architectural process from pre-design to operation, renovation and demolition, and sustainability as a process of development, which requires current and continual actions. Under the traditional perception, at present, because sustainability is not yet attained, there is no architecture that can be claimed *as* sustainability. On the other hand, in the new paradigm, architecture can possibly be '*as* sustainability', if it provides sustainable conditions, has concern for the actual context and whole-life results, continually improves its performance, and supports and collaborates with other sustainable practices.

5. Case studies: Sustainable Schools

As this paper is based on an investigation into sustainable schools, two school projects, from developed and developing countries, were selected as case studies to show how the designed could be categorised according to the definitions set out above. These projects are Sidwell Friends Middle School, Washington, DC (2006) and the primary school at Gando Village, Burkina Faso (2001).

Basically, both projects can be classified as architecture *for* sustainability. They both aim to provide a place for learning within an ethos of sustainability, particularly during childhood when value systems are formed. Sidwell Friends School was committed to being an institution responsible environmental stewardship would be practiced. This concept was applied to its curriculum and the selection of sustainable design was a logical expression of its values. As a result, the renovation and addition of its Middle school in 2006, designed by Kieran Timberlake Associates, obtained a LEED Platinum certification and was chosen as an AIA Committee on the Environment (AIA/COTE) Top Ten Green Project for 2007. In contrast to the devotion to promoting environmental awareness of Sidwell Friends School, the Gando Primary School simply aimed at enhancing local social conditions by improving basic education for local children, the first priority of sustainable education in any society (Hopkins and McKeown, 2002). Architect Diébédo Francis Kéré, who was born in Gando and was the first person from his village to study abroad, reinvested his knowledge as an architect into the urgent need for construction of a school in Gando[3]. The school not only provides education for local children, but its construction is part of a process of passing on new skills and knowledge to the entire community. Consequently, it was the recipient of an Aga Khan Award for Architecture in 2004.

To respond to their objectives, both schools encompassed several sustainable strategies and techniques. Thus, besides being *for* sustainability, they can be *about* sustainability as well. At Sidwell Friends Middle School, rather than demolishing the existing building, renovation and addition were chosen, because of having less impact on the environment. Maximising the use of daylight, but avoiding glare, was combined with several techniques, such as lightshelves, sunscreens, high-efficiency electric lighting, photosensors, and occupancy sensors. Operable windows and solar-ventilation chimneys were designed to work with ceiling fans and mechanical heating and cooling systems. To reduce storm water runoff and support native habitat, a green roof and a constructed wetland were incorporated. A constructed wetland was also used for treating building waste water on site and forms part of a closed system that recycles the water back to the school lavatories and cooling towers. Furthermore, sensor-operated water-conserving laboratory faucets were used. In terms of material selection, 78% of building materials were manufactured regionally, 11% were from recycled sources, and 60% of construction waste was diverted from landfills and recycled (Sidwell Friends School, n.d.). Since the school was located within walking distance of a subway stop and several bus stops, the design was intended to promote a non-automobile commuting option by providing bicycle storage and showers for bicycle commuters and separating vehicle and pedestrian traffic. The school also offered $35 each month to any staff member who reduced car use by 80%. Since the policy started, the number of people qualifying for this benefit has increased 61% (AIA, 2007). Differing from the manifold solutions at Sidwell Friends School, the design strategies for the primary school at Gando were based on the basic idea of designing for climatic comfort with low-cost construction. In term of orientation, three rectangular classrooms were aligned east to west and separated by covered areas. The structure comprised traditional load-bearing walls made from compressed earth blocks and concrete beams. The beams running across the width of the ceiling supported a ceiling also of earth blocks and provided the structural base for the roof. To overcome the difficulty of transporting large elements to the site and economic availability of large machinery, such as cranes, the architect selected small steel bars to create lightweight trusses with a

[3] Kéré is the main motivator behind the project. He designed the school, secured financial support via a fund-raising association Schubausteine für Gando (Bricks for the Gando School), and also obtained government support to train people in building with local materials (AKDN, n.d.).

roof of corrugated metal sheeting, so people could learn how to build the school with a handsaw and a small welding machine (AKDN, n.d.). Earth blocks, used for walls and ceilings, absorb heat and moderate the room temperature. The overhanging roof shades the façades from sun and rain and, by lifting the roof up on the steel trusses above the clay block ceiling, cooling air can flow freely between the roof and the ceiling.

In addition, the construction of Gando Primary School helped to solidify the community connection by engaging all of the villagers in building the school for their children, created opportunities for young trained Gando villagers to be employed on further public construction projects, and empowered neighbouring villages to follow the same model of community mobilisation to build schools for themselves (Ford, 2007; AKDN, n.d.). This construction process was part of an entire process that leads the communities towards sustainability, and makes the project able to be categorised as architecture *as* sustainability. In the case of Sidwell Friends Middle School, although communal learning was not a focus during the construction process, the finished building was used as a tool to learn about the relationship between natural and human-created systems. Because many parts of the building systems were exposed and made visible, the mechanical, electrical, structural and plumbing systems in the school were able to be used for study. Students monitored the building functions and measured the health quality of the facility. The school has developed a tour and signage program for the community. A real-time monitoring program can also be accessed via the internet (Sidwell Friends School, n.d.). In addition, the school became the subject of study for the Yale School of Forestry and Environmental Studies and a case study for green design, found in the LEED for Schools Reference Guide (AIA, 2007). Through the operational activities that aim to enhance environmental awareness and promote learning community, therefore, this project can also recognised as architecture *as* sustainability.

In summary, these two case studies illustrate the feasibility of sustainable architecture that could be *about*, *for*, and *as* sustainability. They also show the practicability of architecture to strengthen sustainable conditions and collaborate with other sustainable practices, in every architectural process from pre-design (e.g. setting aims of the projects), design (e.g. selection of design strategies and solutions), construction (e.g. participation of local community in the construction), operation (e.g. use of schools as a learning tool), renovation and demolition (e.g. decisions to renovate and add), to creation of new projects (e.g. building on lessons from previous projects). Furthermore, they suggest that the process and design solutions to create sustainability can be varied, depending on local conditions and contexts. This affirms that sustainable architecture is inevitably influenced by economic, social, and environmental systems, and is part of a larger system of sustainable practices.

6. Conclusion

According to the discussion above, a sustainable design project can be related to all three categories of sustainable architecture, architecture *about*, *for*, and *as* sustainability. They are connected and combinations of any two or all three are both possible and sensible. Architecture that aims *for* sustainability usually contains sustainable design strategies and sustainable components, which are the essence of *about* sustainability. Furthermore, it is meaningful to speak of architecture *about* sustainability and *for* sustainability at the same time. Meanwhile, some buildings, such as traditional and vernacular architecture, that are *about* sustainability by accommodating sustainable components (e.g. natural and non-toxic materials and sun shading) and use sustainable design strategies (e.g. natural ventilation and appropriate orientation responding to the solar pattern and wind directions), may not seem to aim *for* sustainability, but because they support sustainable behaviours and local sustainable environments and culture can be recognised as architecture *as* sustainability. Additionally, to create architecture *as* sustainability, stakeholders should aim to create at least architecture *for* sustainability, and not just add on terms *about* sustainability into conventional practices.

These connections suggest the feasibility of enhancing the meaning of sustainable architecture to include its elements, objectives and processes. Particularly, an explanation of sustainable architecture that is architecture *as* sustainability suggests an interdisciplinary approach, which helps to improve quality of design as well as sustainable conditions. It also emphasises the fact that the aims of sustainable architecture are not just approaching the goal of achieving sustainability, but architecture for its own sake that is sustainability. With the support of a sustainable milieu, architecture could be part of sustainability or, better, be sustainability. This transformative process will change the meaning of both sustainable architecture and architecture itself. Eventually, there will no longer be sustainable architecture, but only architecture that is sustainability.

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INFORMATION AND KNOWLEDGE SPREADING OF ENVIRONMENTAL FRIENDLY SOLUTIONS IN THE BUILDING SECTOR

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Summary (*11-point Arial, bold, flush left, 11-point line spacing, style name "Heading 1"*)

The Norwegian government and the construction and engineering industries are cooperating in Byggemiljø – a program running in the period 2005-2009. The main objective for the program is to raise the environmental awareness in the construction and engineering industries. The main focus for the program is to spread information and knowledge about existing environmentally friendly solutions, and the web site www.byggemiljo.no was established at the end of 2005. The web site contents information about how to build environmentally friendly, easy hints, environmental subjects, examples, handbooks, laws and regulations, activities etc.

Byggemiljø is also involved in different projects i.e. how to reduce the building's sector green house gas emission, environmental evaluation of building products and materials, how to use and evaluate LCA. These projects are knowledge the building sector needs to perform more environmental friendly.

Establishment of Byggemiljø has also improved the communication between the authorities and the building sector and between builder, architect, engineer, contractor and the owner and different organizations that work with promoting environmentally friendly solutions.

1. Introduction

In the period 1997-2002 the Norwegian government and the construction and engineering industries had a program running to improve the building sector environmental. One of the program's highlight was SB02 in Oslo in September 2002. After 2002 the construction and engineering industries wanted to continue the cooperation with the Norwegian government and after a long discussion period they agreed in the beginning of 2005 to continue the work but in a smaller scale.

In 2005 the Norwegian government and the construction and engineering industries started up again the cooperation with objective to get the construction and engineering industries more environmentally friendly. The following organizations committed the program Byggemiljø for the period 2005-09:

- Ministry of Local Government and Regional Development
- The Norwegian State Housing Bank
- National Office of Building Technology and Administration
- The Directorate of Public Construction and Property
- Association of Consulting Architects in Norway
- Association of Consulting Engineers, Norway
- The Federation of Norwegian Construction Industry
- Norwegian Association of Technical Contractors

The main focus for the program is to spread information and knowledge about existing environmentally friendly solutions, not to develop new knowledge.

The program is financed by the government while the construction and engineering industries have committed to put 3000 working hours into the program.

The builders, the architects, the civil and technical engineers, the contractors, the owners and the authorities are present in the program. In the program running from 1997 to 2002 the architects were not present. Therefore there has been an improvement that the whole building "chain" now is present in the program.

2. Information and knowledge spreading

Since the main focus for the program is to spread information and knowledge and the program has limited resources, it was decided to canalize information thru a web site. www.byggemiljo.no was established in 2005 (see Fig. 1). The objective is that www.byggemiljo.no will be the web site you start when you look for information about how the building sector can reduce the environmental influence and the building sector's environmental influence. The web site is successful and the number of hits is rising both in visitors and visits.

The web site contents the following:

- Practical and easy hints to become more environmentally friendly.
  The hints are easy to implement and will not give extra expenses.
- When to take care of the different environmental challenges in the building process
- Environmental subjects (i.e. energy, waste, life cycle analysis, environmental management)
- Examples of good environmental solutions
- Handbooks for how to implement environmental friendly solutions
- Environmental tools and programs
- Laws and regulations relevant to the environment
- Simple environmental dictionary (relevant to the building sector)
- Activities relevant to the environment and the building sector
- Links relevant to the environment and the building sector
- Education relevant to the environment and the building sector
- News relevant to the environment and the building sector

Figure 1 www.byggemiljo.no.

3. Projects

Even though the main area for Byggemiljø is to maintain a web site with good and interesting information for how the building sector can become more environmental friendly, Byggemiljø is also involved in other projects. The projects are mainly projects that can improve environmental effects from the sector. Examples are:

- The building sector's green house gas emission and how to reduce the emissions. This project involves the construction and engineering industries and has made discussions of how we best should reduce the green house gas emission; during better energy efficiency in the buildings or better production of building materials. The project is still running.
- Environmental evaluation of building products. Development of a method that will simplify evaluation and comparison of EPD's (Environmental Product Declarations), called ECOproduct.

Generell vurdering av materialer

Innendors maling og lakk	Kjemikalier	Miljobelastning: Råmaterialer, utslipp og avfall	Arbeidsmiljo og inneklima	Tekniske egenskaper
AKRYL- OG LATEKS MALING Forholdsregler: - Spesifikke produkter bør sjekkes mot prioritets-/OBS-listen. - Inneklimarelevant dokumentasjon bør fremskaffes. *Alternativer (alle typer):* - *Alkydmaling* - *Lakk* - *Olje*	Kan inneholde biocider og andre tilsetninger. Kan inneholde isotiazoliner.	Produksjon - Bindemiddel produsert på basis av olje/naturgass. De vanligste bindemidlene er polyvinylacetat og polyakrylat (akryl lateks). Bruk Avfallsbehandling - Ikke herdet maling er farlig avfall. - Tomme, tørre malingsbokser er restavfall.	Arbeidsmiljø - Store forskjeller mellom de beste og de dårligste produktene. Lave emisjoner av løsemidler, men tilsetningsstoffer kan avdampe over lengre tid. Inneklima: - De beste produktene har meget lav avgassing selv kort tid etter påføring. - Det er generelt noe høyere avgassing fra akrylmalinger enn lateksmalinger. - Inneklimarelevant dokumentasjon må fremskaffes og vurderes.	Bruksområder Rengjøring - Middels til dårlig rengjørbarhet avhengig av glanstall og underlag. Egne malingssystemer for våtrom finnes. Levetid Vedlikehold - Akrylmaling gir generelt en mer robust overflate enn lateksmaling.
GULVOLJE Forholdsregler: - Spesifikke produkter bør sjekkes mot prioritets-/OBS-listen. Inneklimarelevant dokumentasjon bør fremskaffes. Vedlikehold *Alternativer (alle typer):* - *Lakk*	Inneholder vegetabilske oljer, kunst/natur harpiks og varierende mengder terpentin.	Produksjon - Ekstraherte vegetabilske oljer (fornybare ressurser) og terpentin på basis av olje (ikke fornybare ressurser). Bruk Avfallsbehandling - Ikke herdet olje er farlig avfall. - Tomme, tørre bokser/kanner er restavfall.	Arbeidsmiljø - Potensielt kraftige avgassinger av terpentin under påføring og tørking/herding. Inneklima: - Potensielt belastende på inneklima den første tiden, og der vedlikeholdsbehandling må gjentas ofte. - Det bør velges produkter med laves mulige YL-gruppe og aller helst med høyt tørrstoff innhold (over 80 %).	Bruksområder Rengjøring - Gir tyngre vedlikehold enn lakkerte overflater. Levetid Vedlikehold - Oljebehandling må gjentas hver 6. mnd - hvert annet år alt etter bruk og slitasje.

Figure 2   Material evaluation list

- Environmental evaluation of building materials. Byggemiljø has summed up an environmental evaluation of different building materials (see Fig. 2). The list contents more than 70 general building materials (not products) and gives general information about
  - Content of chemicals
  - Use of raw materials
  - Emissions
  - Waste
  - Working environment under construction and service
  - Technical characteristics
  - Alternatives
- How to use and evaluate Life Cycle Assessment. Handbook in how to use and evaluate Life Cycle Assessment
- National Action Plan for Construction and Demolition Waste 2007-12.
  - Development of the action plan was partly financed by Byggemiljø
  - Course development about new regulations for mapping hazardous waste and safe waste handling
- Open monthly 2 hours meetings for the construction and engineering industries where different environmental aspects are discussed.

Sjekkliste - substitusjonsvurderinger

Du skal i følge substitusjonsplikten erstatte et produkt dersom
• kvalitet • levetid • vedlikehold • kostnad
blir omtrent lik med et annet produkt som inneholder mindre helse- og miljøfarlige stoffer.

1	**Miljøvurderinger av stoffer og produkter skal utføres før det bestilles/kjøpes.**
2	**Skaff deg oversikt over stoffer og produkter din bedrift benytter/skal benytte på byggeplassen.**
3	**Kartlegg risikoprodukter** - Bestem hvilke stoffer og produkter som skal vurderes, velg først de farligste, eks. byggevarer nevnt i denne folderen, samt de du bruker ofte og i store mengder.
4	**Sjekk om produktene inneholder helse- og miljøfarlige stoffer som står på SFTs prioritetsliste.** - Spør leverandør om produktene inneholder helse- og miljøfarlige stoffer som står på SFTs prioritetsliste. Leverandøren har plikt til svare jf. miljøinformasjonsloven. - Sjekk faresymbol og R-setninger. Finnes under pkt. 15 i HMS-datablad. Inneholder produktene ikke helse- og miljøfarlige stoffer, kan du trygt bruke dem.
5	**Finn ut om det er alternative produkter eller metoder på markedet. Vurder risiko ved bruk av disse.** - Spør leverandør om alternativ produkt/metode. - Spør andre i bedriften om alternativer. - Vurder faresymbol og R-setninger på HMS-datablad/ produktinformasjon for alternativene.
6	**Benytt alternativ produkt/metode** dersom det inneholder mindre helse- og miljøfarlige stoffer og har tilnærmet like egenskaper.
7	**Dokumenter vurderingene** du har gjort eks. i stoffkartotek eller møtereferat.
8	**Sørg for å ha oversikt over alle stoffer og produkter på byggeplassen.** - Sjekk at du har gyldig HMS-datablad/ produktinformasjon for produktene. HMS-datablad skal ha norsk tekst. - Ha en samlet oversikt over produktdokumentasjonen i eks. stoffkartotek (elektronisk/perm).
9	**Substitusjon er en kontinuerlig prosess.** Lag en plan for hvor ofte din bedrift skal sjekke om det er kommet nye alternativer på markedet, eks. årlig.

Hjelpemidler og mer informasjon

Foldere om substitusjonsplikten
Folderne "Kjenner du substitusjonsplikten og ditt ansvar som byggherre" og "Vurdering av helse- og miljøfarlige stoffer på byggeplasser" kan lastes ned fra **www.byggemiljo.no.**

Detaljert veileder om substitusjonsplikten:
www.sft.no/publikasjoner/kjemikalier/1715/ta1715.pdf

Substitusjonsverktøy
Det finnes flere elektroniske verktøy eks. Grips substitusjonsverktøy **http://substitusjon.hms.info**, BASS Bygg- og anleggsnæringens stoffkartotek-system **www.cobuilder.no** og ECOproduct – database for miljøriktig produktvalg **www.nbtoda.no.**

Generell informasjon om farlige stoffer
www.miljostatus.no/kjemikalier

Kjemikalielister bl.a. prioritetslisten og OBS-listen:
www.miljostatus.no/kjemikalielister

Klassifisering og merking av kjemikalier
www.sft.no/publikasjoner/kjemikalier/1954/ta1954.html

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Byggenæringen bruker om lag 50 000 ulike produkter. Mange av disse produktene inneholder helse- og miljøfarlige stoffer selv om de omsettes i Norge.

Substitusjonsplikten
beskriver at alle som planlegger å bruke eller bruker produkter med stoffer som kan være en risiko for helse og miljø, har plikt til å vurdere om de kan bruke mindre farlige alternativer.

jfr. Produktkontrolloven §3a

Figure 3 Booklet about how to substitute product that contents chemicals hazardous to health and environment.

- Substitution of products with chemicals hazardous to health and environment. The regulations in Norway have decided that if a product contents chemicals hazardous to health and environment the user has to evaluate if he can use a similar product or method that contents less chemicals hazardous to health and environment. To inform the construction and engineering industries about this regulation Byggemiljø has cooperated with the Norwegian Pollution Control Authority and published small booklets how to fulfil the law (see Fig. 3). This has been successful, and the booklets have been handed out when the Norwegian Pollution Control Authority has carried out controls in the construction and engineering industries.

4. Cooperation between the authorities and the construction and engineering industries.

The program has improved the cooperation between authorities and the construction and engineering industries. Byggemiljø has regular meetings with the authority departments where we can discuss different subject and challenges. This cooperation has lead to better influence on how to develop and implement new regulations and laws for the construction and engineering industries.

Better cooperation is essential to build more environmental friendly. The program has also improved the cooperation between builders, architects, engineers, contractors, and owners and different organizations that work with promoting environmentally friendly solutions.

TRANSLATING SUSTAINABLE BUILDINGS – THE USE OF NETWORKS TO IMPLEMENT PASSIVE HOUSES IN SWEDEN

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Summary

This paper has the aim to show how and why a sustainable building concept is implemented. The case study chosen is a sustainable building concept called the Passive House (PH). The research presented in this paper was conducted in a Swedish setting and explored PHs in the state of implementation. Implementation is studied as a process, in which the concept is translated by different actors. The translation approach reveals how power structures operate in the building process, how decisions are made and thereby why certain technologies are accepted or rejected. The original concept of the PH was developed in Germany in the 1990's. When the PH concept was implemented in Sweden, the technologies were translated by different actors in order to engage other actors in fulfilling the goals of the project. For some actors the project became a tool to fulfil an overall goal of sustainability in society (this was the goal of the public funding body). To others, PHs were means to reach the dream of a dwelling in an attractive neighbourhood (the residents), or the challenge to build the densest house in the country (the builders on site). A conclusion is that it is possible to use other incentives then pure profit in the short run, when implementing a sustainable innovation like the PH.

1. Introduction, aim and objectives

Energy is of major importance in society, influencing many aspects of our daily lives. We depend on energy to keep us warm, heat our food, run electrical appliances, etc. At the same time, energy-related emissions constitute a major environmental load. Any major reduction of carbon dioxide emissions will require an improvement of energy efficiency measures of the building stock. The housing sector accounts for approximately 40 percent of total energy demand in Western European countries, including Sweden, and fossil fuels are used to produce heat and electricity for housing (Swedish Energy Agency 2007). Goals for a reduction of the energy use in dwellings are set both politically and within the housing sector itself.

A Passive House (PH) may reduce the energy demand for heating in dwellings by 80 percent (Feist et al 2005). Germany has been the main market for houses with passive design, where a limit of 15 kWh per square metre per year has been set for household heating. This is achieved because the dwellings are extremely air tight, have thick insulation and rely mainly on passive sources of heating, for example solar heating through window panes and heat surplus from humans and domestic appliances (Schnieders 2003). In 2001 the PH concept became seriously established in Sweden, when twenty terraced PHs were erected in Lindås Park in Göteborg. This was the result of a four year research and building process, called "Houses without Heating Systems", with the aim to develop PHs for a Nordic climate. This building project has then been followed by several building projects with a PH concept. This paper will focus on Lindås Park, and two projects following Lindås Park: Bottnevägen in Göteborg and Oxtorget in Värnamo.

The overall aim of this paper is to show how a low energy house concept, the PH, was introduced on the Swedish context. The processes behind the implementation of low energy concepts are important to explore since Sweden, among many other countries, has targets on reduced energy use to achieve in the near future. Additionally, bridges and barriers for further development and dissemination in Sweden are recognised. The research objectives are to explore how the processes were facilitated by stakeholders and investigate what resources they used to achieve an implementation. To establish PHs in the building sector it requires that actors in their network accept new ideas and technological solutions. In this paper the PH building processes is analysed by using network theories emphasising drivers behind implementation in socio-technical networks.

1.1 Methodology and theoretical framework

The research field of Science and Technology Studies (STS) provides theories and concepts suitable for research aimed at understanding and explaining a socio-technical system. Socio-technical systems, which buildings are, comprise professional actors, end users like the home owners or tenants, and artefacts. Translation is a theoretical concept used in the transdisciplinary field of STS which focus on the negotiations between stakeholders in the application of knowledge. The socio-technical system of PHs includes organisations, participation, building design, building material and technology for heating and hot water etc.

The analytical tools used in this paper are drawn mainly from the work of Michel Callon (1986a; 1986b; 1987; 1991). The works of Callon show how innovations are disseminated and implemented in the hands of engineers and he has developed a concept of translations within the framework of actor-network theory (ANT) (c f Latour, 1987). Translations are used by actors to engage other actors in fulfilling the goals of a certain project. This process-oriented concept reveals the dynamics of power and how people and artefacts become involved in the process. According to ANT people and artefacts are nodes in a network with different connections between them. Furthermore, Callon suggests technologies and applications are representations of different discourses or policies.

Translations are part of the creation of actor networks and it includes stages of *problematisation*, *intressement, enrolment* and *mobilisation* (Callon 1986b). By problematisation Callon acknowledged that engineers with definitie goals of implementing a new technology make themselves indispensible to the project. They define the problems and present solutions in which they are the key part. Therefore part of problematisation is the definition of *obligatory passage points* which include these solutions. In the next phase of translation *intressement*, actors are locked in their designated roles in the project, determined by the key actor. In the phase of *enrolement* the roles are connected in a network of actors and technical solutions, and in *mobilisation* these actors are trained to represent the idea of the project and the collective acts. To conclude, *translation* is the process in which new networks are formed as a result of new connections between actors and technologies. In his work, Callon discovered how engineers in France who were committed to introduce an electrical car in the 1970's worked as *engineer-sociologists* as they addressed both technical aspects of the new vehicle and social and organizational aspects of the project (Callon 1987). The theory of translations will be applied to the PH development in Sweden.

Energy-saving actions are often seen as the consequences of informed rational action on the part of individual decision-makers, which is criticised by Guy and Shove (2000). They mean it is necessary to understand the social structures and the social networks within these decisions are made. Shove highlights the social and institutional context in which decisions concerning acceptance of innovations and sustainable energy solutions are made (Shove 1999:1107). Following studies of STS-scientist such as Callon and Bijker she emphasis that decisions concerning for example implementation of energy efficiency measures and how we use energy are made in social contexts. Practitioners identify and make energy-related decisions within different networks and different contexts according to Shove: "what qualifies as a reliable, cost effective, worthwhile energy saving measure in one socio-cultural domain might count for nothing in another" (Shove, 1999:1109). Applying this perspective technology is formed and developed in networks in which actors meet and negotiate concerning various ideas and issues. The implementation of the PH concept can be expected to be wrapped up and shaped by social processes and built on knowledge, routines, institutions, methods established in networks. When technology is transferred methods and measures are seldom directly transferable, but can be picked up and "domesticated" in different spheres (Silverstone et al 1992, Lie & Sørensen 1996, Sørensen et al 2000). It is possible to identify and visualize new opportunities and new methods for different networks.

The existing networks in the building sector have been named Old Boy Network (Björklöf, 1986) and consist of earlier study and working friends. These networks are important for the spread of innovations, because they are used to solve upcoming problems and to strengthen social relations. The actors have easier to accept innovations presented by other actors in the network and usually innovations are spread by informal phone-calls within the networks. One reason for this is because of the time pressure in building projects and the result from this process is that colleagues act as "filters" that select and value innovations (Björklöf, 1986).

Case study methodology is about following a project in the real life context (Yin 1994) and has been the guiding principle for the empirical work of this research. Some researchers in methodology has emphasised the importance of finding the boundary between the project and the context in case study research (Merriam 1994), while others encourage inductively determining the scope of the research (Ragin 1992). Building processes, like the ones described in this paper, are complex projects with several organisations and different people involved in different parts of the project's timeline. This notion calls for an inductive approach which in this case has been applied using a social context inspired actor network analysis (se next chapter). The *case* can be described as *the implementation of Passive Houses in Sweden*.

In case studies so called thick descriptions are preferred (Geertz 1993). A thick description will not only include stakeholders' actions but the context as well. Firstly, to capture the network of actors involved in the project, information in documents from the building processes and from interviews with stakeholders were used. The documents were mainly collected from the Swedish council for building research, which co-funded the Lindås Park project. For the Bottnevägen and Oxtorget projects documents were provided by the developers (the housing companies owned by the municipalities in Göteborg and Värnamo). Also documents from the municipalities in Göteborg and Värnamo, about the spatial planning processes were used to describe the context of the case. For the later stages, minutes from the construction companies and articles in newspapers provided important information about how the projects proceeded. From the documents, key stakeholders were identified and interviewed about different aspects of the building processes. The purpose of the interviews was to gain more information about the context of the projects and especially learn about how and why decisions about different parts of the projects were made. The data was originally collected for a PhD project (c f Glad 2006). In this paper, the data from these case studies has been re-analysed by applying network theories focusing on the translation of passive houses in Sweden.

2 Lindås Park – A Passive House initiative in Sweden

The PH development in Sweden can be divided into different periods reflecting driving forces within different groups of stakeholders. The first period can be defined as a consequence of the oil crises in the 1970's when the need for low energy housing in Sweden was acknowledged both by the Swedish government and academia. Consequently, funds for experimenting and demonstrating low energy systems in buildings were provisioned by Swedish research councils. Also, techniques for low energy designs were taught at the universities. The Gothenburg University became an informal centre for low energy systems where Sweden's first professor of building services engineering Enno Abel encouraged students to adopt a holistic approach in their future professions (Abel & Elmroth 2007). Thus, the 20 terraced houses erected in Gothenburg in 2001 were not the first attempt to introduce houses with passive energy in Sweden. In the late 1970's and early 1980's, several experimental housing projects were carried through (Swedish Building Research Council 1991). But there were only a few follow-ups and no market introduction mainly because an excess of electricity supply due to the building of several nuclear power plants in the 1980's. The architect who initiated the Lindås Park project in the 1990's, Hans Eek, had been involved in some of the experimental low energy projects earlier, both in Sweden and in Germany, and thought this concept would have potential in Sweden (Glad 2006).

To suit the Nordic climate in Sweden, the German standard had to be adjusted to suit Swedish climate (Wall 2006). This required research on some of the technologies. For this purpose, three Swedish research institutes, the Faculty of engineering in Lund, Chalmers University of Technology and Swedish National Testing and Research Institute (SP), together with Hans Eek's, the architect's office EFEM, applied for funding from a Swedish research council. Similar to what Björklöf (1986) stated, the researchers involved in implementing this radical new concept knew each other before and had previously been engaged in different environmental projects together. In 1997 the group of researchers received funding for the development and improvement of building components, the ventilation system and the design of the building.(Glad 2006) This marks the start of a second period of PH development in Sweden, which is characterised by a sustainability context rising in the 1990's. Sustainable development became high priority in Sweden and research funding for environmentally sound energy systems was available. What attracted attention from the funding body was how the PH concept promised low energy housing without adding extra costs. This was offered something new to the industry and was the main reason for governmental funding.

The same year, the municipal owned housing company Göteborgs Egnahems AB, decided to get involved in the project and take on the role of building proprietor. Major developers on the Swedish market was approached by Eek but rejected the idea. The CEO of Göteborgs Egnahems AB was interested because he expected the company could learn a great deal from this project. Göteborgs Egnahems AB involved a construction company, PEAB, and different consultants at an early stage of the project since the idea was that practitioners and researcher with a more theoretical approach would develop a joint understanding of PHs in a Nordic climate (Glad 2006). The researchers made data simulations of different window areas and scenarios with different household sizes and time spent indoors (Wall 2006). They set the standards referring to a "normal" family as consisting of two adults and two children, all of whom spent a certain amount of time at home using different appliances, and the amount of electricity a normal household in Sweden is expected to use. Other parts of the energy concept included air-heat, which had been debated in Sweden since the 1980's and was partly forbidden in 1994. In 1999 the regulations around air-heat were loosened, but it was still controversial among experts in the energy sector (Harrysson 1999). In the Lindås Park project a reheater of 900 W was installed in the air-to-air heat exchanger to provide a back-up during cold periods, a method referred to as "the reinvention of air heating" (Feist et al 2005).

Hans Eek organised the building process around seminars where the PH concept were discussed and where different parts of the energy system in buildings were presented and debated. The seminars were organised mainly by and for researchers and funded by the research council. Parallel to these seminars were planning meetings and these were organised and funded by the construction company. Similar to the case Latour describes in *Science in Action* (1987) and what Lutzenhiser (1993) found in his studies of energy simulations and modelling, the assumed users were disconnected from the planning phase. At an early stage of the project it was planned to include expertise on residential behaviour and also dedicate one of the seminars to behavioural issues. When costs had to be cut, this expertise and seminar were cancelled (Glad 2006). Results from other research show how the involvement of end-users can influence projects in positive ways and minimising the risk of failure (Wynne 1988). Involving end-users, which would be the residents, was never an option in Lindås Park (Glad 2006).

When the model of *translation* is applied to this case, much of the content in the model can be verified. The concept, including the technologies and how the project was managed, was accepted by the participants. The architect formulated the problem and offered a solution in which he played an important part. The *problematisation* can be described as "we have a problem globally with excessive and unnecessary resource use and the construction industry in Sweden is not acting responsible and is too conservative – PHs is *the* solution" and the *obligatory passage point* being to accept this problem and its solution. A couple of years after the project finished, virtually every participant told the same story about what happened in the project (Glad 2006). The message was repeated within the group and when talking to outsiders, forming consensus about what the project was about. The exception being the construction company, which suffered a financial loss and dismissed the concept based on the financial aspect of the project. According to them, the concept did add extra costs to the project making it an expensive experience for everyone involved.

The domestication process described by Silverstone et al (1992) and Lie & Sørensen (1996) included elements of negotiation when bridges for implementing new technology are built. In the Lindås Park case several parts of the concept were negotiated during the seminars. One example is how the architect insisted of keeping the German PH standard of 15 kWh per square metre per year as a target. The figure was rejected by the construction company who demanded that the target was lowered. The researchers made new calculations and came up with a new figure of 39 kWh, but with a question mark attached to it. Still, the contractor did not accept the target and consensus about the concept were not reached during the planning phase (Glad 2006). At this point, the Swedish PH was an intangible concept described in documents from the seminars and planning meetings and an expression of the participants' ideas of the energy concept. Now, the energy concept had to be transferred to a new context, the building site. How could the concept be domesticated without being accepted by the construction company?

On the construction site, the construction company's representative and head of the project is the site manager. In Lindås Park the site manager was called Gunnar Tejlerdal and he became the missing link in the network for implementing the PHs. Eek and Tejlerdal connected and together they influenced how the rest of the project was carried out. The general ideas of the concept were accepted by the site manager and he was described as seriously dedicated to the project (Glad 2006). According to Guy and Shove (2000). when new technology is domesticated, established methods and the usual routines are challenged. Lindås Park was a project which differed from other projects and both the site manager and the hand-picked construction workers found it rewarding to work with a project which demanded more craftsmanship and meticulous work. However, in the construction process the energy concept would preferably not add any extra costs into the expensive building procedure. But the extra insulation and air-tightness demanded careful craftsmanship and more working hours for the contractor. This in turn resulted in that the construction company suffered a financial loss, and they stated in official reports that the financial aspect of the energy concept did not work. During the years of planning and building, the architect and project manager marketed the concept via mass media with the message that houses could function without a heating system, meaning little or no extra costs. The message was presented in the present tense as if the concept was already realised and worked as expected. In general, the project was presented in positive way and very little criticised (Glad 2006).

Guy and Shove stated that the "techno-economic view of energy efficiency" is predominant in our western societies (Guy and Shove 2000). According to this view decisions made by people to act energy efficiently is a result of having the right information, being aware of the benefits, the price is "right" and there are no conflicts of interests. An example of this view is the evaluation from SP Technical Research Institute of Sweden (Ruud & Lundin 2004). During two years, the energy consumption in Lindås Park was measured and the result showed the energy consumption being higher than expected, 69 kWh per square metre per year. This was explained partly by unexpected household behaviours, for example a demand for a higher indoor temperature and the use of extra heaters to keep the temperature up. According to the assessment, the residents did not have enough information and there was a conflict of interests between the desire to have a relatively high indoor temperature and save energy.

Projects like Lindås Park are sometimes referred to as "demonstration projects" and has since the 1970's been funded by governments and international bodies. However, knowledge from demonstration projects often fails to disseminate, since the knowledge available is usually "incomplete, un-reflected and not very trustworthy" (Femenías 2005:220). An explanation for this can partly be found in the fact that assessments are usually carried out by stakeholders involved in the projects who are usually biased. This was the case in the Lindås Park project since SP played an important part in developing the energy system for Lindås Park. A comprehensive analysis conducted by independent researchers shows that the operational and embodied energy for the Swedish PHs are close to half of a conventional comparable dwelling. The extra costs amounted to 20,000 Euro accourding to the Göteborgs Egnahems AB. These researchers stated that the pay-off period of 19,5 years was reasonable (Karlsson & Moshfegh 2007).

3 Bottnevägen low-energy houses

Conventional developments take time to plan for and build, and the PH is not an exception. On the contrary, PHs require more time for planning and building and more energy is used in this phase than normally. Energy is embodied in the material used and also in the work by builders on the construction site. In this case, the Lindås Park project was to be evaluated and the energy use was measured for two years. Other developers awaited the results from the evaluation but many showed interest in Lindås Park and during the years of measurement approximately 1500 visitors came to the site on study tours, including many developers (Glad 2006). The building proprietor of Lindås Park, Göteborgs Egnahems AB, stated they had positive experiences from Lindås Park, but still they decided not to build more PHs. Instead, they choose to change the concept and concentrate on a low-energy concept, implemented in the Bottnevägen project and without any targets for the energy demand, government funding and involvement of researchers or architect Eek. (Glad 2006) This could to be defined as the start of the third development period of PHs in Sweden constituted by the involvement of end users in the design process.

Ivory (2004) concluded that in construction projects architects are often the ones pushing innovations, and if end users are consulted they usually act rather conservative. In the Lindås Park project, architect Eek was an important driver for implementing the energy efficient innovative concept but the architects involved in the Bottnevägen project had chosen other innovative ideas as their trademark than energy efficient technology. The perception by the architects was that the PHs in Lindås Park were too dark because of the depth of the houses and they wanted to bring in more daylight into the new development. For the Bottnevägen project, the residents in Lindås Park influenced the energy concept based on the communication with Lindås Park residents, Göteborgs Egnahems AB concluded that a more flexible heating system was needed to satisfy the needs of the end users. Unlike Lindås Park, the goal for Bottnevägen was not to build a house with as low energy use as possible, but to satisfy the needs of end users. This could be achieved within the framework of a low energy concept, but not a PH concept. While the official statements from the architect and researchers were that most of the residents were satisfied and with minor improvements the PH concept could work even better (cf Eek 2002, Ruud & Lundin 2004, Isaksson 2005). But Göteborgs Egnahems AB dismissed the PH concept partly based on information collected from residents in Lindås Park and on their interpretation of the assessments. Another experience was that it is difficult to predict household behaviour and figures for heating demand could easily be miscalculated. Therefore it was decided from the start of the Bottnevägen project that the terraced and semidetached houses would have a heating system and no goals for low energy consumption were set. Some parts that were taken for granted in the former project, for example windows with extremely low-emittance glass or solar panels for hot water, were not implemented in Bottnevägen (Glad 2006). Not being part of any funding scheme or research project, a comprehensive assessment of this project is not likely to happen.

In the Bottnevägen project, the PH concept lost important parts of the network involved in the Lindås Park project. This third period of development involved end users but lost the more radical researchers and architects and thereby the original concept. The *problematisation* in this project was not about excessive energy use and the conservative construction industry but about how to get end user satisfaction within a low-energy house concept. The focus shifted from the professionals to lay people and their experience and knowledge about the PH concept in Lindås Park. This raises the question of whether the concept became more sustainable or if some important parts of sustainability were lost in the Bottnevägen project? It is possible to argue that some ecological sustainability was lost, since the Bottnevägen low energy house concept is likely to use more energy than the PH concept, but since experience from a new social group was included in the project and influenced the Bottnevägen concept, the concept became more socially sustainable.

The context in Gothenburg, the city where both the Lindås Park and Bottnevägen projects are found, is significant because of the presence of a particular urban regime called “the Spirit of Gothenburg” (Sydow 2004). In short this regime is characterized by a network of support in the city of Gothenburg including politicians, the industry, Chalmers University of Technology and University of Gothenburg. This network is enabling for innovations because it includes informal agreements about cooperation and flexibility in organising work and decision-making. The Lindås Park project was unusual development in Sweden since it was initiated by an architect (Green 2006). The way of organising the planning, design and building of Lindås Park was enabled by the urban regime since the locally based building proprietor Göteborgs Egnahems AB, owned by the Gothenburg municipality, accepted the unconventional process and an architect as project leader. In addition, researchers based in the city provided support for the project. In the Bottnevägen project the CEO of the group of companies to which Göteborgs Egnahems AB belongs put pressure to do a follow up, locking Göteborgs Egnahems AB in the leading position for the development of PHs in Sweden. All the local actors in Gothenburg were supportive of the projects and became enroled as spokespersons for the PH concept. The most prominent opponent to the concept was the construction company operating on the national level and not a part of the local urban regime. Similar to the case study on electrical vehicles as presented by Callon (1986a) the network of PH advocates failed to mobilise an important part of the industry and the question remains whether this will disable the transfer of the concept to other contexts? An analysis of the Oxtorget project might answer this question.

4 Oxtorget Passive Houses

In contrast to the Bottnevägen project, the municipal company Finnvedsbostäder in the town of Värnamo decided to embrace the PH concept and build four “zero-energy houses” with 40 flats. In addition, the Oxtorget project had the ambition to develop the concept and welcomed researchers and assessments (Glad 2006). In line with the theory of how technology is domesticated through networks of humans, artefacts, knowledge and institutions (Sørenson et al 2000), Finnvedsbostäder invited architect Eek and consultants involved in the former project to help with the concept plan and passive design features. As a result the network for the development and implementation of PHs in Sweden expanded.

From another perspective, the Oxtorget project can be described as an example of how environmental features can be used to negotiate with opponents to a development and building project. In 2002, the municipality in Värnamo made the decision to build dwellings on a site formerly used as a market place for cattle. After the site was abandoned by tradesmen, people from the neighbourhood used the green space as a recreation area and playground for children. When the decision to build on this site was announced, the neighbours dismissed the idea and made an appeal to the spatial planning bodies. In the same year, the managing director of Finnvedsbostäder became interested in the idea of Life Cycle Costs (LCC). Acccording to Finnvedsbostäder LCC could justify investments in more expensive technology if energy efficiency could be achieved during the technology life. Again in 2002, the Finnvedsbostäder yearly study tour went to Lindås Park to visit the PHs there. The managing director as well as the rest of the personnel and board members were all impressed by the concept. The conventional design was appealing to Finnvedsbostäder and even on this rather cold day in the autumn the houses were warm inside.

Parallel to the neighbours in Värnamo making appeals to higher courts, Finnvedsbostäder nourished the idea of LCC and PHs and came to the conclusion that the Oxtorget site would suit the concepts. When the neighbours’ appeal to the Supreme Administration Court was rejected, Finnvedsbostäder announced the idea of building PHs on Oxtorget. The opponents to the development did not object to this project although it would imply buildings on their green space. In addition, the local newspaper Värnamo Nyheter decided to publish a series of articles about the Oxtorget project. An analysis of these articles showed how they served as good PR for the project and being generally positive to Oxtorget (Glad 2006). To conclude, the Oxtorget project involved new stakeholders in the PH network. Massmedia was an important stakeholder already in the Lindås Park project, but the LCC concept was new and justified the PH concept as being financially responsible.

Problematisation in the Oxtorget project differs from the Lindås Park and Bottnevägen projects because dissimilarities in contexts. In Värnamo, the neighbours became part of the translation process and put pressure on the development for Oxtorget and forcing the building proprietor Finnvedsbostäder to think outside the square and expand the concept agreed on for the Oxtorget precinct. The problem was not defined at the global level, but at the local level where a green area was threatened. However, the PH concept offered a solution to both problems and the greening of the development proposed for Oxtorget made the project more acceptable for the neighbours and the local community represented by the Värnamo local news paper. I would propose that the Oxtorget project is an expansion of the network set up for the Lindås Park project. Virtually every part of the concept was copied and transferred to Värnamo and no parts were dismissed. Technologies used in Lindås Park were transferred to Oxtorget and actors involved in Lindås Park were consulted and influenced the final design of the buildings.

5 Conclusions and discussion

Network theory and the translation model offer important knowledge about how sustainable technology can be transferred between different contexts. The main purpose of using this approach is to reveal power relationships in the PH development in Sweden. The network for PHs in Sweden expanded between 1997 and 2005 and continues to expand as more actors embrace the idea. Recently a PH centre was established in the home town of the architect who initiated the Lindås Park project. In Sweden, the main opponents to PHs have been researchers specialising on the indoor climate and major national developers. Air heating is in general controversial in Sweden because bad experience in the past and the opposition from researchers can be framed within this debate and not against PHs as a concept. Since the innovativeness and sustainability efforts of major developers in Sweden had been heavily attacked in official reports from the government, statements from these companies were not credible and little notice was taken to the objections. These companies might have power in other contexts but their influence over the passive house development in Sweden has so far been limited. The Swedish government has in different ways supported the PH concept and governmental bodies have set up programmes to promote PHs and arranged seminars about low energy housing. It is a clever move to form liaisons with groups of stakeholders who will benefit from the PH concept, like building proprietors who will own the buildings and pay the energy bills in the future. Such building proprietors are for example housing companies owned by the municipality, which accounts for 22 percent of the total housing stock and comprise, as a group, the second largest owner of houses in Sweden. As long as the end-users are ignorant about how much it is possible to save on energy costs during the life-time of a building, and about the predictions of rising energy costs, the major developers are able to build conventional and resource consuming houses. The importance of municipal owned energy companies as driving forces for innovations on the energy area is part of the urban regime in Gothenburg and many other cities in Sweden which emphasise the importance of keeping the municipalities as actors on both the energy and housing market.

When the PH concept was implemented in Sweden, the technologies were translated by the initiating architect in order to engage other actors in fulfilling the goals of the project. Although driven by different incentives, the concept was the solution. A common denominator among several actors was the will to avoid unnecessary use of limited natural resources in housing. Many actors were representatives of public bodies, both on the national level with the research council offering financial support, and on the local level with the housing company owned by the municipality. Also researchers from universities and research institutes were funded by the research council and thereby representatives of public bodies. An overarching goal for public activities is sustainable development and all actors mentioned expressed concern about the environmental aspect of sustainability. The notion of environmental sustainability was transferred to other actors during the building process and the builders on site adopted the idea. The general idea of sustainability was translated into the work of the builders and became extraordinary craftsmanship including the goal to attain the densest building in the country. The three housing projects in this case study were located in attractive neighbourhoods adding an important value in the world of estate agents: location. This was a way for the building proprietors to hide extra costs for the PHs. Residents in Lindås Park stated they chose these houses because of their location and attractive design. The low energy concept added extra value to their dwelling but was not the primary reason for their decision to buy a PH. To conclude, the PH concept included many different parts which can be translated to meet different needs in the building sector which include other values than profit in the short run.

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CHALLENGES FACING THE ADOPTION OF SUSTAINABLE BUILDING IN THE AUSTRALIAN COMMERCIAL SECTOR

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Summary

The building sector is being charged with the task of making changes to the way structures are commissioned and built; particularly in its approach to the use of energy and resources. This is apparent in Australia which is driving sustainable construction through the commissioning of buildings that meet Green Star environmental rating requirements. However there are a number of challenges facing the adoption of sustainable building. Construction professionals involved in the design and construction of sustainable buildings in Australia were interviewed as part of a qualitative based study undertaken in 2006. The major challenges they highlighted were: higher capital costs; cohesive knowledge sharing throughout the design and construction processes; and information on materials and technology including lack of research on performance. The principal challenge was therefore surrounding materials selection and justifying the decisions made. Insufficient product specifications and the availability of suitable local products at competitive prices were key issues identified by the interviewees. When a locally sourced material was chosen, it frequently had a higher capital cost and longer lead times; contributing to the higher first dollar costs and construction delays on projects. Aesthetic factors also meant that sometimes the most sustainable material choice was not always made.

1. Introduction

There is a general acceptance within the wider community that use of fossil fuels, consumption of non-renewable resources and greenhouse gas emissions are causing environmental harm. Climate change is 'likely to be the greatest destabilising force politically and socially of the next Century' (Edwards, 1998). The Construction Industry is recognised as a major contributor to the consumption of energy and thereby greenhouse gas emissions. The Organisation for Economic Cooperation and Development (OECD) advising that the building sector 'accounts for around 25-40% of final energy consumption in OECD countries' (OECD, 2006). With growing concerns for the environment and climate change, there has been a focus on the way new structures are commissioned and built; particularly in their use of energy and resources. There is an increasing recognition that buildings cannot be designed without consideration for their social impact on the environment (John et al., 2005). Further 'the impacts of construction and use of any built projects on the environment are at both local level, such as noise pollution, dust pollution, odour pollution; and global level, such as changes of climate and ecosystems' (Shen et al., 2006).

2. Sustainable construction

The issues highlighted above have been the driving force for more sustainable construction and the need to build 'green'. There are many terms for and interpretations of what constitutes sustainable building practice. Rather than providing a definition, the OECD sustainable building project identifies five objectives for sustainable buildings: resource efficiency; energy efficiency (including greenhouse gas emissions reduction); pollution prevention (including indoor air quality and noise abatement); harmonisation with environment; and integrated and systemic approaches (John et al., 2005). Sustainable construction is in effect 'a series of sustainable or 'best practice' decisions, which start well before construction (in the planning and design stages) and continue long after the construction team have left the site: a process that takes in the design, construction and on-going maintenance of what is being referred to as a 'green' building' (Hayles & Holdsworth, 2005).

2.1 Benefits of sustainable approaches to design and construction

According to Guidry (2004), there are three benefits associated with green building, namely: direct economic benefits; indirect social and psychological benefits; and environmental benefits. Cost benefits can be accrued as a result of sustainable building as 'integrating green principles into a building's planning and design process can generate 40% more savings and 40% better performance than simply adding green technologies to a traditionally planned and designed facility' (Lockwood, 2006). In addition, considering material sales and savings from avoiding landfill, deconstruction projects cost less than traditional demolition projects, whilst helping to preserve environmental resources at the same time (Green Leigh & Patterson, 2006).

Further, improving buildings' thermal properties will reduce consumption, the cost to the end user, and reduce CO_2 emissions (Reed & Wilkinson, 2005). The benefits attributed to green buildings include reduced energy costs, reduced employee health problems and increased productivity. These operate in conjunction with other less tangible benefits such as an enhanced company image for occupants of these buildings by demonstrating their corporate social responsibility, and potentially making them an employer of choice by providing a more attractive workplace (Edwards, 1998). Green building in the developed world is driven by a desire to reduce energy consumption and promoted as a financially-sound business decision.

2.2 Challenges to the adoption of sustainable building practices

The challenges facing the adoption of sustainable building described in the literature can be divided into five distinct categories, namely: cost; information; design processes; construction processes; and materials and technology.

2.2.1 Capital cost

The general industry view is that sustainable buildings come at a premium, with a minimal connection made between the up-front (capital) costs of construction and the operating costs, once the building is completed. Indeed, there is a widespread perception that sustainable buildings are higher in cost than the marketplace will pay for; even when they are not (Zerkin, 2006). This is believed to be due to the lack of accurate, thorough, and quantifiable information regarding the financial and economic impacts of high performance buildings (Suttell, 2006). McKee (1998) suggests that office buildings are not the best place to test new green technologies and designs, as developers and investors are not willing to carry the risk. The barriers to developers choosing high performance green buildings centre on the perception of higher first-dollar costs, and that the market is not willing to pay them, further there are not reliable cost models to assist developers to understand the true costs and benefits of high performance buildings. Developers also face a risk that the lending institutions may not understand high performance aspects and their value in the marketplace. Finally any new approaches are perceived as risky, and the developers are reliant on others' information and may not be able to determine who to trust (Zerkin, 2006). Economic barriers to sustainable design can include: lack of information about inherent long-term economic benefits of sustainable building; lack of integration among various incentive programs (rebates, loans, technical assistance, and recognition programs); reality that first cost is the overriding concern among financial institutions and investors; and the inherently conservative nature of the building industry (Townsend, 1997).

2.2.2 Information gathering

It is not always possible to predict whether a building will perform as predicted, whether the green costs are affordable or indeed whether the technology reliable (Edwards, 1998). There is concern that the complexity of some green designs (technological high performance) may bring about obsolescence earlier than conventional design (McKee, 1998). Further issues include a lack of consensus about what sustainable building actually means. There is also disagreement as to: what the minimum performance standards should be; which activities are considered to be environmentally stressful; what the economics are; and how to evaluate or measure sustainable building (Townsend, 1997). Attempts to integrate the vast amount of information currently available and effectively disseminate it have so far fallen short.

2.2.3 The design process

There appears to be limited understanding of available green options by design professionals. This includes: insufficient knowledge to produce specifications; a lack of available high performance materials; difficulties in gaining approval of new technologies for building codes; uncertainty about approvals; regulatory barriers to adoption of technologies and labour issues due to potential labour-saving measures; all providing further challenges to sustainable design (Zerkin, 2006). In order for sustainable building techniques and materials to be adopted they must be specified by the designer. However, there is no standard assessment criterion for products that allows them to be directly evaluated, and therefore design professionals must invest a lot of time in assessing potential materials and technology (Weber, 2005).

2.2.4 The construction process

Building on the issues described in the design process, the construction process can also be a difficult one. Issues include a lack of knowledge and consequently skilled labour to install and maintain new technologies (and minimal availability of training for the industry). There is limited infrastructure to handle and make available recycled material from deconstruction, thereby making costs prohibitive (Zerkin, 2006). The additional workers and time required also make deconstruction seem more costly than mechanical demolition (Green Leigh & Patterson, 2006). Furthermore time and financial pressures can have a negative impact on the effectiveness of environmental management systems on building sites (Shen et al, 2006).

2.2.5 Materials and technology

The challenges described above are all impacted on by materials and technology selection. Sustainable building practices can make a huge difference to global environmental sustainability, particularly through a drastic reduction in the use of natural resource consumption and energy intensive materials like cement, steel, aggregates and aluminum (du Plessis, 2001). The process of transporting materials via road, sea or air can leave a trail of pollution in its wake, making it more sustainable to use local products. Issues arise where, what is considered to be the most appropriate environmentally friendly product for a particular purpose is not available locally, thereby making materials selection extremely complex (Edwards, 1998). Most architects find it difficult to establish the life cycle costs of a particular product and consequently the environmental cost. For example, establishing a balance between harvesting practices, manufacturing processes, shipping, and the positive/negative impact a certain timber may have on indoor air quality once it is in situ (Weber, 2005) not to mention to disposal or re-use at the end of the buildings life, is extremely difficult. While the process of Life Cycle Analysis (LCA) exists to make this evaluation, a number of issues arise, such as the incentive for suppliers to perform this analysis on their products. This is likely to be consumer or industry demand driven, however if the results are not positive in environmental terms they are unlikely to be published (Graveline, 2005). Furthermore, LCA commonly needs to be completed from a whole of installation perspective, which involves obtaining LCA data for a number of components and therefore suppliers. Further, these suppliers often consider this information proprietary and are reluctant to release it into the public domain where competitors will be able to access it; making the information currently in the public domain limited and the process involved obviously expensive, meaning few clients are willing to pay the premium required (Graveline, 2005). How efficiently and environmentally the completed building operates is most commonly measured in terms of energy efficiency and productivity, detracting focus from the cost to the environment of the structure itself, which can often be unsustainable.

3 Australian Construction Sector Study

A research study was undertaken at RMIT University, Melbourne in 2006, which utilized semi-structured in-depth interviews conducted with three project managers to investigate their experiences and identify challenges facing the adoption of sustainable building in the Australian commercial sector. The interviewees had all been involved in projects rated under the GBCA's Green Star Program, in building refurbishment, office fit-out and as-built building. They were all assessed for a 5 or 6 star rating, 5 star being Australian Excellence and 6 star World Leadership (GBCA, 2006). Some of the buildings incorporated significant new technology, some receiving assistance from Sustainability Victoria's Commercial Office Building Energy Innovation Incentive (COBEII)[1]. All

[1] COBEII is a local government scheme which 'assists developers, property owners and tenants to demonstrate innovation in the design and application of sustainable energy' and provides some funding towards these initiatives (SV, 2006).

of the buildings incorporated sustainability criteria to some degree, including water conservation: daylighting: natural ventilation, VOC minimisation and energy conservation.

3.1 Interview Results

The interviews covered the five challenge areas identified in the literature review, namely: cost, information, design processes, construction processes, and materials and technology.

3.1.1 Capital Cost

Capital cost was a major consideration in each case, with all Managers all identifying this as an issue impeding the uptake of sustainable building. While the 'green' option was selected in each case, when queried, there was a vast difference in the Managers' views of cost issues and the reasoning behind cost decisions, these included:

- Preparation of budgets based upon conventional construction and technology alongside the use of green or sustainable construction methods and technology, versus the decision to incorporate sustainable initiatives almost as the construction was commencing.
- In all cases the green budget was more expensive with a premium ranging from approximately 1% to 30% depending on if the rating aspired to was 5 stars to 6 stars.
- In one case the payback period and energy savings from the sustainable initiatives made the project selection justifiable in economic terms. In the case of the other organizations the project selection was based upon less tangible perceived benefits, such as being an industry leader or innovator in these types of techniques or technologies, and demonstrating potential and skills to future investors or customers.
- The selection of the green option also allows these organisations to demonstrate a sense of corporate social responsibility towards both the environment and their employees.
- Industry ignorance creating a reluctance to invest, slowly being overcome by evidence that the buildings are working.
- Difficulty in getting a board or developer to agree to a significant premium to build a green building.
- The need to generate demand for green materials to provide economies of scale and reduce costs.

3.1.2 Information

Information on products, materials and benefits was a major consideration, with key issues raised by the Managers being:

- While there is significant information available from a European context, there is little by way of evidence in Australia.
- Lack of local companies running a scientific assessment of whether a particular project has contributed to reduced absenteeism or a higher health quotient for their employee base and the query of how scientific are any studies and do they have a strong basis for their argument.
- Due to the relative infancy of the sustainable building movement in Australia there is no long term information available.
- Heavy reliance on Green Star as a source of information and guidance, using it as a benchmark.
- Longer lead times on 'green' products causing program delays.
- Websites such as the Australian Green Procurement (AGP) database (AGP, 2006), could be used to source green products, however there was still a great deal of information that was not available on these websites.
- One organisation managed the sourcing of local products to some extent through a tender process, which effectively out-sourced many of these issues.
- A possible general lack of awareness in the Australian general population, with one Manager noting with more educational required.
- Industry level awareness greatly increasing, with high demand for knowledgeable professionals.
- The requirement to deal with complex information, such as volatile organic compounds and formaldehyde emissions, especially with regards to materials and finish selection.

3.1.3 Design Processes

The design process for the various buildings appeared to have run relatively smoothly due to the commitment of the organisations to green or sustainable features. The main issues being:

- Where new technology was utilised, extensive computer modeling was required to ensure that various technology types would work together (e.g. air flow through the building, or heating and cooling loads).
- One manager observed that for their building the planning authority and controlling body had set very high ESD guidelines to follow. These guidelines leading the organisation to the conclusion that as the planning requirements were so stringent that the building was required to be close to a five star building, the organisation should aim for the five star award.
- Organisations who received support from the COBEII scheme (SV, 2006) noted that this was extremely beneficial, allowing the organisations to investigate various alternatives for energy saving measures, and assisting with the design fees.
- This process was assisted by the various web based programs mentioned earlier, but similar to Weber's (2005) findings this was still a complicated part of the design process.

3.1.4 Construction Processes

The main issue for the construction process was the longer lead times required for some products, which had not been planned for and therefore caused some delays. Points being raised by the interviewees often related to items for the fit out of the premises:

- Due to the finish selection to achieve low VOC's, cabinetry had to be made, disassembled, treated, and then reassembled and brought to site, adding one to two months to a traditional joinery project.
- There was recognition of a change in the industry due to the market recognising that people want green star buildings, or people who want green star buildings want to go and buy products that achieve the criteria quite easily.
- New techniques and technologies did present some challenges, simply due to the organisations being first time adaptors, however this appeared to have been allowed for in some instances, and reportedly went quite smoothly.
- Access to skilled labor to implement new technologies did not cause great concern.
- In these cases environmental performance was a requirement of the organisations, who each also took the role of the client, and therefore, the cost of environmental performance was taken into account.
- The selection of environmentally favourable inputs for the construction did have time implications, as some of the projects were not completed on time, due in part to the difficulty in obtaining material.
- Lack of understanding as to what some of the challenges were in terms of sourcing some of the materials.
- Recycling is quite established in the industry with respect to products such as concrete and steel reinforcing mesh.

3.1.5 Materials and Technology

Materials and technology selection appears to cause some difficulty in an Australian context due to the limited number of suppliers of 'green' products, or where they are available, as noted previously they can be subject to long lead times and a cost premium. Key points raised were:

- While a requirement of the project in one case, a tender process eliminated the ability to note if the 95% Australian content was difficult to achieve or not. This requirement for 95% Australian content took the place of any LCA or assessment of the embodied energy of the products selected. In the case of the other organisations LCA and embodied energy were not studied, but rather the requirements outlined by Green Star in order to achieve points were utilised.
- The selection of materials is also driven by economics, many materials choices commercially driven, for example, more cost effective product imported from China would be selected over local products.
- The architectural or aesthetic factor was a strong influence, as buildings need to look attractive, and set the right image for the building owners' clients, or their tenants' clients, and in many cases in order to meet these aesthetic design elements, products were not available locally.

- The Green Star rating tool was valuable to the various Managers, and was much relied upon as a source of information, with the aim of the organisations being to achieve as many points as possible towards their Green Star rating.
- On some of the projects materials with an energy saving or recycled component were imported, however without an assessment of the transport energy used, resultant emissions and resources consumed, any benefit of these items may have been eliminated.

4. Discussion

Cost was a major challenge to the development of green buildings, with the interviewees' experiences noting a cost premium of up to 30% and the potential for investors to be reluctant to invest in a relatively new type of building with no proven returns. Indeed, investment in sustainable buildings was perceived by investors as a risk, with returns not yet considered to be proven within Australia. The cost of 'green' materials is a key factor in the cost premium.

Availability of appropriate information/specifications, especially when choosing appropriate 'green' materials is an issue. Whilst there are websites available regarding 'green' specifications and products, these are not yet sufficient. There is also considered to be a lack of evidence of the benefits of green building in a local context (due to the relative immaturity of the industry when compared to e.g. Europe). In addition, evidence of the whole of life benefits of sustainable building in Australia is not yet available, with no local studies completed.

The construction industry is seeking out more information on sustainable building and the level of expertise is increasing, however clients' knowledge is often very limited, making sustainable building less attractive if they do not understand what they are paying for (including higher capital costs).

Sustainable design and technology do not create difficulty with planning permissions and approvals in Australia. Information on new technologies and the ability of organisations to investigate them during the design process is assisted by schemes like COBEII (SV, 2006), and web-based sources such as the AGP database (AGP, 2006). Materials and technology selection is considered to be the most complex part of the design process. Likewise for the construction process, many of the issues relate to materials and technology selection and accurate, appropriate knowledge transfer. Some 'green' materials have longer lead times than their conventional equivalents which can cause delays. Recycling during the construction process does not cause undue difficulty in Australia, and is relatively well established.

Methods such as LCA and embodied energy calculations are not used to assess the suitability of materials in Australia. Based upon the responses of those interviewed, materials selection in sustainable building is subject to commercial viability as per conventional construction. Using imported products is quite common due to the relatively small market and range of local products available in Australia. Aesthetic considerations have been known to overrule the selection of local products which may be more environmentally friendly.

The availability of indigenous 'green' products and their capital cost are a major issue, which is also magnified by the often longer lead times to manufacture some of the more technical solutions. These long lead times can delay construction processes if the planner is not aware of them, and therefore has not factored them into the construction schedule. Furthermore, if a product is not available locally it is subject not only to longer production lead times, but also the vagaries of international shipping, which will bring into question whether it should be considered a sustainable solution at all.

5. Conclusions and Recommendations

The adoption of sustainable or green building in Australia shares a number of challenges with literature derived from the experiences of other nations in the developed world, including capital cost, and the need for developers to have a proven return on investment for green buildings before they are willing to take on the risk. Issues regarding access to or the availability of information (and knowledge) are also shared experiences, which impact directly on design and construction processes. Aside from capital cost the biggest challenge is the choice of materials and technology and their affordability; with a limited local selection of indigenous sustainable materials, supplied at higher prices and with long lead times.

A number of the challenges highlighted could be addressed by more appropriate approaches to green building including an integrated systems approach which would impact positively on the design and construction process as well rethinking what sustainable building practices aspire to; refocusing sustainability away from energy efficiency and highly technical solutions, to a more holistic examination of the impact of building on the environment. The challenge and the opportunity is cohesive decision making, and the harnessing of capacity and knowledge to ensure the most appropriate strategies are in place to deliver sustainable building solutions.

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FOOD SECURITY AND THE DESIGN OF SUSTAINABLE BUILDINGS AND CITIES

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Summary

Despite the importance of the food sector in the functioning of cities, the link between sustainable built forms and food production, distribution and consumption is a new area of study. The emerging alternative food movement has barely engaged with the possible contributions that designers and the design process can make to develop an alternative to the food supply chain. This paper will discuss a series of projects that speculate about the potential for integrating food production into the design of cities. In particular, Toronto in Canada is used as a model to show ways to tackle agriculture and food issues as design challenges in urban locations. These examples of the connections between food issues and built form have the potential to transform not only food production and distribution; they can also underpin basic assumptions about the spaces and functions required in the design of buildings and urban spaces, and our understanding of the sustainable city.

1. Introduction

"The symbiotic relationship between a productive landscape and the human settlement system is as old as civilization. During the past 200 years, that millennium-old positive relationship deteriorated into a further and further separation of town and landscape." (Viljoen 2005)

Food is a key aspect of most cultures and has contributed to and inspired many creative aspects of our lives from local cuisine to urban form. Food is also among the most basic, primary needs of mankind. Over the millennia, the activity of satisfying this basic requirement has been one of the key ingredients in the formation and evolution of human settlements and cultures. At the same time it is at heart of current problems regarding the misuse of the natural environment, and is the topic of debate over the value of natural processes. Similarly, cities and urban developments are key aspects of human civilization, and now embrace half (and rising) of all humanity. Cities are also central to humanity's relationship with the natural world: they are both huge polluters and cause damage the natural landscape and environment, while on the other hand they offer perhaps the least damaging patterns of land use to enable the huge human populations that now exist on the earth to continue to thrive.

In the past, when transport options were limited and the technology of preserving food was less developed, there existed a very close link between the forms and patterns of cities and towns and their food supply systems which were largely regional. However, since the industrial revolution, growing fruit and vegetables within or close to urban areas has been largely eroded, particularly in western nations. A trip to the urban grocery store will produce a feast of vegetable, fruits and meats from thousands of miles away, made affordable by heavily subsidized transport and often underpaid third world labour. Large-scale industrialized agriculture has become a specialized rural activity, and the distances to market have become long and reliant on cheap transport and preservation techniques.

Now that we are struggling with the implications of building more sustainable and more compact cities, what are the implications of food production within the city on built forms and patterns?

2. Urban Food Production

Over recent years a growing consensus has formed that sustainability within an urban context should mean a more densely populated environment, moving away from suburban development and intensifying land use to accommodate more people, reduce transport and build multifunctional and well-integrated communities. At the same time, food security is becoming a central concern. Long-distance transport may no longer be possible due to diminishing oil supplies and the impact of climate change. There is also an increasing awareness of the health benefits of local fruits and vegetables that do not require artificial methods for preservation and ripening and the desire for more natural methods of food production.

Growing food within an urban or near urban rather than exclusively rural environment can reduce the need for industrialized production, packaging and transportation of foodstuffs to the consumers who dwell in the city. It can also act as a focus for urban community participation and engagement in a practical as well as cultural activity. Movements such as community agriculture, farmers' markets, the 100-mile diet and Slow Food put local food supply at the heart of urban sustainability. They encourage us to consider ourselves co-producers, not consumers, and in this way to engage in the many aspects of the food supply process.

Reconnecting cities to their food systems is now emerging as one of the core components of more sustainable urban settlements.

As the meaning of sustainability widens to embrace net-zero-impact living, the question of net-zero-impact food-supply chains for urban residents becomes directly relevant to the way we design and plan our built environment, so as to "make edible landscapes" (Batt & Kongshaug 2005). These pressures are likely to lead to a need for more locally produced food, including production within cities. So, how are we to reconcile increased urban populations and densities with land use for food production? How can we integrate food production into dense urban areas?

The link between the design and planning of the built environment and its food systems is an emerging area of study, reflecting a new awareness of the importance of food and the agriculture sector in the functioning of cities and communities. The alternative-food movement is just beginning to recognize the possible contributions that designers and the design process can make to the food supply chain; it has not yet tapped the potential that architects and planners can bring to the reintroduction of food systems into urban space. Recently, this subject has begun to attract significant attention and is gaining recognition among the world of architects and related professionals of the built environment, as well as within alternative food movements.

3. Toronto

A series of speculative design proposals in Toronto are described below to illustrate the potential for food production within the city. Toronto, with a population of 2.5 million has an ecological footprint about 200 times its actual land surface area, and almost a third of this is due to the food supply to the city, often from distant suppliers all over the world. Yet it has been estimated that about 22% of the land area, about 15,000 hectares, of the city could be used for food production (Wilcox *et al* 2007). These are vacant sites, underused waste land, roof tops, and yards. Also, Toronto's ravines offer possible agricultural land that could be put to productive use. This land could be used to feed over half of the city population, and could create a 1 billion dollar industry.

Proposals by Chris Hardwicke for Ravine City and Farm City (see Wilcox *et al* 200&) integrate visionary ideas for an urban ecosystem of collective housing that restores and enhances the ravine system of Toronto with a new kind of architecture that would enable the city to feed itself. The Toronto Ravine System is the defining natural feature of the city housing diverse ecosystems and running like fingers through the city. Ravine City creates housing development that runs along the top edge of the existing Toronto ravines, creating artificial ravines by connecting the terraced roof levels of the housing to create a continuous connected ecosystem. The artificial ravines function much like the natural ravines - controlling water flow and regeneration as well as cleaning the air, creating habitat and biomass. This new topographic infrastructure is connected to the natural ravine system and provides public open space. Farm City extends this concept to create agricultural areas integrated into new housing towers. By putting housing and farms in the same building, Farm City creates symbiotic relationships between energy, water and waste. Heat generated from the greenhouses is used to heat the housing units. Biomass from the greenhouses is used for energy. Solar energy is generated from the large glazed surface. Grey-water and compost generated from the housing is used in the greenhouses.

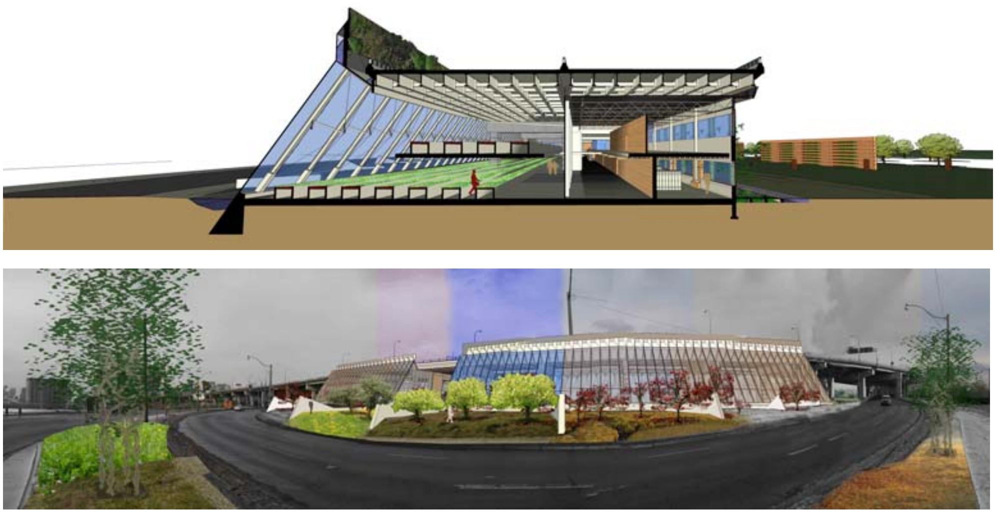

Figure 1: The Gardner Expressway Agriculture Centre

By creating living and growing space in a dense vertical format these proposals reduce the need for sprawling suburbs, reduce food travel distance and create a living architecture that is part of an urban ecosystem.

One fruitful area of research may be the use of undervalued or waste spaces in the city and its potential for community food production. The Gardiner Expressway, a highway overpass that slices through Toronto separating the city from Lake Ontario, includes a raised section. This provides the location for Andy Guiry's project (Figure 1), which investigates the possibility of situating productive greenhouse spaces below a raised highway, utilizing the side facing south to capture sunlight and the heavyweight structure of the highway for thermal mass to store the captured heat. Other features of the project include the reuse of wasteland adjacent to the highway for additional productive land, and the integration of educational facilities and a commercial space that sells garden supplies in addition to food and plants produced in the large greenhouse. Adding to the sustainable agenda for this project, small turbines were conceived for the median strip along the highway to generate electrical energy for the building through the wind from cars passing along the expressway. Materials proposed for the building were to be reused components from nearby wherever possible.

This concept has the potential to be implemented below many raised highway structures with unused, or underused land below.

Figure 2: Fort York community food centre

A second project, looking at underused land and waste material reuse, concentrates on how community development can be focused on food issues. Jordan Edmonds' community food center not only acts as a transitional bridge between housing and park space but also features reused existing structures and includes a farmers' market, community gathering spaces, bicycle paths, greenhouse structures for food production, and a community garden (Figure 2). His design is anchored in the history of the site, which was once a neighbourhood of icehouses and slaughterhouses and had a river running by (now buried). The project is a prototype for future urban landscapes that would be focused on creating a sense of community around the need for food production. It aims to enable the community to embrace food production through provision of growing spaces, both internal and external, preparation spaces, storage, sales space, all facilitating community participation and education in the processes.

The "Unzone" project by Nicholas Seed's takes some of the same ideas but integrates them into one structure. The project proposes the integration of cooperative housing, commercial, retail and community growing spaces all in one building. It is envisioned to be both a center of the local community, and co-op housing, combining adaptive reuse and new construction. The project site is a former office building in a residential area between the University of Toronto and the central business district. The proposals are for an outdoor farmers' market, an indoor market, garden plots, an orchard, mushroom growing in the basement, and rooftop green-roof gardens and greenhouses for multi-season food production serve the larger community.

Figure 3: Community food education centre

There is a need for projects of this kind to act as pedagogical tools, connecting urban Toronto dwellers with the food they eat, and providing educational opportunities for the community. A proposal by Victoria Dimitrieva proposes a teaching and a productive greenhouse/community space, strategically located near downtown Toronto in a neighbourhood of residential lofts and co-op apartments along a linear strip of green space that could provide for allotment garden plots across the street from the community building. The long southern exposure of the lot efficiently uses both vertical and horizontal growing surfaces, with specially designed cylindrical growing surfaces wrapped around structural columns as well as living walls. The north side has community rooms and offices. Solar panels provided energy for water distribution and filtration for the growing surfaces.

A project, by Brad Augustine, adopted a more conceptual approach to teach about the impact of food production on the environment. The goal of this proposal for a high-rise farm culminating in a penthouse restaurant was to demonstrate the size of building and resources needed to grow all the food consumed in the restaurant at the top of the tower. Feeding cattle to produce beef, for example, takes many times the space as producing vegetable. Restaurant patrons would travel in a glazed elevator through the floors of food production: cows, chickens, grain, vegetables, fruit trees, etc. into a restaurant where herbs are grown and the cooking is completely visible. This would provide an experience that was immediate, close, and informative on a very basic level, about the effort and resources involved in food production.

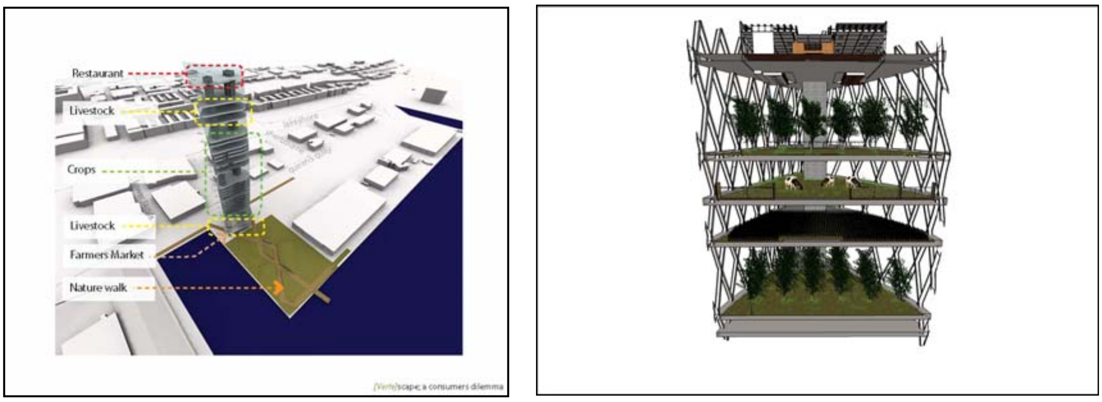

Figure 4: High-rise farm

4. Conclusions

The education of architects, planners and other professionals who impact the design of cities has long failed to address the implications of food supply on city design. As we begin to grapple with the issues of building a more sustainable way of living, food security is becoming a central concern. Food is part of the daily lives of every person in the world, and it is at the core of humanity's functional relationship with natural systems. Agriculture stands at the heart of current problems regarding the misuse of the natural environment; and is the topic of growing discussion over finding new relationships with natural processes.

A greater sophistication in the understanding of the meaning of sustainability and the scale of impacts that issues such as climate change and peak oil will have on food supply are beginning to demand attention. Questions about net-zero-impact food supply chains for urban residents are directly relevant to the way we design and plan our built environment, and therefore how we educate the designers of the future.

The projects discussed above illustrate the serious and diverse nature of possible responses to food supply issues in the city and the potential impact of these issues on the design of the city and its buildings. They start to shed some light on the types of networks of food services that are needed in the city and are the first step in generating ideas for the reintegration of values of community food production leading to change in socioeconomic values. These projects illustrate how providing for a basic human need of food may be possible in an urban context in a way that is socially, economically, and ecologically sound. The next level of thinking about food systems, above specific communities, requires the coordination of these services and segregated landscapes into what has been termed green infrastructure (Benedict 2006). Green infrastructure is essentially a connected network of landscapes within an urban context which is productive in providing for the needs of the people living in that environment. The specifics of how this network functions is dependant on the places that it serves, varying with size and shape of the spaces that are available, as well as the climate, topography, soils, and the needs of the community.

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THE RENEWABLE ENERGY HOUSE: LISTED BUILDING, TECHNOLOGY SHOWCASE.

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Summary

The Leopold quarter of Brussels has been transformed from a prestigious late 19th century housing suburb into the 21st century administrative centre of the Capital of Europe. Within this area, we find the Renewable Energy House (REH). This 2800 m^2 office building houses eleven European renewable energy associations in a refurbished 140-year-old listed building. Not only is it one of the few remaining examples of this type of architecture that has been preserved in the area but it has been renovated with the latest technologies in order to meet the highest energy efficiency standards.

Experts believe that cost-effective technologies exist that could reduce the energy use in buildings by 22% in the European Union (EU). In order to produce an energy efficient and healthy building, one must use materials and products that effectively contribute to the energy performance of the building and its technical building system. This was the case with the REH, which manages a staggering energy saving of 50% and runs on 100% renewable energy. It was rightfully rewarded with a 2006 National Energy Globe Award.

1. Historical Background

After the revolution that erupted in Brussels in 1830, Belgium declared its independence and Leopold I became the first King of the Belgians. A civil Society was then created for the embellishment of Brussels, the capital of a new State. Its objective, to create the "Quartier Léopold", a suburb with new upper middle-class housing, gardens, public squares and horse-riding paths on 75 hectares of farm land. In 1865, Leopold II was crowned and under his reign Belgium became one of the leading industrial powers.

2. Architectural Developments

The "Quartier Léopold"- named after King Leopold I - was the first extension of the city outside its 14th century fortifications. The creation of such suburbs near historical centres is not specific to Brussels but was the consequence of the combined pressures of population growth, rural migration and industrial development. As Brussels had become the capital city, the democratic assemblies took over the prestigious buildings that surrounded the royal park. It is quite naturally that the servants of the new state should establish themselves on the adjoining plot of land just beyond the demolished city walls. "Quartier Léopold" was purposely built for them from 1837 onwards. The importance of this suburb can be proven by the fact that in 1838, only three years after the introduction of the railway in continental Europe, a railway station was built there and partially financed by the king himself.

Within these new quarters, one finds Arlon Street and the houses of numbers 63, 65 and 67. These were built between 1866 and 1868 from natural stone, clay bricks and roof tiles - materials commonly used in Brussels at the time. Such town mansions, most of which have since disappeared, tried to outdo each other in terms of beauty and prestige.

After the end of the Second World War, this residential suburb was gradually transformed into an administrative area and the arrival of the European institutions in the 1950s reinforced the trend. When the Treaty of Rome came into force in 1958, it brought together Germany, Belgium, France, Italy, Luxemburg and The Netherlands and Brussels became the seat of the European Economic Community (EEC). As the EEC established itself institutions tended to group themselves in and around the Leopold quarter because no single site had been chosen for the EEC and the area's grid street pattern facilitated the construction of large, multi-storey buildings (T. Demey 2007).

By 1965, more than 3000 EEC employees were spread across eight buildings in the Leopold quarter. Thus began a town-planning policy which experts agree lacked overall direction and so took its toll on the neighbourhood. In 1987, the demolition of the first railway station was even suggested as the European Parliament (EP) building project was developed. However, neighbourhood committees have endeavoured to ensure that this part of the city maintains and develops its diversity of functions and through their action the station is now a listed building and the EP building is known as the "folly of the gods". The Leopold Quarter is now the called European Quarter with some 30 520 EU officials occupying 77 buildings with a total surface of almost 1.5 million m^2 (T. Demey 2007).

3. The Renewable Energy House (REH)

Located in the European Quarter of Brussels, the REH is now a 2800 m^2 office building, which houses eleven European renewable energy associations.

Figure 1 The Renewable Energy House, Brussels (Belgium)

It was in 2005 that HRH Prince Laurent of Belgium suggested the refurbishment of the 140-year-old neo-classical listed building. His objective was to protect architectural heritage in a rapidly changing part of the capital, whilst integrating clean technologies in the restoration project. The renovation brought together partners from such various disciplines as energy efficiency, architecture and the construction products industry. The REH refurbishment project was completed in two phases. The buildings 63-65 Rue d'Arlon were first refurbished and inaugurated in March 2006. The third contiguous building was opened as an extension to the existing REH at the end of 2007.

3.1 The project

In the course of its life the building had been converted from a house into a shop and would now be transformed into energy efficient offices and accommodation. This called for the installation of a maximum number of renewable energy technologies and the implementation of the fire safety requirements whilst at the same time respecting the existing structure of a listed building in an urban environment.

With Brussels firmly established as the Capital of the European Union (EU), the objective was to bring together under a single roof the European associations representing the interests of the renewable energy industries grouped under the European Renewable Energy Council (EREC). More so, this building would become a showcase for these industries and be used for promotion and education purposes.

3.2 Modelling and Thermal Insulation

An encompassing energy concept was developed with the architect *Atelier d'Art Urbain* and energy consultant 3 E. The system is based on three core principles, i.e. limiting the thermal exchanges with the outside, heat recovery and the use of efficient renewable energy systems. The greatest opportunity in conserving energy is to reduce heat transfer through the building envelope and all the parameters were analysed with the TRNSYS model. The characteristics of such elements as the highly-efficient window frames (U=1.1 W/m^2 K g=0.6), the rear façade (8 cm of expanded polystyrene and rendering) or the roof insulation (20 cm of mineral wool) were determined according to the energy efficiency targets (global K=40).

3.3 Ventilation system with heat recovery

Heat recovery captures waste heat energy and reuses it by returning it to systems. It can give substantial long-term energy savings as it often reduces the need to generate heat in the first place.

The system uses a heat wheel with a heat recovery capacity of up to 85%. The process is based on indirect adiabatic cooling, i.e. air is humidified under adiabatic (evaporative) conditions. The advantage here is that energy is neither added nor removed as the required heat is taken from the air, which consequently cools.

In the summer, before being expelled, the air is cooled via a humidifier and then used to lower the temperature of the incoming air via a heat exchanger. In the winter, the expelled air is used to warm the incoming air and so providing a net temperature gain. Last but not least, to insure maximum efficiency, each room is fitted with a non-return valve, thermal probe and air quality sensor.

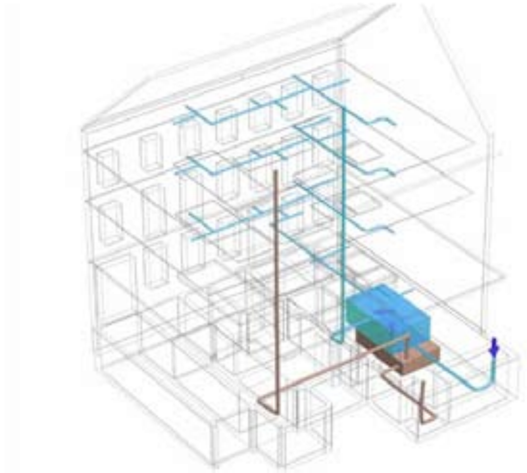

Figure 2 Double Flux Heat Recovery System

Two constraints had to be overcome, i.e. the space required for the machinery and the integration of the tubing.

3.4 Renewable Energy Systems

The Renewable Energy House obtains its complete heating and cooling requirements entirely from renewable energy sources.

Using a combination of solid biomass (wood pellets), solar thermal and geothermal energy, the heating, cooling and ventilation system generates high standards of comfort in the whole building throughout the year, with 21°C in the winter and a maximum of 25°C in the summer.

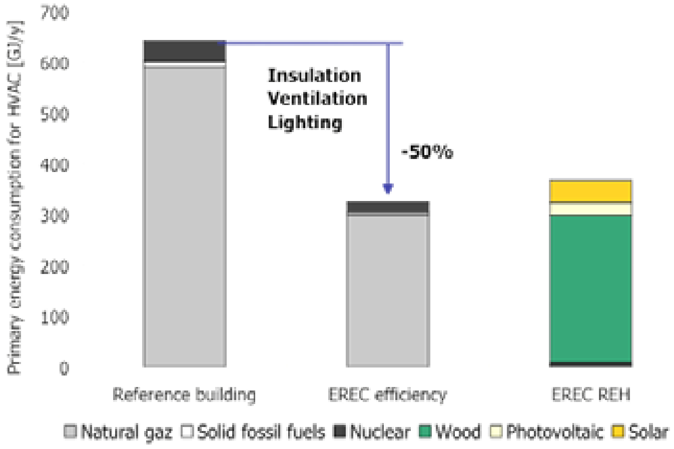

Figure 3 The REH Energy Consumption and Savings

In winter, the energy produced by the pellets boilers (85 kW + 15 kW) and the solar thermal collectors (30 m^2 flat plate collectors plus 30 m^2 evacuated tube collectors) is stored into two 2000 l water storage tanks, which supply both the radiator circuits and the ventilation system. The coal storage rooms were converted to store the wood pellets. Now, twice a year, 13 tons of pellets are blown from a tank truck into two interconnected rooms that are designed to automatically supply the boilers.

These combined solar and biomass energy sources are used to heat the three front buildings (2600 m^2). A ground coupled heat pump heats the back office buildings and conference rooms (200 m^2). This 25 kW heat pump coupled with four vertical heat exchangers (115 meters each) transforms energy from a temperature of 10-12°C into heat at a temperature of 35 to 45 °C. This energy is stored into a 400 l water storage tank which supplies the over-sized radiators circuit.

In the summer, a thermally driven cooling machine is used to refresh the whole building (main front buildings and back buildings). Here, the machine is driven by solar thermal energy with biomass as back-up. The hot water (80-85°C) feeds the absorption cycle to produce chilled water (7°- 9°C). This cold energy is stored into a 1000 l water storage tank and supplies the ventilation system. The waste heat (excess low-grade heat from the absorption cooling system) is released into the ground via the four borehole heat exchangers.

Three types of photovoltaic panels are in use, monocrystalline, multicrystalline and thin film. Semi-transparent cells are also integrated into the windows. The total 3 kW installed capacity is grid-connected and generates an annual production of 2550 kWh. It is foreseen to combine a stirling engine to the already operating 15 kW pellets boiler in order to further enhance the in-house electricity production capacity.

The implementation of energy efficient measures enables energy savings of 50 compared to a reference standard renovation project. On the supply side, 100 % of the building's heating and cooling demands are covered by the renewable energy technologies described above.

3.5 Renovation Costs

The standard renovation costs were estimated at € 984/m^2 (approximately $ 1550 US), whilst the insulation costs for roof and walls were € 23/m^2 (approximately $ 36 US) and the technical installations amounted to € 188/m^2 (approximately $ 296 US). This gave an extra 'sustainability' cost of € 211/m^2 (approximately $ 332 US) from which subsidies for restoring a listed building and for the potential energy saving were deducted. These amounted to € 76/m^2 (approximately $ 120 US) and this gave a total extra cost of approximately € 135/m^2 (approximately $ 212 US). This represents an 11% increase compared to a standard renovation project but of course this building was set up as a showcase of renewable energy technologies, which allowed for some extra solutions being included into the project.

4. Conclusions

In only seven months, a healthy and sustainable building was designed and implemented, having taken into account the existing structure and features, the interaction between building technologies, the technical building systems and the activities in the building. The Renewable Energy House is now characterised by a healthy and moisture safe indoor climate. This can be attributed to the original clay ceramic construction products which provide thermal inertia, efficient insulation, ventilation and a best available technology heating system. It must be added that such results can only be achieved through the use of well-established design procedures that take into account the construction system.

Brussels now has a truly spectacular sustainable energy showcase integrated in a monument-protected brick building and which is accessible to all those interested in sustainability. The Renewable Energy House demonstrates both a significant reduction of energy consumption for heating, lighting, cooling and ventilation through the application of energy efficiency measures, as well as providing as much renewable energy as possible. The tenants have access to a modern, healthy and prestigious office building. The success has been huge with more than 12 000 visitors and reports on more than 20 international TV channels in less than two years of operation.

The revision of the 2002 European Directive on energy performance of buildings (Directive 2002/91) is now underway and based on their own experience EREC and TBE will contribute to the debate. For now we know that the EC is planning to propose EU-wide minimum requirements for the energy performance of buildings. The options being considered include setting overall energy use limits expressed in kilowatt hours per m^2; the establishment of performance criteria for building components, e.g. the external wall; and last but not least, reducing the current 1000 m^2 threshold above which new and renovated buildings must meet minimum performance requirements.

As all countries have such old buildings making significant contribution to their cultural and historical heritage and as energy efficiency is a cornerstone of any sustainable energy policy, HRH Prince Laurent of Belgium established the Global Renewable Energy & Conservation Trust (GRECT) as a private foundation in 2006. More recently, New4Old, a European funded project within the Framework of the Intelligent Energy for Europe Programme (IEE), now aims at facilitating the integration of renewable energy and energy efficiency technologies into historic buildings and at the same time contributing to the protection of these buildings. New4Old is developing a network of REH. The expertise gained through the refurbishment of this historical building in Brussels can now be shared worldwide.

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ENERGY EFFICIENT HOUSING RENOVATION

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Keywords: housing, occupants, renovation, energy, comfort

Summary

In this research the problem of outdated low energy efficient housing built in the 1945-1975 period is discussed. Nowadays it can be observed that large quantities of these 40-60 year old houses are being demolished due to low general performance. The process of demolition generates enormous amounts of waste (over 120 tons per dwelling), and also generates the need for new material, energy and time for new housing. Occupants have to move and are often not able to return to their neighborhood due to increasing prices for new houses, a very unsustainable situation. After having analyzed the present situation and technical condition of the houses involved, possibilities for improving the energy performance have been studied; in this case the passive house approach has been analyzed. The combination of passive house elements applied to the outdated housing stock is modeled. Special attention is given to the comfort of the occupants of the houses during the proposed renovation process. In principle, a smooth renovation process is possible with limited hindrance for the occupants. Results show that technically a serious improvement of energy performance can be reached. However, a very important issue regarding energy performance after the renovation is the behavior of the occupants while living in the house.

Introduction

In the Netherlands some 7,000,000 houses exist for a population of 16,400,000 people. The average amount of newly built houses consists of 72,000 units per year. During the year 2006 many outdated dwellings have been demolished resulting is an annual net growth of only 52,000 houses. New houses are modern and energy efficient, existing houses often are outdated offering limited comfort and show high energy consumption. An entire building stock renewal will take more than 130 years. The situation of limited numbers of newly built houses and a yearly increasing amount of houses being demolished should be considered as an alarming situation [van der Flier, 2004]

Demolishing houses and subsequently building new houses cannot be considered as a sustainable practice. The demolition of estates will produce a lot of debris, involving many transportation movements. The demolished houses have to be replaced by new ones and this involves the production of new material and again related transportation.

If existing 40 to 50 year old neighborhoods are being demolished it also should be taken into account that not only technical infra structures will be lost but perhaps even more important also the social infrastructures will be demolished.

Demolition is a process that can be done in a relatively short time. Building new houses is a complex process with many parties involved and ensues huge bureaucracy. If things go well the building process can be realized in 2 or 3 years. But often delays occur and building realization times of over 8 years is rather the rule than the exception.

An approach consisting of a high level of renovation could prevent the loss of a social infrastructure and offers an almost endless life for social dwellings. After all, history has shown that building structures can perform endless if proper maintained and updated from time to time. In this research the updating of typical Dutch post World War II housing has been modeled into a computer program. First step is the modeling of the existing situation based on general characteristics. The second step consists of an array of possible actions for improvement. The differences in results will enable the designer to make choices for renovation based on the current situation and personal preferences. The third step is to develop an integrated model that will also calculate the consequences in terms of cost and appearance related to the possible choices.

Current situation

After World War II an enormous demand for houses existed, so many houses were built in a rush. Yearly production numbers of over 120,000 units were quite common back in the 1960's. Compared to today's building output of some 72,000 units per year quite an achievement for the 1960's! Of course technical standards in those days were not quite similar to the present. The 1973 oil crisis still was to come. Today, 25 years after the first oil crises the consumption of energy is an important issue in the building industry. Houses built around 1960 show characteristics like single pane windows, cavity walls without any thermal insulation, lots of thermal bridges and non insulated roofs. As a result the energy consumption only for heating will reach some 200 – 300 kWh/m2 per year.

The floor plan of a typical 1960 house shows limited surface. In general the ground floor consists of a footprint of some 40 m2 so the total available space for ground floor and first floor is only 80 m2. As building lots usually are some 150-200 m2 an extension would be a logical option, however in social housing every possibility must be used to ensure low rent, so in this research only an update of the existing house has been studied. A typical floor plan layout and section is given in fig 1.

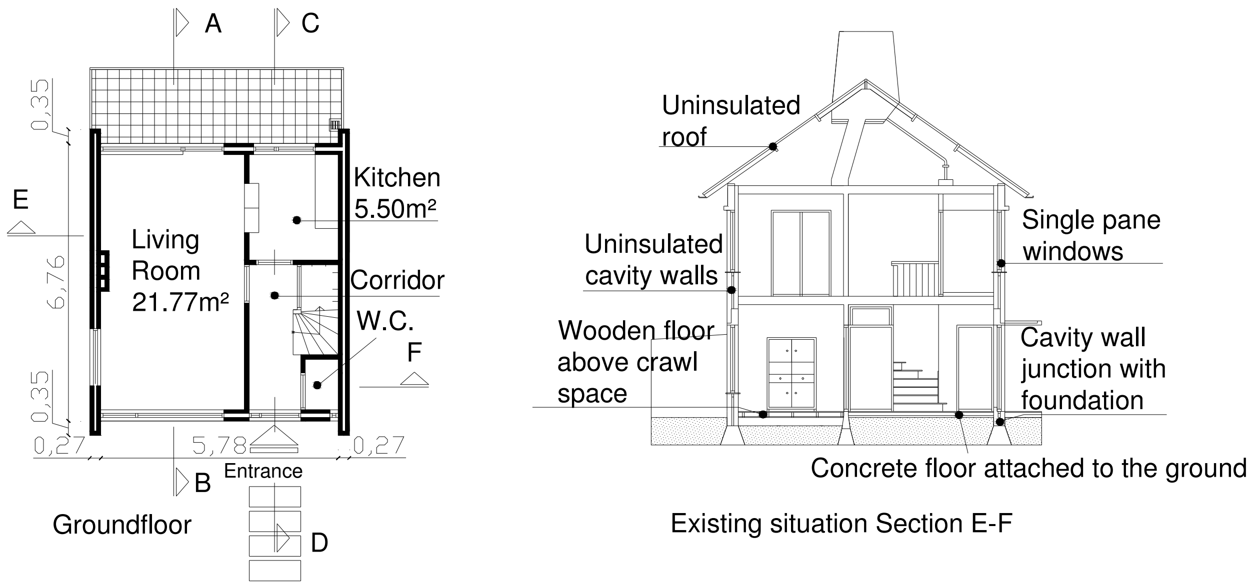

Figure 1 Typical floor plan and section of post World War II housing (1960)

Passive House characteristics

The general climate in Western Europe can be characterized by relatively moderate winters with average temperatures around 2ºC in January and cool summers with average temperatures around 17ºC in July. This means that a house should be heated during the winter period roughly from mid September till April. Cooling in summer generally is not needed. The passive House concept has been developed in Germany as early as 1992. The general idea of the passive house concept is to build a home that will keep the generated heat inside with as little as possible waste. This is achieved by applying thick thermal insulation some 300-400 mm, high performance windows, an airtight structure and a heat recovery ventilation system. Thick thermal insulation and high performance windows are just a matter of choosing the right material and the right products. An air tight construction is more difficult to realize. This can only be attained with dedicated and trained personnel and staff. During the renovation process at regular intervals tests must be done to ensure air tightness and corrections must be made if the required level is not attained. Details are to be designed in such a way that it is possible to realize an airtight result. Contractors must be aware that extra cost may arise. The heat recovery ventilation system is the most drastic change for the occupant. In Western Europe people have been used for ages to "natural" ventilation, simply consisting of using cracks and leaks for ventilation in combination with the opening of the windows. This has always been considered to be healthy. The passive house concept is the opposite of opening windows, in winter all windows need to be closed and ventilation is realized by a mechanical device called the heat recovery ventilation unit consisting of a heat exchanger and four pipes. The fist pipe is installed for the used exhaust air, this air is warm. This warm air passes a heat exchanger connected to the second pipe, the inlet of the outside cold air. The heat from the used exhaust air is transferred to the outside cold inlet air and pumped into the house by the third pipe. The used exhaust air is now cooled off and extracted by the fourth pipe to the outside as used cold air. An example of a heat recovery ventilation unit is given in figure 2. The crossing of the dotted line and the line is the place of the heat exchanger.

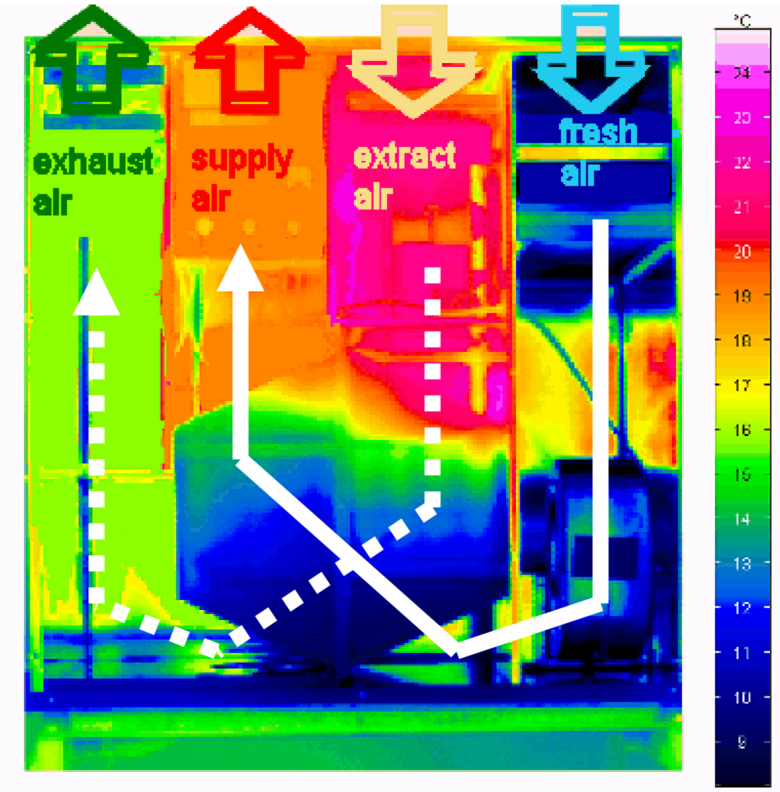

Figure 2. Example of Heat recovery ventilation Unit with 4 pipes.

A heat recovery ventilation unit can have an efficiency of some 80 – 85 % thus forming a significant contribution to the energy savings needed for reaching the passive house standard.

The air is transported mechanically so fans are needed. It is obvious that special attention must be given to noise levels as the thick thermal insulation in combination with the air tight structure and high performance windows will also contribute to the acoustical insulation of the dwelling to the outside noise. The inside noise levels (background noise) is so low that any other noise will stand out. It is even known that in a specific case the acoustical insulation from the outside was so good that an occupant of a passive house complained that she couldn't hear the children coming home from school, they suddenly appeared in the room. If air is forced through pipes obviously pollution is also forced in the system, so filters are needed to prevent pollution coming into the house. Once the filters are installed and are doing their work, they need to be changed from time to time, a task an occupant must get used to.

It can be concluded that passive house characteristics require a different and active approach for both the contractor building the house and the occupant living in the house in order to be successful.

Energy Efficient Renovation

The combination of an outdated dwelling and adding passive house elements is to be realized while occupants live in their house and at minimum cost. Applying outside thermal insulation is possible without any inconvenience, except for some drilling noise. It is important to place the piping for fresh inlet ventilation air also on the outside of the building and than cover the façade and piping with the required thermal insulation. Replacing the windows will cause disturbance as existing windows need to be removed. When using the existing window frame as a sub casing for the new window also in this respect inconvenience can be reduced. An example of this approach is shown in figure 3 (existing situation) and 4 (new situation).

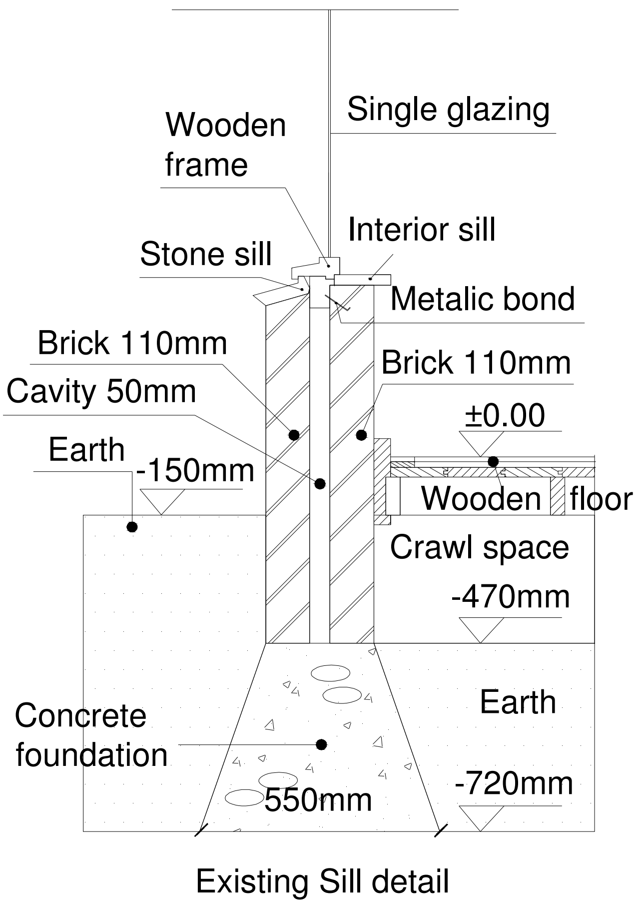

Figure 3. The existing window .

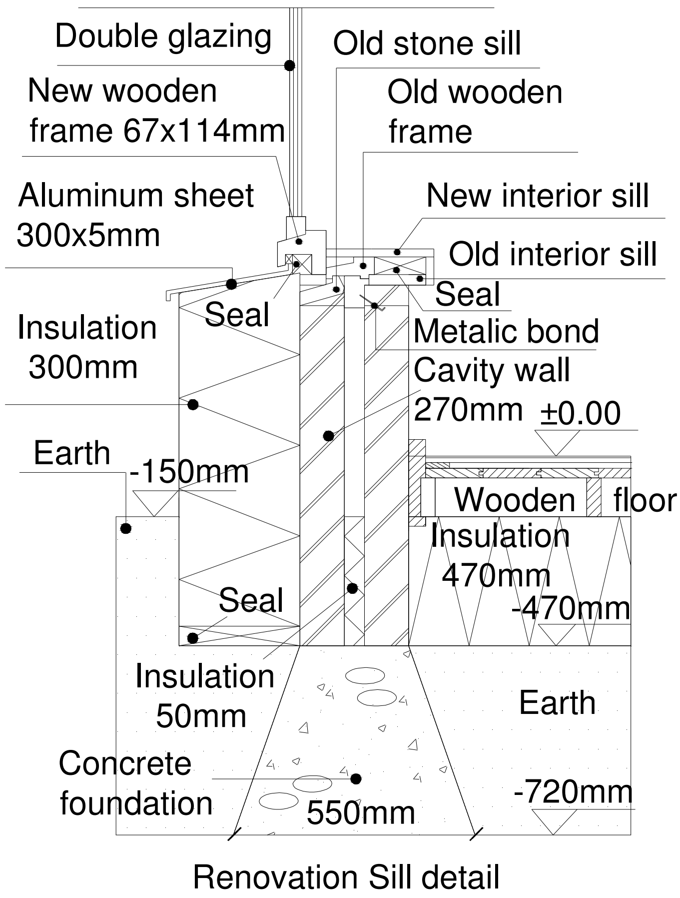

Figure 4. The new situation: the existing window used as a sub casing for the new window

Used air is to be extracted preferably at places where ducts already exist like e.g. in the kitchen, toilet and bathroom. Internal doors are to be adapted to allow fresh air to be blown in from the ducting on the façade to travel to the exhaust points located in toilet, bathroom and kitchen. Every specific situation is different and must be analyzed individually.

In the case of the project involved the energy consumption for heating only in the existing situation calculated according to the HAM base computer program is 240 kWh/m2 year. Under the current energy label according to the European standard EPBD this would mean class D, not very impressive at all, as expected.

Applying the four passive house characteristics (thermal insulation, high performance windows, airtight structure and heat recovery ventilation) the energy necessary for heating, calculated with the same computer program will be reduced to 35.6 kWh/m2 year. It can be concluded that the passive house standard will not be reached. This can be explained due to the influence of the existing ground floor and foundation. Thermal insulation is hard to mount in an existing foundation so thermal bridges will continue to exist.

The savings in energy are some 200 kWh/m2 year. With 90 m2 of surface the total fossil energy savings are 18,000 kWh. In The Netherlands due to vast natural gas resources, heating is usually realized by burning natural gas. 1 m3 of natural gas costs € 0.60 and will produce 10 kWh, so the energy savings will be some 1800 m3 of natural gas representing a cost of roughly € 1080.00

At present (March 2008): € 1.00 = US$ 1.60, € 0.60 = US $ 1.00, € 1,080.00 = US $ 1,728.00

The renovation to passive house standard will entail a significant reduction of fossil energy consumption, however the savings in money will be limited. According to German data [ILS NRW, 2006] the extra cost for additional thermal insulation, high performance windows, air tight structure and heat recovery ventilation system should be estimated to some € 15,000.00 (US $ 24,000.00) This means a payback time of over 15 years, not very attractive for the owner.

Conclusion

In order to reach a sustainable society with limited need for resources and limited fossil energy consumption the renovation of outdated building stock to the passive house level is technically feasible. Energy consumption for operating a house can be reduced seriously. In preserving existing buildings enormous amounts of waste will be avoided, the need for new material is limited, and numerous transport movements of material and people will not be necessary thus contributing to a sustainable society. Demolition of 40-60 year old houses can be avoided thus continuing existing social infra structures.

The direct cost for energy efficient housing renovation is high and the benefits in terms of saved money as a result of the energy savings are limited. Pure economically speaking this leads to a very long payback time of over 15 years. The question is however what society considers important, cheap housing and the well being of the people or new and expensive up to date housing. In the future the price of fossil energy will continue to fluctuate, today it is expected that prices will go up anyway, so an investment in energy efficient housing may be profitable on shorter notice than expected today.

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ECOTOURISM CERTIFICATION TOOLS – WHAT IS THEIR ROLE NOW AND IN THE FUTURE

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Summary

This paper will explore EcoTourism tools and their role in supporting the uptake in sustainability in tourism activities. In a world looking to minimise its ecological footprint, will travelling to far flung corners of the world to have the 'eco' experience be justifiable, and can tools help with this? Will the EcoTourism offerings need to adapt and offer more than access to pristine mature and minimal impact. With this in mind the benefits and short comings of EcoTourism certification tools are explored with a view of looking towards future development opportunities. This is done in the context of the lessons learned by green building tools such as LEED, BREEAM and GreenStar. Finally this paper asks the question about the ability of rating tools to lead to a sustainable future and makes the argument that a shift to regenerative tourism will provide both a new framework for the rating tools and an offering that justifies our ecological investment.

Introduction - ecotourism and certification

Tourism is a sector of the economy that is both large and has a large impact. Ecotourism is a concept from the 1980s that came from an awareness of this impact and the need to protect fast disappearing ecologically sensitive areas. By the early 1990s it was starting to be seen as the fastest growing sector of the travel and tourism industry, Honey and Stewart (2002a:2) describe Ecotourism as:

> *"… a multifaceted concept that involves travel to fragile, pristine and usually protected areas. It strives to be low impact and usually small scale; helps to educate the traveller, provides funds for conservation, directly impacts economic development and political empowerment of the local communities; and fosters respect for different cultures and human rights."*

Yet within this potential many researchers have found a miss-use or miss-understanding of the concept of ecotourism (Buckely 2001b, Preece et al. 1995, Fennel 2003, Caldicott and Fuller 2005), some even pointing to deliberate greenwash (Honey 1999, Weaver 2001, Wright 1993, Synergy 2000, Font 2001b). This drove the need for certification of these types of initiatives, resulting in the proliferation of labels, rating tools, certification schemes and guidelines. The World Tourism Organisation (WTO) in 2002, reported some 500 voluntary certification initiatives of which 59 were regarded as "comprehensive" schemes (Pina 2005a).

Rating tools, certification and labelling

Rating, certification and labelling tools are terms often used interchangeably, a *rating tool* rates a project based on the achievement of certain criteria; examples are Green Star, LEED, energy ratings on appliances and so forth. These tools are widely used for housing, commercial buildings, appliances and products, but tend not to be used for Ecotourism facilities. A *certification tool* assesses a project based on set criteria which may be a demonstration of intent or performance. Based on this the project either passes and gets certified or does not. This is the type of tool most favoured in the Ecotourism industry. *Labels* can be used with both types of tools; with a rating tool the label shows stars or some other mark indicating a level of achievement, where as the certification label will just show that that certification has been achieved. There has also been some merging of the certification and rating tools, for example Green Globe (a certification tool) now has a bronze, silver and gold label to signify the level of commitment and action taken. However, this still does not identify actual performance.

Volumes have been written on the ecotourism certification, labelling and rating tools[1]. The aim of this paper is to briefly outline certification tool types, as these are most used and discuss whether they are indeed helping the consumer to reduce their ecological footprint.

From the literature, the consumers and users of the certification and labelling tools require:

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[1] For further reading on specific tools see Font and Buckley 2001, Honey 2002, Buckley 2003 and Schianetz et al 2007 for a review on tool approaches

- transparency and public accessibility to information;
- global relevance but local implementation;
- auditing – real and relevant categories, targets, performance etc.;
- technical detail and diversity – scale, types, locations, etc.;
- both guts and teeth – rigor in the assessment and methodology and consequences for not meeting requirements – for example procedures that ensure labels are awarded when levels are achieved and taken away if performance decreases, potentially with penalties;
- maturity and penetration – they are used by the majority of the industry and have acceptance within the market as demonstrating a level of environmental responsibility;
- a tiered structure – from an easy accessible level of certification through to world's best practice;
- simple yet thorough frameworks with clear threshold requirements; and,
- third party verification, auditing and certification.

Lessons from other certification and labelling tools

In the building industry there are some very successful rating tools, rather than certification tools, that have begun to create a market shift to more sustainable buildings. These tools have built up the credibility and integrity to be taken up by industry, and though voluntary, are used by government and industry as a measure for requiring a specific standard of design and potential performance. The tools, though developed around a similar timeline as the Ecotourism certification tools, seem to be more mature. For this reason this paper briefly touches on these tools and the ways in which they are expected to develop in the future as a potential input to the development of ecotourism certification tools.

It is clear that the building rating tools, such as LEED, Green Star and BREEAM, have been effective at one level, which is to raise awareness, create a language and a market for green rated buildings. This is demonstrated by the fact that recent US Green Building Council figures show a tenfold increase in membership since 2000, and have over 3,500 registered buildings. On another level though, rating tools seem to be only partly effective, achieving varying levels of incremental improvement in energy use, as well as addressing limited social and indoor environment improvements and providing some financial benefits (Hes 2007, Hes and Syndercombe 2008). Yet, in creating awareness they are an important part of the increased uptake of sustainability in our built environment.

The lessons that could be taken up from these tools are (Hes 2007, Hes and Syndercombe 2008):

- reducing cost and time needed for carrying out rating;
- streamlining the assessment process;
- working towards a performance based tool;
- working towards and international standard with regional variations; and
- improvement of indicators.

Issues related to ecotourism certification tools

Certification programs tend to have either process or performance requirements and lately some have been incorporating both (Honey and Stewart, 2002b). The process approach requires the development of an environmental management system, such as ISO 14000, that guides the way a facility is run. The performance programs require that certain targets be set and reported against. Depending on the program these can be based on internal benchmarking or targets set at the certifier level. Both can include environmental, social and economic sustainability criteria.

Research conducted by Honey and Stewart (2002b:59 quoting Synergy 2000) concluded that the combined approach is the most successful because it: "*encourages business to establish comprehensive environmental management systems that deliver systematic and continuous improvements, include performance targets and also encourage business to invest in technologies that deliver the greatest economic and environmental benefits within a specific region*".

Many of the current certification programs are still based in the process framework; for example Green Globe, Green Flag for Green Hotels, ECOTUR in Spain and Green Key in Denmark (Font 2001a, Font and Buckley 2001, Honey and Steward 2002b:54). The reasons for staying away from performance certification are that it is difficult to have verified and accessible criteria that are relevant across the multitude of ecotourism products and regions. This presents a problem in that many of these programs end up with more of a commitment to improve practice and do so against their own benchmarks, rather than providing concrete improvements based on standard performance levels. This leads to some scepticism on the part of the consumer (Synergy 2000).

The large numbers of tools that are available are another well documented problem influencing the effectiveness of the tools in attracting consumer uptake (Honey 2003, Kahlenborn and Domine 2001, Schianetz et al. 2007, Butler 1998, Buckley 2001a, Pina 2005a, Font 2001a).

> *"The tourists who are the targets of ecolabels are often more put off than attracted by the vast number of schemes available to them. Not knowing which scheme to trust, a large number of them probably ignore these schemes all together." (Kahlenborn and Domine 2001:247)*

Also tools need maturity and penetration, this means that consumers need to understand the consequences of an ecotourism facility not having a label as clearly as if it had one. Further, maturity is achieved by continual re-evaluation and a re-certification over time as technology and knowledge advances (Buckley, 2001a).

There is a call, therefore, for tools to be integrated and for greater consistency and collaboration between them, their organisations and their countries (Font 2003, Honey 2003, Schianetz et al. 2007, Butler 1998, Pforr 2004). Yet complete integration is not possible. The research of Schianetz and colleagues (2007:381-5) found that certification tools not only differ between process or performance, but also by being retrospective or prospective; have global or site specific assessment criteria; be based in the technosphere or ecosphere; and, can focus on different effects (triple bottom line, cumulative, dynamic etc.). They conclude that there is no single tool that brings together all these elements and that the final scheme should ideally combine a variety of these tools to ensure a comprehensive assessment and path to sustainability. This research then did not provide what this 'final scheme' could be as they concluded that the choice of mix of tools needs to be project dependent.

The critique of the effectiveness of the certification tools are summarised by Buckley (2001a:259):

> *"Criticisms of tourism ecolabels are that they are expensive, they require time, usually they focus on hotels or ecotourism providers, the ecolabel organiser has limited marketing power, and the criteria focus on environmental management, not environmental performance."*

The above all suggest that the tools may not be as effective as hoped in moving the industry to sustainability. Further, when looking specifically at whether these tools have actually led to a decrease on ecological impacts, even just carbon footprint, the literature is strangely silent. In part this is because many of the schemes have not required public reporting. More telling though is the research by Sasidharam and Font (2001:105) that concludes:

> *"Despite the potential benefits from ecolabels, to date no conclusive evidence exists to support their assertive claims that ecolabels improve the environment…Social science research suggests that environmental education of consumers does not stimulate environmentally responsive purchasing behaviour."*

One of the main reasons provided as to why the education of the consumer through certification has such limited impact, if at all, is the small percentage of the decision making process that is influenced by ecological consciousness. Location, cost, value for money, availability, convenience, and so forth have a much higher priority (Font 2001a). This may have changed with the swell of environmental consciousness created in the wake of Al Gore's crusade on Climate Change and the Stern report, but no literature has been found at the writing of this paper to counteract the above claims.

Buckley (2001c:195) describes the Nordic Ecolabel for Hotels as having the greatest potential of delivering assured results. In summary he concludes this is because it grew out of a mature, high penetration labelling scheme called the Nordic Swan and it has "*quantitative environmental performance criteria, e.g. for energy consumption per capita, wastewater quality etc which apply uniformly across the entire schemes*". This gives assurance and leads to consumer trust which results in the label being well accepted and 'thriving'. Yet Buckley also shows that the label has low penetration and thus its ability to lead to a reduction in impact is similarly limited.

From the review carried out it can be concluded that certification of ecotourism cannot be said to have a significant impact on the ecological impact of its users (Synergy 2000, Pina 200a/b, Sasidharam and Font 2001, Buckley 2001b, Font 2001a).

> *"Most ecolabels mention the protection of environmental resources as their objective, yet little evidence is available on whether these objectives are met. Advocates of tourism ecolabels will emphasise that these minimise the damage, a more realistic aim than avoiding it, yet critics say that the certification of tourism products is endorsing the use of fragile natural resources". (Font 2001a:14)*

The problem may lie in the fact that we are trying to solve a problem – our 'unsustainability' – within the framework of what has created the problem in the first place. We are using labels and certification that will only work while they present a benefit to the user as they differentiate them within the market (Pina 2005 a and b). Most of the schemes are trying to make the process as simple and implementable as possible without real public reporting and responsibility (Synergy 2000). Further, due to the costs of certification often the few who choose to pay extra for the piece of mind of a 'responsible' holiday are subsidising those who do not (Buckley 2001b)

Moreover, if sustainability is about more than the competitive advantage, if it is about sustainment, reduction of impact or even net benefit then it should be something embraced by all tourism offerings in contradiction to the fundamentals of certification. For this reason Pina and others (Pforr 2004, Pina 2005a and b, Griffin 2002, Buckley 2001b, Wright 1998) argue that the standard environmental and sustainable performance of tourism should be regulated:

> *"…whereas some erosion and pollution of resources is caused by great numbers of visitors, most environmental damage is caused by lack of plans, policies, and action …Tourism cannot be blamed for environmental deterioration caused by bad decisions rather than real visitor impacts". (Wright 1998:75)*

Though labelling may have a small influence on buyer behaviour, it results in piecemeal and incremental improvement rather than sustainability (Pina 2005b). Pforr (2004) agrees with Pina that sustainability is a key public policy driver and that fundamental reforms of the tourism industry need to be led by the public sector because of current ecotourism certification shortcomings are: "*its highly fragmented and little co-ordinated nature, a lack in information exchange and often unclear responsibilities*". Pforr (2004:85) adds though, that the traditional machinery of government may not be able to deal effectively with the complex and dynamic agenda of sustainability and tourism. Something in-between is needed and he argues that this may be rethinking tourism and redirecting it based on the concept of sustainable development. As argued in this paper, due to the contested nature of sustainable development and to a certain extent its subversion into efficiency rather than improvement, this change in placement of the industry might achieve more for the long term if set within a regenerative tourism framework (Owen 2007).

Regenerative tourism framework

So how far has this approach to sustainability lead us? It is around 45 years since Rachel Carson's "Silent Spring" was published, warning of the chemicals we were using. Kenneth Boulding's "Spaceship Earth" came out in 1966 reminding us that we only have one planet, yet currently we seem to be happy with the fact we are using more chemicals and the equivalent of over four earths in resources (in Australia's case). In 1972 the Club of Rome published "Limits to Growth" (Meadows et al. 1972). The Brundtland Commission "Our Common Future" came out fifteen years later (WCED, 1987); 1992, Agenda 21 was presented at the Earth Summit in Rio (UNCED, 1992). A more worrying demonstration of our current way of thinking's failure to deal with these problems is that over 100 year ago Svante Arrhenius (1896) calculated that increasing carbon dioxide emissions from human activities will lead to global warming, sixty-eight years since Guy Callendar (1938) warned that global warming is already underway. It is 17 years since the first report from the Inter-governmental Panel on Climate Change (1990) came out, yet our greenhouse gas emissions have gone up. In fact, the recent Millennium Ecosystem Assessment report concluded that: *"…the results of human activity are putting such a strain on the natural functions of Earth that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted"* (Millennium Ecosystem Assessment, 2005:2). They showed that nearly two-thirds of the essential services provided to us by nature – air, water, resources, etc. are in such decline that collapse is likely.

With increased awareness of ecological issues and the use of certification and rating tools, why are we still depleting our resources at such a great rate? One of the reasons is based in the Cartesian logic that places humans outside of nature, in opposition to it; the reductionist approach to sustainability and the attempt to solve problems within the same framework that has created them. There is a need for a paradigm shift away from this type of thinking, a need echoed by many researchers and commentators for example Schumacher, 1974; Naess, 1995; Sachs, 1995; Devereux, 1996; Capra, 1996 and 2002; Bossel, 1998; AtKisson, 1999; Kumar, 2002; du Plessis 2006.

The regenerative framework stems from the above call for change and by the fact that even with these more mature tools (LEED etc.) are we really on a path to reducing out ecological footprint? These tools seem to be a good start but are they sufficient in scope or tempo of take up to achieve a move to the more sustainable world before we reach a critical tipping point? Is this incremental slow rate of improvement a result of trying to find solutions within the same framework that created the problem? If they are, should we be looking at doing things differently and what could this look like?

To understand how we could approach 'sustainability' differently, regeneratively, we need to understand what we currently mean by the term. Sustainability, depending on who you speak to, is about sustaining. Most of us approach it with a view to keeping things as they are – or not letting them get worse. The problem, and the cause of its contestability lies in what people are trying to sustain - the use, misuse and consequent renegotiation of this term has resulted in a reduction of its potency. In particular, its connection with the conceptually divergent goals of economic growth and production under the popularised Brundtland definition of 'sustainable development' has led to scepticism of the value and meaning of this term. Furthermore, the framework of minimising impacts, or perhaps even more problematically offsetting impacts, is seen as both ineffective and presumptuous since it continues to grant indulgences on behalf of the planet.

This paradigm shift to regenerative development, starts by looking at things as a whole, as a set of interconnected and interdependent relationships. Solutions cannot be linear and cannot be simple, and this new thinking is being supported by current scientific development in quantum physics, complexity theory and complex adaptive systems, and the science of ecology. This means moving away from our Cartesian way of thinking of humans as apart from and in competition with nature. Called the 'ecological paradigm' by Du Plessis (2006:12) this "*requires that our definition of development shifts from the successful domination of nature, forcing it to follow ideas of order that ignore its inherent systemic properties, to embracing nature and participating in and co-evolving through its processes (Lyle, 1994; Eisenberg and Reed, 2003).*"

The second requirement in this shift is a move away from seeing humans as takers. Rather linked to the above point, tourists become not only partakers but also adders of value. This is the key and the pivotal point for this change. Tourists can become a regenerative force in the system, seeing how each activity can add value, leaving the earth better than when arriving. The premise is simple – that our actions should result in net benefits to our ecological and social environments. The application is more complicated, but it is based on what William Reed has described as building capacity rather than things.

This is becoming known as Regenerative Development and for the purpose of tourism, Regenerative Tourism (Owen 2007). This is not a new concept with many leading thinkers also approaching this problem and providing concepts such as regenerative design (Lyle 1994), interdependence (McDonough, 1998), resilience, symbiosis and positive development (Bikeland, 2007). Moving beyond Ecotourism to Regenerative Tourism, does not mean that ecotourism need abandon those aspects that support sustainability principles such as energy and water efficiency. It means for the purposes of this paper:

1 – Adding value - The first point of differentiation between ecotourism and the concept of regenerative tourism is the key issue that is universally shared amongst all proponents of regenerative development. It looks at whether it is possible to develop positively, adding capacity and capital rather than taking and diminishing our resources (Birkeland 2007).

2 – Working with nature as a partner of equal value - Regenerative tourism looks for inspiration in the complexity and symbiosis of nature. Regenerative tourism should move to reconcile the historically constructed division between humans and nature. That is to start looking at issues as a whole, as a set of interconnected and interdependent relationships.

3 – Socio-political aspects inclusion - Much of the Cartesian problem is based in the need to quantify and control. However, there are so many things for which science cannot account. In particular, the socio-political dimension requires value judgements which can never be quantified. Ecotourism does not exclude the socio-political dimension, but it defines it as a distinct realm; one of the four 'pillars' or three 'legs' depending on how the pie is sliced. Conversely, regenerative tourism is concerned with the complex web of relationships that form an integrated whole that cannot so easily be dissected. This is an aspiration rather than a reality and unfortunately social relationships are too readily glossed over or presented as universal and homogenous. One notable point of difference is Steven Moore's work on regenerative design, through an analysis of the Laredo Blueprint Farm in Texas, in which he explores the inter-relationships between the success of environmental initiatives and the politics of ownership, production and education (Moore 2004).

Regenerative tourism and tools

Having discussed what the issues are with current ecotourism certification tools, and having looked at the need to move to a regenerative tourism framework, this section briefly looks at the consequence this may have for how tools develop in the future.

1 – Adding value - There are two aspects to supporting this, the first relates to the opportunity for the tourists to add value, the second is for the facility itself to add capital. Certification tools need to support visitors and stakeholders within the facility to be able to contribute actively. This might be through active promotion of the voluntourism aspects of the area, or through the design and planning of the tourism experience to allow active engagement with the context of the facility. Meanwhile, following Birkeland's concepts of positive development, ensuring that the facility actively contributes through its design; for example, using passive techniques, ensuring that green roves, solar panels, water collection, waste recycling and reuse are all part of the operations of the building. Particularly ensuring that there is no taking of the capital, and where possible adding to it through adding to fresh air, native flora and fauna habitat and food production.

2 – Working with nature as a partner of equal value - Tools can move towards instilling a partnership with nature by highlighting the interconnectedness of all aspects of a tourism facility. Firstly, this needs to be reflected in an ability to see all parts of the certification as important and not trading off say water efficiency with energy efficiency. Secondly, it is about providing educational and experiential opportunities for the tourist to be able to engage with nature and as such gain a richer appreciation and connectedness with the place they are visiting.

3 – Socio-political aspects inclusion - This aspect is the most difficult to put into concrete actions that could be taken by certifying tools as this is centred on equality for all participants. A tool could represent this by ensuring education, participation and ownership is addressed among all stakeholders. Educational opportunities for the local inhabitants as well as education of other stakeholders of the traditional inhabitants

could form one of the measures. Participation in decision making on the facility by all stakeholders through consultation and real representation of their voices could be another measure. Finally, instilling a sense of pride and ownership in the ideals of the facility is a third potential measure, this ownership is not intended in the financial sense, though this may be how value is attributed, but in a ability to identify and understand the ecotourism facility.

Future work is needs to be done on how these can inform tool evolution, as shown by the building rating tools they need to be simple, easy to implement, internationally relevant, using representative indicators and a verifiable communication mechanism for those looking to travel responsibly. This is still required in the short to medium term. The hope is that in the long term the concept of regeneration will become part of the practice of tourism. A practice where no activity is carried out that does not add value to its context, working with nature and the community. Not only an elimination of the ecological footprint of the experience but actually productively adding capacity.

Conclusion

This paper has shown how ecotourism certification and labelling tools have been effective in raising awareness but that they have many flaws; both in the rate of uptake and influence and their ability to support sustainability. This paper also argued that the development of these tools within the framework that created the problems in the first place will not lead to their solutions. Further, this paper introduces the concept of regenerative development and regenerative tourism. It gives a brief outline of the principles and how these differ from the current way of thinking about.

The roles of the tools at present seem to be as a marketing and awareness program, but as argued this does not really result in a decrease in a tourist's impact on the environment nor lead to sustainability. In the future these tools could be developed to support a regenerative frame of thinking, but ultimately this will not lead to certification or a label, but a benchmark which will be fundamental to all tourism facilities.

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Development of an energy saving control system for venetian blind with slats having different angles vertically

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Summary

The authors have developed a “Gradation Blind”, a venetian blind with slats having different angles vertically. The blind reflects more effectively the direct sunlight to the ceiling of a room than ordinary blinds, because the slats of the blind are controlled these angles depending on solar position. Thus the blind increases the brightness of the room and reduces the lighting energy. According to the intimate calculation that the authors made, the lighting energy of the room that was installed “Gradation Blind” in window was lower in 24% than the room that was installed nothing. On the other hand, it is possible that the “Gradation Blind” increases the cooling load as a result of the increased introduction of the solar radiation. So, the authors propose a system to control the blind the best condition to minimize the sum of the lighting energy and the air-conditioning energy. And we proved this control system was available for saving the total energy consumption of the building.

1. Introduction

Because from one-fourth to one-third of building operation energy is from the lighting and the office equipment, it is necessary to reduce this energy in the building. The daylight use technique leads to the reduction in the lighting energy by effectively using the natural energy of sunlight. As for this daylight use technique, various methods are examined, and have been introduced. The authors have developed a “Gradation Blind”, whose lighting performance is higher than a past window shade by having the slats different angles vertically. This paper shows a basic feature of the “Gradation Blind”. On the other hand, it is possible that the “Gradation Blind” increases the cooling load as a result of the increased introduction of the solar radiation. So, the authors propose a system to control the blind the best condition to minimize the sum of the lighting energy and the air-conditioning energy. This paper shows the outline of the new control system of “Gradation Blind”, and the result of verifying the effect of the control system.

2. The outline of “Gradation Blind”

2.1 Control Principle of “Gradation Blind”

“Gradation Blind” is a daylight introduction device that makes the room brighter by reflecting direct sunlight to the room ceiling by changing the interval of the slat on a window side and the indoor side as shown in figure1. The angle of the slat is controlled by the solar position. And each of slats reflects the direct sunshine to the ceiling in the room optimally.

The angle of the slat located on the top of the blind is controlled so that the slat reflects the direct sunshine to the ceiling in the room whose position is farthest away from windows. The angle of the slat at such time becomes like the formula in figure 4, and this angle is assumed to be “ β_1 ”. If the angle of the slat located on the top of the blind is inclined to the angle that is calculated by the formula, the change attaches to the angle of the slat of each height, and direct sunshine is taken in the room as shown in figure 2.

However, direct sunlight might be irradiated directly to the floor in the room when controlled at a specific angle calculated by the formula in figure 4. So the slat angle when direct sunshine is not irradiated just directly to the floor in the room should be calculated at the same time, and it becomes the formula in figure5.

If the angle of the slat that located on the top of blind is inclined to that angle, direct sunshine never leaks between the slat and the slat because the angle of the slat that is under of the top of the blind becomes smaller than the angle of the slat of the top. And this angle is assumed to be "β_2".

If the value of β_1 is smaller than that of β_2, the angle of the slat that located on the top of blind becomes β_1. And if the value of β_1 is bigger than that of β_2, when the direct sunshine irradiate directly at the floor, the slat angle becomes β_2. The method of operating the blind as mentioned above becomes flow as shown in figure 6.

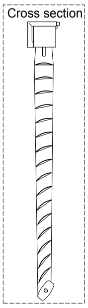


Figure 1. Cross section of "Gradation Blind"

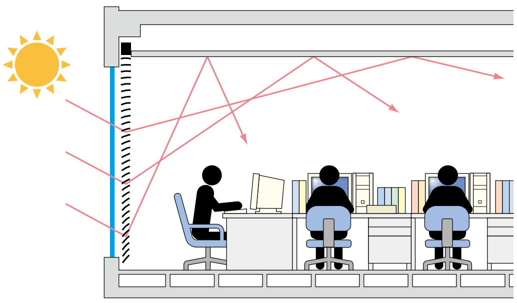


Figure 2. The direction of reflected sunlight in the case of Gradation Blind

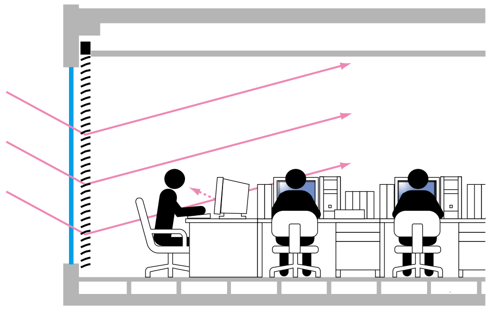


Figure 3. The direction of reflected sunlight in the case of conventional blind

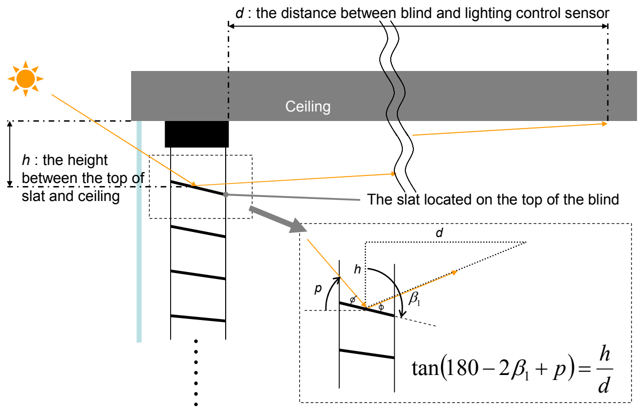


Figure 4. Calculation diagram of slat angle β_1

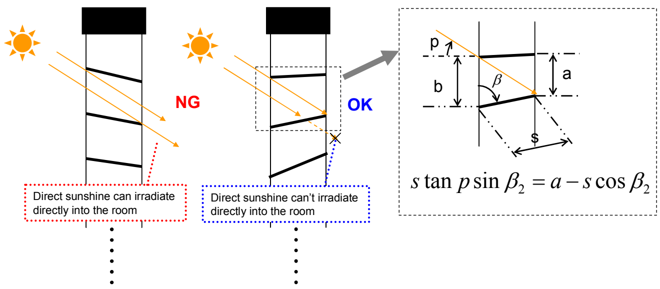


Figure 5. Calculation diagram of slat angle β_2

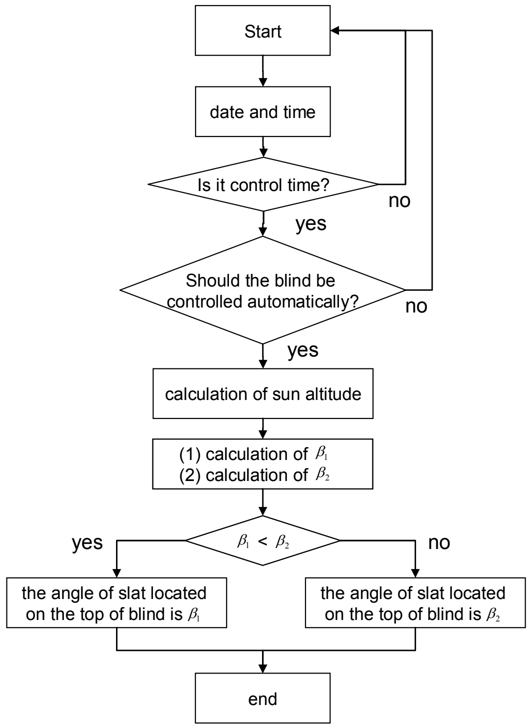


Figure 6. Operating flow of "Gradation Blind"

1.2. The effect of "Gradation Blind"

The following effects can be expected by introducing "Gradation Blind".

(1) Reduction in lighting energy
A further effect of the lighting energy saving is achieved by combining the fluorescent lights with a dimmer switch and "Gradation Blind". (Figure 7 shows that the difference of the brightness in the room between "Gradation Blind" and conventional blind. The room with "Gradation Blind" is brighter than that of conventional blind.)

(2) Securing of effect of shading and view
The view can be secured with the effect of the solar shading by introducing the "Gradation Blind" as shown in figure.

(3) Introduction of daylight into place away from window
The blind reflects more effectively the direct sunlight to the ceiling of a room than conventional blinds, because the slats of the blind are controlled these angles depending on solar position.

(4) Decrease of glare of fenestration
The distance from the fenestration that reflected light from the slat reaches person's eyes directly shortens more than conventional blind, and, therefore, feeling the glare decreases, as shown in the figure 2 and 3.

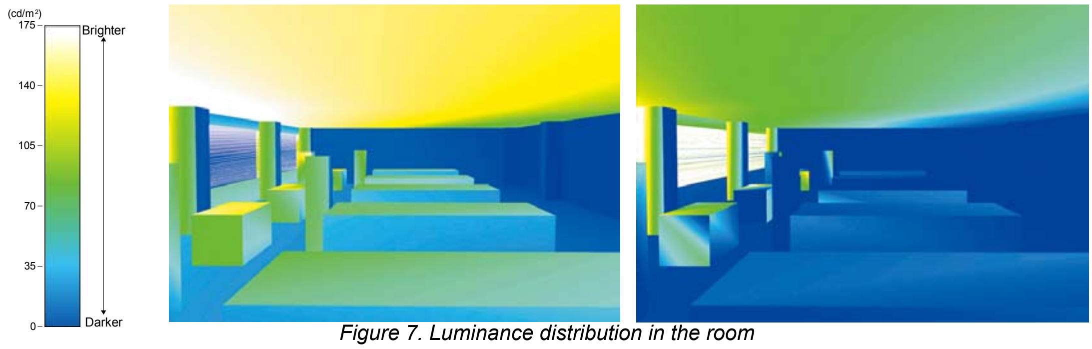


Figure 7. Luminance distribution in the room
The difference between "Gradation Blind" (left) and conventional blind (right)

Figure 8. Ability to view outside
The difference between "Gradation Blind" (left) and conventional blind (right)

2. Case study result in effect of energy saving by "Gradation Blind" introduction

2.1 Condition of model

(1) Shape of the model: shown in figure 9

(2) Condition of pane: float glass of thickness of 6mm

(3) Shape of fenestration: multiple window of 1.6m height as shown in figure 9

(4) Direction of building façade: south, north, east, west

(5) Window shade: Gradation Blind

(6) Range of lighting control: 6m from fenestration

(7) Design illuminance in the room: 750lx

(8) Date and time: 365days, 8:00-18:00 (using Japanese standard weather data at Tokyo)

(9) Lighting fixture: The electric energy is 98W per one lighting fixture. The lighting fixture can dim 25% of luminance flux at the lowest. The amount of power consumption when 100% lighting is 98W, and the amount of power consumption when 25% lighting is 37W. In the relation between the lighting control ratio and power consumption, from 25 to 100% in the lighting control ratio is the relations of linear, and the amount of power consumption is 37W at 25% or less. (Shown in figure 10)

Each of equipment was arranged as shown in figure and lighting fixture was controlled so that the illuminance on the desk in the room may become 750lx. The lighting consumption energy was calculated during year on the above-mentioned condition.

2.2 Calculation method

(1) Method of calculating the indoor illuminance with "Gradation Blind"

The illuminance in the room where "Gradation Blind" was set up was calculated with visual environment simulation software INSPIRER. 8 conditions of Gradation Blind, when the solar profile angle is 10, 20, 30, 40, 50, 60, and 70, 80 degrees, were calculated. And daylight factor was calculated.

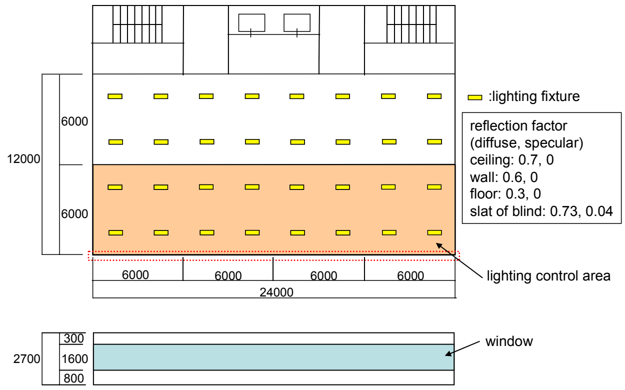


Figure 9. Calculation model (above: plan, below: elevation of façade)

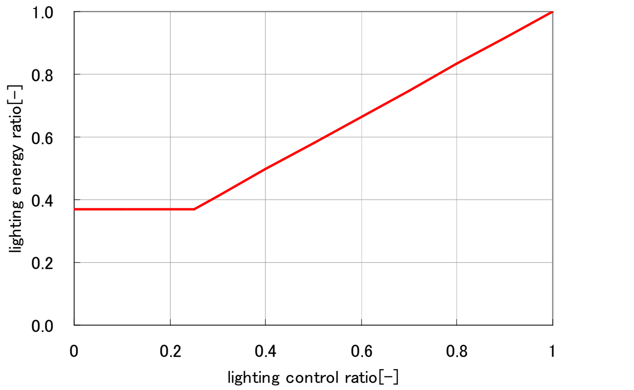


Figure 10. The relationship of lighting control ratio and energy ratio

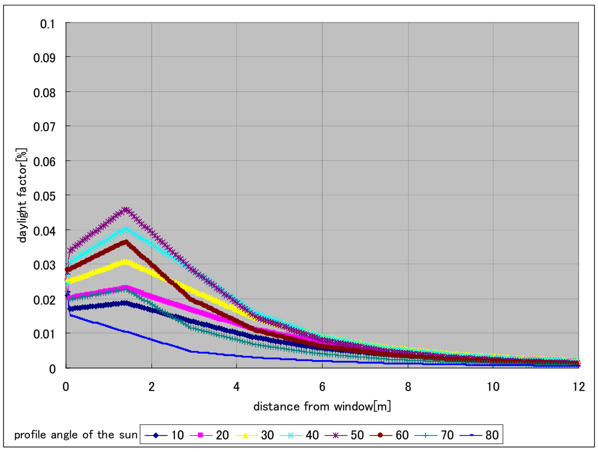


Figure 11. Daylight factor for direct sunlight

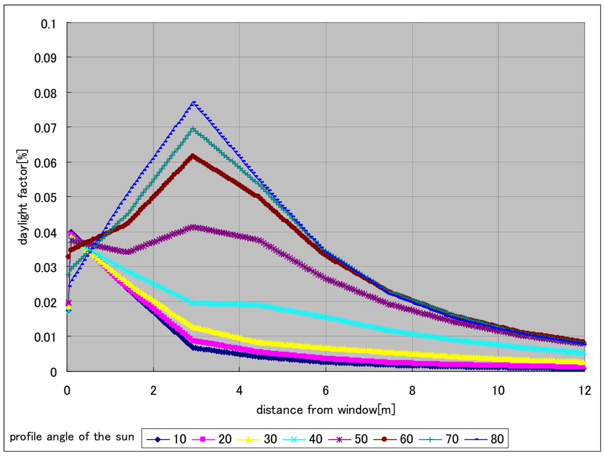


Figure 12. Daylight factor for diffused sunlight

The figure 11 shows the daylight factor when only the direct sunlight is irradiated outside the room at the condition of “Gradation Blind” when the sun’s profile angle is 10, 20, 30, 40, 50, 60, and 70, 80 degrees. The figure 12 shows the daylight factor when only the diffused sunlight is irradiated outside the room at the same condition. It seems that the illuminance in the room depend on solar altitude, because the Gradation blind is the lighting equipment that positively takes direct sunlight in the room. So the daylight factor was divided in the daylight factor of direct sunlight and the daylight factor of diffused sunlight. The daylight factor is calculated as a function concerning the distance from the window, and indoor illuminance is calculated by the following formulas.

$$E_N(x) = D_D(x)E_D + D_S(x)E_S$$

($E_N(x)$:illuminance in the room at the point x m away from window, $D_D(x)$:daylight factor for direct sunlight, $D_S(x)$: daylight factor for diffused sunlight, E_D: illuminance of direct sunlight, E_S: illuminance of diffused sunlight)

(2) Method of calculating lighting energy

The position of the sun of per hour is calculated during year, and the condition of the Gradation blind is judged. The annual indoor illuminance per hour is calculated by substituting the annual outdoor illuminance per hour for the above-mentioned formulas. The annual outdoor illuminance per hour is calculated by Japanese standard weather data. Because light is supplemented to reach the design illuminance by lighting fixture, illuminance by lighting fixture is calculated by decreasing the indoor illuminance by the daylight to the design illuminance. And lighting rate was calculated and lighting energy per hour during year, and then annual lighting energy was calculated.

2.3 Results and consideration

The results are shown in Figure 13 to 20.

(1) Difference by season of energy reduction rate

The energy reduction rate has risen for summer when the outdoor illuminance is large.

(2) Difference by azimuth in window of energy reduction rate

The energy reduction rate has risen more than facing north as for look souths when the north is compared with the south. This is because there is a lot of time that the look south takes light of firing directly than facing north, and the effect of Gradation Blind that can take light of firing directly is frankly shown.

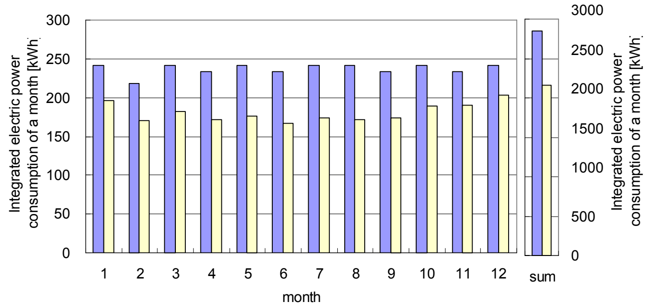


Figure 13. Lighting energy consumption (South façade)
blue: no lighting control, yellow: lighting control with “Gradation Blind “

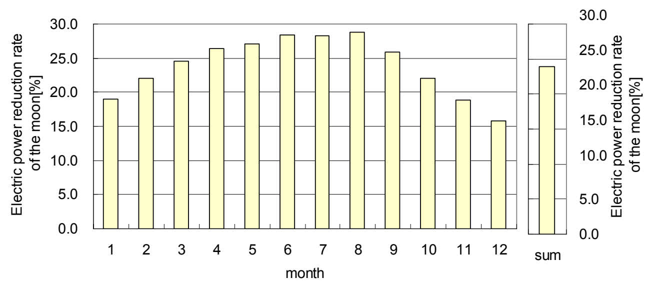


Figure 14. Electric power reduction rate (South façade)

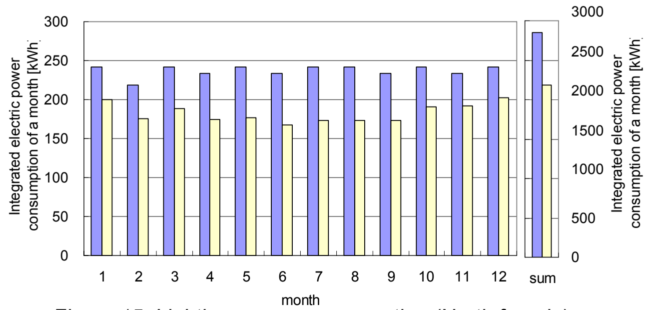


Figure 15. Lighting energy consumption (North façade)
blue: no lighting control, yellow: lighting control with “Gradation Blind “

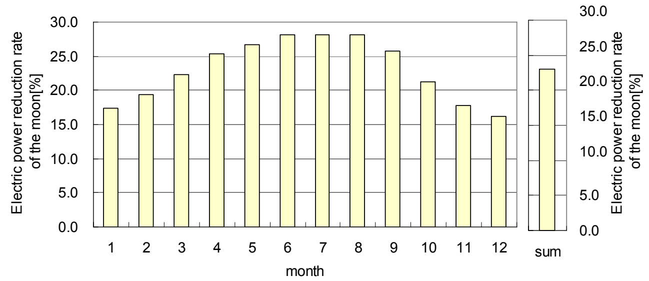


Figure 16. Electric power reduction rate (North façade)

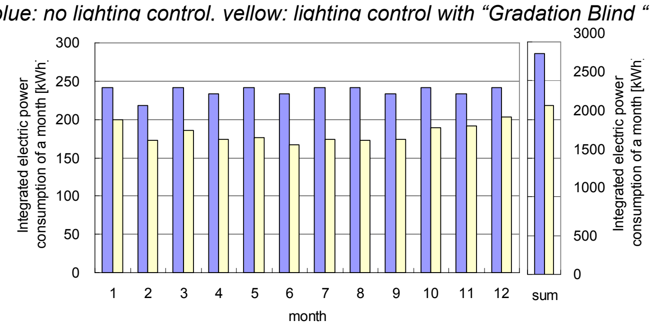


Figure 17. Lighting energy consumption (East façade)
blue: no lighting control, yellow: lighting control with “Gradation Blind “

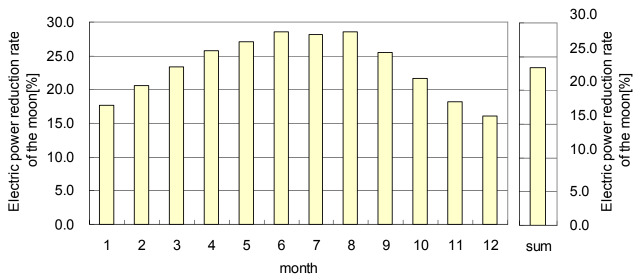


Figure 18. Electric power reduction rate (East façade)

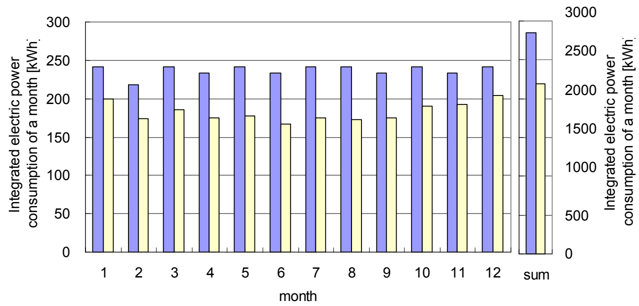


Figure 19. Lighting energy consumption (West façade)
blue: no lighting control, yellow: lighting control with “Gradation Blind “

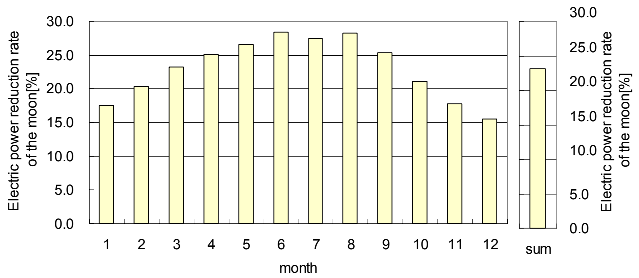


Figure 20. Electric power reduction rate (West façade)

3. New control system of the Gradation Blind

3.1 Outline of the system

Although it becomes a reduction in lighting energy when the daylight is introduced into the room, it is possible that the cooling load in summer increases by introducing a solar radiation. When the Gradation blind is introduced in the building, the same thing can be possible. Then the calculation function of the air-conditioning energy and lighting energy is given to the above-mentioned Gradation blind’s control logic. The air-conditioning energy and lighting energy are calculated from solar radiation and outside temperature. So this system needs the solar radiation sensor and outside temperature sensor. The figure shows that the system configuration.

The blind is controlled to introduce the daylight or prevent the solar radiation. The state of introducing the daylight is that the slat of blind is controlled according to solar position, and this state is assumed to be “daylight using state”. The state of preventing the solar radiation is that blind is all closed, and this state is assumed to be “closed state”. In the control system, sum of air conditioning energy and lighting energy at both stages is calculated. The system compares the two values, and decides which state is optimistic. If sum of air-conditioning energy and lighting energy at "daylight using state" (it assumed to be "E1") is smaller than sum of air-conditioning energy and lighting energy at "closed state"(it assumed to be "E2"), the blind is controlled to be a "daylight using state". On the other hand, E1 is bigger than E2, the blind is controlled to be a "closed state". As a result, the control that synchronizes with air-conditioning can be done, and a further effect of the energy reduction can be expected. The figure 22 shows the flow of control logic.

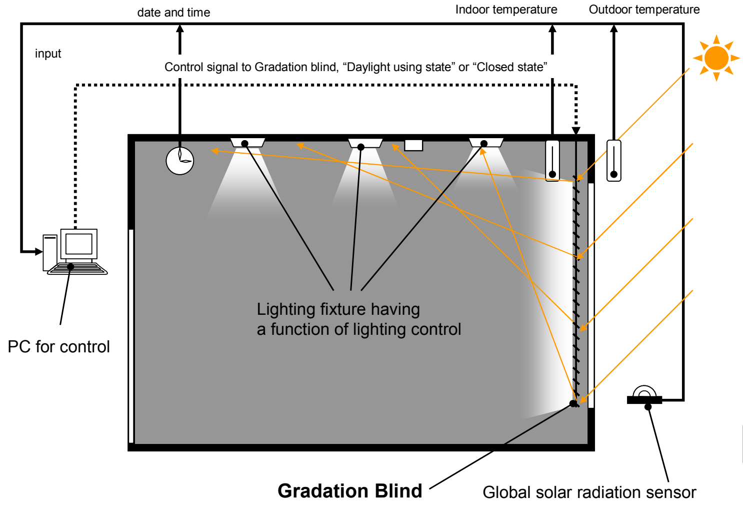


Figure 21. System configuration of new control system

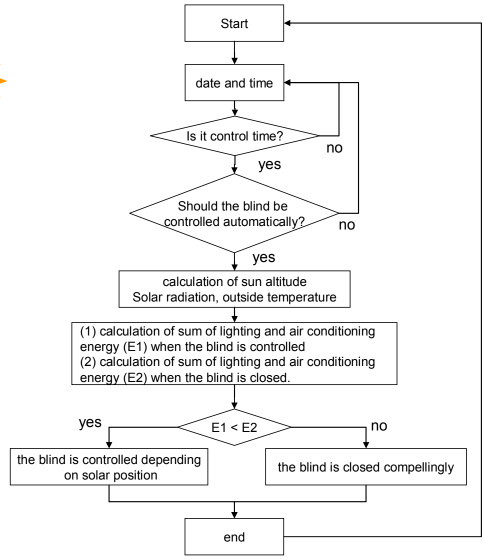


Figure 22. Operating flow of new control system

3.2 Method of calculating air conditioning and energy

Figure 23 shows the calculation flow of the air-conditioning energy and the lighting energy.

(1) The solar position is calculated by location data (altitude and longitude of the site), date and time.

(2) The flux of diffused solar radiation and the flux of direct solar radiation are calculated by solar position and flux of global radiation from the sensor.

(3) The air-conditioning load due to diffused solar radiation is calculated by multiplying the shading coefficient in each state of the blind and the flux of diffused solar radiation, and the load due to direct solar radiation is calculated by multiplying the shading coefficient and flux of direct solar radiation.

(4) The heat of transmission load is calculated by the outside temperature and the room temperature.

(5) The flux of solar radiation is converted into the outdoor illuminance, and lighting energy is calculated by the method where it describes in 2.2.

(6) The air-conditioning energy is calculated by dividing the sum of the air-conditioning load due to solar radiation, the heat of transmission load, and the lighting load (= lighting energy) with coefficient of performance (COP).

(7) Therefore, the sum of air-conditioning energy and lighting energy is calculated.

The solar shading coefficient is different with "daylight using state" and "closed state", and generally the former one is larger than later one. So the effect of preventing the solar radiation is considered. The lighting control is done when the blind is "closed state" because the lighting fixture has the lighting control function, so indoor illuminance was calculated by the daylight factor at the "closed state".

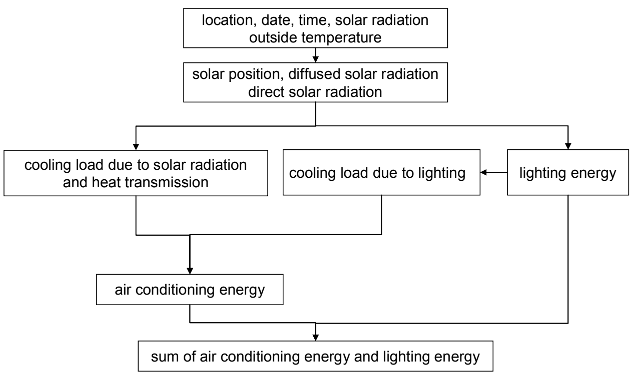


Figure 23. Flow of calculating the air-conditioning and lighting energy

4. Case study result in effect of energy saving by new control system introduction

4.1 Condition of model and calculation method

(1) Shape of the model: shown in figure 9

(2) Condition of pane: float glass of thickness of 6mm,

(3) Shape of fenestration: multiple window of 1.6m height as shown in figure 9

(4) Direction of building façade: south

(5) Window shade: Gradation Blind

(6) Range of lighting control: 6m from fenestration

(7) Design illuminance in the room: 750lx

(8) Date and time: August 30th 8:00-18:00 (using Japanese standard weather data)

(9) Lighting fixture: similar to 2.1

(10) Set point temperature: 26^{o}C

(11) Volume of outdoor air intake: 5m^3/h/m^2

(12) cooling load from lighting: 11W/m^2

(13) cooling load from office equipment: 18 W/m^2

(14) cooling load from occupancy: 12 W/m^2

(15) Coefficient of performance of the heat source: 1.8

(16) Control systems of Gradation blind and lighting: (system 1) Gradation blind is controlled to be "daylight using state" all time, and there is lighting control. (system 2) Gradation blind is closed all time and there is lighting control. (system 3) Gradation blind is closed all time and there is no lighting control. (system 4) Gradation blind is controlled by new control system and there is lighting control.

The conditions of calculation are basically similar to 2.1. The air-conditioning load is calculated by individually calculating each of the loads from the flux of solar radiation, occupancy, lighting, equipment, and the dehumidification load. Then air-conditioning energy is calculated by dividing the load with COP. The method of calculating lighting energy is similar to the method referred in 2.2. About the air conditioning and lighting energy consumed by "system 4", the energy consumed by system1 and the energy consumed by system 2 are compared at each time, and smaller one is adopted as a result of the energy consumed by system 4.

4.2 Results and consideration

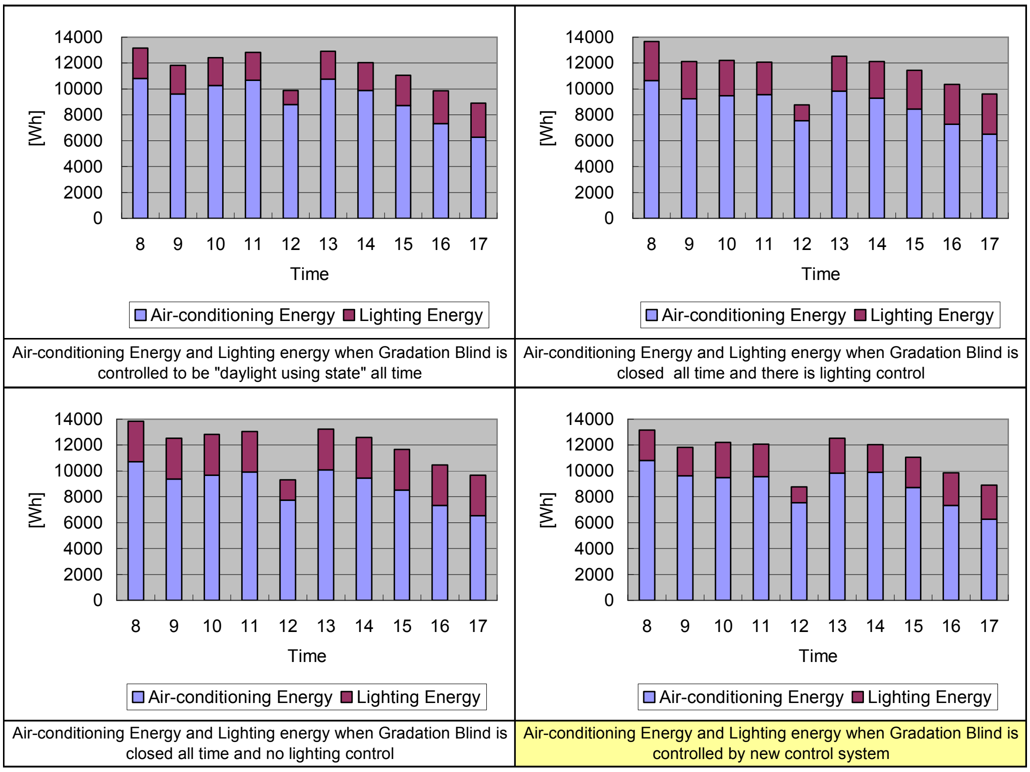
The Gradation blind is controlled to be "closed state" at 10:00, 11:00, 12:00 and 13:00. Because the air conditioning loads from solar radiation at these times are larger than other time, the differences between air-conditioning energy consumed by "system1" and that of "system2" at these times are bigger than the difference of lighting energy, then it becomes such result.

As for other time zones, air conditioning energy consumed by "system1" is larger than that of "system2". But the difference is small, because air-conditioning load from lighting consumed by "system1" is smaller than that of "system2". As a result, the Gradation blind is controlled to be "daylight using state".

As for the energy of the day multiplication, comparing the total energy (the sum of air-conditioning energy and lighting energy) consumed by "system 3" and that of "system 1", the effect of energy reduction of "system 1" is about 4%. Comparing the total energy consumed by "system 3" and that of "system 4", the effect of energy reduction of "system 4" is about 6%. Then, the improvement of the effect of the energy reduction of 2% was able to be achieved from a past control system by a new control system.

Table 1.Calculation results Air-conditioning and Lighting energy
: The total energy during 8/30

	Blind: closed no lighting control (system 3)	Blind: daylight using state light: controlled (system 1)	Blind: depends on the calculation of the energy Light: controlled (system 4)
Air-conditioning Energy	89352	93178 (1.04)	89080 (1.00)
Lighting Energy	29792	21720 (0.73)	23358 (0.78)
Sum of two kind of energy	119144	114898 (0.96)	112438 (0.94)



Air-conditioning Energy and Lighting energy when Gradation Blind is controlled to be "daylight using state" all time

Air-conditioning Energy and Lighting energy when Gradation Blind is closed all time and there is lighting control

Air-conditioning Energy and Lighting energy when Gradation Blind is closed all time and no lighting control

Air-conditioning Energy and Lighting energy when Gradation Blind is controlled by new control system

Figure24. Calculation results, Air-conditioning and Lighting energy: The change in a day

5. Conclusion

This paper shows a basic feature of the “Gradation Blind” and the system to control the blind the best condition to minimize the sum of lighting and the air-conditioning energy. Then the following conclusions are obtained.

(1) The lighting energy of the room that was installed Gradation Blind in window was lower in 24% than the room that was no lighting control.

(2) The sum of the air-conditioning energy and the lighting energy of the room that was installed Gradation Blind with ordinary control system was lower in 4% than the room that was installed no lighting control system and whose blinds are always closed, for a typical day of summer.

(3) The sum of the air-conditioning energy and the lighting energy of the room that was installed Gradation Blind with new control system was lower in 6% than the room that was installed no lighting control system and whose blinds are always closed, for a typical day of summer. And it is proved that the new control system of Gradation Blind was available for saving the total energy consumption of the building.

Acknowledgement

I got big cooperation at the stage of development from Mr. Kuwana and Mr. Wada (Yokota Co., Ltd). We would like to note the gratitude to their cooperation.

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ARCHITECTURE IN QUEST FOR A SUSTAINABLE FUTURE

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Keywords: Energy, Whole Building, Design

ABSTRACT:
Sustainability; physically and economically is to a large extent manifest in the habitat built form, it is the scientific temper that will lend a design methodology and process, in order to render Architecture sustainable. To achieve this; A ' Energy, Resource Flow – Ecological Foot Print' model is suggested which can help optimize input out-put parameters and their relationship. This leads to a process of design and various actual projects in response to critical issues. Thus suggesting **A New Language of Architecture**.

1.0 Preamble

Globally accepted definition of sustainable development is **"development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission Report 1987).**

The beautiful blue planet that we co-habit with 70 million other species, our Mother Earth - is habitat for every species on the planet. While it is a dynamic Eco-system, it is finite: An eco-system that is driven by Sun, a regenerative resource

1.1 The Challenge:

Therefore the challenge for contemporary design is to use the regenerative solar spectrum and design a sustainable habitat within the capacity of the finite eco-system that is our Mother Earth.

Sustainable design must integrate consideration of resource and energy efficiency, healthy buildings and materials, ecologically and socially sensitive land use and an aesthetic sensitivity that inspires, affirms and ennobles, to achieve a culturally appropriate eco-settlement.

2.0 ENERGY, RESOURCE FLOW - ECOLOGICAL FOOT PRINT MODEL:

Human habitat a physical manifestation of socio-economic ecological context is the major consumer and generator of energy and natural, man-made resource. Energy-Resource Flow Model and presented below, illustrates the input-output relationships.

**This input-output intrinsic relationship determines the ecological foot-print: the community, city or the region / country – the ultimate determinant of sustainability.
Yet, central to this entire flow model is the habitat / building (refer figure- 2.1). It is both in the construction and operation of this habitat / building that energy-resource flow can be optimised.**

Outlining the criticality of planning and design of the habitat / building. Wherein, Climate-Responsive Architectural design and Ecological Planning become the determinants of energy-resource flow and offer a powerful tool for optimisation.

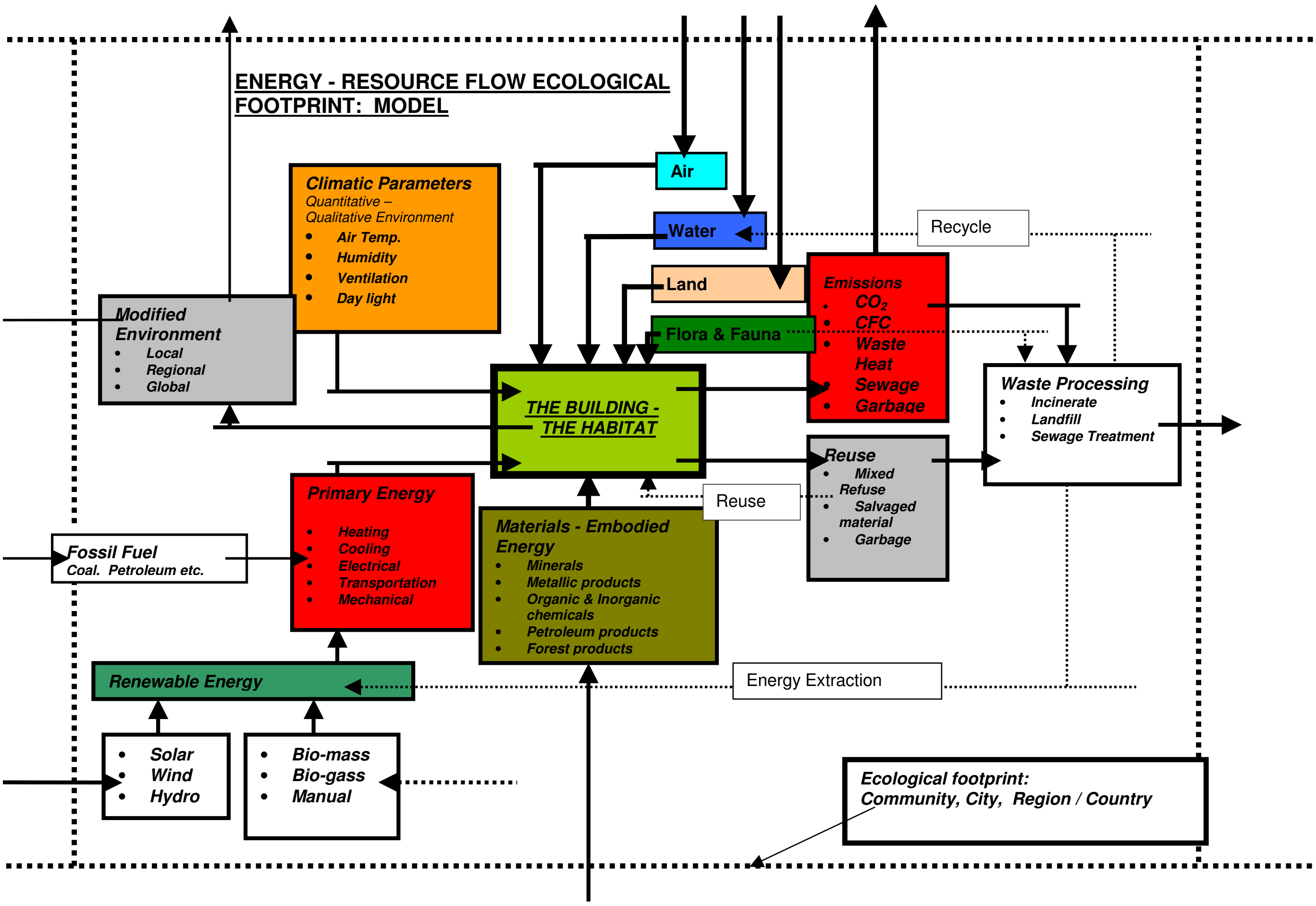
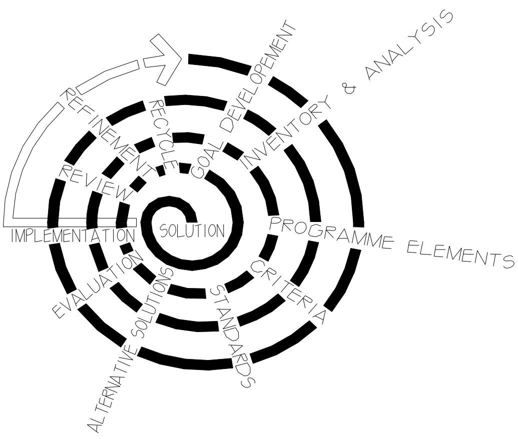

ENERGY - RESOURCE FLOW ECOLOGICAL FOOTPRINT: MODEL
Air
Water
Land
Flora & Fauna
Recycle
Climatic Parameters
Quantitative –
Qualitative Environment
• Air Temp.
• Humidity
• Ventilation
• Day light
Modified Environment
• Local
• Regional
• Global
Emissions
• CO_2
• CFC
• Waste Heat
• Sewage
• Garbage
THE BUILDING - THE HABITAT
Waste Processing
• Incinerate
• Landfill
• Sewage Treatment
Reuse
• Mixed Refuse
• Salvaged material
• Garbage
Reuse
Fossil Fuel
Coal. Petroleum etc.
Primary Energy
• Heating
• Cooling
• Electrical
• Transportation
• Mechanical
Materials - Embodied Energy
• Minerals
• Metallic products
• Organic & Inorganic chemicals
• Petroleum products
• Forest products
Energy Extraction
Renewable Energy
• Solar
• Wind
• Hydro
• Bio-mass
• Bio-gass
• Manual
Ecological footprint:
Community, City, Region / Country

Figure- 2. 1

2

3. CLIMATE RESPONSIVE ARCHITECTURE - THE TOOL AND THE PROCESS:

This leads to defining a process of architectural design that is scientific and developed on an ecological basis.



Graphical Representation of Process

Process of architectural design is a complex exercise, involving interactive relationships between parameters of diverse nature and varying magnitude. Yet, it is the prime generator of architecture as we see and experience.
Various ideas have dominated architectural thought from time to time. Yet, the fundamental issue of energy as an embodiment of Sun, Wind and Light – the ecological context - have not been a basic paradigm of design..

The idea of climatically responsive design is to modulate the conditions such that they are always within or as close as possible to the band of appropriate ecological design.

Ecological Process of Design:
Based on this premise, a design decision making knowledge based expert system has been developed by the author and published in C*limate Responsive Architecture – A design handbook* [1] *(Tata McGraw Hill, New Delhi 2001)*

4.0 SOME CONTEMPORARY SOLUTIONS:

One single parameter that embodies the state and use of natural resources in their various forms is energy. Author presents some contemporary solutions that optimize energy use / consumption through architectural design.

- Design principles elicited from analysis of indigenous architecture and the scientific process of design have been translated into design of following modern buildings at various locations in the country with diverse ecological context.

4.1 What Possible Architectural Responses Can Be Evolved For A Composite Climate And The Context Of Urbanity Of Chandigarh, India ?

4.1.2 PEDA Office complex, Chandigarh, India

Located at Chandigarh, on a flat practically square site with no major topographical variations. Chandigarh as a city lies on the planes at the foot of ‘Lower Himalayas’, in a ‘Composite climate context’.

- With climate swings over the year i.e. very hot and dry period of almost two and a half months (Max. DBT 44 °C) and a quite cold period of shorter duration (Min. DBT 3 °C). The hot dry period is followed by a hot humid monsoon period (Max DBT 38 °C and Max R.H.90 %) of about two months with intervening periods of milder climate.

- Equally important, for Chandigarh is the context in space and time. Chandigarh, a bold experiment in city planning and architecture, was based on the professed ethos of design: ‘build with climate’.

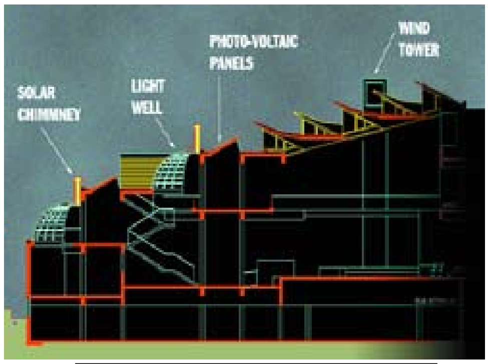


Fig.4.1.1 : Section

Fig. 4.1.2. OVERALL INTERNAL VIEW

- Building configuration has been generated in response to solar geometry, a unique built form thus generated in response to summer and winter requirements. Building form follows solar geometry, it does not follow any pre-conceived notion of design.

- **A holistic office design has been developed wherein the floor plates float in a large volume of air, and the building envelope interacts with the external conditions rather than the conventional stacking of floor plates one on top of the other where each floor plate is segregated.**

Fig. 4.1.3. SOLAR SHELLS DURING CONSTRUCTION AND ON COMPLETION

- **Fenestration design has been innovated as spherical 'solar Shells' in response to solar geometry.**
- A natural movement of air is achieved through a down draft wind tower coupled with vertical cut outs running through various floors with solar chimneys integerated with Solar shells allowing good movement of air.
- A well designed water-body in the center of the building provides a cooling element and restful environment.
- Atrium roof designed as Hyperbolic pre-fabricated units in response to solar geometry allows winter solar access and cuts of summer penetration. Allowing a very good day light distribution.

- ➢ Very good day-light distribution is achieved, thereby optimizing consumption of electrical energy.
- ➢ Architectural design strategies have resulted in fascinating architecture in response to solar geometry.
- ➢ Integeration of renewable energy systems. Building integrates Photovoltaic panels as an element of roof design, thereby generating its own energy.

4.2 Can We Evolve A New Language Of Ecological Architecture For An Innovative Institute?

Sardar Swaran Singh – National Institute of Renewable Energy, Ministry of Non-Conventional Energy sources, Government of India

Author was invited to participate in a limited competition for the above project. **An innovative architectural design evolving a language of ecological architecture presented by the author was selected by the jury for implementation of the project.**

4.2.1 Strategies for Planning and Design:

- Control of micro-climate of the site by generating a water-body drawn off the canal on rear boundary of site and by forestation of the site.
- Entire complex and each building designed as a climate responsive – solar passive building coupled with wind-towers and earth tunnels to maximize geothermal conditioning.
- Architectural design: the primary generator / tool for developing a low energy building design.
- Maximize environmental control through naturally conditioned laboratories and spaces.
- Maximize use of day light to minimize electricity consumption in day time.
- Couple evaporative cooling from water-body with building design.

Ecological Architectural Design of R&D Wings:

- R & D wing has therefore been designed to couple the naturally conditioned laboratories and spaces to the water-body through **Wind towers coupled with earth-tunnels to the laboratory and building spaces.**
- Domical light vault designed for adequate day-light distribution integrated with Solar chimney on domical vault coupled to wind towers.

Fig. 4.2.1: SECTIONAL PERSPECTIVE

4.2.2 Roof System:

- Roof forms the critical element of the building design since it attracts the maximum solar heat gain and can be used as an element to generate efficient day-light distribution.
- Hyperbolic Paraboloid used as the structural element for the roof to: Optimize on structural design and generate a form that responds to solar geometry i.e cut off summer radiative heat gai and allow winter heat gain.
- Double curved surface responds naturally to solar geometry cutting of solar heat gain due to summer sum and allowing penetration solar heat gain for winters.

4.2.3 Integration of Renewable Energy Systems:

- Solar chimneys integrated with building design for natural ventilation
- Photovoltaic panels sandwiched in translucent panels on the south facing central spaces for generating electricity and allowing penetration of diffused day light.
- Water management system to be coupled with entire building complex for recycling of water and waste management.

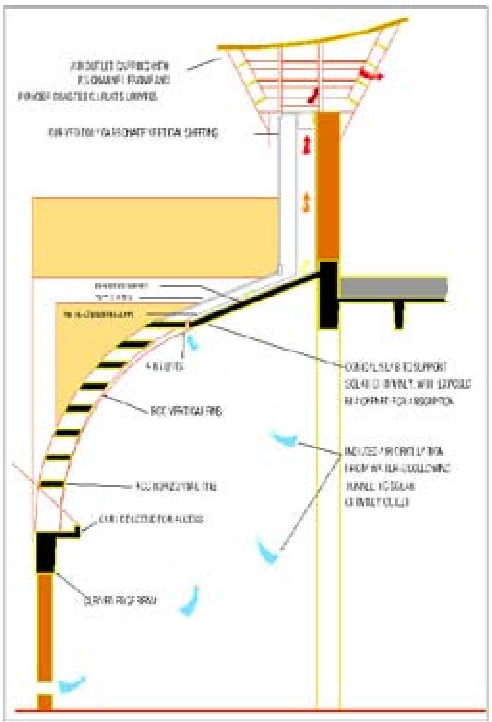


Fig. 4.2.2 Typical Section through Domical Vault and Solar Chimney

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5.0Conclusion:

TO MY MIND DESIGN IS A VERY POWERFUL TOOL TO ACHIEVE BALANCE BETWEEN MAN AND NATURE

THE ONLY LIMIT TO WHAT ONE CAN DO IS ONES OWN IMAGINATION

SUSTAINABILITY AND THE BRITISH BRICK INDUSTRY

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Keywords: Brick, building, regulations, emissions, sustainability, construction.

Summary

During the 1990s it was clear that Sustainability would become an important issue for the Brick Industry. The case study will show how the Industry faced the challenge of proving its sustainability credentials and will look at the threats and opportunities that the current situation poses in the United Kingdom.

The study will discuss how the current regulatory regime in the UK has developed, investigating the inter-relationship of Government aspirations, research results, and manufacturing reality. It will report on how sustainability is being reduced to considerations of environmental assessment in the Code for Sustainable Homes published by the UK Government in 2007.

The study will conclude with an indication of the likely impact of the Code for Sustainable Homes on the design of dwellings and the knock-on effect on the Construction Products Industry in general and the Brick Industry in particular.

1. The UK Brick Industry

The United Kingdom brick industry produces 2.5 billion bricks per year from nearly 90 plants. It employs around 4,500 people and has a turnover approaching 550 million GBP. It is a well-established industry with many of the plants in rural locations where they are often the major employer in the area. Brick is a popular material, well liked by the public and appreciated by designers. 60% of the output is used in housing, 25% in repair and maintenance and the remainder in public projects, education, health and commerce.

Ten years ago "sustainability" was a word that was hardly part of the brick-maker's vocabulary but the growing awareness of sustainability in the industry and the impact that the introduction of sustainability assessment methods has had on the industry makes an interesting case study.

2. Sustainable Construction

The Building Research Establishment (BRE) at Watford made one of the earliest moves towards sustainable construction in the UK in the 1990s. The BRE assembled a set of elemental specifications for walls, roofs, floors and building components and then provided the relative environmental impacts of each one. In order to make the environmental assessment BRE created a database of the environmental profiles of the materials involved measuring each one against a range of impacts such as climate change, toxicity, fossil fuel and ozone depletion, levels of emission of pollutants and material for water extraction.

The brick industry was party to this operation and cooperated with the BRE in the production of a generic environmental profile for brick. The results of the study were published in the Green Guide and they became fundamental to the schemes for the environmental assessment of buildings produced by BRE.

3. The Brick Industry's Early Involvement with Sustainability

There is no doubt that this involvement with the BRE prompted the brick industry to take an interest in sustainability and in 2000 a Sustainability Working Group was set up. The Group was tasked with investigating ways that the industry could respond to the challenge of proving sustainability for the product to ensure that it did not suffer unduly in the market place. It was also to consider how the industry should respond to the challenge issued by the Government in its Sustainable Development Strategy of 1999 in which Trade Associations were invited to develop sector sustainability strategies that would provide a framework for sectors to assess their economic, environmental and social performance; identify areas for improvement in the light of future opportunities and threats; set targets and implement action plans to bring about their improvement and then to report back on the process to stakeholders.

In order to progress this the Government set up a Pioneers Group in which a number of Trade Associations were given the opportunity to develop a sustainability strategy for their own sector in conjunction with other associations. The Brick Industry accepted the offer and embarked on the Sustainability Trail – a journey that has already had twists and turns and certainly shows no sign of finishing.

The Government was clear that Sustainable Development was about delivering a better quality of life for everyone now, and for generations to come. The four key objectives of social progress, protection of the environment, prudent use of natural resources and maintenance of high and stable levels of economic growth and employment were seen as central to the enterprise. The brick industry refined the definition of sustainability into "the responsible use of resources be they human, physical, or financial". A number of measurable objectives were to be declared and responsibility shown by the willingness to report annually on progress towards the objective. These Key Performance Indicators were also to be reviewed annually so the activity of the industry was kept under scrutiny.

The industry declared 17 objectives; 4 under social progress, 4 under effective protection of the environment, 5 under the prudent use of natural resources, and 3 under the maintenance of high unstable levels of economic growth and employment. The spread across the 4 fields is important as it demonstrates that all aspects of sustainability are measured. As the story develops this broad spread is gradually focused into a narrow band that is concerned primarily with environmental aspects. One reason for this must be that this is where BRE started. Once you have developed a technique for producing an environmental profile and are using it as part of an assessment process then there is a temptation to continue working in that way. Another reason is that the UK Government has made commitments to reduce carbon emissions and inevitably efforts are intensified to achieve those targets. If they can be under the heading of "Sustainability" so much the better, even if it is in a restricted area of the concept.

However, the brick industry made its case across all aspects of sustainability. Probably the strongest point is that manufacturing is dispersed around the UK in factories located near the clay deposits. Hence it is possible to specify a material that is made locally reinforcing the aesthetic impact of buildings by using local materials and reducing delivery costs. The manufacturing process has received massive investment since 1990. The industry was well aware of the need to reduce energy costs long before sustainability became fashionable. Alternative sources of energy have been investigated and there are now factories fuelled by the methane gas taken off the land-fill that has been encased in exhausted clay pits. Although the industry is cited as an "intensive energy user" the reality is that the industry only consumes 1.5% of the total energy consumed by the UK manufacturing industry. The UK Government, working with the EU, now issues increasingly stringent targets for the reduction of energy use for individual industries. The brick industry has always met the targets imposed.

Beyond the factory gate brick contributes to the sustainability of the structure of which it is a part. It is extremely durable with little maintenance and will provide an attractive façade to a building almost indefinitely. It fulfils a variety of roles in building technology in providing physical support, security, protection from sound and fire, weather resistance and an appearance that is enhanced by age. Buildings built in masonry are easy to alter and adapt. We have examples of brick buildings entering a third or fourth life because they have been altered to accommodate new functions; the ability to change means that the initial investment is enhanced many times over.

Looking ahead, and considering the threat of global warming, it has been shown that as temperatures rise the heavy masonry structure with its high thermal mass will be able to moderate the effects of high temperature without recourse to air-conditioning. This is likely to be an important asset when the "future-proofing" of buildings is considered.

The Sustainability Strategy produced by the Brick Industry rehearsed the arguments outlined above. It was one of the first strategies to be produced by a sector working with the Pioneers Group but the context in which it had been produced was changing – something those of us concerned with sustainability are learning to get used to.

4. UK Building Regulations

Building Regulations in the United Kingdom have a long history that can be traced back to 1666 and the aftermath of the Great Fire of London. More recently the Government has used the Regulations to control all aspects of building, and especially the insulation of buildings through "Part L" of the Regulations. The idea being that if you increase the insulation in a building you reduce the amount of energy required to heat it. This simple idea had been refined by the introduction of SAP or Standard Assessment Procedure. This is a method of analysis that looks at not only the insulation of a building but also at solar gain, heat production, siting and orientation to achieve a better understanding of how each aspect contributed to the thermal efficiency of the building. It was a cumbersome tool but it was significant because it was the first time that the Regulations had acknowledged that there are many inter-dependent factors that contribute to the performance of the building. Basic insulation standards under Part L were also raised but as far as brick was concerned the insulation material could still be accommodated in the 75 – 100 mm cavity brick / cavity block wall or within the framing of a lightweight frame with brick as an external skin.

However, when Part L values were reviewed in 2001 it was made clear by the construction industry that the regular increase in performance standards was difficult to handle. What was required was a longer-term prediction of how values might move with a number of milestones along the way that gave a programme for implementation. This suggestion was to become part of the strategy behind the Code for Sustainable Homes.

5. The Building Industry and the Drive for Improved Efficiency

The efficiency of the building industry had been addressed in a number of reports that had been compiled in the 1990s. The Latham Report 1994 and the Egan Report 1998 proposed a number of measures to improve the situation but a common theme was that by removing construction from the site into the factory there would be worthwhile benefits. It was claimed that factory production would give greater accuracy, guarantee performance standards, and reduce construction waste. Site assembly rather than site production would give faster build times with predictable performance and fewer defects. This halcyon vision had been a reality in the 1960s when, in an effort to solve the housing crisis, the Government had backed the introduction of factory-produced site-assembled building systems. The point that we are still paying the price of this venture was ignored. There was faith that a more experienced industry would be able to make it work the second time around.

The prospect of “modern methods of construction” was seen as an opportunity not only to increase the number of dwellings built per year but also to ensure that they were technically superior to any mass housing produced previously. This was good news for the Government who were anxious to increase the rate of build from around 180,000 to 250,00 per year and also to ensure these homes were technically sophisticated.

6. The Code for Sustainable Homes

The upshot of all this activity was the publication in December 2006 of the “Code for Sustainable Homes”. This document claimed to herald a step change in sustainable home-building practice. Based on the proposition that in 2004 more than a quarter of the Uk’s carbon dioxide emissions came from the energy used to heat, light, and run our homes it concluded that it is vital to ensure that homes are built in a way that reduces the use of energy and harmful emissions. In addition to the reduction of CO_2 the Code also suggested standards for the use of water within the home and the collection of surface water, the promotion of health and well-being and the reduction of waste and pollution from materials as well as the sustainability of the materials themselves. Code compliance is voluntary but it is likely that assessment under the Code standards will be mandatory in the future. The key point is that the Code sets out six levels of performance so that industry is able to understand how the standards will change with time. These code levels each show an improvement in “carbon performance” when compared with the Target Emission Rate (TER) defined by the 2006 Building Regulations Standards.

- Level 1 shows a 10% improvement over 2006 TER
- Level 2 shows an 18% improvement over 2006 TER
- Level 3 shows a 25% improvement over 2006 TER
- Level 4 shows a 44% improvement over 2006 TER
- Level 5 shows a 100% improvement over 2006 TER
- Level 6 shows a “zero carbon” improvement over 2006 TER

When the “carbon performance” for a building is determined a number of credits are assigned to the building. Credits are also scored for:

- The environmental profile of materials used
- The predicted water consumption per person per day
- Means of controlling surface water run-off
- Facilities provided for minimising waste during construction and recycling / composting waste during habitation
- The limitation of the global warming potential of insulants and emissions of nitrous oxide from space and water heating systems
- The standard of daylight and sound insulation
- The quality of a management system for the building itself and the ecology around it

Each of the headings has a number of sub-headings that are also potential credit earners. The credits are converted to points by a multiplier that is different for each category and the code level is determined by the number of points achieved.

This system has much to commend it. It provides industry with a clear development path, it is flexible in that there is no one way of achieving a particular level, it considers the whole house and the way in which it is used, it is voluntary and therefore housing developers are able to gain market advantage by complying with higher code levels. It has stimulated debate and activity in an industry that has realised if the Government is to stick to its intention of requiring all new private sector homes to be Code level 3 by 2010, Code level 4 by 2013, and Code level 6 – zero carbon by 2016 there is no time to be lost.

Now that the dust has settled it has become clear that level 3 can be achieved by improving current standards, level 4 will require some innovation, especially with regard to renewable energy, and level 5 and 6 require some major shifts in the way energy is supplied to, and used, in the house. It appears that once the fabric of the house is able to achieve level 4, the higher levels will be achieved through other means.

7. Implications of the Code

A number of “demonstration” homes have been constructed at the BRE’s Innovation Park. Initially it was considered that conventional brick and block construction would not be able to provide the air-tightness required by the higher levels of the Code but this perception has proved false and it is the framed structures that are struggling to achieve the standards.

The debate about standards and methods of construction is vitally important to the masonry industry in general and the brick industry in particular. If there is wholehearted acceptance that the only way to solve the problems of constructing these homes is by lightweight frameworks manufactured off-site then its likely the designer will use alternative material on the external face. There is a temptation to go down that road, especially as it seems to offer the easy “quick-fix” solution.

However, there are also strong arguments, not just for the use of a brick / block solution, but also for a serious research programme to investigate the development of what is called “traditional” construction.

There are 180,000 homes built each year in England, Wales and N. Ireland. Of these some 15% are made from lightweight framing – so “traditional” construction is providing the bulk of homes. What is needed is a thorough examination of the “traditional package “. Greater efficiency could be achieved by rationalising the dimensions of brickwork and components, investigating ways of incorporating standard units, such as pre-fabricated floors and service pods, the use of wiring looms and prefabricated plumbing. There is also room for the development of alternative methods of insulation. Currently the solution to increasing the ‘U’ value of a wall is seen as making it wider to allow more insulation to be inserted. There is potential in vacuum insulation panels that would satisfy the most stringent code level in a thickness of 30mm. It would be a neat trick if the insulation became a positive element around which the building is built, rather than a void that is simply filled.

The assembly of brick and block will also need to be carefully considered. There are sufficient bricklayers to cope with the predicted increase in the provision of homes but the higher standards of air-tightness will demand that the work is carried out with greater care and attention to detail. There are also new techniques for providing brick / block walls. The “Hanson House” on the BRE Innovation Park has cavity walls assembled in a factory using glued mortar and delivered to site in large panels 2,400 x 5,000 mm. Thus combining the timeless qualities of brick with off-site techniques.

When the brick industry produced the original Sustainability Strategy, no one imagined that within a few years we would be involved in a project like the Code for Sustainable Homes. The irony is that in the Code the only aspect of sustainability that is considered in the material section is that of “Environmental Sustainability”. However, lurking in the Code is the possibility of points for Responsible Sourcing of Materials. Current thinking between BRE and the Trade Associations is that this is an area where credit will be obtained for an all-round approach to sustainability. Once more we will have the opportunity to demonstrate that the brick industry promotes “the responsible use of resources be they human, physical or financial”.

- END -

3048 words

INTELLIGENT CONTROL FOR OPTIMIZING OCCUPANT COMFORT AND ENERGY CONSUMPTION IN BUILDING ROOM

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Keywords: fuzzy logic, energy saving, occupant comfort, intelligent blinds

Summary

The paper introduces the intelligent way of controlling light and cooling sources in the office to provide comfort for the room occupant using fuzzy control theory. The system is particular useful for the hot climate countries, such as Malaysia. The system under the control consists of motorized window blinds to monitor and control the amount of light and heat admitted into the room, the split air-conditioning unit to control the low temperature source inside of the room, and dimming device to control brightness of electrical bulb. The joint intelligent control of all three subsystems provides two goals simultaneously, comfort for the room occupant as well as minimum energy required for operation of internal light and cooling devices. The paper for the first time analyses and offers a solution for the problem of energy savings through optimizing simultaneously the energy consumption by electric light and air-conditioning devices. In the mean time the system autonomously provides comfort for the room occupant by offering an appropriate level of light and temperature.

1. Introduction

The fenestration system of a commercial building drives much of the building's energy consumption for heating, ventilating, air-conditioning and lighting. When exterior shading is inadequate, building occupants must rely on interior shading devices such as venetian blinds and shades for controlling the amount of light and heat that enters their offices. Even though such devices can make conditions more comfortable for building occupants, previous research has shown that venetian blinds are adjusted infrequently as indicated by Rubin (1978), Rea (1984), IESNA (2000), and that blinds and shades are usually set for worse-case conditions as indicated by IESNA (1999), Bordass (2001). When used correctly, shading devices can greatly reduce the amount of direct sunlight admitted into office space, substitute light with daylight, and thus reduce energy consumption. In order to achieve such energy-saving benefits from daylight, many fenestration systems with automated components integrated with daylight dimming systems have been developed. Most studies in building control were written by the architectural and natural environment community, such as Foster et al. (2001), Guillemin (2003), Lee et al. (1998) the primary focus was on energy- efficiency while user comfort was only subsidiary constrain in finding the optimal device states. Guillemin, for example, uses fuzzy rules to incorporate expert knowledge. Adaptation to user wishes is provided through tuning the fuzzy membership function by a genetic algorithm. Guillemin showed that energy savings of up to 20% compared to a manual system could be achieved. Hagras et al. (2003) focuses primarily on user-comfort. They also use fuzzy logic, but adaptation is done through automatic generation rules. They use a supervised learning algorithm that gets its input by interaction with the user, called *machine-user dialog,* but do not describe it explicitly. Rutishauser et al (2004) took a similar approach. The difference is that they use an unsupervised learning algorithm that does not require a special user interface. The training of the controller is done through normal interaction with building devices.

Al-Sudani et al. (2005) has used a simple approach to build the automated window blind system. They use several light dependent resistors to detect whether it is day or night and detect the position of the sun.

These resistors then send respective signals to the microprocessor and it, in turn, operate the servomotors to close, open or adjust the angle of blinds. The system also activates a dimmer to reduce the used internal light to save the energy. This method does not consider variation of internal temperature due to the blinds rotation. In more extensive research Trobec et al. (2005) have developed a system for managing the movable roller blind which is based on the alternative control approach. It contains two basic control loops for thermal and for lighting regulation. Each loop contains a cascade control with a fuzzy and conventional PID controller to provide a user set values of light and temperature. However these loops work independently .and the illumination control loop is given a priority. The roller blind is managed with illumination loop first and when the desired internal illumination level is achieved, the thermal loop takes over the control of the roller positioning. Within the illumination tolerance range (2 %) the thermal loop pushes the blinds as much as possible to follow the set-point temperature profile. Thus there is an error between the set-point temperature and actual temperature as well. This work does not consider the possibility of variation of internal temperature by adjusting the air-conditioning unit. The Center for Building Performance and Diagnosis (CBPD) Khee Poh et al. (2005) has developed intelligent workspace tools for the entire building data management. The center has also developed some strategies to support individual control over personal work space environment. The system is complex and expensive. It may be effective if implemented at earlier stages of building construction and utilities installation.

Present paper describes one goal approach, i.e. the monitoring internal temperature and the lighting in the separate office space through one single fuzzy controller which is able not only to control the blinds opening angle for light admission but also adjust the cooling power of split air-conditioning unit to achieve an acceptable level of temperature for occupants comfort.

2. System Modeling and Components Setup

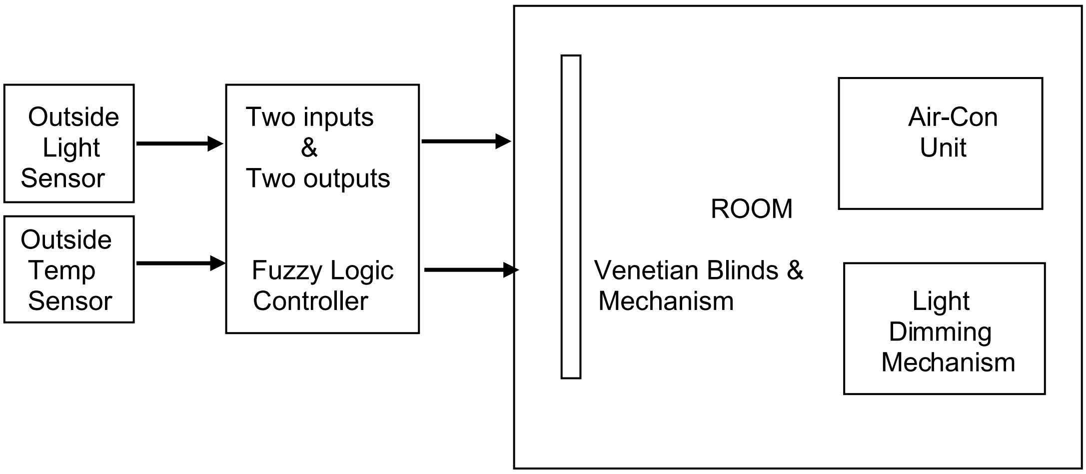


Figure 1 System Setup

This work is based on simulation of office room conditions and some assumptions are made. Figure 1 shows basic system components and their connections. The core of the system is fuzzy controller which receives real time analog data from two different sensors located outside of the room: one measures the amount of daylight and signals about night; the second provides outdoor temperature values. The fuzzy controller intelligently estimates the amount of light and temperature right outside of the room and outputs two simultaneous driving signals: one to the motors of the venetian blinds and light dimming mechanism; the second to the air conditioning unit. The comfort of the room occupant is provided by the fuzzy controller and expressed in the form of fuzzy sets and membership functions of input values as well as fuzzy logic rules of fuzzy inference system that forms the required outputs. This approach does not maintain approximately user selected values for the internal temperature or light as it was described by Trobec et al. (2005). Instead the system suggests by itself the range of acceptable room temperatures during the day by intelligently manipulating power of the air-conditioner and closing of the blinds. It also compensates for light shortage in the room due to the blinds closing by reducing the dimming of internal light in proportion to the blinds closing. To simulate the entire light and temperature management system and define the anticipated internal temperature as a function of a specific set of input variables a simplified mathematical model of heat conduction through the window glass and blinds material as well as heat convection form the window to the air conditioning unit, low temperature source, has been developed.

2.1 Mathematical Model of Room Temperature Distribution

A simplified model of heat transfer from the source of high temperature outside of the room down to the source of low temperature inside of the room can be represented in three different modes of operation:

1. Blinds are fully opened
2. Blinds are fully closed
3. Blinds are partially closed

In the first mode of operation, as shown in Figure 2a, the heat transfer and temperature distribution is due to conduction via the window glass and heat convection inside of the room. In the second mode of operation, as shown in Figure 2b, the heat transfer and temperature distribution is due to conduction through the window glass and blinds and then heat convection inside of the room. In the third mode of operation, as shown in Figure 2c, the heat transfer is combination of two conduction processes: the first conduction is through the glass only for uncovered areas of window and the second conduction is through both, the glass and blinds covering the glass. It generates the zone of mixed temperatures right after the blinds. The thermal system under the consideration is assumed to be a static one in which heat capacity of the materials involved into the process is not considered as well as time of the process is long enough to ignore the rate of change of temperature with time.

For the first mode of operation (Figure 2a) the equation of static temperature distribution can be derived by equating the heat flow through the glass and the convection through the air [13], i.e.

$$\frac{k_g \cdot A}{L_g}(T_{out} - T_g) = h \cdot A(T_g - T_a) \tag{1}$$

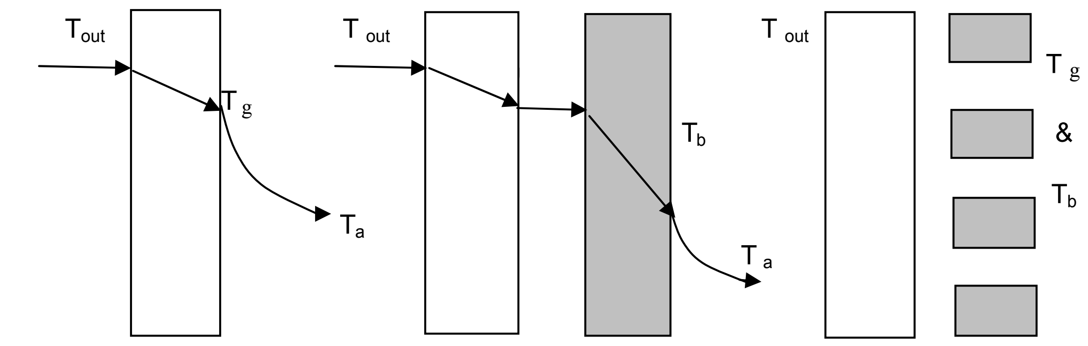
where: k_g is the thermal conductivity of glass , 0.81 W/(m· °K)
h is the free air convection coefficient, 18.0 W/(m^2· °C)
A is the active areas of widow glass
L_g is the thickness of the glass, 6· 10^{-3} m
T_{out} is the outer surface temperature on the glass
T_g is the inner surface temperature on the glass
T_a is the temperature of the free stream air at some distance away from the glass surface (temperature at air-conditioning unit at the other end of the room)

The equation (1) yields the following expression for the maximum possible inner surface temperature on the glass in case the blinds are fully opened:

$$T_{\max} = \frac{T_{out}(k_g / L_g) + T_a \cdot h}{(k_g / L_g + h)} \tag{2}$$

Substituting the numerical values of k_g, h, and L_g suggested for the simulation studies the equation (2) reduces to:

$$T_{\max} = \frac{T_{out}(15) + T_a(2)}{17} \tag{3}$$



a) Glass

b) Glass and Blinds

c) Glass and partially closed blinds

Figure 2 Heat losses through the window glass and blinds

For the second mode of operation (Figure 2b) the equation of static temperature distribution can be derived by equating, firstly, heat flow through the glass and fully closed blinds and, secondly, the heat flow through the blinds and the convection through the air [13] i.e.

$$\frac{k_g \cdot A}{L_g}(T_{out} - T_g) = \frac{k_b \cdot A}{L_b} \cdot (T_g - T_b) \tag{4}$$

$$\frac{k_b \cdot A}{L_b}(T_g - T_b) = h \cdot A(T_b - T_a) \tag{5}$$

where: k_b is the thermal conductivity of blind material (linoleum) , 0.081 W/(m· °K)
A is the active areas of widow glass and the blinds
L_b is the thickness of the glass, 6· 10^{-3} m
T_{out} is the outer surface temperature on the glass
T_g is the inner surface temperature on the glass
T_b is the inner surface temperature on the blinds
T_a is the temperature of the free stream air at some distance away from the blinds surface (temperature at air-conditioning unit)

Excluding T_g from two equations (4) and (5) yields the following expression for the minimum possible inner surface temperature on the blinds when the they are fully closed:

$$T_{\min} = \frac{T_{out}\left(\frac{K_g \cdot K_b}{L_g \cdot L_b}\right) + T_a\left(\frac{K_g}{L_b} + \frac{K_b}{L_b}\right) \cdot h}{\frac{K_g \cdot K_b}{L_g \cdot L_b} + \left(\frac{K_g}{L_g} + \frac{K_b}{L_b}\right) \cdot h} \tag{6}$$

Substituting the numerical values of k_g, k_b, h, L_g, and L_b suggested for the simulation studies the equation (2) reduces to:

$$T_{\min} = \frac{T_{out}(7.5) + T_a(11)}{18.5} \quad (7)$$

In the third mode of operation (Figure 2c) the temperature on the inner surface of the widow is assumed to be somewhere between two extreme temperatures, T_{min} and T_{maz}. If P is the percentage of blinds opening then the actual temperature at the inner window surface can be approximated as a composition of two extreme temperatures and can be represented by the following expression:

$$T_w = T_{min} + P \cdot (T_{max} - T_{min}) \quad (8)$$

In the expression (8) P can vary from 0 (fully closed blinds to 1 (fully opened blinds). It means that T_w is directly proportional to the percentage of blinds opening.

For the purpose of temperature and light controller simulation the check point for temperature control is selected somewhat away from the inner window surface where the room occupant is assumed to be physically located. The temperature at this point should be somewhere between T_w and T_a due to further losses of heat in the room itself. Actual drop of temperature is a non-linear function of distance from the window. To simplify the analysis the drop of temperature is assumed to be a linear function of distance from the window and to minimize the error we assume only 20 % of drop of temperature from T_w down to T_a, i.e. consider a point of interest to be closer to the window (T_w) rather than to the air-conditioning unit at the end of the room (T_a). The following expression takes into the account the temperature calculation for the point of interest T_p and it is used as output temperature for the process simulation:

$$T_p = T_w - 0.2 \cdot (T_w - T_a) \quad (9)$$

2.2 Fuzzy Logic Controller Design

The fuzzy controller receives light and temperature signals, estimates them carefully based on selected fuzzy sets and membership functions of two inputs, passes it through fuzzy inference system where the process of mapping from a given input to an output takes place, and finally by aggregating and defuzzifying all outputs the controller generates two appropriate signals to control indoor devices. The occupant comfort, i.e. acceptable level of internal light and heat is controlled by the controller's fuzzy logic rules. General components of the designed fuzzy logic controller are shown in Figure 3.

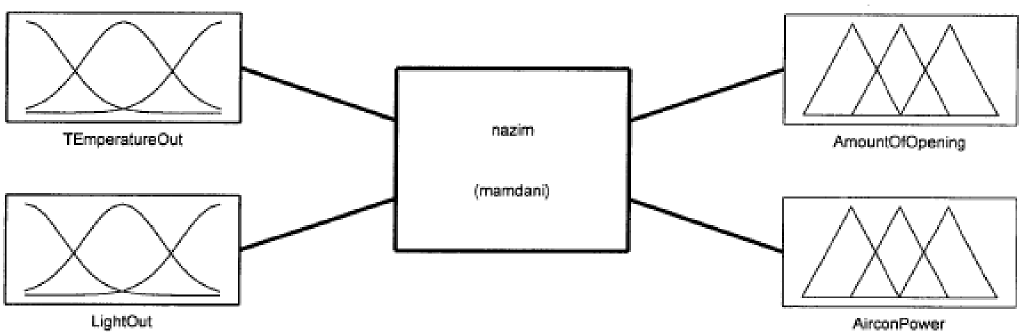


Figure 3 Components of Fuzzy Controller

The fuzzy sets and membership functions of the input 'Temperature Out' is shown in Figure 4. The range for the output temperature has been selected to be from 20°C to 50°C Similarly membership functions for the input 'Light Out' and two outputs 'Amount of Opening' and 'Air-Con Power' have been selected to be either trapezoidal or triangular shapes. The 'Air-Con Power' is set to vary temperature from 10°C (high power) to 25°C (lower power) in the fuzzy controller.

Fuzzy inference system of the designed fuzzy controller, i.e. the process of formulating the mapping from a given input to an output using fuzzy logic is based on Mamdani method. In general, it consists of fuzzifying current inputs by determining the degree to which they belong to each of the appropriate fuzzy sets via membership functions; applying fuzzy operator AND for each rule to obtain one number that represents the result for that rule; applying implication method for each rule to obtain an appropriate output fuzzy set reshaped according to the number generated by previous step; aggregate all outputs from all the rules, i.e. to obtain the list of truncated output functions and their single aggregate fuzzy set; applying defuzzification process to extract a single number as an output from the aggregate fuzzy set . The single number is the location of centroid of area under the aggregate fuzzy set shape. The fuzzy logic rules forms a basis for the designed fuzzy inference system and defines linguistically the degree of human perception between the outside light and heat on one hand and the necessary amount of blinds opening and air-con power control on the other hand

The three-dimensional surface that shows the interrelation between the two inputs and one of the outputs is shown in Figure 5. It shows that the higher percentage of blinds opening (close to 0) falls on the regions where the outside light is relatively high (close to 1) and the outside temperature is relatively low (close to 20 °C).

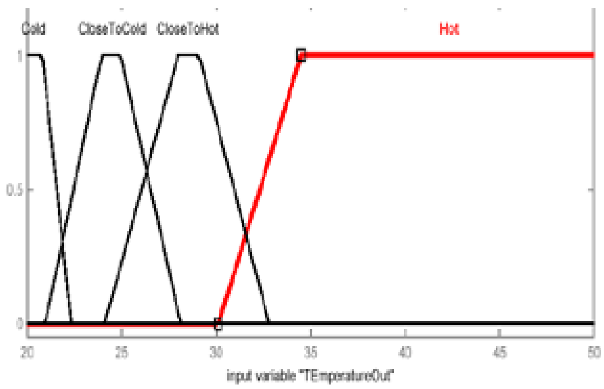


Figure 4 Membership functions of the input Temperature Out

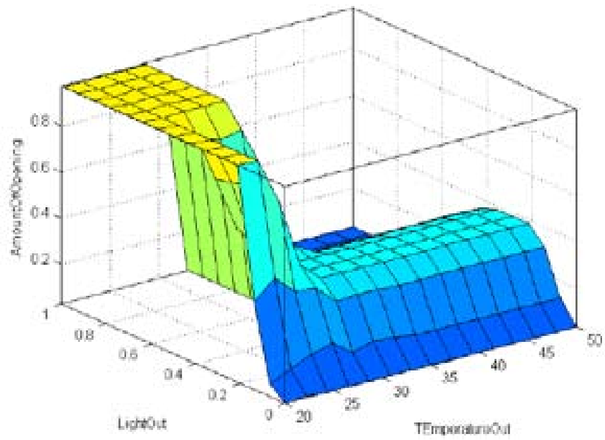


Figure 5 Fuzzy surface

3. System simulation using MATLAB Simulink

The entire block-diagram of the simulation is shown in Figure 7. The two inputs to the fuzzy controller 'Temperature Out' and 'Light Out' (Figure 6) are presented by trapezoidal function to approximate the change of outside temperature and light conditions during the day time. The ascending portion of the trapezoidal signal represents the rise of the light and temperature values from early morning till afternoon, and the descending portion of the signal represents the fall of that from late afternoon till full night. In the middle of the day both signals from outside of the room remain constant and high in values. The simulation is conducted for the duration equivalent to 12 hours of day time. The output signals generated by the controller, i.e. fraction of blinds opening and required temperature at the air conditioning unit, are entered to the thermal processing potion in the simulation block diagram. This potion of block diagram simply executes all necessary thermal calculations using formulas (3), (7), (8), and (9). There are two types of outputs from this simulated system. The 'Tem Window Adjusted' output controls variation of temperature value at the point of interest in the room during the day. The 'Bulb Brightness' output controls variation of bulb power during the day from 0 to 1, where 0 means the bulb is off and 1 meant the bulb is at its maximum brightness. The increase in the bulb power is inversely proportional to the blinds opening. The simulation was conducted for two distinct weather conditions:

i) Sunny day, when the temperature rises in the simulation experiment from 20°C (night) to 50°C (noon) and the brightness of daylight rises from 0 (night) to 1 (noon)
ii) Cloudy day, when the temperature rises in the simulation experiment form 20°C (night) to 32°C (noon) and the brightness of daylight rises from 0 (night) to 0.75 (noon)

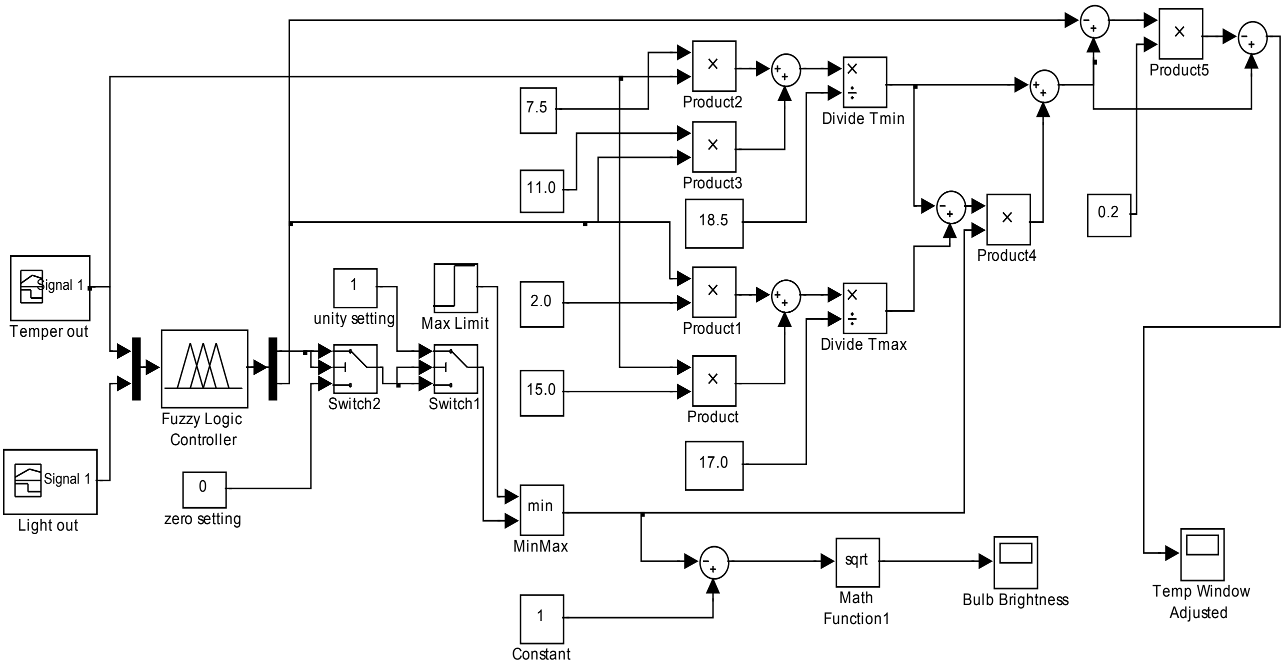
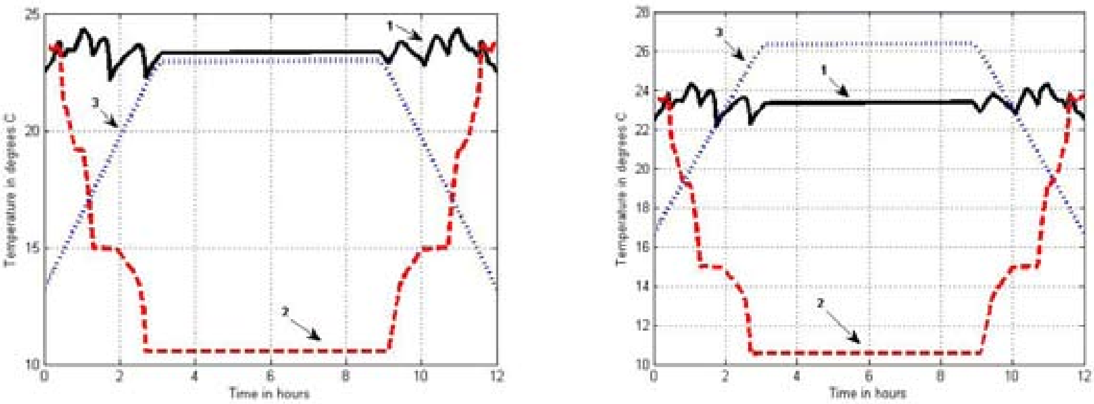


Figure 6 Simulink block diagram



(a) (b)

Figure 7 Results of temperature control simulation for hot day

For the first weather condition the temperature simulation results are shown in Figures 7a and 7b. The first curve in both graphs demonstrates the variation of temperature at the point of interest due to the controller action. The second curve demonstrates the variation of temperature at the air-conditioning unit due to the controller action during the day. The third curve is used to compare it with the first curve. It demonstrates possible variation of temperature at the point of interest in case the controller is disabled, the blinds are fully closed and the air-conditioning unit set to produce one temperature of 10°C in Figure 7a and 15°C in Figure 7b. The controller demonstrates its advantage by maintaining one single value of the temperature (around 23°C) regardless of temperature variation outside of the room. In contrast, in case of room without the controller the temperature during morning and late afternoon time is much lower than comfort level (between 14°C and 22°C) as shown in Figure 7a and it rises above the comfort level (26.5°C) during the noon time as shown in Figure 7b. The second curve in both figures shows the energy savings due to variation of air-conditioning unit temperature by the controller especially during morning and late afternoon periods. Similar results have been obtained for the cloudy day simulation, i.e. in the second case, as is shown in Figure 8. The third curve in both figures demonstrates possible variation of temperature at the point of interest for the case when the controller is disabled, the blinds are fully closed and the air-conditioning unit set to constant temperature of 10°C (first figure) and 15°C (second figure). These figures indicate that in case of temperature control mode the room temperature still remains stable and it is about the same value of 23°C. However, for the uncontrolled conditions the room temperature drops significantly below the comfort level (curve 3).

Figure 9 shows the variation of power consumption by the light bulb in the room during the simulated sunny and cloudy days. The controller successfully manages to admit day light into the room not only during the morning and late afternoon periods for hot and sunny day (Fig. 9a) but during the noon time for cloudy day (Fig. 9b). In both conditions the temperature automatically sustained at the occupant's comfort level.

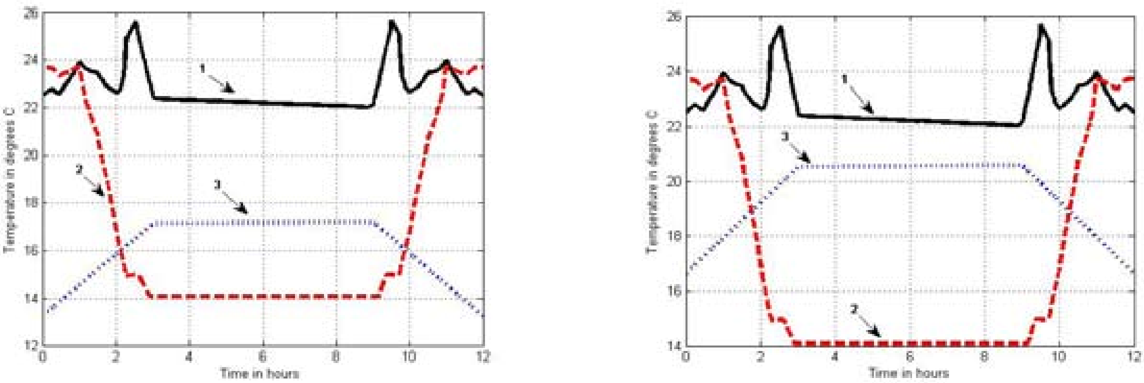
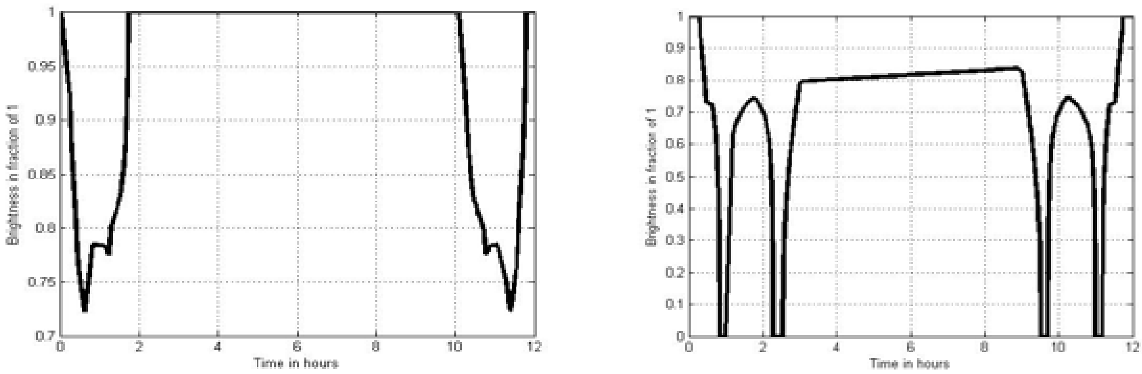


Figure 8 Results of temperature control simulation for cloudy day



(a) (b)

Figure 9 Results of bulb control simulation for hot and cloudy days

Finally, Figure 10 demonstrates the ability of the system to manage internal temperature and light for changing weather conditions during the day. The temperature variation outside is similar to the third curve in Figure 10. That means the system was tested against sunny day at the beginning and end of the day and against cloudy condition in the middle of the day when the intensity of light and heat has been diminished by the clouds. As the figure shows the system could maintain the temperature at about the same level inside of the room and in the meantime has reduced the use of bulb light by opening the blinds during the midday.

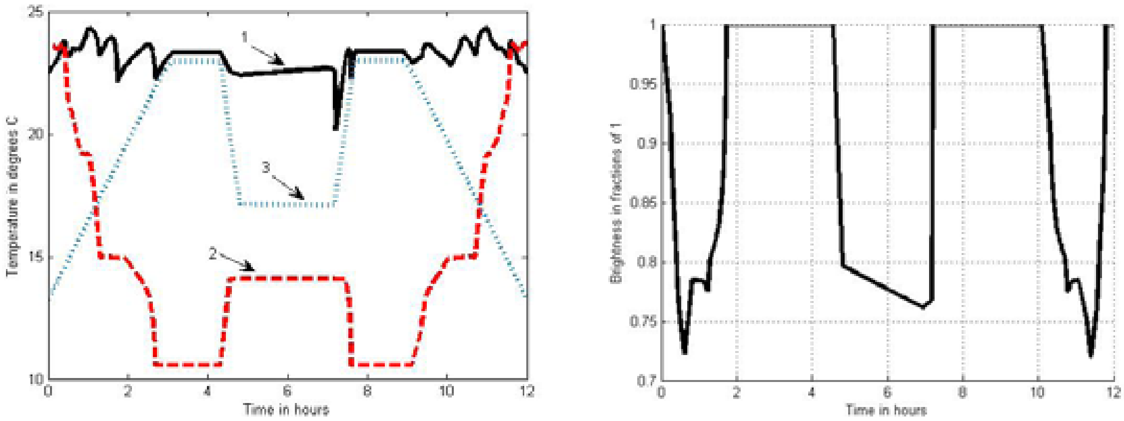


Figure 10 Results of temperature and bulb control simulations for combined hot and cloudy day

4. Conclusion

The paper describes the new concept of temperature and light control in a room. It is able to provide temperature and light comfort for the occupant as well as energy savings for the optimal building energy management. The core of the system is a fuzzy controller that provides comfort and energy savings through properly selected fuzzy rules in the fuzzy inference system. This system by itself generates and successfully maintains the acceptable levels of temperature and light in the room by manipulating with window blinds, light dimming mechanism, and temperature of the air-conditioning unit in response to changing weather conditions outside of the room. The mathematical simulation of the system in a hypothetical room for two distinct weather conditions (sunny and cloudy) obviously demonstrates advantage of the designed system as compared to non-controlled or manually controlled room conditions. Energy savings are accumulated from the intelligent variation of energy consumption by the air-conditioning unit and the light bulb during the day.

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STUDY ON THE MOISTURE BUFFERING EFFECT AND ENERGY IMPACT OF INTERIOR MATERIALS IN TAIWAN

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Keywords: moisture buffering, passive control, numerical simulation, indoor air quality, energy consumption

Summary

Taiwan is located in a sub-tropical climatic region. The hot and humid climate in Taiwan provides a fertile environment for microbe contamination sources such as fungi and mold, and leads to significant microbial pollution. A moisture buffering effect that provides passive moisture control by using interior materials with large internal surface area was proposed as an effective way to alleviate such dampness problems and improve IAQ (Indoor Air Quality). In this paper, numerical simulations including heat/moisture transportation inside the interior materials are carried out to evaluate the adsorption/desorption phenomenon quantitatively. Indoor air temperature, humidity and energy consumption analysis are carried out to study the moisture buffering effect and energy impact of interior materials in three major Taiwanese cities.

1. Introduction

Many indoor air pollutants have been extensively studied during the past decade. In recent years, issues concerning health problems related to dampness in buildings have been widely reported in Europe and America. Taiwan is in a sub-tropical climatic region. The mean annual relative humidity is over 75% in Taipei, Taichung and Kaohsiung, three major cities in Taiwan, with monthly average values for each month exceeding 70% (Central Weather Bureau of Taiwan). Dampness in buildings can lead to significant respiratory symptoms and damage to buildings. Indoor humidity can affect a building¡s energy consumption and its structure, as well as the occupants¡ comfort and health (Andrade, C. et al. 1999 and Bornehag, C.G. et al. 2004). In some related studies, a moisture buffer effect that provides passive moisture control (reductions in peak humidity levels outside the humidity comfort zone) using interior materials was proposed as an effective way to alleviate such dampness problems in humid climates (Hameury, S. 2005 and Osanyintola, O.F. et al. 2006). In this paper, numerical simulations including heat/moisture transportation inside the interior materials were carried out to evaluate the adsorption/desorption phenomenon quantitatively. Indoor air temperature, humidity and energy consumption analysis were carried to study the moisture buffering effect and energy impact of interior materials in the three main cities in Taiwan.

2. The Simulation Model and Boundary Conditions

2.1 The Simulation Object and Method

In this paper, a single room in a residential building was used as the simulation object. The room dimensions were 3.30 x 5.70 x 2.40 (meters) [L×W×H] (area: 18.81 m^2; volume: 45.144 m^3). Outdoor temperature and humidity were defined by typical annual weather data (typical meteorological years) for Taipei, Taichung and Kaohsiung cities in Taiwan (Lin, H.T. et al. 2005). Table 1 shows the boundary conditions and physical properties of the interior materials. The room was assumed to be occupied only at night (20:00 ~ 08:00), heat and moisture generated indoors were set as 203 W and 160 g/h, which included sensible and latent heat generated from two occupants and a sensible heat load for lighting. During the day (08:00 ~ 20:00), the

Table 1 Boundary Conditions and Physical Properties of Interior Materials

Boundary Conditions			
Room dimensions	L 3.30m × W 5.70m × H 2.40m (Area: 18.81m^2, Volume: 45.144m^3)		
Ventilation conditions	Daytime (08:00~20:00): 22.57m^3/h (ACH=0.5 times/h) Nighttime (20:00~08:00): (ACH=3 times/h)		
Mesh division	20 equal portions (Material thickness: 20 mm)		
Heat transfer coefficient of surface	9.3 W/m^2/K	Difference scheme	Crank-Nicolson
Mass transfer coefficient of surface	1.26 x 10^{-2} kg/m^2/s/(kg/kg)	Time step	1 second
Air-conditioning system	No heating. Cooling room air to 26°C when room temperature exceeds 26°C at night.		

Physical Properties of Interior Materials		
Material	Plywood	Gypsum Board
Net density (kg/m^3)	600	680
Specific heat (J/kg/K)	1,300	870
Thermal conductivity (W/m/K)	0.15	0.24
Porosity (m^3/m^3)	0.57	0.68
Vapor conductivity (kg/m/s/(kg/kg))	4.355 x 10^{-6}	1.03 x 10^{-5}
κ (kg/m^3)	Curve approximation (Figure)	
v (kg/m^3/K)	3.56	0.618

room was assumed to be unoccupied, thus no heat or moisture were generated indoors. An air-exchange rate of 3 (times/h) is used at night, and 0.5 (times/h) during the day.

A program written by the authors based on Finite Difference Method (FDM) was used, and the validity of the program was verified in a benchmark test performed by the Architectural Institute of Japan (AIJ). In the simulation, both gypsum and plywood with a thickness of 20 mm and area of 18.81 m^2 were considered as the interior material. The simulation cases carried out are shown in Table 2, which includes weather data for the three cities and three kinds of interior surface (without material, gypsum board and plywood).

Note that in this paper, the main issue is to study the affect of the interior materials, thus heat transmission via the outer walls was not taken into account at this stage. Therefore, the wall surface of the room was defined as completely insulated in terms of heat and humidity except for the adsorption/desorption of the material surface.

2.2 Diffusive and Adsorptive Transportation in Material

Heat and vapor transportation inside the material was described using Matsumoto¡s model (Matsumoto, M. et al. 1990/91). This model assumes humidity under hygroscopic conditions. That means transportation of free or capillary water in the material can be ignored, and only vapor transfer and bound or hygroscopic water are taken into account. In the model, temperature T (K) and absolute humidity X have been chosen as the heat and vapor transport potentials. The governing equation for unsteady-state isothermal vapor transfer through a porous material is given as Fick¡s second law and the mass transfer caused by adsorption/desorption, as shown in Equation 1 in one dimension.

$$\Phi\rho_{air}\frac{\partial X}{\partial t}=\frac{\partial}{\partial x}\left(\lambda'_X\frac{\partial X}{\partial x}\right)-\left(\rho_{mat}\frac{\partial\theta}{\partial t}\right) \tag{1}$$

Where Φ (m^3/m^3) is the porosity of the material, λ'_X (kg/m/s/(kg/kg)) is the mass conductivity of vapor, ρ_{mat} (kg/m^3) is the net density of the material, and θ (kg/kg) is the liquid water content of the material.

The governing equation for heat transfer through a porous material layer is assumed to follow the second law of Fourier and the latent heat caused by adsorption/desorption, as shown in Equation 2.

$$C_{mat}\rho_{mat}\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right)+r\left(\rho_{mat}\frac{\partial\theta}{\partial t}\right) \tag{2}$$

Where $Cmat$ (J/kg/K) is the specific heat of the material, λ (kW/m/K) is the thermal conductivity of the material, and r (kJ/kg) is the latent heat of vapor.

To close the moisture transfer system of equations, the phase equilibrium equation for the material has to be given. According to the assumption that the rate of adsorption becomes equal to the rate of desorption and thus an equilibrium is achieved in the material, the relationship can be described by Equation 3,

$$\rho_{mat}\frac{\partial\theta}{\partial t}=\kappa\frac{\partial X}{\partial t}-\nu\frac{\partial T}{\partial t}\quad,(\kappa=\rho_{mat}\frac{\partial\theta}{\partial X},\nu=-\rho_{mat}\frac{\partial\theta}{\partial T}) \tag{3}$$

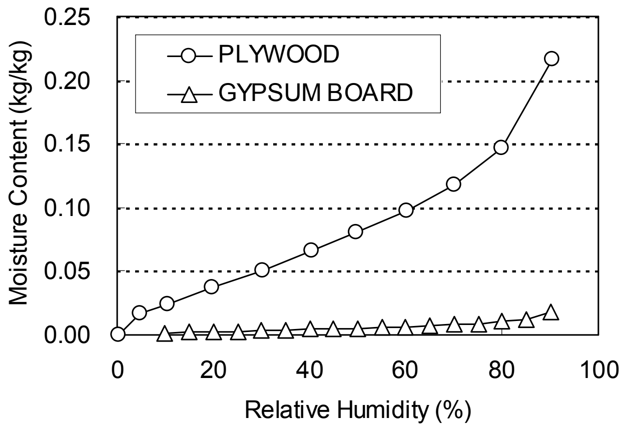

Figure 1 Equilibrium moisture content of materials at 23°C

Table 2 Setting of Simulation Cases

Case	Weather	Interior Material
Case TP0	Taipei City	None
Case TP1		Plywood
Case TP2		Gypsum Board
Case TC0	Taichung City	None
Case TC1		Plywood
Case TC2		Gypsum Board
Case KH0	Kaohsiung City	None
Case KH1		Plywood
Case KH2		Gypsum Board

and the term of adsorption/desorption can be given by the equilibrium moisture content at various temperatures and relative humidities (sorption isothermals) as shown in Figure 1. The equilibrium moisture content of gypsum board was measured by Kato et al. (2005), and that of plywood was determined from documentation (International Energy Agency, 2001).

2.3 Simulation of Room Temperature and Humidity

For room air simulation, a well-mixed indoor air (complete diffusion) is assumed to simplify the calculation. The heat and moisture transfer equations based on the law of conservation of enthalpy and mass for indoor air are written as:

$$VC_{air}\rho_{air}\frac{\partial T_{in}}{\partial t}=\sum_i \alpha^i A^i\left(T_S^i-T_{in}\right)+q_{OA}C_{air}\rho_{air}\left(T_{OA}-T_{in}\right)+q_{SA}C_{air}\rho_{air}\left(T_{SA}-T_{in}\right)+G_H \tag{4}$$

$$V\rho_{air}\frac{\partial X_{in}}{\partial t}=\sum_i \alpha'^i A^i\left(X_S^i-X_{in}\right)+q_{OA}\rho_{air}\left(X_{OA}-X_{in}\right)+q_{SA}\rho_{air}\left(X_{SA}-X_{in}\right)+G_X \tag{5}$$

Where V (m^3) is the room volume, C_{air} (J/kg/K) is the specific heat of the room air, ρ_{air} (kg/m^3) is the density of the room air, T_{in} (K) is the room temperature, α (W/m^2/K) is the heat transfer coefficient of the material surface, A (m^2) is the area of the interior material, q (m^3/s) is the ventilation rate, G_H (W) is the heat generation rate, X_{in} (kg/kg) is the room absolute humidity, α' (W/m^2) is the vapor transfer coefficient of the material surface, G_X (kg/s) is the vapor generation rate, subscript i indicates a different inner surface, S indicates the material surface, OA indicates outdoor air, and SA indicates supply air from the air-conditioning system. The vapor and heat transfer between the surface of the material layer and ambient air is governed by the boundary conditions shown as

$$\lambda\frac{\partial T_{mat}}{\partial x}=\alpha\left(T_{in}-T_S\right) \tag{8}$$

$$\lambda'_X\frac{\partial X_{mat}}{\partial x}=\alpha'\left(X_{in}-X_S\right) \tag{9}$$

2.4 Simulation Model for Air-Conditioning System

Consider the behavior of the inhabitants of Taiwan, heating does not need to be considered in the air-conditioning model, and only cooling power is taken into account. The room is cooled to 26°C when occupied if the room temperature exceeds 26°C. If the temperature of the supply air drops below the dew point, resulting in condensation within the air-conditioning system, the relative humidity of the supply air is 100%, and moisture dehumidified is calculated from the difference of absolute humidity between inlet and outlet of air-conditioning system. A formula, (6-7), to calculate the dew point was brought forward in the work by Barenbrug (1974).

$$T_d=\frac{b\cdot f\left(T_C,RH\right)}{a-f\left(T_C,RH\right)} \tag{6}$$

Where $f\left(T_C,RH\right)=\dfrac{a\cdot T}{b+T}+\ln\left(RH\right)$ (7)

and a=17.27, b=237.7°C. T_C (°C) is temperature in degrees Celsius, RH is relative humidity, T_d (°C) is dew point temperature.

3. Simulation Results and Discussion

3.1 Moisture Buffering Effect

Figure 2-7 shows the variation in indoor temperature and relative humidity during Jun. 23~27. Compared with cases with no interior material, the relative humidity shows smaller variation range in cases using interior materials, and plywood shows better moisture buffering than gypsum board. On the other hand, those cases with interior materials show lower indoor air temperature and higher relative humidity than those without materials during the day. This is due to the sensible heat loss via the room air moisture desorption phenomenon, and the influence of the specific heat capacity of the materials.

3.2 Indoor Air Quality

Some studies indicated that fungi, mould and mites multiply more quickly in conditions of high relative humidity, and respiratory health problems increase in areas with high relative humidity (Ezeonu, I.M. et al. 1994, Lacey and J. et al. 1994). Figures 8~10 show the cumulative ratio of relative humidities of indoor air. The cumulative time is the sum of the calculation time. The cumulative ratio is calculated by the sum of the time (hours) when the indoor relative humidity is over 70%, 80% and 90%, divided by the sum of the simulation time (8,760 hours). Compared with those cases without interior materials, the cumulative ratio of relative humidities over 90% were reduced in cases with interior materials, but the cumulative ratio of relative humidities over 70% was higher in Taichung and Kaohsiung cities. This is also evidence of the adsorption and desorption process of the interior material.

3.3 Energy Impacts of Moisture Buffering

Some studies (Osanyintola, O.F. et al. 2006) have evaluated the energy impacts of moisture buffering in cold climates, but the effect in hot and humid climates has not been studied to the same degree. Figures 11~13 show the total heat removed by air-conditioning systems (heat load) in all cases. When using plywood as the interior material, the heat load is higher than that with no materials. On the other hand, the heat load is higher in Taipei, and lower in Taichung and Kaohsiung when using gypsum board as the interior material. Note that the energy impacts of hygrothermal materials are influenced by many parameters such as the air exchange rate and heat/moisture generation rate, and the effect requires further study for precise evaluation.

4. Conclusions

In this paper, the moisture buffering effect and energy impacts are studied by numerical simulation under hot and humid climates for three major cities in Taiwan. The conclusions are as follows:

(1) Compared to cases with no interior materials, the relative humidity demonstrates a smaller variation range in cases using interior materials, and plywood shows better moisture buffering than gypsum board.

(2) Compared to cases without interior material, the cumulative ratio of relative humidities over 90% were reduced in cases with interior material, but the cumulative ratio of relative humidities over 70% were higher in Taichung and Kaohsiung cities.

(3) When using plywood as the interior material, the heat load is higher than that with no materials. On the other hand, the heat load is higher in Taipei, and lower in Taichung and Kaohsiung when using gypsum board as the interior material.

Acknowledgements

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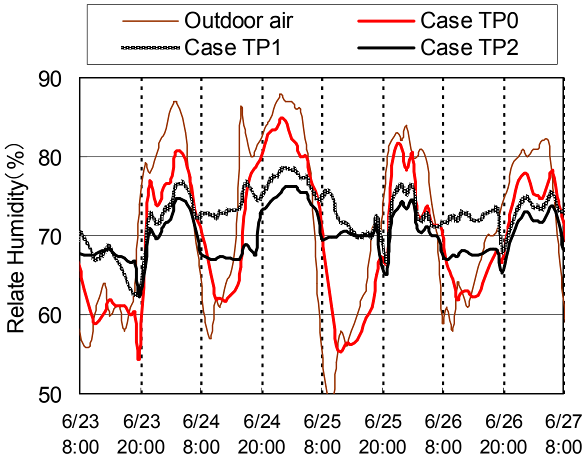

Figure 2 Indoor relative humidity for Case TP0-2 (Taipei)

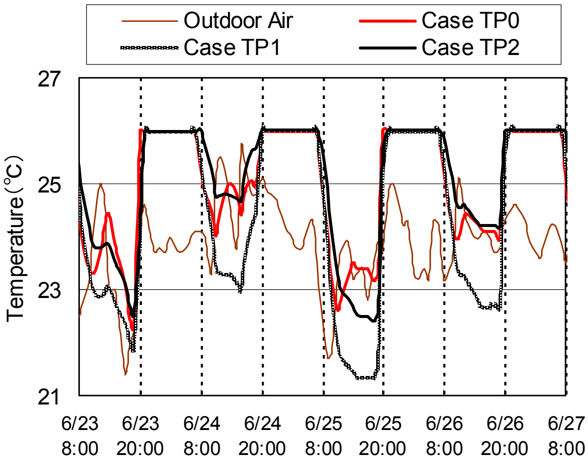

Figure 5 Indoor temperature for Case TP0-2 (Taipei)

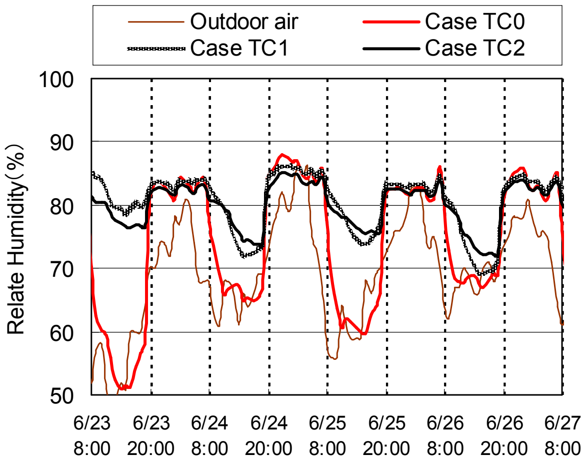

Figure 3 Indoor relative humidity for Case TC0-2 (Taichung)

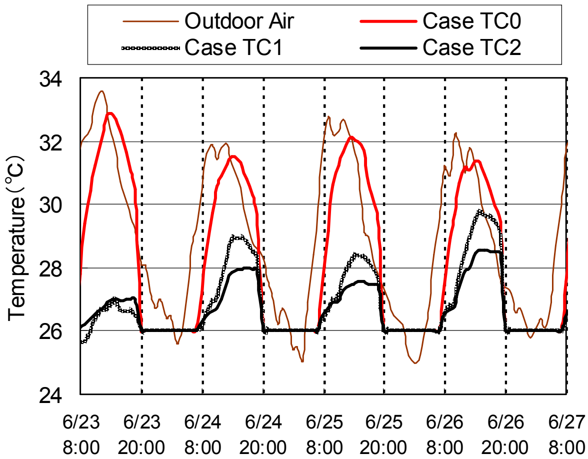

Figure 6 Indoor temperature for Case TP0-2 (Taichung)

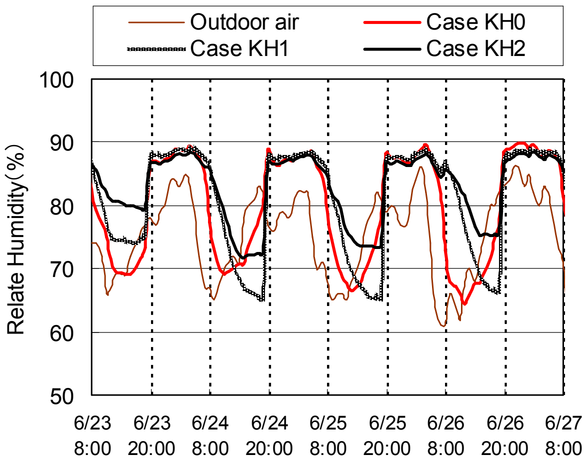

Figure 4 Indoor relative humidity for Case KH0-2 (Kaohsiung)

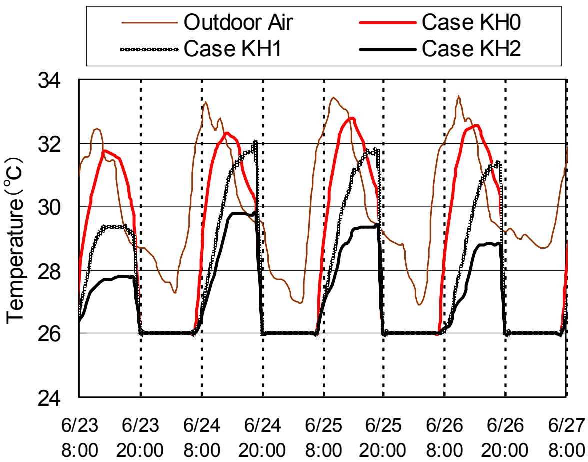

Figure 7 Indoor temperature for Case KH0-2 (Kaohsiung)

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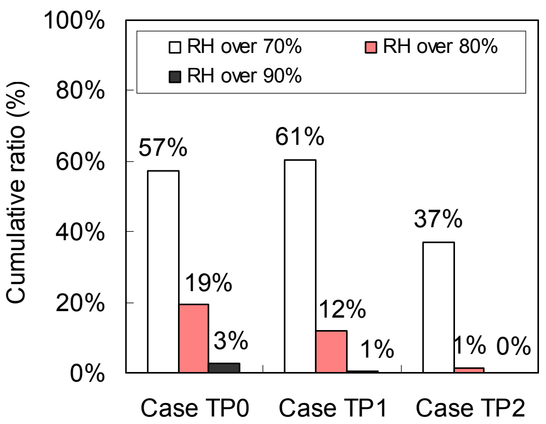

Figure 8 Cumulative ratio of indoor relative humidity for Case TP0-2 (Taipei)

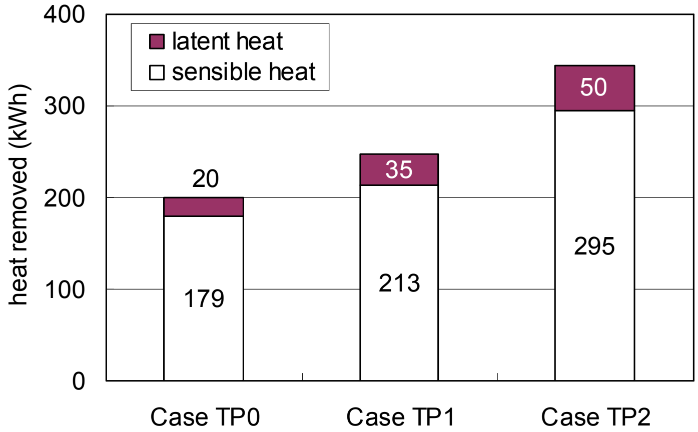

Figure 11 Heat removed by air-conditioning system in Case TP0-2 (Taipei)

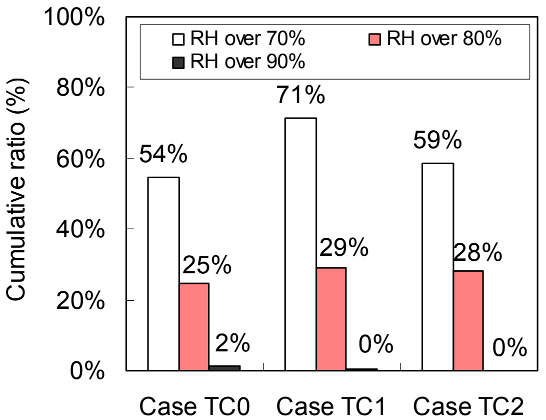

Figure 9 Cumulative ratio of indoor relative humidity for Case TC0-2 (Taichung)

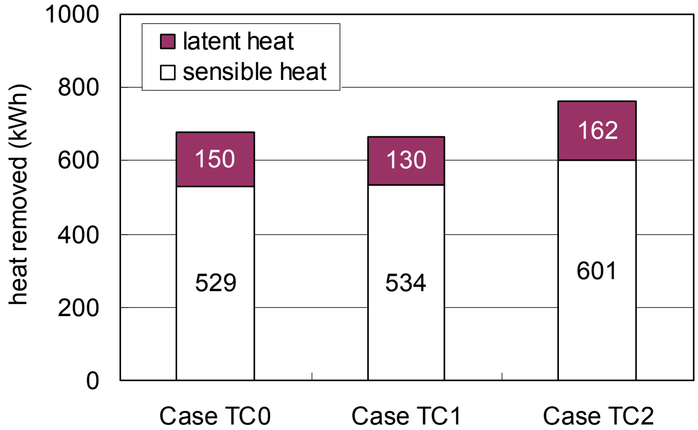

Figure 12 Heat removed by air-conditioning system in Case TC0-2 (Taichung)

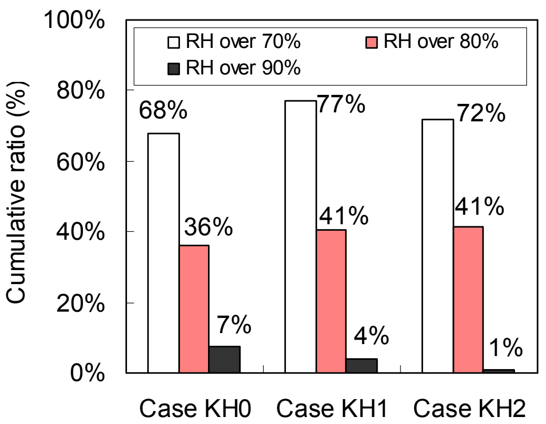

Figure 10 Cumulative ratio of indoor relative humidity for Case KH0-2 (Kaohsiung)

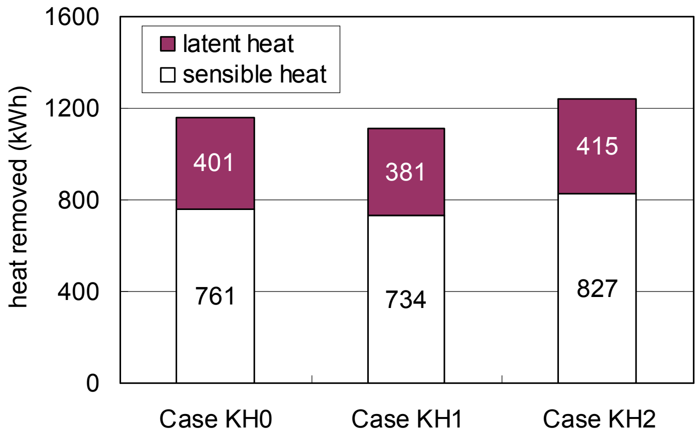

Figure 13 Heat removed by air-conditioning system in Case KH0-2 (Kaohsiung)

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THE ENVIRONMENTAL IMPACT OF DETACHED WOODEN HOUSES CONSTRUCTED BY CONVENTIONAL METHODS IN JAPAN

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Keywords: detached wooden houses, measurement survey, CO_2 emission, $LCCO_2$, construction materials, construction waste, energy consumption, inhabitants' daily schedule

Summary

CO_2 emissions from the construction and use of houses have been increasing. In order to promote the reduction of CO_2, it is necessary to know the exact amount of CO_2 emissions from houses. First, the authors measured the exact weight of the construction materials and waste. Next, the authors researched the inhabitants' daily schedule and measured the energy consumption from the daily use of the house. The following results were obtained: 1) the weight per floor of construction materials and waste was 1.03×10^3kg/m^2 and 12.9kg/m^2, respectively 2) the amount of CO_2 emissions per floor of construction materials and waste was 0.319×10^3kg-CO_2/m^2 and 13.1kg-CO_2/m^2, respectively 3) the amount of electricity consumed was 30.6GJ/year for the first year and 28.9GJ/year for the second year 4) the amount of CO_2 emissions from both the construction and two years use of the house was 389.07kg-CO_2/m^2.

1. Introduction

CO_2 emissions from the construction and use of houses in 1990 were about 18% of the total CO_2 emissions in Japan, and the total amount of emissions from the construction and use of houses has been increasing. In order to promote the reduction of CO_2, it is necessary to know the exact amounts of CO_2 emissions from houses.

Well-insulated and airtight houses are constructed from various materials, some of which result in a lot of CO_2 emissions during their factory production. The authors measured the exact weight of the construction materials and waste to determine their environmental impact. Since most researchers in Japan calculate CO_2 emissions using construction material measurements from housing blueprints, the values are not accurate. The reason for the inaccuracies is the difficulty in calculating the weight of the construction materials and waste over the long construction period. This leads to a difference between the weight based on actual measurements and the estimated weight based on calculations. From our measurements, the exact weight of construction materials and waste was determined and the amount of CO_2 emissions was calculated.

CO_2 emissions from energy consumption in a household after construction are an important design factor. For the houses whose construction materials and waste were measured, the amount of electricity and water consumed was recorded. The hot water supply system, cooking system and air conditioner use electricity in this house. The amount of CO_2 emissions due to energy consumption from 2005 to 2007 was calculated from a measurement survey.

Methods to reduce CO_2 emissions related to construction materials were considered. Here, the use of materials with lower emissions is proposed as one CO_2 reduction method.

2. Outline of Target House

Figure 1 shows the floor plan of the second floor and figure 2 shows the floor plan of the third floor. Figure 3 shows the elevation plan of the south side of the house. The house that we measured was constructed in Nagano Prefecture, Japan. The house had three floors. The first floor was constructed with reinforced concrete. The second and third floors were constructed with wood and by conventional methods. The total floor area is 162.0m^2. The house was insulated with glass wool. The thickness of the ceiling's insulation is 200mm and the insulation for each wall is 100mm. The insulation for the floor is 80mm. The density of the ceiling's insulation is 10kg/m^3, with each wall at 16 kg/m^3 and the floor at 32 kg/m^3. Each window has a sash made from plastic and aluminum with double glazing. The exterior is made with a ceramic material which has a thickness of 13mm. The roof uses a coated sheet steel which has a thickness of 0.4mm. The interior decorations consist of wallpaper made from vinyl. The flooring material uses an adhesion bond. The thickness of the flooring materials is 12mm.

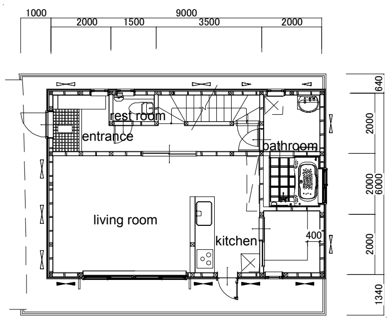

Figure 1 : Floor plan of second floor

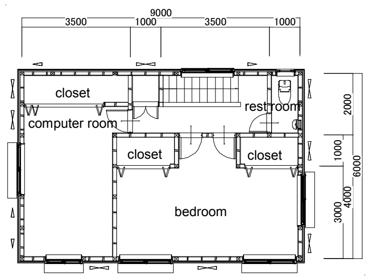

Figure 2 : Floor plan of third floor

Figure 3 : Elevation plan of the south side of the house

3. Attribution of Inhabitants and Outline of Facilities

The inhabitants are a husband and wife and two children. The husband and wife are in their 30's. The two children are under 5 years of age. The husband is a company employee. The wife is a full-time housewife. The hot water supply system, cooking system and air conditioner are run by electricity. There are two air conditioners, one located in the living room and the other located in the bedroom. The PTC (positive temperature coefficient) floor heating system was put in the living room. The inhabitants used the PTC floor heating system for the first year. They used an electrical carpet for the second year instead of the PTC floor heating system. The halogen heater was put in the computer room. The hot water supply system consists of a heat pump using CO_2 as the heating medium. The cooking device is an induction heater. The rating power consumption for the air conditioner is 585W (heating), 645W (cooling). The power consumption of the PTC floor heating system is 2,070W. The power consumption of the halogen heater is 800W. The power consumption of the electrical carpet is 606W. The power consumption of the induction heater is 4,000W.

4. Weight of the Construction Materials and Waste

4.1 Outline of Measurement Survey

The authors measured construction materials using a scale whenever these materials were brought to the construction site. The authors pooled together all of the construction waste, again measuring this with a scale. Each type of material was recorded. The authors calculated the weight of the materials that could not be measured by scale, such as concrete and wood, using a standard density. The authors figured out the weight of rebar by weight per unit length. The weight of the hot water supply system and the air conditioner was calculated through data obtained from the manufacturer.

4.2 Result of Measurement Survey

Figure 4 shows the weight of construction materials. We classified the construction materials into the eleven following categories: wood, metals, plastics, soils and stones, paper, glass, chemical products, rubber, cloths and threads, cables, and combined materials (material made from more than two materials).

The total weight of construction materials was 166 x10^{3}kg. The top three categories in terms of weight are soils and stones, wood, and metals. The breakdown of these three largest categories is as follows: soils and stones - 89.7% (149 x10^{3}kg), wood - 6.0% (9.95 x10^{3}kg), metal - 3.1% (5.08 x10^{3}kg). Soils and stones have the highest weight because the house's first floor was constructed with reinforced concrete.

The main materials that make up the eleven kinds of construction materials are as follows: 1) wood: laminated wood, lumber, plywood, etc. 2) metals: rebar, structural metal, nails, etc. 3) plastics: wallpaper, airtight sheet, PVC pipe, etc. 4) soils and stones: concrete, broken stone, plaster board, etc. 5) paper: base sheet of roof 6) glass: window, glass wool, mirror 7) chemical products: adhesion bond, paint, repellent for ants, etc. 8) rubber: urethane foam, sealant, etc. 9) cloths and threads: curtains 10) cables: electrical wiring, antifreeze heater for pipe, etc. 11) combined materials: home electric appliances, etc..

Figure 5 shows the weight of construction waste. The total weight of construction waste was 2,090 kg. The top three categories in terms of weight of construction waste are soils and stones, wood, and paper. The breakdown of these three largest categories is as follows: soils and stones - 41.2% (859kg), wood - 34.4% (718kg), and paper - 12.9% (268kg).

The main materials that make up construction waste is as follows: 1) wood: mill ends of lumber and plywood and flooring material, etc. 2) metals: mill ends of coated sheet steel, nails used for formwork, etc. 3) plastics: polypropylene band, buffer material, etc. 4) soils and stones: mill ends of plaster board and exterior, etc. 5) paper: cardboard, center core of airtight sheet 6) glass: mill ends of glass wool, etc. 7) chemical products: remover for formwork, etc. 8) rubber: mill ends of electrical wiring, etc. 9) combined materials: case of adhesion bond and sealant, etc..

Table 1 shows the disaggregated data of construction waste. Excluding mill ends, construction waste consisted almost entirely of packaging material. Soils and stones, glass and cables were only mill ends. Excluding mill ends, paper and chemical products were mostly construction waste.

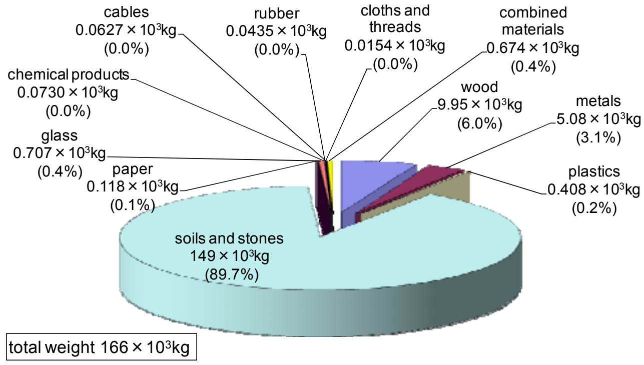

Figure 4 : Weight of construction materials

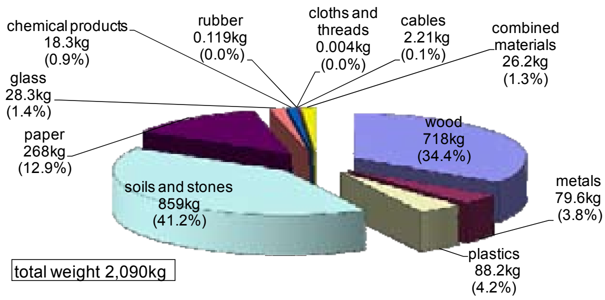

Figure 5 : Weight of construction waste

Table 1 : Disaggregated data of construction waste

Materials	Weight of mill ends(kg)	Weight of construction waste excluding for mill ends(kg)
wood	704	14.2
metals	56.9	22.7
plastics	42.7	45.5
soils and stones	859	-
paper	1.40	267
glass	28.3	-
chemical products	0.794	17.5
rubber	0.053	0.066
cloths and threads	-	0.004
cables	2.21	-
combined materials	12.4	13.8
total	1,708	381

5. CO_2 Emissions

5.1 Method for Estimation of CO_2 Emissions

We measured the exact weight of construction materials and waste. We multiplied the weight of construction materials and waste by a basic unit. This basic unit was calculated based on an input-output analysis. The Architectural Institute of Japan officially announces the basic units.

5.2 Amount of CO_2 Emissions of Construction Materials and Waste

Figure 6 shows the amount of CO_2 emissions from construction materials. The total amount of CO_2 emissions from construction materials was 51.7 x10^3kg-CO_2. The top three categories in terms of the amount of CO_2 emissions from construction materials are soils and stones, wood, and metals. The breakdown of these largest categories is as follows: soils and stones - 60.8% (31.4 x10^3kg-CO_2), metals - 12.4% (6.42 x10^3kg-CO_2), wood - 12.4% (6.42 x10^3kg-CO_2).

Figure 7 shows the amount of CO_2 emissions from construction waste. The CO_2 emissions from construction waste emerged during production. The total amount of CO_2 emissions from construction waste was 2,120kg-CO_2. The top three categories in terms of the amount of CO_2 emissions from construction waste are soils and stones, wood, and paper. The breakdown of these largest categories is as follows: soils and stones - 26.6% (562kg-CO_2), wood - 25.0% (529kg-CO_2), paper - 24.7% (523 kg-CO_2).

6. Improvement of Index of Environmental Load

We recalculated the data obtained thus far into a per floor unit of measurement in order to compare it with other data taken from housing blue prints. The target house's first floor is constructed with reinforced

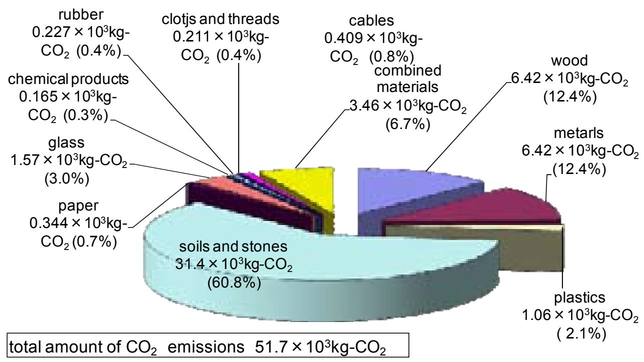

Figure 6 : Amount of CO_2 emissions from construction materials

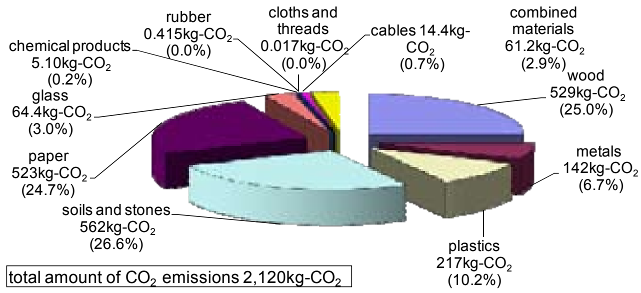

Figure 7 : Amount of CO_2 emissions from construction waste

concrete, so it uses larger amounts of concrete than normal houses. We calculated the data from the groundsill up and arranged this data into a per floor measurement (second and third floor:108m^2). Table 2 shows the weight per floor of construction materials and the amount of CO_2 emissions per floor from construction materials. Table 3 shows the weight per floor of construction waste and the amount of CO_2 emissions per floor from construction waste. The weight per floor of construction materials and waste was 1.03×10^3kg/m^2 and 12.9kg/m^2, respectively. The amount of CO_2 emissions per floor of construction materials and waste was 0.319×10^3kg-CO_2/m^2 and 13.1kg-CO_2/m^2, respectively.

Table 2 : Weight per floor of construction materials and the amount of CO_2 emissions per floor from construction materials

Materials	Weight of construction materials		Amount of CO_2 emissions	
	weight per floor(kg/m^2)	weight per second and third floor(kg/m^2)	amount of CO_2 emissions per floor(kg-CO_2/m^2)	amount of CO_2 emissions per second and third floor(kg/m^2)
wood	61.43	92.10	39.61	59.41
metals	31.35	10.17	39.63	23.75
plastics	2.52	3.48	6.57	9.15
soils and stones	921.49	106.27	193.96	73.14
paper	0.73	1.09	2.12	3.19
glass	4.37	6.55	9.68	14.52
chemical products	0.45	0.68	1.02	1.53
rubber	0.27	0.40	1.40	2.10
cloths and threads	0.10	0.14	1.30	1.95
cables	0.39	0.58	2.53	3.79
combined materials	4.16	6.24	21.38	32.07
total	1,027.24	227.70	319.21	224.59

Table 3: Weight per floor of construction waste and the amount of CO_2 emissions per floor from construction waste

Materials	Weight of construction materials		Amount of CO_2 emissions	
	weight per floor(kg/m^2)	weight per second and third floor(kg/m^2)	amount of CO_2 emissions per floor(kg-CO_2/m^2)	amount of CO_2 emissions per second and third floor(kg/m^2)
wood	4.43	5.02	3.27	3.31
metals	0.49	0.55	0.87	0.68
plastics	0.54	0.75	1.34	1.81
soils and stones	5.31	7.55	3.47	5.12
paper	1.66	2.45	3.23	4.75
glass	0.17	0.26	0.40	0.60
chemical products	0.11	0.01	0.03	0.02
rubbers	0.00	0.00	0.00	0.00
cloths and threads	0.00	-	0.00	-
cables	0.01	0.02	0.09	0.13
combined materials	0.16	0.24	0.38	0.57
total	12.89	16.85	13.08	16.99

7. Research of the Inhabitants' Daily Schedule

The authors researched the inhabitants' daily schedule in order to discover its relationship to the amount of energy consumed. The research targeted only the husband and wife. The research periods were as follows: fall (November 14-20, 2005), winter (February 13-17, 25-26, 2006), spring (May 15-21, 2006), and summer

(August 28-September 3, 2006). The research periods included all five weekdays, and Saturday and Sunday. The inhabitants reported their actions and whereabouts every 15 minutes.

Figures 8-11 show the weekday results for the times the inhabitants were inside the house and awake (the percentage of stay and awake). Figure 8 is the husband's winter results. Figure 9 is the husband's summer results. Figure 10 is the wife's winter results. Figure 11 is the wife's summer results. The graphs below (Figures 8-11) also include the results of an NHK (Japan Broadcasting Corporation) research project in order to compare our findings.

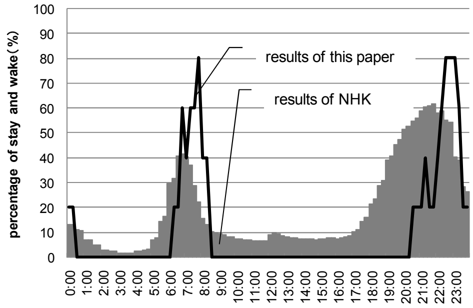

Figure 8 : The weekday results of the husband (winter)

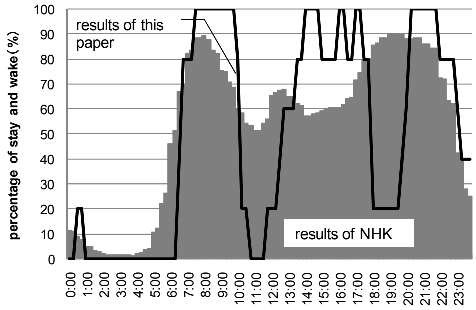

Figure 10 : The weekday results of the wife (winter)

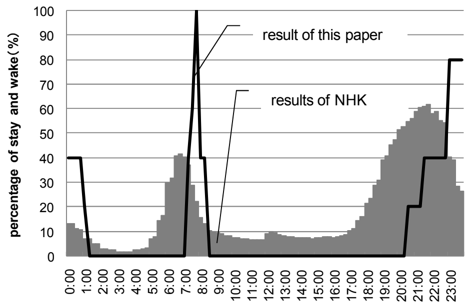

Figure 9 : The weekday results of the husband (summer)

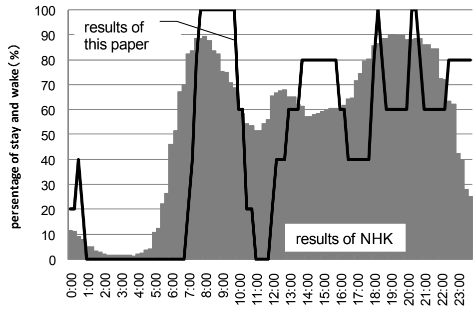

Figure 11 : The weekday results of the wife (summer)

8. Room Temperature

The authors measured the room temperature every 10 minutes. The target rooms were living room, bedroom and computer room. Figure 12 shows the room temperatures during the winter for the weekdays. Figure 13 shows the room temperatures during the summer for the weekdays. During our research of the inhabitants' daily schedule, the average winter room temperature for three target rooms were as follows: the living room was 18.3℃, the computer room was 13.9℃, and the bedroom was 16.5℃. The average summer room temperatures for the living room and the bedroom were 26.9℃, and 27.4℃, respectively. The summer room temperatures for the computer room had incomplete data. The authors infer from the data obtained that the inhabitants rarely use the air conditioner during the summer.

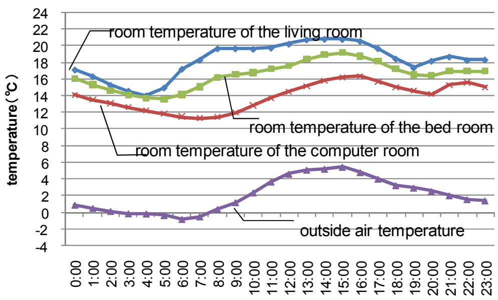

Figure 12 : Room temperatures in winter

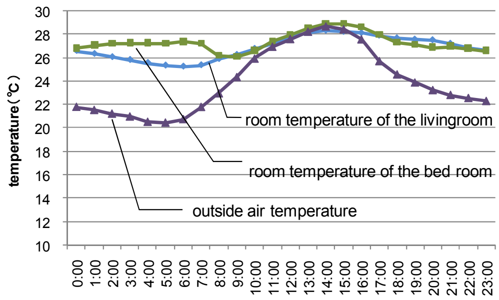

Figure 13 : Room temperatures in summer

9. Energy Consumption

9.1 Outline of Measurement Survey

For the houses whose construction materials and waste were measured, the amount of electricity and water consumed was recorded. The electricity consumed was recorded every minute. The electricity consumed for the total use of the house, except for the hot water supply system, was recorded. The amount of electricity consumed by the hot water supply system, the air conditioner, the electric carpet and the halogen heater was recorded. The measuring period for the hot water supply system and total use of the house, except for the hot water supply system, was from September 9, 2005 to October 11, 2007. The measuring period for the second floor air conditioner was from August 19, 2006 to October 11, 2007. The measuring period for the third floor air conditioner, the electric carpet and the halogen heater was from December 1, 2006 to November 11, 2007. The total consumption for electricity and water was confirmed using the utility companies' billing system.

9.2 Electric Power Consumption

Figure 14 shows the electric power consumption per month. The amount of electricity consumed was 30.6GJ/year for the first year and 28.9GJ/year for the second year. There was no significant difference between the amount of electricity consumed during the first year and second year. For the second year in winter, heating accounted for 20.2% in December, 20.0% in January, and 10.9% in February of the total consumption. The hot water supply system accounted for 36.9% in December, 38.6% in January, 43.1% in February of the total consumption. For the second year in summer, the air conditioner accounted for 5.9% of the total consumption and the hot water supply system accounted for 11.3% of the total consumption.

Figure 15 shows per hour consumption of electricity in winter. The data is the average of a typical day for February (February 19-23, 2007). The times when the heating was in use coincide with the times when the inhabitants were at home and active. Figure 16 shows per hour consumption of electricity in summer. The data is average of a typical day for August (August 6-10, 2007). The times when the cooling was in use coincide with the times when the wife was at home and active.

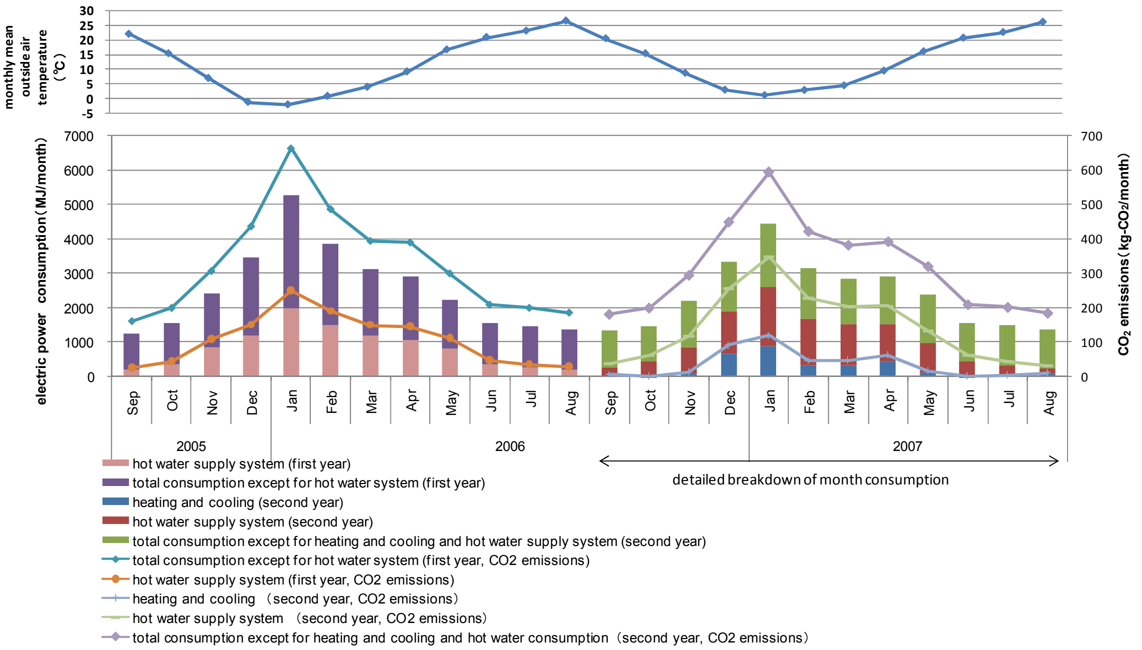

Figure 14: Electric power consumption per month

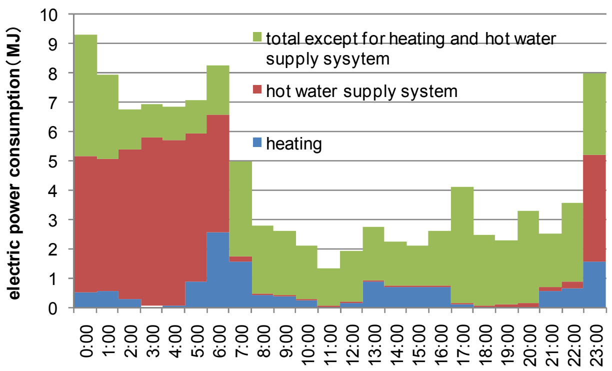

Figure 15 : Per hour consumption of electricity in winter

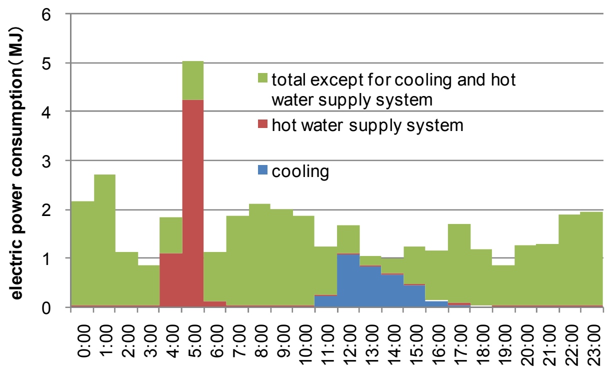

Figure 16 : Per hour consumption of electricity in summer

9.3 Water Consumption

Figure 17 shows the water consumption per two months. (Note: The first year's data for September and October also includes the amount of consumption for August.) Total water consumption was 170m^3/year for the first year and 191m^3/year for the second year.

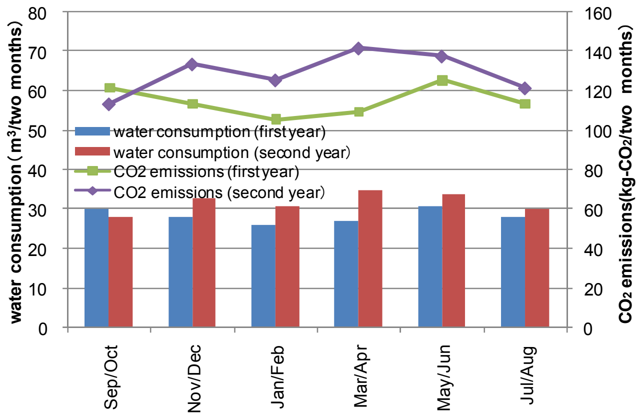

Figure 17 : Water consumption per two months

10. Value of $LCCO_2$ Based on Measurement Survey

Figure 14 shows the amount of CO_2 emissions from electric power consumption. Figure 17 shows the amount of CO_2 emissions from water consumption. The amount of CO_2 emissions from electric power consumption was 3,918 kg-CO_2/year for the first year and 3,816 kg-CO_2/year for the second year. The amount of CO_2 emissions from water consumption was 689.0 kg-CO_2/year for the first year and 774.1 kg-CO_2/year for the second year.

Table 4 shows the amount of CO_2 emissions from both the construction and two years' use of the house. The amount of CO_2 emissions from both the construction and two years' use of the house was 389.07kg-CO_2/m^2.

Table 4 : The amount of CO_2 emissions from both the construction and two years' use of the house

The amount of CO_2 emissions from construction(kg-CO_2/m^2)	Construction materials	319.21
	Construction waste	13.08
The amount of CO_2 emissions from electric power consumption of heating and cooling(kg-CO_2/m^2)	First year	-
	Second year	2.55
The amount of CO_2 emissions from electric power consumption of hot water supply system(kg-CO_2/m^2)	First year	7.94
	Second year	8.10
The amount of CO_2 emissions from total electric power consumption except for heating and cooling and hot water supply system(kg-CO_2/m^2)	First year	16.25※
	Second year	12.91
The amount of CO_2 emissions from water consumption(kg-CO_2/m^2)	First year	4.25
	Second year	4.78
The amount of CO_2 emissions from both the construction and two years' use of the house		389.07

※includes the amount of CO_2 emissions from electric power consumption of heating and cooling

11. Method to Reduce CO_2 Emissions

11.1 Change the Structure of the Groundwork and Take Away the First Floor

The first floor of the target house was constructed with reinforced concrete. The amount of concrete and rebar used was greater than what is found in other detached wooden houses constructed by conventional methods. The authors made an improved plan that took away the first floor and changed the structure of the groundwork. The authors calculated the weight of construction materials for the improved plan. Table 5 shows the weight of the construction materials that we had reported and the amount of CO_2 emissions from these materials (only the altered materials). The total weight of construction materials was reduced by 73.4×

10^3kg, with soils and stones accounting for 70.9×10^3kg, and metals accounting for 2.52×10^3kg. The reduction of CO_2 emissions was 15.7×10^3kg-CO_2.

Table 5 : Weight of construction materials and the amount of CO_2 emissions from construction materials (only the altered materials)

Materials	Weight of construction materials(kg)		Amount of CO_2 emissions(kg-CO_2)	
	actual plan	improved plan	actual plan	improved plan
metals	5,078.1	2,559.7	6,420.6	4,013.3
plastics	407.7	402.9	1,064.2	1,053.0
soils and stones	149,282.1	78,358.4	31,421.0	18,136.0
total (only the altered materials)	154,767.8	8,1321.0	38,905.8	23,202.3

11.2 Change the Interior Decorations

The authors planned to use interior decorations which emitted less CO_2 during their factory production. The interior decorations, excluding the kitchen, consist of natural wood instead of wallpaper made from vinyl and plasterboard. The interior decorations for the kitchen consist of wallpaper made from vinyl and plasterboard to protect against fire. The flooring material uses natural wood instead of materials that use adhesion bond. Table 6 shows the weight of materials and the amount of CO_2 emissions from construction materials (only the altered materials). The amount of CO_2 emitted by interior decorations with lower CO_2 emissions during their factory production was 1.48×10^3kg-CO_2. The new interior decorations reduced CO_2 emissions by 5.13 ×10^3kg-CO_2.

By changing the structure of the groundwork and taking away the first floor and by using interior decorations with lower CO_2 emissions during their factory production, the total amount of CO_2 emissions was 30.9× 10^3kg-CO_2. The countermeasures that the authors described in their improved plan reduced CO_2 emissions by 20.8×10^3kg-CO_2. The improved plan reduced CO_2 emissions by 40.3%.

Table 6 The weight of materials and the amount of CO_2 emissions (only the altered materials)

	Actual plan			Improved plan		
	material	weight ［kg］	CO_2 emissions ［kg-CO_2］	material	weight ［kg］	CO_2 emissions ［kg-CO_2］
floor	flooring material	482.8	614.1	Japanese oak	691.0	220.4
wall and ceiling	plaster board	4,005.5	5,603.7	Japanese oak	2,910.1	928.3
				plaster board	211.4	295.7
	wallpaper made from vinyl	86.8	213.2	wallpaper made from vinyl	8.2	20.0
	adhesion bond, etc.	79.8	175.6	adhesion bond, etc.	2.2	15.2
total (only the altered materials)		4,654.9	6,606.6		3,822.9	1,479.8

12. Conclusion

The authors measured the exact weight of construction materials and waste. Next, the authors calculated the amount of CO_2 emissions based on exact weight. Then, the authors measured the energy consumption from using the houses. The authors calculated the amount of CO_2 emissions from both construction and two years' use of the houses. The authors' plans to reduce CO_2 emissions in constructing houses were centered on using materials with lower CO_2 emissions.

The authors need to continuously measure energy consumption.

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CLIMATE CHANGE AND THE RISE OF (ARCHITECTURAL) FUNDAMENTALISM

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Summary

We are witnessing a global retreat to architectural rhetoric and 'fundamentalist' beliefs, relating to the role of architecture in the 'sustainable development' of the planet. Architects from around the world continue to create mechanistically based 'solutions' to address climate change, without questioning fundamental assumptions around measuring criteria. Globally, programs like LEED® have created an artificial system of measurement that implies that our new and renovated buildings can move towards a 'net zero' impact. Meanwhile, we continue to rapidly increase the total net building stock of the earth without guilt. To quote Dr. David Suzuki, the Canadian scientist and environmentalist: "Our personal consumer choices have ecological, social, and spiritual consequences and it's time to re-examine some of our deeply held notions that underlie our lifestyles." In our practice, we never assume that what we do with architecture has a predictable effect on the global climate; we believe that we don't yet have the predictive tools to measure even the local impact of our designs. We prefer to work within the Integrated Design Process (IDP) (Figure 2), a concept we introduced at the 1998 Green Building Challenge conference in Vancouver. This enables us to address issues that we can measure, without creating a corresponding belief system around the 'sustainability' value of our work.

1. Mechanistic Thinking and the Rise of Fundamentalism in Architecture

"There are those metaphysical moments in the life of empires when their sheer size and their overwhelming power become the reason for their loss of purpose, direction, and flexibility." The way in which we approach building design is always subject to the philosophical paradigm of our epoch. Currently we are in a transitional phase. We are leaving the 'mechanistic' paradigm of Newtonian Mechanics and the calculus he invented to describe it, and we are moving towards a 'natural systems' based paradigm reflected in concepts like bio-mimicry, systems theory, fractal geometry, chaos theory and non linear algebra. Our current building stock and our approach to it is very much embedded in the mechanistic paradigm, while our climate change modelling and our building performance modelling rests solidly in the realm of fractal geometry and 'fuzzy logic'. I believe that this is the reason why so many experts in the field of development and climate change analysis struggle with the complexity of this problem and continually revert to an overly simplified solution based on individual components rather than dynamic systems. Addressing the dynamic would force us to design holistically, measuring the consequences of our developments at different and far more complex scales.

The reality of our age is that we have become too comfortable measuring our buildings by literally breaking them apart into structural, mechanical, electrical and landscape elements. We have been forced to work in 'disciplines' and we look for comfort and reassurance that, as specialist professionals, we have done 'our' job correctly. As a result, our mechanistically based 'solutions' to climate change issues fail to question fundamental assumptions around the measuring criteria. Programs like LEED® are 'discipline' based and reflect the mechanistic paradigm at their core.

At the present time, a really interesting phenomenon is occurring in architecture. Buildings have moved away from highly mechanised boxes to robotic edifices mimicking the natural form, which is in fact a higher form of mechanised evolution. For example, the acclaimed architect Santiago Calatrava celebrates the *City of Arts & Sciences in Valencia* with a robotic eye (Figure 1). While beautiful, I believe that this form of building is the dark side of bio-mimicry. It remains endlessly fascinating to us because we are still fundamentally vested in the art and science of the mechanistic paradigm. There is far less embodied energy and far more durability in a simple 'non building', that uses biomass and natural systems, than in a complex engineered building embracing multiple mechanical systems within a complex skin.

Figure 1. City of Arts & Science in Valencia

It is clear to me that we are currently witnessing a global retreat to architectural rhetoric and fundamentalist beliefs, directly related to the role of architecture in the 'sustainable development' (oxymoron) of the planet. The original environmental concerns of the 1980's came out of the energy crisis, when fuel costs rose at an alarming rate. At this time, studies conducted by the Rocky Mountain Institute and the R-2000 program in Canada were developed strictly to reduce the energy consumption of homes and buildings. For example, the R-2000 program was created as a partnership between the Canadian Home Builders' Association and Natural Resources Canada. "It began with a research project in the Prairies to develop ways of building homes that were comfortable and healthy to live in during the frigid winters, but used much less energy than conventional homes." The assumption at that time was that buildings that used less energy would do less harm. Now we see a transition where 'net zero' is rapidly moving away from 'net zero footprint' to 'net zero carbon'. We need to understand why James Rust, a Southern Sierra Miwok elder, believes that, "The white man sure ruined this country. It's turned back to wilderness." Native generations stewarded the land harmoniously with natural principals and served their own needs for grains and meats in perpetuity. They radically transformed the landscape, but their alterations were not destructive. Ours are.

Fundamentalism occurs at the point where knowledge systems transition into belief systems. Currently, we believe, for instance, that green roofs are 'good'. Yet, there is in fact a body of knowledge that suggests that green roofs are not viable as functioning ecosystems and will continually fail. Green roof design has been based on engineered facilities, to address storm water management and temporarily detain water. These remain structures based on an open, flow through, piped designed criteria. We need to rethink roof design as functional landscape elements – lift the vegetated ground and slide a building underneath. Green roof design must be part of an economic benefit both of the building, (Corpus), and the landscape, (ecosystem). We need to adopt closed-loop natural design principles using a decentralized 'fit-for-purpose' approach for water management, rather than the present 'potable water' for every use from a thirst quencher to making concrete, flushing toilets to bathing. In short, we must first understand how our landscapes functioned before we altered their structure and established non-sustainable functional processes and attributes. Yet, in an era where it is felt that we must do something to reverse climate change, thoughtful or constructive questioning of sustainable building practices is perceived as unhelpful.

Renewable energy systems like wind, methane and PV energy generators are made from non-renewable materials like aluminum and glass in systems with limited life spans and dubious performance. If a 'net zero' footprint truly is the goal, I maintain that it is far too early in the sustainable development practice for us to solidify our knowledge system into a codified set of rules. Now is the time for us to step back from prescriptive doctrines in order to understand what positive co-evolution could mean for the future of this planet.

2. Artificially Restricted Measures

If we look at the most commonly used sustainable design systems of measurement in use today, we find that although systems vary, they all measure energy 'in' and 'out'. This presupposes that energy is the only component worth considering when evaluating the environmental impact of buildings. The fact is there is an equally pressing need for us to assess the human impact on our atmosphere, our land and our oceans at a global level. We can then use this understanding as a reference for the evaluation of our human development impact. Specifically there are three known human effects on the atmosphere:

1. The emission of CO2e or GHG's
2. The generation of particulates from fossil fuel burning
3. An increase in the albedo of the planet due to rice paddies and urban development

There are also three natural mechanisms that influence climate. These are changes in the sun, changes in the amount of volcanic dust in the atmosphere and the internal variability of the coupled atmosphere-ocean system. All of these processes can add heat to the atmosphere. Even with the Kyoto targets in place, there will be an average temperature rise of two degrees by 2030, wherein the expansion of the warm zone top layer of the ocean will have exceeded coral reef temperature tolerance in eighty percent of the world's oceans.

There are two even more critical impacts on the land and its ecosystems that are, in many ways, independent of the three effects stated above. They result from our agriculture, aquaculture and urbanization.

4. The disruption of ecosystem corridors
5. The disruption of transpiration of water across the earth's surface

Our disruption of ecosystems is due mainly to our interference with natural passageways including avian corridors, coastlines, rivers and forest corridors.

It is a principal of nature that, "Islands are a dead-end road; islands are where species go to die". When we create a Roman block urban landscape, each block is an island and is not ecologically viable. Additionally, when we break up our landscape with hard surface roadways, we disrupt the eco corridors creating forest islands that eventually will also fail, unless they too are of a sufficient size.

Our dealings with water are also misguided. We mistakenly believe that we should return clear run-off to the 'groundwater' and we will 'recharge the aquifers'. Actually, what biology teaches us, is that the first principal of nature is to keep water on the land as long as possible, where it is available for plants, birds, animals and insects. Water evaporating from our oceans is condensed as rain over coastal areas and there begins a series of evapo-transpiration micor-cycles of water across the land through the biomass and soils. Our cities therefore are functioning, in natural terms, as irrigated deserts.

When we examine the five major human impacts on the earth, it is evident that our current sustainable design system of measurement addresses only the first two effects (i.e., GHG's and particulates). For instance, the systems that we use at present do not assess the impact of the albedo effect. A dark surface can be a forest that photosynthesises the sun's energy, or an asphalt parking lot that demands more and more fossil fuel for its maintenance. Yet currently we apply the same albedo factor to them. Our current systems also fail to examine the city-block based urban planning effects on ecosystem corridors. Perhaps most importantly, these sustainable design measuring systems actively encourage the return of water through porous paving and drainage systems to the groundwater, without considering the needs of plants, birds, animals and insects which require access to water on the surface. When you think about it therefore, it should not be possible for an aluminum-clad building, located on acres of land in a city block environment, containing a huge mass of embodied energy and a wealth of mechanised systems, to earn a platinum or gold award. Yet it is done every day! Our current systems of measurement are helping us rationalise high impact development without questioning basic fundamental assumptions. By codifying things so quickly and so early on in terms of our understanding, we are stealthily moving away from true zero footprint or impact to zero CO2 impact. In this way we may, in fact, increasingly be doing more harm than good.

3. The Integrated Design Process and the move towards Living Breathing Buildings™

In his book "Happier", Harvard professor Dr. Tal Ben-Shahar evaluates the ever-elusive state of happiness. He suggests that, "The accumulation of wealth would often determine whether we would survive the next drought or the next cold winter (…) the accumulation of wealth is no longer a means towards survival, but an end in itself. We no longer accumulate to live; we live to accumulate." His views are supported by the writer and academic Thomas Homer-Dixon in "The Upside of Down: Catastrophe, Creativity and the Ruin of Civilization". He concludes that, "The average income in poor countries won't fully catch up to that in rich countries until the year 2291 – almost three centuries from now – at the staggering level of $27.7 million a person a year". In short, this means that, "The more people perceive that today's globalized capitalism is making the already rich vastly richer while simultaneously leaving the world's population behind, the lower will be its moral standing as a set of principles for ordering people's social and economic lives".

In our desire to understand what 'drives the drive' to overbuild our cities and our communities, my practice worked with the National Research Council of Canada to develop the Commercial Buildings Incentive Program. Out of this was born our original Integrated Design Process, a formal eight step procedure that enables any team anywhere to achieve a superior level of high performance building construction and sustainable development.

All of the architects in our practice still use the IDP today to successfully create millions of square feet of environmentally sustainable commercial and institutional work. Indeed we now have more square feet of LEED® NC Gold-certified projects than any other architectural firm in North America. In our experience, the Integrated Design Process reduces the need for complex building solutions and almost completely eliminates most mechanical systems. The Integrated Design Process lets architecture do the work for us as a form of global bio-mimicry, wherein the buildings themselves ultimately become the energy producers, working to protect and preserve the ecosystems around them. In short, the Integrated Design Process has enabled us to move away from the machines that have come to dominate architectural design. We address each project and its unique issues without reference to any codified program and actively promote a dynamic questioning atmosphere in the project development team. In such an atmosphere creative solutions abound and the points based measure or certification program is only brought in at the end as a sort of complimentary cross check. It no longer acts as a definitive guide. Many of the strategies that come out of the IDP will not, in fact, earn points on something like

LEED®. Conversely, we have found that by using the IDP we are able to raise the ultimate number of points we can get in LEED®.

Experience has taught us that the first step of the Integrated Design Process, known as *Orientation and Massing*, is perhaps the most crucial as it creates the foundation for all future building performance. We make effective use of the north light to maximize daylight potential and prevent overheating and examine opportunities to enhance neighbouring communities with connections to green-spaces, public amenities and urban pedestrian links.

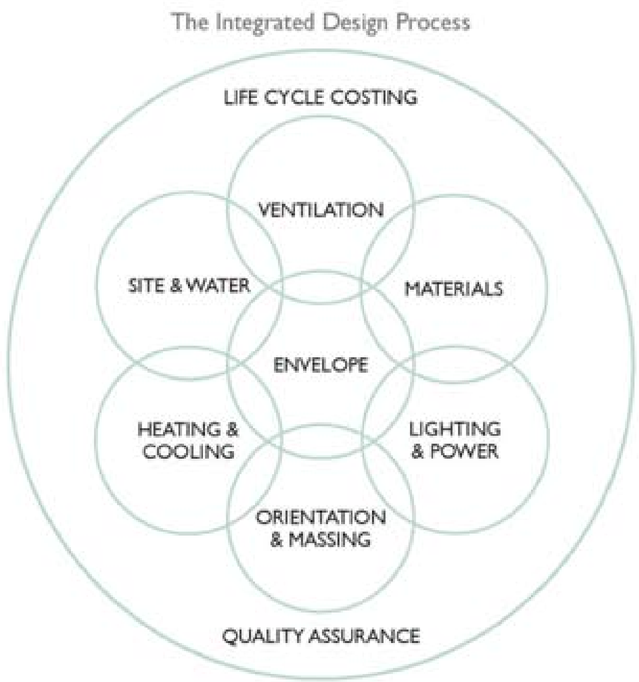

Figure 2. The Integrated Design Process

In our second step, *Site and Water*, we actively look for the natural features of the site to create and maintain ecosystems and water sources. "Climate has used different weapons to bring down the mighty. Most of the time it is drought that upsets the balance of power. (…) 'Through history it has been changes in precipitation, not temperature, that has brought down civilizations'." We take particular care to complement the mass of the building with defined site strategies, thereby enhancing both building performance and site ecosystems. This may mean planting trees, or creating a green parking facility around the building. We specifically look for opportunities to creatively define the site within revised boundaries or, alternatively, we set aside part of the location as a protected green space. This ensures that the site becomes an integral part of the building and can connect to other eco-corridors.

Once we reach the third step of our Integrated Design Process, we focus on developing the *Envelope*. This is almost the reverse of the normal design process in which the outside of the building is initially developed as an image. In our interpretation of the envelope stage, we define the area of windows to be used on each face for day-lighting and specify the types of windows and skylights. We detail the insulation values of the walls and the construction type, developing the shading and transmission values of the glazing. This helps us to create a balanced energy model effect around the building as the glass on each face is rarely the same and the insulation values of the walls can also vary. In particular, we give careful consideration to the roof. We develop light-wells down into the space below and ventilation chimneys or louvers may be added to exhaust warm air out. Options for surfaces, including a green roof or use of other innovations, ensures that the building remains warm in winter and cool in summer.

Our next consideration, and the fourth step, is to develop an exceptional *Ventilation* strategy. Except in horrifically polluted areas, we target ‘natural’ ventilation. This means we draw a clear line firstly between natural and mechanical ventilation systems and secondly for the air used for the heating and cooling of the space. We always look at the most effective way to get fresh air into the building, and to its occupants.

Our fifth step is *Day-Lighting Design*. We consider each face of the building separately and set a target for optimizing the use of natural daylight without attracting solar gain or glare. We do not approach this in a traditional architectural way. Instead, we work with the landscape architects to use trees to screen the building. We also work closely with electrical engineers to develop light wells through the spaces and with energy engineers to refine the openings on the building, making sure we are not creating peak load zones with overlit areas.

It is only at this point that we truly consider the building mechanical conditioning systems after refining the base building to passively condition itself as much as possible. We develop the energy model for the building form and the building envelope, and then see what is left to condition with mechanical systems. This ideally means a very small or nominal heating load and no cooling load at all. It is in this, our sixth IDP step, that we look at renewable H*eating and Cooling System Design.* This could include ‘geothermal’ heating through radiant piping embedded in the mass of the building, or ‘photovoltaics’ linked to fuel cells, or methane gas converters, or wind turbines.

Our seventh IDP step is connected to the *Materials* we select for the building. Our prime concern here is to ensure the health and safety of the building occupants. We select materials that do not off-gas, harbour mould or mildew, or breakdown resulting in particulate contamination. Where possible, we select local materials that are durable but do not have a high embodied energy factor. We work as a team to reduce the materials in the building, using recycled or reused materials wherever possible.

Finally, our eighth and most critical step is to develop a Q*uality Assurance* protocol to ensure the building can be understood and looked after long after the first generation of maintenance staff has left. This is a key step; innovations in buildings can quickly be rendered ineffectual if they are inadvertently compromised. Detailed operational manuals are produced to take the building through into the future.

In “*The Living Building Challenge”,* the Cascadia Region Green Building Council, (Cascadia), invites us to, “Imagine buildings that are built to operate as elegantly and efficiently as a flower. (…) It is time to move beyond Platinum to the Level of the Living Building”. As architects and designers, we must not limit our thinking to our immediate project boundary, because the impact of our work is cumulative and the effects are global.
In order to achieve this, we must first recognise the first three human effects on the atmosphere that must be mitigated in order to achieve true “zero footprint” buildings. Firstly, with regard to GHG emissions, (or CO_2e), we need to begin to think outside the box. For instance, we need to target the waste our buildings produce at source for heat energy. One molecule of methane is equal to 28 molecules of CO_2 and our cities could theoretically substantially heat themselves with the methane gas produced through energy produced from solid/liquid resource streams. Secondly, with regard to particulates as they are emitted into the atmosphere, we need to absolutely stop the burning of fossil fuel for operating energy, transportation of materials to building sites and manufacture of building materials. This means that we need to consider renewable energy systems. In our practice we emphasize the use of locally produced materials in the design and creation of our buildings.

Finally, we also need to be aware of the albedo effect of our developments and move towards greenspace photosynthesizing solar energy, rather than high albedo surfaces reflecting it back into the atmosphere.

As we begin to imagine new forms, we look at the macro level of impact where we must begin to identify eco-system corridors and preserve and protect them. Forest corridors must be reconnected to restore their vitality and along with avian flyways must be marked on every map as 'no go' development zones. Water courses must be understood and protected. Instead of developing an urban form based on the Roman city block system that is convenient for cars and other forms of mechanised transport, we must eliminate the 'city block islands' in our urban planning and create greenbelts instead of asphalt deadzones. In short, we have to allow nature to restore itself through accelerated adoption of bio and eco-mimicry, using the fundamental patterns that underlie life on earth. This can be summarised as the Six Pillars of Biological Wisdom:

1. Nutrition (by allowing water to remain at the surface)
2. Respiration, by creating eco-corridors which will lead to,
3. Growth and
4. Homeostasis (the steady state of a healthy eco system)

This supports:

5. Procreation/reproduction
6. Adaption (which will lead to natural evolutionary processes).

Nature cannot develop and evolve unless we feed it.

Our human impact must be understood as an historical change in nutritional mode and the adaptation of a sedentary lifestyle based on the co-evolutionary, eco-system deforming technologies of agriculture and civilisation, for both agriculture/aquaculture and civilisation/urban development. We have co-evolved with our earth. Stewardship of the planet does not mean a return to wilderness, but rather development informed by a complete understanding of these "Six Pillars of Biological Wisdom". As a practice, Bunting Coady Architects focuses on Creating Living Breathing Buildings® that are ecosystems in their own right.

It is my belief that we can never truly create a Living Breathing Building™ unless we integrate completely with our culture. We know that on every level we are failing to connect to the human condition. Our fast paced culture is creating junk food, disposable clothes and transient buildings, all of which cause great harm and never truly satisfy the spirit. Our buildings used to be inspirational and one of the highest forms of human expression. We must bring the art and craft back into buildings as a reflection of the human condition so that our buildings, once again, have meaning for us. This, in turn, will allow us to give them the time, care and attention to commensurate with their impact on the environment. Ironically, part of responding to the climate change challenge will be to bring the art back into architecture. If we don't value what we create, we will destroy it. If we want our buildings to last, they have to be symbolic and beautiful and connected to our lives on every level.

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COMBINED LCA AND LCC STUDY OF 5 BUILDING ARCHETYPES IN PEARL RIVER DELTA

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Keywords: holistic and life-cycle approach, environmental impacts, cost implication, life cycle assessment, life cycle costing, selection of materials

Summary

A combined Life Cycle Assessment (LCA) / Life Cycle Costing (LCC) Study for a 40-storey standard HKHA (Hong Kong Housing Authority) public rental housing block - New Harmony Block (Option 2) (NHB) was completed in 2004. The study was conducted by a consortium comprising of the University of Hong Kong, Department of Architecture, Davis Langdon & Seah Management Ltd., and the Business Environment Council. The objective of the study quantitatively measured the following ten environmental impacts generated and the life cycle costs from the NHB block from the whole building life-cycle perspective, including (1) raw material extraction; (2) building material manufacturing; (3) transportation stage; (4) construction; (5) building operation; (6) repair and maintenance, and (7) disposal stage:

Energy (MJ)
Resource depletion (kg Sb eq.)
Water consumption (m^3)
Waste (kg)
Climate change (kg CO_2 eq.)
Acid rain(kg SO_2 eq.)
Photochemical smog (kg C_2H_4 eq.)
Ozone depletion (kg CFC-11 eq.)
Toxicity to humans (kg toxic eq.)
Toxicity to ecosystems (kg toxic eq.)

From 2004 to 2007, the combined LCA and LCC study has been extended to other building archetypes in Pearl River Delta, including office, carpark, retail, and hotel buildings. This paper will report the LCA results for each building archetype in the region.

1. Introduction

Thegreenroom, The University of Hong Kong, Davis Langdon & Seah Management Ltd (DLSM), and Business Environmental Council (BEC) completed a combined Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) decision-support tool in 2004. The tool is capable of measuring the following ten environmental impacts and determines the following three financial implications of buildings from the whole life cycle perspective, including (1) raw-material extraction, (2) building material manufacturing, (3) transportation, (4) construction, (5) building operation, (6) repair and maintenance, and (7) disposal stages (Wong et al., 2005):

1. Energy (MJ)
2. Resource depletion (kg)
3. Water consumption (m^3)
4. Waste (kg)
5. Climate change (kg CO_2 eq.)
6. Acid rain(kg SO_2 eq.)
7. Photochemical smog (kg C_2H_4 eq.)
8. Ozone depletion (kg CFC-11 eq.)
9. Toxicity to humans (kg toxic eq.)
10. Toxicity to ecosystems (kg toxic eq.)

A. Capital cost (HK$)
B. Recurring cost (HK$) (operational, repair and maintenance cost)
C. Disposal cost (HK$)

The building in assessment was the New Harmony Block (Option 2) (NHB), a 40-storey concrete-framed residential building for public-rental that accommodates a total of 3,196 individuals. (Fig. 1)

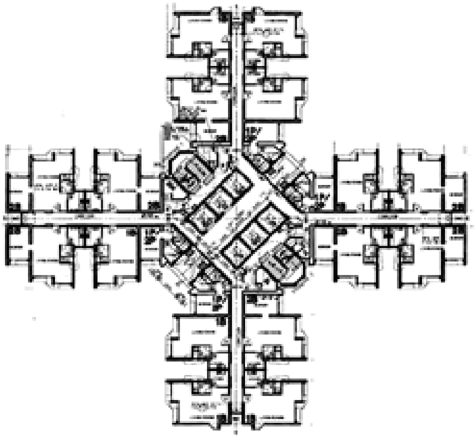 

Figure 1 Typical floor plan (left) and the appearance (right) of the New Harmony Block (Option 2)

From 2004 to 2007, thegreenroom, The University of Hong Kong and DLSM conducted a combined LCA and LCC assessment for the following building archetypes in Pearl River Delta:

- A 40-storey concrete-framed office tower in Pearl River Delta
- A 28-storey concrete-framed hotel tower in Pearl River Delta
- A 4-storey concrete –framed shopping arcade in Pearl River Delta
- A 4-storey underground carpark in Pearl River Delta

To measure the environmental impacts of buildings in Pearl River Delta, a unique material-impact database was set up for 200 building materials. The resultant database is relevant for the Southern China/ HK production, energy mix and transportation profile. To accurately assess both LCA and LCC implications, the decision-making tool relied on the following quantum data for the assessment:

- The quantities of building materials used were sourced from the bills of quantity or the cost plan of these building archetypes.
- The repair and maintenance frequency of building component were sourced from the repair record of building archetypes in-use.
- Water, electricity and gas consumption were sourced from real electricity, gas and water bill of building archetypes in-use.

Based on the above quantum data and regionalised material-impact database, the tool characterizes[1], normalizes[2] and weights environmental impacts of buildings into a notional HK environ-point (HK E-pt) which was equivalent to the ten environmental impacts generated by one HK citizen annually (Amato 2006). Alternatively, the tool can measure the building in terms of individual impacts, such as the global warming potency in kg CO_2 equivalent. This decision-making tool could assist accurate carbon footprint reporting in sustainability report of the building assets.

[1] HOWARD N. et. al., (1999) described characterization as: "For each category of impact, characterization will be taken to define the contribution of an environmental burden (intervention) to the impact. The purpose of this is to translate different inventory inputs into directly comparable impact indicators. For example, characterization would provide an estimate of the relative human toxicity between lead and zinc. One burden which makes a contribution which is considered to have a contribution to that impact, or 'potency', of 1. Other burdens are considered with a potency factor relative to that. Alternatively, the burden can be characterized by measuring it in a particular unit, such as cubic meters of water. The characterization process follows international practices in the characterization of inventory data for their potency with the different impact categories."

[2] HOWARD N. et. al., (1999) described normalisation as: "The characterized impact will then be normalized. The purpose is to express impact indicator data in a way that can be compared among impact categories. The procedures normalized the characterized results by dividing by selected reference values, which can be:

- *The total emissions or resource use for region that may be local, regional or global*
- *The total emissions or resource use for an area on a per capita basis"*

2. THE LCA PATTERN OF THE BUILDING ARCHETYPES

Fig. 1 shows total whole life HK E-points of the assessed building archetypes. Fig. 2 shows the whole life HK E-points/ CFA. Fig. 3 shows the whole life HK E-points per inhabitants of the assessed building archetypes.

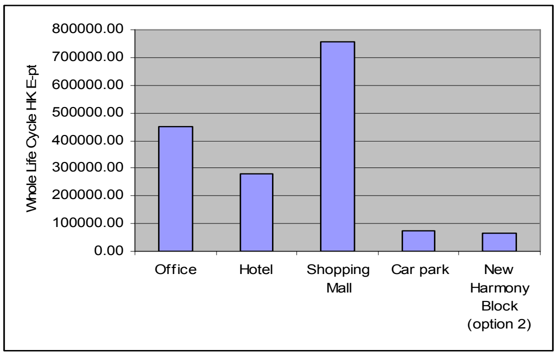

Figure 2 Total HK E-pt of the assessed building archetypes

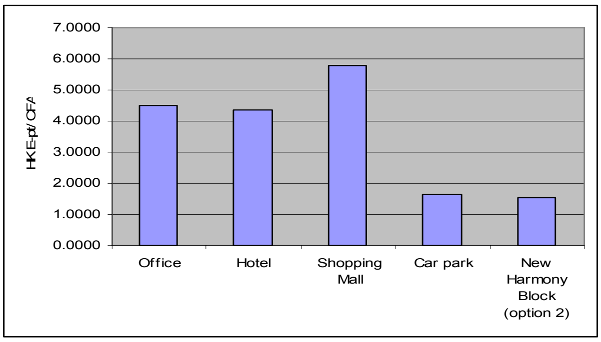

Figure 2 HK E-pt/ CFA of the assess building archetypes

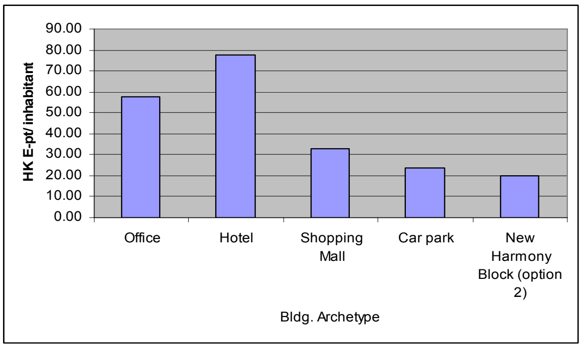

Figure 3 HK E-pt/ inhabitant of the assessed building archetypes

It shows that NHB in HK has the best LCA performance in respect of the three types of indicators. This is because NHB have the lowest energy consumption at operation stage and building-material consumption at initial stage. Underground carpark has the 2nd best LCA performance. 90% of the electricity fuel mix in Pearl River Delta was sourced from coal mix. It increased the environmental impacts of underground carpark in operational stage.

Shopping mall has the worst LCA performance for the HK E-pt/ building and HK E-pt/ CFA indicators. However, in respect of the HK E-pt/ inhabitant, it has the third best LCA performance archetypes. The long operating hours which consumes huge amount of energy that shoot up the whole life E-pt and HK E-pt/ CFA. However, in respect of the HK E-pt/ inhabitant, the figure is lowered down due to the large amount of users. The social attraction in staying at a comfortable shopping mall improve the sustainability performance of these building archetype in view of HK E-pt/ inhabitant indicator.

Office and hotel have the second and third worst LCA performance in view of HK E-pt/ building and HK E-pt/CFA. This is because the office and hotel have higher operating energy demand from office, guestroom and conferences rooms. Office and hotel also have high repair impacts as they have high churn rate. In respect of HK E-pt/inhabitant, office has better performance than hotel due to higher population density in office archetypes. Conclusively, office and hotel can have better performance in view of HK E-pt/inhabitant indicator if population density can be optimised through re-layout or major renovation.

Fig. 5 shows the distribution of HK E-pt across the whole life-cycle for each building archetype. Different building archetypes have differences on distribution of environmental impacts across the whole life cycle. Office and hotel have higher proportion of repair and maintenance impact (27%, 17%) because of the high churn rate and high maintenance frequency, respectively. The significance of repair impacts encourages careful selection of duration building materials at design stage for office and hotel building archetypes. Retail and carpark archetypes have a higher proportion of operation impacts (82%, 76%) because of the longer daily operation period on lighting, cooling, ventilation and other small power loadings. Designers should choose more energy-efficient equipments and renewable energy source to reduce the operational impacts.

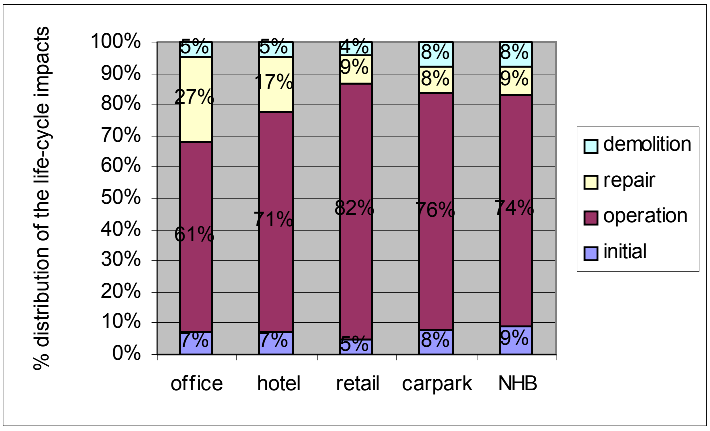

Figure 5 HK E-pt distribution of building archetypes in the life cycle

3. Conclusion

In all assessed building archetypes, New Harmony Block (option 2) has the best performance in the total HK E-pt, HK E-pt/CFA and HK E-pt/ user or inhabitant indicator. This is because NHB have the lowest energy consumption at operation stage and building-material consumption at initial stage. On the other hand, hotel archetype has the poorest performance in HK E-pt/ user indicator. This is because hotel has higher operating energy demand from guestroom and conferences rooms and low population density. From the comparative LCA assessment, each building archetypes has its own pattern of environmental impacts across the whole life-cycle. For example, the hot-spot life cycle stage focus of shopping mall was operational stage. The second hot-spot stage for office was repair & maintenance stage. Designer should select the strategy, such as optimising material or energy efficient strategy, to reduce the environmental impacts of each building archetype across the whole life cycle in order to improve the overall sustainability of the buildings. To strive the sustainability for the whole Pearl River Delta, a combined LCA and LCC study for all building archetypes can help the decision maker to identify alternative way to optimise the overall environmental impacts of buildings in the region.

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THE QUALITY OF LIFE OF LOCAL COMMUNITIES: AN ASSESSMENT TOOL. A CASE STUDY IN LOMBARDY REGION-ITALY

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Keywords: urban quality, urban sustainability, indicators, participation

Summary

The quality of living is a complex concept that includes different meanings. In this paper, quality of living was assumed as a mix of qualitative and quantitative aspects with reference to urban built environment.

The paper describes the results of a Preliminary Study for the Plan of Quality of Living (PSPQL) of a town in the hinterland of Milan, conducted by an interdisciplinary group of researchers, involving also facilitators, town councillors, administrators, technicians and citizens. Main aim of the work is identifying the most sustainable actions to be taken for improving conditions of living. A bottom-up and participative approach has been followed. A deep analysis has been carried out, elaborating a set of 33 indicators, defined with the help of the town councillors, administrators and technicians. Indicators investigated 6 different systems: environment, territory, mobility, society, economy and health. Results of different indicators have been represented and communicated by graphs, images and maps, with the help of GIS-based model. On the basis of the results of the indicators, fields of intervention for each topic have been indicated, in order to improve built environment performances and quality of living within different time steps. This study can be considered as a promising, interdisciplinary and experimental start for developing actions for the sustainable development of communities.

1. Introduction

Target setting is extremely important in the searching for sustainability process because it aims at a desired quality of life. Targets are generally a compromise or trade off between what is envisioned and what is feasible.

The evaluation of sustainability and quality of life at the local level has been identified as a strategic goal during the Rio Summit in 1992[1]. In 1994, Aalborg Charter underlines these needs, by committing the signatory local authorities to the use of indicators as an on-going supporting tool for long-term policy-making. Responding to these calls, a lot of initiatives in Europe tried to measure and monitor the level of sustainability and quality of life of local communities by different set of indicators with reference to environmental, social and economic issues.

This paper describes the outcomes of a Preliminary Study for the Plan of Quality of Living (PSPQL) of Senago, a town of about 20.000 inhabitants, located in the hinterland of Milan, in Lombardy Region (North of Italy).

[1] The quality of life issue has been studied for a long time, even if its measurement is a more recent matter (Iezzi, 2006). It's possible to distinguish two main approaches: the first one, depending on which the quality of life corresponds to the social wellbeing and it can be measured objectively (Bauer,1996; Oecd, 2001; Osberg, 2004); the second one, that emphasizes the perceptive dimension of quality of life, such as needs, feelings and aspirations (Andrews, Whitney,1976; Campbell et al., 1976).

The PSPQL has been defined in the framework before described and follows a bottom-up approach. According to the complexity of the meaning of quality of life, in this paper this concept was assumed as a mix of qualitative and quantitative aspects with reference to urban built environment[2].

The study started in summer 2005 and ended in spring 2006, with a short addition in summer 2007, but his concept has been developed during many years, in which, the governance try to focus his interests and resources on the improvement of urban sustainability. The study has been commissioned by the municipality and has been carried out by an interdisciplinary group of young researchers (architects and engineers), involving also facilitators, town councillors, administrators, technicians and citizens. A participatory approach requires that Local Governments shift their understanding of governing and define their role primarily as important partner for local sustainable development. As a matter of fact, agreement on targets by all relevant stakeholders and actors will develop ownership of the process and responsibility to implement respective measures.

The most important aim of this study is to give a multidimensional vision of the town, investigating the actual conditions of living with reference to all the citizens (children, teenagers, young people, adults and old people) and prioritizing the needs emerging from the previous analytical steps, in order to define actions with different term: short, mid and long. Furthermore, there is the intention of putting on trial a new tool, finalized to create a clear base of common knowledge, an interchange platform supporting actors involved in urban planning and management in taking actions in order to promote sustainable development.

2. Methodology

The concept of the study has been promoted and discussed during several occasions of interaction among researchers, councillors and technicians. The study was challenged starting from the concept that not only what is mandatory has to be done, but also what is actually feasible in order to improve living conditions. In fact, the so called Plan of Quality of Living is not a defined or mandatory plan; it is an optional plan, not defined before in any other town planning experiences. For this reason, since the beginning, it was very important to define the methodology of the study, including different phases, aims, contents, sources, dissemination tools and scheduling. The requirements emerging from this first discussions and shared between all participants were the followings: give an overall picture of quality of life topics at the local level; support sustainable community strategies with the aim to set local priorities and goals; monitor progress by assessing changes over time; promote comparisons of performance between different communities; increase public awareness. In order to meet all of these demands, a set of performance indicators was developed.

2.1 Definition of the set of indicators

Many efforts were made in order to define an effective set of indicators for giving a picture of the present situation, but also for simulating and predicting effects of different choices on living conditions in the future. The set has been established by specifying a number of selected issues identified according to local priorities and strategies, with the help of the town councillors, administrators and technicians. After that, a deep analysis has been carried out, elaborating a set of 27 indicators. Most of them relies on existing indicators (i.e. European Common Indicators, National and Local Planning Strategies); others, called *User Defined* (UD), have been defined “ad hoc” and elaborated for the first time for Senago. Afterwards the Municipality of Senago required to develop more in deeply the cultural issues. So were added 6 new indicators (from 28 to 33) in order to better measure this topic.

Indicators investigated 6 different systems: environment, territory, mobility, society, economy and health (see Figure 1). More specifically the indicators selected, ordered by systems, are:

- Environment: 1. air quality, 2. energy consumption, 3. waste production, 4. waste collection, 5. waste management and disposal, 6. environmental accounting
- Territory: 7. proportion of woodland, 8. sustainable land use, 9. availability of local public open areas and services
- Mobility: 10. availability of pedestrian street, 11. local mobility, 12. children’s journeys to and from school
- Society: 13. citizens' satisfaction with the local community, 14. education degree of population, 15. proportion of 19 year olds with secondary school qualifications, 16. availability of childcare places, 17.

[2] American researchers prefer to maintain a clear distinction between the two concepts of Quality of Life, the European ones often suggest an integrated approach (Zajczyk, 1997).

cultural services-associations, 18. crimes committed, 19. proportion of strangers, 20. computer knowledge, 28. public libraries system: supply, 29. public libraries system: staff paid, 30. public libraries system: opening hours, 31.leisure and cultural services, 32. sportsman, enrolled and sports association, 33. sports services

- Economy: 21. affordable housing, 22. proportion of people of working age in employment, 23. poverty rate, 24. local businesses e jobs
- Health: 25. death rate by cause, 26. people with disabilities and demand for social assistance services, 27. public health services.

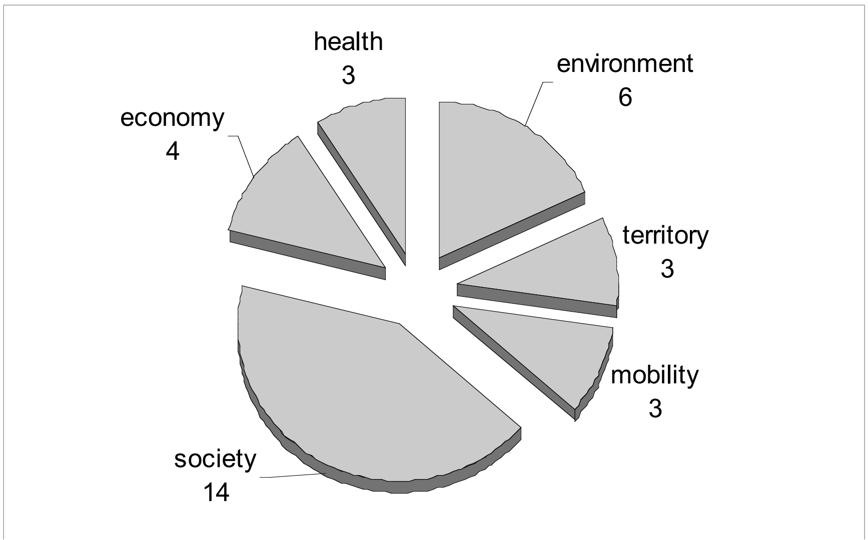

Figure 1 Repartition of the 33 indicators in the 6 systems.

Each indicator is identified by a code and is supplemented by a methodological sheet that specifies object of measurement, data collecting and elaborating methodology, data sources, references and typology of outputs. This sheet is useful not only to make the decision making process clear, but also to support the assessment of the local sustainability level in the future.

The collection and analysis of the available information about urban environment was one of the most important step of the work. Some difficulties were encountered because of the different data base supports and reference offices. Furthermore, data were often not homogeneous, because were referred to different years. It was very hard to collect updated local plans and programs and to interpret them for having an overall view of the territory, considering it as a system and not as the sum of different parts. Firstly, data was ordered by theme: environment, including energy, waste management and water cycle; territory, including contaminated soils; mobility, including availability of pedestrian paths and accessibility of services; utilities, including library, nurseries, schools, green areas, sport facilities, other services for handicapped and old people; economy; society and health. Because some information about territory and environment were lacking or out of time, several survey “in situ” have been carried out for rendering the actual living conditions and for checking the reliability of existing plans and programs. After that, measures, observations and remarks were transferred from papers to information support, based on Geographic Information System (GIS). The improvement in quality and availability of information has allowed to build-on a cross-sectoral vision and the use of GIS technology have also made easier communication between different sectors by integrating spatial and statistical data in the same format, structure and map (see Figures 2 and 3).

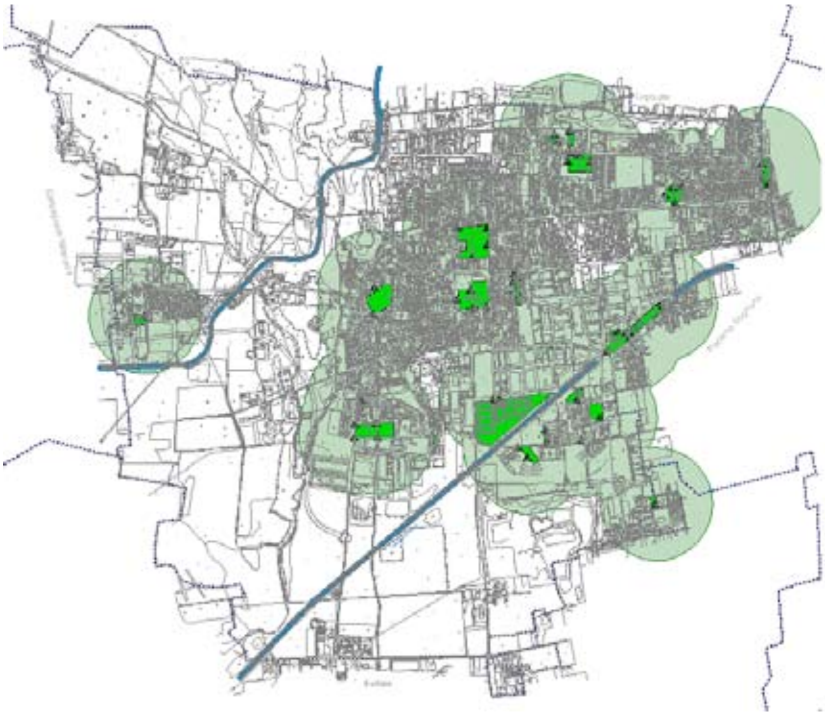

Figure 2 Map of the availability and accessibility of local green areas

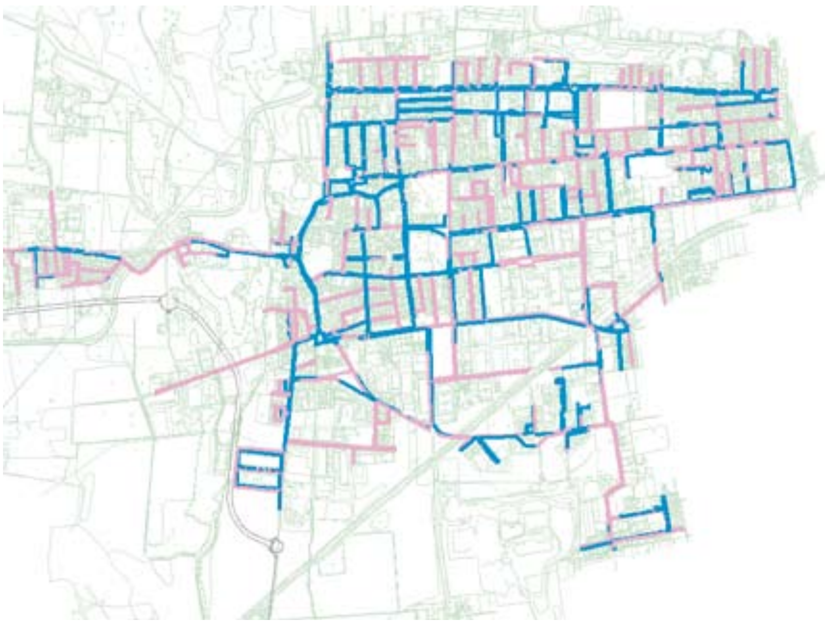

Figure 3 Map of availability of pedestrian paths. Different colours are used to point out the outcomes of the evaluation of these path with reference to the following aspects: width, lighting, flooring and the presence of barriers for users

The overall analysis permitted to investigate, discuss and underline the strong and weak points of living standards and to study in depth the actual meaning of the uninspired numbers, usually called standards of living in plans and programs.

2.2 Calculation of the indicators, results and considerations

Despite the lacks of data and the non homogeneity of them, the 33 indicators (previously described) were calculated. Full information about procedure of calculation, proxy indicators used and quantitative results are reported in the official deliverables. Results of different indicators have been represented and communicated with graphs, images and maps. An overall and qualitative view of the results is available in the following table. In order to briefly describe the complex picture emerging from the analysis carried out in the previous steps, has been assigned a qualitative score to each indicator. The judgment has been scaled in three different levels: bad, medium, good. This kind of assessment means losing the quantitative information and the critical interpretations developed for all the indicators. Even so it can contribute to promote understanding and communication about the territory between government, stakeholders and citizens.

Table 1: overview of the evaluation through indicators; results were translated in a qualitative score (*: bad; **: medium; ***: good; user defined – UD – indicators in bold)

indic.	score	indic.	score	indic.	score	indic.	score	indic.	score	indic.	score
1.		6.	**	**11.**	*	**16.**	**	**21.**	**	**26.**	**
2.	*	7.	**	12.	*	**17.**	***	22.	**	**27.**	**
3.	***	8.	*	13.	***	18.	***	**23.**	**	28	**
4.	***	9.	***	**14.**	*	19.	***	**24.**	*	29.	**
5.	**	**10.**	*	**15.**	*	20.	***	25.	**	30.	**
31.	*	**32.**	***	**33.**	***						

Furthermore, this overview underlines the more critical topics, that needs interventions in order to improve the urban quality. The most crucial topics are built environment (action: to improve rehabilitation interventions), territory (action: to promote conservation and protection of natural resources), mobility (action: to optimize services in order to minimize the use of private cars), economy (action: to encourage sustainable and high technology productive assets).

3. Energy Performance of Built Environment

The calculation of the 33 indicators pointed out important results about the built environment (i.e. buildings performance and energy consumption in buildings and transportation). For calculating indicator “2. Energy consumption” (one of the six indicators of system ENVIRONMENT), a rough survey of energy performance of existing buildings has been carried out. On the basis of the collected data, it is possible to state that main residential conditions are quite suitable and the availability of spaces is quite good (see Table 2).

Table 2: statistical data about built environment of Senago (year 2001)

Num. of families	7238	Aver. residential surface per person	32 m^2
Average num. of person per family	2.6	Average num. units per buildings	3.9
Average surface of residential units	84 m^2	Average num. rooms/Unit	3.6

But, looking at the actual characteristics of built environment and buildings system, it is possible to find out that a scheduled and adequate program for refurbishment is needed. In fact, more than 50% of buildings were built more than 30 years ago and the most part of them were built during years 1946–1961, period in which no performance requirements were considered nor fixed by law (see figure 2, on the left, in which reported data represent a situation that is very popular in Italy). Looking at the shape of buildings and considering surface/volume ratio (S/V), it is possible to suppose a bad thermal behaviour of buildings and high thermal losses (see figure 2, on the right).

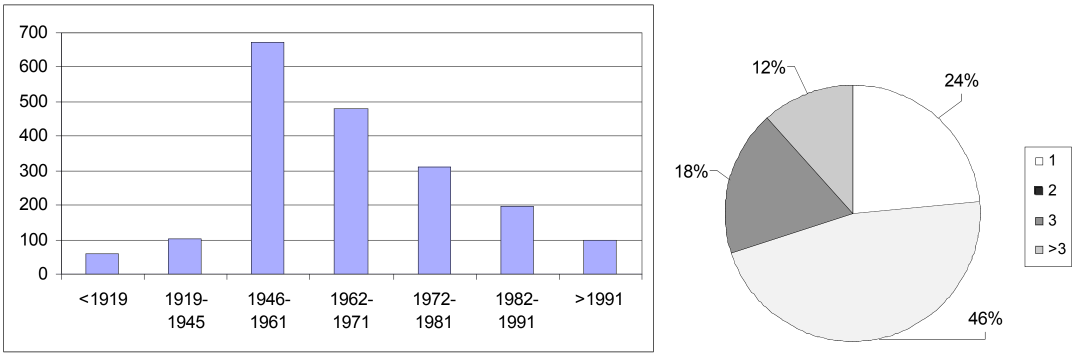

Figure 4 Number of buildings ordered by age (left) and percentage of buildings with 1, 2, 3 or more than 3 floor above the ground (right)

All these considerations are confirmed by data about energy consumption in buildings for heating, cooling and appliances. It was very difficult to find homogeneous and correct data about natural gas (most used source for heating) and electricity and to define the reference built surface and lived space, but at the end it is possible to assert following data:

- natural gas consumption in buildings (all, public and private): about 750 m^3/inhabitant, otherwise more than 200 kWh/m^2 per year, in term of primary energy; analogous results were obtained considering natural gas consumption in public buildings that represent about 3-4% of total consumption; worst performance in term of natural gas consumption was observed in a nursery
- electricity consumption in buildings (all, public and private): about 26 kWh/m^2 per year
- electricity consumption in public buildings: about 40 kWh/m^2 per year.

On the basis of a rough analysis carried out in few public building, these high consumptions do not correspond to good comfort conditions. Further, considering results of a campaign for monitoring air pollution in 2004, it is possible to find out that heating systems and plants contribute for half of the total CO_2 and NO_x emissions. Therefore, despite final result of indicator “2. Energy consumption” represents an average situation if compare with the national Italian one, a wide potential for reducing energy consumptions and, as consequence, CO_2-eq emissions has been pointed; and this information is more important if considered in the framework of new European Directive on Energy Performance in Buildings and following national and local laws and regulations.

4. Participative Approach

Local involvement in planning and management of the environment allows strategies to be tested and refined before adoption, ensuring built environment that satisfy both individual and community needs. Nowadays, there is a growing range of methods that has been developed in different experiences from many countries. They include different ways of listening to what local people have to say about their surroundings referring to different level of participation.

The approach adopted in this study rises from the principles of Local Agenda 21 processes and includes, in particular, three different stages of community involvement: surveying citizens’ satisfaction with the municipality as a place to live and work and the modes of transport of children travelling between home and school, according to European Common Indicators recommendations; inquiring visitors of the local trade exhibition about quality of public spaces by interactive displays; awakening people to environmental issues by public conferences and graphic materials shown during the same exhibition to capture the views of a large number of citizens.

Even if this kind of participatory approach has been applied only ex-ante, because of the term of the assignment, local authority was requested to consider identifying communities’ needs as an ongoing action: before to planning strategies, this gives an idea of how to improve their surroundings; during implementation of actions, it makes sure that you are on target in order to get the maximum impact from the resources spent; after the actions has been carried out, the review of outcomes and outputs is useful to further the development of a community initiative.

5. Developments and Conclusions

In order to improve built environment performances and quality of living by the action plan according to different targets and time steps (short-, middle- and long-term targets), on the basis of the indicators for each topic have been indicated the fields of intervention. More in deeply, has been defined procedures for maintaining and refurbishing existing buildings, for providing low energy and renewable in new buildings, promoting public transportation system and use of bicycles, improving public lighting efficiency, developing environmental protection and monitoring campaigns.

Identifying clearly the targets with the aim to outline an action plan is a very difficult step and needs to carry out deep analysis about available resources, simulation/modelling of interventions, forecasting of outcomes and impacts, in order to optimize them. It will be useful to set up a Planning Office, with the task to check the development of the action plan by updating indicators and to promote communication between local government and communities.

After all, because one of the aims of the PSPQL was to give an overview and to put in communication existing plans and programs for optimizing their effects and evolution, relationships among PQL and the most important defined by law plans and programs have been underlined, as development of the study. For all these reasons, the study can be considered as a promising, interdisciplinary and experimental start for developing actions for the sustainable development of communities.

Furthermore, in this way all decision-makers involved in the process are accountable to citizens, as well as to institutional stakeholders. Transparency is built on the free and accessible flow of information. The process built-up since now has tried to serve all stakeholders by producing results that meet needs while making the best use of resources. Partner relationships are encouraged among authorities and also the creation of networks of cooperation and knowledge transfer which can go beyond the local context.

Acknowledgements

All the people that have contributed to the study. R. Madella and G. Scudo.

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The model simulation of the architectural micro-physical outdoors environment

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Keywords：WRF model、micro-physical environment、weather forecast system

Summary

To pursue higher security, better healthy, and more comfort for dweller, it is very important to study the correlation about outdoor and indoor atmosphere status and the sensitive information of micro-climate meteorology which the building provided. Through the latest meso-scale model "WRF" to process numerical emulation about the Archilife research living center, it could make up the space and time resolution deficiency in traditional weather observed tools, then in accordance with the model emulation results to retrieve information back to the background data of indoor micro climate and weather station, so it could provide more scientific evidence to clarify the relation between indoor, outdoor physical environment and buildings.

The research results reveal that the ability of WRF model emulating the micro climate and weather status is well generally, as for the problem of higher weather factors magnitude in model simulated result than real observed one, especially in wind field, this maybe caused by terrain characteristic and geographical features over there, that could be fixed by improving the terrain parameter and tuning the boundary condition of model in the future.

1.Introduction

The main function of the modern buildings, in addition to provide the residents a secure living environment, the ability of pursuing the quality of life and offering comfortable living is also more and more subjected by people as time goes by. Perceiving the characteristics of weather system and environment around buildings thoroughly, and controlling the period and frequency of variety by the way of following tendency, turning resistance into assistance, and adverse status into fortunate status, the life property will be advanced more effectively and the restriction produced by natural environment will also be reduced. To retrieve the environmental static data into reality generation, then identify the relation between various weather systems owning different scales, and find out the optimum experiment scheme, the scientific significance will be acquired and extracted more legitimately.

2.Research method

The research method is applying the WRF meso-scale model to process numerical emulation about the Archilife research living center. The latest WRF model (Weather Research Forecasting model) adopts the sigma coordinate in vertical plane and Arakawa B cross grid in horizontal plane, and the multi-nest grid scheme could simulate the interaction between various weather owning different scales effectively. For the complex meso-scale weather system, WRF model could make up the space and time resolution deficiency in traditional weather observed tools. Recently, because of improved boundary layer condition, cumulus parameter, and Four-Dimension Assimilation, the WRF model had been used to study and emulate the meso-scale weather system extensively by scientist so far.

There are two level in model grid nested scheme, the procedure is so-called "two-way interactive" method, which could retrieve the fine grid data back to coarse grid data. In order to raise the time and space resolution of model, the grid interval is set from 0.5 to 1.5 km (Fig.1 and Fig.2 shows model coarse and fine grid integral region, respectively) and time interval is set 1 hr to emulate the characteristics of meso- and small-scale weather systems. For model fine grid region, the maximum terrain height in Taiwan area is about 3731 meter, cumulus parameter is set Kain-Fritsch Scheme（Kain and Fritsch, 1993）, then boundary layer is set Yonsei University scheme（YSU, Hong, and Pan,1996）, and micro physics parameter is set WRF Single-Moment 5-class scheme（WSM5, Hong et al., 2004）. The total model integral time is 48 hr, and apply the NCEP（National Center for Environmental Prediction）GFS AVN model data to be model initial data.

3. Verification and examination

For the purpose of understanding the ability of WRF model emulating various weather system more clearly, we choose weather systems occurred from Oct 2006 to Jan 2007 (there are 20 weather systems cases, 80 samples during four month totally), in which including a variety of weather systems (e.g. front, front pass through Taiwan northern ocean, northeastern monsoon in the winter season, cyclone flow near and outside typhoon, cold surge, continental high pressure, and continental high pressure backflow etc.) and weather phenomenon (e.g. low temperature, small rain, rain, rain shower, sunny, and cloudy etc.), we try to investigate the long-term weather characteristics and organization around and near the Archilife research living center in favor of following verifying and examining the simulated capability of WRF model.

Real observed data was adopted from two micro climate observation stations, one constructed at and another constructed near the Archilife research living center, above two stations data was compared each other to get the optimum observed data. Observed data time is 02, 08, 14, and 20 o'clock local time, and observed weather factors include temperature, pressure, humidity, precipitation, and wind field etc, beside verifying and examining WRF model, the model initial time is set 12hr early than the observed data time to avoid the problem of model “spin up”.

Table 1 shows the evolution and variation of temperature factor in this research, in which, the blue line represents the real data recorded by micro climate and weather station, called ”observation-1”, the red line represents the high-resolution WRF model simulated data, called ”simulation-1”, and the brown one represents the low-resolution WRF model simulated data, called ”simulation-2”. The research result reveals that the high resolution model data is more sensitive, exact, and much similar to real atmosphere status then low resolution one, no matter in variation magnitude, profile, and amplitude of temperature factor. For simulation-2, on the other hand, appears excess magnitude and exists some phase shift (displacement) then observation-1, especially in sample from 46 to 52 and from 61 to 67. In general, in simulation-1 and simulation-2, there are more or less excess magnitudes temperature factor (but there are some magnitude shortage samples in simulation-2, that maybe generated by the stable characteristic of wave), especially in simulation-2. As for relative humidity, pressure, and precipitation, the variation tendency of model emulated results are very similar to observed data (figure not shown), that also can illustrate the great ability of WRF model simulated the meso-scale weather system in local area.

4.Simulational results

For the purpose of displaying the excellent ability of WRF model simulated the meso-scale weather system around and near the Archilife research living center and providing residents the latest model data in time to satisfy their living needs, so select the cold surge case occurred during 16^{th} to 17^{th} Dec 2006.

Severe continental high pressure moved southward and northeastern monsoon penetrated directly during 16^{th} to 17^{th} Dec 2006, because the specific location of the Archilife research living center (windward side for northeastern monsoon), there would be obvious variation in various atmospheric weather factors in this period. Fig.3 shows the variation of temperature factor in all Dec month, there were two low temperature phenomenon appeared in 16^{th} and17^{th} Dec which was the minimum temperature value in all Dec month(14℃ in 16^{th} and 13.5℃ in 17^{th} Dec, respectively), followed by cold surge weaken and temperature raised. If consider the pressure variation simultaneously, then the transformation and development procedure of cold surge moving southward can be described expressly. The Severe continental high pressure started to move southward in 14^{th} Dec, then the strength of continental high pressure arrived strongest in 16^{th} and 17^{th} Dec, the center pressure magnitude of continental high pressure is about 1017-1018hPa during this period, followed by strength weaken produced by the characteristic distinction between continent and ocean and far from away the formatted source area of high pressure. The wind field pattern, in which reveals when severe continental high pressure moved southward, accompanied by strong wind field, speed from 8 to 10 m/s in average and sustained 36 to 48 (or above) hr. Clearly, this is a traditional severe cold surge case in winter season because of the obvious variation in temperature, pressure, and wind field factors. For precipitation, on the other hand, there was no obvious magnitude observed by research weather station, this maybe caused by a little amount of water vapor in atmosphere and the track of continental high pressure moved southward.

The model simulated weather factors were a little bit great than observed one in magnitude, the temperature factor was 13-14℃ in 16^{th} and 12-13℃ in 17^{th} Dec in average, this was very similar to real observed data, but there was much variation in wind field, speed about 12.5-15m/s in 16^{th}, and 15-17.5m/s in 17^{th} which maybe caused by the simulated continental high pressure burst southward suddenly. Although the simulated wind field was higher than reality data in magnitude, but the variation tendency is very similar each other (Fig.5 shows the relation of temperature factor between model simulated result and observed data, in which, the correlation coefficient is 0.8667), this maybe formed by terrain characteristics and geographical features over there, so this problem could be fixed by improving the terrain parameter and tuning the boundary condition of model in the future.

5.Discussion and Conclusion

In general, through verified and examined the model simulated results, the ability of WRF model emulated the micro climate and weather system well can be identified, so the simulated results can be retrieved back to the basic information of micro climate and weather data, then provide the more scientific information to clarify the relation between buildings and indoor, outdoor environments, and supply the important parameters of designing and selecting the material of buildings to fit the needs of residents. As for the problem of model simulated weather factors is excess than real observed data in magnitude, especially in wind field, this maybe caused by terrain characteristics and geographical features over there, and that could be fixed by improving the terrain parameter and tuning the boundary condition of model in the future.

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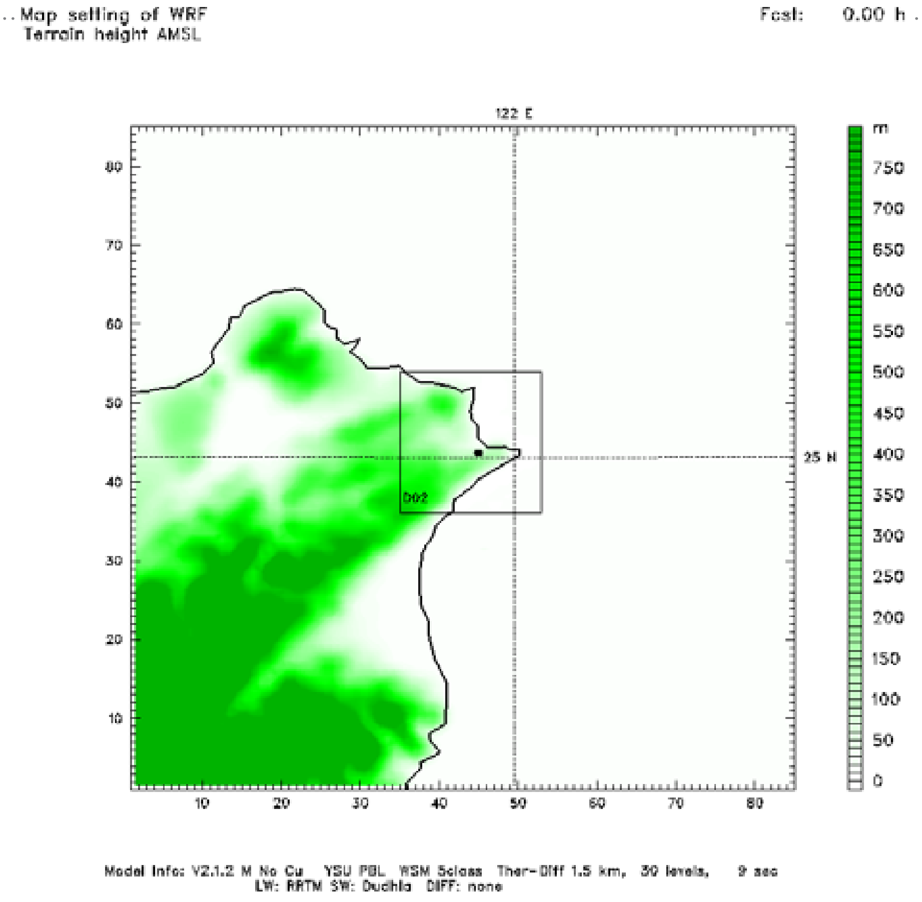


Figure 1. Model coarse grid integral region.

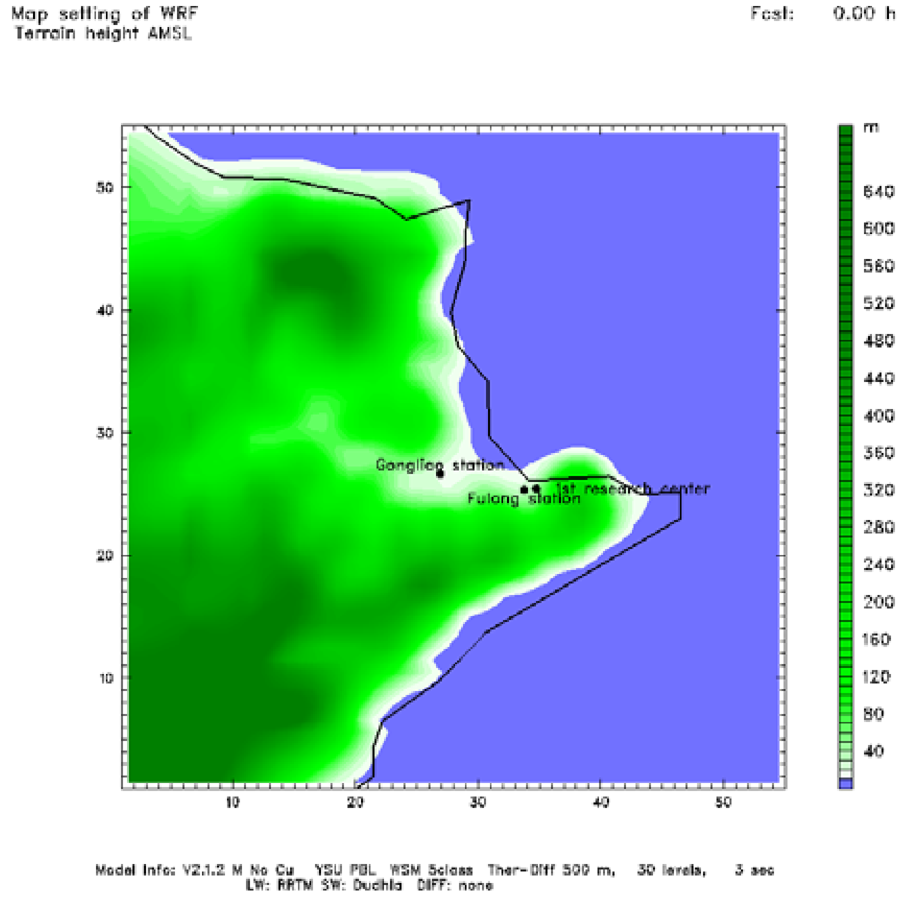


Figure 2. Model fine grid integral region.

Table 1.The evolution and variation of temperature factor at the Archilife research living center in Oct 2006 to Jan 2007 research period (the blue line represents the real data observed by micro climate and weather station, the red line represents the high resolution WRF model simulated data, and the brown one represents the low resolution WRF model simulated data.)

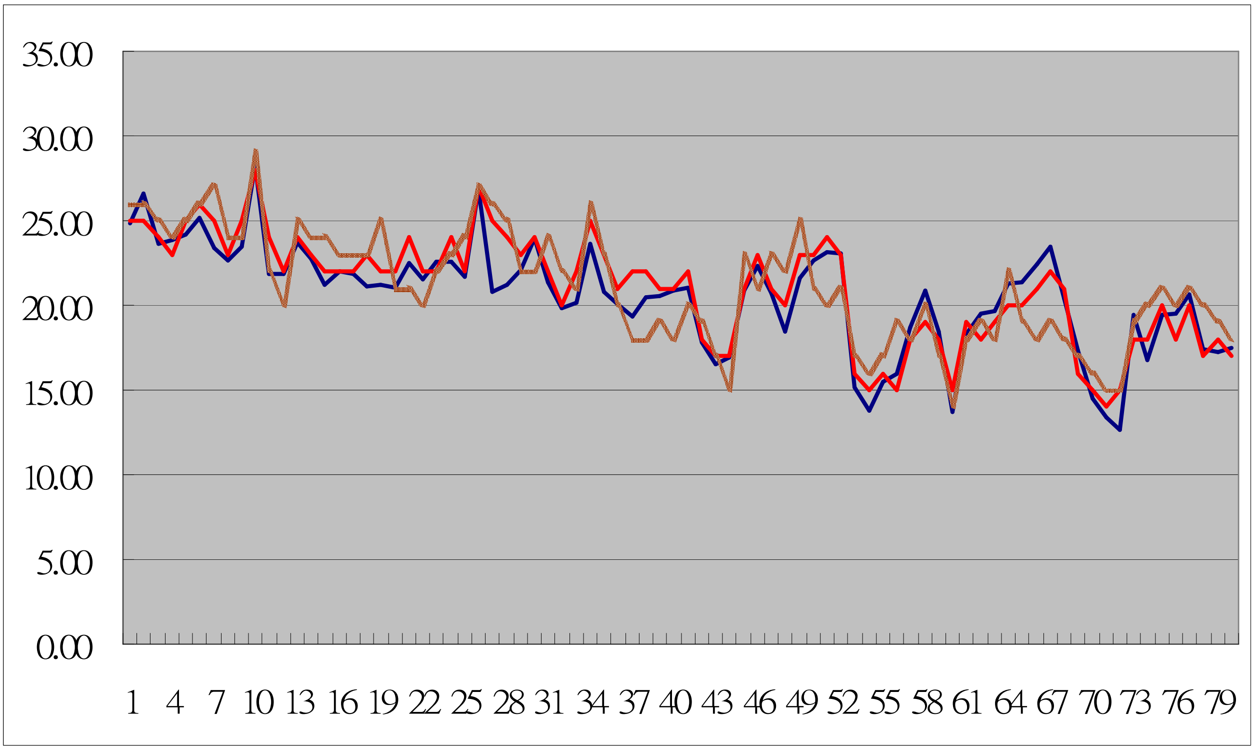
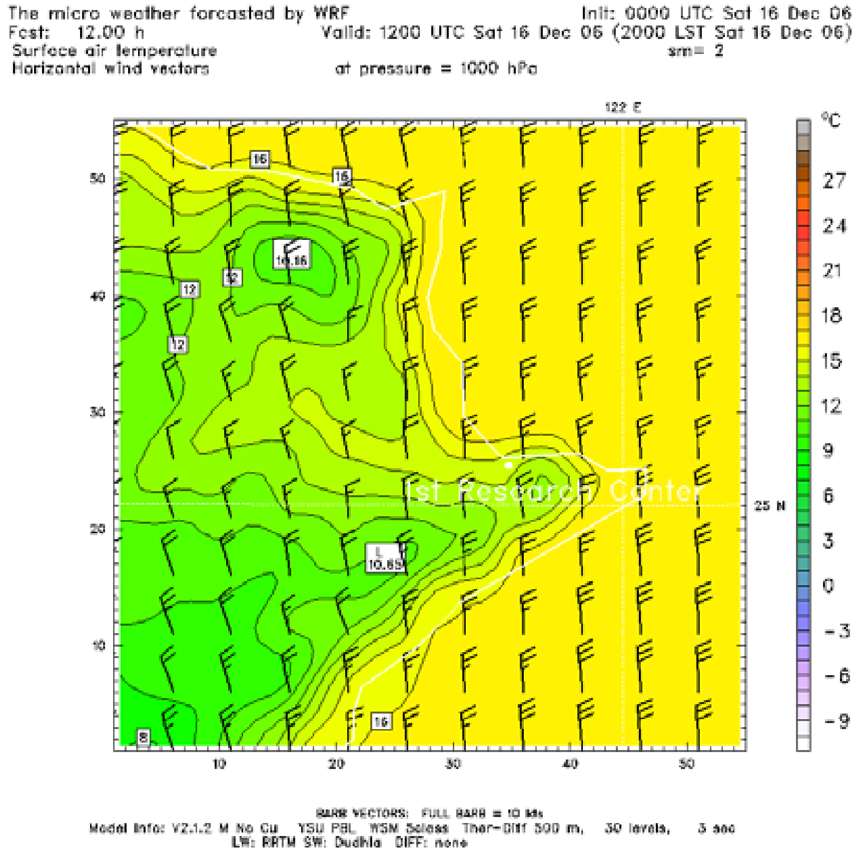
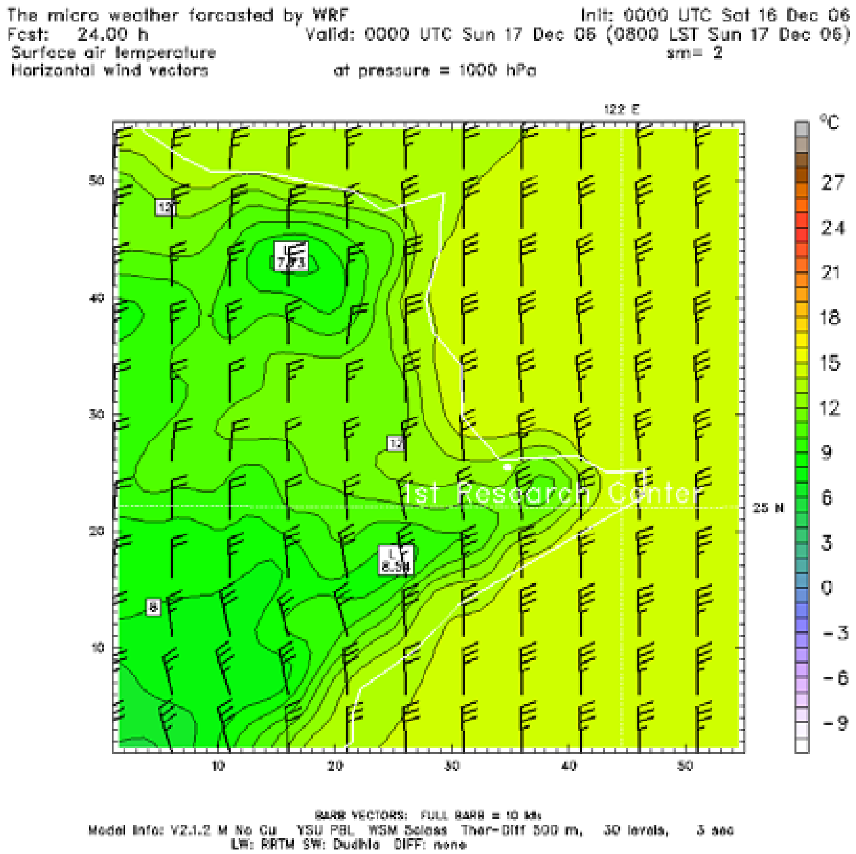


Figure 3. The variation curve of temperature factor observed by micro climate and weather station at the Archilife research living center in Dec 2006.


The micro weather forcasted by WRF
Init: 0000 UTC Sat 16 Dec 06
Fcst: 12.00 h
Valid: 1200 UTC Sat 16 Dec 06 (2000 LST Sat 16 Dec 06)
sm= 2
Surface air temperature
Horizontal wind vectors
at pressure = 1000 hPa
122 E
25 N
°C
27
24
21
18
15
12
9
6
3
0
-3
-6
-9
1st Research Center
BARB VECTORS: FULL BARB = 10 kts
Model Info: V2.1.2 M No Cu YSU PBL WSM 5class Ther-Diff 500 m, 30 levels, 3 sec
LW: RRTM SW: Dudhia DIFF: none

a.


The micro weather forcasted by WRF
Init: 0000 UTC Sat 16 Dec 06
Fcst: 24.00 h
Valid: 0000 UTC Sun 17 Dec 06 (0800 LST Sun 17 Dec 06)
sm= 2
Surface air temperature
Horizontal wind vectors
at pressure = 1000 hPa
122 E
25 N
°C
27
24
21
18
15
12
9
6
3
0
-3
-6
-9
1st Research Center
BARB VECTORS: FULL BARB = 10 kts
Model Info: V2.1.2 M No Cu YSU PBL WSM 5class Ther-Diff 500 m, 30 levels, 3 sec
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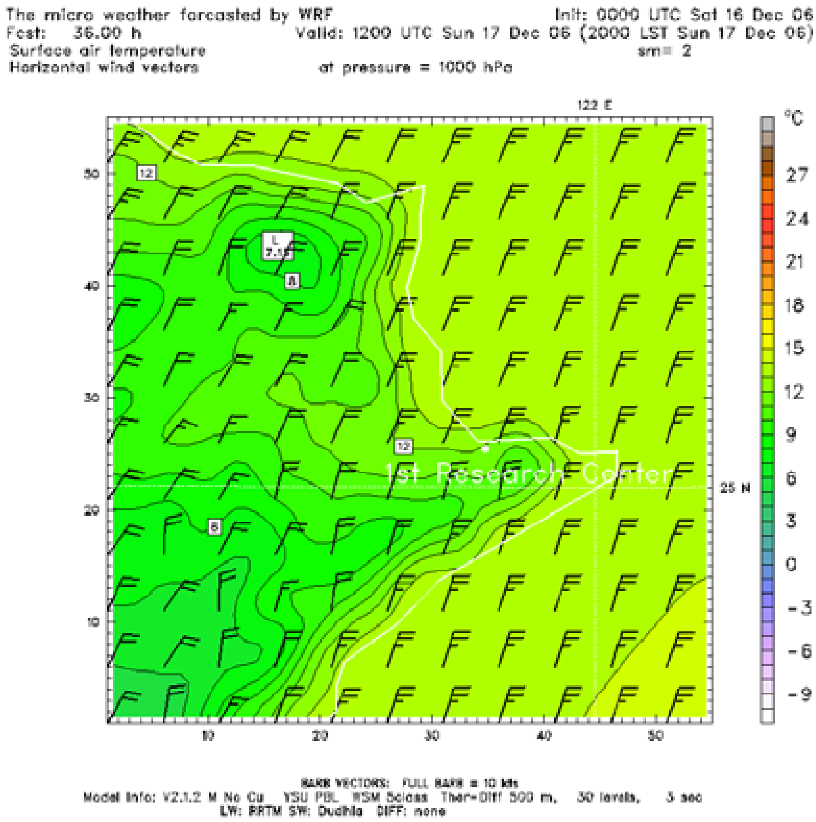
b.



c.

Figure 4.The WRF model simulated temperature and windfield factors, the data time is (a) 20L 16th, (b) 08L 17th, and (c) 20L 17th Dec, respectively, the model initial time is 08L 16th Dec 2006.

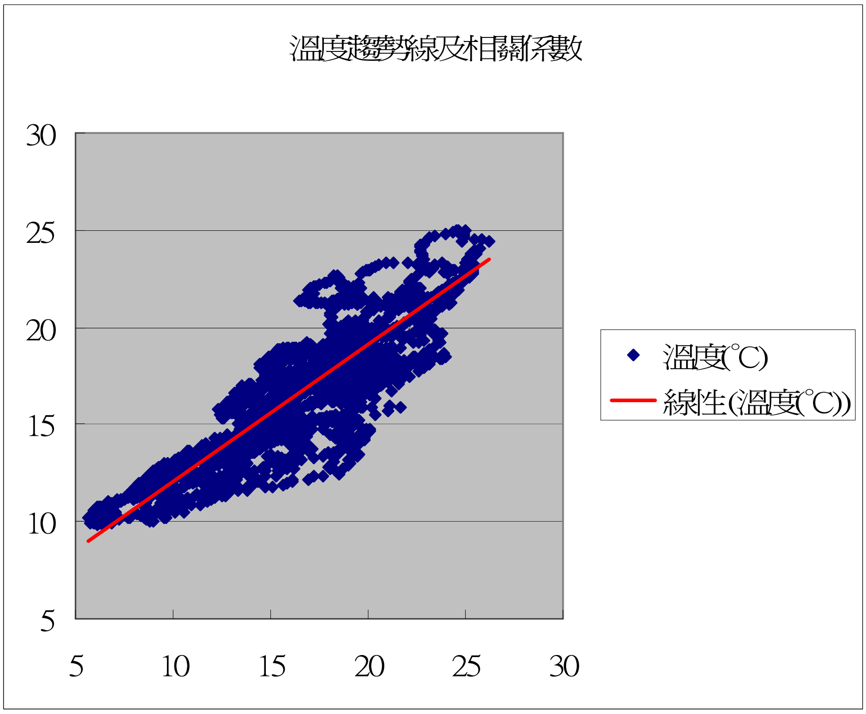


Figure.5 The correlation of temperature factor between WRF model stimulated and station observed.

Design and Development of Natural Ventilation Products and Associated Improvement of Indoor Environment Quality.

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Keywords: Natural ventilation, wind ventilators, Skylight vent

Summary

The Australian / New Zealand Standard, 4740 (2000) *Natural Ventilators- Classification and Performance,* is discussed in this paper. It has provided an ideal platform to standardise and make accurate comparative analysis of natural ventilators exhaust flow rates.

Experiments with various manufacturers' ventilators were undertaken, comparing them to, the relative performance of an unimpeded 300mm diameter opening; the methodology employed and the results of this testing are disclosed in this paper.

New advanced ventilation designs and test procedures are also described in this paper, such as the long volume turbines and improved wind directional vanes, with increased exhaust flow rates.

Product innovation and improved performance and test results utilising the test facility developed for the Australian / NZ ventilation standard has led to the commercialisation of new products such as the Wind Directional Skylight Ventilator and the roof siphon that utilises the hot air in the roof space to further drive the natural ventilation process.

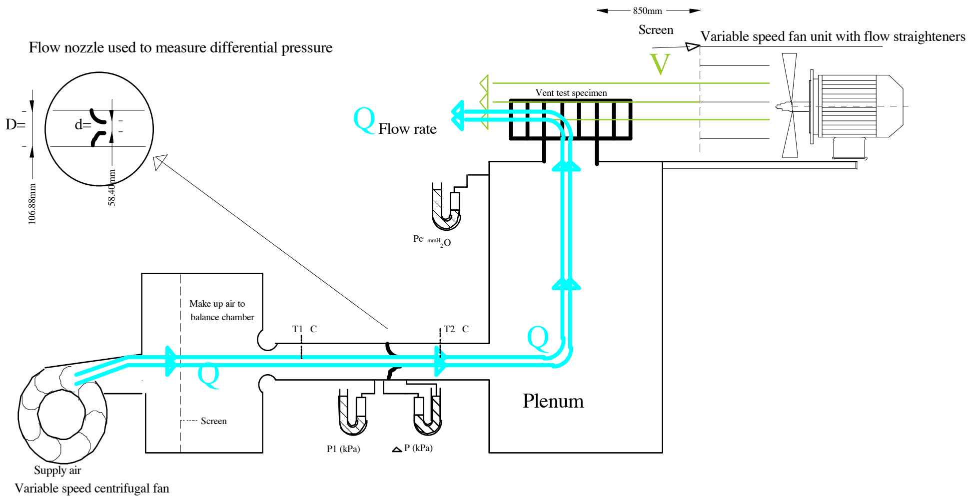
The paper concludes with discussion on the detailed product design of the unique Wind Directional Skylight Ventilator, its measured exhaust flow rates, ability to reduce condensation and improve indoor environmental air quality via natural ventilation and daylight.

1. Introduction

An initial approach by the Australian Consumers' Association (CHOICE) and a leading ventilator manufacturing company to see if low wind speed testing was achievable at the University of Technology, Sydney aerodynamics laboratory, developed into a very successful industry and cross Faculty collaboration. The research outcomes have significantly advanced the understanding of wind driven turbine ventilators and natural ventilation in general.

Following exhaustive trials, a suitable test rig was developed, (please refer to figure No.1.) and a comparative analysis undertaken of most of the ventilators on the Australian market supported by the Australian Consumers' Association.

Following the results of the testing and comments submitted to Standards Australia/New Zealand regarding a draft Standard on Natural Ventilators, the author was invited to join the Standards Committee on Natural Ventilators
This work has resulted in the Australian/New Zealand Standard AS/NZ 4740 2000 Natural ventilators- Classification and performance.



UTS pressure differential ventilation test rig

Figure No.1. The UTS pressure differential ventilation test rig later adopted as the test method for Australian / New Zealand Standard AS 4740.

Several wind siphonage test configurations were evaluated at the UTS aerodynamics laboratory, with reference to results achieved by other testing facilities and to manufacturers published performance. From these attempts at finding the best test methodology to employ, an appropriate testing standard was sought.

No official standard was available so, guidelines were established following trials including variables such as:

Air flow to be measured using a flow metering device as described in AS 2360.1.1 1993 *Measurement of fluid flow in closed conduits.*

A controlled airconditioned environment was considered essential to allow for consistent result which would have otherwise been affected by pressure and temperature differentials, as each ventilator would be required to be mounted on a stack and the pressure and temperature needed to be controlled within the stack, to allow for consistent results, as a decrease or increase in temperature will affect density and subsequent flow rate measurements.

It was assessed that a variable wind speed would be required to be applied as Free Field (unbounded fluid flow field) instead of a closed test station such as a wind tunnel, which would lead to blockage effects. And subsequently each ventilator should be mounted on a stack / plenum chamber and the pressure and temperature controlled within the plenum chamber

It was a requirement to make the testing procedure as realistic as possible to field applications so the results obtained from these tests would establish the relative performance of several ventilators measured to the control- (300mm diameter open pipe 200mm high) as depicted in Figure No.1.

2. Methodology

To test ventilators performance a comparative analysis was undertaken, utilising the developed pressure differential facility. A suitable fan produced the required wind velocity over the ventilator, opening or wind directional vane, giving rise to suction, drafting air out of the plenum chamber. Air pressure is balanced by an input supply fan to achieve ambient air pressure and this in turn is measured applying Bernoulli's principle across a flow metering nozzle as shown in Figure.1 and mathematically expressed, to derive the appropriate flow rate formula:

3. Results

3.1 Comparative analysis of ventilators performance

Ventilators tested were those that are sold commonly in the Sydney market and experimental designs aimed at increasing performance. A fair analysis was sought to compare the ventilators performance at Sydney's average wind speed of 12km/hr.

Ventilators on the market had a range of manufacturers performance and options such as fans (refer to figure No 2.) stated as improving exhaust performance. In fact throat restrictions in the case of some fans actually impeded performance.

Figure No 2. 380mmm throat vent with fan blade fitted.

A significant result of the comparative performance was the effect that throat area had on the flow rate. Comparing a 250mm throat diameter to a 300mm throat diameter,(0.049m^2 and 0.071m^2 respectively) showed a 30% increase in throat area but there is not a proportional association i.e. as the throat increases in diameter the flow rate does not increase proportionally, but increases by an extra15% over the 30% throat increase giving a 45%

increase in flow rate. In experimental designs the limitation of throat diameter was recognised and the ability to increase the blade height was also assessed as being a possible variable affecting exhaust flow. In other words the throat area remains constant but the vent lengthens in blade height to increase its volume, hence the term, long volume turbines (refer to figure No.3).

Figure No. 3. Variable blade height / Long Volume Turbines (LVT's)

In this experiment, keeping the uniform 300mm throat and allowing only the blade height as a variable showed the poor performance of the 170mm blade height model, which only had half the exhaust performance of the 340mm blade height model, which also corresponded to a 25% increase in the blade height over the normal 250mm model and correspondingly increased the exhaust flow by 15%.

The 50% blade height was not manufactured correctly and a 50% increase on the standard 250 should have been 375mm not 340mm, however the hypothesis was proven correct and results were scientifically unique. Blade separation, shape and reduced bearing drag were other factors that were shown to contribute to exhaust efficiencies.

4. New Product development-Wind Directional Skylight Vent

With the on going energy reduction / greenhouse emission campaigns and in line with ESD principles the relevance of stack effect and wind siphonage to provide energy neutral effective ventilation is now gaining the attention of building designers around the world.

Experimentation and extensive CFD analysis with new designs resulted in a unique omni directional aerodynamic foil that ventilates by rotating into the wind and generating negative pressure to extract efficiently and at the same time provides daylight as a vertical light pipe. The Wind Directional Skylight Vent (WDSV) was a product designed to incorporate cost efficient componentry and was laboratory tested to the Australian/New Zealand Standard AS/NZ 4740 2000 requirements. The product is a clear aerofoil skylight that ventilates by turning as an omni directional vane into the wind, giving rise to increased air extraction flow rates, (as seen in Figure No 4 below)

Figure No 4. 300mmm throat Wind Directional Skylight Vent.

The WDSV product will be particularly useful in New Zealand, which has condensation problems. The WDSV has been demonstrated to ventilate at twice the air changes per hour (ACH) compared to the 250mm rotary vent. Another useful feature for local conditions is the purported benefits of daylight into attic spaces discouraging possums and vermin that being nocturnal like to sleep during the day, in the darkened roof space.

Another major benefit of the vent is the ability to locate it over sources of moisture to remove hot and moist air at ceiling height via a tube to the outside (please refer to Figure No.7). As inside temperatures rise, the ability for air to hold moisture rises, which is usually exasperated by warm humid sources such as showers, kitchen sink, clothes dryers etc.

Above the point of the moisture source is an ideal location to have a ceiling vent that will via light tube and WDSV, extract the humid air to the outside environment saving potential dew / condensation forming inside the house as would be the case if warm humid air touches cool windows or walls and results in mould issues leading to asthma and material decay.

The results shown in figure No 5 were all tested at the UTS aerodynamics laboratory, under AS/NZ 4740 requirements, those in yellow by the author on the 20.7.05 and those in red by (Low 2006).

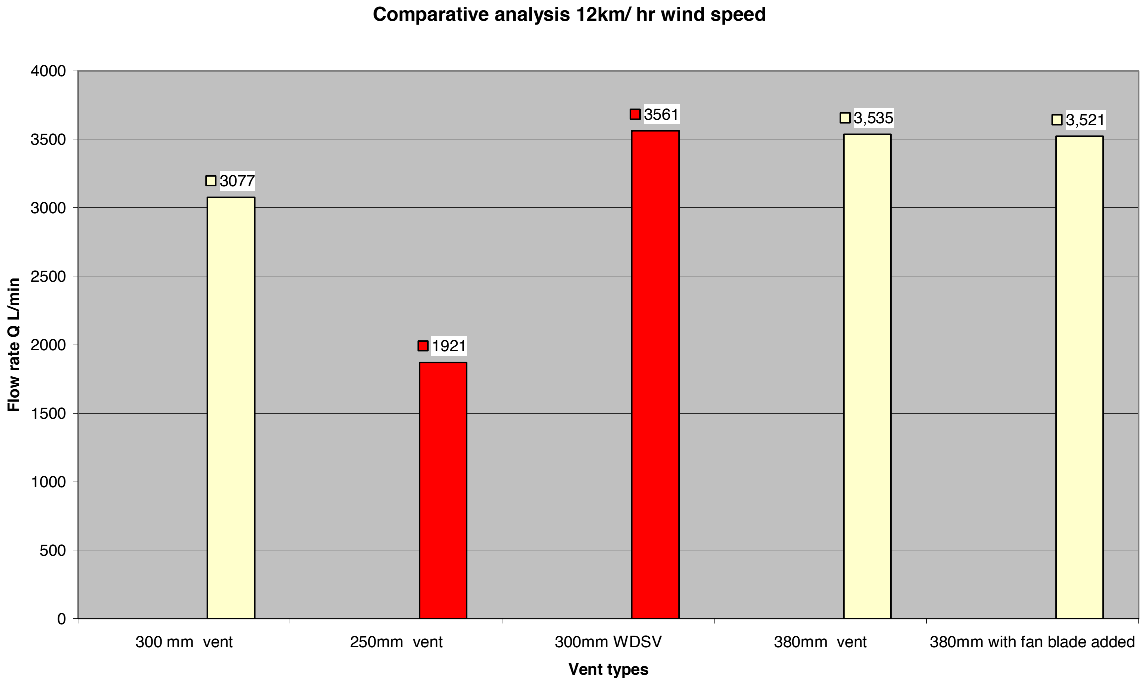


Figure No. 5 Vents tested, 300 mm throat, 250mm throat, WDSV 300mm throat, 380mm throat with and without fan.

The efficiency of the WDSV having a smaller throat size than the 380 mm throat vent but better performance is a notable experimental result as is the slight reduction in flow rate caused by blockage to the throat of the 380mmm throat fitted with a fan blade compared to the relative performance of the same vent with the fan removed.

5. Condensation- IAQ Health Issues

Indoor Air Quality is well known and growing concern and reports have consistently shown that indoor air pollution may be twice or up to five times worse than outside air (Hess-Kosa, 2002). Breathing trapped polluted air, is one definition that could be used to describe the indoor air quality that occupants may be subjected to in some buildings. Even in airconditioned buildings, contrary to the name "conditioned", implying improved air quality; the internal air may have poor filtration and have less than 15% fresh air intake, (Australian Standard 1668 Pt 2 1991, recommends offices to have a ventilation rate of 10 litres per second per person.) leaving the internal air space full of contaminants.

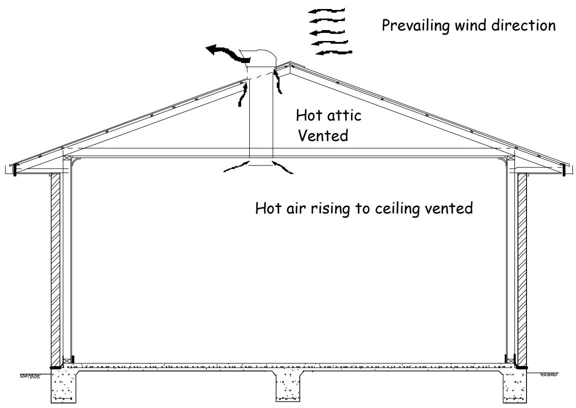
The value of increased ventilation and desired removal at ceiling levels above sources has been identified in several studies such as (Li & Delsante 1997) where range hoods and direct bathroom exhaust ceiling extractor efficiencies were measured. This study showed the efficiency and ability to reduce the spread of moisture and contaminants were best achieved at source before dispersal throughout the building.

The need to further increase and induce air movement in bathrooms and kitchens of Malaysian houses was expressed by (Zain –Ahmed Et al 2005).

Many mould issues associated with bathrooms and carpets having high moisture content have also been shown to have higher dust mite concentrations. In New Zealand studies have suggested that higher ventilation rates are required to overcome the situation of tighter houses requiring greater drying ventilation to reduce moisture content. (Cunningham et al 2001) suggested the need to alter bio climatic conditions and reduce humidity levels to reduce mould growth and associated micro organism proliferation.

The WDSV's ability of reducing moisture laden air at its source over shower recesses is combined with an energy free operation that allows for ventilation to continue unabated and provide a suitable outlet that is required for tight buildings that operate with roof ventilation supply systems that push drier air from the roof attic space or outside into the house, relying on the moist inside air finding seepage out of the building via ill fitting doors etc..

The effectiveness of reducing the moisture at the source, providing daylight to further reduce mould growth and the ability to ventilate at ceiling level are the features incorporated with the WDSV operation that enhances the anti condensation pressure systems by providing a flow path of air to the outside that is capable of greater exhaust than a rotating cowl by also utilising attic pressure, better wind siphonage, and internal stack pressures as shown in figure No 6.



This system has three way extraction: Stack effect, wind assisted, attic siphonage

This arrangement ventilates the room space and the attic space, whilst providing daylight to both the room and attic space.

Roof Siphon

Figure No 6. The Wind Directional Skylight Vent operating as a ceiling daylight and vent combination.

6. Conclusion

The testing procedure developed at UTS and incorporated into the Australian / New Zealand Standard 4740 has provided an ideal platform to standardise and make accurate comparative analysis of natural ventilators exhaust flow rates.

The need to provide ventilation, reduce or dissipate heat and moisture levels inside buildings to improve health and comfort conditions and hence productivity is desirable. However, the costs associated with redesigning, air conditioning and insulation may be prohibitive and simple cost effective natural ventilation methods are now being considered as more sustainable options.

In the experiments conducted, advanced aerodynamic designs have been shown to have increased exhaust flow rates and improved ventilation rates for stack flow and wind siphonage. The increased flow rate will in turn provide reduce heat load and moisture by increasing the air exchange rate. The WDSV's application into ceiling fixtures in conjunction with attic exhaust will assist in reducing mould growth conditions associated with bathrooms and laundries, by exhausting warm moisture laden air to the outside of the building envelope, helping in turn to improve IAQ.

Further to these advances, the development of WDSV technology described in this paper will make another contribution to improving energy efficient building operations, cleaner / healthier internal environments by providing a cost efficiency saving in the product design. Cost efficiency (economic sustainability) needs to be considered in sustainably designed products, in the case of the WDSV by simplifying and reducing the need for expensive mechanical ventilation, and reducing artificial lighting it is a straight forward design that does the role currently of two or three products associated with higher energy demand.

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INDOOR ENVIRONMENT AND ENERGY CONSUMPTION PATTERN OF THE EXPERIMENTAL HOUSE WITH ENERGY EFFICIENT DESIGN

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Keywords: field measurement, simulation, energy consumption, indoor climate, experimental house, energy efficient design, CASBEE

Summary

The aim of this study is to understand the influence of energy efficient design on energy consumption and indoor environment. For this reason, an environmental house was built in Dec. 2005 in the north of Sendai city, northwest of Honshu Island of Japan. It is a three-story house, including a basement, a first floor and a second floor under the pitched roof. The first and second floors were constructed in wood, while basement was built by concrete. The total floor area is about 240m^2.

Many sustainable design components were included for the house. For example, it is well insulated and airtight. The heating transmission rate and equivalent leakage value is 0.86 W/m^2·K and 0.94cm^2/m^2 respectively. It equipped with a 5.64kW solar panel on the roof for electric generation, a solar hot water system is placed in the garden. First floor is heated by thermal storage floor heater using midnight power and cooled by air-conditioner, according to the seasonal conditions. A number of low or no VOC building materials are used, including less polluting paints, wood product, etc. As it is an experimental house, it is only occupied twice a year, a week each in summer and winter. In order to predict the energy consumption and indoor environment of the investigated house in line with the actual state of inhabited residence, simulation was carried out with the condition of 4-person dwelt in the house.

1. Outline of Investigated House

The experimental house (Fig.1.) is a three-story house, including a basement, a first floor and a second floor under a pitched roof. The floor plans of the said house are given in Figure 2. It is an electrified and detached house completed in Dec. 2005. The house is located in the north of Sendai city which is in the northeast area of Honshu Island in Japan. The first and second floors were constructed in wood, while the basement was built by concrete. The total floor area is about 240m^2 and it is well insulated and airtight. The heating transmission rate and equivalent leakage value is 0.86 W/m^2·K and 0.94cm^2/m^2 respectively. Air tightness was measured by the pressurization method. It is equipped with a 5.64kW solar panel on the roof for electric generation, a solar hot water system is placed in the garden. First floor is heated by thermal storage floor heater using midnight power and cooled by air-conditioner, according to the season. The guest room in the basement and the child's room on the second floor are heated and cooled by air-conditioner. As it is an experimental house, it is only occupied twice a year, a week each in summer and winter.

Figure 1 Exterior of experimental house

2. Measurement

2.1 Outline of measurement

Measurement items included energy consumption, indoor temperature & humidity, wall temperature, indoor air quality and airflow rate of the ventilation system. Measuring points of temperature & humidity are shown in Fig.2. The measurement intervals of energy consumption, electric generation and indoor temperature were 1 minute and 15 minutes, respectively. The measurement was carried out from Jan.1 2006 to Oct.31 2007.

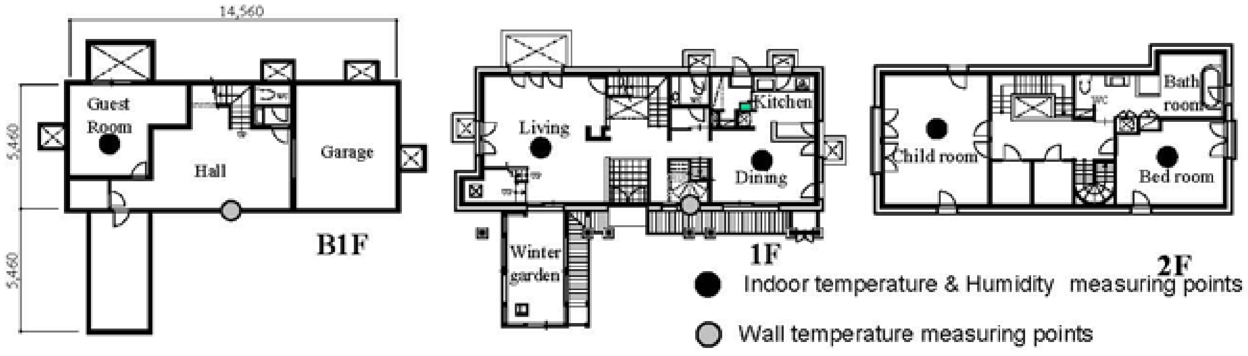


Figure 2 Floor plans of experimental house

2.2 Profile of daily energy consumption and mean temperature

The profiles of daily amount of energy consumption and electric generation by PV, daily mean temperature of the experimental house over the measurement period, Jan. 2006 to Oct. 2007, are shown in Fig.3. In the lower graph under Figure 3, plus and minus signs of y-axis are the amount of energy consumption and electric generation respectively. Hot water supply means the consumption of electric-heated hot water, which does not include the usage of the solar hot water system.

In the beginning of January, indoor temperatures gradually rose from 12~13°C to 20°C. During this period, the heat began to be stored in the building frame. Since the end of January, indoor temperature was maintained constantly at about 20°C. In summer, the temperature on the second floor was generally higher compared to outdoor temperature, while that of the basement was constantly at 20°C due to the ground cooling effect. The operation of floor heater began at the end of November. Since then, the fluctuation of indoor temperature became bigger because of frequent changes of heating set point.

Space heating constitutes a large portion of the overall energy consumption, while electric generation varied between 0 and 34kWh/day. Nevertheless, it is expected that the energy consumption for other end uses would be higher, if the house was occupied.

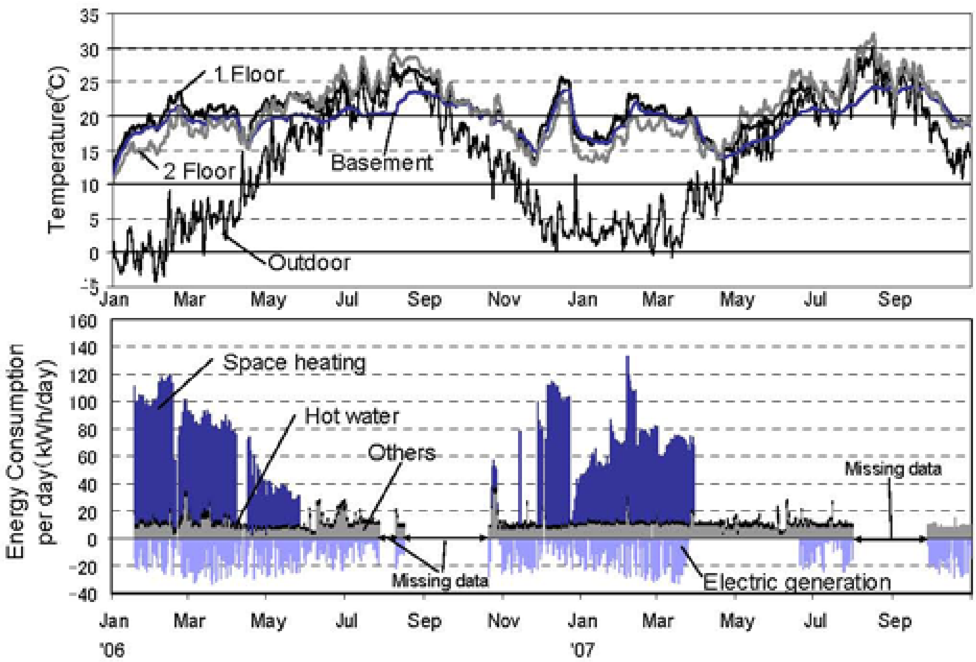


Figure 3 One year profiles of daily mean temperature, energy consumption and electric generation

2.3 Temperature and energy consumption profiles during occupancy periods

For the purpose of this study, 4 persons were living in the experimental house a week each in summer and winter for a week. The temperature and energy consumption profile during the selected three days within the occupancy periods are shown in Fig.4. The per day energy consumption and electric generation are shown in Fig.5.

2.3.1 Winter

Although outdoor temperature varied from -1.0°C to 11.8°C, the temperatures of the first floor and basement were maintained constant at 22°C and 20°C respectively. The energy was mainly consumed from 1 am to 6 am everyday by using mid-night electricity for space heating and hot water supply, while energy consumption was small during other times. In this three-day time, energy consumption for space heating constitutes about 73% of the total energy consumption, while the ratio of electric generation against energy consumption was 17%.

2.3.2 Summer

The fluctuation of indoor temperature was more stable compared to outdoor temperature which varied between 18°C and 32°C. It must be noted that the temperature of the basement floor was maintained constantly at 20°C due to the ground cooling effect.

With respect to energy consumption, there were some peaks of about 3.5kW during cooking hours. The total energy consumption was 0.3 times lower compared to that in winter, while the ratio of electric generation to total energy consumption was 80%.

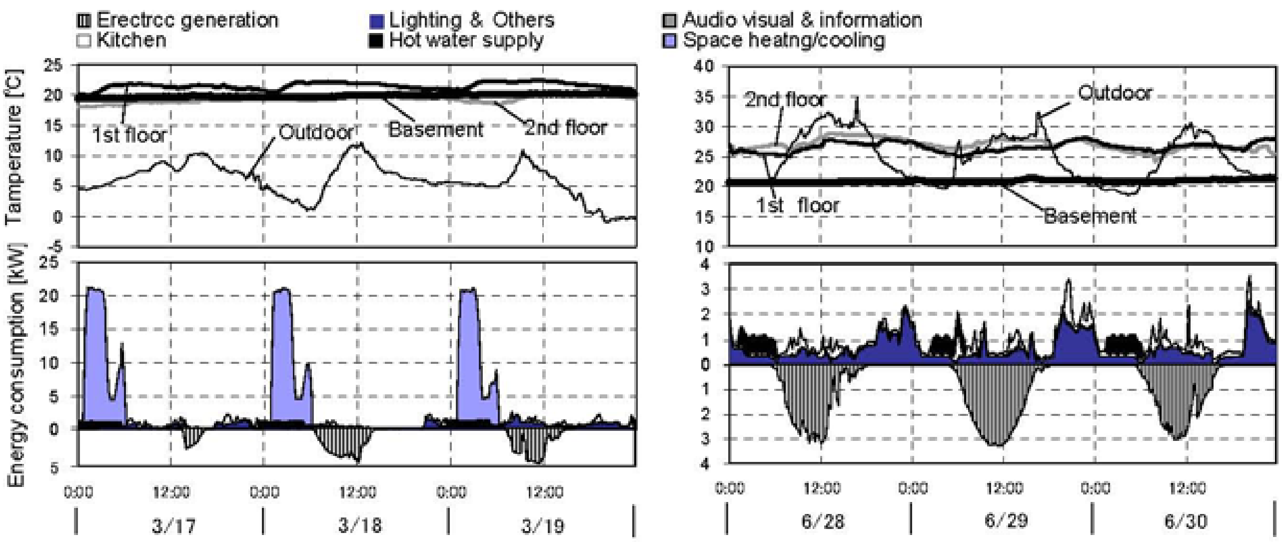


Figure 4 Profiles of temperature and energy consumption during the 3-day occupied period

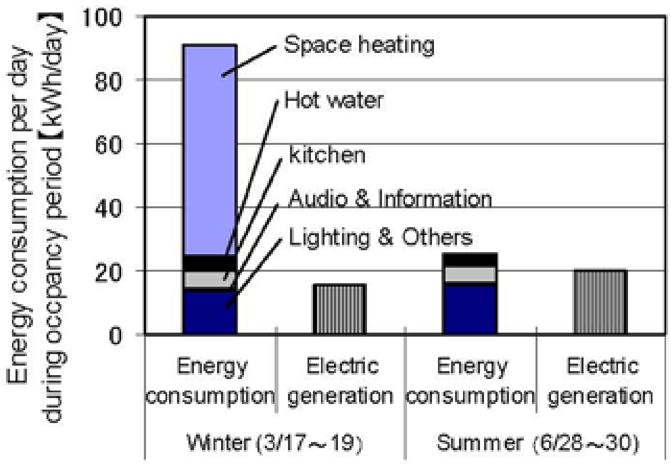


Figure 5 Energy consumption by end use per day of occupancy period

2.4 Indoor air quality

Investigations of indoor air quality were carried out in summer and winter. The results showed that the concentration of formaldehyde was higher than the guideline value (0,08ppm) in summer. In addition, the generation of α - pinene from the woods resulted in that the concentrations of TVOC were much higher than the guideline value both in summer and winter.

3. Calculation

3.1 Outline of Calculation

In order to predict the energy consumption and indoor environment of the investigated house in line with the actual state of inhabited residence, simulation was carried out with the condition of four persons living in the house. Energy consumptions for appliances, lighting and hot water supply were calculated using the program of SHEDULE Ver.2 (SHASE House Energy Simulation Subcommittee (2000). Electric generation by PV was calculated from Sakai's predicted relation (Sakai et al. 2004). Heating/cooking load was calculated, and the data of internal heat generation, building and climate were input into the TRNSYS program (Solar Energy Laboratory University of Wisconsin-Madison. 1996). In the simulation, climate data was the typical climate data in Sendai. A family of two adults and two children was assumed to be living in the experimental house. The set points for heating and cooling were 20°C and 27°C respectively.

3.2 Verification of the simulation model

In order to verify the simulation model, calculated results were compared with the measurements during the occupancy periods, which are shown in Fig.6. (Left: Winter; Right: Summer). The results obtained from calculation for summer and winter show good agreement with the measurements. Thus, the said simulation model can be used to predict the annual energy consumption in a typical family.

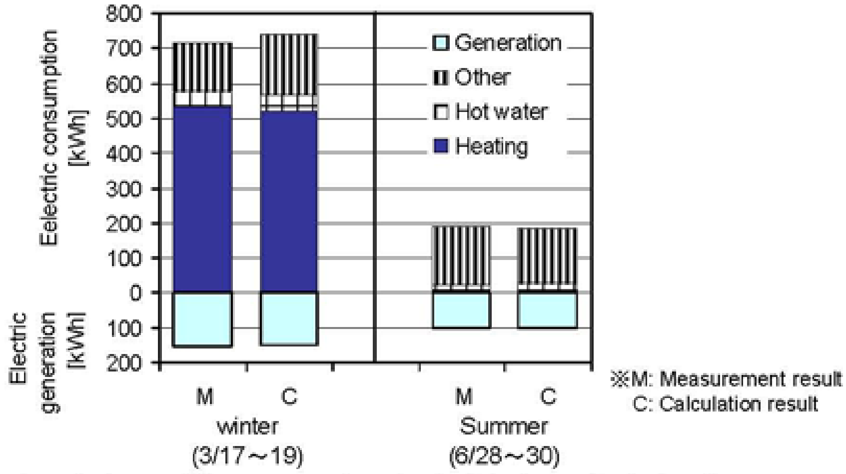


Figure 6 Comparison between Measurement and calculated results during the occupancy periods

3.3 Results of monthly energy consumption and electric generation

The calculated results of monthly energy consumption and electric generation are shown in Fig.7. Monthly energy consumption varied between 2.1 and 9.0 GJ/month. Energy consumption was large in winter due to floor heating, with the maximum value approximately 9.0GJ/month in January. Monthly amount of electric

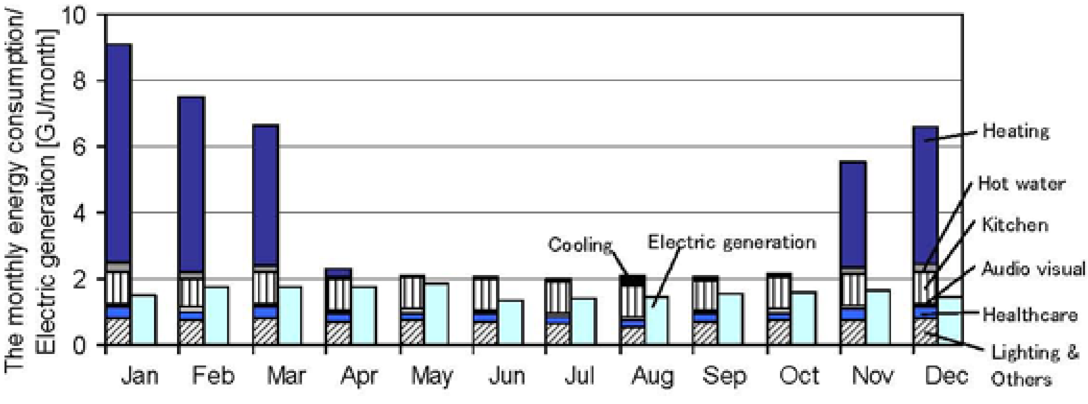


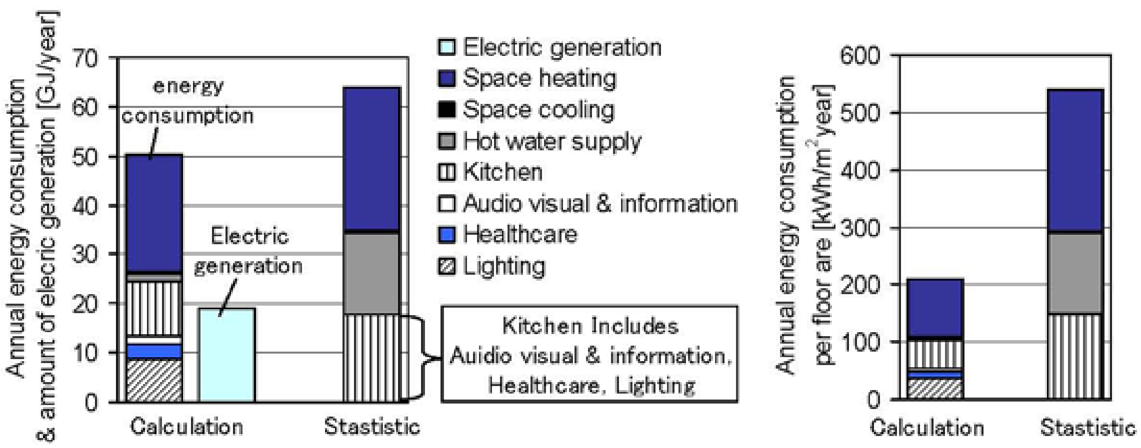
Figure 7 Calculation results of monthly energy consumption and electric generation

generation varied between 1.4 and 1.9 GJ/month. Although electric generation varied according to season, it was less than energy consumption throughout the year. January and May have the minimum and maximum ratios of electric generation against energy consumption i.e. 15% and 88% respectively.

3.4 Annual energy consumption and amount of electric generation

Fig.8. shows the annual energy consumption and electric generation in comparison with the statistical values in the northern region of Japan (Jyukankyo Research Institute Inc. 2004). As shown in Fig.8. (a), the total energy consumption in the modeled house was 50.1GJ/year. The amount of electric generation is 19GJ/year and its ratio against the total energy consumption was 37.1%. The percentage of energy consumption for space heating and hot water supply was 47% and 3% respectively. Hot water supply shared smaller percentage compared to the statistical value due to the usage of high efficiency water heater and solar hot water system.

Fig.8. (b) presents the energy consumption by end use per floor area. The results show that the total energy consumption per floor area was less than 50% of the statistical value in Tohoku region. The reduction rate of energy consumption for space heating was 40% due to high insulation and air-tightness.



(a) Annual total (b) Annual total per floor area

Figure 8 Calculation results of annual energy consumption by end uses

3. Trial of Assessment with Japan's comprehensive Assessment System for Building Environmental Efficiency (CASBEE)

In CASBEE, sub-items are classified into two assessment categories, which are building environmental quality and performance (Q) and reduction of environmental loadings (LR). Table.1 shows the contents of each sub-item. BEE (Building Environmental Efficiency) which indicates the final assessment results is defined by

$$BEE = \frac{Q}{L} = \frac{25 \times (SQ - 1)}{25 \times (5 - SLR)} \qquad (1)$$

In CASBEE, a five-level scoring system is used; SQ and SLR in the above-mentioned definition represent the scores of Q and LR respectively.

Fig.9. shows the final assessment results of the investigated house obtained by CASBEE. The scores of each sub-item are shown on the left hand side while BEE value is shown on the right.

Table 1 The contents of each sub- items

	No.	content
Q	Q1	Indoor Environment
	Q2	Quality of Service
	Q3	Outdoor Environment on Site
L	LR1	Energy
	LR2	Resources& Materials
	LR3	Off-site Environment

Scores of the six sub-items excluding Q3 are above the score of level 3 ("Average"), among them the score of Q2 is the highest (SQ2=4.4) due to the utilization of materials which have long life span (e.g. the life of the building frame is more than 100 years). In addition, the scores of Q1 and LR1 are also very high due to the installation of high performance insulator and renewable energy systems, such as installation of solar panels and solar hot water systems, etc. On the other hand, however, since the investigated house was an experimental house which was not built inside any usual residential area, there were some difficulties in evaluating the outdoor environment on site and off site. Thus, in this assessment, the items concern with the surroundings in Q3 and LR3 were given the scores of Level 3 ("Average").

The calculated BEE value of this investigated house is 3.1 while it is only 1.0 of the general houses only 1.0.

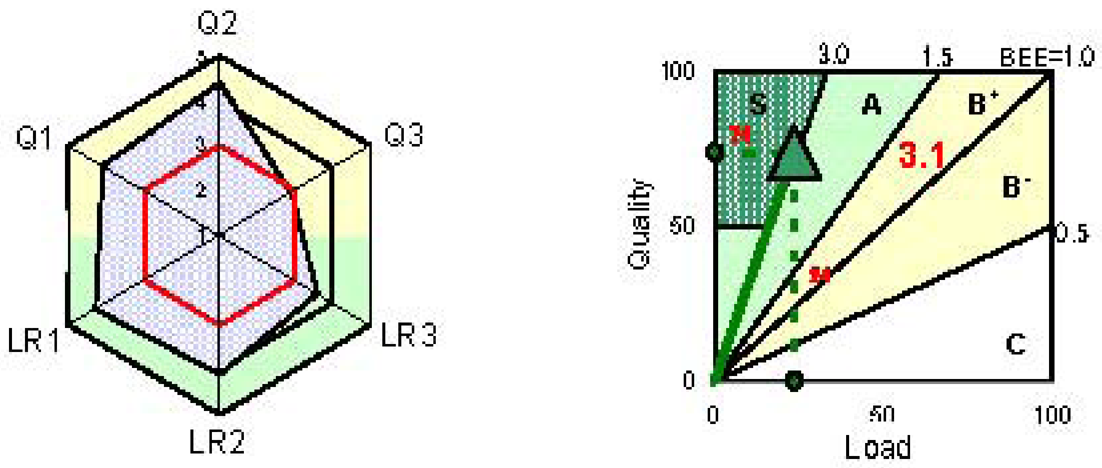


Figure 9 Final assessment results of the investigated house obtained by CASBEE

4. Conclusion

This paper provided a detailed description of the indoor environment and energy consumption of the experimental house in Tohoku district of Japan.

Measurement

(1)The temperatures of the first floor and basement were maintained constantly at 22°C and 20°C, respectively, during the occupancy period of winter. In summer, the temperature of the basement was stable at 20°C due to the ground cooling effect.

Calculation

(1)Energy consumption ranged from 2.1 to 9.0 GJ/month. The ratio of electric generation to energy consumption was maximum in May i.e. 88%, and minimum in January i.e. 15%.

(2)In term of annual energy consumption, the energy consumptions for space heating and hot water supply constituted 47% and 3% respectively of the overall energy consumption. The ratio of electric generation against energy consumption was 37%.

(3)The annual energy consumption per floor area was 0.4 times lower than statistical value for Tohoku region.

(4)The calculated BEE value of this investigated house is 3.1.

Acknowledgements

This study was carried out in cooperation with many people who participated in "Sustainable house program workshop". The authors would like to express their appreciation for the cooperation of those who were involved in this study.

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LIDERA - AN ASSESSMENT SYSTEM TO SUPPORT ENVIRONMENTAL MANAGEMENT – FACTORIAL APPROACH

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Keywords: sustainable construction assessment, environmental management system, factorial analysis, regenerative sustainable construction

Summary

LiderA is a Portuguese voluntary assessment system, developed by the author at the Civil Engineering and Architecture Department in IST/TULisbon, and it is in place since 2006 (www.lidera.info). The system has a new component methodology, trying to support the challenge of identifying the opportunities to improve the performance like factor 2, 4 or 10, involving new measures, ways of use and environmental management of the building, its components and the main stakeholders involved. The factorial approach involve: (1) environmental aspects identification, (2) factorial improvement analysis to the project and/or to the users, (3) the LiderA criteria environmental improvement performance is compared with major life cycle cost and other viable analysis in order to (4) support design decision, user mode or management. The results of the analysis applied to the certification cases show important variables of control, influence and management and also new possibilities to the project, renovation or management. This paper presents this new factorial analysis approach, major cases results and implications to project design and environmental management in the building.

1. LiderA – What is it?

LiderA is a Portuguese voluntary building assessment system, developed at TULisbon (Pinheiro e Nunes, 2005). It has a global approach that in the limit could have 50 assessment criteria organized in: Site and integration, resources consumption efficiency, load impacts, indoor environment and functional aspects (durability, accessibility, environmental management and innovation).

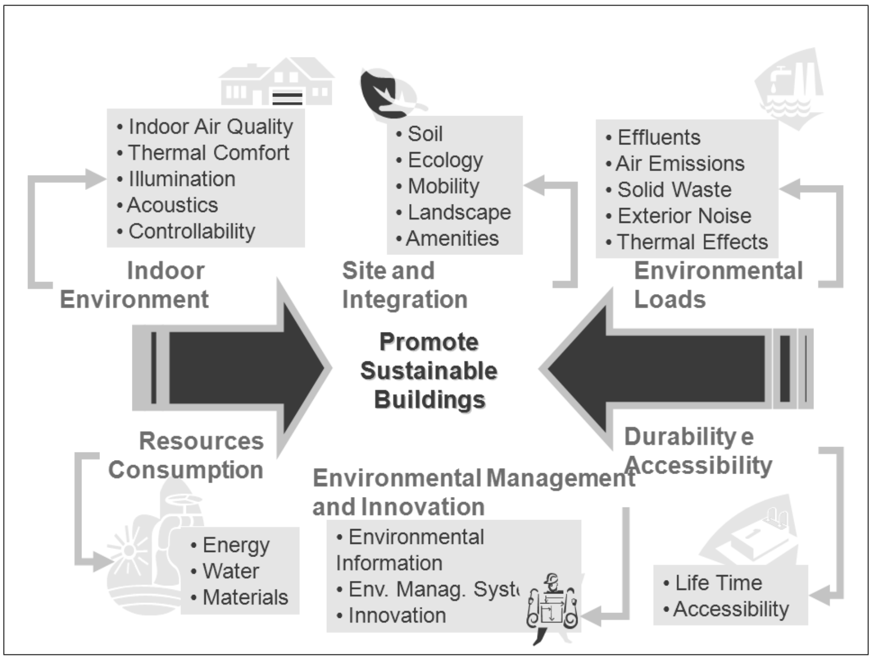

Figure 1 LiderA main areas and aspects

Each of the criteria has environmental performance levels from the point of view of sustainability that can be compared with different performance levels, which should be better than existing practices, supplying a final evaluation of the building and built environment. The system allows the assessment of the building's life cycle development in all phases and is applied to different typologies.

The LiderA system performed in 2007 five certifications with class A, and is estimated that in 2008 will certify 27 others. The first five Portuguese certifications in 2007 show an important environmental performance improvement of the different buildings in the standard use mode that, in average, represent an increasing of 50%, that is a A class in LiderA.

Figure 2 First five LiderA certifications (Class A)

Nevertheless the search of sustainable level, challenge the building design, the users and managers in order to get a structural improvement of the environmental performance, in energy, water, materials, loads, interior environment, and other functional areas. The main questions lie in knowing how it can be build a performance level that lead to sustainable construction not only in a design phase but also in the use and management of buildings and infra-structures.

2. Sustainable construction and performance level?

The sustainable construction definition has a broad variation and aspect (Cole, 2003; Kibert 2005). But in general that include a better environmental performance improvement (that must support future balance), social benefits, that in some ways of thinking at least do not create a strong increase of economic construction costs to other, although that is acceptable to others, even if in the framework of the whole cost cycle, it will lead to equal or even smaller costs.

In each of the approach one of the fundamental questions is to know **what are the levels to be pursued in order to achieve sustainable construction and promoting the changing process**? Looking, for example, to Portuguese data, there is strong evidence (Figure 3) that construction works and its products impacts (Pinheiro, 2006) are of huge importance and in some cases, like energy and water, this impact is growing.

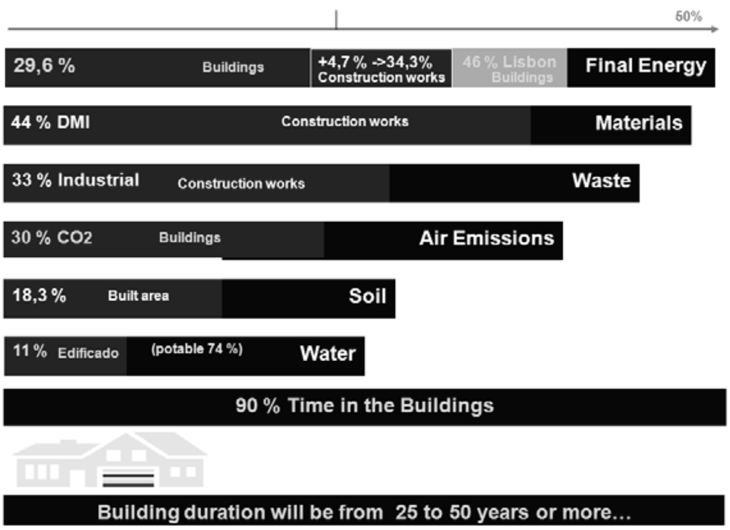

Figure 3 Portuguese construction environmental impact profiles

If the new buildings or the refurbishment of older will lead to increase performance when compared with the existing, for example by 25% or 37.5% or 50 % that is an important achieve and is a progress towards sustainable construction. In LiderA system that levels will mean a class C, B or A.

The international certification is begin to show that costs can be reduced (Landgon, 2004), that value can be create (RICS, 2005) and that it is possible and economically viable, as the LiderA practice in the first certification constructions in 2007 (class A) show it is possible to achieve those levels with good practice and to be economically viable.

The results and costs depend of measures taken, but the mainly important aspect is that, from the beginning, one should try to include a holistic approach that try to assure the main ecological local characteristics, a bioclimatic approach and to include solutions that allow the reduction of water consumption and comfort improvement.

When we look to ecological footprint (pointing out that Portugal need two more areas equivalent as available, direct material inputs (DMI), with 17 tons per capita per year) and to the actual impact level and trend, it is a point of the major importance to change the actual trend in increase of consumption and environmental impact changes, in order to begin to reduce those impacts.

So, if society wishes to achieve sustainable levels, the performance level must be done in the framework of the buildings and construction project life time that is 25 to 50 years. In that time period performance must be greater than 50 %, for example in Portugal must be at least a factor four improvement. In some cases, like materials, we can speak about a factor 10 (Schmidt-Bleeck, 1993) or even a factor 20 (Ryan, 1998).

Is there that variation in the environmental building performance? If you look to possible environmental performance in buildings we find that the potential performance variation, when compared with the practice, could be larger that a 50 % increasing, for example in energy, from 1-10 until to 1-20 (Ratti *et. al*, 2005), and that also happens in others areas like water and natural habitats (Pinheiro, 2008).

In some specific and more precise areas it is possible to have solutions that could improve to factor 4 with viable solutions, for example after assure natural illumination in energy illumination the classic lamps could be replaced by CFL (compact fluorescent lamps) that represent a factor 4 improvement with economic viability and in the future the led lamp can be a viable factor 10 solution. Nevertheless, actually there is no substantial evidence that some of these levels could be economically viable in several areas.

Even there is strong beliefs that an holistic approach, as bioclimatic solutions, can have synergetic results when performance improves and can pass the cost barrier and even achieve levels in which the result could be not necessarily a zero level, but a positive net balance in terms of energy, water and ecosystems, what can be defined as regenerative solutions (Reed, 2006).

These new levels factor 10 or regenerative can be define as the level that truly assures sustainability since it inverts the negative impacts not only to a low level but in order of a positive impact. In LiderA factor 4 is an A+ class, Factor 10 or regenerative is an A++ Class and further get an A+++ Class.

3. Factorial approach

The system has a new component methodology trying to support that challenge and to identify the opportunities to improve the performance, like factor 2 or 4 or 10, involving new measures, ways of use and environmental management of the building and its components. The factorial approach involve: (1) environmental aspects identification and what is the performance position in that criteria, (2) factorial improvement analysis to the project and/or to the users, (3) the LiderA criteria environmental improvement performance is compared with major life cycle cost and other viable analysis in order to (4) support design decision, user mode or management and identifications of the opportunities to improve the performance.

3.1 Performance position

The first step in the analysis involve the understanding of what is the environmental performance level, namely if it is equal to usual practice or if is better by a factor 2 (A), 4 (A+), 10 (A++) or other. In that logic the solutions must be assess in a global level in order to obtain what is the factorial improvement in relation with the usual practice.

The performance position must at least be defined in a standard building use, for example if it is an hotel there will be an average annual use of the system during an average day, concerning for example the energy systems (it could be illumination during six hours, computer working during one hour, cooling or heating during six hours and several support systems during twelve hours).

The first five Portuguese certifications show the important environmental performance of the different buildings in the standard use mode and in four of them the results in real use. As it can be seen, in Figure 4, in these five buildings most of the criteria's (50 x 5) are better than practice, including 83 criteria classified as factor 2, that means 33,2% (50 criteria x 5 cases =250 criteria), 21 criteria achieved factor 4 (8,4%) and 14 criteria reached the 10 factor (5,6 %).

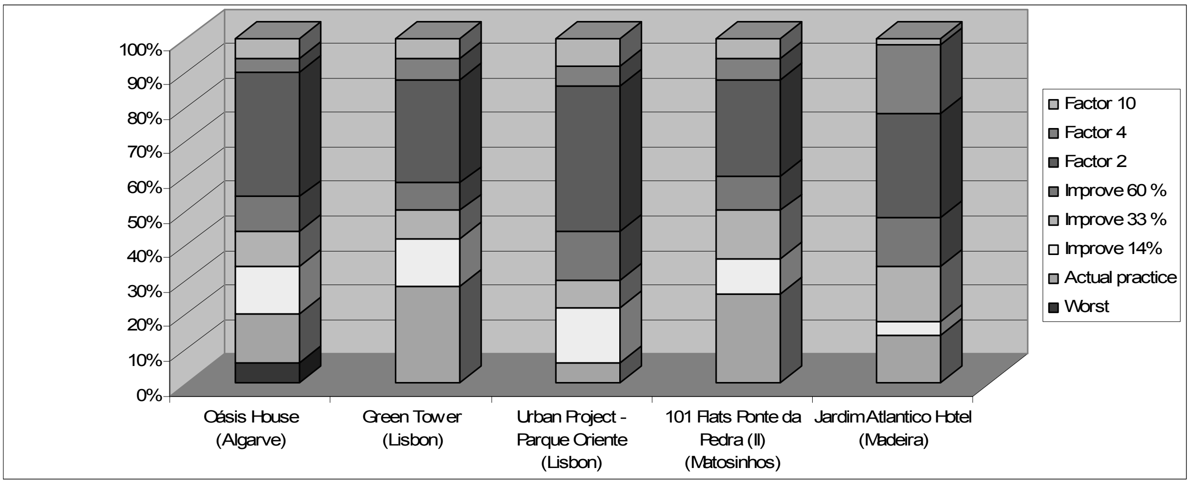

Figure 4 Actual factorial levels of the five first LiderA certifications cases

3.2 Potential Factorial Improvement

Nevertheless the search of sustainable level, challenges the building design, the users and the managers, in order to get a structural improvement of environmental performance, in energy, water, materials, loads, interior environment, and other functional areas.

So, one of the potential analysis is to see what kind of solution or measures will improve the performance, according to two perspectives, one from the project (new or refurbishment) and another from the operation actors, like user, maintenance or management.

There are several studies about what are the different components contributions, like building project, equipment systems, users and environmental conditions; for example Ratti (*et al.*, 2005) found a variation of 1 to 20 in energy consumption in offices, and pointed out (Figure 5) that it explains 2.5 by options of project design, 2 by the type of system, 2 by the environmental context (climatic and urban) and 2 by the user contributions.

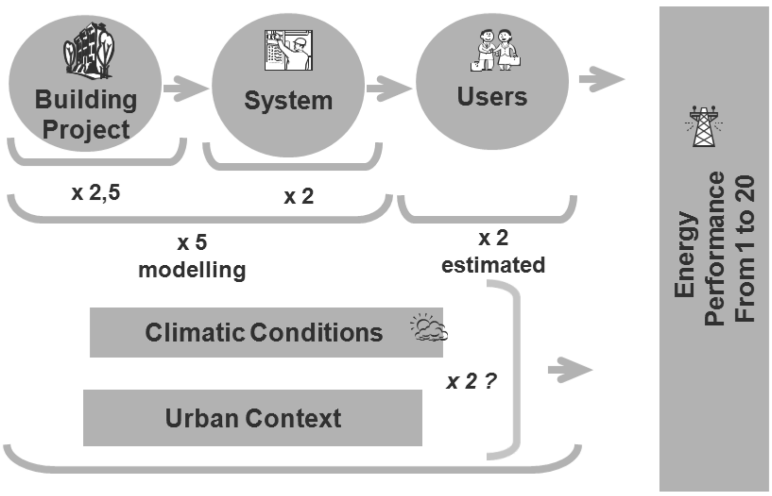

Figure 5 Example of different component contributions in case energy operation offices (Ratti, et al., 2005)

The importance of each component can be different, but in general the contributions result from one side from design, that includes project and equipments and also a response to context (as bioclimatic architecture) and from the other side are related to the users. In specific studies it has been shown (Pinheiro, 2008) that the user can have a contribution of 2 and in some areas, like water, the users and management can achieve a contribution up to 10 times.

The main aspects to factorial improve performance must look to solutions to be include in the building and also to the users. In order to see the approach it is presented the analysis of one of the LiderA certificated buildings, namely the Hotel Jardim Atlântico.

Even with an environmental performance that, in average, is 50% better than other similar hotels, the LiderA factorial module application at Jardim Atlântico Hotel found opportunities for improvement, both in refurbishing of the buildings as well as in use and management of energy and water, among other aspects.

For example, the hotel applies several measures that significantly contribute to water use reduction. One of them is a roof drainage system for collection of rainwater (C19). However, this system isn't working because there is not an appropriate storage and pump system. If a storage tank and a small pump were installed, the rainwater could be reused in the pool and for other purposes (toilets, floor cleaning). With this solution the hotel could achieve an additional consumption reduction in water from public supply of nearly 25%. Together with better use of wastewater, which could be treated to irrigate green areas, it can be achieved a final water consumption of less than 25% of the usual practice in hotels, which is factor 4.

The energetic field was targeted with several measures and special attention was given to the main goal, which was to reduce the electricity consumption (C11). At a mid term, the increasing of the equipment efficiency and wind energy and photovoltaic integrated façade will allow to achieve at least factor 4 in electricity consumption and electricity from renewable sources.

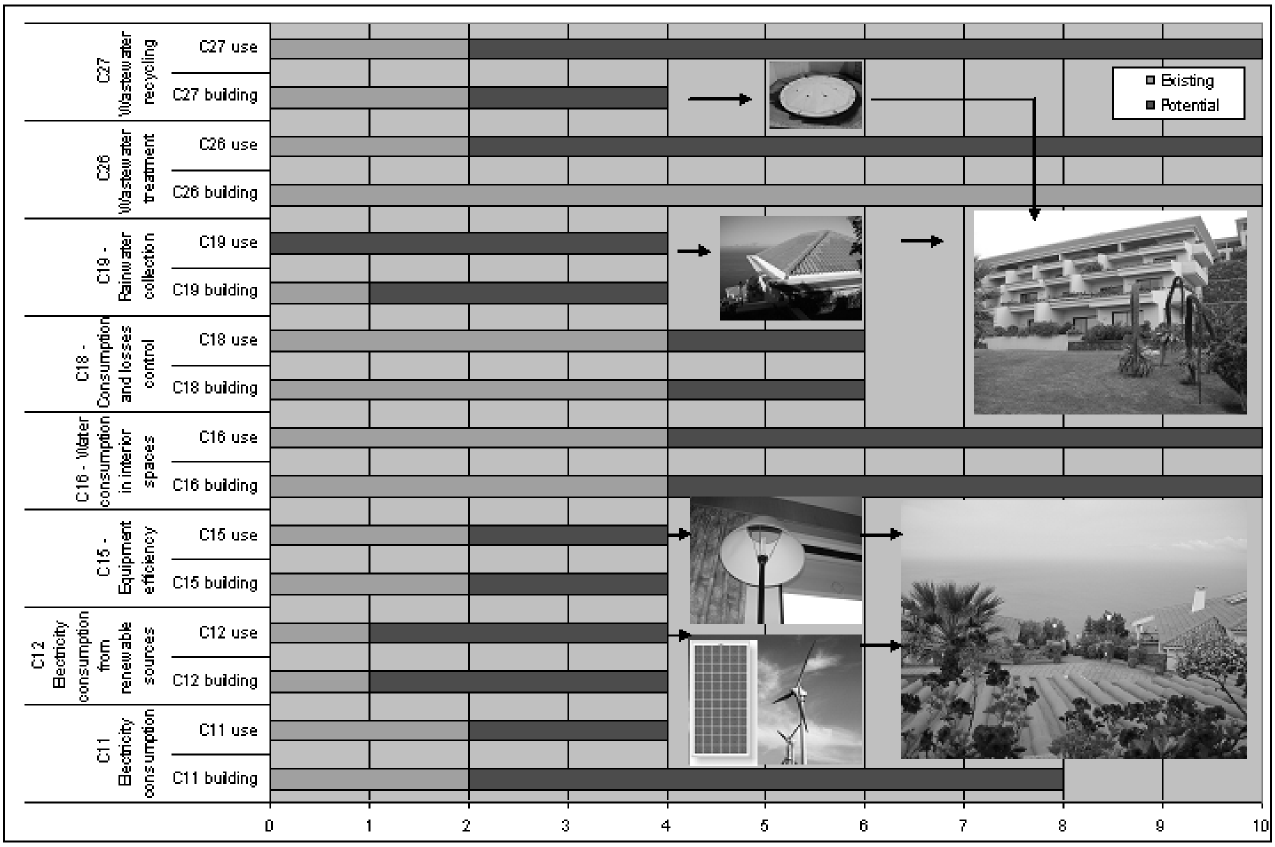

Figure 6 Profile examples of some possible environmental measures to be applied to Jardim Atlântico Hotel (Pinheiro, 2007)

Naturally each solution proposal can have a direct and secondary impact, for example when CFL is used, this reduces the thermal loads from lamps and have an indirect impact in the need of cooling, or when new taps with lowers flow are introduced that will also lead to reduce the effluent flow and wastewater treatment requirements.

So, after the definition of solutions to be considered, there must be a global analysis in order to obtain the global result from the measures including the direct and indirect impact, decreasing or increasing of the performance level. That analysis will give the new building proposal level in a standard use, allowing to know what will roughly be the energy consumption, like electricity (C11), water consumption (C16) and the other LiderA criteria's.

Another important point is that the real performance will result from these building characteristics (solutions and system present) but also, not from a standard use, but from the real use in practice in a day and day base. So the factorial analysis also considers what kind of information and actions can be done in order to have a better conduct by the manager and the users.

For example, it is available in Jardim Atlântico Hotel a system that collects rain water (C19 building) but this system is not actually in use to irrigate green areas, because that is not a practice and requires further collect system, which means that even if that will be a possible use there will be the need to give training in order to have a new practice (C19 use).

So the potential factorial improvement analysis consider not only the possible changes in building measures and its factorial progress but also the potential actions, practices and procedures to management and other users. So that analysis will allow reaching an enhanced in factorial real improvement.

3.3 Viability Analysis and support to decision and management

In the next step of this factorial analysis it is assessed the life cycle cost of the proposed measures, including payback time and environmental improvement resulting from its applications. In the analysis it will be seen what aspects must be changed, in order to fulfill the performance of the measures.

Based in this information the decision is made by the responsible and that can be: (a) to implement the measures, for example in the renovations of the buildings, including a meter to monitor the water losses (C18 building) or a training program to the workers to reduce water losses (C18 use); (b) prepare the building organization to progressive changes in order to get a timeline to be applied, this is the case of photovoltaic solutions (C12 building) or the use of pluvial waters (C19 building) or (c) solutions to support better management, for example introducing a mechanism allowing the use of recycled wastewater in different green areas (C27 use).

From this analysis solutions were identified, in order to be included in the building design as measures to be taken in the environmental management, both applied to workers and suppliers, in a base of command and control or awareness, and also to the users as influence logic.

4. An approach that support environmental management

In most of the cases there is an informal environmental management, and in other more structural approach the environmental management is done in a formal way with the most common environmental management system (ISO 14001).

Nevertheless the ISO 14001 system is not a guarantee of achievement of a good environmental performance or of the promotion of a sustainable management in general areas including sustainable construction (Pinheiro, 2008). Because the ISO 14001 standard allows choosing the targets and goals to achieve, it does not have a specific focus in sustainable issues.

Sustainable construction is challenging the environmental management in order to have the appropriate requirements. To support sustainable construction through environment, LiderA approach propose a supplementary requirement to the most common environmental management system (ISO 14001) in order to achieve sustainable construction.

The main lines include an environmental performance assessment process with factorial increasing level (as previous defined) and an organization process that adjusts formal requires together with control and influence management.

LiderA system have a standard performance use in the different areas defined, for example electricity consumption (C11 building) and that level can be compared with the real electricity consumption (C11 real) allowing management to understand how well is the real performance and if there are opportunities to do actions in order to get a reduction in real consumption.

These actions can involve the working forces (in the case of offices, hotels or other) with orders, indications, or influential actions, but also the users, in this case concerning mainly to influential actions. Since we have also measures to the users, managers and other agents in factorial analysis (C11 use) this can lead and support management in that actions.

For example in Hotel Jardim Atlântico there is in place an ISO 14001 environmental system that control environmental aspects and involve workers and other parts in the search of a better environmental performance, but also have an extensive and appellative information to the users explaining the measures and what can be done in order to have a better environmental performance.

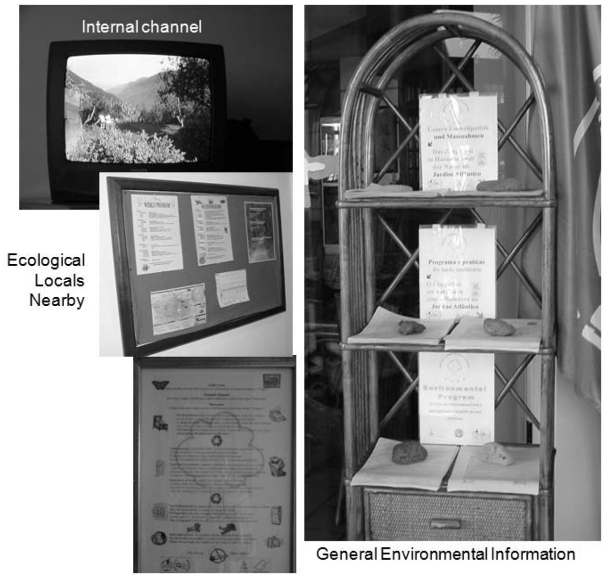

Figure 7 Environmental information's to the users (in Portuguese, English and German) in Jardim Atlântico Hotel

In another case, known as green tower in Lisbon, there is a guide (Manual) to the users and building administration that explain how to use bioclimatic system like Trombe wall and other specifications in order to improve performance and also assure how, when and what must be done to have the system function, including maintenance.

Even if there is no ISO 14001 system in Green Tower, besides the Manual, there is an intranet where it is presented the month consumption and costs that allow each user to understand the environmental performance and react if he wishes so. Until now this is not available but LiderA give recommendations in order to have also a list of good practices.

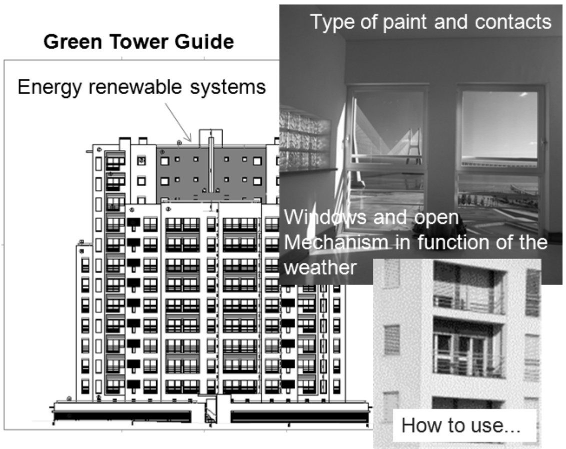

Figure 8 Example of Green Tower Guide

The five study cases above designated show the approach application in phases like design, operation and support to construction phase, to different uses as residential, tourist and others. The results point out the potential effectiveness and efficiency in the sustainable search with improvement opportunities in design and also in supporting the management.

5. Performance level will lead to regenerative environmental management?

The application of factorial analysis to construction using LiderA shows the actual performance level, Class A, that is a factor 2. The approach allows, even in the preliminary design, to know where you are in environmental performance and which steps must be taken in order to structurally improve environmental performance; for example the global measures that includes others than the present in Figure 6, can allow Hotel Jardim Atlantico achieve a performance near factor 4 (Class A+) in the next five years.

Results of the analysis applied to the certification cases, show that, even besides the performance, they still have important variables of control, influence and management and also new possibilities to the project, renovation or management.

Also the promoters, designer or owner that achieved an A class, begin to question what they can do to get a higher performance class, and, when they achieve a level, what can be done if they want to get better results (in the base of their viability). So this can create a new dynamic and *momentum* that can lead to a performance that might be regenerative and in that point, possibly will be understand as strong sustainable.

6. Concluding

The use of LiderA approach allows, even in the preliminary design, to know where you are concerning environmental performance and which steps must be taken to improve environmental performance, in a factorial order given a timeline to medium and long term search.

The results of the analysis applied to the certification cases show important variables of control, influence and management and also new possibilities to the project, renovation or management. This paper presents this new factorial analysis approach, major cases results and its implications to project design and environmental management in the building.

The first five Portuguese certifications show the important environmental performance of the different buildings in the standard use mode and in four of them the results in real use. Nevertheless, the search for a sustainable level, challenge the building design, the users and the managers in order to structural improve the environmental performance, in energy, water, materials, loads, interior environment, and other functional areas.

So, this analysis allows a search of important solutions to design, to manage, and also how to use and maintain, identify and promoting structural environmental performance, in a factorial order, that support design and environmental management in the way of sustainable construction.

This approach opens new methodological possibilities, new needs and further applications in sustainable construction. The method described is one the first steps to other potential holistic approach involving design, maintenance and the users in order to achieve sustainable buildings and also to support management to walk in the direction of sustainable communities.

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An initiative to establish a sustainable building based on an ecological symbiotic planting method and healthy food supply system

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Keywords: Symbiotic relationship, Indigenous wild vegetable planting method, Healthy food supply system

Summary:

To create a sustainable building our objective held that the focus could not be on just the infrastructure of the building itself, but had to integrate the symbiotic relationship of human and the other be chosen organisms.

Based on the premise that food cannot be replaced in our daily lives but can be modified, we turned to experimenting with indigenous edible plants. A very important step is taken toward sustainability by increasing the recycling efficiency of the food materials and decreasing the food material input. A vertical planting system was integrated onto our experimental sustainable building. We developed an ecological symbiotic planting method dependent on the growth and various seasonal characteristics of the wild vegetables. Most of these wild species have special physiological functions according to Chinese medical theory. The subsequent development of eleven different functional diet types provided along with guidelines and recipes in a manual help not only to alleviate various symptoms of disease, but guard against malnutrition and climate changes.

The project has been successfully operational for the past four years and presently provides abundant nutrients for the residents in the twenty-four existing units. Minimum maintenance is required as the selected vegetables have a strong propensity for growth and self-propagation.

This viable regenerative food supply results in a green web-like cover for the experimental sustainable building. It has an additional effect of regulating internal temperature and reducing overall carbon emission.

1. Introduction

To create a sustainable building our objective held that the focus could not be on just the infrastructure of the building itself, but had to integrate the symbiotic relationship of human and the other be chosen organisms. It becomes more important than before that because of the pressure of climate change.

Global food supply deficiency will happen in climate impact that had been proved by many scientists. A very important step is taken toward sustainability by increasing the recycling efficiency of the food materials and decreasing the food material input in our daily life. Based on the premise that food cannot be replaced but can be modified, we turned to experimenting with indigenous edible plants.

Indigenous wild vegetables are the most important symbiotic species to human being in our system. There are many sustainable factors to grow wild vegetables becoming human being's foods, including no pesticide and without chemical fertilizer, containing special nutrition and with medicinal purpose, and friendly to surrounding environment.

A vertical planting system was integrated onto our experimental sustainable building. We developed an ecological symbiotic planting method dependent on the growth and various seasonal characteristics of the wild vegetables. Most of these wild species have special physiological functions according to Chinese medicinal theory. Following these functions, we developed a series of healthy food supply system.

The result is the Symbiosphere Center 1 (SBC-1) with its unique eco-cycle of material recycling; planting; composting; and food supply.

2. Material

Wild vegetables, Map, Tools for wild vegetables collection, Vertical planting system, Plant taxonomic textbook, Chinese medicinal textbook

3. Method

For understanding the resources of wild vegetables to set up the ecological symbiotic planting method and healthy food supply system, we investigated the species of vascular plants within the radius of five kilometers around SBC-1. Some wild vegetables were collected and chosen to be planted on the vertical planting system in SBC-1.

The planting strategy is mix planting by cultivated different varieties together. The cultivated vegetables and wild species were mix planted with equal ratio. Following the characteristics of plants, a stable symbiotic ecosystem was built by this way.

Most of the wild vegetable varieties can be planted and grown together very well except for some intruder species. Following the characteristics of these indigenous edible plants, several good mix planting models were identified and set up.

Under severe climate impact, the relationships of environment, body constitution, and wild vegetables were very important for health regulation. For this reason, we focused on studying the features of wild edible plants, medicinal plants and the relationships with health regulations.

4. Results

4.1 Investigated Indigenous Wild Vegetables for Ecological Symbiotic Planting Method

Wild vegetables are the key point to develop the ecological symbiotic planting method. These indigenous plants can be cultivating very easily and becoming good foods, environmental controllers, and healthy resources. It is very friendly to environment and saving energy and resources to cultivate wild vegetables in our planting system.

For introducing these wild plants into SBC-1, we investigated the plant resources within five kilometers radius around the building（Figure 1, Figure 2）. In our investigation, we found 564 species of vascular plants. There are 132 species of wild vegetables in these varieties of vascular plants（Table 1）. Some of these varieties had been introduced to SBC-1. There were 51 varieties of wild vegetables had been transferred and recorded their growth conditions in the first year.

Figure 1.　Within the radius of five kilometers around SBC-1.

Figure 2. Investigated the plant resources and collected wild vegetables

Table 1 Number of plant resources

Item	Number of vascular plant species	Number of vascular plants with medicinal purpose	Number of wild vegetable species	Number of wild vegetables with medicinal purpose
Pteridophyta	34	21	6	4
Gymnospermae	6	3	0	0
Angiospermae	488	173	126	107
Dicotyledones	418	152	105	87
Monocotyledons	70	21	21	20
Total	564	197	132	111

4.2 Introduced Wild Edible Plants into Symbiotic Center 1

In the second year, we transferred and bred 71 kinds of plants from SBC-1 nearby again, and planted them on the vertical planting system（Figure 3, 4）.The planting strategy was mix planting to let different wild edible plants were cultivated together. We cultivated vegetables and wild vegetables with equal ratio and mixed planting them. A stable symbiotic ecosystem was built by this way.

We found this system need one or two months to become a stable ecosystem. The wild vegetables, insects, microbes, environment, mankind reached a dynamic balance. Through the season changed, their relationships changed. Some wild vegetables replaced by the other species, and attracted different insects. Wild vegetables were the main stable factors that reduced cultivated difficulties and let this system work easily.

This strategy let plants growth very well, abundant and harmony. Mix planting wild vegetables and cultivars reduced the pest and pathogen. By way of observation about four years, we found this system still can work very well. Most of wild vegetables can propagate their descendants by themselves, the new generation of plants appeared on the vertical planting system. This is a very new system to plant vegetables easily, and supply healthy foods providing abundant life.

Fig 3 Vertical planting system

Fig 4 Mix planting

4.3 Studied on the characteristics of symbiotic wild vegetables

It is a good way to approach the sustainable building from combining the wild vegetables and buildings. Based on the premise that food cannot be replaced in our daily lives but can be modified, we chose indigenous edible plants as the foods and medicines of residents.

Most of these wild species have special physiological functions according to Chinese medicinal theory. In total 564 species of vascular plants near by SBC-1 were including 197species of medicinal purposes. On the other hand, in all of 132 species wild edible plants, there are 111 species with medicinal functions. All of the medicinal functions are including 11 types: body constitution regulation-45 species trend to cold and cool, 10 species trend to hot and warm; 16 species related to satiation; 32 species for improving immune system. Related to gastrointestine system, there are 14 species help antidiarrhea, 12 species advantage egest; 16 species related to bone and skin; 10 species improve eyesight; 22 species related to circulation; 55 species related to metabolism. There are 61 species for hemostasis (stop bleeding) and detumescence (reduction of swelling); 9 species for reproduction adjustment; 47 species salve symptom of cold. Then we compiled the medicinal functions manual of wild edible plants for residents to maintain or improve health.

4.4 Healthy Symbiotic Wild Vegetable Diets

Under the global climate change, healthy wild vegetable diets must be considered about the interaction of human, wild vegetables and environment to bring this system into full play. In order to check the healthy food supply system from Chinese medicinal theory, we developed series diets by indigenous wild vegetables to enrich the living of habitants in SBC-1. In our study, wild vegetables were recombined to become salad or other style foods to neutralize the effect of body and weather interaction. Four types wild vegetable diets were classified：Dry materials, raw, cooked, and reproduced products（Figure 5, Table 2）.

We focused on studying 5 parts of diets including salad, sauce, oil, fresh tea or soup, and spirits. The typical sauce is combined with oil, vinegar and protein. We suggested using the light sauce for spring and using thick sauce for winter. The oil in the sauce can use non-saturated fatty acid from wild vegetable seeds.

On the other hand, we made the wild vegetable sauce bases especially for sauce with different flavors easily. For example, we chose Ailanthus or Tarragon for summer, and Chinese mahogany, perilla and basil for spring.

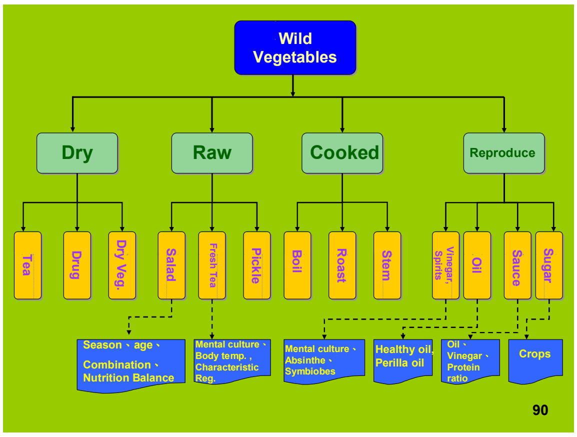

Fig 5 Four types wild vegetable diets

Table 2 Principles for Wild Vegetable Recipes by Seasons

	Spring（2,3）	Summer（4,5,6,7,8,9,10）	Autumn（11,12）	Winter（1）
Wild Vegetable Salad	Cold 5% Cool 30% Neutral 30% Warm 30% Hot 5%	Cold 20% Cool 50% Neutral 20% Warm 5% Hot 5%	Cold 5% Cool 20% Neutral 30% Warm 40% Hot 5%	Cold 0% Cool20% Neutral 20% Warm 50% Hot 10%
Sauce	Light Oil	Light Oil	Thick Oil	Thick Oil
Vinegar	High Ratio	High Ratio	Low Ratio	Low Ratio
Soup	Major Light Soup	Major Light Soup	Major Thick Soup	Major Thick Soup
Tea or Spirits	Herbal Tea	Cool Wild Vegetable Tea	Herbal Tea	Herbal Spirits Herbal warm Tea

We found there are two potential oils can join our symbiotic wild vegetable diets. One is perilla seed oil, the other one is Oil tea camellia oil. Perilla seed oil contains most of the α-linoleic acid in all of known plants. The α-linoleic acid is the precursor of EPA and DHA. We chose the traditional way to produce perilla seed oil by hand made, including four steps: fried, crash, steam, make shape, and press. Finally, we got the perilla seed oil with light yellow color. The other important component in sauce is vinegar, it comes from wild vegetables interact with symbiotic microbes. The wild tarragon is the best material to produce high-class vinegar.

On the other hand, soup can change the body's feeling about warm or cold very fast in our daily food. We suggested to prepare light soup for summer; thick soup for winter.

The other choice when we finish abundant salad is the soft drink. We suggested to prepare the cold wild vegetable tea or herbal tea for summer; hot wild vegetable tea, herbal tea, herbal spirits or herbal wine for winter.

4.5 Confront Future Climate Change and Impact

For the future climate change, it is very important to make the recipes of wild vegetable diets by seasons. The principles to set up the recipes of seasonal wild vegetable diets are using the properties of wild vegetables to balance the weather effect(Figure 6). For example, in summer, people can eat more wild vegetables with cool or cold properties, in winter, is opposite. In spring and autumn, we suggested tending to neutral and more flexibility about diets because of the weather change quickly（Figure 7）.

Figure 6 Spring healthy salad

Figure 7 Summer cool meal

The habitants lived in SBC-1 had a health checkup per season in Taipei Medical University. The average results of biochemical and physiology test, including the index of uric acid and anemia, were better than the data of urban habitants.

The subsequent development of eleven different functional diet types provided along with guidelines and recipes in a manual help not only to alleviate various symptoms of disease, but guard against malnutrition and climate changes.

5. Conclusions

The project has been successfully operational for the past four years and presently provides abundant nutrients for the residents in the twenty-four existing units. Minimum maintenance is required as the selected vegetables have a strong propensity for growth and self-propagation.

This viable regenerative food supply results in a green web-like cover（Figure 8）for the experimental sustainable building. It has an additional effect of regulating internal temperature and reducing overall carbon emission.

Figure 8 Green web-like cover

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PLANNING TOOLS AS AN INTEGRATED QUALITY CONTROL DEVICE IN URBAN SUSTAINABLE PROJECTS. THE CASE OF THE NEWS PDZ IN ROME

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Summary

The housing market finds itself facing an emergency due to the difference between supply and demand, in particular in the social housing market. Faced with a demand for cheap social housing, that runs the risk of creating new situations of poverty and profound social marginalisation, the residential buildings market is proposing, at the medium and high end, to turn to the private market and a set of requirements and questions that are more easy to resolve.

At the dawning of a new era in social housing, the quantity requirements have to be viewed alongside research that privileges many aspects of environmental and technological quality, characterised by both interactivity and its relationship with the natural environment.

The reflections on the technological aspects of the building organism are reflected in the transformations it aims to assist: the new materials introduced on to the market are joined to conventional technology, the new and elevated performance levels required have to face up to the behaviour patterns and functional schemes of contemporary life.

In this context, we consider the experience of the Municipality of Rome, an experience that marks a very important step in an initial stage of innovation and sensitivity to the new mode of conceiving and managing building elements.

1. New actions for social housing

1.1 Actual urban planning: the new Zone Plans (PdZ) in Rome

In the last twenty years, the City of Rome, like all other administrative bodies of big European metropolitan areas, has had to confront, at various times, the housing crisis, in other words, the problem of a strong demand for social housing in response to the housing needs of many parts of the population in marginal social or economic conditions.

The City of Rome confronted these questions by drawing up the Plans for Popular and Economic Buildings (Piani per l'Edilizia Economica e Populare – PEEP) that were used from time to time to determine the quantity of buildings to be constructed; in particular, the 2nd PEEP, proposed in 1985, was redefined and refinanced many times until 2005. At this point, the City, due to the requirements of regulations aimed at alleviating the "housing problem" (Law 8, February 2001, n 21), passed a new series of measures to launch a truly valid Plan to deal with the Housing Crisis.

Under this plan, the City identified various initiatives, including the promotion of the transformation of 36 areas within its territory. In these territories it promoted detailed town planning, local urban planning, Zone Plans (Piani di Zona - PdZ) which are prerequisites for the operative planning of the building and infrastructure interventions that are necessary for the creation of new residential installations and their services. In this case, an in-depth study of quality definitions for the interventions to be carried in the territory was carried out, in such a way as to supply the citizen with a services and housing offer that doesn't merely satisfy a need for quantity, but also satisfies the aspects of housing relating to greater environmental quality.

In order to achieve this, the administration proposed accompanying the traditional structure of actual urban planning with a "code of practice", as a set of guidelines for the planning of future installations to be built; the code will gather together and place at the disposition of the planners and promoters of future installations all of the indicators and tools for the definition of an integrated planning strategy, to control the overall quality of the interventions. In this way, alongside the traditional indications of technical regulations relating to the construction of residential buildings it is possible to place a system of best practices, of innovative guidelines about environmental quality of constructions, about energy and environmental management systems for sites and buildings, about the knowledgeable use of technological solutions aimed at the overall improvement of the performance of the building and the urban complex.

1.2 The need for quantity and the demand for quality: the qualification of the project

Despite the housing market always reporting an emergency due to the gap between housing supply and demand, in particular in the social housing market, faced with a need for low-cost social housing, that runs the risk of creating new situations of poverty and profound social marginalisation, the residential buildings market is proposing, at the medium and high end, to turn to the private market and a set of requirements and questions that are more easy to resolve.

In both the social requirement for quantity and the private demand for quality, the market responds in a uniform and unimaginative way, using very traditional technological definitions and typological solutions, blocked partly due to current regulations, offering as an added value only extra space or fittings. Faced with this picture of the relationship between housing supply and demand in the market, it is possible to state that the need for quantity springs from the perception of the inadequate quantity of the existing housing stock, while the demand for quality springs from the knowledge of the necessity to establish a new relationship with the surrounding neighbourhood, on the scale of the building and the urban complex.

Quality is not an objective characteristic, it's not the qualifying characteristic of a product; instead it is the response to the expression of a need. Therefore, a new demand for quality presupposes a dissatisfaction among the users of current building stock; when speaking of the quality of an architectural or urban project, its level of quality must be discussed, the degree to which it responded to the need that generated it.

It is possible to acknowledge at least two different levels of quality in a project: the intended quality and the end quality.

The Municipality intends to go precisely in this direction with the planning process for the interventions included in the new Zone Plans, by supplying guidelines to improve the intended quality of a project to improve its end quality, thanks to this more finely tuned and more complex control tool relating to expected performance. In this instance, all of the planning indicators in force today can be applied in an organic way by the city with single measures and the new regulations of the General Regulatory Plan regarding environmental sustainability of building interventions, overcoming at the same time a certain traditional rigidity in these same urban instruments.

The code of practice is conceived as a support tool and pointer for the realisation and control of sustainability in constructions, in particular social housing, that proposes a highly integrated approach to planning. The code looks again at housing requirements in terms of economic, social, functional, environmental and energy sustainability; these proposals for innovative functional "add-ons" to the creation of urban spaces are analysed in terms of both the comfort of public spaces and as a functional and social mix, in a way that obviates the phenomenon of social and economic segregation that is typical of metropolitan suburbs.

The code also appraises the appropriate and measured technological solutions to the types of buildings to be constructed in a way that doesn't differentiate them from the current approach of local promoters, though it does require a higher level of final technological performance for the environmental sustainability of the interventions. An analysis of the innovative technological solutions in the construction of residential buildings needs to be carried out, including the study of the construction materials used, in such a way as to direct intelligently the choice of the construction solutions and successive control in phases of building through management procedures. Using the same logic, the most appropriate system devices for efficiency in light of the indications of recent regulations regarding energy control management were analysed and evaluated. To support these indications, the code proposes an integrated model of analysis of the sites where interventions are being carried out that includes all of the environmental aspects and characteristics of the single sites, and to bring to the project and planning strategy the indications that derive from the natural and cultural characteristics of the sites in question.

2. Technical solutions to adopt in the planning of sustainable residential housing

2.1 The role of environmental analysis in the identification of the technical solutions to be adopted

The code of practice for the Zone Plans of the city of Rome foresees a reasoned appraisal, because good architecture depends on informed energy choices. The role of the architect, from this point of view, has to necessarily tend towards integrated planning, even if the specific object of the project is the planning of a city or on the scale of industrial design. Underlining the importance of logical planning throughout in terms of needs analysis, evaluation of requirements, and optimisation of performances, any architectonic element that doesn't look for a balance between the building system and the environment in which it is to be found and on which it will have an impact should be considered incoherent.

The experience of the code of practice for the Zone Plans of Rome explicitly inserts into this logic: an organised sequence of work phases in which every option, to do with timing or systems, is a consequence of the analysis of the environmental variables and their possible synergetic interaction in with planning. Environmental parameters, typological models, approved technical solutions, requirements, technical norms, synergy and compatibility matrices all assume great value within this research, in full coherence, therefore, with the objectives of the programme.

Specifically, with regard to methodology, as with environmental analysis, the use of Ecotect software (with particular attention on the Weather Tool module) is placed alongside traditional bibliographic research.

The idea on which the entire study of the code of practice is structured is as follows: to analyse the potential of a building-environment system, identify its eventual compatibility or incompatibility with the technical possibilities present on the market. A fundamental role, therefore, is assumed by the very concept of compatibility, intended in its widest sense, in terms of regulations, technology, economics and use. To delineate a process in this sense inevitably imposes a preliminary survey in merit of the characteristics of the urban environment, but this implicitly means looking at the technical performance of the functional models of the building envelope, successively defined as compatible.

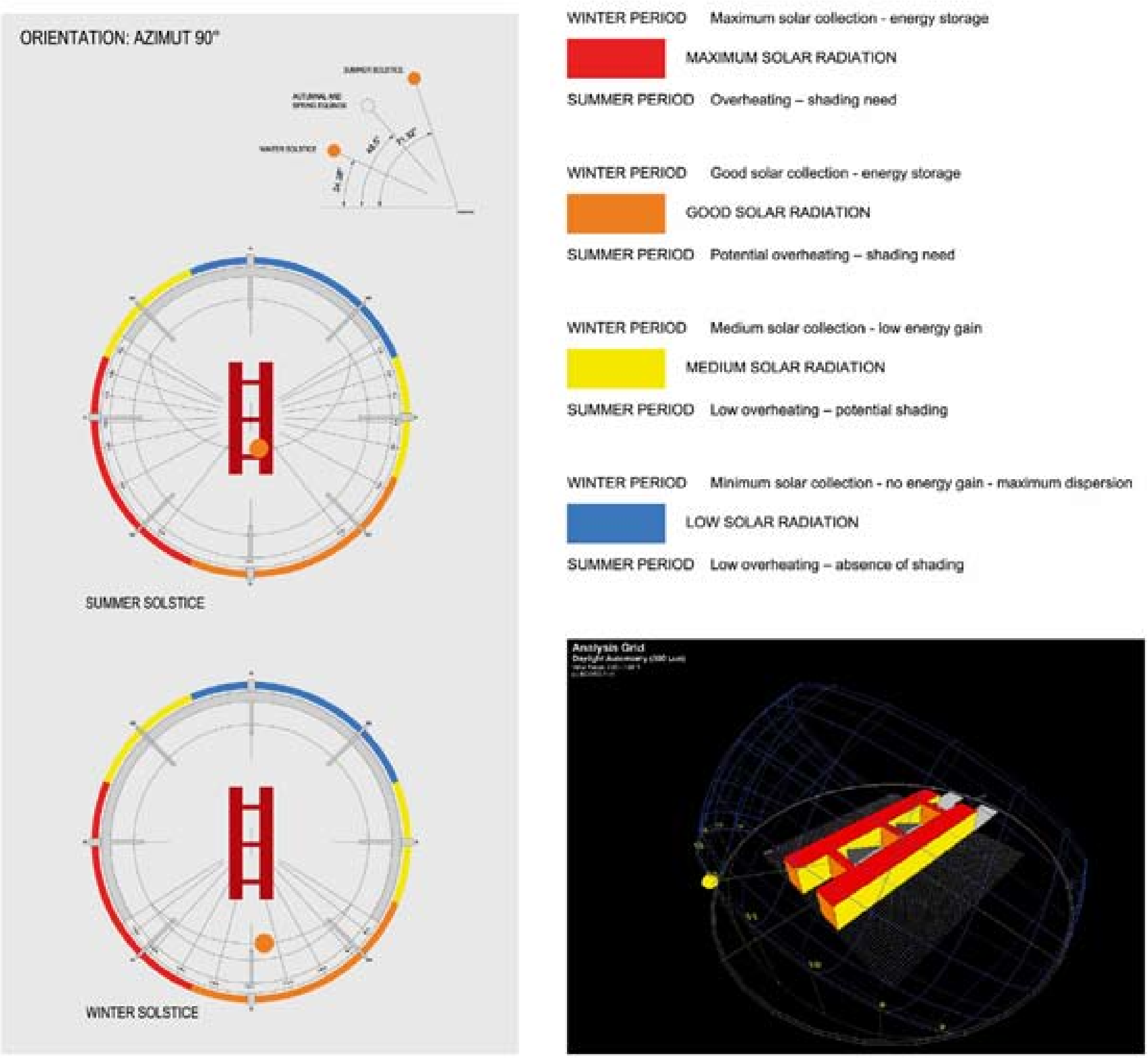

Figure 1 Building system solar analysis

The objective is to draw from the valid planning indications on both the scale of the neighbourhood and the scale of the single building: with this in mind, it should not be limited to a single vision of the phenomenon in a generalist and quality key, the imposition, rather than the option, of a specific deepening of knowledge where conditions are verified that require particular attention. These intentions are made concrete by means of a timely appraisal of the adoption of methods that verify and consolidate matters primarily concerned with solar radiation. It is a considered choice to deepen that environmental parameter over others: firstly, solar radiation is configured on the scale of the whole building, as having major significance in relation to the passive performance of closure packets and to their potential in terms of solar panel systems. In support of this position, it is necessary to underline the analysis of pre-existing urban environmental data: for example, the code has agreed from the outset to exclude an approach on the theme of energy optimisation in terms of the exploitation of wind systems; the reviewed data clearly show that wind phenomena are substantially negligible in terms of intensity and frequency in the City of Rome. The analysis of solar radiation at the level of the building gives quality indications for the exteriors of buildings, shared public spaces and the divisions of the project.

The promotion of an integrated approach to the sustainable planning is translated therefore into the suggesting of multi-level intervention strategies that take into consideration the planning and possible interactions between all the elements of the interaction between the urban and natural environment.

2.2 Integration of technical solutions in building design

The sustainability of a project and the quality of the construction from the energy point of view depend largely on, among various factors, how the building is built.

The reflections on the technological aspects of the building organism are reflected in the sometimes profound transformations that accompany it: new materials introduced on to the market are added to conventional technology, the new and elevated performance levels asked for are compared with the behaviour and functional schemes of contemporary living.

On the one hand, the need for greater operative clarity in the aiming of adoptable planning choices is gained, and, on the other, the importance of an explication of the criteria that subtend the choice of the technological solution, privileging one alternative over another.

In particular, it is necessary to pay particular attention to the definition of the superficial and border elements through the external and internal ambience of buildings (the envelope) that determine the requirements of the building and respond to the needs of the users who will live there.

On this theme, the most evident aspect is the emergence of environmental and economic advantages that have an impact not only on the external environment, but place first the user's quality of life. The adoption of new rules and new performance requirements will lead to a reduction in energy consumption for heating and air conditioning, therefore a notable reduction of electricity bills (installation of air conditioners, hot-water plant for cleaning, electrical plant) in the course of the useful life of the building.

On the other hand, the environmental advantages are a direct consequence of improving the efficiency of buildings and their plant systems: lower fuel consumption in fact means less emission of gas into the atmosphere and a lesser impact of materials used in the environment.

The theme of eco-efficiency should be attacked head on not just through the technological qualities that the technical solutions will be able to guarantee. The importance of building management - highlighted in the objectives of the European Council on spring (OR. EN 7224/07 of March 8th 2007), taken up then by national (Legislative Decree 311/2006) and local regulations (Del. 48/2006 City of Rome) - underline an ulterior element of reflection: the constantly growing role and importance of plant in the management of building stock. In this discussion we find the growing incidence of alternative plant needed to sustain buildings, as much from the point of view of initial costs as the dimensional impact of the same on an area under consideration.

The increase in requests to use renewable sources along with the demand to reduce energy consumption and CO2 emissions into the atmosphere, translates therefore into the need to think about the integration of plant both as a means to reduce the country's energy demands and as a source of co-generation able to guarantee positive economic returns in the conduction of the buildings.

In this context, the existing ties between plant systems and the building envelope assumes particular importance: every choice made in one of the systems weighs significantly on the planning and dimensions of the other.

The most evident aspect of the evolution of the legal framework for building activity is, therefore, the beginning of a demand for legal performance that can prime a "normal" practice of intelligent planning that is energetically and environmentally sustainable.

This leads to an evaluation not only of the immediate cost but also, and above all, for the projected future cost with regard to any of the fundamental components such as health, efficiency, life cycle and maintenance, that will continue to be evaluated case by case in single projects in relation to the urban context of the building.

The choice of the planner will undoubtedly be that of finding the most suitable solution within a combination of conditions, opportunities, and links that are reference points for the environmental characteristics of the site in the course of the seasons during the year, with a control of the external part of buildings in relation to their orientation and to the activities carried out internally, as well as - in virtue of the errors of the past – attributing to the morphological quality of buildings the specific character that distinguishes the history of each and every place.

The problem of sustainability encroaches on many distinct disciplines and demands their inter-relationships be taken into consideration.

In light of this last consideration, the control of environmental and technological requirements, as well as their satisfaction, are both essential objectives that should be reached in respect of architectural language proper to and expressed in each single culture.

Among the innumerable aspects contemplated in the concept of project sustainability, the aspects that relate to the different needs of individual countries should not be overlooked. This theme, which in the past was partly ignored, led to the problems that the current recovery of buildings tries in a diffused manner to overcome.

The monotony, the repetition and continued lack of aesthetic appeal of buildings in the recent past, in Italy as much as in other European countries, are the evident results of an approach to planning that is distant from the context into which it is to be inserted.

From the point of view of this “virtuous” planning in residential buildings, new building is assisted by research into envelopes that are characterised by innovative forms, technologically and formally, that encourage planners towards a careful analysis and conceptual experimental flexibility in both the search for new rules for the codified distribution of living spaces, as well as often importing construction techniques from other types of buildings.

The technological transfer of some solutions from analogous building sectors leads to an increase in its repertoire, performance and systems on offer, and, on the other, to the introduction of material that is more or less sophisticated and has the ability to satisfy the required performance levels with a minor impact on its environment but that is not always easy to control over time.

In this historic period, it is well known, in fact, that there is a construction industry with the ability to always offer new products that gives the planner many choices from a catalogue of more or less complex elements.

This last consideration points to the fact that, on the one hand, the more components become complex, the more they are composed of individual layers, or sub-elements; on the other, it is established that as much more of the element’s technical performance is the sum of its layers’ individual performances, it will be of great importance to control their final technological quality. It will also be necessary to verify analytically the performances that respond best to both the requirements and actions that define the needs picture of the residence, and the priorities that are used to define the objectives of the effective sustainable plan.

We can see, therefore, how the external envelope is one of principle areas called upon to satisfy a building project’s sustainability. At the same time, the elements that make it up are called on to provide, in a coherent manner, all those aspects of volumetric and spatial composition the building was not able to respond to.

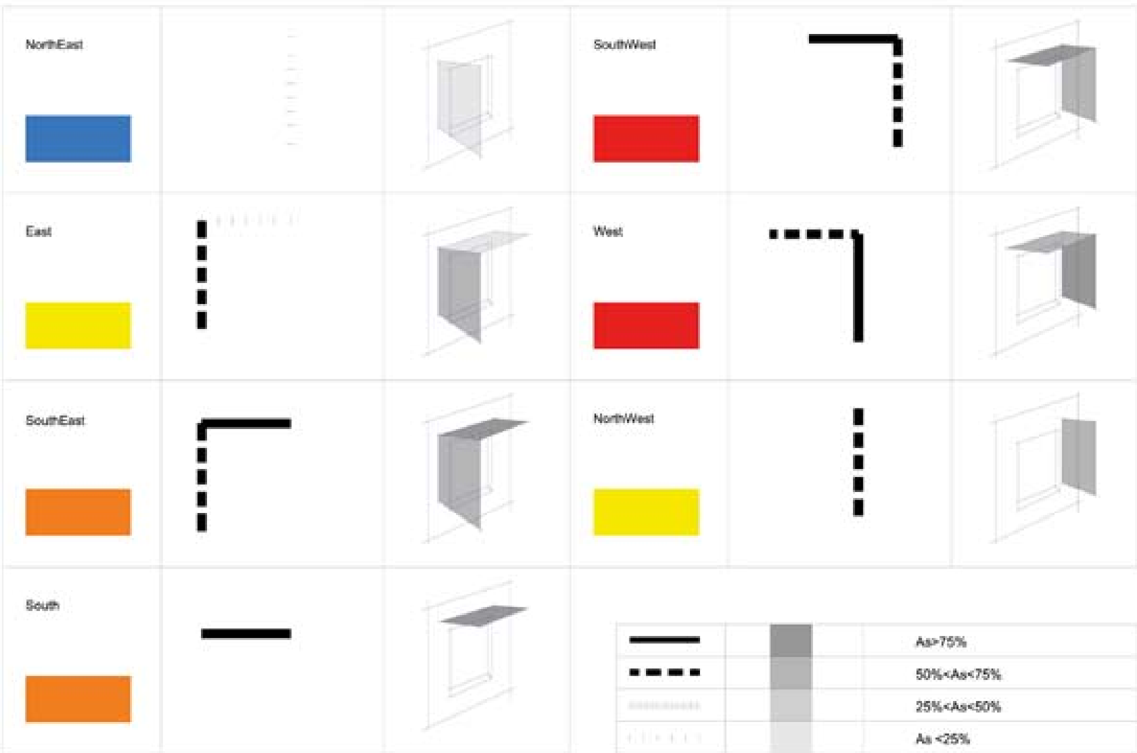

Figure 2 Design of solar shading in respect of façade orientation

Research into the envelope elements has therefore led to a moment of reflection and analysis about the morphological characteristics and specific performances of the solutions that may be considered meaningful and adoptable.

Given the great variety and complexity of systems and elements, it was felt necessary within the code of practice to include a methodological-operational indication guide and support for the choices to be made, through which to identify and choose the solution considered most suitable within currently available technology.

The new manner of thinking about technological sustainability is sought in the acknowledgement process of the values of architecture and in the adoption of a new planning method appropriate to the transformation of the natural environment into a man-made environment aimed at a new more knowledgeable community.

A similar approach modifies the planning of the technical elements, which must be thought of not only as a connection and/or separation from the other elements of the building system, but also as effectively "able to be integrated" thanks to an interdisciplinary meeting of the various specialists involved in the planning process.

2.3 Construction materials. Product and process innovation for residential buildings.

The code of practice for the Zone Plans of the city of Rome foresees a reasoned evaluation of construction materials to employ in projects; the identified evaluation criteria don't aim to construct an abacus of materials to use or not to use for these buildings, but intends to supply tools to the person who will plan and realise these buildings to choose materials and construction solutions in a way that will answer a system of technical requirements identified as determining for the efficiency and sustainability of the proposed solutions. The choice to use or not to use a certain product is reached through various selection criteria that are defined to satisfy the need to obtain good physical-technical performance but at the same time guarantee a low impact on the environment.

The evaluation parameters proposed are constituted in part by measurable elements, referring to the quantity level, and in part derive from numerical data and considerations referring to quality.

The evaluation takes place on materials that are able to guarantee performance of good thermal and acoustic isolation; these material are entrusted with creating comfortable environmental conditions in the internal habitation space at a perceptive and sensorial level. In particular, the choice proceeds through the following three levels.

The first level is through the reading of a numeric value of thermal conductivity choosing materials with a low value and technological solutions with greater insulator capacity.

The second level considers the volume of the material. In Rome's climatic conditions, a high amount of mass guarantees comfortable internal living conditions contributing to limited energy consumption, supporting and in some cases rendering superfluous air-cooling systems.

The thermal inertia or mass effect uses the physical property of the materials to increase the time (thermal lag) that the heat wave takes to cross the walls; this produces a stabilization of the temperature, guaranteeing a lower internal temperature during the day as well. Along with the good thermal qualities materials with large mass are associated with a better capacity for noise reduction. The attenuation of noise, measured in decibels, grows in relation to the mass interposed between the source of the noise and the environment to be protected. A decent quantity of acoustic isolation material leads to a greater level of internal comfort and quality of life of the space.

The data relating to volume mass is moreover connected with the regime of preferred use. This regards the difference of performance offered in case of either summer or winter. The code of practice has opted for the hot season as its preferential regimen. Buildings in the city of Rome, as in Italy and the centre-south of Europe, due to environmental conditions in the Mediterranean basin, which is characterized by mild winters and hot summers, present a greater need to defend themselves from low temperatures, the need to minimize the use of artificial air conditioners during the summer season and finally to limit energy consumption and create good internal conditions of comfort.

The third level of selection is based on LCA (Life Cycle Analysis) and the PEC value (Primary Energy Consumption). Through the LCA, the complete life cycle of the material is evaluated, from the sourcing of the first materials to the completion of the project; to evaluate the LCA of a material, multiple aspects are examined, some of which can't be directly measured and compared. In particular, the consumption of primary energy (PEI) offers a partial evaluation of the product's lifecycle. This constitutes an ulterior parameter of comparison; it is always preferable, wherever possible, to use an isolating material that uses low energy consumption in the production phase, because of the total minor impact on the surrounding environment. Some synthetic insulators, for example, even with a good level of performance of thermal isolation are characterized by a high consumption of primary energy: in their place, insulators of a mineral (fibreglass) or vegetable (wood fibres) nature should be preferred.

The three levels of evaluation contain elements relating to quantity and quality don't answer definitively the question of what would be the best solution; rather, they supply some indications which provide the possibility to make a choice with the aim of arriving at technological solutions for the Zone Plans that adhere to the principles of sustainability and biocompatible construction.

Table 1 Comparison between insulator materials parameters

Material	Use	Conductivity (W/mk)	Volume mass (kg/mc)	Potential environmental impact PEI (MJ/K)
Fibre glass	insulator	0.040	55	34.60
Expanded Polystyrene (XPS)	insulator	0.035		107.15
Wood fibres (cork)	insulator	0.040-0.046	100-300	7.05

3. Conclusion

The experience of the code of practice for the Zone Plans of the City of Rome proposes an integrated methodology of approach to planning, an organised sequence of phases of work, in which each option, temporal or systematic, is the fruit of the analysis of environmental variables and their possible synergetic interactions. Environmental parameters, typological models, legal and technical solutions, needs, technical legislation, compatibility matrices, all assume a great value within this research in full agreement with the programme's objectives.

The strategic relationship of the code of practice to the process of planning, designing, building and managing interventions is that of impacting on the definition of a complex quality profile that is expected or required from interventions on buildings, supporting the administration up to the phase of urban planning in the definition and detailing of the level of technological and environmental quality in building interventions.

The code of practice, therefore, functions as a preliminary technical briefing document or as a strategic planning document aimed at obtaining high levels of urban and environmental quality, influencing both the quality of the use of space in buildings, as well as the management of the resources used by the integrated system formed by the surrounding urban complex, of the building and of the plant system in the whole life cycle of the surrounding planned system.

The promotion of an integrated approach to sustainable planning translates therefore into suggesting multilevel intervention strategies that take into consideration the planning and possible interactions between all the elements of the manmade and natural urban environment.

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A RESERCH ON THE ASSESSMENT METHOD OF THE SUSTAINABLE BUILDING PERFORMANCE FOR A DEVELOPING COUNTRY

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Keywords: sustainable building, sustainable performance, assessment method, conceptual framework, obligatory practice, recommended practice, voluntary practice, flexibility to handle circumstantial changes

Summary

The aim of this study is to develop a sustainable building performance assessment method that is suitable for specific attributes of a developing country like South Korea. For a developing country in the stage of rapid economic growth, there is a need for appropriate intervention from outside the market to secure sustainable performance of buildings, as well as a need to develop an assessment method that can flexibly deal with fast changing conditions. Accordingly, we will suggest the assessment method of sustainable building with flexibility and with intent to improve sustainable performance of overall building. This study seeks to advance sustainable performance of buildings through conceptual framework of assessment method. The conceptual framework of assessment method refers to classifying assessment standards and adjusting category method for intervention in the market. Also it seeks to present an assessment method with flexibility to handle circumstantial changes through variable sub-goals. as well as through differentiation between constant and variable indicators. The variable sub-goals and indicators are proposed based on technical levels, market conditions, international pressure, and so on. Furthermore, by classifying the detailed standards as obligatory practice, recommended practice, and voluntary practice, and making them adjustable regular, we expect that the assessment method can provide flexible and effective measures.

1. Introduction

In conditions that the interest in environment and development issues increased and international efforts on related agenda were needed more and more during the past 10 years, many developed countries introduced various assessment methods, certification systems and policies for sustainable buildings. And then assessment methods have improved in consequence of analysis of successes and failures based on real examples. As a result, the assessment methods of sustainable building performance in developed countries appear to have reached a level of stability.

Contrastively, although diverse sustainable building performance assessment methods are being proposed in light of international requirements, energy cost increase and growing interest in environmental issues, the developing countries like South Korea are at a level of merely translating and applying the primary stage assessment methods of developed countries without modification to suit their own particular circumstances. Hence, there is a need to develop assessment methods that take into account each country's particular circumstances such as political situation, or technological level, market situation and so on.

In developing countries, due to their rapid economic growth compared to developed countries, energy and resources consumption and toxic material discharge will increase drastically. As well developing countries cannot be free from international agreements. Therefore, this is a very critical time for their sustainable building market. Proposing an appropriate assessment method for a developing country in such time of changes is urgent and useful.

As stated previously, developing countries have characteristic of rapid changes in external circumstances such as technological levels, market conditions, requirement degree of international agreements, and so on. Also, lower technological levels and weaker market conditions compared to developed countries make voluntary participation in the relevant market difficult. Therefore, it has a greater need to develop an assessment method of sustainable building performance that can flexibly deal with such circumstantial changes and give relevant market appropriate regulation or recommendation standards for advance in sustainable performance of building sector. If an assessment method can provide such function to be proposed by this study, it will contribute to the improvement of a developing country's sustainable building performance.

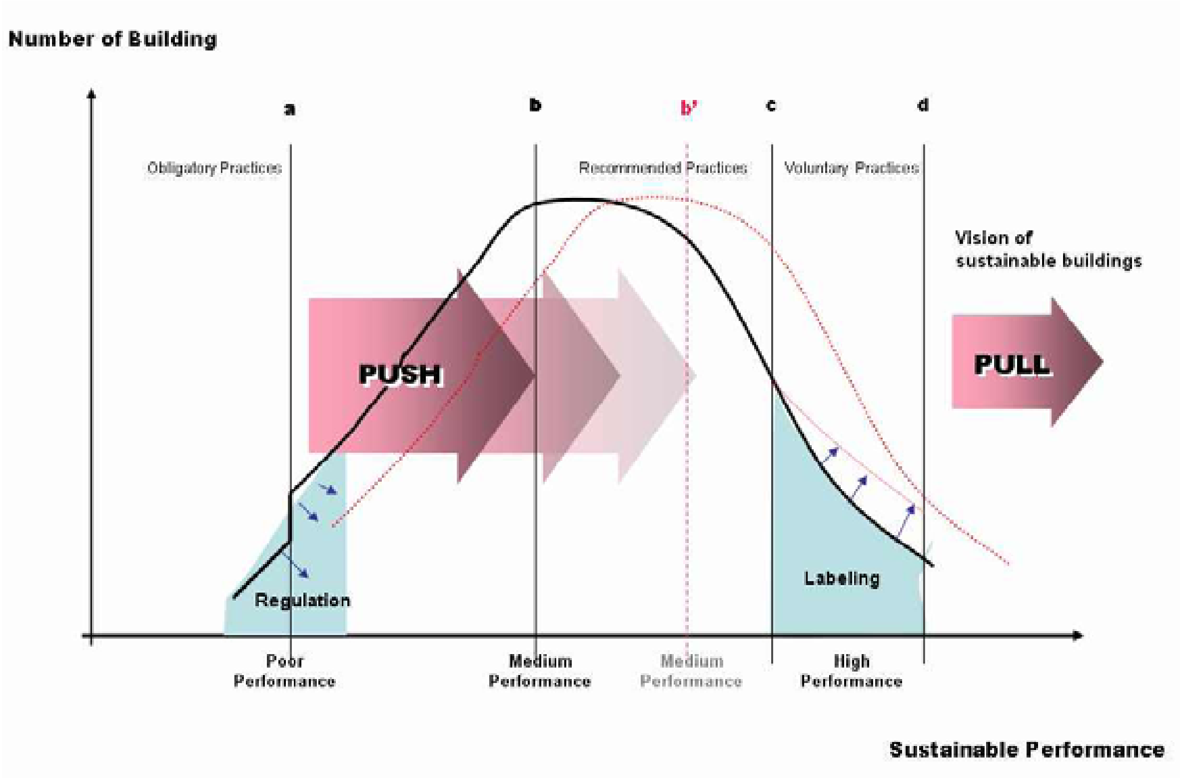
Accordingly, the assessment method to be proposed by this study comprises the following:

First, this study proposes a conceptual framework to evaluate sustainable performance of buildings. The conceptual framework refers to systematic classification method of assessment standards. It can help attain an assessment method's final objective more efficiently with integrative approach to improvement of environmental performance. Through this work, an assessment method will be able to appropriately intervene in the market and serve its role of regulating and providing recommendations.

Second, it proposes an assessment method with flexibility to deal with circumstantial changes. The assessment method can get flexibility by differentiation between constant and variable indicators. In this study, variable indicators refers to sub-goals that are, by periods, proposed based on circumstantial changes and classifying the detailed standards as obligatory practice, recommended practice, and voluntary practice, and making them adjustable regular.

2. What to Expect from an Assessment Method?

The fundamental goal of assessment method is to evaluate sustainable performance of buildings. And, it can provide information on the environmental impacts of detailed sustainable technology and related policy and help respond international agreements such as the United Nations Framework Convention on Climate Change, through objectively evaluating energy efficiency, greenhouse gas emissions and so on. Furthermore, if measures appropriately, an assessment method can be expected to serve a positive role as follows:



Figture 1. Roles of an assessment method proposed in this study

First, it can regulate and guaranteeing a minimum level of sustainable building performance. If the detailed indicators, classified as obligatory practice proposed in this study, are made to tie in with government regulations, the double burden of checking separately the government regulations and the detailed standards of assessment method can be eliminated. Moreover, because obligatory practices are adjustable to changing circumstances, this can prevent the unnecessary difficulty arising from continually having to amend the law or from failing to adapt by rapid changes. (See Fig. 1, line a).

Second, as seen from Fig. 1, line b and b', it can guide to improve sustainable performance of building sector by push and pull principles. Through the structuring of assessment standards category to be proposed by this study, an assessment method can be expected to serve the role of encouraging the advancement of the overall sustainable building performance for an entire country and not end at merely evaluating the performance of a product called building.

Third, it can encourage that more buildings attain high sustainable performance by providing consumers with information on and incentive to superior sustainable buildings through labeling systems, and so on. And, it will continuously provide models for future sustainable buildings and vision for the sustainable building sector. It can pull sustainable performance of building as intention of assessment method maker and policy maker

3. Proposals Based on Examination of Earlier Studies

3.1 Definitions of Sustainable Building Performance from Earlier Studies

As growing interest in environmental and developmental issues, the nature-centric architectural concept[1)] of ecological architecture, green architecture, and so on appears on the architecture area. Thereafter, the concept of sustainability emerged in relation to ecological development, and the sustainable development concept[2)], subsequently widely discussed in the international community. And then, the sustainable development concept became internationally accepted as the ESSD concept[3)] via the Rio Summit, and various related international agreements are being discussed with this concept as the foundation. Therefore, this study, also using the ESSD concept as a basis, wants to discuss sustainable building performance. In this study, the sustainable building performance means minimizing adverse impact on the ecosystem by construction- and habitation-related activities and managing an environmentally comfortable habitation within the human comfort zone.

3.2 Sustainable Building Performance Categories on Ken Yeang's Framework

Ken Yeang stipulated that organizing the consideration factors for the design of ecological architecture helps designers to select diverse guidelines for minimizing the adverse effect of construction on the ecosystem. This study believes that such structuring is useful not only from the perspective of determining the factors to be considered in the planning stage of building, but also from the perspective of evaluating the sustainable building performance, i.e., evaluating the adverse impact of construction on the natural environment. As such, the assessment categories of this study's assessment method will be classified based on the framework proposed by Ken Yeang.

As stated above in section 3-1, this study proposes the definition of sustainable building performance to be minimizing the adverse effect of construction- and habitation-related activities on the ecosystem and managing an environmentally comfortable habitation within the human comfort zone. If this concept of sustainable building performance is substituted into Ken Yeang's framework and examined, the results are as follows:

Table 1 Conceptual Framework for evaluating sustainable building performance

Interactions	Symbol	Description	Concepts of sustainable building performance
Its external relation	L22	This refers to the totality of the ecological processes of the surrounding ecosystems. It is these elements which are either altered, depleted, or added to by the built environment.	The preservation of eco-network
Iits internal relation	L11	This refers to the sum of the activities and actions that take place in or are related to and associated with the built environment.	The operation of environmentally comfortable habitation within the human comfort zone
Tthe system's inputs	L21	This refers to the total inputs into the built environment.	The minimization of natural resources consumption
The system's outputs	L12	This refers to the total outputs of energy and matter that are discharged from the built environment into the ecosystem.	Low environmental loadings.

1) Germany's Ecological Architecture (1978): Defined as architecture that makes healthy habitation and working possible from a nature-centric perspective by emphasizing harmony with the natural environment, as well as from an ecological perspective, by maximizing efficient use of resources and energy

2) The UN Bruntland Report's Sustainable Development (1987): From an anthropocentric perspective, defined as "sustainable development that meets the needs of the present without compromising the ability of future generations to meet their own needs" and has as its goal, the economical use of natural resources, participation and equal use by residents, and protection of the environment.

3) ESSD of United Nations Framework Convention on Climate Change (UNFCC) (1992) : To prevent environmental disaster from global warming, declared the principle of environmentally sound and sustainable development (ESSD) and required CO_2 discharge in developed countries to be reduced by 5% of the 1990 level.

L22: Minimizing the adverse effect of construction-related activities on the ecosystem. That is, using the land appropriately to cause minimum change and making sure the eco-flow is not blocked by a built-environment.

L11: Minimizing the artificial intervention needed to attain adequate comfort within the comfort zone for human habitation. That is, reducing environmental loadings and minimizing exposure of human habitation to environmentally toxic materials.

L21: Minimizing the consumption of energy (fossil fuels, non-recyclable energy), water, and materials due to construction-related activities.

L12: Reducing environmental loadings, especially, decreasing the discharge of HCFCs, HFCs, CO_2, Sox, NOx and others that destroy the ozone layer and cause global warming and soil acidification, reducing waste that are non-recyclable or take long time to decompose.

3.3 Proposed Concept of Structuring Assessment Method and other proposals

To effectively implement the role of assessment method proposed in chapter 2 above, the structuring of an assessment method is first needed. The assessment method structuring proposed in this study refers to classifying the assessment standards with particular intentions. The primary purposes sought with the assessment method are placed at the highest category level, and under them are placed specific content categories and sub-purposes. Under these, in turn, are placed more detailed goals, and at the lowest category level are criteria on detailed essential techniques. By doing so, the ultimate purposes of assessment method can be effectively accomplished, and detailed goals and criteria permit flexible measures to be taken depending on the circumstances of the specific time period. Furthermore, by classifying the detailed criteria as obligatory practices, recommended practices, and voluntary practices, and making them adjustable, the detailed criteria can provide flexible and effective measures.

Second, an assessment method must be linked to national policy. Especially in a developing country like South Korea, it is yet premature to expect voluntary participation, and there needs to be regulatory controls and incentives.

Last, continued publicity and education as well as evaluation results should be made available to consumers more user-friendly, and consumers' right to information should be satisfied. Through this, the vision of sustainable building should be persistently presented to consumers. Such efforts will improve the awareness level and change the life pattern of consumers, and will be effective in accomplishing the expected objective of a sustainable performance assessment method.

4. Structuring of Assessment Standards category

As stated previously, this study, by structuring the assessment standards category, aims to take on a leading role in improving the sustainable building performance for a whole nation through the assessment method. The assessment standards category method proposed in this study is as follows:

(1) Assessment Method's Purpose

This indicator placed as a topmost concept among assessment categories becomes an ultimate purposes. As proposed in section 3-2, the purpose of this assessment method shall be preserving eco-network, operating environmentally comfortable habitation within the human comfort zone, minimizing natural resources consumption, and maintaining low environmental loadings. This is topmost indicator in this assessment method.

(2) Assessment Method's Category

The second highest concept in this assessment method refers to the more detailed content within each purpose, or sub-purpose. For example, within a purpose, reduction of natural resources consumption, there may be categories of low energy, low water, low material and so on.

(3) Sustainable Performance's Goal

This refers to the concept of detailed goal required at a specific time point. This concept, as mentioned earlier, is proposed to enable more flexible response to changing circumstances. For example, the category of CO_2 reduction within the purpose of maintaining low environmental loadings is a indicator that rarely changes, but a goal of 5% CO_2 reduction for year 2000 can be changed, due to stronger international requirement, to a goal of 10% CO_2 reduction for year 2000.

(4) Sustainable Performance's Criteria

As the lowest level indicator, criteria comprise the detailed standards presented by experts from various fields to meet the detailed goals. These standards are classified and differentiated into obligatory practices, recommended practices, and voluntary practices. In addition, these criteria classification can be changed according to changes in circumstances. This is also one of the ways to provide flexibility in response to circumstantial changes. For example, if technological levels improve compared to existing standards, then some standards may be reclassified from voluntary practices to recommended practices. While other standards, although they may have been obligatory practices in the past, because the levels of technology and awareness have improved and other circumstances have also improved enough so that currently the majority of buildings satisfy given standards without regulatory control in a particular area, they may be reclassified to voluntary practices.

The outline of the assessment indicator category structuring proposed in this study is as follows.

Table 2 A Part of the Assessment Category System

PURPOSE	CATEGORY	GOAL
1.Eco-Network	1-1 ….	1-1-1. …
2. Environmentally Comfortable Habitation within the Human Comfort Zone	2-1. …	…
3. Low Natural Resources Consumption	3-1. Low Energy	3-1-1. ▪ 15% reduction of heating, cooling and lighting energy for year 1990 (2006. 01) ▪ 20% reduction of heating, cooling and lighting energy for year 1990 (2007. 01) ▪ 25% reduction of heating, cooling and lighting energy for year 1990 (2008. 07)
		3-1-2.
		3-1-3.
	3-2. Low Material	…
	3-3. Low Water	…
4. Low Environmental Loadings	4-1. …	…

Each indicator, such as Purpose, Category, Goal by proposed this study, is numbered as each positions. It represent by this numbering that each Goal serves what Purpose. As seen from Table 2. Goal 3-1-1., this Goal can be proposed newly and amended in changing conditions. So, we get several detail goals in Goal 3-1-1. Also, if the Goal 3-1-1 is needed no more, it can be deleted. If new Goal 3-1-4 is needed, it can be supplemented at that time. This point can help to get an assessment method with flexibility. In this assessment category system, the Purpose and the Category are constant indicators and the Goal and Criteria are variable indicators.

Table 3 The Example of Criteria List

Criteria	Goals to be contributed each criterion	Requirements Degree (2008.09)
…	3-1-1, 1-3-4, 2-5-1	Obligatory Practice
…	1-1-1	Recommended Practice
…	…	…

Because this list is presented that each criterion can help to achieve some Goals, evaluators can take cognizance how each criterion contributes for sustainable performance of buildings and consumers can be aware of the building's sustainable performance more clearly. One criterion may contribute to attain a Goal or other Criteria may contribute to attain several Goals. This point can exercise when we determine weighting of each criterion. As stated previously, requirement degree of each criterion can be altered as changing conditions. It is represented as 'Obligatory Practice ', 'Recommended Practice' and 'Voluntary Practice'. Criteria checked 'Obligatory Practice' is mandatory. They are linked national policy or local regulations. 'Voluntary Practice' is related to various financial or legal incentives. This exercise encourages stakeholder to get high performance of sustainable building. For fill out blank of Criteria, we want to use existing standards be proposed by experts in related area. It is useful that we skip similar studies over and over again.

Weightings of the assessment method proposed this study will complete through subsequent studies. But this study proposes basic concepts of weightings. Weighting of our assessment method will include priorities of each ultimate Purpose or second Goal, degree how much each criterion contributes to accomplish second Category or detailed Goal, how many times each criterion belongs to each Goal and so on.

5. Conclusion

This study aimed to develop a sustainable building performance assessment method suitable for South Korea, a developing country where there is still a need to promote improvement of sustainable building performance through strong intervention from outside the market, and where there is a need to be able to respond flexibly to changing circumstances. Accordingly, this study structured the assessment category system to help achieve intended goals effectively through the assessment method, and proposed a sustainable building performance assessment method that is flexible in responding to circumstantial changes by differentiating between constant and variable indicators.

However, because completing the intended assessment method is rather huge in scope, this study proposes the basic concepts of the assessment method and shall leave the completion of the assessment method for subsequent studies. Discussion will be needed on how to promote the completion of structuring the assessment method and to propose the detailed goals and indicators and the method of classifying them through subsequent studies. Discussion on how to link this with the national policy will also be needed. Study on how to properly place weighting and rating on the assessment results of each assessment guidelines needs to be done. There is also a need for continued discussion of how to provide consumer with information on final assessment results and to present a vision for the sustainable building market.

Acknowledgement

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The Power of Symbiosis: Spiritual Life in the Symbiosphere

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Abstract

This proposal presents a research on symbiosis, with the premise of "material reduction and mental explosion". This premise leads to a question: how can we successfully transform the world—before it reaches its critical point of materialistic economy—into a state of higher spiritual living? This proposal will attempt at a construction of "spiritual life" in accordance with the idea of symbiosis from three aspects: "memory of time," "coordinate of space," and "spiritual wellness". This kind of "spiritual life" will achieve symbiotic convergence through spiritual pursuit. It will be undertaken by investigating how we can establish a community of symbiotic living in the symbiosphere. This kind of life will supply the "spiritual power" to reach the goal.

Introduction

The most urgent issue that the human race is concerned with at present is how to cope with environmental deterioration: climate change and its severe threat to human life. To be prepared for the potential disasters of the future, a feasible solution has been formulated, that is, the philosophy of "symbiotic living". It is carried out by the Archilife Research Foundation in building the "Symbiosphere 1". In it, experiments were made and results were collected. Symbiotic living has become a reality in the material aspect, but we are still anticipating for the spiritual aspect. The latter is the goal that the research is aiming at, for which it proposes the theme of "spiritual life in the symbiosphere".

According to the report in a British periodical named *New Scientist*, published January 14, 2006, a "Doomsday vault" was being built in Norway in the Arctic mountain region. It has the capability to cope with global warming and withstand the impact of all external blasts. On February 10, 2007, Reuters reports that the construction has been completed at the cost of approximately five million dollars. This vault will keep the seeds of crops at maximum security; thus it is called a "seed bank". The construction is scheduled to be completed by the end of 2008. However, human sheltering is not included in the project. In other words, the designers have not considered how to keep human beings from the potential disasters. On the contrary, Symbiosphere 1 does put basic human needs into consideration, affirming that the ability of self-preservation during catastrophes is the key for "livelihood and life-prolongation". In other words, the Archilife Research Foundation pays attention to the strength needed in symbiotic living. This research is in view of constructing a kind of "spiritual life" in the symbiosphere in accordance to the idea of symbiosis.

Firstly, we need to clarify the relationship between the material and the spiritual.

> **A spiritual life is the first and foremost issue. The needs for the material are both limited and superficial. What man really wants is spirituality. Therefore, to pass through the trial of material shortage, one cannot simply decrease the dependence on material in a passive way. He should try to look at the material from a different angle, and try to transform the needs into spiritual power.**

The second is to have an understanding of the "twenty-four solar terms" in the agricultural society, and to elucidate how it responds to the time of material shortage.

> **The most dramatic and significant transformation of the society during the second half of the 20th century, a transformation that cuts us off from the past world, is the death of peasant life. The modern capitalist society has destroyed the enormous political structure of the agricultural civilization. It did not take long for the powerful agricultural empires to disappear. Therefore, we find that solar terms are not exactly helpful for us to improve the relationship between man and nature. The reason is not that the calendars are no longer in use, but that industry has replaced agriculture, and that the city has replaced the countryside. The primary issue is whether we can be brought back to countryside living and return to the life style of the agricultural era. The answer is negative.**

Thirdly, Symbiosphere 1 is set up as the empirical background and a component of the project of "symbiotic force". This project includes: clarification and construction of the special relationship between man and the environment, measures to avoid the weakening of the ability to adapt to the environment when the spiritualizing process is being internalized, as well as the structure and content of the new civilization.

This research believes that "symbiosis" is not inaction. On the contrary, it is a kind of "new involvement", different from that of the agricultural and the industrial society. According to our primary envisage, this kind of transformation of *Weltanschauung* is inevitably "religious" to a certain degree. Therefore, based on the related concepts mentioned above, we can imagine life in the symbiosphere that concerns nature, humanities and spirituality. We can also further arouse the "symbiotic force", which is firmer and stronger.

> **A symbiotic life is similar to a monastic life. A symbiosphere is like a monastery. The monks (symbiotics) are of one mind in the pursuit of elevation of the soul or the spirit (the internet replaces the Bible). The regular routine of life is based on the regulations of the program (getting up when the sun is out, resting when it's dark). Specified tasks are to be undertaken in specific time (mainly concerning manual labor). However, it is the idea of symbiosis that guides their minds, that is, a life-experience of symbiosis with the others, nature, and everything else in vicinity.**

Section One

Mankind, living with limited power and facing unpredictable natural disasters, has no right to be optimistic or pessimistic. Finding a way out is an instinctive reaction, and the philosophy life called "symbiotic living" is such a reaction. It shows an attempt to bear the burden. Though we cannot take hold of the future, at least all the efforts are worth trying.

The summarization of commune life in the symbiosphere these years is the philosophy of symbiotic life. The premise includes the following aspects:

1. Accepting Restrictions

Since the Enlightenment, freedom has become the highest value of the human race. It is commendable in the activities of humanities, but the interaction with nature is another matter. "Symbiosis" means to realize that the present world cannot be upheld anymore. Therefore, from the starting point of symbiosis of man and nature, we can understand the pertinent function of restrictions. Appropriate restrictions are necessary. It gives us space so that we can have time needed for adaptation and finding a more favorable way for mankind to survive. It is the very reason why we have to examine our understanding of democracy and the method of administration.

2. Full-scale Interactions

A pertinent mode of interaction, originated from the wisdom of construction and biology, is the one that determines our life style. Symbiosis is a mechanism of negotiation. Human involvement, with all its limitations, is the means to undertake a harmonious and benevolent interaction. As long as the human race is preserved, any mode of interaction can be put into consideration. However, though it is in the ultimate interest of mankind, "survival" can also cause problems. Symbiosis has to resolve the complications and dilemmas. Therefore, our interactions have to be in the prospect of a distant and shared future, instead of a short-sighted and partial "here and now". Thus, "full-scale interactions" refers to interactions in all aspects. It is more than an integration of intellectual disciplines, but also interpersonal interactions, as well as in-depth interactions with the natural and the spiritual.

3. Spirituality First

In history, mankind has made it safely through many an age of material deprivation. What they depended on is spirituality. However, we are living in an age of abundance, and are growing unaccustomed to relying on the spiritual power. Paradoxically, in the age of abundance, people are more inspired for the spiritual pursuit. This is evidence that, regardless of want or abundance, the spiritual alone can bring satisfaction. This is how we came to the conclusion of "material reduction and mental explosion".

The philosophical premise of the three afore mentioned aspects of symbiotic living is the basis, from which we start anew with the wisdom of traditional life. The "solar terms and festivals" demonstrate the symbiotic power of interactions with nature, and an awareness of the strength of traditional commune life. It also expresses *accepting restrictions, full-scale interaction, and spirituality first*. As for "coordinate of the soul", the gratitude for life, elevation of the spirit and full-scale interactions all receive the function of *accepting restrictions, full-scale interaction, and spirituality first*. In the view of "ease as happiness", this form of fellowship can be applied to promote each other's spirituality. Prayers, reflections, contemplations, and sit-in meditations can be the means for a returning to the inner self. When the self is cared for and reenters peace, then even the ease one feels at heart can be strength to ascertain the happiness and overcome difficulties.

Section Two

With no doubt, mankind's spiritual needs have never waned. A spiritual lifestyle answers to the needs of the soul, that is, psychological and spiritual needs, needs for security, leisure, friendship, care, joy, individuality, information, knowledge of one's limitations, and respect. All these are directed to the human conceptions, passions and customs, which are the major component of the human culture.

If the future is a time of "material reduction", then spirituality will be our only way out. If reducing dependence on the material is to turn for the spiritual, then, which kind of spiritual life is the one we should pursue? In a symbiosphere, the spiritual lifestyle appropriate with the idea of symbiosis is a further affirmation to "material reduction". In this way, spiritual life can become a force, strong enough to overcome the crisis caused by environmental deterioration and material want.

The spiritual life of Symbiosphere 1 should contain three aspects and their interactions with each other. These aspects are nature, humanities and spirituality.

First of all, the festivals and solar terms have been commercialized in the modern era. As a result, we have separated ourselves from a close relationship with nature. Besides, we are also cut off from the medium of the interactions between man and nature. What's more, mankind's spiritual life has been severely damaged. Therefore, we should restore the relationship between man and nature. The meaning of nature to man is reflected in the festivals and solar terms. Since the ancient times, the wisdom of human beings has been primarily revealed in the proper treatment of the delicate relationship between nature and themselves, especially in the rhythm and tempo of life, which is "in accordance with the solar terms and festivals based on the natural phenomena". On the one hand, the first chapter is devoted to finding the wisdom manifest in festivals and solar terms. This kind of wisdom can teach mankind to get closer to nature, and also embodies the value of symbiosis when mankind is living with the rhythm and tempo of nature. In other words, "festivals and solar terms" represent the fruit of the interactions of mankind and nature, which is mainly reflected in the advancement of human spiritual life.

"Festivals and solar terms" reflect the memories of the interactions between man and earth, the sea, and the stars. Their origins date back to a close tie with agricultural activities (such as the lunar new year, which symbolizes a resurrection of the plants), religious rituals (such as the Lantern Festival, when people pray for blessings in memory of their ancestors; Mid-Autumn Day, on which people pray to the moon; as well as the Double Seventh Festival or the Chinese Valentine's Day, on which girls pray to the Seventh-Star Princess and the Bed Protector for an adroit hand in knitting), ethics (such as the Pure Brightness Day or Tomb-Sweeping Day, on which people pay homage to the ancestors and mourn for the dead relatives), going after the auspicious and avoiding the inauspicious (such as the Dragon Boat Festival, when people hang up Asiatic Wormwood and drink realgar wine; and the Double Ninth Festival, when people attach Chrysanthemum branches to the windows and doors to "get rid of the evil and filthy" and to receive blessings).

"Festivals and solar terms" should be understood as a kind of "memory in time", which inspires awe in man, and help to form a symbiotic fellowship between man and nature, as well as between the individual and others. The purpose is to remind mankind of the close relationship between man and nature, of the respect for life, and of gratitude to the earth. We can see that only "memory in time" can help us to remember how our hearts have been touched with the nurturing of life. Similarly, we should treat nature with this kind of feelings.

Therefore, the interactions with nature in the symbiosphere are more than the personal ones recorded in www.archilife.org. Festivals are also to be celebrated to in the symbiosphere, and the preserved customs are to be heeded. Moreover, the transform “ill at ease” into a bearable feeling, and furthermore, into “comfort”. However, it should not be mistaken for a spiritual “dallying”. This is why we choose certain compositions to be played in the symbiosphere on a regular basis. Among them, the Western romantic works are the most suitable ones for the theme of “the natural transformed into the spiritual”. With its help, one can better adjust himself to the environmental hazards and other changes, with fortitude and enthusiasm.

Section Four

Unlike those afore mentioned sections, which deals with the relationship between nature and the humanities, the third chapter concerns spirituality. As a matter of fact, “spirituality” can be very personal. It is a returning to the secrecy of the soul, or, the spiritual realm. Contemplation and meditation are the means for one to attain introspection. The key is to have a strong will power and a sharp mind. Inner (or spiritual) strength and alertness are especially necessary when one faces the harsh and crude environment, which can help us to return to the inner self and find peace.

A spiritual life is consisted of reading and maintaining silence. The reading materials should be the classics, especially those on spiritual practice and the inspirational ones, from all great religious traditions. They are indispensable resources, serving as the model references and sources of strength. Silence is a regaining of peacefulness and a reentering of unity of person and “the spirit of the earth” via prayer, reflections, meditations, sit-in practices and contemplations.

Strict regulations are recommended for life in the symbiosphere. One should arrange for himself ten to fifteen minutes after he gets up in the morning and also before goes to sleep at night. This is a peaceful time for himself, spent in contemplation and prayers. The quiet time in the morning should be devoted to thoughts on the goals of the day. One can encourage himself to be strong and face all the challenges of life. The quiet time in the evening should be devoted to reflections and recollections of the day. On the one hand, one should be joyful and thankful. On the other hand, he should make self-examinations and corrections. Only by repeated thinking, praying and reflections can the strength to lead a symbiotic life be gathered, the idea of symbiosis be carried out methodically, and the interactions between man and nature as well as between individuals be undertaken.

Man does not only need to interact with nature and others. He also needs to have interactions with his own soul. But there must be a medium or material for the interactions to take place. The spiritual nurturing in symbiotic living is carried out by concrete practices according to the pre-designed schedules. The following schedule is drafted for all the residents of the symbiosphere to participate. The residents also have other interactions besides book clubs, ritual performances, and the weekly conference on the living condition. "Reports on the mood" and "sharings of the soul" are included as well. In the evening, there is "fellowship time" from half an hour to one hour for everyone to sing, play games, chat, and hold discussions. This is the reference of "spiritual parameter" in Symbiosphere 1.

The elevation of spirit emphasized here is not an isolated action. In other words, solitude is not self-enclosure, but strength to face others once again. Without this kind of experience, one cannot get to have a full grasp and knowledge of his inner self, nor can he reflect on the relationship between himself and others, between himself and nature, in an open and honest way. Therefore, solitude is a preparation to be ready to deal with others. Without this experience, all our actions and interactions would be blind and selfish.

One needs to face the challenges of life as well as his own self. In facing himself, he faces others as well as nature. Therefore, the symbiotic fellowship is a means for us to turn from the interactions with others in our daily labors to a kind of introspective and reflective interactions. "The renewing force would be missing in action, if there is no solitude for the soul." This is a link necessary in the commune life. It is lacked in today's life style, for people fail to realize the value and philosophy of the symbiotic life. To be symbiotic means to live together, which means to have a deeper understanding of oneself, which means to have a deeper understanding of the others. The symbiotic fellowship is an effort towards establishing a closer relationship. The opposite of "symbiotic" is "alienated", "indifferent" and "selfish". Symbiosis can help us to adopt an attitude of openness and enthusiasm. How can we face the harsh environment yet retain the hope and strength? How can we be prepared for action without enthusiasm?

A tentative brochure of "life plan" for fourteen days has been finished. It can be put into the "schedule for daily life" in the symbiosphere, so that the residents can make their response, meditations, and hold discussions.

Conclusion

From analysis of climate change and the existing fauna and flora, we can know much about the environment where the evolution of our ancestors took place. During the past several million years, the climate has been dominated by the instability of the Ice Age and unpredictable weather changes. These changes have given a new appearance to the living environment and the external environment of animals and plants. Thus the species can have more varieties that are highly adjustable and can fit into all biological niches. The adaptable and fast-growing ones can better adjust to the ecological disasters. The human beings are such species, who might have been the typical products of the Ice Age.

Climate change has transformed the general configuration of the earth's surface as well as the vegetation. Animals and plants have to learn to adapt, and the same goes for mankind. But they have different ways of adaptation; this is how the human society becomes more and more diverse. We have brought about environment transformations from the agricultural era to the industrial era: the agricultural revolution has changed the earth's surface, while the industrial revolution has changed the atmosphere. After all, any intervention means change, even symbiosis is no exception.

The emergence of agriculture has drastically changed the relationship between man and nature. Human behavior has affected other species as early as the Paleolithic Age. However, since the day when the human beings first engaged themselves in agriculture, they began to change the living environment—earth, rivers and the landscape—to create a new one to satisfy their needs. Agriculture means to change the natural courses to satisfy human needs. Therefore, it is an intervention into the biological cycles of nature. By eliminating the undesirable species (i.e. weeds), the farmers carefully create a man-made landscape. In this process, the natural replacement that could have restored the original state of the earth is prevented. The earth, without the removed species, is maintained below the natural level of productivity. On the other hand, the species favored by mankind are flourishing, for they have attained extra nutrition, water and sunshine. However, the decrease of vegetation has augmented the erosion of the earth, for the massiveness of the roots has been reduced. They could have kept the earth from being washed away by the rain.

As mankind has begun to rearrange their environment to live more comfortably, they have become more and more aware of the separation of man and nature. The idea of "man and the environment together as one community" is manifest in the modern food-collecting communities, but it may have disappeared in the agricultural communities.

The ecological crisis is very obvious to those who are executing power in the modern society. Thus, the people's attitude, especially in the developed countries, must see a change. Attitude is a decisive factor for everything. "It is good to keep the producing process going" is a widespread notion. But it is one of the hindrances to the change. As long as we are accustomed to pursue the so-called beautiful life via means of capitalist consumerism—that is, consume endless "better" products—then this notion will never cease. The change of the definition of "beautiful life" might be one important step towards maintaining a sustainable relationship between man and nature.

The industrial society has also come to a bottleneck. The ecological crisis and global warming are the result of the development. At the same time, we can still preserve the spiritual power in the traditions of all nationalities and make use of it, despite the fact that we cannot return to the agricultural society and adopt an agricultural lifestyle anymore.

Many ancient civilizations have vanished, yet some remains till this day. In all these cases we can find a massive "spiritual power". Their external environments can be harsh, they may be put at a disadvantage when facing other powerful nations; however, they still have considerable strength for survival. The destiny of the nation is supported by their old spiritual traditions. In other words, we have underestimated the power of spirituality. Of course, we should not overestimate it either. After all, many civilizations that are preoccupied with the spiritual rather than the material have done so at the price of extinction.

The relationship between man and the environment is by no means passive. Agriculture and industry are intervening into the environment, and so is symbiosis. Only by active intervention can this special relationship be maintained. Symbiosis is not passive. Through this means, the spiritual power is not overestimated, nor is the material over-relied on. There should be more and more balanced interactions of the environment and the mind, the body and the soul, the material and the spiritual. Only in this way can the deadlock—the spiritual is over-elevated to the effect that the people are passively restricted or even bound by the environment—be broken.

In conclusion, the structure of the future civilization should contain the element of "the spiritual transforming the material". The relationship between man and nature should be a separate-togetherness. We should not be over-dependent on the material, nor overlook the undertakings to transform the material. Frankly speaking, it is difficult to achieve the balance between the spiritual and the material. Nevertheless, it is the very aim that symbiosis endeavors to achieve.

TITLE: TO SET UP AN EFFICIENCY BIO-COMPOSTING SYSTEM FOR MATERIAL RECYCLING IN ARCHILIFE RESEARCH 1 CENTER

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Keywords: resource use , material efficiency , recycling, microorganisms

Summary

In the past, people in the field of building a green house have put a lot of efforts on the research and development of the construction materials. Unfortunately, many people did not think if the green house is the real candidate for living in a long term. If treating a green house as if it is a big tree, this big tree can use its organs like leaves and roots to absorb nutrients from photosynthesis or water from the soil. Once the matters in the trees lose their internal functions, for example, falling of the leaves in the winter, these matters will fall on the soil and thus will form a recyc ling system that can be reused. In 2002, we started to imitate the behavior of Mother Nature, we used microorganisms to recycle those soil substances. B y treating the vertical planting system as if it is a leaf, it can undergo photosynthesis to produce con sumable vegetables; in addition, is it suitable to be used as a natural air conditioning system. However, how do we deal with feces and food residues produced from human? According to the past experiences, we came to two attempts: 1. using the traditional manure system, but this system is not stable nor time efficient; 2. using composting machine. However, it is not energy efficient and will decrease manure compositions. After 2006, we continuously reviewing the best solution and decided to use earthworms t o achieve the best material recycling efficiency in the biological manure system. Ultimately, we want to obtain one answer: in order to support the group of people living in a recycling system, yet, closed system, how many earthworms do we need to fit the environment?

1. Introduction

Manuring is an ancient technique, and this technique plays an important role inc ontrolling the utilization and reuse of solid substances from the natural resources. From the beginning of agricultural revolution, people started to explore a more advanced manure technique by the aid from the nature. After the industry's revolution, we can possibly control the air ratio, temperature changes and the bacteria abilities to enhance the development of manure industry. Until today, we are still in searching of how to efficiently and optimize the use of solid wastes like human feces, urea, and food residues, etc. Those organic matters are still the challenges for us to face. Only through the completion of composting, matter substances can eventually recycle in a closed space, and only this kind of space is suitable for human being thus becoming a long term living environment. This idea is exactly what we have been spreading upon: SB = GB + symbiosis, meaning what kind of biological ani mals are suitable to live with human symbiotically.

1.1 Origin of the experiment

In the past NASA had made a series of experiments. They wanted to build a completely closed system that human beings can support for themselves. This thinking is known as L ife-support system. I believe it is now the best green house so far. What so ever, NASA has encountered a crucial problem. The physicists are responsible for constructing a preferred physical living environment, the agricultural biologists are responsible to solve the food problems, and the biochemists attempt to find ways to effectively utilize and reuse matters. However, every delicate design or knowledge is difficult to put together as a whole.

1.2 Our goals

The meaning of symbiosis for many is simply the relationship between wild vegetables and us, which is the capability of vegetables providing nutrients for us in our diet. In the true meaning of symbiosis, eating vegetables are input, human produces output like feces, and urea. Those outputs have to become input for the plants in order to be considered as recycling. In other words, for these two to be interacted well, one has to be the input and the other has to be the output, and furthermore, the tighter the interaction, the tighter the ring. For humans the vegetables are just purely food, and for the vegetables, their leaves are their organs. Photosynthesis is their main food source, therefore, leaves are not for humans to eat, but humans eat them anyways. Through the concept of in and out, the relationship between human and wild vegetables is interconnected. The rest of problems are the human feces and urea. You might wonder if the wastes are the vegetables input? The answer is no. The vegetables are not necessary eating our feces as nutrients directly, so that is why we do not plant vegetables on top of the septic. There must be an essential process in the interaction between vegetables and our wastes, and this process is our main research topic.

2. Material and Method

2.1 Material

The experimental matters in this experiment do not influence the daily life routine of these inhabitants of the center in order to achieve many possibilities of this research. All the inhabitants live in the center were not less than one season. Experimental procedures are followed under the regulation of the PSA (Public Service Administration) committee.

2.2 Method

Culturing of the bacteria is done through the traditional method or through molecular biology. Add 10 grams of sample (wet weight) into 90 ml of sterilized distilled and de-ionized water to get suspension and continue diluting (10^{-2} 10^{-3} 10^{-4} – mould; 10^{-4} 10^{-5} 10^{-6} – actinobacteria ; 10^{-5} 10^{-6} 10^{-7} – bacteria), then inoculate to Rose Bengal Agar, to Actinomycete Isolation Agar, to Nutrient Agar (NA) for culturing mould, actiobacteria and bacteria, respectively.

3. Result

3.1 The quantity of solid wastes produced from each citizen per day

Table 1 The quantity of solid wastes produced from each citizen per day

Solid wastes	Mass（g）	participator
Human waste	220	3
Kitchen waste	80	6
Farming waste	30	4
Fallen leaves	100	10
Total	430	23

From 2002-2005, the wastes produced by the citizens per day are 220 g, and food residues are 80 g. Farming and natural falling leaves produced about 30 g and 100 g, respectively. In these 3 years, the centered formed four public committees who are responsible for taking care of the plants, food, clean environment and circulation of manure. All the numbers provided here are from the long-term experiment results and also provided by the participants. Finally, we accumulate the amount of reusable solid wastes from each person per day, and that is about 430 g.

3.2 The efficiency of different manure methods

Table 2 The efficiency of different manure methods

Products（Kg）	Traditional manure	Composting machine	Vermicomposting
Time（month）	6-9	1	2-3
Organic mass（Kg）	0.3	0.1	0.5
Microbial biomass	medium	low	high
Demanding energy	×	high	×
Stability	Low	high	high

According to time efficiency, the traditional manure method spends the longest time and the composting machine is the fastest to obtain manure products. However, the actual products from composting machine will fall short instead, which means many organic matters will become carbon dioxide and water. At the same time, composting machine is not energy friendly. Later, we spent time on breeding earthworms and were inspired by them. Earthworms can eat the digested organic matters of themselves body weight per day and have the ability to transform into half the weight of rich soil. In table 3, the results relieved us. In the past, we worried about using earthworms in the biological manure would not efficiently decrease the amount of harmful microorganisms, but the results tell us this is not the cas e of concern anymore.

Table 3 To analyze the microorganism of the casting of earthworms

Composition	Range
bacteria	1.1×10^{8}
Fungi	3.1×10^{8}
Actinomycetes	$10^{7}\times10$ c/g
Salmonella	none
E. coil	none

In the process during traditional manure method, the hig h temperatures could kill harmful microorganisms since they are mesophilic and leave out the thermophilic microorganisms. A mechanical composting machine uses heater plate can increase the temperature from 45 ℃ and above, and humidity of final products will keep at 30%. The earthworm method can substitute the beneficial bacteria for the original species due to substrates digested from intestine, and this method can be achieved under room temperature.

4. Conclusion and Disscussion

4.1 Conclusion

Figure 1 A prototype of symbiotic high efficient recycling system in ARF 1 center before 2002.

Figure 2 the comparison between the products produced from three different manure methods and the roots grow from carrots. (left: earthworm casting; middle: traditiona l manure: right: product from commercial composting machine

Figure 1 shows in the past when we were building the symbiotic high efficient recycling system, we hoped through the improved technology we could efficiently achieve a substance recycling system. However, during the first time of experiment between 2002-2005, we faced few challenges. For example, the cabbage and water spinach are easy to grow and produce in a large amount for us to eat, but before we harvest, the insects had eaten them all. In this way, we had to use wild vegetables as our main plants; in a ddition, in order to grow the vegetables in an adequate environment, the vegetables we obtained are within 5 km of the center. Secondly, manure is our matters, but according to the past agricultural manure experience, manuring is labor intensive and easily to produce smells. Finally, we chose to use commercial composting machine, but it wasted a lot of energies, plus the manure composition will decrease dramatically. Therefore, in 2006 we started to use earthworms as our final target.

Figure 2 is when we compared ability for growing carrots using different manure methods under the same condition. During the process of cultivating carrot seeds, the carrot is surprisingly grew the best in earthworm casting. This organism, known as "the stomach of earth" is efficiently aid in the recycling system.

4.2 Disscussion

Advantage of the earthworm composting system :

- Worm composting is an incredibly efficient way to convert kitchen scraps into nutrient -rich compost.
- Worm could digest the most recycle material ,even n ails and hairs.
- These elegantly efficient organisms have been on earth for hundreds of thousands of years longer than humankind, largely untouched by evolution due to their nearly perfect adaptation to their role in nature.
- Humankind has studied and learn ed to appreciate the talents of the earthworm, developing systems that capitalize on the natural role it plays in recycling organic matter back into humus.
- It's not easy to account for microorganisms by measuring the chemical factors.
- Earthworms are rich in protein contents. We can produce them in large amounts and use for food for the fish, or can be used for the citizens delicacies.
- In full operation, the Worm Tower houses 10,000 to 12,000 worms, consumes 5 to 8 pounds of food a day, allowing you to harvest a full tray of castings per month.

In the near future, we want to test if the earthworms can increase fertility of the soil and if they can survive in the dry stool? In addition, the pre-processed urea is fermentable and is efficient for organi c matter recycling? Maybe I will share with you all next time!

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OPEING DESIGN OF DOUBLE-SKIN FAÇADE FOR IMPROVING THE NATUAL VENTILATION PERFORMANCE IN HIGH-RISE RESIDENTIAL BUILDINGS

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Keywords: double-skin facade, opening design, natural ventilation, high-rise residential building

Summary

Double-skin façade, as envelope system composed with 2 layer glasses while placing the Intermediate façade between both glasses, has the strong point that the Intermediate façade decreases wind pressure and it can positively respond to the external weather conditions and the internal ventilation requirements through the various openings, which is an alternative to resolve the problem of natural ventilation appeared in high-rise residential buildings.

Double-skin facade is planed according to each case. As the components of double-skin façade generally influence thermal, lighting, sound and air environment, although the study on the procedure of plan has been executed, the planned and applied buildings were mainly limited to office buildings and did not aim for the positive natural ventilation. Accordingly, to apply to residential buildings, the consideration on natural ventilation performance in planning also should be added.

In this study, to consider natural ventilation performance in planning double-skin façade for high-rise residential buildings, firstly, the characteristics and the status of the envelopes of existing high-rise residential buildings were grasped, secondly, the factors of double-skin façade plan influencing to natural ventilation performance were selected and then the evaluating model was determined. Finally, the distribution of Intermediate façade and internal air flow from the inducement of external windows for natural ventilation performance were evaluated and then the instructions for double-skin façade were derived.

1. Introduction

Whereas the residential sites in the downtown are recently decreased from the congestion of urban space, occupants' requirements on residence in the downtown for the convenience of life are increased and then the high-rise residential buildings are being accelerated. High-rise residential buildings restrict the openings of windows by the reasons such as wind pressure, stack effect and safety, etc and then the forms of envelopes were mainly changed. The envelope planned similarly with that of office building increased the value of house but could not consider the characteristic of residential building that natural ventilation was a main ventilation means, which was different from office building. Furthermore, from the legalization of balcony expansion, the balcony used as the thermal buffer space was modified as a residential space and the big differences not only in the form of envelope but also in performance were appeared. The problem of ventilation was largely appeared no less than the weakened insulation performance. As sliding window applied at balcony was changed into the shape of top-hinged out swing window of which opening area is small, the psychological feeling of opening of occupant was decreased and the occupants used to appeal the stuffiness because they cannot feel the feeling of air flow even in opening the widow. And the natural cooling inducing external air becomes difficult and then the problem like the increase of energy cost was increased also.

Another problem of high-rise residential buildings are that the households of which one side only faces the external air within unit household due to the core structure located at the central part of plane were frequently occurred. This made cross ventilation which efficiently utilized the natural ventilation impossible and then largely fell down the efficiency of ventilation.

To resolve these problems, the façade which can satisfy the requirements on the natural ventilation of residential building should be planned. However, at the present façade, because there is the limit of opening area and opening width from the safety reason, not only it is difficult to increase the opening area, but also it is difficult to decrease the wind pressure properly. As an alternative which can resolve the problem of wind pressure and safety at high-rise building of which opening area is restricted and simultaneously promote the natural ventilation, there is double-skin façade on which the active studies are being progressed recently. Double-skin façade, as the façade system composed with 2 layer glasses while Intermediate façade is being placed between them, has the strong point that Intermediate façade decreases wind pressure and it can

Figure 1 Non-expansion of balcony

Figure 2 Expansion of balcony

positively respond to external weather conditions and internal ventilation requirements through the various openings.

This study is to plan to consider the natural ventilation performance of double-skin façade to improve the natural ventilation performance as applying double-skin façade to high-rise residential building. In this study, firstly, the characteristics and the problems of the envelope of high-rise residential building were grasped. Next, the factors of double-skin façade plan influencing the natural ventilation performance were reviewed and evaluated.

Natural ventilation in this study means the ventilation which internal occupant can directly feel the effects of ventilation and what discharges the heats of Intermediate façade through air flow was not included. And rather than dealing with all planning factors influencing the natural ventilation performance, as increasing the evaluating factors based on the reviews on each factor, the evaluation was performed while focusing on the factors to be importantly considered for the plan considering the natural ventilation performance.

2. Field Survey

As double-skin facade should be planned according to the usage and the characteristic of building, this study wants to grasp the characteristic of high-rise residential buildings, the applied object of double-skin façade. For this purpose, the envelopes of high-rise residential buildings were investigated and the problems related to the natural ventilation through the questionnaire and the interview to the occupants and managers of existing high-rise residential buildings were investigated. Through the investigated matters and the standards and the laws related to natural ventilation, the required performance of natural ventilation of residential building was summarized to become the standards in evaluating natural ventilation performance after then.

2.1 Data Analysis

As planning the envelope as considering the natural ventilation performance is the purpose of this study, firstly, the investigation on the vent is surely necessary. The opening form of vent is an important factor determining ventilation rate along with the area of vent and determines the induction rate of external air. Accordingly, as the opening form of vent of the envelope of high-rise residential building, the present practice of the induction of external air was grasped. The investigation was executed to total 15 buildings at Yeouido, Yongsan-Gu, Gangnam-Gu and Yangjeon-Gu, Seoul where high-rise residential buildings were most distributed.

As the results of investigating on the form of envelope parts, most of investigated buildings applied curtain walls on the envelopes and divided a part of curtain wall area into the frame to use as the vent. As the kinds of vents, like Table 1, all cases except for the lower floor parts of T high-rise residential building at Yeouido were appeared to apply the method of top-hinged out swinging window and only at the lower floor parts of T high-rise residential building at Yeouido, the method of top-hinged out swinging window and of side-hinged out swinging window were combined. The case of ensuring the area of vent more widely as dividing the

Table 1 Opening window of the envelope of high-rise residential buildings

			
Top-hinged out swinging window		Top-hinged out swinging window + Side-hinged out swinging window	

districts widely despite of the same method of top-hinged out swinging window could be found.

To grasp the environmental performance related to the envelope which the occupants of high-rise residential buildings felt, the questionnaire and the interviews to mangers were executed. Through this, the problems on internal environment which the occupants of high-rise residential building felt at the real life were tried to be grasped. The questionnaire was executed at high-rise residential buildings, z and to improve the reliability of questionnaire, the objects of questionnaire were selected in order for the height and the direction of household in the building to be regularly distributed. And as the interviews to managers being executed together, the complaints come from occupants after the completion of construction were grasped.

As the result of questionnaire, the problems of envelope part which might influence to internal environment performance were pointed out. As the weak points of envelope part were raised by the expansion of balcony, heating and cooling load were increased and cold draft in the winter season was appeared to be induced. At the envelope, the water leakages and the infiltration were occurred, which means that the considerations on high external wind pressure at the higher floor parts were poor. And there was the opinion that, due to small opening area of vent ,the speed of air flow was decreased and then natural ventilation was poor, psychological feeling of opening was small and the stuffiness was felt.

2.2 Problem Analysis

The followings are the summary of the performances and the improving directions related to the ventilation among internal environment performances required by the occupants of high-rise residential building in planning double-skin façade to improve natural ventilation performance of high-rise residential building based on the problems appeared as the results of data analysis of envelopes and the analysis of those reasons .

1) The security of natural ventilation performance through the inducement of external air

As the buildings have the aspects of high-rise residential buildings, cooling load was increased and the increase of cooling load was deepened by the use of curtain wall envelope that the area rate of glass was high. On the contrary, the opening area of vent became small due to the problems of wind pressure and safety, which could not have the effects of free cooling and then make cooling period longer to have the negative effects on the energy use directly. Even at the same opening method of window, the security of opening area and opening angle making ventilating rate increased are necessary.

2) The security of the air flow speed

It was appeared that the occupants of high-rise residential building wanted to feel the feeling of air flow through the inducement of external air. The occupants who had experienced cross ventilation at existing plat type apartment before the residing at high-rise residential building appeared this tendency furthermore.

Accordingly, the opening method of window, the opening area and the opening angle, etc making air flow sufficiently induced into the inside should be considered.

3) The security of psychological feeling of opening

Table 2 Applying method of double-skin facade design through the analysis of problems of existing buildings

Characteristic of residential building	Requirement	Application to DSF
Floor height is lower than office building.	To maximize buoyancy force	Inlets and outlets are located in front of spandrel.
	To prevent short circuit	Inlets and outlets are located diagonally.
There is high demand of natural ventilation.	To increase ventilation rate	External openable windows can be added. (optional)
	To let occupants feel air flow	
Children should be considered.	To make occupants safe	The type of external openable windows cannot be sliding.
		The depth of external openable window is 15 ㎝.
The reduction of the living area is critical issue for occupants.	To maximize the living area	The depth of Intermediate façade is 30 ㎝.
Occupants maintain and clean DSF by themselves.	To give occupants convenience for maintenance and operation of DSF	The type of internal window is sliding.
Most occupants use curtain for interior decoration.		
-	To provide better view	The openable bays are placed at the edge of façade.
		The frame area is minimized.

Occupants wanted psychologically opened feeling regardless of actual ventilation rate. High-rise residential buildings questioned to occupants satisfied the required ventilation rate and was measured to have the good internal air quality. But, because the vents were not widely opened like sliding method used at the existing plate-type apartment and the opening areas were small, the occupants are judged to feel the psychological stuffiness. To resolve these, it is required to secure the effective opening area to the maximum as being away from the application of present top-hinged out swinging window.

And the matters to be considered in planning double-skin façade reflecting the requirements of occupants through the characteristics of high-rise residential building and the analysis of problems are as per the following Table 2.

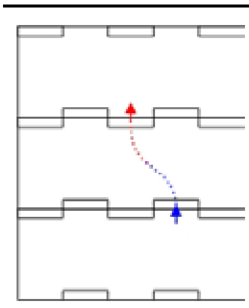
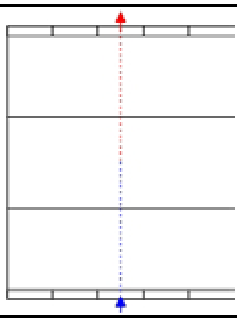
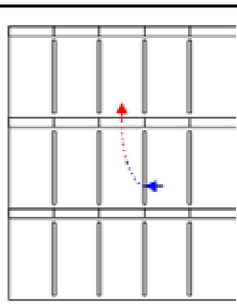
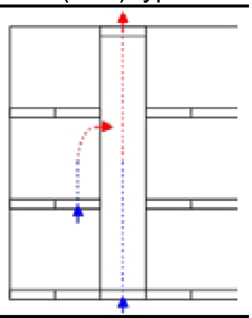
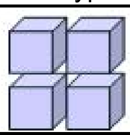
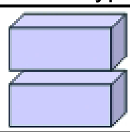
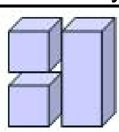
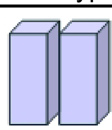
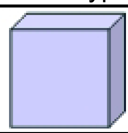
3. The procedure of double skin façade plan considering natural ventilation performance

Double-skin façade largely consists of external façade, internal façade and Intermediate façade between both sides.The components influencing to natural ventilation performance are external opening, Intermediate façade space, Intermediate façade floor and internal opening and there is the necessity to review these planning factors to plan double-skin façade as considering the natural ventilation performance. In making decisions, the usage of applied building, high-rise residential building, was reflected. And because the natural ventilation performance should be considered together to make decisions, the procedure of double-skin façade plan was summarized.

3.1 Factors of double-skin façade plan

External façade is classified into the outlets and inlets and the external windows and the arrangement types of inlet are classified into diagonal, parallel, perpendicular and perpendicular type. Separately from the outlets and inlets, if external windows are placed at external façade, they can make external air positively enter into the inside during the intermediate period and make it possible to ventilate at the least to improve the quality of internal air during cooling and heating period and then double-skin façade can be variously

Table 3 Factors of double-skin facade plan influencing to natural ventilation

<table>
<tr><th colspan="2">Components</th><th colspan="5">Factor of plan</th></tr>
<tr><td rowspan="3">External façade</td><td rowspan="2">Outlet and inlet</td><td>Diagonal type
</td><td>Parallel type
</td><td colspan="2">Perpendicular type
</td><td>Perpendicular (side) type
</td></tr>
<tr><td>Height and width of outlet and inlet, Height gap of outlet and inlet, Ratio of inlet and outlet</td><td>Height and width of outlet and inlet, Height gap of outlet and inlet</td><td colspan="2">Height and width of inlet, Height and width of outlet</td><td>Height and width of inlet, Height and width of outlet</td></tr>
<tr><td>External window (Optional)</td><td colspan="2">Height, width, perpendicular location, horizontal location, opening method</td><td colspan="2">-</td><td>-</td></tr>
<tr><td rowspan="5">Intermediate façade</td><td rowspan="4">Interme-diate facade space</td><td colspan="2">Single story cavity</td><td>Hybrid cavity</td><td colspan="2">Multi story cavity</td></tr>
<tr><td>Box type</td><td>Corridor type</td><td>Shaft-box type</td><td>Shaft type</td><td>Whole type</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Depth</td><td>Width
Depth</td><td>Width
Depth</td><td>Height
Depth</td><td>Height
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Depth</td></tr>
<tr><td>Floor</td><td colspan="5">Opening rate of floor</td></tr>
<tr><td>Internal façade</td><td>Internal window</td><td colspan="5">Height, width, perpendicular location, horizontal location, opening method</td></tr>
</table>

operated by the season.

The planning factors of Intermediate façade space are the height, the breath and the width of cavity. The height and the width of Intermediate façade are initially determined by the types of double-skin façade. The height of Intermediate façade is determined equally to the floor height at double-skin façade of singly story type. At the double-skin façade of hybrid type and multi story type, by the unit of how many floors the height of Intermediate façade will be planned should be determined.

Internal façade has been applied to the cases in the various forms like slit or window, etc but it is difficult to secure the sufficient ventilation rate in the form of slit in considering the required performances of natural ventilation of residential building. Internal window is at the most internal side and thus has the characteristic that it should be determined as laying stress on the conveniences of occupants (the use of internal space and the convenience of maintenance and repair and cleaning, etc) and the psychological feeling of opening. As the planning factors, there are the height, the width, the horizontal location, the perpendicular location and the opening method.

Table 3 is the summary of planning factors considered so far.

3.2. Procedure of double-skin façade plan considering natural ventilation performance

After considering the components of double-skin façade previously reviewed, the procedure of double-skin façade plan considering the natural ventilation performance of high-rise residential building was estimated.

3.2.1 The selection of double-skin façade type suitable to high-rise residential building

According to the study (Park et al, 2002) selecting double-skin façade type suitable to high-rise residential building according to the procedure, as a first step, it is suitable to apply single floor double-skin façade due that it is high-rise building. As the next step, due that the requirements of occupants are various and it is important to intercept the privacy among rooms and the expansion of pollutants, box type double-skin façade can be selected to be most advantageous. This study judges box type as the double-skin façade applicable to high-rise residential building after passing through the process of selecting the type of double-skin façade like the above and progresses the research on the components and the planning factors at box type.

3.2.2 The decision of arrangement type of outlet and inlet

Arrangement type of outlet and inlet decides the kinds of outlet and inlet planning factors and, in case of box-type double-skin façade, outlet and inlet is repeatedly installed every floor and largely influence the elevation. Among arrangement types of outlet and inlet previously reviewed, perpendicular is used only at shaft-box type and outlet and inlet can be arranged by parallel, diagonal and perpendicular type at box-type double-skin facade. This study applies parallel and diagonal type of double-skin façade which is applied to prevent air flow discharged from outlet from being flow again in the inlet of upper floor due that the gap of height between outlet and inlet of high-rise building.

3.2.3 Decision of façade module

As double-skin facade has the high cost of construction and requires the precision, planning as making into the unit is desirable. Accordingly, it is reasonable to applying to all rooms as fixing the external module.

As the basic dimension system of architecture, the basic module of ISO, 1M=100mm, was used and the multiple of 3M and 6M is commonly selected in the world. And considering that the house mainly uses 3M unit of horizontal plan module, 900mm is determined as the external module. But, as the view and the feeling of opening is regarded as the important at high-rise apartment, the fixed window which is not opened uses 1,800mm module to improved the psychological feeling of opening and the quality of view. Horizontally, 5,400mm was determined as the breath of studied space. To determine the layer heights of studied space, the layer height of domestic high-rise residential buildings were investigated and the layer heights were the range of 3,050~3,300mm. At this time, the size of studied space applied layer height of 3,250mm as the height of studied space. Of 3,250mm, layer height of studied building, ceiling height is 2,500mm and the height of spandrel part is 750mm.

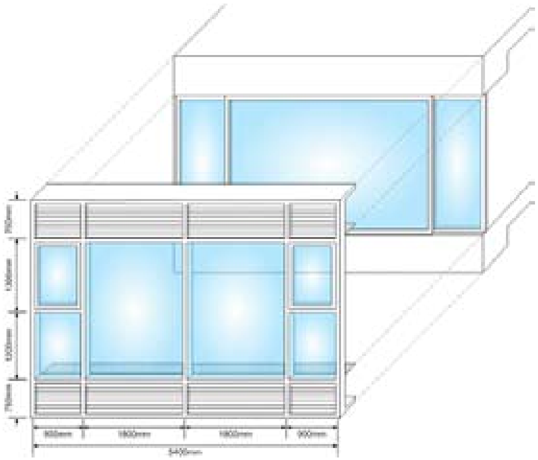
3.2.4 Determination on the inducement of external window or not

External window, as an optional component, has not been applied at the cases of double-skin façade so far and most of cases installed only inlet and outlet. However, some cases like Devbis tower positively induced external air as opening the front side of external façade without outlet and inlet. In case that the opening area of external façade is big, not only many quantities of external air can be induced but also occupants can feel the psychological feeling of opening and the feeling of air flow and thus the natural ventilation performance of residential building is expected to be satisfied. According to the study (Kim et al, 2002) in the ventilation rate when the window was induced at the external side of double-skin façade was appeared 1.4times to 3times higher than the case without the window. Thus, this study induced PAF type window at the external side.

3.2.5 Decision of internal window

Internal window has the characteristic that it should be determined as laying stress on the conveniences of

Table 4 Diagram of double-skin façade

Continents		Characteristic	Diagram of double-skin façade
External Façade	Outlet and inlet	Diagonal type	
	External window	PAF type	
	External glass	Kind: Tempered glass Thickness: 6 ㎜	
Intermediate façade	Type	Box type	
	Blind	Kind: Venetian blind Location: 150 ㎜ from facade (Assuming the blinds are pull up in inducing the natural ventilation)	
Internal Façade	Internal window	Sliding	
	Internal glass	Kind: Low-E duplex glass Thickness: 6 ㎜ +12 ㎜(cavity) +6 ㎜	

occupants and the psychological feeling of opening as it is at the most internal side. Accordingly, sliding type which does not influence to the residing space even in opening and makes it easy to approach to the Intermediate façade due that the opening area is wide is most suitable. Internal glass was planned to have lower coefficient than 3.84W/㎡·K of coefficient transmission of the window facing external air stipulated at the laws as analyzing U-Value of general duplex glass and Low-e glass with WINDOW 5 program developed by Lawrence Berkeley National Laboratory(LBNL).

Diagram of double-skin façade planned by the procedure of double-skin façade considering natural ventilation performance is like Table 4.

4. Evaluation of Double Skin Façade Performance

To plan the façade to improve natural ventilation performance, the evaluation on the effects which each planned factor has on natural ventilation performance is necessary. For this purpose, among planning factors of several components influencing the natural ventilation performance of double-skin facade, the evaluating factors which is actually planned through the evaluation were selected and the model for evaluation was established.

To interpret the natural ventilation characteristic of double-skin façade for the evaluation, air flow was assumed as normal state 3 dimensional flow and 3-D steady state governing equation was used. As the model of turbulence, standard k-ε model of turbulence was selected and used. For the interpretation, STAR-CCM+ program coded to be suitable to the interpretation of air flow, heat transfer, pressure and pollutant movement among the general-purpose CFD interpreting model programs was used.

4.1 Evaluation Model

The installation of external window becomes the factor which can largely increase the ventilation rate. As evaluating factors, there are the opening method and the height of external window. Regarding to the opening method of external window, the evaluation on PAF type and top-hinged out swinging type used in the existing high-rise residential building were executed. At the diagonal type, the evaluation on each wind direction was performed. The basic mode of evaluating factors is like Table 5.

Table 5 Basic model of evaluating factors

Component	Explanation
Outlet and inlet (Diagonal type)	Height of outlet and inlet: 600mm Ratio of the breath of inlet and outlet: 1:1
Width of cavity	300mm
External window	Opening method: PAF, Height: 1300mm

At the high-rise apartment and stores building, the rooms are not oriented to the specific direction. Says, there is the possibility of facing all directions. Accordingly, assuming the plane of building as the plane of square which is most common and basic at tower type buildings, the incident angle of wind, ϴ, at each household, ϴ, has the value of 0~90°(absolute value). Thus, the evaluation on the speed of wind and the incident angle, 0°, 30°and 90° according to wind scale table by Beaufort is performed, provided that the value of the direction of wind required according to natural ventilation performance is analyzed.

4.2 Simulation result

The results of evaluation are as per Figure 3 and, as compared with the basic model without external window, in case that the incident angle is 30°, the ventilation rate is increased more than 1.5times and, in case that the incident angle is increased more than 8 times. Figure 4, even though the superiority and inferiority of ventilation ratio becomes different by the opening method according to the direction of wind, considering that 90° direction of wind is frequent, it seems that PAF method which has much higher

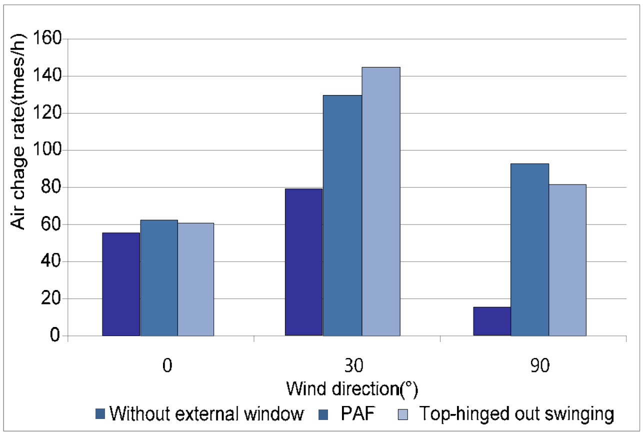


Figure 3 Ventilation rate according to the opening method of external window

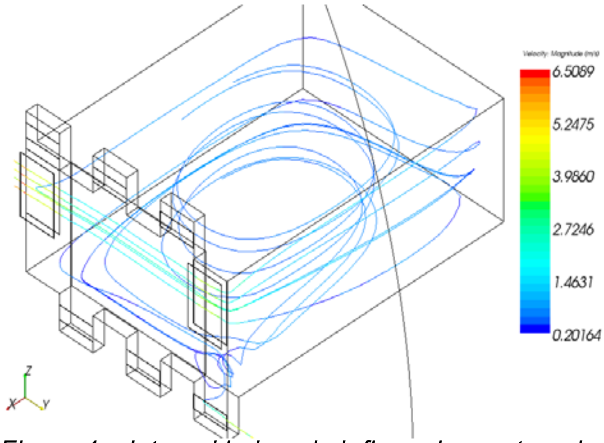


Figure 4 Internal induced air flow when external window was installed

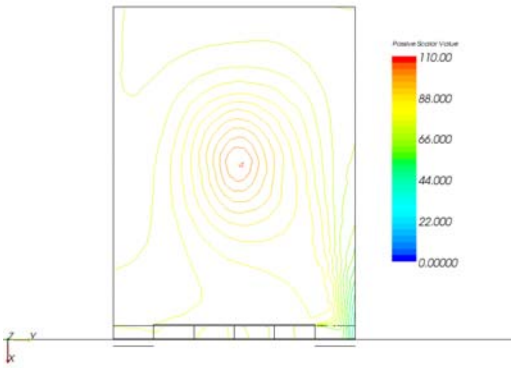


Figure 5 Average air age when PAF window was installed

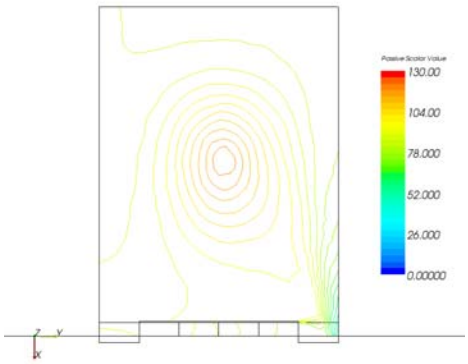


Figure 6 Average air age when 5Top-hinged out swinging window was installed

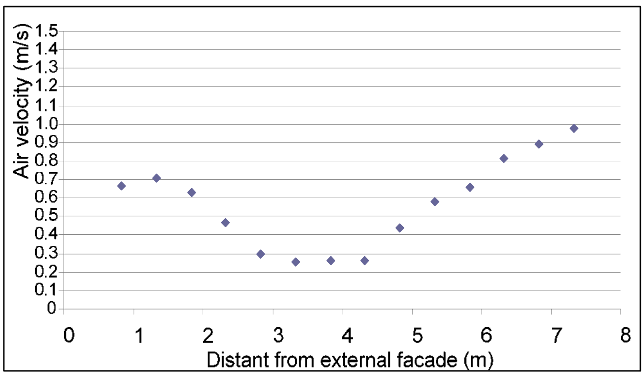


Figure 7 The speed of internal air flow when PAF window was installed

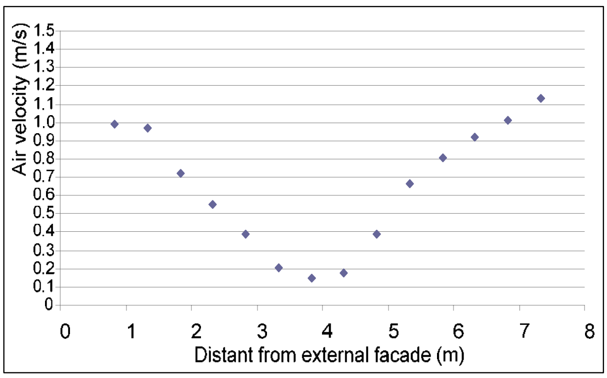


Figure 8 The speed of internal air flow when Top-hinged out swinging window was installed

ventilation ratio at the incident angle of 90° is advantageous. And, the case that the incident angle is 90° was decreased to less than 1/7 as compared with the maximal value in the basic model without external window and the efficiency of ventilation was improved and it was confirmed that the air circulated the whole room.
The case that external window was PAF type, due that the maximal value of air age was small, was appeared to make it possible to ventilate more efficiently.
As the ventilation rate was increased, many quantities of external airs were induced and thus the speed of air flow was also increased together. However, it did not exceed 1.5m/s and then the unpleasant was not occurred. On the contrary, the speed of air flow between 0.25~1.50m/s was generally occurred in the room and then there was the pleasant feeling because the occupant could feel the feeling of air flow.
As the result, when the height of external window was decreased from 1,300mm to 1,100, the number of ventilations was decreased by 14%, when decreased to 900mm, 8% of that of 1,100mm was appeared to be decreased again. However, even in case of 900mm, the ventilation of more than 70 times per hour was possible and then if external window is induced, ventilation rate is sufficient even though the size is planned small. As the result of reviewing the opening method which can secure the ventilation rate while keeping the stability as the external window, PAF type and top-hinged out swinging are judged to be suitable and PAF type was appeared to be more advantageous at the aspect of ventilation rate and ventilation efficiency under the condition that the incident angle was 90°. And the speed of internal air flow did not exceed 1.5m/s. And the speed of air flow of 0.25~1.50m/s was appeared at the room generally and the occupants could feel the feeling of air flow, which is expected to have high satisfaction.

5. Conclusions

This study, as establishing the evaluating model after selecting the planned factors of double-skin façade influencing the natural ventilation performance to consider the natural ventilation performance in planning double-skin façade for high-rise residential building and evaluating the distribution of air flow of the cavity and the inside, tried to verify the performance of double-skin façade system considering the natural ventilation.

1) It was appeared as the result of investigation that the occupants of high-rise residential building want the security of natural ventilation performance, of the speed of air flow and of the psychological opening feeling through the inducement of external air.

2) Among the components of double-skin façade, the components mainly influencing the natural ventilation were external openings, inlet and outlet, external window, cavity space, opening ratio of cavity floor and internal openings and the evaluating factors were derived from these planning factors. The parts where decision-making was necessary as the aspect of architectural plan had priority were the arranging type of outlet and inlet, the module of façade, the inducement of external window or not, internal window and opening ratio of cavity floor and, according the decision of these items, the evaluating factors are derived.

3) Among the opening methods of external window, PAF type can furthermore increase ventilation rate at the direction of wind of 90° and has low average air age as compared with top-hinged out swinging window which is presently used at most of high-rise residential buildings, which was appeared to have high applicability.

The guides of plan presented in this study were determined through the simulation based on the conditions of the direction of wind and the speed of wind at high-rise residential building. Even though this was to plan the façade with which natural ventilation performance was improved through the relative comparison among the cases, it should be additionally verified through the experiments in future to design the concrete values. As to the planning factors influencing both the ventilation by the buoyancy and the ventilation by wind pressure, the interpretation which is closer to the actual practice at the state that all of the temperature, sun rate, wind speed and the direction of wind are inputted should be additionally executed.

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STUDY ON THE HUMAN RESPONSES AND PRODUCTIVITY WITH THE REGULAR WORK AND REST PATTERN IN HIGH QUALITY ILLUMINATION ENVIRONMENT.

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Keywords: Ryodoraku, sympathetic nervous system, physiological responses

Summary

Due to the overdevelopment of industry that contributes to the disassimilation of the earth's environment, in order to engage the limited resources in terms of energy saving and good use, this research proposes a regulation of daily sunlight strategy, simultaneously giving dual attention to the human physical labor productivity aspect and the development of spiritual thought productivity aspect, and analyze the influence of the factor of intensity of illumination, includes 50Lux, 500Lux and 2000Lux. The study evaluates human physiological responses by means of analysis of the Ryodoraku values, which could reflect the condition of sympathetic nervous system entirely, and the result was further analyzed statistically.

The experimental result shows that the higher intensity of illumination is, the greater influence of Ryodoraku is more obviously. It reflects that the lighting environment of high intensity of illumination contains the influence that the neural excitement degree change can't be ignored.

1. Introduction

Due to the overdevelopment of civilization and industry that contributes to the disassimilation of the earth's environment- the speed of which is increasing possibly towards a violent event, or even human extinction. To avoid such possibilities and for the survival of humans and their cultural extensions when the environment changes is the background for a realization of a specific research incorporating paragenesis, demarcating a new civilization and its use limited resources.

1.1 Schemes for Daily Sunlight Succession Regulation Pattern.

In order to engage the limited resources in terms of energy saving and good use limits the human material demand aspect and the inflation of the spirit of civilization aspect. This research proposed is an appropriately feasible sunlight daily succession strategy, a constructed mutual correspondence daily life type, time interval and the space, simultaneously giving dual attention to the human physical labor productivity aspect and the development of spiritual thought productivity aspect, as basis of and criterion for the future life style.

According to the investigation result and in view of ‘To strive for the survival, to seek the livelihood, to extend the life’ different faces, the immigrant in daily activity may differentiate in two types, and aims at its daily activity characters.

(1) Physical labor productivity aspect

Because of the payout of physical labor, to gain the concrete achievement, including: immigrant in literary arts, technology, daily necessities and craft correlation creation and so on is engaged in each kind of public service and is engaged in ...... and so on.

(2) Spiritual ponder productivity aspect

By participation, the observation, reading and the ponder, the discussion to enriches and promotes the knowledge and the energetic stratification aspect, including: engaged in each learning activity, individual ponder, the associates discusses ...... and so on.

But to meet with it's the spatial illumination environment characteristic needs, including low intensity of illumination (50Lux), ordinary intensity of illumination (500Lux) and high intensity of illumination (2000Lux).

1.2 The Human Physiological Reaction Evaluation Method

In the previous studies, the relationship between the changes of intensity of illumination and the corresponding human physiological responses was usually surveyed by using single physiological measurement such as electrocardiogram, brain waves, etc. The whole body responses were seldom evaluated. In this study, the ' systematic measurements of Ryodoraku ', which is currently widely used in the area of Chinese medicine to assess the benefits of acupuncture treatments, was used to study the effects of the ' non-contact environmental stimulation ', such as illumination changes on human physiological responses. The study evaluates human physiological responses by means of analysis of the Ryodoraku values (Nakatani Y, 1956), which could reflect the condition of sympathetic nervous system entirely and was based on Chinese medicine. Systematic measurements of Ryodoraku are to measure the change of electric conduction amount of. By measuring the change of electric conduction amount of 12 collateral channels present points with quantity in order to understand that the quantity examines the physiological state of the corresponding viscera organ of position. (Table 1 and Table 2)

Table 1 The meanings of Ryodoraku measurement value

The change of Ryodoraku measurement value	Meanings
Measurement value rises	Feel excitedly and nervous, high awaken degree
Measurement value reducing	Mood is steady, feel tired or relaxed

Table 2 12 channels and collaterals of spot and corresponding internal organs

12 collateral channels present points	Corresponding human organs
Lung Meridian	Lung , Nose , Skin
Pericardium Meridian	Pericardium, Blood vessel
Heart Meridian	Heart , Tongue , Eyes
Small Intestines Meridian	Small intestine , Eyes , Tongue
Triple Heart Meridian	Lymphatic vessel , Ear , Eyes
Large Intestines Meridian	Large intestine , Mouth , Tooth , Nose , Tongue , Skin
Spleen Meridian	Spleen , Pancreas , Stomach , Brain
Liver Meridian	Liver , Eyes , Genitals , Muscle
Kidney Meridian	Kidney , Brain , Eyes , Bone , Nasal cavity
Bladder Meridian	Bladder , Ear , Nose , Eyes , Brain
Gallbladder Meridian	Gallbladder , Head , Eyes , Muscle
Stomach Meridian	Stomach , Mouth , Tooth , Nose

The main focus of this research is to discuss the influence of different lighting environments on human bodies based on local weather conditions, including temperatures and humidity. In addition, the research will propose a more suitable model with choices of degreed Illumination of lighting environment from the result analysis.

2. Experiment Design

2.1 Experiment interpretation

In this study, we stimulated 22 participants with 3 different lighting environments with an intensity of 50Lux, 500lux and 2000lux respectively under precise controlled indoor environment qualities, such as thermal comfort, sound noise level.

Experiment time is all 60 minutes and under the different lighting environments of experiment, determine the change of physiological reactions of participants with human physically responses system- ' systematic measurements of Ryodoraku ', and carry on statistical analysis of the experimental result. Via than to the change that the human body reacts before and after the experiment, we can find out about the human influence received of physiology of different moments under each lighting environment experiment. Experimental result via all group meanwhile one to right to analysis, can differentiate the difference that different lighting environmental impact on human physiological reaction in order to be clear.

2.2 Subjects and Workplace Conditions

In this study, 22 healthy participants were selected (12 females, 10 males; age 22–30 years), all subjects were clothed in shirts and slacks, total thermal resistance from the skin to the outer surface of clothing was 0.7 clo. The experiment utilizes a full-scale laboratory as the target and evaluates the effects of different lighting environments on human bodies under long- term exposures. Measurements were performed under steady conditions: room temperature 28.5±0.5• ; humidity 70±0.5, wind velocity under 0.09m/s, background noise level between 48dB(A).

3. Results and Discussion

3.1 Influence on the Psychology of the Lighting Environment

In this experiment, the factors of the questionnaire of psychology experience include ' sense of comfort ', ' sense of stable ' and ' awaken degree ' to analyze with Microsoft Excel to assess the experienced changing and influence by the persons who examine psychology under different lighting environments for 60 minutes.

3.1.1 The lasting of sense of comfort changes

Under the 50Lux lighting environment make the person not comfortable after turning on the light and lasting 30 minutes, but under the general lighting environment of intensity of illumination (500Lux),this kind of lighting environment makes people feel more comfortable after turning on the light and lasting 60 minutes.(Fig. 1)

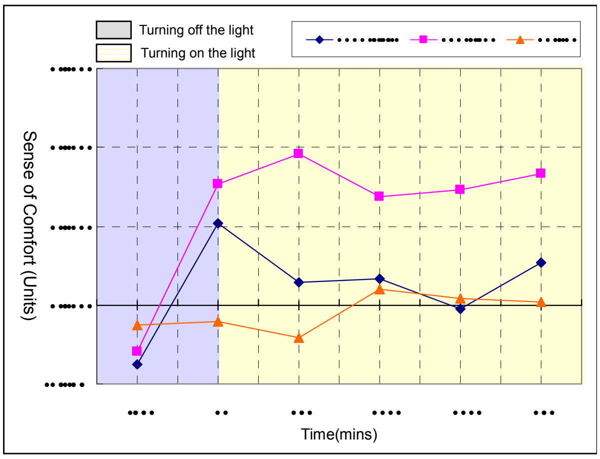

Figure 1 The lasting of sense of comfort changes under 3 kinds of lighting environment for 60 mins.

3.1.2 The lasting of sense of stable changes

As fig. 2 shows that under the high lighting environment of intensity of illumination (2000Lux), make participations begin to feel unstable after turning on the light between 15 minutes and 60 minutes. To compare the psychology experience under 3 kinds of different lighting environment, we can know that the low intensity of illumination (50Lux) give participants more stable sense.

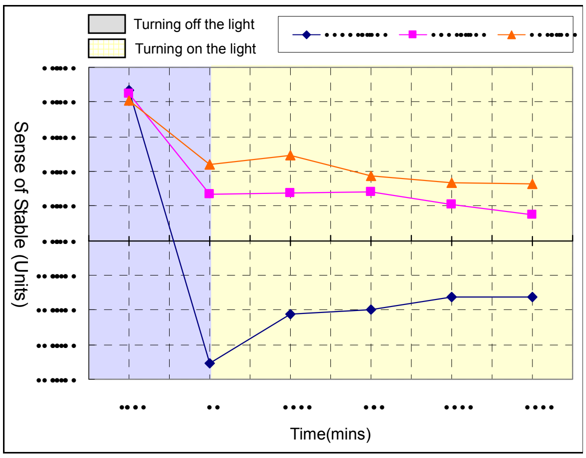

Figure 2 The lasting of sense of stable changes under 3 kinds of lighting environment for 60 mins.

3.1.3 The lasting of awaken degree changes

Under the entire lighting of the high intensity of illumination(2000Lux) could improve the participations' awaken degree after turning on the light between 15 minutes and 60 minutes, but under the low intensity of illumination(50Lux) lighting environment make the person feel low-spirited after turning on the light and lasting 60 minutes.(Fig. 3)

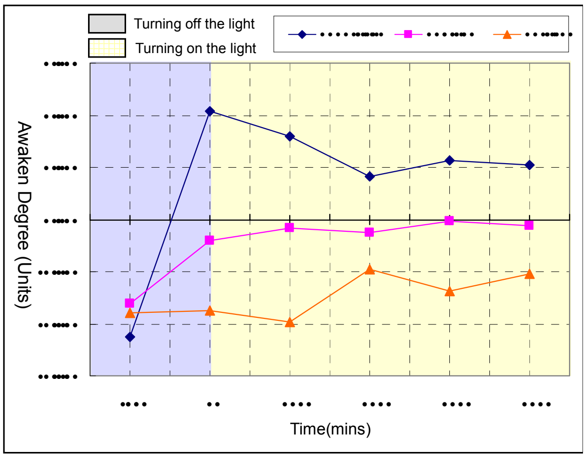

Figure 3 The lasting of awaken degree changes under 3 kinds of lighting environment for 60 mins.

3.2 The Result of Physiological Response

3.2.1 The whole reaction of Ryodoraku at different examine period

Under the entirely lighting environment of color temperature 2700 K of light source, in 3 kinds of lighting environment change, 50Lux, 500Lux and 2000Lux, the result of reaction of Ryodoraku as figure 4 shows. The experimental result show that under the environment of 3 kinds of lighting, the average of participations' Ryodoraku improving after turning on the light, but there are different variation tendencies during 60 minutes.

Under the high lighting environment of 2000Lux, the average of participations' Ryodoraku improving with time, while lasting 60 minutes after turning on the light, the average of participations' Ryodoraku increase 14.8μA than basic value. Under the lighting environment of 500Lux, the average of participations' Ryodoraku improving 4.6 μA lasting in 15 minutes after turning on the light, but while lasting 45 minutes after turning on the light , the average of Ryodoraku has no obviously difference.

To compare the physiological experience under 3 kinds of different lighting environment, under the high lighting environment of intensity of illumination (2000Lux), Ryodorku leads and holds the trend appearing and rising well gradually in increase that reacts and perceives time lasting in 60 minutes after turning on the light, but after lasting 30 minutes, the influence power of general and low lighting environments of intensity of illumination (500Lux and 50Lux) to human physiological reaction is reduced gradually. So we have to pay more attention to the sustained influence to human sympathetic nervous system responses, when under the high intensity of illumination for a long time.

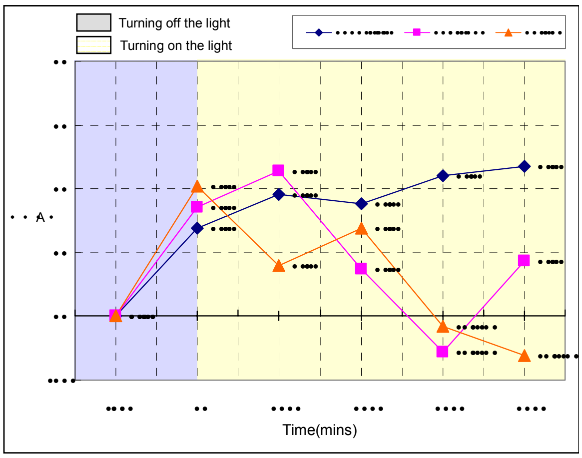

Figure 4 It shows the different changes of human body 12 Ryodorru average value under the environment of 3 kinds of different lighting for 60 mins.

In order to realize the changes of whole reaction of Ryodoraku under different lighting environments at different percipience period, this study carry on statistical analysis of the experimental result. Via than to the change that the human body reacts before and after the experiment.

As table 3 showed that under the lighting environment of 2000Lux, the participations' Ryodoraku value has difference (P< 0.05) counted after turning on the light in lasted 45 minutes. Under the lighting environment of 500Lux, the participations' Ryodoraku value have difference• P• 0.05• counted in the twinkling of an eye turning on the light and in lasted 15 minutes, but while lasting 30 minutes after turning on the light, the

Ryodorku value has no obviously difference• P• 0.05• counted. Under the lighting environment of 50Lux, the participations' Ryodoraku value have difference (P<0.05) counted in the twinkling of an eye turning on the light. But the change of the Ryodorku value has no obviously difference• P• 0.05• counted, while lasting 15 to 60 minutes after turning on the light.

From Fig. 4 analysis and Table 3 statistics show that within lasting 60 minutes after turning on the light, the higher the intensity of illumination is, the more obvious the influence to human physiological reaction is.

Table 3 It shows the comparative result of the participations' Ryodorku value average value before and after turning on the light.

••	2000Lux		500Lux		50Lux	
	mean•s.d.	P value	mean•s.d.	P value	mean•s.d.	P value
Before turning on the light	38.47•11.27	0.136	41.72•11.19	**0.015***	41.60•9.99	**0.026***
Turning on the light wink	41.24•14.18		45.13•10.29		45.69•12.54	
Before turning on the light	38.47•11.27	0.137	41.72•11.19	**0.016***	41.60•9.99	0.478
Turning on the light in lasted 15 minutes	42.29•11.16		46.27•12.00		43.18•12.09	
Before turning on the light	38.47•11.27	0.112	41.72•11.19	0.470	41.60•9.99	0.110
Turning on the light in lasted 30 minutes	41.99•10.23		43.19•11.08		44.35•10.50	
Before turning on the light	38.47•11.27	**0.039***	41.72•11.19	0.624	41.60•9.99	0.910
Turning on the light in lasted 45 minutes	42.89•10.03		40.61•10.32		41.29•12.16	
Before turning on the light	38.47•11.27	0.113	41.72•11.19	0.491	41.60•9.99	0.696
Turning on the light in lasted 60 minutes	43.19•10.40		43.46•10.98		40.37•11.18	

Note• 1.Unit• • A•• 2."• • is representing P value• 0.05

3.2.1 Analyze the collateral channels position which be influenced

Because 12 collateral channels correspond to human body's change of different viscera and relevant organ separately, therefore, different white light source impacts on human body can be found out by the change of 12 collateral channels Ryodorku value under 3 levels of lighting environment. So all that this research examines in every period amount the experiment lighting environment of every group is led the statistical analysis of all the participations' 12 collateral channels Ryodorku value. To exanimate 12 collateral channels Ryodorku value having a dominance difference (P<0.05) counted before and after lighting.

The analysis result shows that under the high intensity of illumination (2000Lux-2700K), the Pericardium Meridian and Large Intestines Meridian are obviously influenced by the stimulation of lighting. Under the general intensity of illumination of lighting environment (500Lux), left side Pericardium Meridian, Heart Meridian, Gallbladder Meridian and Both sides of Large Intestines Meridian are also beginning to be influenced , but the change of 12 collateral channels Ryodorku value has no obviously difference• P• • 0.05• •under the low intensity of illumination (50Lux).

Table 4 It shows the comparative result of the Ryodorku value which 24 present points average value before and after turning on the light under the high lighting environment of intensity of illumination (2000Lux).

Measure value / Meridians	Left side Ryodorku value (μA)		P value • P• 0.05• •	Right side Ryodorku value (μA)		P value • P• 0.05• •
	Before turning on the light mean± s.d.	After turning on the light mean± s.d.		Before turning on the light mean± s.d.	After turning on the light mean± s.d.	
Lung Meridian	41.80±17.22	41.47±18.26	0.936	45.33±18.11	40.33±17.91	0.234
Pericardium Meridian	39.67±15.10	49.13±12.29	**0.012***	38.60±14.97	48.33±14.84	**0.002***
Heart Meridian	38.67±13.58	40.60±12.09	0.616	40.73±12.01	44.40±13.65	0.258
Small Intestines Meridian	37.13±14.86	42.13±18.00	0.249	40.13±19.43	39.87±18.56	0.944
Triple Heart Meridian	50.67±17.77	54.53±18.56	0.158	53.67±16.71	57.00±16.54	0.142
Large Intestines Meridian	40.93±15.70	49.09±18.62	**0.013***	42.93±17.86	49.60±19.04	**0.018***
Spleen Meridian	32.07±17.10	35.73±15.23	0.472	31.93±13.48	36.93±12.41	0.180
Liver Meridian	44.07±19.23	45.87±20.31	0.573	44.87±18.24	46.53±19.39	0.650
Kidney Meridian	27.20±15.90	29.33±14.63	0.694	30.00±18.75	29.00±15.19	0.831
Bladder Meridian	28.20±17.64	32.73±15.51	0.294	29.33±14.20	30.27±11.22	0.735
Gallbladder Meridian	34.53±22.53	36.87±18.64	0.534	33.73±16.32	39.00±19.16	0.210
Stomach Meridian	38.47±18.78	42.33±18.43	0.294	38.53±15.06	43.93±17.92	0.146

Table 5 It shows the comparative result of the Ryodorku value which 24 present points average value before and after turning on the light under the general lighting environment of intensity of illumination (500Lux).

Measure value / Meridians	Left side Ryodorku value (μA)		P value • P• 0.05• •	Right side Ryodorku value (μA)		P value • P• 0.05• •
	Before turning on the light mean± s.d.	After turning on the light mean± s.d.		Before turning on the light mean± s.d..	After turning on the light mean± s.d.	
Lung Meridian	42.07±16.56	47.40±17.75	0.146	50.33±19.15	51.93±21.95	0.724
Pericardium Meridian	43.87±15.53	55.27±12.25	**0.002***	42.33±16.95	47.40±13.57	0.116
Heart Meridian	38.33±12.96	47.20±16.12	**0.033***	36.13±12.09	41.20±13.31	0.116
Small Intestines Meridian	40.27±14.48	46.07±17.41	0.096	42.60±16.80	45.27±18.23	0.559
Triple Heart Meridian	53.20±16.91	55.67±17.63	0.382	56.00±13.63	58.80±16.38	0.167
Large Intestines Meridian	44.60±15.07	53.33±18.62	**0.0005***	49.20±14.88	54.20±19.51	**0.015***
Spleen Meridian	32.00±15.84	37.47±18.33	0.109	38.13±14.49	42.60±11.81	0.233
Liver Meridian	46.73±20.45	48.47±19.99	0.367	51.47±20.13	53.40±19.84	0.348
Kidney Meridian	31.07±16.12	35.47±18.03	0.179	32.13±17.26	34.67±18.09	0.292
Bladder Meridian	31.87±10.38	37.20±15.59	0.062	33.60±12.87	37.60±10.33	0.249
Gallbladder Meridian	36.40±20.00	41.87±18.42	**0.016***	41.33±19.64	43.00±17.33	0.524
Stomach Meridian	41.60±19.51	45.93±19.19	0.153	46.07±16.42	49.13±19.12	0.157

Table 6 It shows the comparative result of the Ryodorku value which 24 present points average value before and after turning on the light under the low lighting environment of intensity of illumination (50Lux)

Measure value / Meridians	Left side Ryodorku value (μA)		P value • P• 0.05• •	Right side Ryodorku value (μA)		P value • P• 0.05• •
	Before turning on the light mean± s.d.	After turning on the light mean± s.d.		Before turning on the light mean± s.d.	After turning on the light mean± s.d.	
Lung Meridian	39.60±15.24	42.60±16.87	0.320	50.93±17.43	53.47±17.93	0.489
Pericardium Meridian	43.80±18.17	48.67±17.63	0.175	40.93±10.78	46.33±17.51	0.151
Heart Meridian	40.13±17.71	42.20±17.14	0.582	36.93±13.10	41.53±17.25	0.301
Small Intestines Meridian	41.00±16.03	38.47±16.28	0.486	44.73±15.13	42.07±16.88	0.475
Triple Heart Meridian	51.93±14.80	51.67±17.81	0.959	58.07±15.87	55.73±18.18	0.642
Large Intestines Meridian	48.00±17.65	49.00±18.97	0.817	53.40±16.10	48.93±17.32	0.114
Spleen Meridian	31.93±18.41	37.33±18.20	0.213	32.33±12.19	40.87±17.02	0.053
Liver Meridian	45.13±17.71	47.20±19.87	0.578	52.00±17.28	50.60±18.49	0.621
Kidney Meridian	30.60±15.62	34.07±15.84	0.318	30.27±15.04	35.40±15.38	0.118
Bladder Meridian	31.33±15.90	36.27±16.99	0.120	28.47±16.26	32.40±14.73	0.080
Gallbladder Meridian	36.93±15.39	38.20±18.39	0.534	40.40±16.49	37.93±21.21	0.339
Stomach Meridian	43.60±18.29	40.87±18.03	0.417	45.93±16.98	44.60±19.58	0.665

4. Conclousion

In order to engage the limited resources in terms of energy saving and good use limits the human material demand aspect and the inflation of the spirit of civilization aspect, this research proposed is an regular work and rest pattern, simultaneously giving dual attention to the human physical labor productivity aspect and the development of spiritual thought productivity aspect, and carry on the discussion to human body reactions to the 3 kinds of corresponding lighting environment.

To compare the physiological experience under 3 kinds of different lighting environment, the analysis result shows the higher the intensity of illumination is, the more obvious the influence to human physiological reaction is, and under 2000Lux lighting environment, human Ryodorku value rise continuously, it shows this kind of lighting environment has constant influence on human sympathetic nervous system, especially to such organs as the pericardium, circulatory system and large intestine, etc.

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THE RESEARCH ON THE PER-COOLING SYSTEM OF UNDERGROUND VENTILATION TO THE INFLUENCE OF INDOOR THERMAL ENVIRONMENT IN SUBTROPICAL CLIMATE, TAIWAN.

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Keywords: indoor thermal environment, computation fluid dynamics（cfd）, underground air channel system.

Summary

While Taiwan spares no effort in fully developing a livable and sustainable environment, various regions are facing and aggressively considering the topic of how to make the architecture design of existing and newly constructed buildings to be sustainable, forward-looking and environmentally sound. This study is mainly to ensure the performance of underground air channel system that draws the ambient air into a building. It focuses on the specially designed underground air channel system for this case to overall evaluate the performance of the system. The results of the actual tests suggested that under the normal usage mode air-conditioning and underground air channel systems were used simultaneously,, the overall PMV value of the indoor tepid environment was -1.1, a low value that indicated an environment leaning toward the cool side. Under the mode of turning on the air-conditioning and shutting down the underground air channel systems, the PMV value was -1.07, an environment leaning toward the cool side as well. Under the mode of shutting down the air-conditioning and turning on the underground air channel systems, the PMV value was 0.51, an environment leaning toward the comfortable side. A Computation Fluid Dynamics was developed in this study to analyze the structure of space airflow field through the simulation and analysis of different scenarios and conditions, in order to find the best effect of the underground air channel system and to derive the related performance and recommendations.

1. Introduction

At the same time Taiwan's going ahead with developing sustainable environment, how to design the existing and new-constructed buildings for being sustainable, environmental and visionary, is a challenge that different areas must to be deal with. Therefore, this research is based on the foundation of underground ventilation per-cooling technology analysis, then to take feasibility study on the technology for underground ventilation per-cooling in subtropical areas like Taiwan. Further more, the research assay the construction of airflow space through the simulation of different surrounding conditions to find the most appropriate tunnel wind system.

According to the evaluation in ecological housing of World Health Organization (WHO), we find out that buildings are that only protecting people from invasions, but also effecting users' lifestyles and indoor environment quality (IEQ).in our daily life.

2. Analysis of the research subject

2.1 Analysis of environment climate

This area's average temperature is about 25℃ because located on the south of the Tropic of Cancer. With the variation of average temperature, the coldest month average temperature is about 19.4 ℃ and occurred in January. Summer is obviously felt. The time of temperature witch exceeded 24℃ lasted more than 8 months long. And August is the hottest, the highest temperature is about 32℃.

2.2 Building and the underground ventilation system

There are about 60 occupants in the office-type building. To afford the occupants a comfortable working environment, even being more efficient and easily management, we separate the office and public service functions, avoiding the interference between them. Nearly existing landscape park can supply fresh air as figure 1.

Underground ventilation system with fresh air importing device is a method that burying the wind pipe into ground and let it been naturally cooling, as follows figure 2.

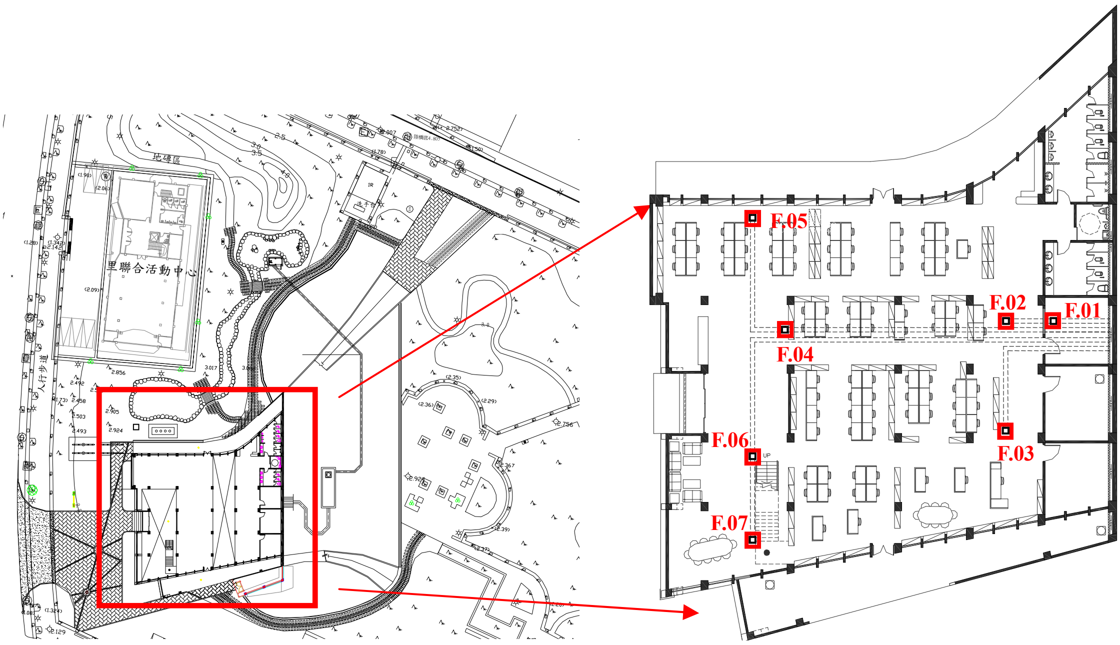


Figure 1   actual testing building and the outlet positions of underground ventilation system

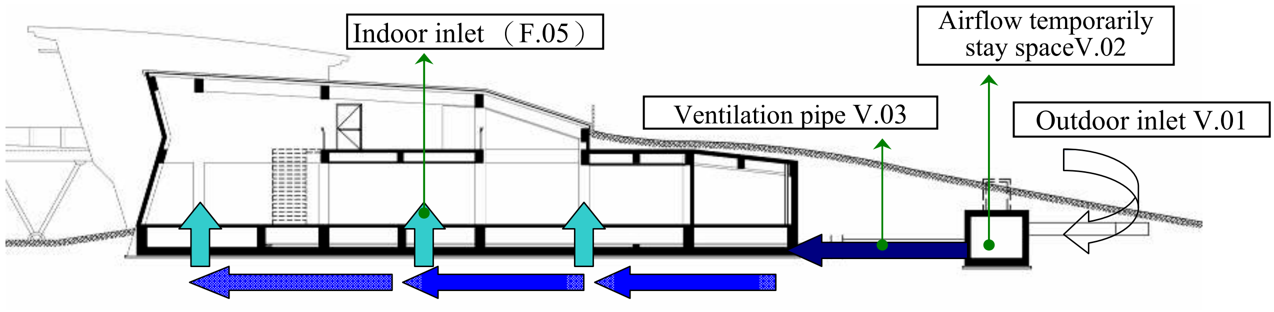


Figure 2   section of underground ventilation system

3. Research Content

3.1 About indoor thermal comfort:

Standing on the building occupants' point of view, we can decrease the air condition cost by raising the air condition setting temperature in summer time using; in winter time, we can turn off all the air condition system and completely using underground ventilation system to achieve indoor thermal comfort.

The results of the actual tests suggested that under the normal usage mode (air-conditioning and underground air channel systems were used simultaneously), the overall PMV value of the indoor tepid environment was -1.1, a low value that indicated an environment leaning toward the cool side. Under the mode of turning on the air-conditioning and shutting down the underground air channel systems, the PMV value was -1.07, an environment leaning toward the cool side as well. Under the mode of shutting down the air-conditioning and turning on the underground air channel systems, the PMV value was -0.51, an environment leaning toward the comfortable side. other relative thermal factors as table1.

Table1 numeric of different type to thermal environment factors

Indoor ventilation type			temperature	humidity	velocity	PMV	PPD
Air condition	On	indoor	24.36	68.63	0.36	-1.10	30.84
Underground system	On	outdoor	29.05	52.25	0.51	9.82	100
Air condition	On	indoor	24.49	68.44	0.34	-1.07	29.76
Underground system	Off	outdoor	28.55	52.9	0.22	9.77	100
Air condition	Off	indoor	27.74	60.42	0.01	-0.51	10.91
Underground system	On	outdoor	29.30	45.08	0.49	9.9	100

3.2 About underground ventilation per-cooling:

According to the test data, per-cooling system of underground ventilation does really have its effect. While the testing day, the average outdoor temperature was 29.1℃,but the at outdoor inlet and in the pipe of per-cooling system of underground ventilation are 27.8℃ and 26.1℃. Even the average temperature at indoor inlet had dropped to 24.9℃, as follows table2:

Table2 Temperature measurements at different position

No.	Position	Numerical	No.	Position	Numerical
1.	Outdoor	27.8℃	7.	F.01	25.8℃
2.		29.7℃	8.	F.02	25.5℃
3.		29.8℃	9.	F.03	24.9℃
4.	V.01	27.8℃	10.	F.04	24.8℃
5.	V.02	26.6℃	11.	F.05	24.5℃
6.	V.03	26.1℃	12.	F.06	24.1℃

3.3 Computational Fluid Dynamics

Before running the whole numeric simulation, we should proceed the relativity contrast between the simulation and actual examination. The relativity between the numeric simulation and actual testing value had achieve to R^2=0.94. We can use CFD simulation for follow-up research on different variation factors.

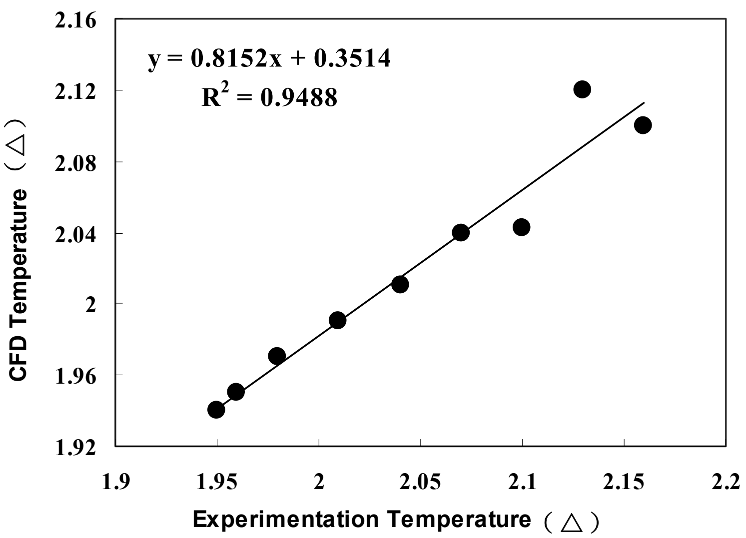
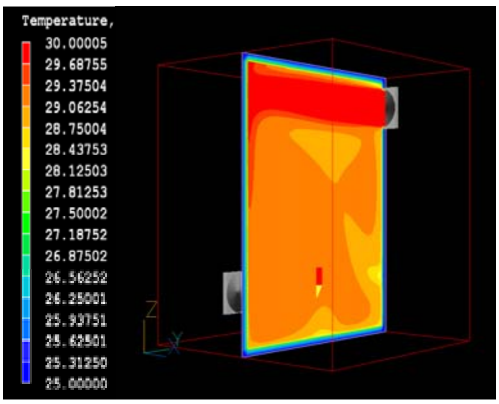


Figure3 Contrast of the relevance between CFD and actual test data

This research proceeded computer numeric simulation (As figure 4) to find the possibility of appropriate extension for the place in the future. And the result is showed as table2. Through the efficiency of different cross-section size of underground ventilation pipes' cooling performance, we can conclude that the more suitable length for space is 6m, 8m 10m.



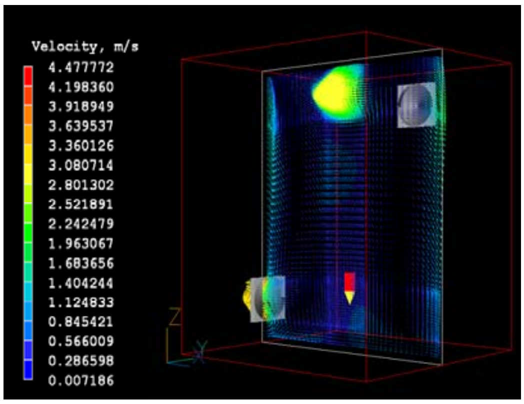
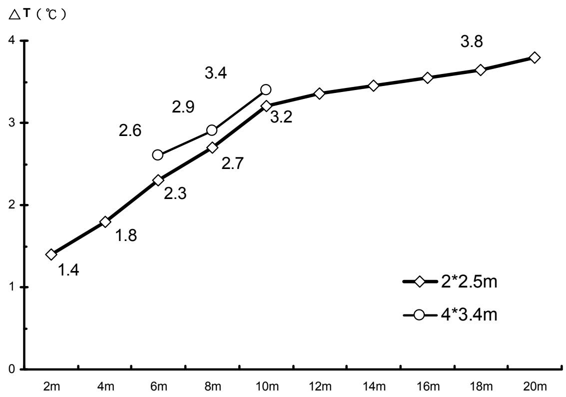


Figure 4 computation fluid dynamics（cfd）model.

By calculating the result of Computational Fluid Dynamics（CFD），we could discover the difference of temperature dropped tendencies. And according to results of different cross-section size, we know that range of 0-10m is a rapidly cooling distance. The temperature lower slowly when the distance is longer than 10m. So 10m is a critical point for distance.

Table 3 CFD simulation data of different cross-section size

No.	Length of space	Cooling performance（△T）		notation
		200cm∗250cm	400cm∗340cm	Boundary condition: inlet temperature is 30℃
1.	2 m	1.4℃	—	
2.	4 m	1.8℃	—	
3.	6 m	2.3℃	2.6℃	
4.	8 m	2.7℃	2.9℃	
5.	10 m	3.2℃	3.4℃	
6.	20 m	3.8℃	—	

4. Conclusion

Underground ventilation system can lower the load of fresh air and the air temperature could decrease through the distance of ventilation pipe. We can achieve energy saving by underground ventilation system. And by increasing the length of ventilation pipe, we can lower fresh air load. Indoor thermal environment in normal condition (air condition and fresh air input are both working) will cause lower PMV value. The whole prediction value is slanted towards cool. The whole prediction average value can be controlled in comfortable range if air condition setting is about 23-28℃ and being used with the underground ventilation system at the same time. In the condition that underground ventilation system is on but central air condition system is off, the velocity would be lower. But the velocity could be controlled in the comfort range in both of the condition above.

Having a wish to complete the indoor environment health quality and increase people's living value through establishing "UNDERGROUND VENTILATION SYSTEM". And using strategies like "preventive design", "diagnosing to improvement" and methods to integrate other fields as a specific way to promoting indoor environment health quality in Taiwan.

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RENOVATION OF THE BUILDINGS ON THE INDUSTRIAL AREAS

(TECHNICAL-OPERATING CONCEPTION OF THE REGENERATED BUILDINGS ON THE INDUSTRIAL AREAS)
(*see Section 2.1.4*)

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Keywords: regeneration, industrial areas, building, heating, energy consumption

Summary

This paper deals with buildings located in industrial areas in the Ostrava region, Czech Republic. Poor maintenance in past as well as considerable impacts of industrial plants located in the region is rather typical for the buildings. Some buildings are located in the centre of Ostrava, on undermined territories (escape of explosive methane, land subsidence, higher level of ground water, air pollution, industrial seismicity, noise, land contamination caused by industrial plants...). In the second half of the 20th century, many apartment blocks from panels were built there. Living conditions lack comfort there and general reconstruction is needed in order to improve building parameters and to decrease energy performance. 5 buildings where the reconstruction is essential have been chosen. Studies have been prepared in order to find out future applications for the buildings, to regenerate them in line with state-of-the-art building requirements and to decrease the energy performance, using as much renewable sources of energy as possible. Best alternatives are being looked for so that the optimum combination of finances and technologies can be used for future regenerations of various types of buildings.

1. Czech Republic, Ostrava region and industry

The Czech Republic is located in the centre of Europe. For more than 100 years, some parts of the country have been heavily loaded with industrial activities. This results in problems that affect both the people living there and the environment that suffers considerably. After the Second World War, the industry became more intensive in those regions and the situation continued deteriorating. This is in particular the case of the North-West (near Most) and North-East (near Ostrava). Before 1989 the priority of the communist regime was, in particular, heavy industry. After the communist regime had been thrown off, the oppressive situation started improving. Other big cities in the Czech Republic were influenced by that situation too. But the region of Ostrava is rather specific because the heaviest industry was concentrated there: mining, metallurgy, engineering and chemical industry. The city and wide surroundings have been affected by those industries up until now. At the beginning of the 20th century, the mining activities in the city of Ostrava were totally closed. Now, black coal is mined in neighbouring land only. Many heavy industry plants have been closed down and measures have been taken to decrease air pollution. The Czech Republic, being a EU member state, has undertaken to decrease emissions in the Kyoto Protocol. It accessed the Kyoto Protocol in 2001. With the production of almost 12 tons of emissions per head, it ranked among worst contaminators in Europe and all over the world. In the Czech Republic, the power generation produced 42 % of CO_2 emissions (source: UNO, 1996). The state has been trying so far to fulfil the obligation. The Kyoto Protocol is closely connected with the EU Directive No. 2002/91/EU on the Energy Performance of Buildings.

The Ostrava region suffers most, because of the heavy industry, from increased CO_2 in the air, noise, dust, seismicity (both transport and industrial seismicity), escape of methane from abandoned mines, soil contamination and disappearing influences after underground mining.

All this influences people living in Ostrava, being the third biggest town in the Czech Republic, but also those who live in conurbation near Ostrava (cca. 780.000 people). During the communist regime (1947-1989), construction of prefabricated elements (frequently from panels) and mass housing construction was preferred – about 45 % of housing stock and many industrial plants were built in that way.

2. Research

In 2005, three biggest universities in the Czech Republic and three construction companies established, under auspices of the Ministry of Education and Sport, CIDEAS (Centre for Integrated DEsign of Advanced Structures). CIDEAS focuses on advanced materials, constructions and technologies in terms of service life and reliability throughout the living cycle. General aspects of interactions between the building structures and environment are taken into consideration from a long-termed perspective of sustainable development. One department deals with management and maintenance of buildings in industrial areas. In Ostrava, where many buildings were built from panels, it is necessary to address various issues because the panel buildings are affected by the aforementioned influences (such as seismicity, air pollution, noise, escape of methane, disappearing mining effects) and also by bad conditions caused by lack of maintenance or poor production. And people living there have been more and more demanding, requiring more comfort. Consumption of energy has gone up, and prices for energy have increased too in past years. Therefore, it is necessary to renovate and maintain the buildings, because their service life is far from being exhausted.

Since 2006 when CIDEAS has started working, five buildings have been chosen and analysed in detail. The buildings are located in Ostrava and are typical samples of buildings (except for industrial buildings) located in the industrial region. Studies have been prepared, the objective being to identify steps to be taken, most efficient repair methods and the lower energy performance in the future.

3. Evalution in therms of energy demands

The key weakness of the buildings and not only those on the industrial sites is that the heat-insulation parameters are not sized enough. Originally, the standards for the heat insulation of cladding were derived from masonry walls lined with kiln bricks with the thickness of 450 mm. Those standards have become more restrictive in the course of time. Figure 1 shows the development of the required heat insulation since 1954. Therefore, it is clear that the buildings that have been constructed in past do not meet often the present-day stringent requirements. The reason for the severe requirement has been the growth of energy prices and pressure of the company to decrease the energy demand and, in turn, to improve the quality of the environment, namely reduce undesirable emissions of carbon dioxide CO_2 that gives rise to green house effects.

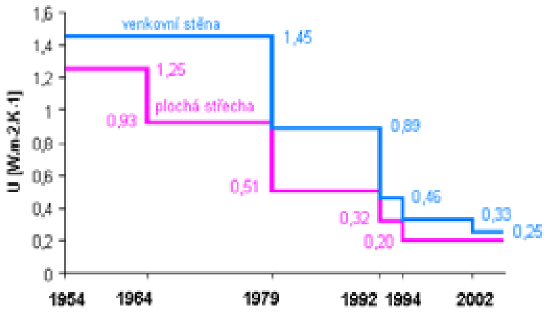

Figure 1. Development of coefficient of thermal transmission U [W.m^{-2}.K^{-1}]. U is calculated from the heat transmission resistence (R) that was stipulated in Czech standards in past, (venkovní stěna = outdoor wall, plochá střecha = flat roof).

A suitable solution within the general reconstruction of the building would be to improve the heat insulation parameters by over-cladding all structures where heat loss and thermal break occurs. At the same time, it is advisable to take other measures, for instance to reduce the loss of heat through windows, doors, gates, and passages. Another solution is to optimise the heating system. The thermal insulation not only improves the heat protection of the buildings but also reduces the energy needed for the heating, minimises mould fungus on inside surfaces of enclosing walls, decreases temperature dilations of building structures, improves appearance of the building if the over-cladding is carried out, and enables cost-saving heat systems and alternative sources of energy (such as solar, water, or wind energy) to be used. The purpose of the energy measure is, as mentioned above, to reduce the energy demands of the building. This means the total quantity of energy to be consumed for the adjustment of the environment inside the building should go down. This energy is needed for: heating, heating of water, cooling (A/C), ventilation, and lighting.

When rehabilitating a building, particular attention is paid to those components that are most important for the energy demand of the building. Following buildings have been investigated: a four-floor living building from T06B panels in Ostrava-Poruba, a school facility with a MS-0B skeleton system in Ostrava-Poruba, an office building made from MS-KO systems in Ostrava-Přívoz, a brick building in Ostrava-Přívoz that was used as a health facility for a mining company, and a brick building from the 1930s that ranks among national protected buildings.

4. Panel building (T06B system) and school facility (MS-OB system) in Ostrava-Poruba

The thermal assessment has been carried out for two buildings: for the living building made from T06B-BTS panels with minimum building adaptations throughout the service life of the building, and for the civic amenities building made from typified MS-OB units used by the school where actions have been performed that were proposed within an energy performance audit.

For the living panel building, following values have been calculated: heat transmission coefficients, inside surface temperatures and total quantities of evaporated and condensed water vapours for the year balance inside the cladding for the current situation as well as for two alternatives of building modifications the objective of which is to reduce the energy performance/heating costs for the building. In case studies, the assessment has been made of total heat losses of the buildings (where such heat losses comprise heat losses caused by heat transmission through structures as well as ventilation heat losses) and a heat demand level resulting from U_{em}, an average heat transmission coefficient.

Figure 2. Panel building (T06B system) and school facility (MS-OB system) in Ostrava-Poruba

U_{em} being the average heat transmission coefficient is determined for the building and areas heated there as a H_T [$W.K^{-1}$]/total area ratio where H_T [$W.K^{-1}$] is the specific heat transmission loss and the total area represents all cooled structures that define the volume of the building, the zone to be heated.

$$U_{em} = \frac{H_T}{A} \left[W.m^{-2}.K^{-1} \right] \quad (1)$$

The requirements of the standard have been fulfilled for the skeleton MS-OB structure used by the school. The studies focused in particular on evaluation of the current situation as well as on modification of building services and facilities, in particular of the heating system. Within the study, new efficient uses of the heating system as well as heating management have been proposed. Attention has been also paid to a training programme and a regular maintenance of the system.

One of most important and main changes in the heating system is the installation of an interactive system of management and control. The interactive system controls the heating in real time, using optimally the supplied heat. Almost in each room, there are sensors that are connected with the central PC controlling the whole system. In main branches, the difference pressure needs to be modified. Because of the over-cladding, a temperature gradient of the heating medium must go down. Te balance between the heat supply and heat demand will be maintained. Other partial modifications and recommendations are listed in case studies (see the Literature).

All this has finally resulted in improved thermal comfort inside the building and, in particular, in a lower energy performance of the building. This is proved by the chart drafted for one of the buildings under study. It is evident that the heat consumption has gone down by 39 per cent. Energy costs have decreased by cca. 35 % (including a lump sum fee).

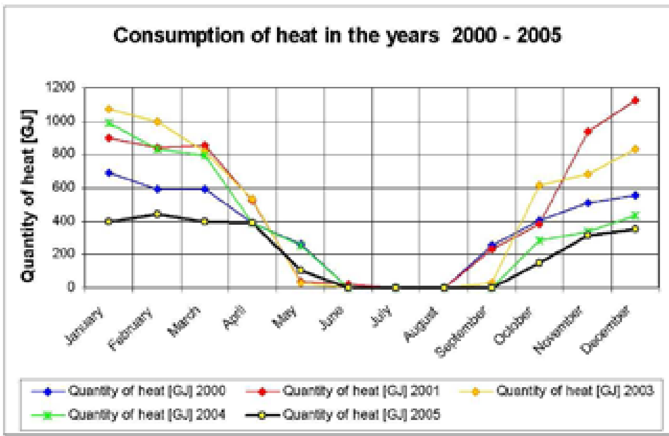

Figure 3. Development of heat consumption from 2000-2005 (excl. 2002) Note: source data from 2002 were not available

5. Administrative building (MS-KO system)

From the point of view of heat performance, the current conditions of the headquarters have been assessed. As expected, the building has not met requirements set forth in the heat performance standard ČSN 730540.

Two alternatives have been proposed for the external cladding in order to improve the energy performance and heat properties. In the first alternative, the existing external cladding will be removed, the skeleton will be covered with accurate porous concrete formed bricks (Ytong). Additional insulation will be created by the thermal system Stomix and polystyrene foam insulation. The result will be that the requested (or recommended) values of the heat transmission coefficient pursuant to ČSN 730540 will be met.

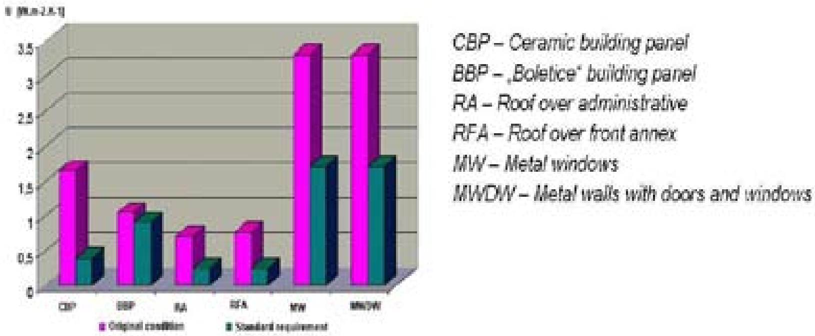

Figure 4. Administrative building with system MS-KO v Ostrava-Přívoz

Figure 5. Heat transmission coefficient of the constructions for original conditions and standards requirements

5.1 The first alternative

The first alternative is preferred if the function of the building changes and some floors will be used for apartments. Plastic windows with thermal double-glazing will be installed. (Note: It is necessary to check whether the Ytong bricks and additional insulation of the external cladding is feasible in terms of the mechanical resistance and stability).

5.2 The second alternative

The second alternative also reduces the energy demands: the existing cladding will be partly removed (glass, aluminium rail, supports, and windows will be removed). The bearing construction of the cladding (the steel frame of each panel) will be kept and used for a new lightweight steel cladding made from Kingspan thermo-insulation panel. Special plastic windows with insulating double-glazing will be installed in the external cladding. In the second alternative, the load of the bearing structure will not be so high. The main advantage of that method is the speed of building works.

Table 2. Values of heat transmission coefficient for a part of the external cladding of the headquarters building

	Original condition	Alternative 1	Alternative 2
U - real	1.03	0.3	0.29
Un - requested	0.89	0.89	0.38
Un - recommended	0.62	0.62	0.3

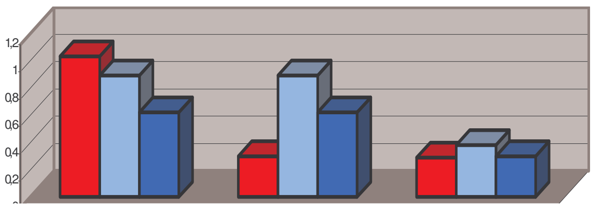

Figure 6. Heat transmission coefficient for a part of the external cladding (original condition) and two alternatives in comparison with standard requirements

In both alternatives, the flat single-cladding roof will be additionally insulated with mineral fibre insulation, simple metal covers will be replaced (in order not to interrupt the heat bridges), and single-glass windows, doors, and glass walls will be replaced with insulating double glazing in plastic frames. Next year, the team will deal with other alternatives for the external cladding. The heat transmission conditions for particular parts are stated in the figure 5. (Different between original conditions and standard requirements, nowadays, is approximately 33 years).

5.3 Building services

From the point of view of building services and facilities, the building is absolutely non-compliant. Originally, the building was heated with hot water with the gradient 90/70 °C from the near-by Svoboda coke plant. The heating system is out of order now. Sewers in top floors might be used, while those in the basement are heavily corroded. Water pipelines in top floors are not damaged, while those in the basement are also heavily corroded. In some places, discharge valves are missing. Wiring is also heavily damaged. Lighting switches and junction boxes have been removed in some places, and wiring is exposed now. HVAC has been removed and is missing now. Two solar energy systems have been proposed for use of renewable sources of energy:

In the first case, solar collectors will be installed on the roof. In summer, they will heat up the hot water, in transitional periods (winter-spring and autumn-winter) the solar collector will maintain the temperature. Bivalent reservoirs will be used there.

In the second case, the solar energy will be used in a photovoltaic system that will supply the alarm system, circulation pumps, or lighting in some areas (where intensive lighting is not necessary – such as staircases or corridors).

5.4 Solution results

The proposed revitalisation of the building will reduce the energy demands of the building. If the proposed actions are taken, the heat demands will decrease from 290% to 100% the solar heating of water will cover demands of people living/working in the house. The photovoltaic system will save 17 kW/d only but will be able fully to supply the power to dedicated consumers. The comfort of use of the building will increase, and impacts on the environment will be more positive. In this time is building in the reconstruction phase, and owner want use about 70% suggested solving witch were mentioned in the case studies.

6. Brick building and traditional historical protected brick building

6.1 Heating and energy performance of the buildings

The energy performance of the both buildings was analysed in terms of consumption of heat needed to heat up the buildings. The energy performance is given by an average heat transmission coefficient, U_{em}, and is based on individual heat and technical characteristics of the structures. The existing condition of the buildings does not meet thermal and technical requirements set forth in standards. Two alternative solutions were proposed for the administrative building in Ostrava–Přívoz, the aim being to reduce the energy demands. Over-cladding and replacement of windows/opening panels as well as changes in a layout of the building have been proposed. The proposed alternatives meet the required and recommended values of the heat transmission coefficient. The total energy performance resulting from the energy label of the building envelope has been determined based on those alternatives.

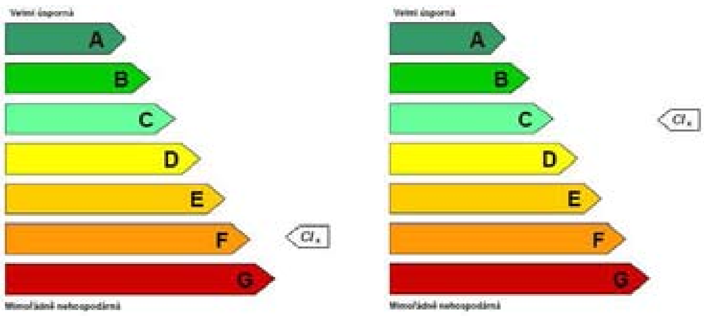

Figure 7. Chart of the energy performance for the original building and overcladded building

In order to evaluate the energy and thermal characteristics, thermo vision snapshots were recorded of the multiple dwelling houses that is protected as an national registered building.

6.2 Building services

A recommended solution resulting in a lower energy performance total is heating of hot water by means of solar collector panels. This solution is rather easy to be applied in the Czech climate and consumption of hot water and energy is more or less constant during the year, this not being the case of solar energy used to heat up the building. In summer when the incident solar energy is maximal, the consumption of heat for heating is zero.

Other renewable sources of energy cannot be used. A *heat pump* cannot be installed because the territory is exposed to disappearing mining effects. *Photo voltaic cells* do not repay for generation of electricity in the current price situation as this would need an island connection system and the photo voltaic cell area should be rather extensive. Since the housing development is rather dense there and one building is listed among national registered buildings this solution is difficult to implement.

Figure 8. Brick building and multi-flat historical protected brick building

When designing the method and type of over-cladding and replacement of windows in the existing administrative building in Ostrava-Přívoz, the aim was to meet recommended and required heat transmission coefficient of steel structures. For both alternatives, the resulting total energy perforce was “C”, this means the building was compliant. Thanks to the over-cladding, the original building with the “F” energy rating (very uneconomical) becomes a building with a considerably better energy performance. It is however essential to point out that even for the alternative 2 applied in order to meet the recommended heat transmission coefficient, it was impossible to reach a better power performance rating than “C”.

The proposed changes in the building services and facilities resulted in a lower energy performance of the both buildings. Installation of a gas boiler and solar collectors ranks among best solutions (this solution is better that “central heating delivery” in Jubilejní street no. 51) because the existing facilities are used and operated all the time during the year. The equipment is used and does not lose its value. The solar energy is among most environment-friendly methods where harmful substances are not discharged into the air.

7. Conclusion

Utility properties of all buildings have improved in general. The living comfort has increased too. Some buildings have been regenerated using same or similar procedures that are mentioned in studies prepared for individual buildings. The volatility on the outside sources and the total energy consumption for building operation decreased. The buildings have become more ecological. After these reconstructions were insert in the classes “C” of the energy performance, MS-OB and MS-KO to the class “B”, from the classes “E” and “F”. The energy consumption decreased over 30%! (see the Figure 3., MS-OB). Buildings‘ owners save. The buildings will take less energy. For the production of the electric energy is needed atomic fissure or coal’s burning (volume of CO_2 emitted to the air by power-station decrease). There is 60% of the electric energy made in coal power stations in the Czech Republic! It is too high number. Atomic energy is about on 30%, and other sources on 10% in the Czech Republic. And the consumption of the whole world still grows up! Now, steps are taken to create an optimum single approach that should be taken as a guide when dealing with regenerations of different buildings in the future. Whole project will we finished in December 2009. The state direction will be produced - recommending to owners how to proceed by the reconstructions. The economic, energy reduction, service life, investment return and spending on operating viewpoints will be accented.

This outcome has been achieved with the financial support of the Ministry of Education, Youth and Sports of the Czech Republic, project No. 1M0579, within activities of the CIDEAS research centre.

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EXPERIENCE FROM MEASURING ACOUSTIC PARAMETERS IN BUILDINGS

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Keywords: Reduction of noise, sound reduction index, impact sound transmission loss.

Summary

This paper shows an issue of measuring and assessment of acoustic parameters in building constructions.Examples, which demonstrate the building acoustics problems – air and sound transmission loss, have been chosen and described here. It summarises information and experience which the team deals with the most often. It also focuses on the possibilities of solving the particular acoustic problems regularly occurred in practice which are caused by underestimating or disrespecting the principals of noise-proof protection. The author's experience shows the evidence of underestimating the acoustic problems in buidings. Building constructions do not have reasonable sound reduction parameters and that is the reason why they are not able to reduce undesirable surrounding sounds. Supplemental adjustments in buildings leading to rectification of failures are complicated from technical, social and financial point of view.

1. Introduction

Buildings, as a product of human activities, have accompanied us from everlasting. The objective has been always to create an insulated (perfect, controllable and controlled by people) area that would not depend on climate so much. The inside environment of the structures plays an important role. A number of requirements have been set for that. An attention is paid, among others, to architecture, ergonomy, functionality, optimum microclimate, optimum light and thermal comfort. It is also necessary to consider acoustics because quiet environment is regarded as a pre-requisite for comfortable living. For a human body, it is not possible to prevent reception of sound stimuli. We are exposed to noise all the time, even when sleeping. An increased level of noise results in stress and dysfunctions of internal organs.

Noise parameters of surrounding structures, such as walls, ceilings, windows and roofs, must be such so that the users would not be disturbed with outdoor noise that is generally out of their control.

While measuring, non-compliant structures in terms of acoustics are often found. In particular, in apartment blocks this can be a matter of dispute.

2. Sound reduction index

The sound reduction index R_w represents a loss of acoustic power of sound transferred through the air in a structure. The higher the sound reduction index of the structure is, the better the sound insulation is. The sound reduction index is influenced by surface density and bending rigidity of used materials. Requirements relating to the sound reduction index for structures are defined in [1].

Sources of sound inside the buildings are typically music and loud conversation. Most often, separating walls between apartments are measured. This situation is shown in Example 2.1.

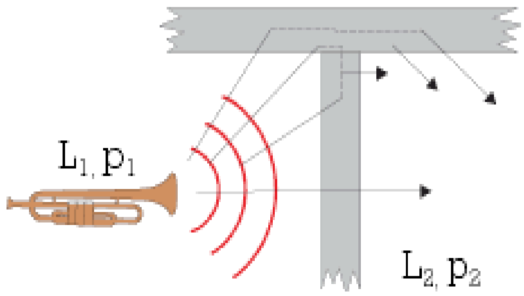

Fig. 1 Sound reduction index (source: www.rockwool.cz)

Sound reduction measuring is followed by the ČSN EN ISO 140-4 standard. Evaluation of measured processes and indication of one-figure number data is done according to the ČSN 717-1 standard. Evaluation of building constructions according to the set requirements are based on the ČSN EN ISO 140-4 standard.

2.1 Example from practice – a block of apartments in Frýdlant nad Ostravicí

Characteristics:

This house was built in 2004 from hollow moulded bricks (Porotherm).

Reason for measurements:

To verify real properties of the structures. People living there have complained often about noise from neighbouring apartments.

Measured construction:

Wall between two apartments made from Porotherm 24 P+D (240 mm), plastering on both sides, thickness 15 mm. Total wall thickness: 270 mm.

Fig. 2 Apartment block in Frýdlant nad Ostravicí

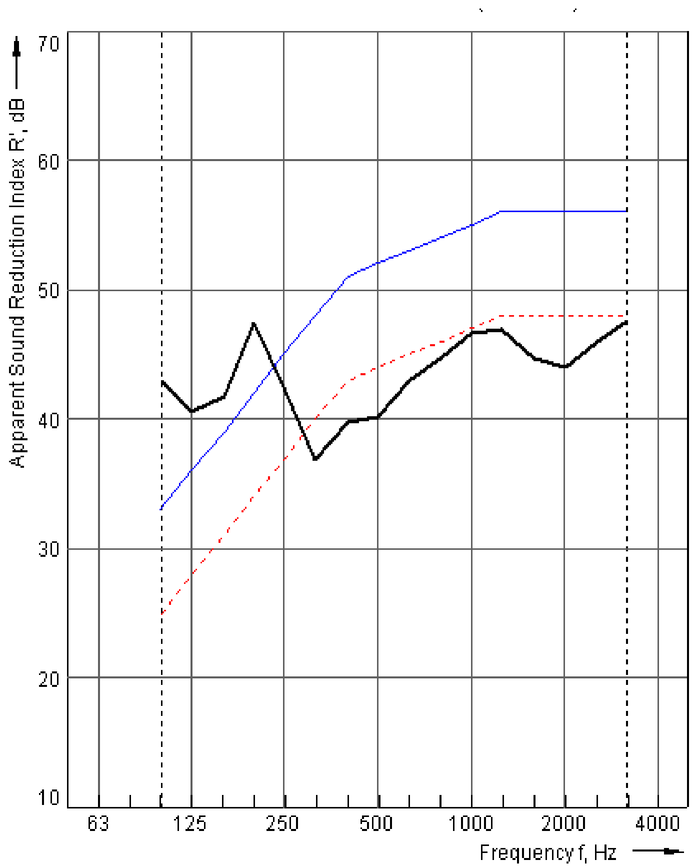

Fig. 4 Course of R'_w - Porotherm 24 P+D.

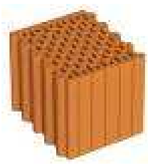

Fig. 3 Moulded bricks, Porotherm 24 P+D

Fig. 5 Measured wall in the apartment

Comments to the measurement:

In terms of acoustics, the construction was deteriorated by wiring/pipes. This is absolutely unacceptable from the acoustic point of view. The measured value was $R'_w = 44$ dB. In order to make the construction compliant with requirements set forth in [1], the minimum value should be $R'_w = 52$ dB.

This means that incorrect actions have been taken when preparing a project for the construction. A material has been proposed the sound insulation properties of which ((R_w - communicated by the manufacturer) decreased by correction routes for sound propagation (k) make it impossible to use it for that wall between the apartments and to fulfill requirements of [1]. $R'_w = R_w - 2 = 52 - 2 = 50$ dB(!)

Tab. 1 Parameters of walls between the apartments

construction	thickness (mm)	type of room	note	R´w (dB) required value [1]	R´w (dB) measured value	Rw (dB) as given by the manufacturer
Porotherm 240	270	living room/bathroom	wiring/pipes	52	44	52

Improvement proposals:

It is impossible because of building and technology aspects to demolish the wall and replace it with another one with better sound parameters. A solution might be to install an offset wall with sound absorbing materials. The offset wall should be flexibly separated from other structures.

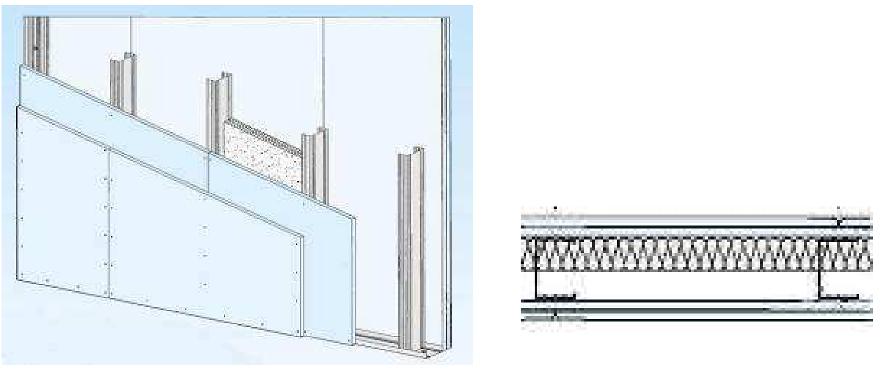

Fig. 6 Offset wall from gypsum board

2.2 Example – Building of Ostrava University

Characteristics:

Reconstruction of a building located in a historic centre of a city.

Reason for measurements:

To verify real parameters of the structure before the structure is handed over for use.

Fig. 7 Building of Ostrava University

Fig. 8 Location of devices

Measured construction:

Walls separating classrooms - the walls are made from moulded bricks Porotherm 30 AKU (145 mm), plastering on both sides, thickness 15 mm. Total wall thickness: 175 mm.

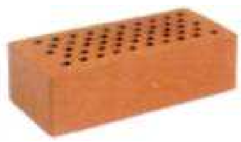

Fig. 9 Moulded bricks, Porotherm 30 AKU

Comments to the measurement:

The designer used the material with $R_w = 48$ dB (this value is given by the manufacturer). After correction routes (2 až 3 dB) for sound propagation are deducted, the material does not meet requirements in [1].

The acoustic performance of the construction is also reduced by A/C pipes and water pipes. The measured value $R'_w = 35$ (36) dB is well below the required value $R'_w = 47$ dB.

When both classrooms are used at the same time, it is highly likely that people in both classrooms will be disturbed with noise that passes through the wall.

Fig. 10 *Measured wall between the classrooms*

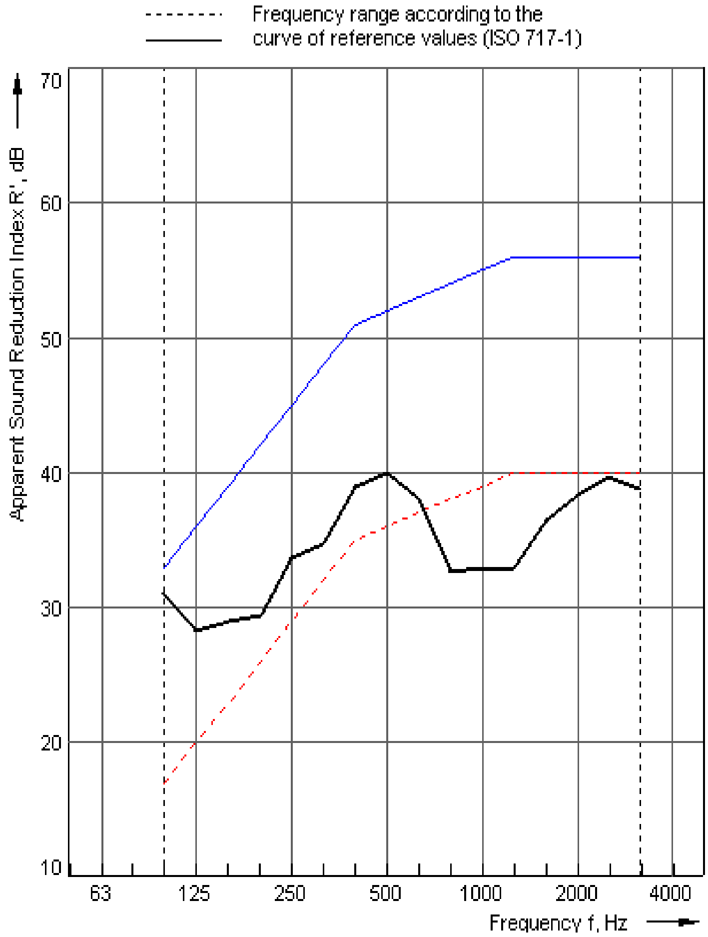

Fig. 11 Course of R'_w - Porotherm 30 AKU.

Tab. 2 Parameters of walls between the classrooms

					Rw´ (dB)		Rw (dB)
room #	construction	thickness (mm)	type of room	note	required value [1]	measured value	as given by the manufacturer
401-402	Porotherm AKU 30	175	classroom/classroom	deteriorated by pipes	47	36	48
201-202	Porotherm AKU 30	175	classroom/classroom	deteriorated by pipes	47	35	48

Improvement proposals:

Alternative 1: This is not a bearing wall. Theoretically, the wall can be demolished and completely replaced with another one. For instance, Porotherm 24 AKU (produced by the same manufacturer) can be walled up to the thickness 240 mm $R_w = 48$ dB. In practice, demolition is possible only within a claim procedure. More frequently, Alternative 2 is preferred.

Alternative 2 – a pre-wall will be built in front of the existing wall. The pre-wall will be made from sound absorbing materials (similarly as in Case 2.1). Reasons are both technical and economic.

3. Impact sound transmission loss

This represents construction's ability to attenuate noise caused by a direct contact of a source of sound with structure. A typical pattern inside the buildings is the walking on walls, moving furniture, or elevator equipment.
Basic rule: The lower the impact sound transmission loss (L'_{nw}) is, the better.

Impact sound transmission loss measuring is followed by the ČSN EN ISO 140-7 standard. Evaluation of measured processes and indication of one-figure number data is done according to the ČSN 717-2 standard. Evaluation of building constructions according to the set requirements are based on the ČSN EN ISO 140-7 standard.

3.1 Example – Apartment Block in Ostrava

Characteristics:

Panel building built in 1971. Building system: T 06B.

Fig. 12 Panel building in Ostrava

Fig. 13 Tapping-machine.

Reason for measurements:

An owner of the apartment complained of excessive noise from the apartment above him. Verification of properties of the ceiling structure.

Measured ceiling structure:

Because people live in the apartments, it was not possible to install a probe to find out construction layers. During the inspection it has been found out that ceramic tiles were laid in the upper apartment. This damaged the floor finish.

For the original composition see Table 3.

Tab. 3 Original composition of the ceiling in T 06B

structure of ceiling with floor	thickness [m]
flooring - PVC	0.003
varnished particleboards	2x0.010
alveolate board plate - IZOPLAT	0.012
polyethylene plastic	0.001
dross sand	0.015
ceiling reinforced concrete panel	0.150
plaster	0.015
Total thickness	0.216
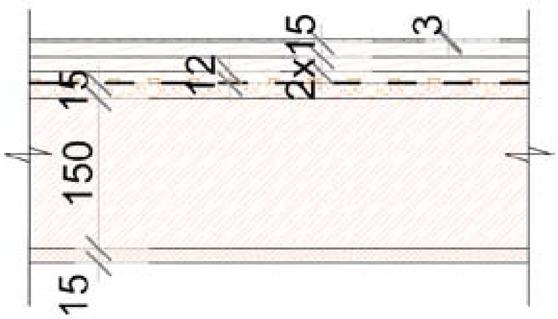
Fig. 14 Composition of the original floor

Comments to the measurement (Fig. 15)

The weighed normalised impact sound transmission loss of the ceiling with the original floor structure is L'_{nw} = 55 dB. After unprofessional change, the weighed normalised impact sound transmission loss of the modified ceiling (with tiles on the floor) is L'_{nw} = 70 dB ⇒ this means, requirements set forth in the standard [1] are not met. The reconstruction decrease the sound loss of the ceiling structure by 15 dB!

A reason for the worse impact sound loss of the structure is probably that an incorrect technology was chosen for the new floor. Some layers of the original floor were removed (for instance, shredded wood boards) and new sound insulation was not placed under the tiles. Dilation along the floor is also missing there.

People living in apartments make such undesirable changes rather often.

Tab. 4 Parameters of the ceiling between the apartments

construction	thickness (mm)	type of room	L´nw (dB) required value [1]	L´nw (dB) measured value
modified ceiling	220	room/room	58	70(-9)
original ceiling	220	room/room	58	55(1)

Improvement proposals:

To remove the files and lay a new floating floor with a dampening insert (for instance, Rockwool Steprock).

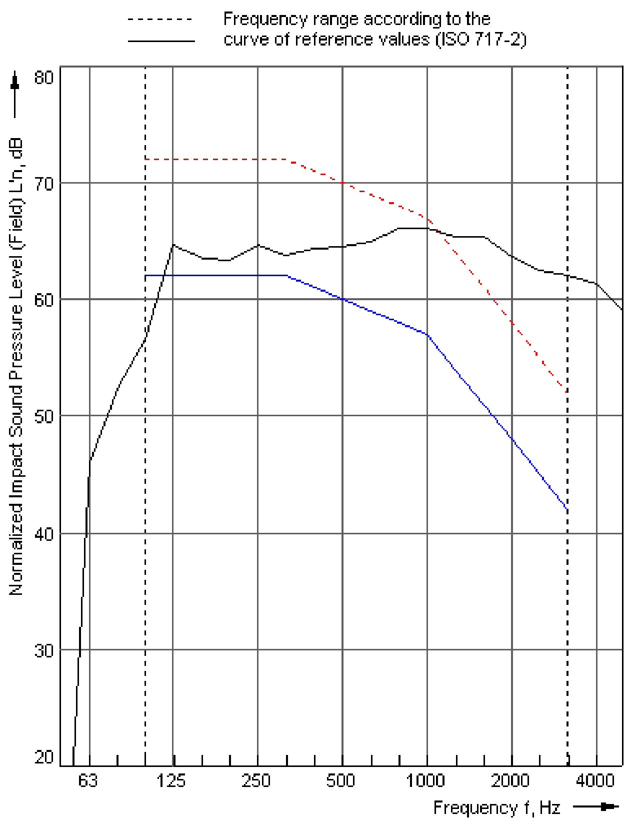

Fig. 15 Course of L'_{nw} – tiled ceiling

Fig. 16 Measuring devices

4. Apparatus equipment

The Building Faculty disposes of the top measuring apparatus from a Dane company Brüel & Kjær. System consists of:

1) Investigator 2260 D – programmable sound analyser.
2) Programme for sound analysis BZ 7204.
3) Sound source OmniPower type 4296.
4) Normalized source of impact sound transmission loss – Tapping machine 3207.
5) Amplifier - Power Amplifier type 2716.
6) Calibrator.
7) Microphones, cabels and attachements.

Fig. 17 Apparatus equipment.

5. Conclusion

Because of differences that occur as a result of installed structures, it is rather complicated to describe the sound propagation inside buildings, if currently used methods are applied for the calculation of sound transmission loss (graphic or course methods). Laboratory parameters of elements found out in a sterile environment of acoustic chambers can also hardly consider the situation on the site. The situation of designers is rather difficult: they can rely neither on calculations nor on laboratory values (after deduction of necessary corrections in order to acquire construction values). It is necessary to avoid situations where pipes and wiring are laid in a separating wall! The measurements have proved that the deteriorated structure has considerably impaired sound parameters. Though this unacceptable solution is not visible, it can make people living there "hear" too much.

[1] ČSN 73 0532/2000, amendment Z1/2005 Acoustics – Protection against noise in buildings and related acoustic properties of building elements – Requirements.

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SBTOOL CZ – CZECH ASSESSMENT METHODHOLOGY FOR SUSTAINABILITY

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Keywords: SBTool, assessment method, sustainable development, sustainable construction, weighting

Summary

The SBToolCZ is a building performance assessment tool designed for assessment of buildings in various phases of their life cycles. For a new tool (called SBToolCZ) has been developed adapted structure of indicators, benchmarks and weights based on the original SBTool structure and using some experiences from development of LEnSE methodology (Methodology Development towards a Label for Environmental, Social and Economic Buildings – EU FP6 research program). The parameters included in the system cover sustainable building issues within the three major areas: environment, social and economic issues. The system is designed on three levels including the core of the application, an expert level and the user's boundary-line. The core of the application is accessible only on the level of the program language. The expert level enables the forming and modification of evaluation methods. The middle level enables the description of methods and evaluations algorithms, by the user's way. The user's level serves the evaluation of specific building.

1. Background

1.1 Situation in the Czech Republic

The Czech Republic followed the international process Green Building Challenge and iiSBE organization in 2005 and established Czech Sustainable Building Society (CSBS) iiSBE Czech. The CSBS is an official representative of iiSBE in the Czech Republic and keep the key role in promotion of SBC principles into the Czech construction sector. CSBS iiSBE Czech together with the research centre CIDEAS (at the Czech Technical University in Prague) started the process of adaptation of GBTool/SBTool for specific Czech conditions. For a new tool (with the working name SBToolCZ) has been developed adapted structure of indicators, benchmarks and weights based on the original SBTool structure and using some experiences from development of LEnSE methodology (Methodology Development towards a Label for Environmental, Social and Economic Buildings – EU research programme).

The SBToolCZ is a building performance assessment tool designed for assessment of buildings in various phases of their life cycles. The parameters included in the system cover sustainable building issues within the three major areas: environment, social and economic issues.

The system is designed on three levels including the core of the application, an expert level and the user's boundary-line. The description of the evaluated building and the form of the output are oriented towards practical use.

1.2 SBToolCZ – principles and localization of the tool

The SBTool (formerly GBTool), has been chosen as a basis for development of the Czech buildings assessment methodology because it offers a complex approach in association with a wide scale of reasonable detailed criterions.

SBTool is represented by a set of assessment criteria organized in a tree structure. The particular criterions are first converted to relative value in compliance with achieved performance level, second count up according to the preset weights.

When the works on localization had started, some problems occurred. The original SBTool software was developed in MS Excel which is a powerful solution for a rigid assessment tool. However it is not suitable for adaptation to different languages and specific local conditions and keeps everything up to date at the same moment.

Therefore a new structure of the assessment tool based on database architecture and new methods for distribution of information has been developed. The effort resulted into a new universal assessment tool named SBToolCore.

2. SBToolCore

2.1 General structure of the system

SBToolCore is a universal methodology and tool for complex assessment of buildings. It enables maintenance of origin and derived assessment methodologies and their national or regional localizations (see Figure 1).

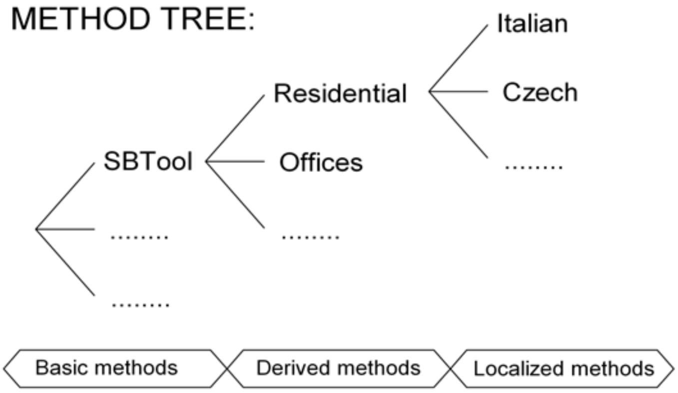

Figure 1 Method tree

The tool is suitable for development, testing and comparison of different assessment methods as well as for their practical applications. SBToolCore has three strictly separated functional levels (Figure 2):

- system level (tool setting and maintenance);
- expert level (definition of assessment methods);
- user level (assessments of buildings).

Assessment methods are described in a database form and presented in a simple and user friendly form.

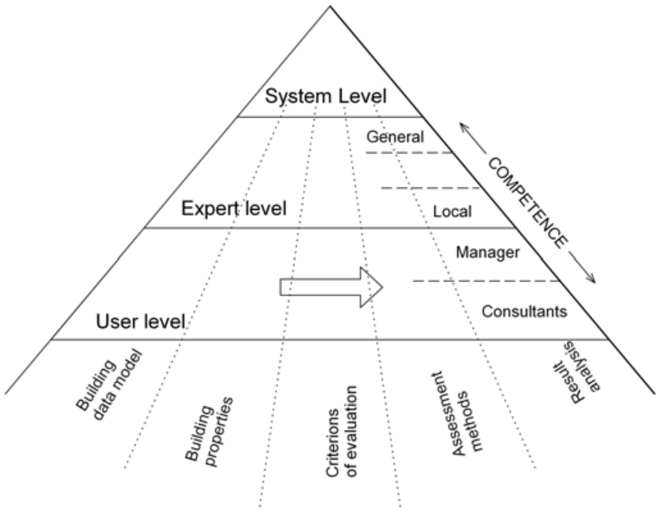

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Figure 2 System levels and competitions.

2.2 Database of building properties, boundary conditions and criterions

Building properties, assessment boundary conditions and criteria are described in a database form. Ease of description and transparence of the system is improved by organization all categories into tree structures.

Building properties can be described by verbal indicators, by exact values or even by fuzzy values. Two value types of properties and boundary conditions are set – basic and localized.

Data for criterions are dynamically obtained from building properties and boundary conditions. Benchmarking operations can be user defined using symbolic script formulas.

2.3 Multicriterion analysis

Assessment method is in the SBToolCore system defined by criterions selection, their mutual organization and weights.

For simpler weightings are criterions first relativised (meaning transformation from measurement units to relative scale from -1 to 5) and then summed up according to weights.

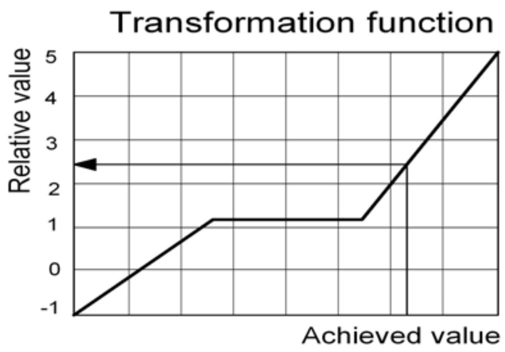

Figure 3 Transformation function

Criterions are placed in the method tree and impact tree.

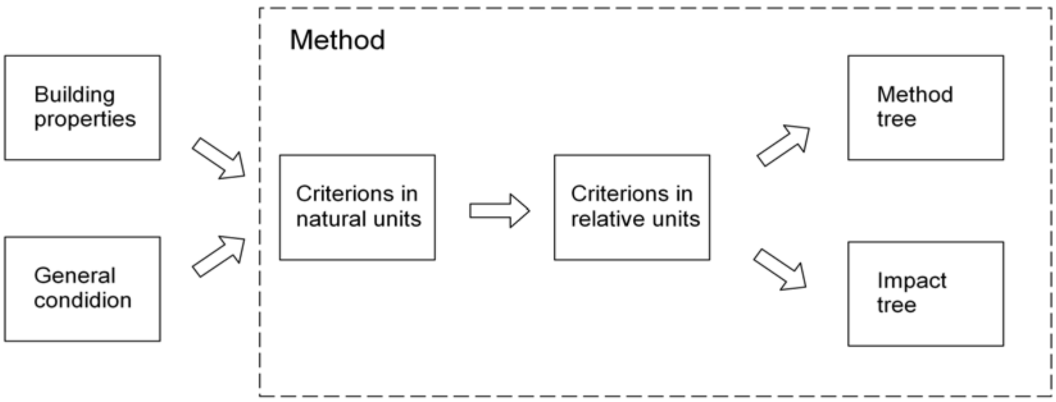

Figure 4 Assessment scheme

The position of the criterion in the method tree expresses its belongings to a particular subsystem of assessed building. Positioning the criterion into the impact tree represents belonging to the selected impact category.

Both method tree and method tree together make a multilayer criterion tree that enables not only complex quality of proposed building project but also the quality of its particular subsystems. The latter dimension enables to connect the assessed quality of the particular subsystem with the specialists' responsibilities in the project team (see Figure 5).

Criteria organization in the multilayer SBToolCore tree enables:

- independent weights settings;
- detailed complex analysis of proposed project;
- splitting expert and political weights;
- easy modification of the methodology for several purposes.

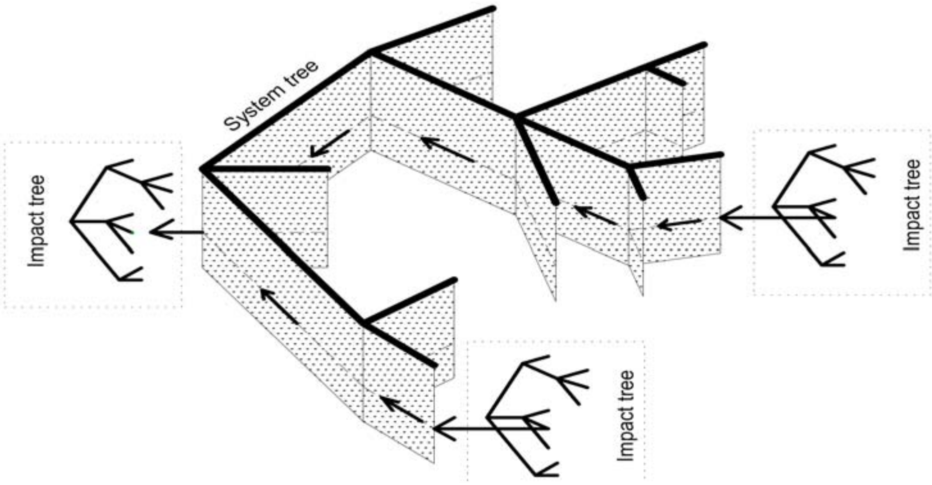

Figure 5 Multilayer tree structure

2.4 User level and assessments outputs

Assessment algorithms are in SBToolCore system extracted straight from the methodology definition on the expert level. The tool supports building assessments using more methods at one moment. It also handles more variants of one project and their comparison. The user can choose what data sets are for the derived variant inherited (when a change is made in original basic variant, it automatically changes values that has enabled inheritance) and what are settled rigid.

The outputs are very illustrative and enable to perform a complex assessment of any part at different detail levels (Figure 6).

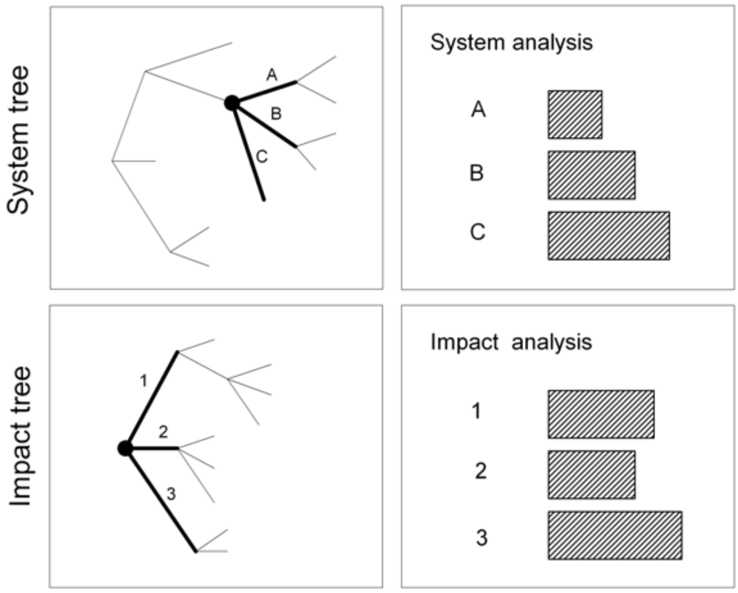

Figure 6 Analysis levels

The final result consists of total score of environmental, social and economic issues and can be represented for example by a TRICRI graph on Figure 7.

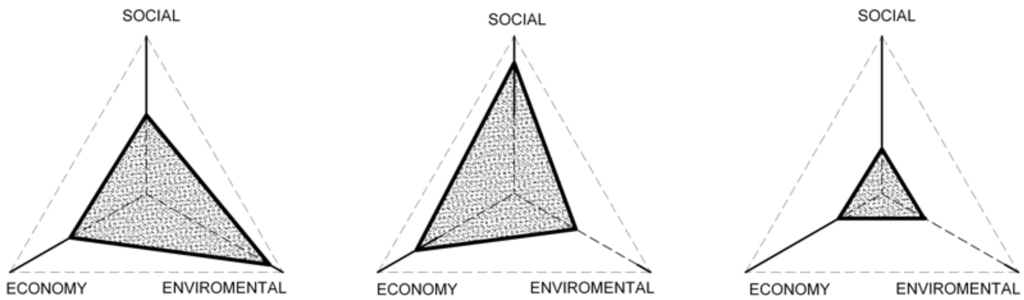

Figure 7 Example of possible results: a) building having very high environmental performance; b) economical building having high social performance; c) low-quality building.

2.4 SBToolCore implementation

SBToolCore implementation employs the latest IT technologies (MS SQL Server, NET Frameworks 3.5). The tool is designed to manage international cooperation on development and localization of complex assessment methods. System supports multilingual user interface as well as multilingual methodologies definitions. System implements multi-user management on both expert and user level and enables efficient control of projects preventing information duplications. Access rights management handles different roles (international expert, national expert, project manager, specialists). Principle of information inheritance enables easy creation and modification of building properties and criterions according to the national specifics. SBToolCore is open data system ready for interconnection with IFC data model (Industry Foundation Classes).

3. SBTool CZ

The structure of criterion used in SBToolCZ is presented in the next tables (Tab. 1, Tab. 2, Tab. 3).

Table 1 Environmental assessment issues

Main category	Assessment issue
Climate Change	Greenhouse Gas - CO_2 emissions – operation of buildings & transport Embodied emissions CO_2 Destruction of the stratospheric ozone layer
Air Quality	NOx emissions - buildings & transport Operation SO_2 emissions
Biodiversity	Ecological value of land NFA compared with green area Ecological value impact of land
Resource use and waste	Nonrenewable primary energy consumption Renewable primary energy consumption Embodied energy Use of freshwater resources Use of rainwater Use of renewable construction material Use of recycyled construction material Use of toxic construction material Construction waste Waste in operation of building
Environmental Risk	Floods Outcome of rainwater
Management	ISO 140001 ISO 9000

Table 2 Social assessment issues

Main category	Assessment issue
Occupant wellbeing	Lighting comfort Acoustic comfort Thermal comfort Indoor air quality
Accessibility	Provision of place for free time Public transport accessibility Provision of safe and adequate cycle lanes and cyclist facilities Key amenities - provision and proximity
Security	Site security Building security
Social and cultural value	Community impact consultation Aesthetic quality External neighbourhood impacts
Functionality	Critical management Adaptability Spatial efficiency Availability of as-built drawings and documentation

Table 3 Economy assessment issues

Main category	Assessment issue
LCC	Investment cost
	Operation Cost
	Additional Cost
	Added value
Support of local economy	Use of locally produced materials
	Local employment opportunities
Externalities	Externalities in transport
	Externalities of waste water
	Site quality
	Innovation

Each issue has it own assessment list, which contains the name of assessment issue, for which stages it is set, for which type of building it is set, intent of assessment, indicator, benchmarks for relevant type of building and relevant stage, information source, methodology of assessment and responsible administrator. The most of benchmarks is set for the level -1 (negativ), 0 (acceptable practice), +3 (good practice) and +5 (BAT – best practice). It is possible to interpolate intermediates values.

The structure of indicators is in progress. Comparison between issues included in SBToolCZ and LEnSE gives not only experiences in European trends, but ensure the compatibility of SBToolCZ with other European tools as the BREEAM for example.

There will be stated the final benchmarks of criterion and weights among criterion in the next steps of research. These weights will be set according to the questionnaire of researcher.

The main objective of the LEnSE project in the nearest future is to form an international framework for the development of a common building labelling methodology with creating a set of the main assessment criteria. On the basis of the main criteria there will be designed a prototype assessment tool that facilitates testing of the methodology on a specific building types (new residential and commercial buildings). After analysing the results the methodology will be expanded for the other types of buildings.

4. Conclusions

The evaluation and optimization of buildings have a practical meaning only when they can influence the final design of the building. Design is a process of gradual decision making, where conceptual decisions done at the beginning have the biggest effect. For the evaluation to have an effect on the project solution, it has to be done simultaneously with the decision process.

The project work in buildings at present comes from evolution algorithms. This work well in the environment with long term stability and feed-back and then offer suitable solutions relevant to actual needs and possibilities.

Current development is typical of it's intense demands on energy savings, use of renewable materials and satisfaction of new needs, while exploring the use of new materials and technologies. That is why the traditional way of designing, based on the use of empirical experience, does not have good results.

This problem can be solved by computer simulated variation of designs, with following complex evaluations. A starting-point is the development of methods for integrated designing and complex evaluation of buildings.

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THE ASPECT OF BUILDING EFFICIENCY ADAPTED TO THE METHODOLOGY OF DATA ENVELOPMENT ANALYSIS FOR THE PERFORMANCE OF EXISTING BUILDINGS IN TAIWAN

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Keywords: Sustainability, ISO Series, DEA, Existing Building Performance, Efficiency, Life Cycle Cost (LCC)

Summary

"Sustainability" is meant to be the desirable concept of human development that meets the present demands without compromising the future supply of next generations for their own liveability. This concept needs to be adapted relevant object of assessment to fulfil the term, sustainability, with regard to environmental, economic and social conditions. Based on the "Sustainability in Building Construction-Framework for methods of Assessment for Environment Performance of Construction Works-part.1: Building" covered in ISO 21931-1 and the evaluation method of building Life Cycle Cost in ISO 15686 and ISO14040, this study will aim at 97% of the buildings ratio occupied by the existing buildings in Taiwan to preliminarily structure a new model to assess the Existing Building Performance in the life cycle of a building. The assessment adapted the methodology of Data Envelopment Analysis (DEA) is discussed using a case study to offer the "decision-making references" to management personnel, users and designers for "upgrading the building performance" approaching the perspective of Sustainable Building Environment.

1. Introduction

In the 21st century, an age of sustainability, in response to the concept of sustainable environment, building construction industry must develop "a method of assessment to building performance" in order to meet different phases of the building life cycle assisting to effectively cope with the issues of global warming and harmfulness to environment and health. International organization OECD (Organization for Economic Co-operation and Development) investigated the current situations of the buildings in member countries. The statistical data indicated that the ratios of new buildings in many advanced countries were almost below 2% (shown in Table 1). The ratio of new building license from 1990 to 2006 in Taiwan has reduced by 3% and ratio of the existing buildings was up to 97% (shown in Figure 1). With the increase of building duration, there will be many problems generated. The metropolis is the population and economy centre in the world and with the major pollutants of energy consumption and Greenhouse air emission. Therefore, the functions and environmental quality of existing buildings were deteriorating and these buildings also caused environmental pollution and landscape damage. If we can propose correctly sustainable improvement strategies and accelerate reactive usage of the buildings, human environment will also be improved.

Table 1 Rate of new except exist of OECD country

OECD Country	Housing starts/stock
Australia	1.7%
Canada	1.3%
France	1.0%
Germany	2.1%
Japan	2.8%
UK	0.8%
US	1.4%
NL	1.3%

Year	Construction Licenses		Total Floor Area（one thousand m^2）			
	Case	Total Floor Area（one thousand m^2）	Housing	Mercantile	Bussiness and Service	Other
1990	49,122	40,066	12,059	7,929	1,868	4,490
1991	65,100	53,671	12,289	8,101	2,500	4,696
1992	86,539	76,436	15,657	8,982	2,508	5,140
1993	76,578	72,490	21,769	12,644	2,371	8,944
1994	67,431	61,214	28,584	15,364	2,164	6,660
1995	54,295	45,687	26,459	15,341	2,902	6,161
1996	42,669	37,689	20,631	10,858	2,484	7,801
1997	42,207	45,779	14,593	9,637	2,902	7,545
1998	37,221	42,784	13,916	9,217	2,467	8,473
1999	28,067	37,154	13,561	8,937	4,089	7,841
2000	29,493	34,986	8,429	6,351	2,751	6,340
2001	22,175	21,629	4,854	2,447	1,529	6,074
2002	25,282	23,078	7,066	2,466	2,202	4,886
2003	34,468	28,356	11,961	4,077	1,696	4,657
2004	45,934	42,497	18,891	7,856	1,746	5,372
2005	43,805	43,200	17,673	9,938	1,711	6,542
2006/01-09	26,068	28,077	15,042	1,793	2,322	1,440
New/Exist	3.36%	3.82%	5.71%	1.26%	5.77%	1.40%

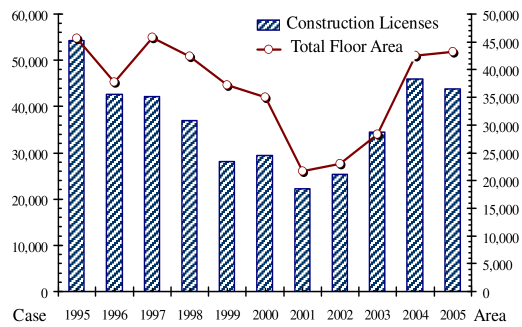
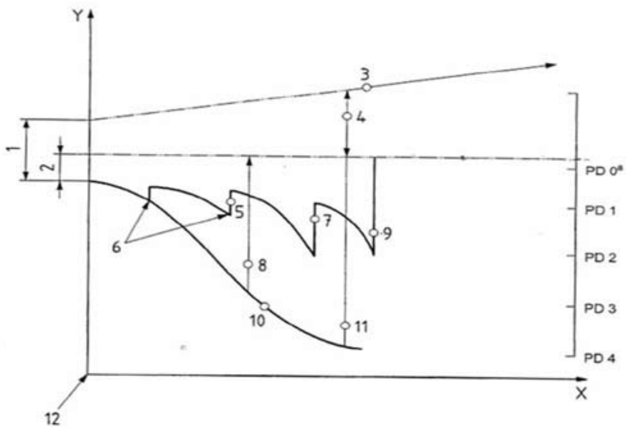


Figure 1 1990-2006 Construction Licenses statistics of Taiwan

Based on, consequently, the “Sustainability in Building Construction-Framework for methods of Assessment for Environment Performance of Construction Works-part.1: Building” covered in ISO 21931-1 and the evaluation method of building Life Cycle Cost in ISO 15686 and ISO14040(Shown in Figure 2),



Key

Y quality/function	5. preventative and periodic maintenance
X operation and management of building over time	6. limit states
1. expectation / achievement gap	7. refurbishment
2. building failure/damage	8. repair
3. new requirements -public -market -business	9. replacement
	10. performance without preventative actions
	11. renewal
4. development upgrading	12. ”as built”

■ Performance degrees (PD) are defined in 5.4.3.2.2.

Figure 2 Life Cycle Performance of Construction this study will aim at 97% of the buildings ratio occupied by the existing buildings in Taiwan to preliminarily structure a new model to assess the Existing Building Performance in the life cycle of a building. In addition, a sustainable building is meant to be a building that contributes through its characteristics and attributes to sustainable development. By safeguarding and maximizing functionality and serviceability as well as aesthetic quality a sustainable building should contribute to the minimization of life cycle costs (Thomas and David 2007). However, the built environment of today uses large amounts of energy and materials affecting the health of humans and natural environment in negative effects. Obviously, rising interest in developing environmental assessments of the built environment generates a large number of tools for the assessment of built environment focusing on energy use in buildings, the sick building syndrome, indoor climate, building materials containing hazardous substances and many other aspects in fragmented or integrated manners (Anna and Fredrik 2004). In association with these divergent tools of environmental assessment, the concept of Integrated Building Performance approach (IBP) was proposed and led to a wide range of discussion for assessing a building's contribution to sustainability including the spectrum of functionality and serviceability as well as the quality of planning, construction and management process (Thomas and David 2006) (Shown in Figure 3).

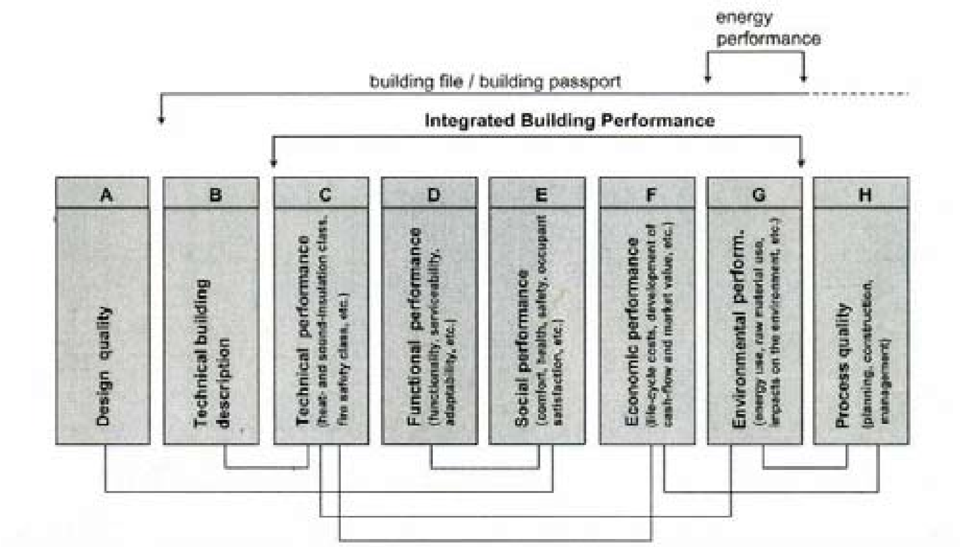


Figure 3 Integrating sustainability aspects into an overall framework

To extend, the purposes for the assessment of sustainable buildings are to satisfy the needs of the building users in aspects of environmental performance, social performance, economic performance and technical performance; this statement has also revealed a new vision as a supplement to current assessments of LCA-based tools. As a result of the above mentions, the series of ISO standards and IBP approach attempt to clarity the cross effects of Cost or Loading and Quality on its individual role as indicators for robustly assessing the performance of existing buildings.

2. Life Cycle and Building Life Cycle Costs

ISO-EN-UNE-14040 regulation, defines life cycle as the consecutive and interrelated stages of a product system, from the acquisition of raw materials or the generation of natural resources until its final elimination. Life cycle is closely related to cost-accounting system as conducting the life cycle assessment (LCA) that has been applied for some time to assess the environmental impact of industrial products (ISO14040), also makes senses in construction and may be equally applied to civil works and architecture (Yokohama, Oka and Kibert etc. 2000). Nevertheless, many traditional cost-accounting systems lead to incorrect investment decisions concerning environmental costs. One problem is for example that demolition and recycling costs appear outside the boundary of the traditional accounting system. A popular way of solving this problem has been to suggest the use of life cycle costing (LCC) which includes such costs. The main difference between traditional investment calculus and LCC is that the LCC approach has an expanded life cycle perspective, and thus considers not only investment costs, but also operating costs during the product's estimated lifetime (Pernilla and Henrikke 2004). As well known, in the life cycle of a building, the major activities can be defined where environmental performance can be assessed: construction of a new building, rebuilding, extension, operation, maintenance and demolition. By the research from Martin and Per 2005 conclude that rebuilding is an environmentally better choice than building a new building, if the essential functional performance is the same. This conclusion indicates the cost of a building over its lifetime is no longer the general feeling that the lowest capital cost option will also be the lowest total cost option because of operation and maintenance costs incurred either annually or at periodic intervals over the life cycle of a building.

According to the aforementioned the percentage of new and existing buildings (3%: 97%) in Taiwan, it is important to orient building life cycle costing tools adapting the evaluations for operational and maintenance efficiency.

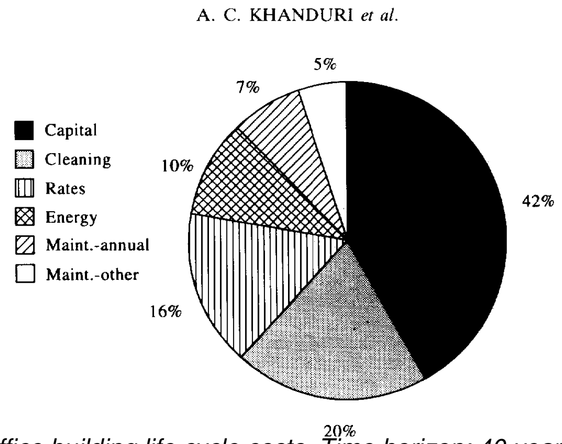


Figure 4 Office building life cycle costs. Time horizon: 40 years, discount: 2%.

The figure 4 illustrates the life cycle cost commitment for a typical office facility.' In this figure, operation and maintenance costs, which are incurred either annually or at periodic intervals over the life of the facility, account for 58% of the total life cycle costs, are thus greater than the capital costs which are incurred at the initial construction stage. It can be seen that the long-term costs can far outweigh initial capital costs (A.C. Khanduri 1996). LCA methodology should take into account preventive maintenance programmes which will require an effort and commitment by future generations (Eduardo Peris Mora 2007). Neely and Neathammer have presented several different maintenance life cycle data bases developed by the U.S. Army Construction Engineering Research Laboratory to assist in life cycle cost analysis. Computer-aided procedures to evaluate the financial feasibility of construction projects have existed for some time, but their use has frequently been cumbersome, requiring too much data. The methodology of Data Envelopment Analysis (DEA) developed by Farrell et al. (1989) that proposed a nonparametric mathematical programming technique is software for calculating the efficiency both technically and environmentally.

3. Evaluation Methods Adapted Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) is a methodology based upon an interesting application of linear programming. It was originally developed for performance measurement. It has been successfully employed for assessing the relative performance of a set of firms that use a variety of identical inputs t was originally developed for performance measurement. It has been successfully employed for to produce a variety of identical inputs to produce a variety of identical outputs (R. Ramanathan 2003).

3.1 Decision-making Units

Data Envelopment Analysis is a linear programming-based technique for measuring the performance efficiency of organizational units which are termed Decision-Making Units (DMUs). This technique aims to measure how efficiently a DMU uses the resources available to generate a set of outputs (Charnes et al. 1978). Decision-making units can include manufacturing units, departments of big organizations such as universities, schools, bank branches, hospitals, power plants, police stations, tax offices, and defence bases, a set of firms or even practising individuals such as medical practitioners. The performance of DMUs is assessed in DEA using the concept of efficiency or productivity, which is the ratio of total outputs to total inputs that can be formulated as the following:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} \tag{1}$$

Efficiencies estimated using DEA are relative, that is, relative to the best performing DMU (or DMUs if there is more than one best-performing DMUs). The best-performing DMU is assigned an efficiency score of unity or 100 per cent, and the performance of other DMUs vary, between 0 and 100 per cent relative to this best performance (R. Ramanathan 2003).

3.2 Frontier Analysis in DEA

The economic treatment of Frontier Analysis is normally explained using the concept of production possibility frontier (Samuelson and Nordhaus 1989; Thanassoulis 1999). A production possibility set for the example in this section can be constructed by considering all possible combinations of the two inputs (capital employed and employees) that will result in the same, given level of output (value added), and the production possibility frontier is the frontier enveloping the production possibility set. The efficiency frontier is indicated in Figure 5. It represents a standard of performance that the firms not on the frontier should try to achieve. Firms on the frontier (Firms A and C here) are considered 100 per cent efficient.

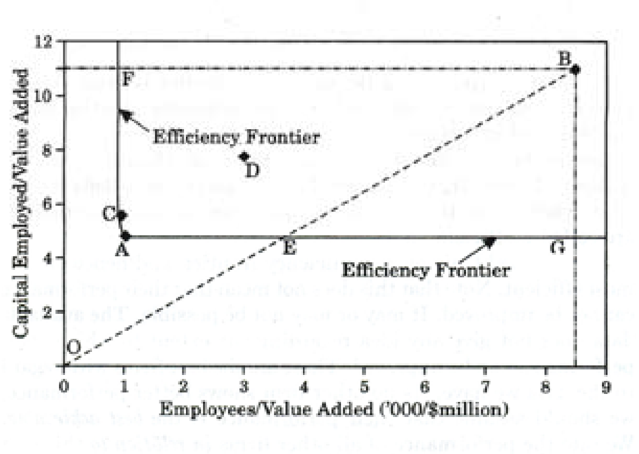


Figure 5 Frontier Analysis in DEA

Such an analysis using the efficiency frontier is often termed Frontier Analysis (Farrel 1957). This efficiency frontier forms the basis of efficiency measurement. The efficiency frontier envelops the available data. Hence, the term Data Envelopment Analysis. In the DEA literature, Firms A and C are called efficient firms while Firms B and D that do not lie on the efficiency frontier are called inefficient firms (R. Ramanathan 2003).

The purpose of DEA is to offer a method for the evaluation of efficiency that have been broadly used by Non-Profit Organization (NPO). This is because the value of the products and services from NPOs are very difficult to be appeared by quantitative figures as same as their prices in a free market. Nevertheless, the DEA method can be a useful tool for the evaluation of productivity by the scores of relative efficiency between departments in a firm, firms and regions.

In the field of building industry, evaluations of a building performance involve a wide range of factors, including initial cost, construction cost and maintenances etc.. These factors are so complicated that quantitative analyses for a building performance and efficiency are not easy to be conducted. Generally, evaluator will set up some indexes and weightings that normally based on surveys or questionnaires to compute the building efficiency that become subjective results by the valuator due to the lack of reliability and validity. Consequently, this paper attempt to apply DEA, which takes different spaces in a building as DMU, for assessing building efficiency and performance. By the comparisons of relative efficiency to find out the most efficiency DMU is to provide references for the future improvement and to help the decision making for the building owner (refer to Figure 6).

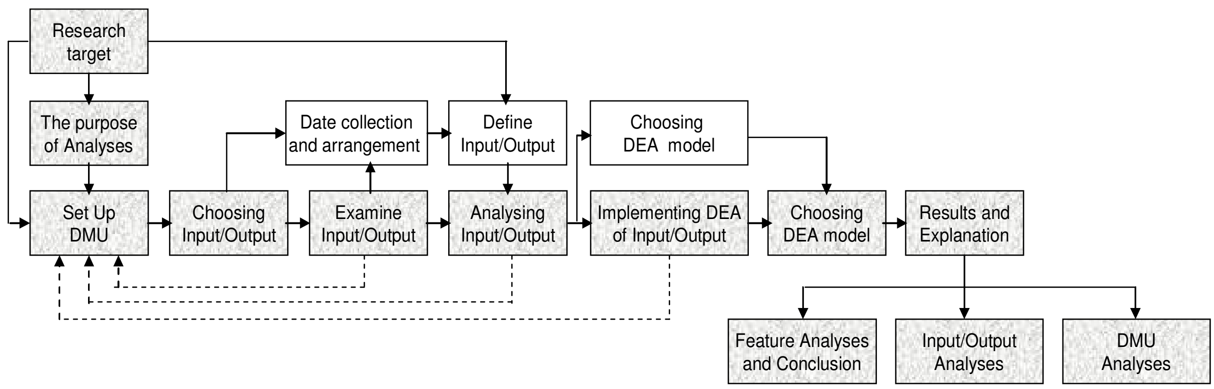


Figure 6 DEA Procedure

4. Case Study- Proposed Evaluation Model of Existing Buildings Performance

A well operated building should meet the status of High-Performance and Low-Energy consumption with Healthy-Quality of users to illustrate the efficiencies of use and economy in a building lifecycle.

Therefore, this study takes a research building of Academia Sinica as a case study to adapt the methodology of Data Envelopment Analysis (DEA) for the evaluation of indoor environment quality monitored the correlations between factors of indoor environment quality (IEQ) and the building performance. It also provides the quantitative data as the references for Life Cycle Costs analysis (LCCA) to enhance the technical and environmental efficiency. This case chooses 14 research units with the same floor area as DMUs to set up the employees and the indoor decoration costs as INPUTS and the factors of indoor air quality (IAQ) as OUTPUTS (ie: TVOC and CO2) to explore feasible approaches for the evaluation of building costs toward overall efficiency in a building lifecycle. This research target is chosen 「Genomics Research Center」 as a case study, selecting 14 spaces become research DMU that listed as Figure 7-Standard Plan and Table 2-DMU Layout.

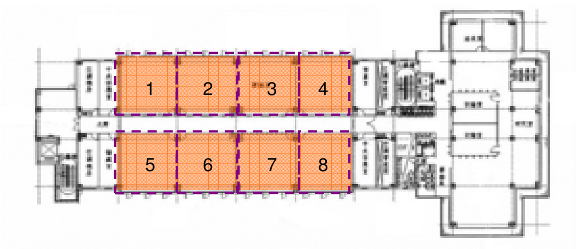


Figure 7 standard plan

Table 2 DMU Layout*

DMUs	Floor	Location
A	2	1
B	2	7
C	3	3
D	3	8
E	4	1
F	4	3
G	4	2
H	5	5
I	5	1
J	5	4
K	6	3
L	6	4
M	7	6
N	7	8

* DMU A, E, I marked as 1 because these DMUs have the same spatial type as same as the reason for DMU C, F, K, D and N.

4.1 The Factors of Indoor Air Quality (IAQ) and Scoring Method

4.1.1 Converting the questionnaires results of on-site survey and Analytic Hierarchy Process (AHP)

This study converts the questionnaires evaluation of interviewed users in 14 types of research units into scoring for comparisons. Simultaneously, AHP method was conducted to further verify the factors of IAQ need to be prior improved. To help compare physical and mental scorings of various spaces, X-axis in Table 3. is converted into mental scoring as 20, 40, 60, 80, and 100. Y-axis represents the scoring of physical evaluation from the measurement results.

Table 3 Scoring of the IAQ Factors in physical aspect

Indoor Air Environment	Score / Factors	20	40	60	80	100
Indoor Air Quality	CO_2 (ppm)	>1200≥	>1000≥	>800≥	>600≥	
	TVOC (ppm)	>4≥	>3≥	>2≥	>1≥	

4.1.2 Proposed Evaluation Model Adapted DEA Methodology

To adapt DEA methodology for the evaluation model of the building performance is prior to identify INPUTS and OUTPUTS. In this case as aforementioned, INPUTS are the employees and the indoor decoration costs, while OUTPUTS are the factors of IAQ (TVOC and CO2) listed as below Table 4. the list of Inputs and Outputs for DEA.

Table 4 The list of Inputs and Outputs for DEA

INPUTS	EXPLANATION
Number of Employees	The Employees of Each research units
The Decoration Costs	The Decoration Costs of Each research units
OUTPUTS	
The Factors of IAQ	CO_2 and TVOC as the factors。

4.2 Results and Discussion

4.2.1 Variables of DEA

The calculable variables between INPUTS and OUTPUTS for 14 are listed below:

Table 5 The list of calculable variables in 14 DMUs

DMUs	Number of Employees	The values of Decoration Costs	IAQ
A	12	527988	**20**
B	12	523345	**40**
C	16	509839	**20**
D	12	527988	**60**
E	15	527988	**40**
F	25	543489	**20**
G	16	563301	**20**
H	24	527988	**20**
I	13	498831	**80**
J	10	498831	**100**
K	15	527988	**60**
L	12	529842	**80**
M	11	493468	**100**
N	26	597331	**20**

4.2.2 Analysis of DEA results

There are three aspect analyses included Efficiency analysis, Benchmark analysis and Slack analysis.

Efficiency analysis:

From the comparison of 14 DMUs (Table 6. and Fig.7), J and M are the DMUs with better efficiency and performance scored as 100%. The others are K, D, B, E, C, H, A, F, G and N scored under 60%, and DMUs with inefficiency are C, H, A, F, G, and N.

Table 6 The comparisons of 14 DMUs

No.	DMU	Score	Rank
1	A	0.2	9
2	B	0.4	7
3	C	0.2	9
4	D	0.6	5
5	E	0.4	7
6	F	0.2	9
7	G	0.2	9
8	H	0.2	9

9	I	0.8	3
10	J	1	1
11	K	0.6	5
12	L	0.8	3
13	M	1	1
14	N	0.2	9
No.	DMU	Score	Rank

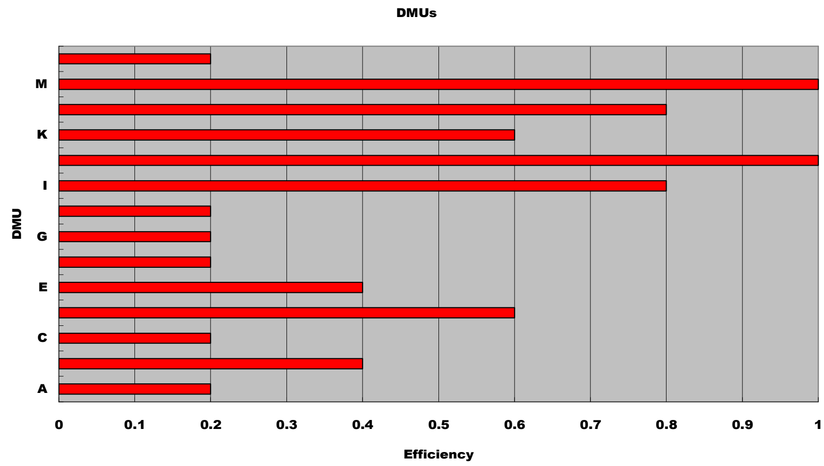


Figure 8 The comparisons of 14 DMUs

Benchmark analysis:

The purpose of Benchmark analysis is to examine DMUs with relative efficiencies that had been referred by the numbers of comparisons among other DMUs with inefficiencies. It is to be a foundation for inefficiencies DMUs to be improved in the future. Table.5 represents M and J is efficient DMUs, M however, had been referred 13 times of comparison by the others. Therefore, M is the Benchmark unit contributing the better value for the references of future improvement than unit J.

Table 7 The numbers of comparison between unit M and J

Unit name	Comparison 1	Other spaces referred
M	13	A, B, C, D, E, F, G, H, I, K, L, M, and N
J	1	J

Slack analysis:

Slack analysis is to provide the solutions and recommendations of improving DMUs with inefficiencies by understanding the differences between Inputs and Outputs variables. Unfortunately, this case study is limited by the data collections at the period of choosing Inputs and Outputs that can be firmly conducted in the future researches to complete the contributions of DEA applications for evaluating existing building performance in Taiwan.

Table 8 Slack analysis

No.	DMU	Score	Excess Cost S-(1)	Excess Employs S-(2)	Shortage IAQ S+(1)
1	A	0.2	29157	2	0
2	B	0.4	24514	2	0
3	C	0.2	11008	6	0
4	D	0.6	29157	2	0
5	E	0.4	29157	5	0

6	F	0.2	44658	15	0
7	G	0.2	64470	6	0
8	H	0.2	29157	14	0
9	I	0.8	0	3	0
10	J	1	0	0	0
11	K	0.6	29157	5	0
12	L	0.8	31011	2	0
13	M	1	0	0	0
14	N	0.2	98500	16	0
No.	DMU	Score	Excess Cost S-(1)	Excess Employes S-(2)	Shortage IAQ S+(1)

By DEA analyze, the DMUs with better efficiency are J and M, DMU A, C, F, G, H and N are relatively inefficiency. Therefore, DMU A can consider to dismiss two employees and to reduce 29,157 NT dollars of decorating cost for the improvement of the building efficiency.

5. Conclusion and Recommendations

The results of this study have paved an alternative for the evaluation model of "Life Cycle Cost" in building lifecycle for existing buildings in Taiwan to apply for the methodology of DEA as a new assessment tool. In the future, conducting the further researches on the diagnosis of existing buildings is needed to find (1) the impact factors for the quantitative evaluations of the Environmental Load as well as the analysis of building duration, (2) the Life Cycle Costing with DEA model for the evaluations of the existing building improvement in different phases, (3) that can be converted other factors of Indoor Environmental Quality into the phases of "Design", "Construction", "Use" and "Renovation" demonstrated a variety of building Performances, in order to effectively complete the cost evaluation of building overall features.

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THE EFFECTS OF MULTI-LAYER POROUS SCREENS ON WIND CONTROL STRATEGY FOR DWELLING OPENINGS IN TAIWAN

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Keywords: multi-layer porous screen, ventilation, openings of dwelling, wind drop effect

Summary

It shows strongly relationship for living comfort among the surrounding topography, location patterns and the interface of the building when thinking about the natural ventilation of buildings. Taiwan, as Formosa, located on tropical of cancer with high temperature and humidity situation, and also caused mosquito disasters all over the year. Porous screen is one of the most effective applications for building openings to prevent the insects into the house. However, the ventilation efficiency will be cutting down for installing with these screens. (B.J. Taylor, 1999) This study focuses on the wind control strategy utilizing multi-layer porous screens in concerning of natural ventilation effects and to figure out the better strategy of porous screens. Both small scaled wind-tunnel experiments and computational fluid dynamics (CFD) method were taken to verify the characteristics of multi-layer porous screens. The layer was selected as popular used PVC screen with alumina frame and its opening ratio is 64.0% with 256 nets per square inches. The inlet velocities were set on 0.13m/s, 0.27m/.s, 0.57m/s, 1.0m/s, 1.36m/s, 2.0m/s, 3.0m/s and 10.0m/s types, and the layers were from one to nine. The results show that decline ratio with different layers gets a flat curve when installing with one to three layers, and more than 4 layers will have rapid down effects. More than 8 layers, the effect will be almost the same with 9 layers. Moreover, interlace of screens and wind inlet angle will be the most important control strategies when building ventilation design. The results can be effective reference to natural ventilation building with wide-open-openings installed with porous screens.

1. Introduction

Most buildings in Taiwan utilized porous screens on openings between indoor and outdoor environment to prevent harmful factors getting into rooms, such as insects and particles. There are also benefits in controlling the physical factors in subtropical region, which can reduce the inlet wind velocity, maintain thermal environment, cut down sunshine exposure, among other functions. However, it appears that the porous screen also worsen the indoor environment in most structures located in urban area operating natural ventilation. The characteristics of the porous material with the wind through were seen as some researches, (Hagen and Skidmore, 1971), (Perea,.1981), (P.J.Richards,1999) (Antonio, 2000) The results and conclusions show the wind flow through one-layer porous screen has the effect to cut down the wind velocity and it depends on the ratio of the net. The situation can be concluded as *Bernoulli's Equation*, and the following research made by Antonio show the Reynold Number will take the important role in viscosity effect.

However, the green building issues has rised to let the building research institute in Taiwan to review the construction and the envelop of the building to see the proper way for the region as Taiwan, with the typical climate. Thus, considering the building typology in south-east region or the traditional house located near the equator, such as the Indonesia or Malaysia, alomost all faces will be the ventilation inlet or outlet, and it really shows good thermal condition in hot and humid weather. At the same time, the building envelop in cold and temperate zone shows highly thermal capacity or the isolation to keep the heat in house, and the ventilation system will be installed to maintain the air-exchange. Taiwan, located in-between these two typical zone as hot-humid in summer and cold-humid in winter. Is there any suitable and effective solutions to face this kind of climate and create a better thermal condition for living? Therefore, the multi-layer porous screen concept will be proposed to verify the capability and performance when installed in typical dwelling.

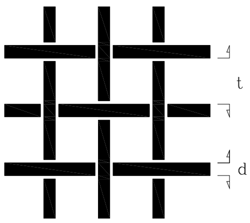
This study therefore aimed to identify the effects of the multi-layer porous screen interfaces when the wind get in and how 's the characteristics for different number of the screens. The wind inlet volume can be the data to calculate the volume of the fresh air and estimate the indoor air and thermal conditions. I was hoped that such an conclusion could be applied to establish a new thoughts of building envelop.

2. Materials and methods

2.1 Selection of the porous screens

The climate in Taiwan usually is hot and humid, and the average relative humidity level is always more than 80% outside. Thus the selection of the porous screen used in Taiwan is the PVC net. This material has the advantages of flexible, cheap, easily to change and keep good looking. Therefore, this study tries to focus on the PVC material with multi-layer screens to test the characteristics of the wind cut-sown influence. The variables control as same material with same porous ratio in the same opening size, and each of the net has the same 2cm distance to combine together for testing. The characteristics of the screen are listed as follows:

Table1. The characteristics of the selected PVC porous screen

Selection of the PVC porous screen	The detail of the PVC porous screen	Definition of the characteristic	The detail specifications of the selected screen
		$\varepsilon = \frac{Ah}{At} = \left(1 - \frac{Tn}{Dn}\right)^2 = \left(1 - \frac{0.32}{1.6}\right)^2 = 0.64$	Porous ratio: 64.00% Width of the mesh: 1.6mm Height of the mesh: 1.6mm Width of the wire: 0.32mm Thickness of the wire: 0.32mm Per mesh area: 1.6384 mm^2 Numbers of the mesh per square inch: 16*16 = 256
The PVC wire is produced as round section and same diameter as	t=width of the mesh d=thickness of the PVC net	ε : porous ratio Ah : area per mesh At : area of the wires Dn : height of the wire Tn : diameter of the wire	

2.2 Small-wind-tunnel chamber experiment with full-scaled porous screen

In order to verify the wind effect of the multi-layer porous screens, and to measure the quantity data in a stable situation, small wind-tunnel chamber was taken with the full-scaled screens for several numbers of layers to measure the differences of the velocity in several before and after positions. The chamber was constructed by acrylic plates with 7 sampling points. The distance for each was set as 10 cm. In order to realize the velocity difference and profile, seven vertical sampling points in center of the width were measured. The steady tests were conducted to check for the stability of the system. After the validation of the system, five inlet velocities, 1.36m/s, 1.00m/s, 0.57m/s, 0.27m/s and 0.13m/s, were set for experiments. The layers of the porous screens were set from 1 to 9 layers, and there was 1 cm distance for each of the layer. The wind velocity was measured by TSI model 8346 hot-wire air-velocity meter. Figure 1 shows the structure of the chamber, and figure 2 shows the variables of the experiments.

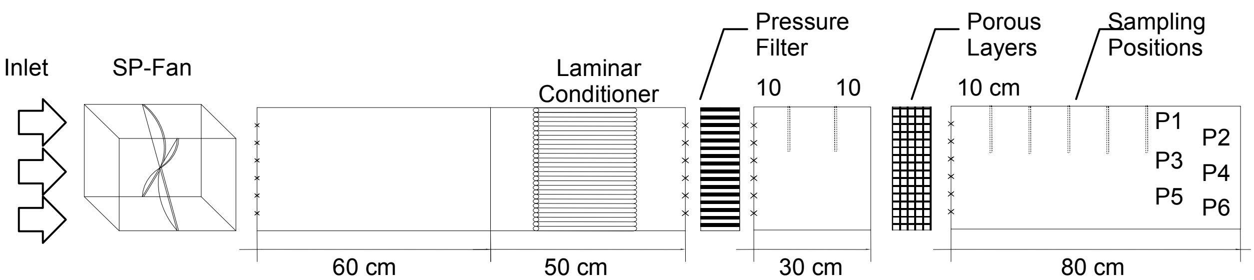


Figure 1 the small-wind tunnel chamber experiment with full-scaled porous screen

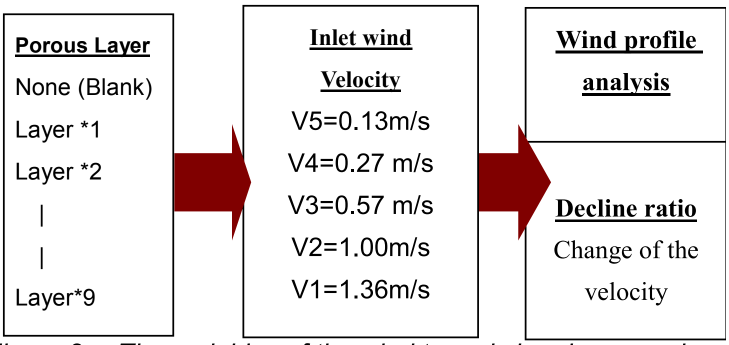


Figure 2 The variables of the wind tunnel chamber experiment

2.3 Computational Fluid Dynamics Simulation (CFD)

The numerical simulations of the current physical problem were performed using a finite volume method to solve the governing equations associated with the boundary conditions. Specifically, this study applied the SIMPLEST (semi-implicit method for pressure linked equations) algorithm to solve the pressure-linked equations using a hybrid scheme in order to calculate the convection and diffusion terms. The turbulence of the airflow was described by a standard k-ε model, in which k denotes the turbulent kinetic energy and ε the dissipation rate. Furthermore, the inlet airflow velocity was assumed to be normal and uniform across the section, no-slip boundary conditions were applied on the walls, and Neumann boundary conditions were applied for the velocity boundary conditions on the inlet side. No energy equation was applied. Iterative calculations were performed until residual values of 10^{-3} were obtained for all of the field variables. The calculating grids were set through optimized process with NX * NY * NZ ＝151 *138 *151. The inlet velocities were set as the experiment as 1.36m/s, 1.00m/s, 0.57m/s, 0.27m/s and 0.13m/s. The porosity of the porous screen was set for 0.64 and the boundary condition of the wire is set as no-slip on the surface. Figure 3 shows the CFD model of different layers.

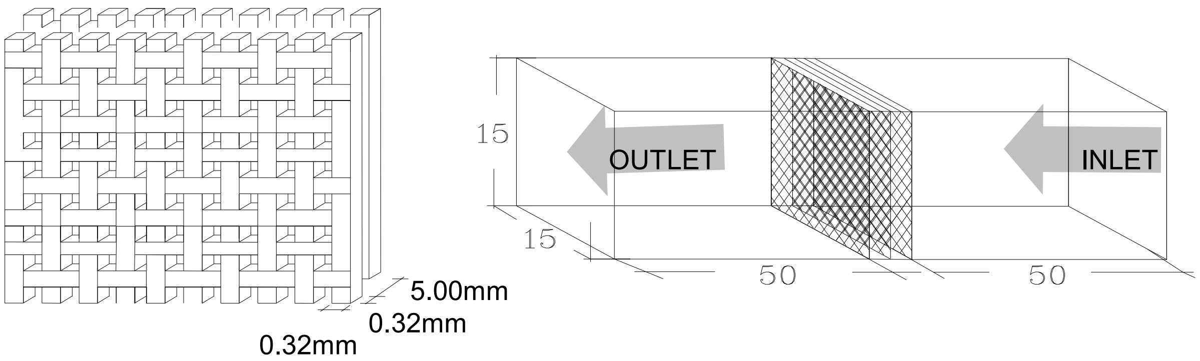


Figure 3 The CFD model for multi-layer porous screens

3. Results

3.1 Chamber test results

The experiment results are shown as figure 4 to figure 9. The characteristics of the wind effect through porous screen can be conducted as following results:

1. When the velocity is large than 0.8m/s, the more number of the layer used, the higher ratio of the wind declined effect, especially when the number of layers are large than three.
2. The wind velocity showed the semi-jet effect happened after the wind going through the porous screen. Especially just right the hole of the wires. However, the energy soon transferred and let the velocity became average.
3. When the velocity is less than 0.2m/s, and the difference of effects which caused by the layers are all weak.

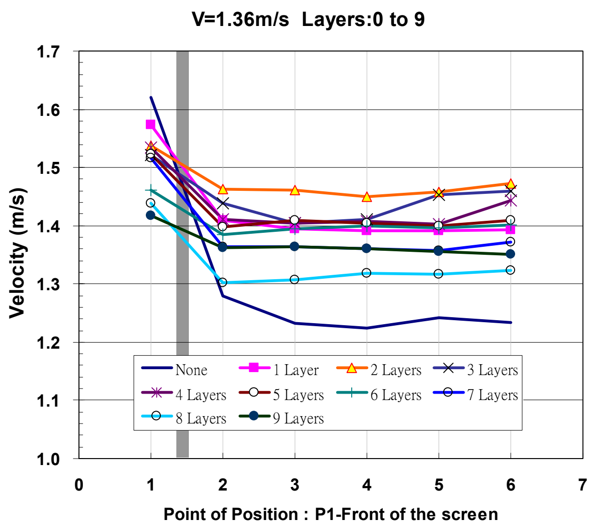


Figure 4 V=1.36m/s experiment results

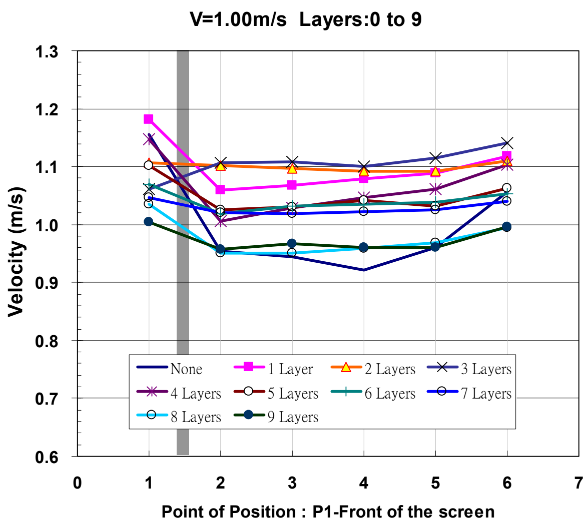


Figure 5 V=1.00m/s experiment results

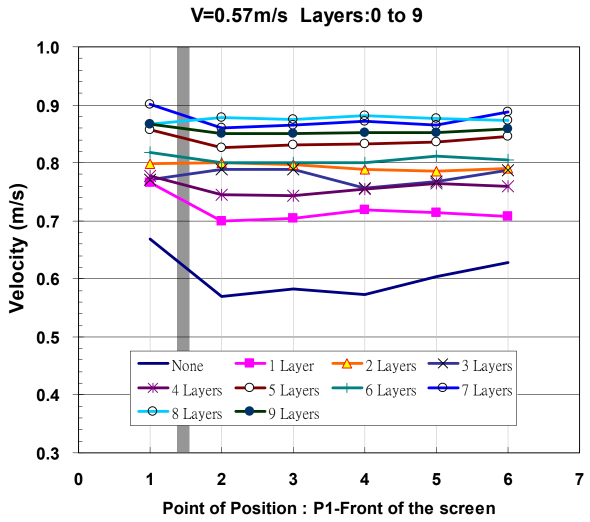


Figure 6 V=0.57m/s experiment results

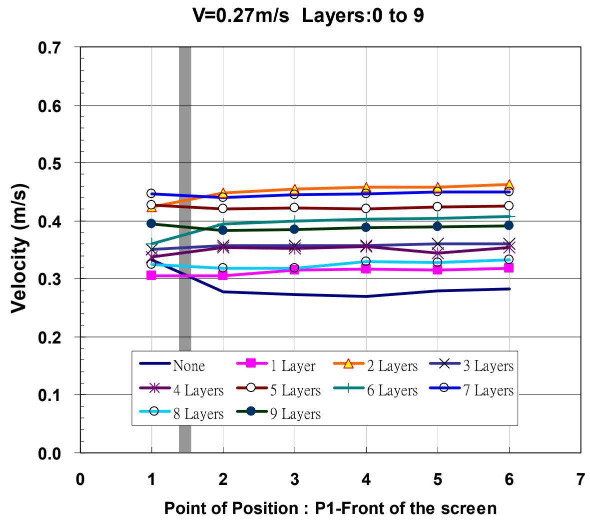


Figure 7 V=0.27m/s experiment results

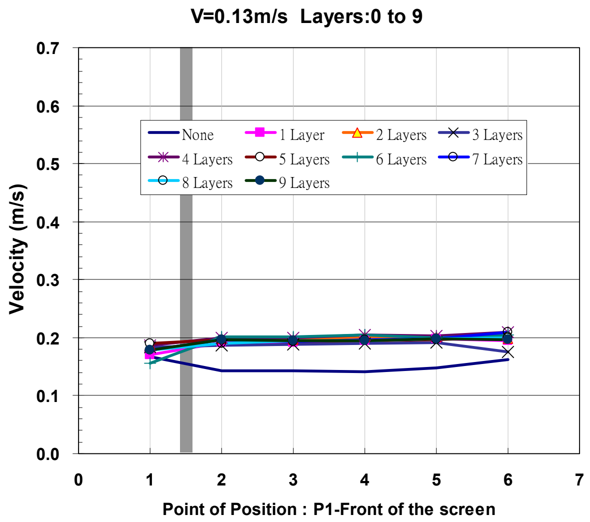


Figure 8 V=0.13m/s experiment results

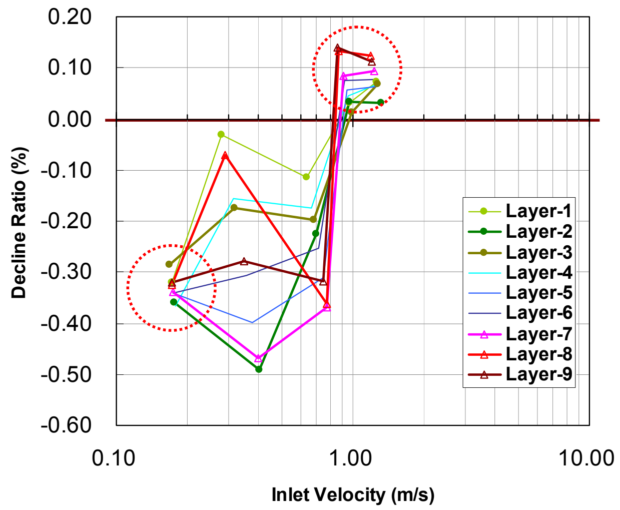


Figure 9 experiment results analysis

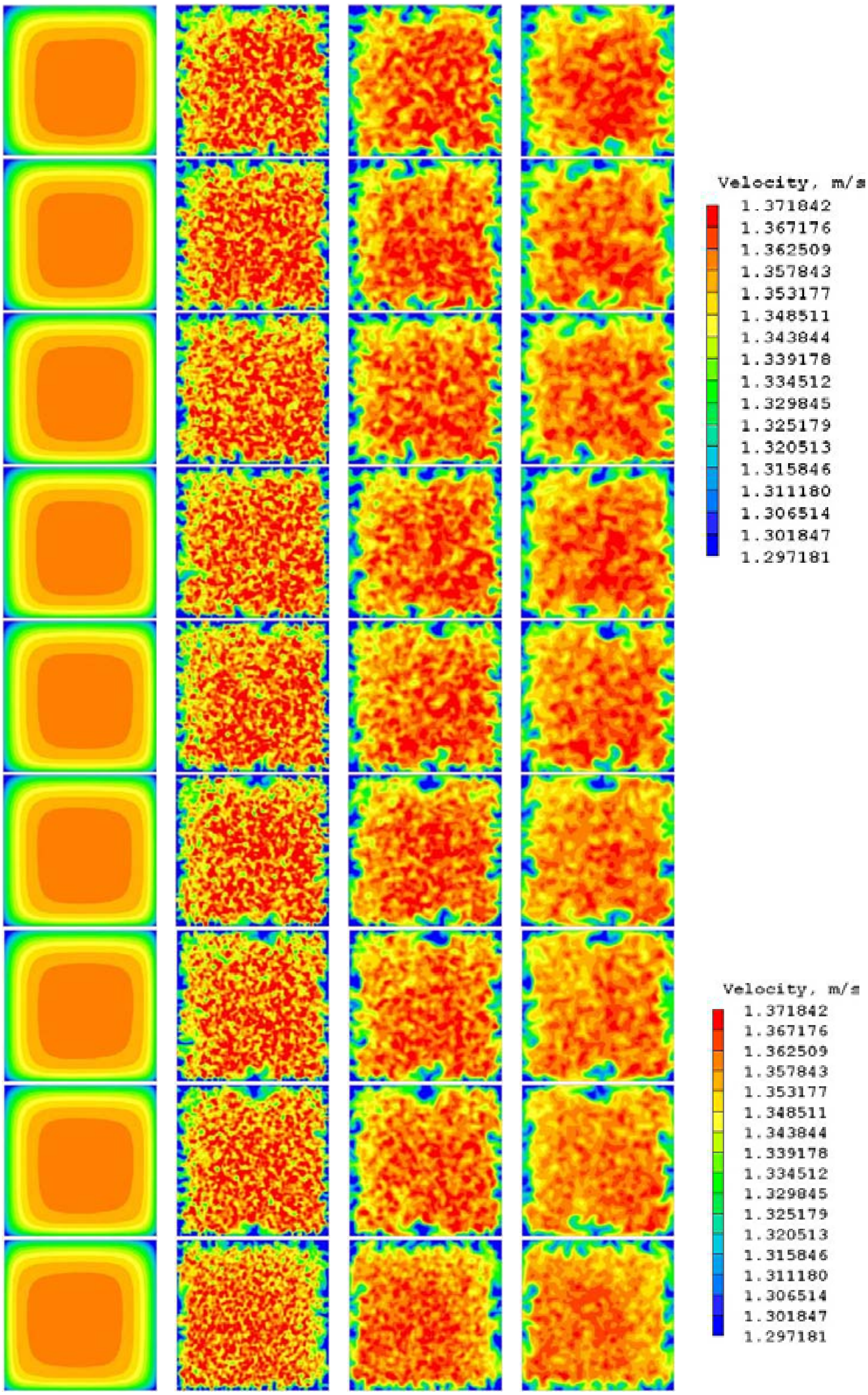
Figure 9 shows the relationship between decline ratio and inlet velocity. According to the results, the characteristics shows the decline effect happened, and the screens let the wind go through when the velocity is less than 0.8m/s. Furthermore, when the inlet velocity is higher than 1.0m/s, it shows the increasing velocity just after the porous screen. The chamber design for forced the same volume of the wind went through the chamber could be the reason to explain. The transformation of the energy and pressure could cause the effect.

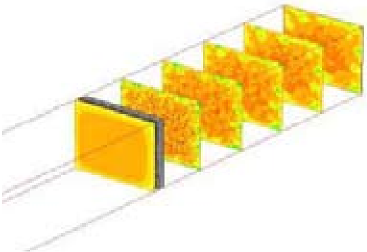
3.2 CFD solutions

In order to realize more about the wind situation, the CFD method was taken to check and visualize the possible situation. The results show that the wind distribution pattern in front of the screen has higher resistance effect in 8 to 9 layers than 1 to 2 layers. Moreover, the wind distribution after the screen shows the spotted focus area of the enforced wind acceleration, and the wind velocity mixed more and more well by the distance away from the screen. There are three results were conducted to explain the situation.

1. When the inlet wind velocity is lower than 0.5m/s, the decline ratio is getting almost the same with the lower velocity.
2. When the inlet wind velocity is larger than 2.0m/s, the decline effect is getting larger as the growth of both the velocity and the layers. Moreover, it shows a critical change at the screens with 4 layers.

Table2. the Y-section CFD results in one of the inlet velocity group V=1.36m/s

Cases	Front of screen	10 cm away after screen	20 cm away after screen	30 cm away after screen
Layer-01 V=1.36m/s				
Layer-02 V=1.36m/s				
Layer-03 V=1.36m/s				
Layer-04 V=1.36m/s				
Layer-05 V=1.36m/s				
Layer-06 V=1.36m/s				
Layer-07 V=1.36m/s				
Layer-08 V=1.36m/s				
Layer-09 V=1.36m/s				



Part of the model and Y-section

4. Discussions and Conclusions

The results show that decline ratio with different layers gets a flat curve when installing with one to three layers, and more than 4 layers will have rapid down effects. More than 8 layers, the effect will be almost the same with 9 layers. Through the CFD simulation, the characteristics of the wind through the porous screens may be conducted as the following figure 10. There apparently is the critical change of the flow pattern for low wind speed and high wind speed. The energy transfer and consuming caused by the wire friction can be the answer. Therefore, the slight wind can let the wind passed with full development of the wind profile, and the strong wind could be developed as a mountain shape. However, if the multi-layer porous screen interface has been adopted with interlace setting, the strong wind could be interrupted for the development of the wind profile, and it caused more energy consumption. It can be conducted with utilizing the PVC screens with regular 66% porosity as multi-layer interface, and the distance for each screen is set as 5mm, there will be the three flow types: 1. Friction effect: the wind velocity less than 0.5m/s. 2. Pressure resistance effect: the wind velocity is higher than 1.00m/s. and the 3.Mixed situation: the friction resistance almost equals to pressure resistance effect at the range of 0.57m/s to 1.00 m/s.

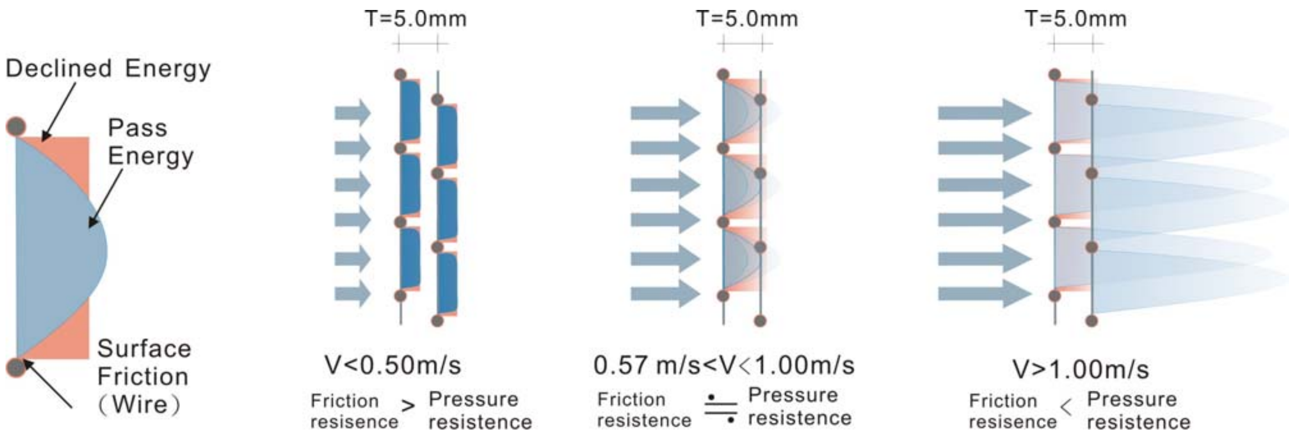


Figure 10 experiment results analysis

Moreover, interlace of screens and wind inlet angle will be the most important control strategies when building ventilation design. The results can be effective reference to natural ventilation building with wide-open-openings installed with porous screens. The conclusions can be a good impact to rethink the interface of the outdoor wall with the necessity of screen using in Taiwan. The “slight wind come and strong wind cut” with large and effective openings will be the best usage for the housing design in sub-tropical region.

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EVALUATION OF ENERGY SAVING MEASURES IN LONG-TERM SCENARIO IN JAPANESE RESIDENTIAL SECTOR

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Keywords: Residential energy consumption, Household type distribution, Energy-saving measures

Summary

Energy consumption in the residential sector of Japan was modeled on a nation-wide scale. In this study, we estimated the energy consumption and CO_2 emissions from 2005 to 2025, considering the change in various parameters with time. In addition, we evaluated the effect of implementing energy conservation measures in this period, such as improving the thermal insulation in buildings, introducing high-efficiency water heaters and distributed generation systems, and changing the preset temperature. If all the energy-saving measures are implemented by 2025, the energy consumption and CO_2 emissions will be reduced by 41.1% and 50.5%, respectively, as compared to the 2005 levels. Consequently, it was proved that only a combination of measures that are already feasible will have a drastic effect in 2025.

1. Introduction

In Japan, the energy consumption in the residential sector has increased steadily in response to the increase in the standard of living, which has resulted in larger houses, widespread use of various types of appliances, and increase in the number of small families. In the last 25 years, energy consumption in this sector has doubled, while the population has increased by only 10% (The Energy Conservation Center, 2002).

Consequently, the “Guideline for Measures to Prevent Global Warming,” adopted by the Japanese government in March 2002, aims to maintain CO_2 emissions related to energy usage at the 1990 levels. In April 2005, the “Kyoto Protocol Target Achievement Plan” was also adopted. By improving the energy efficiency of household appliances and improving buildings’ thermal insulation, the objective of the plan was to reduce CO_2 emissions from the residential sector to a level that is only 6% higher than that in 1990. A revision of the “Law Concerning Rational Use of Energy” established one of the highest energy efficiency standards in the world for appliances. The standard, commonly referred to as the “top runner standard,” required that the average energy efficiency of an appliance manufactured in 2004 had to be higher than that of the most efficient model manufactured in 1999. This standard was revised in 2005 to extend its application to a greater variety of appliances. In addition to the top runner standard, the Guideline for Measures to Prevent Global Warming prescribed a variety of energy conservation measures, including increasing energy efficiency of residential buildings, reducing standby power consumption, and promoting the use of high-efficiency water heaters. The program also encouraged changing the consumer behavior, such as changing the preset temperature, encouraging family members to spend more time together in the living room, and reducing the time watching TV (Global Warming Prevention Headquarters, 2002).

Thus far, we have evaluated the potential of various energy-saving measures. However, these evaluations are not realistic because all the measures have been implemented at once. We have to consider the update rate of houses or home appliances stock to evaluate the measures practically.

In this study, we evaluate the effect of introducing 7 energy-saving measures—improving energy efficiency of household appliances, improving thermal insulation in buildings, introducing high-efficiency water heaters and distributed generation systems, changing preset temperature, and all family members watching TV together—for a long period from 2005 to 2025, considering the rate at which each measure is implemented.

2. Simulation Model

2.1 Structure of End-use Simulation Model

The authors developed an original bottom-up model to simulate the city-scale energy consumption in the residential sector considering various types of households and buildings. In the simulation, the annual energy consumption of one household is calculated iteratively for 19 household categories and 12 building categories, six of which were classified as detached houses and the other six as apartments depending on the floor area. In addition, four different thermal insulation levels in buildings were considered. In the model for appliance energy consumption, the energy consumption of each appliance was simulated separately, which depended on the consumer behavior. For heating and cooling of rooms, dynamic heat load simulations were carried out using both building data and weather data. The ventilation and heat conduction between rooms were determined using a thermal circuit network. Heat loads were simulated relative to the internal heat gain, which was calculated using the appliance energy consumption model and the behavior of the family members. The time step of the heat load and energy consumption simulations was 5 min.

The total residential energy consumption in the target region was estimated by multiplying the simulated energy consumption by the number of households in each category and summing up the results. Further, it was confirmed that the results of our model was in a good agreement with actual data (Shimoda Y, 2007).

2.2 Structure of Stock Simulation Model

The authors have previously developed a "stock model" (Shimoda Y, 2007), which has been used in this study to estimate the average energy efficiency of appliances and the distribution of buildings' thermal insulation levels in the target region. This model enables us to generate input data, e.g., the average energy efficiency of appliances, for the target year. Figure 1 shows the change in the efficiency of appliances estimated by the stock model.

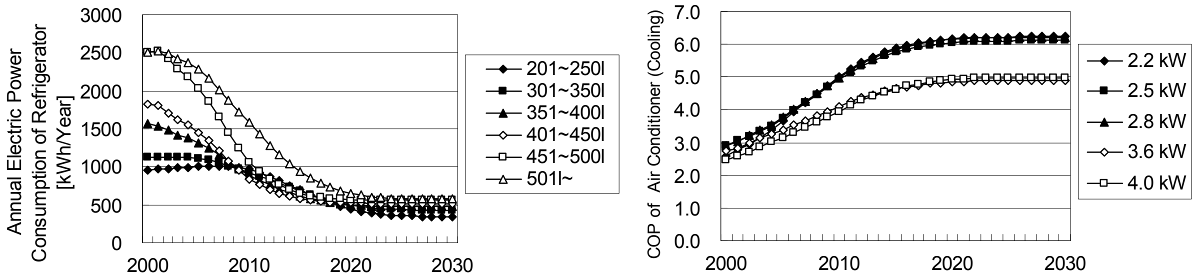

Figure 1 Change in efficiency of appliances (left: refrigerator, right: room air conditioner)

3. Simulation Results for 2005

3.1 Region-wise Classification and Major Cities

The climate of Japan varies significantly from north to south. In addition, the standards set by the Law Concerning Rational Use of Energy with regard to households vary for different regions. Therefore, when we calculated the energy consumption in the Japanese residential sector, we divided the entire country into small regions, calculated the energy consumption in each region and then summed up the results.

Table 1 lists the region-wise classification based on the Law Concerning Rational Use of Energy and the major cities, which are the most populous cities in the region. We used the weather data from the major cities and the others from the prefectures included in the regions.

Table 1 Region-wise classification and major cities

	Prefectures in the Region	Major Cities
I - 1	Eastern Hokkaido	Asahikawa
I - 2	Western Hokkaido	Sapporo
II	Iwate, Aomori, Akita	Morioka
III - 1	Miyagi, Fukusima, Yamagata	Sendai
III - 2	Ibaragi, Tochigi, Gunma, Yamanashi	Utsunomiya
III - 3	Niigata	Niigata
III - 4	Toyama, Isikawa, Fukui, Shiga	Otsu
III - 5	Nagano	Nagano
IV - 1	Saitama	Urawa
IV - 2	Chiba, Tokyo, Kanagawa, Shizuoka	Tokyo
IV - 3	Gifu, Aichi, Mie	Nagoya
IV - 4	Kyoto, Nara	Kyoto
IV - 5	Osaka, Hyogo, Wakayama	Osaka
IV - 6	Tottori, Shimane, Okayama, Hiroshima, Kagawa, Ehime, Tokushima, Kochi	Hiroshima
IV - 7	Yamaguchi, Fukuoka, Saga, Nagasaki, Kumamoto, Oita	Fukuoka
V	Miyazaki, Kagoshima	Kagoshima
VI	Okinawa	Naha

3.2 Parameters Examined for Each Region

The parameters that have been examined for each region are as follows:

- Thermal resistance of insulation
- Duration of heating and cooling
- Proportion of different energy sources used for heating rooms and water
- Heating schedule at nigh in Hokkaido
- Number of households in each category
- Weather data
- Relative proportion of room air conditioners and electric heaters
- Frequency of bathing
- Equation for estimating city water temperature

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- Number of appliances

3.2.1Thermal Resistance of Insulation

Heating and cooling loads were simulated for four levels of thermal insulation: no insulation, insulation up to the 1980 standard, insulation up to the 1992 standard, and insulation up to the 1999 standard. The values of thermal resistance of insulation for the exterior walls of the buildings in each region are listed in Table 2. We assumed that there were no houses with no insulation in Hokkaido and made original standard; below 1980.

Table 2 Thermal resistance of exterior wall insulation

	Thermal Resistance [$m^2 \cdot K/W$] (Apartment)						Thermal Resistance [$m^2 \cdot K/W$] (Detached House)					
	Region I	Region II	Region III	Region IV	Region V	RegionVI	Region I	Region II	Region III	Region IV	Region V	RegionVI
Below 1980	0.56	-	-	-	-	-	1.10	-	-	-	-	-
1980 Standard	1.13	0.75	0.75	0.50	0.00	-	2.20	0.90	0.90	0.60	0.00	-
1992 Standard	1.72	0.95	0.95	0.77	0.52	0.00	2.49	0.95	0.95	0.86	0.52	0.00
1999 Standard	2.30	1.80	1.10	1.10	1.10	0.30	3.30	2.20	2.20	2.20	2.20	2.20

The energy consumption in heating and cooling for each category of household and buildings was obtained from the weighted average of the simulation results for each thermal insulation level relative to the proportion of each thermal insulation level estimated using our stock model (Figure 2). Since there was no regulation regarding buildings' thermal insulation in Japan, the proportion of houses that conformed to the 1992 and 1999 standards was very less.

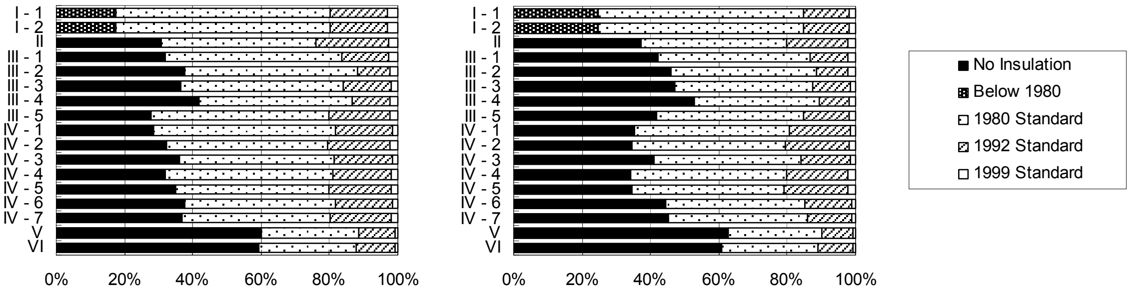

Figure 2 Proportion of different thermal insulation levels (left: apartments, right: detached houses)

3.2.2 Duration of Heating and Cooling

The duration of heating and cooling was defined as for SMASH; the Japanese residential thermal load calculation model.

3.2.3 Proportion of Energy Sources Used for Heating and Hot Water

The proportion of energy sources used for heating and hot water (electricity, city gas, and kerosene) was obtained from the Annual Report on Residential Energy (Tables 3 and 4).

Table 3 Energy sources used for heating

	Electricity	City Gas	Kerosene
Hokkaido	6.3%	33.6%	60.1%
Tohoku	8.2%	47.0%	44.9%
Kanto	4.4%	83.0%	12.6%
Hokuriku	15.8%	60.7%	23.5%
Tokai	12.7%	72.8%	14.5%
Kinki	7.8%	81.6%	10.5%
Chugoku	18.8%	54.2%	27.0%
Shikoku	19.9%	53.3%	26.8%
Kyusyu	14.4%	61.2%	24.4%

Table 4 Energy source used for heating water

	Apartment			Detached House		
	Electricity	City Gas	Kerosene	Electricity	City Gas	Kerosene
Hokkaido	4.6%	1.6%	93.8%	4.0%	1.6%	94.4%
Tohoku	9.7%	3.6%	86.7%	8.6%	3.6%	87.8%
Kanto	36.4%	23.7%	39.9%	37.2%	23.4%	39.4%
Hokuriku	30.9%	18.7%	50.5%	35.7%	17.4%	46.9%
Tokai	18.6%	20.0%	61.4%	13.6%	21.2%	65.2%
Kinki	47.7%	18.8%	33.5%	49.5%	18.1%	32.4%
Chugoku	36.3%	10.6%	53.2%	38.0%	10.3%	51.7%
Shikoku	38.1%	8.8%	53.1%	39.8%	8.6%	51.6%
Kyusyu	32.8%	10.1%	57.1%	33.2%	10.0%	56.7%

3.2.4 Heating Schedule at Night in Hokkaido

In this model, heating/cooling at night was estimated using a timer-controlled operation. In Hokkaido, it was assumed that heating continued throughout the night.

3.3 Annual Energy Consumption in Residential Sector

Figure 3 shows the simulation results for energy consumption per household and per person. Interestingly, the energy consumption per household for heating and cooling vary significantly for different regions, while the energy consumption for other purposes was considerably low. Further, the energy consumption for heating was high in I-1, II, III-3, III-4, and III-5, while the energy consumption was considerably low in I-2 and III-2, despite the regions being located in a cold area. The reason for this apparent anomaly is I-2 and III-2 have a high proportion of apartments.

The difference in energy consumption per household has been found to be higher than that per person. This is because it is the average number of people per household that affects the energy consumption.

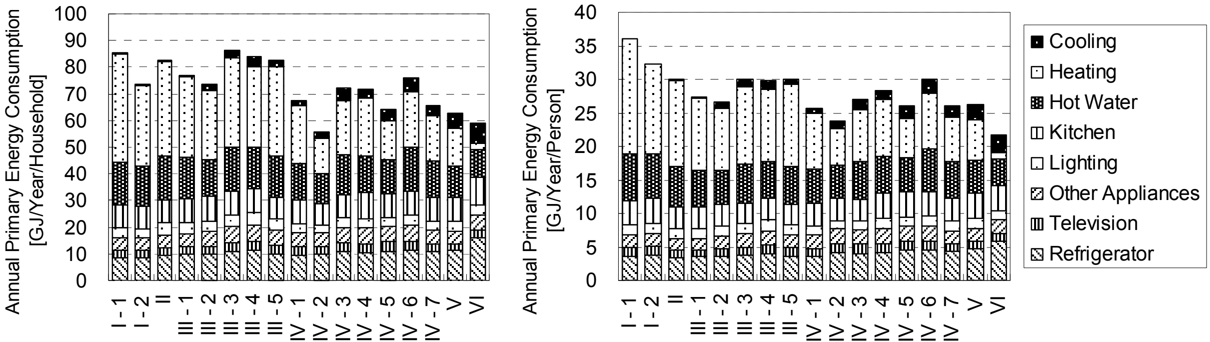

Figure 3 Simulated annual primary energy consumption (left: per household, right: per person)

4. Simulation Results for the Period 2005-2025

4.1 Parameters Examined for Each Year

The parameters that have been examined for each year are as follows:

- Number of households in each category
- Proportion of different thermal insulation levels of house stock
- Number of appliances
- Efficiency of appliances
- Proportion of energy sources used for heating rooms
- Electric power generation efficiency and CO_2 emission rate during electricity generation

4.1.1 Number of Households in Each Category

The numbers of households in each category for the period 2005–2025 were estimated on the basis of the estimation results obtained from the "National Institute of Population and Social Security Research." Initially, we estimated the number of households in each category in a prefecture and summed up the results to obtain the number of households in each category for the 17 regions. Figure 4 shows the change in the number of households in each category in Japan.

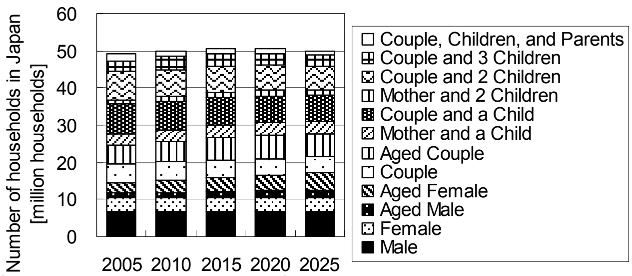

Figure 4 Change in the number of households in each category in Japan

4.1.2 Proportion of Different Thermal Insulation Levels of House Stock

The proportion of different thermal insulation levels of house stock for the period 2005–2025 was estimated by accumulating data of new houses considering house type, thermal insulation level, lifetime function, and the year in which they were built. Figure 5 shows the proportion of different thermal insulation levels, for example, in Tokyo.

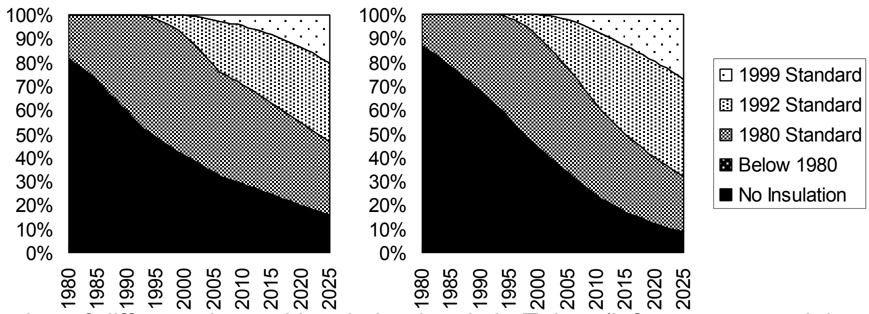

Figure 5 Proportion of different thermal insulation levels in Tokyo (left: apartment, right: detached house)

4.1.3 Number of Appliances

Figure 6 shows the change in the numbers of some appliances for the period 2005–2025, which were estimated by classifying the appliances into 3 groups: (1) Constant appliances which spread enough, (2) gently increasing appliances which spread in part, and (3) increasing appliances which not spread.

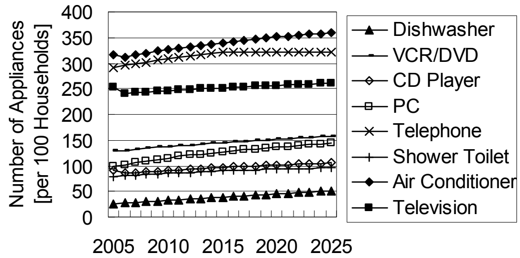

Figure 6 Change in the number of appliances for the period 2005–2025

4.1.4 Efficiency of Appliances

The efficiency of TVs, PCs, refrigerators, VCR/DVDs, and air conditioners for the years 2005 and 2025 was estimated. The efficiency of other appliances did not change. The efficiency was estimated by accumulating data of new appliances considering type, efficiency, lifetime function, and the year of manufacturing (Table 5).

Table 5 Efficiency of appliances

	Power Consumption [W]					
	TV		VCR/DVD		PC	
	Operating	Standby	Operating	Standby	Operating	Standby
2005	114	1.6	23	3.7	58	2.0
2025	198	0.5	26	4.2	52	1.2

	Annual Electric Power Consumption of Refrigerator [kWh/Year]					
	201~250l	301~350l	351~400l	401~450l	451~500l	501l~
2005	1002	1116	1320	1446	2031	2291
2025	356	437	475	515	556	582

	COP of Air Conditioner									
	Cooling					Heating				
	2.2 KW	2.5 KW	2.8 KW	3.6 KW	4.0 KW	2.2 KW	2.5 KW	2.8 KW	3.6 KW	4.0 KW
2005	3.65	3.73	3.78	3.40	3.16	3.96	4.10	4.08	3.93	3.47
2025	6.22	6.10	6.21	4.89	4.99	6.71	6.53	6.52	5.70	5.58

4.1.5 Proportion of Energy Sources Used for Heating

We converted the energy consumption of each source in statistics into demand, and the proportion of demand was set as the proportion of energy source for heating. The proportion of energy sources for the future was estimated from the past trend. Figure 7 shows the change in the proportion of energy sources in Hokkaido and Tokyo.

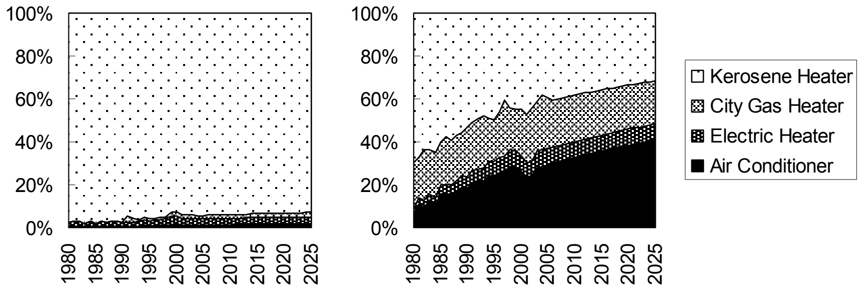

Figure 7 Change in the proportion of energy sources used for heating (left side: Hokkaido, right side: Tokyo)

4.1.6 Electric Power Generation Efficiency and CO_2 Emission Rate during Electricity Generation

We set the electric power generation efficiency and CO_2 emission rate for the future on basis of the target values for 2015 by different electric power generation companies (Figure 8).

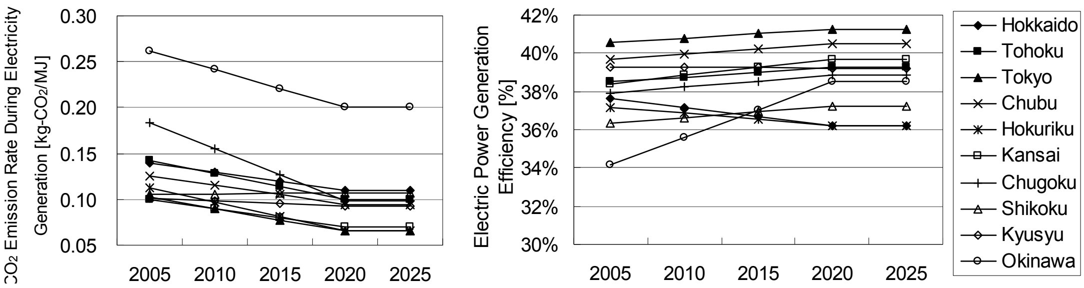

Figure 8 Electric power generation efficiency and CO_2 emission rate during electricity generation

4.2 Annual Energy Consumption in Japanese Residential Sector

Figure 9 shows the simulation results for the energy consumption in Japan. In Japan, the energy consumption in the residential sector changed from 3311 to 2649 [PJ/Year], and the proportion of change was –20.0%. This change was influenced by the population, number of households in each category, efficiency of electric power generation, etc. Figure 10 shows the various factors influencing the change in energy consumption from 2005 to 2025.

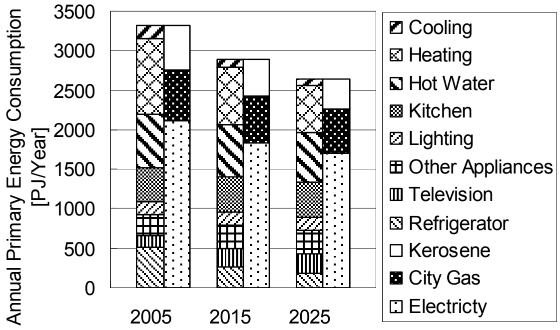

Figure 9 Annual primary energy consumption

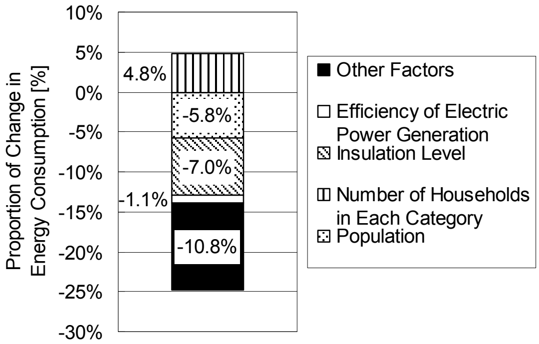

Figure 10 Proportion of change in energy consumption

5. Evaluation of Long-term Effects of Energy-saving Measures

The effects of the energy-saving measures have been evaluated for the period from 2005 to 2025, considering the update rate of houses or household appliances stock. The measures are as follows:

- Step 1: Setting an energy efficiency standard for household appliances
- Step 2: Improvement in buildings' thermal insulation
- Step 3: Introduction of high-efficiency water heaters and distributed generation systems
- Step 4: Introduction of HEMS (Home Energy Management System)
- Step 5: Change in the type of house—from a detached house to an apartment
- Step 6: Change in preset temperature
- Step 7: All family members watching TV together

These measures are implemented in the order mentioned above. From steps 1 to 5, the measures can be implemented without affecting the quality of life, but the measures in steps 6 and 7 affect the quality of life.

5.1 Step 1: Setting an Energy Efficiency Standard for Household Appliances

In this step, we set an additional top runner standard and evaluated the effects. Table 6 shows the efficiency and power consumption of various appliances.

Table 6 Efficiency of appliances (step1)

Annual Electric Power Consumption of Refrigerator [kWh/Year]					
201~250l	301~350l	351~400l	401~450l	451~500l	501l~
320	370	394	422	432	462

Power Consumption [W]						COP of Air Conditioner									
TV		VCT/DVD		PC		Cooling					Heating				
Operating	Standby	Operating	Standby	Operating	Standby	2.2 KW	2.5 KW	2.8 KW	3.6 KW	4.0 KW	2.2 KW	2.5 KW	2.8 KW	3.6 KW	4.0 KW
145.5	0.10	32	2.0	51	1.2	6.47	6.25	6.36	5.26	5.19	6.76	6.51	6.60	5.68	5.65

5.2 Step 2: Improvement in Buildings' Thermal Insulation

In this step, all new houses built after 1999 conform to the 1999 standard. Figure 11 shows the proportion of different thermal insulation levels in Tokyo calculated by our stock model for this step.

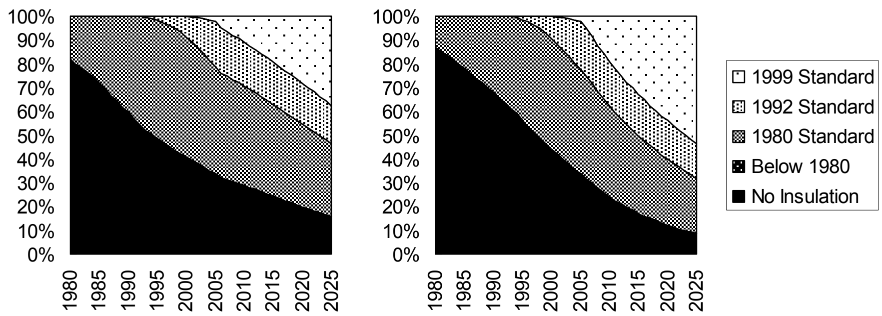

Figure 11 Proportion of different thermal insulation levels in Tokyo (left: apartment, right: detached house)

5.3 Step 3: Introduction of High-efficiency Water Heaters and Distributed Generation Systems

In this step, we evaluated the effect of the introduction of high-efficiency water heaters and distributed generation systems, such as a high-efficiency gas water heater (HEGWH) that can recover the latent waste heat, solar thermal water heater (STWH), heat pump water heater (HPWH), and micro gas engine cogeneration system (MGECGS). Initially, we calculated the energy consumption for each household when a system was introduced and determined suitable systems for each household for reducing CO_2 emissions. Then, assuming that the lifespan of water heaters were around 10 years and all water heaters have to be replaced in 2025, we calculated the energy consumption in the Japanese residential sector and evaluated the effect when the suitable systems were introduced in all households. Figure 12 shows the proportion of suitable systems in each region for the reduction in CO_2 emissions.

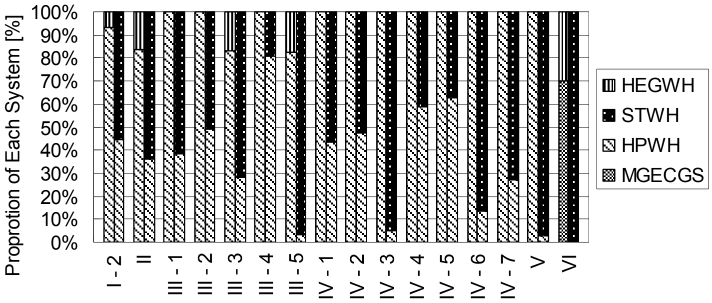

Figure 12 Proportion of systems in different regions (left bar: apartment, right bar: detached house)

5.4 Step 4: Introduction of HEMS

In this step, we evaluated the effect of the introduction of HEMS. By the introduction of HEMS, the standby energy consumption of some appliances was reduced, and thermal insulation mode of electric pots and rice cookers was set off as it was not required.

5.5 Step 5: Change in House Type—from Detached House to Apartment

In this step, we increased the proportion of apartments by using an estimation method (Figure 13).

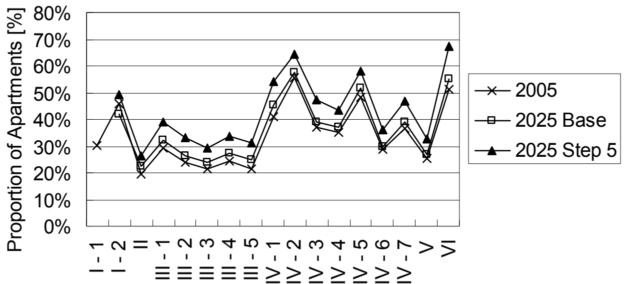

Figure 13 Proportion of apartments

5.6 Step 6: Change in Preset Temperature

The implementation of this measure affects the quality of life. In this step, the heating and cooling preset temperatures were changed as listed in Table 7.

Table 7 Preset temperature

	Heating [°C]		Cooling [°C]	
	Base Case	Step 6	Base Case	Step 6
No Insulation	18	18		
Below 1980	20	19		
1980 Standard	21	20	27	28
1992 Standard 1999 Standard	22	21		

5.7 Step 7: All Family Members Watching TV Together

In this step, the family members watch TV and relax together in the living room in order to reduce the energy consumption of TVs, lighting, and heating or cooling.

5.8 Results of Each Step

Figure 14 shows the results of each step. It reveals that we could bring out a gradual reduction in the energy consumption and CO_2 emissions. In the business as usual case (BAU), CO_2 emissions reduced by 27.2% as compared to the 2005 level because of the change in various parameters such as efficiency or diffusion of household appliance, thermal insulation levels in buildings, and population. In step 1, CO_2 emissions reduced by 29.4% as compared to the 2005 level because of the enhancement of the efficiency of appliances. In step 2, by improving buildings' thermal insulation, CO_2 emissions reduced by 30.4% as compared to the 2005 level. In step 3, CO_2 emissions reduced drastically by 43.0%; hence, the introduction of high-efficiency water heaters and distributed generation systems were highly effective in saving energy. In step 4, since the standby energy consumption of some appliances has reduced by the introduction of HEMS, CO_2 emissions reduced by 45.3% as compared to the 2005 level. In step 5, by increasing the proportion of apartments, CO_2 emissions reduced by 47.5% as compared to the 2005 level. In step 6, by changing the preset temperature of heating and cooling, the energy consumption due to air conditioning reduced and CO_2 emissions also reduced by 48.6% as compared to the 2005 level. In step 7, because the energy consumption of TVs, lighting, heating, and cooling reduced due to the family members spending more time in the same room, CO_2 emissions reduced by 50.5% as compared to the 2005 level.

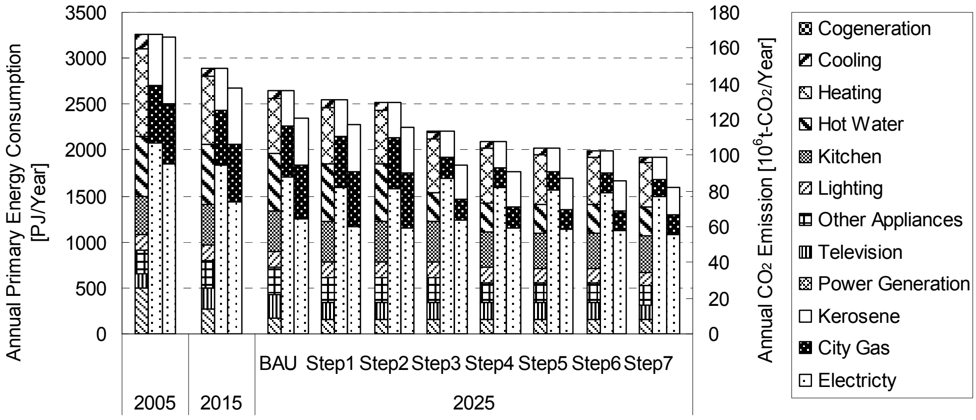

Figure 14 Annual primary energy consumption and CO_2 emissions in each step (left bar: energy consumption based on use, middle bar: energy consumption based on sources, right bar: CO_2 emissions)

6. Conclusion

In this study, the implementation of energy conservation measures in the Japanese residential sector was evaluated for a long period using a residential energy end-use model developed by us. We estimated the practical reduction in energy consumption associated with the implementation of 7 energy-saving measures—setting an energy efficiency standard for household appliances, improvement of thermal insulation in buildings, introduction of high-efficiency water heaters and distributed generation systems, introduction of HEMS, changing house type from a detached house to an apartment, changing preset temperature, all family members watching TV together—which were implemented in succession.

As a result, the annual primary energy consumption and CO_2 emissions reduced by 37.8% and 47.5%, respectively, as compared to the 2005 levels in step 5, in which all energy-saving measures were implemented without affecting the quality of life. Then, in step 7, in which all measures were implemented, the annual energy consumption and CO_2 emissions reduced by 41.1% and 50.5%, respectively, as compared to the 2005 levels.

Acknowledgment

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The Green HVAC Concept --- Analysis of a National Research Program on HVAC System Renovations

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Keywords: green HVAC, renovation, energy conservation, Oversize reduction,

Summary

Since 2003, a national research program has been launched to renovate the HVAC systems of governmental buildings. Up to the year of 2007, 97 projects have been completed, with Chiller plant over-design capacity reduced in 3,000 RT, and overall energy savings of 24%. The budget spent on actual engineering cost was around 20 million US Dollars, with an average payback of 5 years.

This paper highlights the essence and most important points during the retrofitting process, and is discussed in detail with demonstrative examples.

1. INTRODUCTION

Being located in subtropical area, the weather in Taiwan is constantly hot and humid, with ambient temperature around 35℃ and relative humidity of 85%, which imposes heavy cooling load on commercial buildings. In 2003, the Ministry of the Interior (MOI), Taiwan decided to conduct an HVAC renovation program for the existing HVAC systems of governmental buildings. This program not only constructs an important step in responding to the national movement toward the Green Building concept, but to the quest of Kyoto protocol on energy savings and CO2 emission reductions.

It is a common problem in Taiwan that HVAC systems were designed with rough hand calculation methods, instead of using detailed computer simulation process, so that chiller plants were very often, over-sized. An over-sized chiller, which runs under a very low partial load factor, will suffer from poor energy efficiency, and results in higher operation cost in addition to the excessive investment in installation. This kind of chiller plant not only needs to be downsized, but should also adapt a better-fitted chiller size combinations so that optimal operational strategies can be applied during various load conditions.

In addition, chilled water distribution system was normally designed with constant speed pumps, which runs on their maximum capacities all the time, no matter how cooling load was fluctuating. A Variable Water Volume, or VWV system, which can change the pumping speed by inverters should be adapted, so that pumping power can be saved during low load conditions.

Furthermore, some ice storage air-conditioning systems, which can shift the on-peak power demand to off-peak hours and thus saves tremendous amount of operating cost, had been removed from commercial operation due to lack of proper maintenances, presenting a huge loss of the investment. To restore these systems, it takes a lot of technical challenge and innovation, but the result could be very fruitful. In this paper, the restoration and revival of such an Ice storage system in the NMMR Aquarium has been selected as a demonstrative example to explain the whole procedure.

2. RENOVATION PROCEDURE

After this program was officially launched, applicants all around the country sent in their basic data of HVAC systems for evaluation. Following the selection criteria, in considering the chiller plant capacity and number of years of operation, significance of operation cost, a handful of candidates were selected for the first run of field survey. The chiller plant energy auditing would then be performed to construct the baseline data, in recording the cooling capacity provided using temperature sensors and ultra-sonic flow meters . The accumulated cooling capacity provided was then compared with the power consumption to yield the COP (Coefficient of Performance) of each chiller. The measured COP value creates a solid figure where it can be compared with the COP threshold value issued by the Bureau of Energy. Later on, a comparison between the COPs before and after renovation, energy savings effect can be realized quantitatively and accurately .

This selection process to estimate the energy savings potential, and thus priorities for renovation, is a typical bottom-up procedure. As the old Chinese saying depicts: "To catch the thieves, catch the Chief first."

Furthermore, the scope of the renovation work would then be determined by the research team, such as to replace the chiller , to convert it into an VWV or VAV system , or to renovate the cooling towers, etc, with engineering budget allocated accordingly. The total budget was finally allocated and fine-tuned in considering the balance among the northern, central, and southern parts of the country and then offered for open bids. This Green HVAC Drive also provided a lot of good business opportunities for the local HVAC industry and was highly welcome.

3. RESULTS AND OUTCOME OF THE PROGRAM

3.1 Chiller Plant Oversize Reduction

The chiller plant of each renovation project has been carefully simulated and re-calculated, using DOE 2.1, a computer program developed by the Department of Energy in the U.S., as a tool, to achieve a new chiller combination, so that each seasonal cooling demand can be met with energy-efficient operation modes.

For example, in the NPNU project, the administration center is a 10-story building. The chiller plant, originally equipped with 2 sets of 15-years-old 500 RT centrifugal chillers, was replaced with 3 chiller sets, including a 180 RT, 300RT, and 400RT capacity each. The new chiller plant total capacity is thus reduced by 12% accordingly. And the new chillers, with higher energy efficiency in complying with the COP criteria, saves tremendous energy and operation cost as shown in figure 1. In addition, the new chiller plant has a better combination in operating its multiple chillers as shown in figure 2. For example, in the winter, the 180 RT chiller alone, will operate, which accounts for 32% time of the year. Originally, this would have to be done by operating the 500 RT chiller, but in an exceedingly low load factor of 40%, resulting in low energy efficiency and mechanical problems. In intermediate seasons, such as in spring and fall, the 300 RT or the 400 RT chiller should be able to take care of the cooling load, accounts for 49% time of the year. While in hot summer, based on the historical operation data, the 480 RT chiller combination should be able to meet the peak cooling demand, counting for 19% of the total operating hours. Even in rare cases, in an extra-ordinary hot summer due to the global warming effect, the 180 + 400 , or 580 RT chiller combination will be able to meet the exceedingly hot summer demand, representing a safety factor of around 20%, unlike the original design, claiming for 100% redundancy all the time. In addition, the actual cooling capacity under operation modes now, is 580 RT vs. the original 1000 RT, or a 42% reduction! The chiller plant is now operating under its optimal conditions all year round ---thanks to the computer simulation in predicting the seasonal cooling load conditions beforehand, and the timely renovation process to cut down the chiller sizes and to reach a smarter combination.

The whole renovation program within 4 years results in an overall chiller oversize reduction of 3000 RT, or accounts for 21% of the total cooling plant capacity, with 24% energy efficiency improvement.

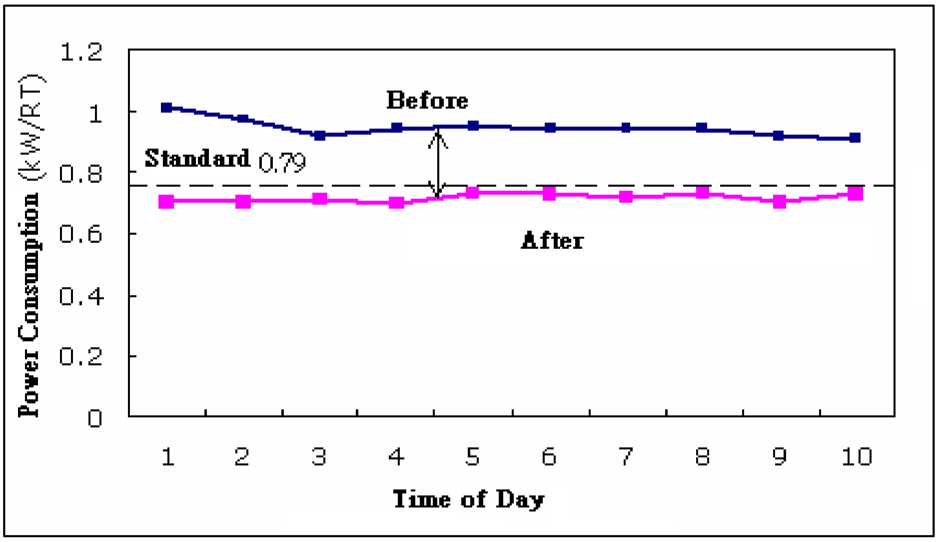

Figure 1 The Comparison of Chiller performances before and after renovation indicating an 23% energy savings effect

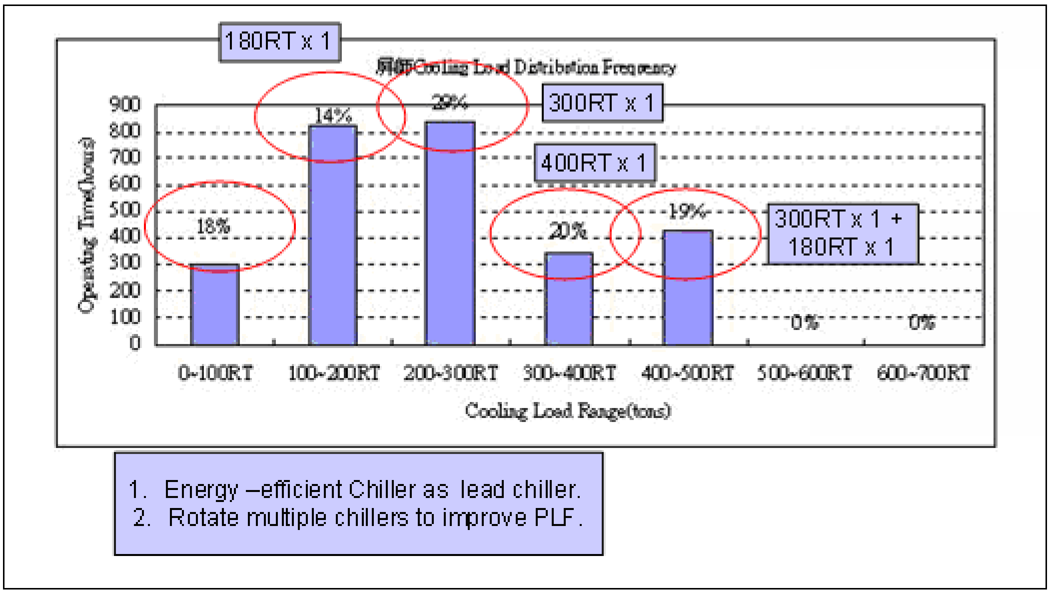

Figure 2 In NPNU Project, Intelligent Operational Modes of the renovated, smaller, Chiller Plant Enables an Optimal Combination in Operating Chillers and with Higher Energy Efficiency as Predicted by Computer Simulation

3.2 PARASITE POWER SAVINGS

Among the 97 projects, totaled 228 KW power demand was reduced by adapting the VWV system, while the VAV systems also reduced 19.7 KW power demand.

In most cases, the chilled water distribution system were designed with constant speed pumps. When cooling load is reducing, lower amount of chilled water is needed but the system is still pumping the same volume flow rate, and depending on closing valves to introduce the additional system resistances. This is similar to an automobile, always on full pedal, but hitting the brake at the same time to slow down. The inverter-driven pumps, on the other hand, runs in a lower frequency and speed in a lower load condition, thus saves significant pumping energy.

In addition to this obvious merit, the VWV system, by pumping the exact volume flow rate needed, enabled a better system hydronic balance. This is crucial in some projects where primary-secondary pumping system had been designed. For example, it is common practice for these systems to design a “common piping” to alleviate the overflow chilled water flow when cooling demand is reducing.Yet, this will create an undesirable mixing problem between the supply (7 ˚C) and returned (12 ˚C) chilled water . The “mixed” chilled water, with a relatively higher temperature such as 9 C, cannot meet the cooling load, and thus demanding even higher chilled water flow rate, creating a cyclic defect. The system then goes on hunting until a biased equilibrium situation is achieved, which is highly energy consuming.

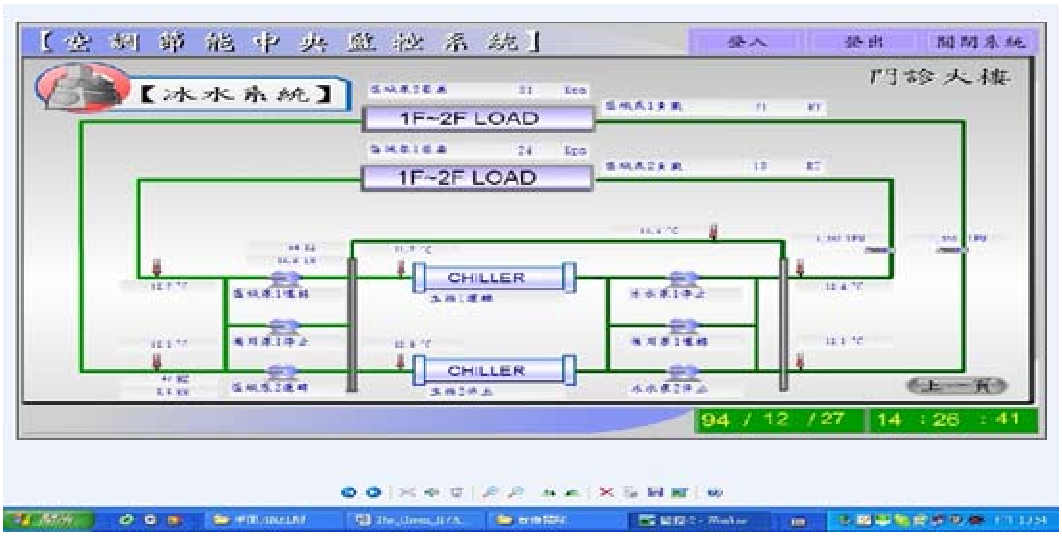

Figure 3 A typical mixing problem occurred when system flow is unbalanced causing cyclic performance defect

The VWV system, instead, lower the pump speed when the demand is low, and solves this problem totally and energy-efficiently and in a simple way. As the horse power of a pump is in cubic proportion to its speed, tremendous power is thus saved this way. Figure 4a and 4b indicated the commissioning process in tuning up the optimal pressure differential settings for the VWV system through the newly-established BEMS (Building Energy Management System) remotely from through the internet.

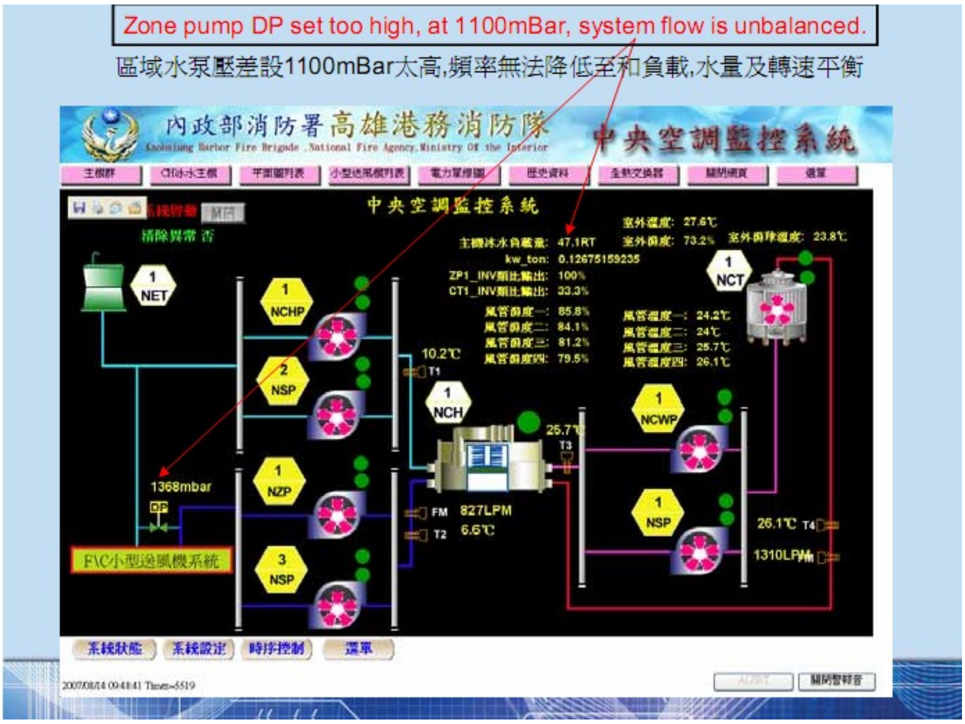

Figure 4a Before commissioning, the pressure differential across the zone pump was set too high, causing system hydraulic unbalances

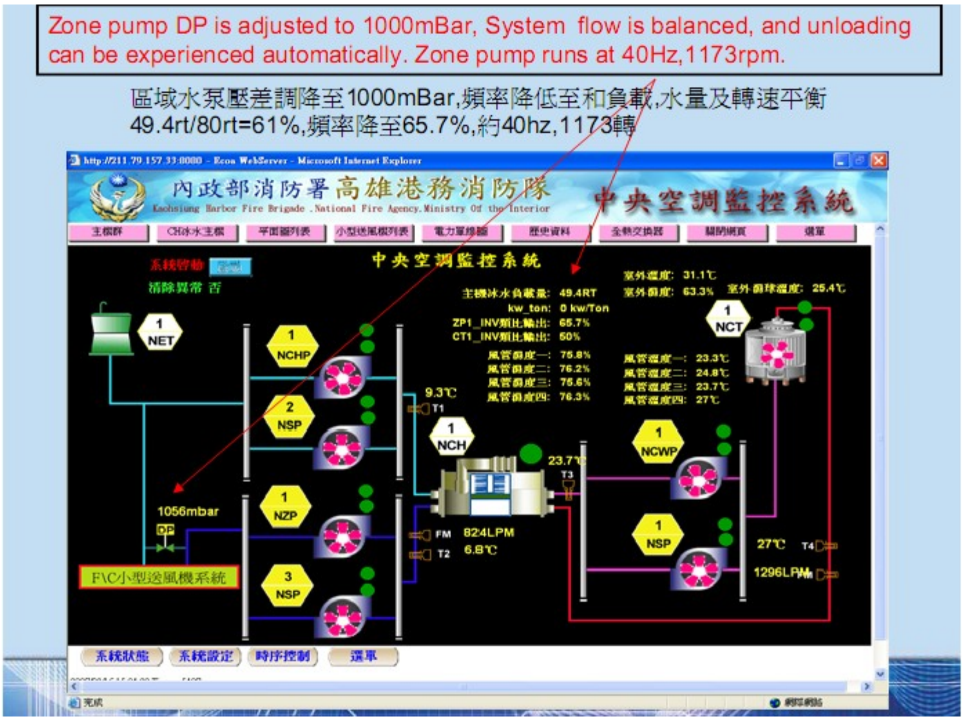

Figure 4b After renovation, pressure differential was reduced, system balance can be maintained. Zone pumps were running at 40 Hz, or 1173 rpm. Energy savings was realized.

It is similarly true for the airside VAV systems. In addition, the VAV system can be coupled with a CO_2 sensor to lower the outdoor air supply intelligently. The reason is that all airside equipment of an HVAC system, especially the AHUs (Air Handling Units), were normally sized and designed with peak occupancy assumptions, but which seldom occurred. An VAV system system adjusts its fan speed to coupe with the smaller cooling demand, and thus saves energy without sacrificing thermal comfort.

4. AN OUTSTANDING CASE STUDY --- THE NMMB AQUARIUM PROJECT

4.1 Original System Problems Description

The NMMB aquarium is the most popular marine science museum in this country for educational and recreational purposes. Located inside a national park, the aquarium is constructed along the beach by the Pacific Ocean where the ambient temperature is around 35□ with relative humidity at 85% in the summer. The huge crowd of sight-seers and hot weather introduce heavy cooling load and keep on increasing year by year.

To coup with this cooling demand, a partial ice-storage air-conditioning system had been designed, consisting of three centrifugal chillers with 500 RT capacity each, and an ice-making screw chiller of 400 RT. The ice chiller was designed to operate during the night, taking advantage of the low cost nighttime off-peak power, to produce ice at its evaporator and harvested during each defrost cycle. The tubular ice was then stored in the ice storage tank located at the basement, where it was melted for cooling during the day to shed the on peak power. The ice storage system only shares part of the cooling load with the centrifugal chillers which are running during the day with secondary zone pumps distributing chilled water to the load.

Unfortunately, this ice storage system was not fully functional since its first installation in 1998.The tubular ice, which was accumulated on the evaporator coil, had been experiencing the “ice-bridging” effect and thus causing the ice scraper severely damaged. The ice storage system was completely shut down in 2002 after several attempts to maintain it.

In this study, a challenging engineering approach has been proceeded to revive the system in 2003. An on-site system diagnostics was conducted first to evaluate the central HVAC system performances. Chillers COP and power consumption of the plant were recorded as baselines for comparison. Secondarily, the ice-storage system was renovated, but not totally replaced, which is the main theme of this project. At last, the completely renovated ice storage system had been commissioned and fine-tuned to achieve system optimization. The benefits of this renovation process has been assessed technically and economically to justify its potential for further engineering applications.

4.2 ESTABLISHING THE RENOVATION STRATEGY

Since this original “ice-on-coil” system was not functional at all, emphasis was put on completely modify it into another “ total-freeze-up” ice storage system. For this, it would be necessary to change the ice chiller into a brine chiller. Instead of a direct chiller replacement, which is too costly in this case, an innovative approach had been adapted to replace the original chiller evaporator, which runs on R22 refrigerant in producing chilled water, into a brine evaporator, which exchanges heat with brine consisting of 30% ethylene glycol. The rest of the chiller components remained intact which could save up to 80% of the total cost compared with a direct chiller replacement. Figure 5 shows a snap shot of the newly replaced evaporator with thermal insulation. As brine was used as the new heat exchange medium among the refrigerant, brine, and chilled water, the heat transfer process was further changed from “external-melting” into “internal- melting” , and a plate heat exchanger was added. Figure 6a and 6b indicated this process modification with a schematic diagram.

Figure 5 The renovated ice chiller with its evaporator replaced and turned into a brine chiller in the NMMB project

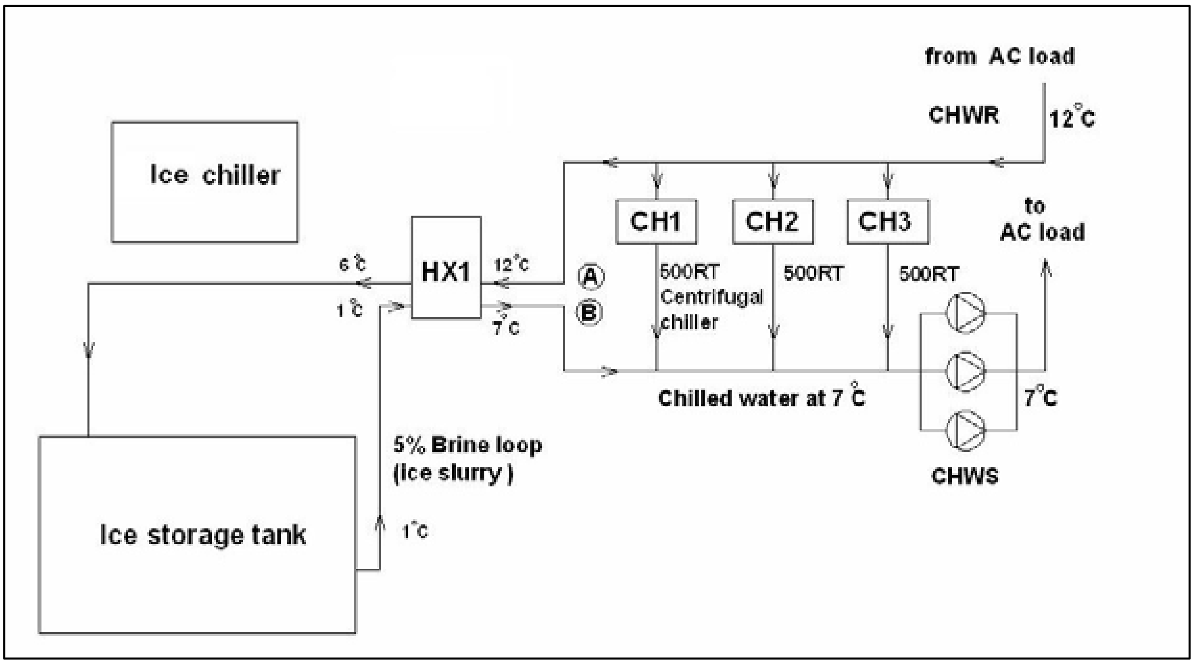

Figure 6a Original Ice Storage AC System under Ice-melting Mode

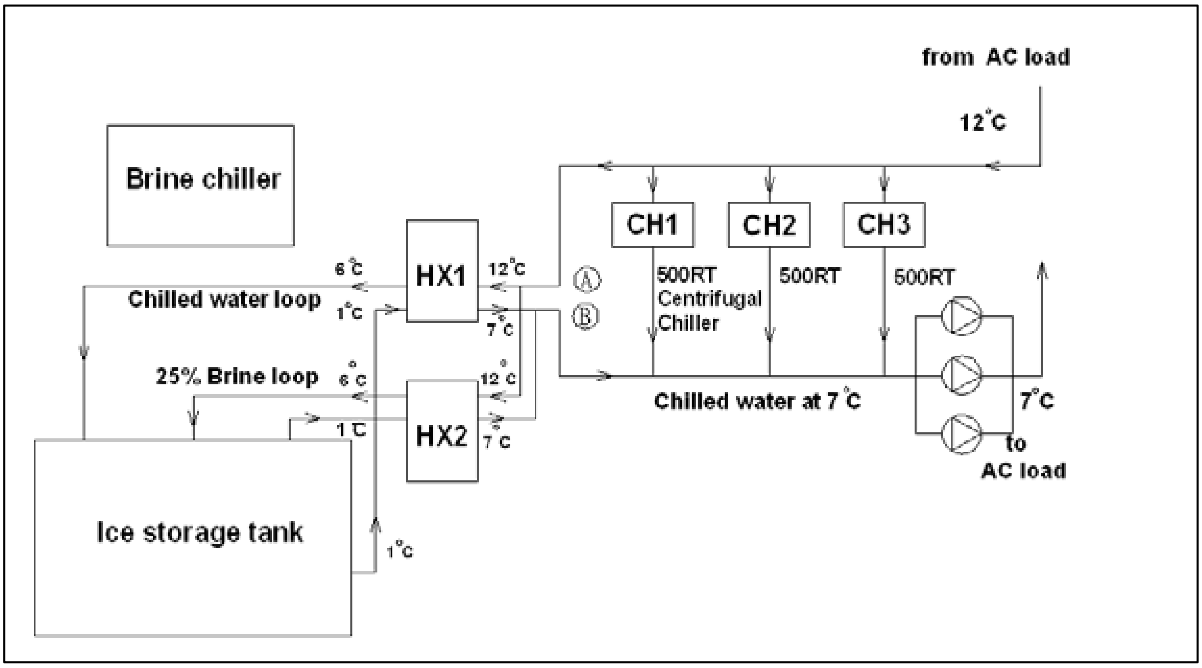

Figure 6b The Renovated Ice Storage System under Ice-melting Mode

4.3 SYSTEM PERFORMANCE VALIDATION UNDER OPTIMAL OPERATION STRATEGY

The revived ice storage system had been operated and audited for one year and compared with original system historical operation data as shown in figure 6 .

In the summer, the strategy is to operate two centrifugal chillers contributing 750 RT shown as curve (3) in figure 6, plus ice-melting providing 250 RT during the day as shown in curve (2). At night, one centrifugal chiller operates plus the ice chiller running under the ice storage mode. On the other hand, the original system operated totally on three centrifugal chillers contributing 1000 RT as shown in curve (1).In other words, curve (1) is now replaced by “curve (2) plus (3)” after renovation. That means, around 25% of the cooling load has been shifted to nighttime in the renovated system paying a much lower power tariff, with an additive 300 RT cooling capacity available ---a double benefit with a minimal renovation investment!.

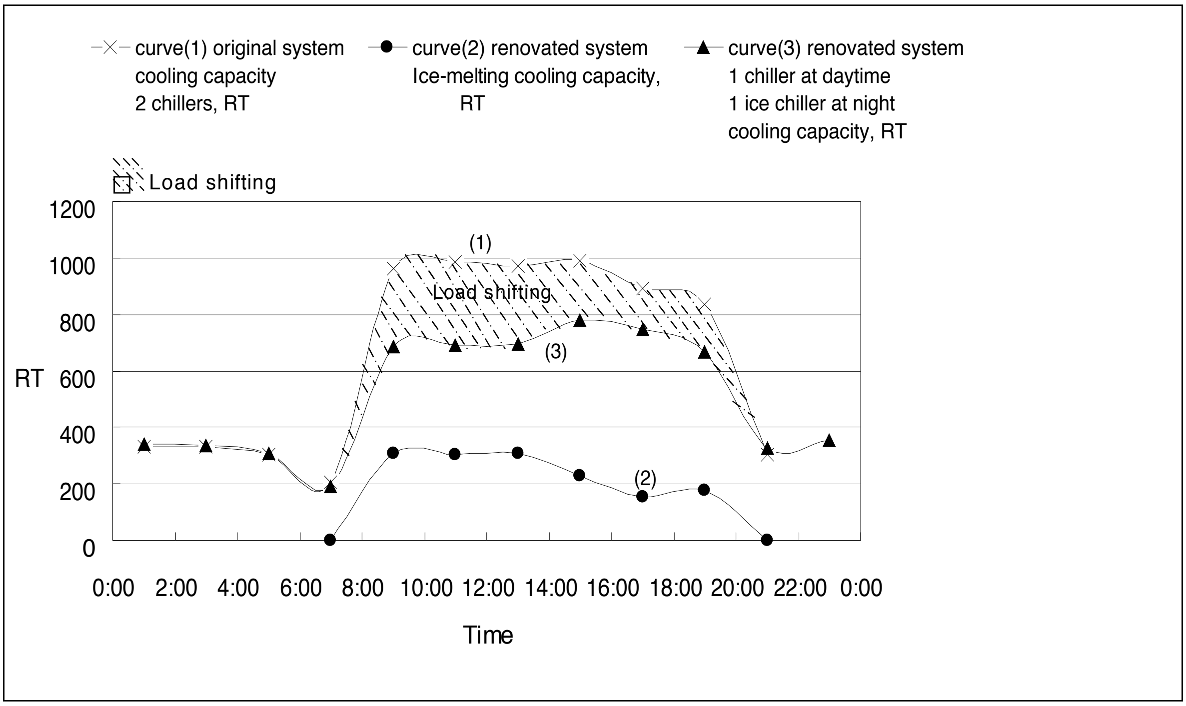

Figure.6 Cooling Output of the Original vs. Renovated System indicating a Significant Load Shifting Effect in a Hot Summer Day

4.4 ECONOMIC ASSESSMENT

The annual ice inventory was recorded in detail and converted into cooling energy stored and released per month. The total cooling capacity released during the year 2004 reached 850,000 RT . The renovated system has been operating smoothly, with ice storage subsystem working at around 80% of its full capacity all the time. There has been no system malfunctioning reported and no system shutdowns, except routine maintenance jobs needed twice a year.

To further assess the economic feasibility, a present worth method using cycle cost analysis has been implemented.

The contracting budget for this renovation project is around 350,000 USD, With the bank prime rate of 4%, in an 25 years life cycle, the calculated payback period is around 8.11 years.

In this NMMB renovation project, the ice storage system has been revived with good thermal performances. The year-long energy auditing revealed that the system provides an extra steady source to meet cooling demand effectively. In the summer, it had successfully shifted 25% of cooling load to off-peak hours. In spring and fall, the load shifting significantly increased to 50%. While in winter, the ice storage system takes the cooling load totally without the necessity to run a chiller. The system runs at around 80% of its full capacity, warrants a steady, reliable and energy-efficient operation.

5. CONCLUSIONS

The Overall renovation research program has obtained significant energy savings effect during these 5 years operation.

For example, the total renovation engineering budget for the year 2003 was 228,000,000 NT (6,846,000 USD), with annual operation cost savings of 46,273,465 NT (1,389,000 USD) realized, the payback is around 5.2 years. While for the year of 2004, the total engineering budget was 93,000,000 NT (2,792,000 USD), with annual operation cost savings of 14,777,338NT (443,753 USD) realized, the payback is around 6.3 years.

The success of this program encourages the MOI Taiwan to launch a Phase II program, and further focusing on fine tuning and commissioning. Successful result is expected after 4 more years.

6. Acknowledgement

The support and sponsoring of this program from the Architecture and Building Research Institute, Ministry of the Interior, Taiwan is highly appreciated.

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Thermomodernisation of public buildings conducted in accordance with the conditions of sustainable development STEP

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Keywords: Public buildings, energy performance, environmental impact, educational programs and course materials about sustainability

Summary

Thermomodernisation in Poland has already nine years of official record as in 1998 the Act of Thermomodernisation was accepted by the Parliament. During these years many buildings have undergone investments lowering their energy use. The modernizations were related to energy savings and theirs economic efficiency, but not much attention have been paid to sustainability issues, and only the housing sector was the main beneficent. This situation guided to suggestion of the area of research that may help to fill the gap in existing scope of thermomodernisation, also taking into account the mandate provided by the Energy Performance on Buildings Directive 91/2002/EC. Thus, the proposal of STEP research project was accepted in December 2006 by European Economic Area Financial Mechanism aiming at implementation of a better energy performance of public buildings in Poland. General objective of the STEP project is scientific and research support aiming at implementation of a better energy performance fulfilling at the same time the sustainability requirements of public buildings in Poland . The detailed aim is to supply materials and tools helping to undertake decision as to the most efficient choice of technical solutions in new and already existing buildings.

1 Introduction

Over 80 per cent of the EU's oil requirements are imported, and similar levels of natural gas are imported, with over 51 per cent of total energy requirements in Europe coming from abroad. Higher dependence of Poland and other European Union countries on external supply of energy resources shows that actions dedicated to a more effective energy use are very important from the point of view of energy safety as well as due to the fulfillment of Kyoto Protocol.

General objective of the STEP project is scientific and research support aiming at implementation of a better energy performance fulfilling at the same time the sustainability requirements of public buildings in Poland. The detailed aim – is to supply materials and tools helping to undertake decision as to the most efficient choice of technical solutions in new and already existing buildings, which at a later stage will form a database for the change from contemporary construction solutions to those optimised in accordance with the chosen criteria. Public buildings are usually used by local governments and administration to perform the statutory duties such as: education, health and cultural facilities etc. Energy standard of those buildings is low and refitting or modernisations works are very limited. At the same time, these buildings act as a determinant for local construction practices and should be constructed in reference with standards displaying possible use of energy and environment efficient technologies. The energy technologies for residential buildings, being in a scope of thermomodernisation for nine years, are relatively well known, but the sustainability issues were not, so far, taken into considerations. In a case of non-residential even energy use is not deeply investigated. The only requirements related to these buildings are prescriptive and refer to energy losses.

Table 1. The coverage of scope of STEP project vs. buildings types.

Issue	*Residential buildings*	*Non-residential buildings*
Energy effects of thermomodernisation	Method exists	**STEP**
Sustainability related to thermomodernisation	STEP (partly)	**STEP**

The needs settled up by the Directive 91/2002/EC on the Energy Performance of Buildings, impose new demands in front of the owners and facility managers to upgrade the buildings in such a way that they will fulfill new energy performance requirements. Analysis of the Thermomodernisation Program, which has been executed in Poland for the past 9 years, shows that traditional thermomodernisation techniques might be insufficient for the more demanding recent standards and for new issues that nowadays are taken into concern and should respond to the sustainability paradigm.

Additionally, contemporary modernisation should accept as the priority aims - the quality of the indoor environment quality as well as influence of the building on existing natural environment. This increases the need to widen the scope of research to such issues as: artificial lighting and day lighting, emissions indoors and outdoors, productivity of users, management of water and resources, facility management of the building and surrounding site, waste management as well as new architectural solutions. The STEP project plan is executed in the co-operation with Norwegian Technical University of Trondheim (NTNU), with special care taken on such tasks as: day lighting, hybrid ventilation system and Norwegian experiences concerning assessment of impact of buildings in line with conditions of the sustainable development.

The whole project is divided into 12 work packages:

WP0 Management, administration and coordination

WP1 Analysis of the state of art, existing scope of knowledge on the modelling of thermophysical processes and phenomena in public buildings

- WP1.1 Heating
- WP1.2 Ventilation
- WP1.3 Air-conditioning
- WP1.4 Hot Water Preparation
- WP1.5 Day- and artificial lighting
- WP1.6 Choice of external media
- WP1.7 Utilisation of renewable energies and passive solutions in public buildings
- WP1.8 Aquis Communautaire within the scope of new energy requirements in buildings

WP2 Environment – impact of public building

- WP2.1 Consumption of resources
- WP2.2 Quality of indoor environment
- WP2.3 External environmental loads
- WP2.4 Environmental impact assessment of public building

WP3 Education programme and methodology concerning sustainable development in construction

WP4 Building modernisation guidelines. Case study – Building of Faculty of Environmental Engineering, Warsaw University of Technology, Poland

WP5 Analysis of software required for the modelling of the processes discussed in WP 1, update of the software to Polish conditions, preparation of verification and attestation methods. Preparation of calculation algorithms

WP6 An experimental verification of the calculation methods in real conditions. Energy performance of an office building

WP7 Catalogues of the best technological and architectural solutions in public buildings

- WP7.1 Catalogue of the best architectural solutions in public buildings
- WP7.2 Catalogue of the best technological solutions in public buildings

WP8 Preparation of the education materials to be used In faculties and post diploma courses conducted at the Warsaw University of Technology and other didactic centres

WP9 Preparation of a website course concerning the tools supporting the decisions required for the final choice of low energy solutions

WP10 Monitoring of the investment Project within the scope of public building thermomodernisation, financed by the EOG and Norwegian Mechanism

WP11 Promotion and dissemination of the Project’s outcomes.

2 Energy - the most important element of sustainability

The work package 1 consists of 6 parallel sub-tasks and two vertical – integrating the results of first 6. The scope of the tasks is in line with the objectives of the Directive 91/2002/EC that lays down requirements in regards to:

- the general framework for a methodology of calculation of the integrated energy performance of buildings;
- the application of minimum requirements on the energy performance of new buildings;
- the application of minimum requirements on the energy performance of large existing buildings that are subject to major renovation;
- energy certification of buildings; and
- regular inspection of boilers and of air-conditioning systems in buildings and in addition an assessment of the heating installation in which the boilers are more than 15 years old.

The annex to the Directive defines obligatory elements of energy balance to be taken into account in calculation procedure. To support the implementation of Directive, European Commission ordered set of new CEN standards. These standards, all together 32 new items (as reported April 2007 by CEN), are now already accepted or under the Formal Voting stage. However, due to the passed implementation date – 4th of January 2006 - most of the Member States decided to develop own methods of calculation declaring at the same time the use at the maximum possible extend of CEN standards once they will be accepted and adopted. Even standards as such, should be easily adaptable, as they represent the engineering knowledge of the state of the art, they often require so-called national data or other country specific parameters. Such data have to be provided as a result of research. Thus, the WP1 is dedicated to research to support implementation of the Directive in Poland with particular emphasis on public buildings. WP1 provided an answer about the scope of the energy analysis of public buildings, the calculation method, data requirement, performance indicator, and at the integration stage - methodology of setting the requirements and potential use of renewable energy for every purpose of use in the building. Thus the WP1 is divided into 6 sub-tasks related to technical systems in buildings: heating, ventilation, air-conditioning, hot water preparation, day- and artificial lighting, choice of external energy media, and 2 horizontal tasks - one related to use of renewable energy in all building installations mentioned above, the second about harmonisation with CEN in undertaken legal solutions. The example of this activity's results is presented in the work of Panek and Sowa published in Proceedings of CLIMA 2007. The results of WP1 formed a significant support to new (published in April 2008) official project of regulation about the scope and form of energy certificate that implemented mentioned Directive in Poland. The 5R1C simplified hourly calculation method taken from FDIS ISO CEN 13790 has been adopted for calculation. This adaptation is introducing new dimension in analysis of energy demand in Poland as at first time the adequate data is provided in order to perform hourly analysis. So far, by regulations, only monthly balance method has been used. The STEP project helped in preparing climate data, profile of use of buildings data, and the prototype of calculation procedure that can be used by public.

3 Sustainability of public buildings

During the last 19 years considerable research has been focused on the development of systems to assess the environmental performance of buildings, based on different initial assumptions and prepared for different purposes. The best-known existing system is the Building Research Establishment Environmental Assessment Method (BREEAM), developed by BRE and private sector researchers in the U.K. This system provides performance labels suitable for marketing purposes, and has captured increasing interest of the new office building market in the U.K. Many national systems have been developed by different countries world wide as HQE in France, Eco-profile in Norway, Ecoeffect in Sweden, LEED in US, CASBEE in Japan. There is no country in Europe, which does not attempted to develop adaptation of existing or entirely new system. Several other systems (largely inspired by BREEAM and Green Building Challenge initiative) are in various stages of development in Europe and the World. There are also more specialized systems of interest that are more closely tied to Life Cycle Assessment (LCA), including ECO QUANTUM (Netherlands), ECO-PRO (Germany), EQUER (France) and ATHENA (Canada). Several of these systems have gone the next step, to result in a labeling system that indicates clearly the building's approximate performance to end users. In Poland, the environmental assessment sytem e-Audyt was based on a concept of GBTool but adopted to local conditions and tailored to local data availability (Panek, 2002).

Taking into account this situation ISO TC 59 reactivated in 2002 Sub Committee 17 Sustainability in building construction composed of four working groups which elaborated series of standardisation documents related to assessment of buildings :

CD 21932 - Building Construction – Sustainability in Building Construction –Terminology, recommended for Committee Draft.

WD 15392 - Building Construction – Sustainability in Building Construction – General Principles, recommended for Technical Report.

CD 21929 - Building Construction – Sustainability in Building Construction – Sustainability Indicators – Part 1 – Framework for development of indicators for Buildings, recommended for Technical Specification.

CD 21930 - Building Construction – Sustainability in Building Construction – Environmental Declarations of Building Products, recommended for Draft International Standard.

CD 21931 - Building Construction – Sustainability in Building Construction – Framework for Methods for Assessment of Environmental Performance of Construction Works – Part 1 – Buildings, recommended for Technical Specification

In 2004 CEN got the EC mandate M350 for development of horizontal standardized methods for the assessment of the integrated environmental performance of buildings. The goal of the Commission is to provide a method for the voluntary delivery of environmental information that supports the construction of sustainable works including new and existing buildings (not all construction works will be included). These buildings should provide all of the necessary functions to the users whilst minimising their environmental impacts. Following documents are foreseen to be prepared up to 2009:

1. Framework standard for integrated environmental building performance. Framework standard is intended to provide the methodology for the assessment and the subsequent declaration of the integrated environmental performance of complete buildings and construction works.

2. Horizontal standard on the aggregation of LCA results of individual materials into the building, standard that will provide the methodology for the aggregation of materials data or data on components to provide the overall integrated environmental performance of a building.

3. Standard on the LCA methodology for building products/materials, standard will be based on the ISO TC 59 SC17 standard for the environmental declaration of building products, should provide an answer to the issues beyond the scope of ISO.

4. Standard on the communication format/EPD. This standard should be based on the results of the standard for the LCA methodology for construction products/materials. The outcome of the LCA is one of the communication items of an Environmental Product Declaration.

5. Technical report on the assessment of the environmental performance of the construction process of a building, which will provide LCA-based method for the assessment of the environmental impact of the construction process on relevant scenarios. It should identify which factors should be taken into account and which should not, what climate and what generalisations are acceptable regarding transport, etc. The results should be able to fit in the aggregation step for the integrated environmental performance of complete buildings and construction works.

6. Technical report on the assessment of the environmental performance of the end of life phase process (demolition, recycling, waste treatment processes) of a building and products. The deliverable will be a technical report that provides an LCA-based method for the assessment of the environmental impact of the end-of-life (demolition) process.

7. Technical report on the assessment of issues of building products related to the lifetime of the building (service life, durability, design, maintenance and replacement). The deliverable is a technical report that provides an LCA-based method for the assessment of the environmental impact of the maintenance and repair processes based on relevant scenarios.

The two, above described, standardisation activities formed a basis for the works covered by WP2 Environment. There are three main issues, which are considered in creation of assessment systems. These are environmental impact, indoor environment and impact related to production of building products – every issue is related to separate sub-task. Integration of all of them is a purpose of whole work in WP2.

4 Conclusions

The STEP project is a challenge for the whole team coordinated by Warsaw University of Technology. Within this article only the first two work packages have been presented. The rest altogether 8 meritorious packages will use results from WP 1&2 and will constitute educational framework, textbooks, guidelines and software that will be available for wide public for non-commercial use. The work of WP1&2 are already completed and were very helpful for providing research support to implementation of Energy Performance Directive in Poland.

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ETHICS AS THE FUNDAMENTAL OF SUSTAINABILITY AND SUSTAINABLE ARCHITECTURE

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Keywords: sustainable architecture, social aspects, ethics, environmental evaluation methods for buildings.

Summary

The adjective sustainable, both in general and when applied to architecture, involves the consideration of environmental, economic and social aspects. However, advances in research on sustainability in the last decade have confirmed the need to incorporate a new approach to what we understand as basic: Ethics.

The dimensions of current approaches in sustainable architecture widely surpass those usually analysed which are based on time and space. The definition of sustainability in itself, as a link between generations, expands the time coordinate: the research and activity of architecture includes much more than the project itself or a building's useful lifespan. The space coordinate has also widely surpassed the limits that have been used up to now: the idea of thinking globally and acting locally expands the *locus* of architectonic design on to the planet as a whole. These new limits of building horizontally—the whole planet, and vertically—throughout generations to come, makes ethics the base, the fundamental and the field from which we should study sustainability.

First, we must establish the rules that will guide the analysis: Ethics are understood as the study of what is good and bad, proper and improper in accordance with the norms set by society at a given time.

Sustainable architecture and methods of evaluating the environment's behaviour of current buildings is moving towards this field, even though unconsciously. It is important to think about sustainability's reasons and original framework in order to exactly understand what are the aims and scope in which it is developed. The study of sustainability in architecture from an ethical point of view determines the criteria under which the evaluative methods should evolve, noting the ways for proper development.

1. Readopting the meaning of ethics as a concept

At first glance ethics in daily life is understood as a concept applied only to the study of matters on the fringe of human life: the beginning and its origins (cloning, genome, abortion, eugenics, eu-Genesis), or the end and the limits of existence (euthanasia, eu-Thanatos, etc). This is an extreme view, set on the confines of life. However, between these two extremes, humans develop a wide range of life, full of activities and projects that become concrete facts.

The meaning of ethics, from academic definition, is "the branch of philosophy concerning morality and human obligations" (according to Real Academia Española, Dictionary 2001). If morality (or descriptive ethics) describes and studies human customs in each specific moment in history, ethics is the part of philosophy that studies the underlying reasons for these customs. If the description of customs makes up part of morality, a study on "why" and a valuation of this morality would also correspond to the field of ethics. That is, all human activity understood as a custom could and should be an object of study from this point of view. Any human activity is susceptible to being valued and studied in terms of correct or incorrect usage, of what is appropriate or inappropriate. The science or study of making an abode or habitat for a human being is one of these human activities, and an important one at that.

The distinguishing aspect between morality and ethics is an essential difference: Morality adduces "customs," that is, what is common human and social behaviour in a specific moment in time, leading us to a temporal structure. Customs change with time, adapting to their moment in history, surroundings and social complexity; they change and are flexible. Valuating them is thus attained through an understanding of society in time. But a human being also has an unchangeable essential core, which endures and is shared by all human beings throughout all generations and places. In our western culture, our concept of knowledge from Plato, and our Aristotelian reasoning have not lost meaning throughout history; instead they are fundamental to our way of thinking. Their contributions remain, along with the reasoning added by many later intellectuals. This implies an added sense of complexity in this study: knowledge of that which is common in all human beings, and to a specific historical moment.

2. Applied ethics

And what does this have to do with architecture? Can we talk about what is good and bad or reasonable and unreasonable in such an industrialised world submitted to the laws of commerce and the hard, relentless economic and real estate pressures? Can we connect Aristotelian ethics with architecture? Are there stagnate spaces in which philosophical thought is completely absent? Is this study useful to any degree? The response to these questions is yes. The study of general concepts must conclude useful guidelines. Fox (2006) notes this through a definition of different levels of the study of ethics, specifically defined for constructed environments:

- There is a descriptive ethic that studies human behaviour through an observational approach: What do they do, how do they develop behaviours. This description would correspond to what previously was defined as "morality."

- There is standards ethics, which in comparison to the former handles the source of human standards and objectives, through a more philosophical approach in comparison to observation.

- There is a meta-ethics which tries to understand the good and bad, proper and improper, of the purpose, discussion and meaning on what humans are concerned about.

- And finally there is a practical ethic, which applies theoretical reflections in specific contexts, determining how these reflections should be used in specific cases.

With respect to Fox's description of the different focuses on ethics: descriptive, standards, meta-ethics and practical ethics, a comprehensive study should gradually include all four of these levels or phases as applied on construction in order to reach the latter: a practical ethic that provides a guide for specific moments, for our case, this involves the present, with our peculiar historical circumstances and within the context of our society.

3. Aim and application of a classic concept

The aim is purely utilitarian: To have a well-thought out base and a researched theoretical foundation to guide on what to do, how to behave and what decisions to make when confronted up against specific decisions in certain contexts. The problem lies in how to apply such broad, comprehensive and complex concepts like philosophical judgements, how to come up with practical applications and how to carry out the process.

This is where the concept of ethics can be applied to the specific field of architecture. It is about knowing which aspects must be specifically treated within the framework of social relations and behaviours, understanding that we must provide a solution and response to the debate held in our society. These are new problems, since these are new situations, and society is continually changing. With this we hope articulate between the scientific and the common, between theory and practice, between contemplation and action.

For this, and to start the process, we must try to return to the study and origin of the discipline of architecture itself, initially erasing the limits of space and time, taking a step back from the short-sighted view of the daily activity, changing from an immediate focus to a greater dimension in order to understand the meaning of our actions. In order to understand the concepts, it is necessary to return to the origins and definitions.

4. What in architecture can be associated to ethics?

Architecture is understood as the space in which man inhabits and lives his life. Under the title of architecture or architectures in plural, we understand other associated complex activities, like the creation of a city as a collective building and the creation of spaces and environments for human relations. Construction and public works as industrial activities are the practical and technical consequence of this need to provide human beings with a shelter for their life and activities. All of these activities may and should be studied under an ethical point of view. That is, the first or final study of the purposes—why carry out certain human activities.

Architecture ("the art or science of building," according the Merriam-Webster dictionary) is an art for a need, a use, an aim and a purpose. Architecture works with space and light, supporting itself on materials and providing utility. Vitrubio´s *Firmitas, utilitas, venustas* is still valid and lasting. This peculiarity, this practical application of an artistic activity in itself makes it a study of ethics. This is an art, but one requiring responses to questions: For who, for what and how.

We should also distinguish between art and the creator: the architects, those working in this line of work. According to Wasserman et all, (2000), Architecture is 1) the particular places we shape in the landscape for our inhabitation, 2) about their consideration, design and fabrication, end 3) a professional practice. There should be a distinction between the discipline/art and the people as architects, Lagueux (2004) says. This way, the codes or rules of conduct regulating both can be independently studied. On the one hand we would see the reasoning behind the good or not, what is proper or improper in developing art; and on the other hand what is proper or improper in terms of the people's practices. The latter aspect is regulated by the professional codes of conduct that must be applied to the personal relations within a competitive environment and context: Between the professional and his/her client; between professionals themselves, and professionals and the state.

Although the ethical position of the designer is crucial issue as starting point in sustainable design, for this paper we hope to discuss the former aspect: where should architectural theory be directed? The architect's personal or professional behaviour is not discussed here. We will study concepts and criteria that should serve to guide the decision making process involved in the architectural process. The aim is "the moral consideration of architecture", as Levine (2204) says.

5. Different interpretations throughout history

Architecture has always had a conscious ethics that it has been defining throughout historical moments: from the most classic architecture to the latest in architecture. The most primitive societies have created theist, colossal architecture in which the buildings could be either temples or sacrifice places, like Hollier (1992) argues about Bataille thought. There is nothing more descriptive of each period's social structure and morality than that placed in its architecture. The coliseum, the forum, the fortress, the market, the cathedral, the palace…are defining more than just their historical moment, but also a society's beliefs, moral structure and ideology. Studying the ethical purpose of architecture has been the base for modern architecture. Frampton (1980), Pevsner (1951) and Giedion (1976) started their study of 20th Century architecture through the moralist reactions of John Ruskin and William Morris on the growing industrialisation of the 19th century times, which they saw as alienating human beings, while architecture was an element that would elevate human dignity. The driving force behind the rigid architecture of Beaux Arts to modernism is the adaptation and reaction of industrialisation that has changed and regulated a new lifestyle for man. This same industrialsiation would years later be admired by Le Corbusier (1936): "Toute construction (objet d´utilité, unité de logis, moyen de transport, autos, bateaux, avions, etc) répond à des besoins modernes, la forme est dictée par les matériaux, les moyens d´exécution, les machines et une qualité d´esprit qui est la manifestation d`étique d`une époque" Science and techniques have not been the only elements that have modified the architectural process.

Others study the ethical aspects from different points of views. Maybe one of the easiest to approach is the power exhibited, which establishes a way of practicing architecture. The most obvious and crude example is the architecture of powerful dictators and dictatorships. The architectonic language can be used in obvious fashions: oppressive, grandiloquence, imposing. The space in which man lives is his elemental shelter and home, but it is also the collective meeting space, for social relations and joint participation, where relations and situations are established. And for this, the architectonic language can propose, suggest take-in and promote these activities, or reduce, limit, control and even annul or eliminate them. Architecture has technical and functional purpose, but also an expressive one, to create spaces and produce feelings.

This same point of view can give way to confrontational ideological solutions. Dictatorial architecture takes specific stances. Bucharest´s traditional historic quarters were banally and artificially substituted by a single, colossal and megalomaniac institutional building, describing both Ceausescu's dictatorship and its belief and sustenance through the change from a vernacular, anonymous and collective architecture to an imposed and hierarchical form changing the scale of man to annul their sense of participation as citizen's.

From totally opposing ideological positions, but based on the same principles of the power of architecture, the French Internationale Situationniste (from 1958 to 1969) understood the city and space as a place for establishing situations, meetings and forms of free, spontaneous, creative and diverse expression thus establishing a spatial and temporal participation for human relations.

These brief and synthetic examples have been chosen in unique historical moments. From this point of view, architecture is not just a reflection of its time; instead, architecture is creator of its times. The relationship between them (architecture and time) is interconnected, and is established in both directions. Architecture reflects its historical moment, but also makes and creates the space that forms, covers and makes this historical moment visible. Each period's society is defined not only by its advances or technical evolution, but by its determinations, by choosing what is important or by placing priority, thus creating a particular value scale.

Architecture is a functional art that modifies space, making man's shelter into art. This is the discipline that transforms the need for space into the development of an expression. This is an art with a need, a function. This function is carried out through the collective interpretation of people's needs, those that will use the buildings, those who need it. To interpret these needs and adopt to the criteria that society demands at each moment is a necessity and the previous step to making good architecture.

6. Current circumstances

It is not easy to clearly determine what the values of our times are: we live intuitively, collectively, unconscious, without formally declaring them, which are also in continuous evolution. However, there are circumstances that objectively make our times different from the rest, and that have influenced the position we take on our value scale. Society is now confronting challenges it has never had to confront, which require a solution.

The problems of sustainability, arising from the alarms from global warming and the environmental changes and damage, have changed our focus of attention of the problems. While before we did not grant importance to that outside our country's borders, today we understand that this scale is limited. We must expand it; our concept of the limits of space and time must change. The Kyoto treaty and those following have shown that it is useless for a single country, or a small group of countries, to operate independently. On the other hand, the "financial centres" Saskia Sassen (1998) discusses, rewrite the map of economical power. They go beyond countries and continents, through operative networks that function independently, or more appropriately, beyond borders and continents, beyond geographic distribution, in order to determine a non-spatial geography: a "virtual" geography through information networks.

What happens in London is not isolated from what occurs in Baghdad: what happens in Darfur is not disconnected from what occurs in Beijing. The so-called "butterfly effect" describes the interrelation of the cause and effect that go beyond the limited diplomatic, political or economic connections, raising them to a higher scale of possible relationships in space and time. The ease and abundance of communication, both physically and in situ, and virtual or through waves, create a permanent transfer of people, knowledge and information.

The new concept of an ecological footprint, "the amount of biologically productive area (crops, pastures, forests or aquatic ecosystems) needed to regenerate the resources consumed and assimilate the waste produced for a given population with a specific, undefined lifestyle," from Rees and Wackernagel (2001) have provided us with a single figure, in specific units, a resource distribution problem between different societies and countries on the planet. It has shown what societies are using the majority of our common resources. We can no longer be indifferent to not being energy efficient, to the use of certain materials, surpassing energy consumption or building exclusively for a small percentage of the population, etc. We already know the data and all the figures that show the cost this has on the planet.

These new circumstances in constant flux have changed our lifestyle and work, giving a new dimension to our surroundings. That is, the eternal concept of architecture is now given the specific concepts from our times: a holistic or general, complete, universal concept has changed scales. .
Is it advisable to understand the big picture, expand it, expand the conventional margins, and go on from a limited conception of cities installed in our current industrialised welfare society, and take this view to the largest possible spatial scale: the complete planet; and temporally: from one generation to the next.

7. Environmental ethics and environmentalism

The debate on ethics applied to the environment has been called environmental ethics. Its origins can be traced back to Thoreau (19th century), Des Jardins, even Gandhi (20th century), and even further back to Spinoza (17th century). The late 20th century has seen its strongest development. According to Taylor (1986) "Environmental ethics is interested in the moral relations between humans and the natural world. The key ethical principles guiding these relationships define our tasks, obligations and responsibilities, paying attention to the planet's natural environment and the animals and plants living in it." This subject also studies matters concerning environmental problems in solidarity with time (the well-being of future generations) and place (problems the whole planet faces), with the aim of achieving a less unsustainable method of construction throughout the world. The International Sustainable Construction Convention CIB W082 (1998) under titled Sustainable Development and the Future of Construction, already connected these aspects:

"The problems of poverty and underdevelopment or social equity are sometimes part of sustainable construction. In addition to economic prerequisites or social questions, numerous other variables and their importance vary from country to country. Features such density and demography of population, national economy and standard of living, geography and natural hazards, availability of land and water, energy production and supply, the structure of the building sector or the quality of the existing buildings stock, etc., all have a measure of influence and interpretation in national approaches".

The concept is closely tied to what some authors like Raudsepp (2002) have called environmentalism: "Environmentalism is usually operationalised as a certain way of thinking about the environment (beliefs and attitudes concerning nature and human-environment relations) and/or practical way of relating to it (ecological behaviour, e.g. self-restriction in consumption, participation in ecological movements, willingness to sacrifice for environmental quality"

The current view of environmental ethics refers to topics that share specific environmental goals. There are non-anthropocentric concepts (those taking into consideration moral values beyond the mere human interests) and anthropocentric ones (prioritising the individual). Recent environmentalism has focused towards the former. Craig Delancey (2004), in his suggestively titled article "Architecture can save the world: Building and environmental ethics", concludes that from the first point of view, we can reach a well-being for all types of organisms and ecosystems on the planet, at least to some extent. Concepts those are compatible with architectonic practices, according to this same author. Designing and building should benefit all classes of organisms and ecosystems, assuming that even reduced damage is already a relative benefit. Applying this principle to architectonic practice supposes, obviously, certain restrictions, but also new opportunities.

8. Evolution of the study of sustainable architecture

Sustainable architecture—what is equivalent to green architecture, or low-impact architecture in other contexts, is a conscious or unconscious response to the new wave of environmentalism applied to the world of construction. What at first was a reaction to the energy challenges confronting climate change, has gradually become a more complex problem. The study of low energy consumption architecture, as the initial urgent problem to solve, has progressively given way to richer and deeper studies. The first texts in conferences concerning this subject focused on energy efficiency as a paradigm: the aim has been slowly changing, merging with economic criteria and going on to social criteria (including the socio-cultural and historic) as research and evaluative subjects. This expansion and merging of aims has reached public works, infrastructures, construction, terrain interventions and landscape, biodiversity and nature as an entity in itself.

Moreover, the conception of environmentalism in developing countries reaches fairly different aspects, but is also an object of study and research. Our geopolitical and macroeconomic structure has generated an apparent resistance to the phenomena, but the entropy generated by these structures is precisely the cause provoking this environmental consciousness. The concept of sustainable development arose out of necessity. Naturally, environmentalism has expanded into all aspects of this field, just like gas expands throughout its container. The environmental, the origins of the study, was then followed by the economical, and then the social—much like the paradigm: planet, people, profit." The three supports of sustainability that must be united under a general concept. The conceptual triad of environmental, economic and social has become a tetrahedron, which for some authors such Duijvestein (2004) says, the fourth, main vertex is "the project." The geometric analogy of the phenomena must somehow also include the ethical and environmentalist aspects as the concept catalyst.

9. Conclusion

The expansion into these factors has favoured a holistic conception of architecture that inevitably has reached the need for a more essential research into architecture: into the field of ethics. The ethical aspects of architecture are not new to this field. However, when specifically applied to sustainable architecture they are somewhat newer. They do not stop from being steps in a direction that go from the detail to the general concept, from the practical application carried out through an intuitive point of view to a general concept, to underlining reasons, justifications and guidelines. That is, ethical aspects.

The now universally understood sense that architecture is the task of settling the landscape, natural or urban, and that man is no longer the centre of the planet, but just a part of it, in a growing non-anthropocentric culture, imposes a new architectural ethic. What are the current ethical problems? Equity and social justice criteria applied to the planet as a whole, once having excluded the boundaries of space and time. Build for everybody, including everybody throughout the planet, the current inhabitants and the future ones. Build with respect to nature, which encompasses the existence and maintenance of biodiversity, using the scientific support and techniques that are now available.

Sustainable architecture finds its area of performance in the necessary response to the current problems form an environmentalist ethics point of view; Sustainable architecture is not a new paradigm, train of thought or technical speciality. It is the architecture of a period with environmental concerns, and must operate keeping in mind the sensibility of environmental matters; architecture from a period that reinterprets the traditional limits of space and time must capture these concepts and reflect them in its proposals. Each era's architecture has had its own ethic, and our era has its own, with a strong emphasis on environmentalism. And this path is the path architecture must follow, without being obstructed by the entropy of the resistance from our geopolitical and macroeconomic structures.

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THE URBAN METABOLISM AS A BASIS FOR INTEGRATION STRATEGIES AND ORGANISATION AND REALISATION OF SUSTAINABILITY IN URBAN AREAS

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Summary

Ecological and environmental conditions in and around cities are under pressure: transportation distances grow, protection and qualities diminish, and infrastructures get more complex, less robust and less visible, which result in a decline of sustainable commitment and behaviour of users. Yet, citizens are concerned that environmental degradation is affecting the quality of life in their neighbourhood.

Composite measures of sustainability provide useful insights to the environmental impacts associated with human activities, but, in themselves, are not the solution for abandoning traditional paradigms. Spatial planning must be able to conduct the spatial consequences of these developments. Therefore, it is necessary to look beyond boundaries: not only physical boundaries (between areas or countries), but especially boundaries of the various scale levels of solutions, the interrelated networks, the public space and, particularly, of their reciprocity. It induces the explicitation of the 'urban metabolism' with underlying social needs and the finding of instruments and strategies that allow the spatial planning and renewed infrastructure to fit the changing social objectives, especially as for sustainability, and another way of dealing with "public affairs" better.

The presented approach promotes sustainable management of the environment and its resources through a renewed focus on existing, mostly ignored resources and local 'quality-cascading' (exergy), together with stategic niche planning to improve knowledge on the interactions between natural resources, human activities and environmental impact and in doing so, facilitate continuous urban change. Especially the introduction of solutions on an intermediate scale-level of the neigbourhood or city district offer opportunities.

1. Introduction

Cities are like organisms, sucking in resources and emitting wastes. The larger and more complex they become, the greater the necessity of infrastructures and the greater their dependence on surrounding areas, and last but not least, the greater their vulnerability to change around them. With recent and coming perturbations of the weather due to climate change, as well as constantly increasing global demand of energy, water and materials, this aspect of vulnerability and dependence is becoming essential for sustainability, as the world may be entering a period of scarcity. Therefore, a renewed look on "the urban metabolism" is necessary. There are several strategies to cope with sustainability and the increased dependence and vulnerability. In general due to the urgency it comes down to "effectiveness before efficiency". More specific, two future paths could be determined. Within the globalizing world, centralization through interconnection of sustainable (re)generation and (re)use, connecting sustainable solutions in the different regions, and especially balancing sustainable demand and supply of both hemispheres is one. The other option is exactly the opposite: decentralization, trying to interconnect supply and demand sustainably on smaller scales, near to users and settlements, and therefore near to the origin of environmental problems, ánd potentials (Timmeren, 2008).

The scope of this study is formed by the most important flows related to the first necessities of life, viz. energy and sanitation, which implies energy, water and waste. Systems are called "sanitation systems" (after the French "sanitaire", meaning "health" or "hygiene") if the systems concern the flows dealing with health aspects. In this study, for reasons of the importance of the organic part of the solid waste, we adhere to the general definition of sanitation: waste water systems and solid waste.

The central questions will be how, and especially at what scale level, these "essential flows" in the built-up environment can optimally be made sustainable. The essence of the chosen scale level and role of connecting structures and infrastructures will follow from this.

In practice, it turns out more and more often that the relation between infrastructure (to a lesser degree technical systems) and social needs has been reversed. The newly planned and constructed infrastructure largely drives the social needs and is the result of the balance of power or habits of certain institutions (dominant actors), or "path dependent development".

When we consider the question concerning the various types of infrastructure, whether necessary or not, and their manifestations and scale levels chosen today, it can be established for the sanitation infrastructure and the energy infrastructure that the flows transported within this infrastructure are still characterized by a structure which has been optimized from the viewpoint of efficiency in (centralized) management and of other economic aspects, rather than of far-reaching ecologizing and dematerialization. Hence, looked on from the angle of sustainable development, the infrastructure seems insufficiently efficient. As a result of this inefficiency of the essential (or critical) energy and sanitation flows (water and waste) and the usual large application scale of solutions, the technical infrastructure to be built is not optimally adjusted to the quality as well as the quantity of these flows, seen from an environment-technical point of view.

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2. Permanent Cycles

The presented research attempts to contribute to "cyclic thinking" and "cyclic design" in the (actual) built-up environment, with as little as possible extra work, energy, waste and capital as a starting point. It takes the three-step model by the Dutch authorities concerning sustainable development as a starting point: (1) extending energy consumption; (2) closing of cycles of 'materials / nutrients' and (3) supporting quality / life span of products.

A cycle may be part of one or more ecosystems. Cycles are the key condition for stability in nature to come into existence. In a closed system, matter cannot go beyond its boundaries. In principle, energy can go beyond a system's boundaries (2^{nd} Law of Thermodynamics). Water, nutrients, and other materials, by contrast, having no source of new supplies, are not lost or dissipated but instead are continually recycled.

Usually, ecosystems are defined as parts or areas in a more or less isolated state that are capable of preserving their own balance, always open to influences from outside (Tillman Lyle, 1994). In this study, ecosystems are considered as natural parts of technical systems (e.g., buildings, districts or towns), in their turn being elements (parts) within larger ecosystems. The scope of this study is formed by the most important flows related to the first necessities of life, viz. energy and sanitation, which implies energy, water and waste. The sanitation subflow 'waste' is described as those elements or materials that are left, together with one or more products from a production process or after consumption, and that have no market value in the current market circumstances. By now, waste actually almost always is a product, since it has become to represent an important and increasing market value, and there are markets at regional, national and international levels. Within the area of "water", a sanitation system contains: the entirety of the water chain, viz. the collection, production, distribution and use of drinking-water, the collection and use of rainwater, facilities for toilet water and use of water in housing, the collection, transport and processing of refuse, discharge and/or dumping/reuse. The "urban water cycle" is defined as a cycle, but is not a (closed) cycle: it is part of larger cycles. Drinking-water and waste water form the elements of the so-called "small hydrological cycle" within the "large hydrological cycle". It is not necessary that the small water "cycle" is defined as a closed cycle. It is better to consider it as consisting of various (created and) interrelated "small cycles", including nutrients, energy, carbon, metals. The urban part is only one of the parts in the cycles concerned. Each of these small hydrological "cycles" can be repeated many times, but strictly speaking is not to be defined as a genuine cycle. Then, the objective of sustainability can be set thus: the urban system is not allowed to exhaust or overload the surroundings. In this point of view, it is not necessary for the urban system to be fully autonomous. However, if the created "small cycle" is not closed at an urban level, town and surroundings should be complementary, so that they can minimize, or balance the environmental load together.

Cyclic thinking is often linked up to autonomy and "autarky". Autarky is then defined according to the limited, ecological interpretation of autarkic systems: systems which are closed as regards matter and energy, with the exception of the continuous flow of solar energy. Apart from this, autarky is often linked up to (ecological) holism because of its comprehensiveness. Autonomous concepts in environmental technology and in the building industry (mainly) concern autarkic attempts to subaspects. Here, autonomy is contrasted with "heteronomy". In this study "heteronomy" is used in the limited interpretation of interconnection, and the instictively experienced forced latency, especially applied for the essential networks and services.

3. Private or Public Management of Energy and Sanitation (Infrastructures)

The decision-making concerning the system selection and accompanying infrastructure for the essential facilities, such as energy and sanitation, is often – or too often – established stealthily. Political choices can determine the market hierarchy of changes in the infrastructure, e.g., through the speed of the market opening, policy on competition, price regulation, tax constructions, environmental regulations and supervision. The original objectives and needs of the project will keep slipping further and further to the background, particularly when new (innovative) systems and ways of (sustainable) generation (energy supply) or treatment (waste / output) are introduced, through the investment of effort and time when running through the process and the many interests that come into being. On account of the continuous adjusting of objectives and starting points, and on account of the fragmentation of the moments of decision, decision-making becomes "stealthy".

The argumentation to carry out a project or not changes when criticism on the project (or arguments to not carry out the project) cannot be refuted sufficiently, or when time outruns the arguments. One of the negative effects of stealthy decision-making is "shift of objectives".

The absence of a general theory of sustainability is also a topical problem. Particularly, the role of spatial planning in this respect: the connection between local, communal and global sustainability is characterized by uncertainty, ignorance and inexperience. Too often, developments follow paradigms, which often leads to a development with a fixed end, as an assumed "nec plus ultra". They can lead to an "a priori" brake on attempts to get a better alternative. There is growing consensus that a reductionist command and control approach is perhaps not the most appropriate way of interacting with what is in essence a dynamic complex adaptive living system, a regenerative system, and that resilience and adaptation are factors of urban sustainability as important as (if not more than) conservation, efficiency and equity. This necessitates a quite dramatic mind shift in how cities are viewed and therefor in how spatial planning and design should address to this. Spatial planning must be able to conduct continuously the spatial consequences of developments. Therefore, it is necessary to look beyond boundaries. This does not only concern physical boundaries (between areas, regions or countries), but also boundaries of the various scale levels of solutions, of the interrelated networks, of the public space and, particularly, of their mutuality.

Spatial policy will be able to have a guiding function in a limited way only, since spatial planning is mainly guided by economic interests. In most countries, the general basis for spatial policy nowadays is still too much of a certain pragmatism focused on specialism. The "public interest" is translated into the own scale", a narrow spatial coherence, that is insufficiently characterized by the creation of conditions for the diversity and changeability of society. Private preferences are fundamentally contrary to public wishes. Infrastructure and a certain spatial development at a higher scale level, e.g., that of the region, is often a public wish, a collective good, that should be to the profit of the whole society. Decision-making where collective goods are concerned, should be accomplished in a collective way. Cost-benefit analyses address people as consumers, rather than citizens. Private preferences often differ from public preferences" (Sagoff, 1988).

There is much left to be improved in this matter. First of all, it is the case that many infrastructures are (still) paid out of the general means of the authorities, without there being hardly any incentive to earn back the costs made. Second, there are "external costs" that are often not charged or settled. Finally, costs are still not made to depend on the extent to which the infrastructure or space is used, the so-called "variabilization" of the costs. It is particularly important to consider management aspects of shared spaces and infrastructures, and in some cases charge systems connected to them:

- More clarity is needed with respect to the practical and principal reasons for the preference of private or public management.
- The charges are independent of distance, and the internalization of costs for environmental aspects and reliability of supply will be or will have to be introduced.
- How to handle the (improper) derivation of legal rights from the infrastructure and "public" space, or how to change this.
- The option of so-called "delocalization" as a proposed solution: a shift from responding to local circumstances and making use of them towards having control over the physical conditions. Delocalization is closely interrelated with the "programme design" or the "drawing up of the agenda" of the urban and regional development. It is of particular importance to make spatial interventions leading through the concrete formulation of the commissions and the strategic use of this.
- How to handle the "first mover" problem in spatial development. The sheer risk of specialization in the various professional specialisms is that one loses sight of the entirety, while this is a prerequisite for being able to accept one's responsibility for one's own contribution. Each group, each individual member becomes more functionally dependent on others because of specialization of one's own functions. The "chains of interdependence" branch off and become longer, and, consequently, become less transparent and less verifiable for each individual and each group.

Spatial planning and, within this area, the planning of networks and infrastructures will have to be inspired more by aspects of flexibility and alternative network geometries. This points to the importance of strategic “location development”. One of the background features is that the necessity of extension and/or change of infrastructures become less predictable and involves higher risks (big investments and/or structural changes will not be able to take place so easily, unless collectively supported by several parties). In this, the importance of urban direction and of the guarantee (protection/defence) of specific public services increases. However, the interpretation will differ from the present one, one of the reasons being the so-called “open” economic structures resulting from globalization. Companies break off ties, often historical ones, with national and/or regional authorities. At the same time, however, it is exactly these companies that more and more design the infrastructures and manage logistic chains, and in doing so they control the networks, spatial layout and in the end dependence.

Private property implies heavier supervision (with more rules/bureaucracy) and extra costs for the companies and the supervisor. Therefore, there is some risk of the competition expected to result from the liberalization of public services not leading to lower prices, and not guaranteeing higher reliability of supply and more sustainability. This is mainly caused by strategic behaviour of “key players” (dominant participants), including national authorities and the energy companies concerned on and near the energy market. Take for instance the debate on nuclear power and the role of France with respect to the European electricity supply, but also the natural gas related incidents between Russia and Ukraine. A free-market system is based on a theoretical-economic approach: “Authorities would behave as ideal market superintendents, and players on the market as producers and consumers according to the book.” Reality is more complex: all players show strategic behaviour, with some large concentrations of power ruling the roost as a result. At the international scale level the dilemma of “competition or dominance” plays its role: those countries that behaved “according to the spirit of the letter” of liberalization may become the victims. E.g. with respect to energy supply in Europe, a European market arises with a more or less oligopolistic character, little effective competition and, consequently, few incentives for innovation, real sustainability and permanent cost reduction. In addition to dominance and oligopoly, another important result is that the various processes, that used to be confined within the various borders of the countries or of the regions because of restrictive regulation, can now “march on” to those countries or regions where they can be carried out best, looked at from an angle of business economy. Hence, the processes become “footloose” and authorities (and society) lose their grip of them. This, together with the “economies of scale” and the ongoing centralization of processes, causes more difficulty in preserving the “direction” (sustainability) or in adjusting the processes. It results in an increasing pressure on aspects of “general or public interest”, and a general increase in the pressure of transport and increasing complexity of the connectiveness and heteronomy. Consequently this leads to an increase of the load on infrastructures and environmental load, and to a spatial planning following an unbridled development of infrastructures, with the corresponding negative consequences for liveability, sustainability and “beauty” at various scale levels.

4. Different Network aproach with Alternative Configurations

As stated in the previous chapter, the ecological and spatial conditions of the open areas in and around towns are more and more under pressure. Relatively speaking, distances become larger, technical infrastructures become less visible, whereas traffic infrastructures and technical infrastructures cause impediments more often. This produces inefficiency and irritation for various user groups and stakeholders. When supported and managed well, a spatial planning strategy based on a changing approach starting from the user, whether or not organized into new types of being a commissioner, to be classified is more positively than the usual “issuing do’s and don’ts”. Although the latter should also be a specific part of the new approach in order to guarantee a minimum of guarantees. The main advantage from the built-up environment will then be that it reinforces the aesthetic and functional qualities, improves the entire flexibility of the system, makes use of vulnerable, scarce existing public areas, such as parks, squares and public buildings, and enhances the “readability” of solutions.

An alternative network principle can help break through the relations, that have come about as a result of historical factors, between the internal organization within the administrative organizations themselves and the connections with each other and with the more general social structures in the specific places. Policy seemingly obvious and independent of the paths chosen, and a role of the dominant participants supportive of a paradigm is prevented in this way. Moreover, such a principle has a clear spatial component. The spatial policies of the various national authorities suffice are less and less satisfactory. The systems used mainly at this moment facilitate standard solutions. Moreover, they more and more often lead to lengthy procedures and delays causing the launching tempo, relatively slow as it is, hardly to be able to follow society’s needs, not to mention to guide them. Therefore, a larger differentiation in the planning processes with a closer co-operation between the local, regional and national authorities is argued to be necessary. In this matter, a planning which is more regionally orientated may be the answer to the division between town and country, which is fading away more and more, and the changed organization or geometry of the mutual connections and spatial planning, which has earlier come forward as essential. The concept of “external economies of scale” developed at the beginning of the twentieth century, and the principle of “cumulatively self-reinforcing agglomerations” introduced in 1920 by Marshall could be the basis for this approach (Saxenian, 1994).

Especially the principles of “clustering” and “integrality” (physically and administrative-organizational) are of importance here. Composite measures of sustainability provide useful insights to the environmental impacts associated with human activities, but, in themselves, are not the solution for abandoning traditional paradigms. Finding a new approach to clustering implies a totally different approach of the networks, also described as the pursuit of a different network architecture or geometry on the one hand and different network control or network constitution on the other (Timmeren et al., 2007): In energy supply, there should be more emphasis on increasing the flexibility in the current (infra)structures, including Town and Country Planning in its entirety. The more so since it can be expected that there will not be only one decisive future technology to solve the coming problem(s) concerning security of supply and sustainable development. Especially with respect to energy this asks for a simplification of the processes, products (or rather: services) and parties involved. A larger concentration on integral provision of services, or, in other words, the supply and management of integral packages, offers possibilities. This seems to be reinforced by the (ongoing) liberalization processes. Another solution is having the level of application attune better to the lifestyle and direct surroundings of the users. The desired changed philosophy described has far-reaching consequences for the way in which infrastructures are designed and integrated. It is important to realise that the stability or resilience of networks is directly related to their complexity. Composite measures of sustainability provide useful insights to the environmental impacts associated with human activities, but, in themselves, are not the solution for abandoning traditional paradigms. Resource reduction strategies in close collaboration with urban planners, infrastructure developers, and representatives of key social groups is the basis to achieve environmental improvement, decouple environmental pressures from economic growth, and to restore and develop the functioning of lively neighbourhoods and natural systems in urban regions. This can be supported by an alternative organisation based on decentralized clusters (Timmeren et al., 2007).

5. Introduction of Decentralization and the support of change

The application and fitting in of new decentralized techniques and/or alternative network structures, does not suffice for the accomplishment of sustainable development. Too often there is tension between the mechanisms and the institutions that regulate motivation on behalf of individual or joint wishes. The integration of complementary functions will make or break of the proposed new approach to spatial planning. However, tackling environment-related problems in spatial planning by means of infrastructures often still directed by authorities may be a good start for guarantees of a sustainable arrangement within the various networks and chains. At higher scale levels, many environmental measures still fail through bureaucracy and too large differences in the target groups. Opportunities for a widely supported need for innovation are neglected here, and so is the chance of more significant “sustainable development”, for example through scale invariance. Lately, especially where the essential infrastructures for waste water and energy are concerned, there has been a growing awareness that there should be an end to the unidirectional approach.

In the study presented in this paper (Timmeren, 2008) it was concluded that decentralized systems can only be successful if they are combined with other functions (or supports of structure), and that it is necessary to try and reuse the recycled flows of energy, water and nutrients as close to the (local) solution as possible, or to insert them into the natural system. In this, one might postulate that it is less probable that the optimum scale of the subflows restructured into sustainable cycles will be found at the highest or lowest scale levels. This was supported by Papanek (1995), who claims that one of the central problems is the incorrect level at which ecological design problems are solved. Thus, his proposition that “Nothing big works – Ever!” should be completed with “…and neither do many autonomous small entities”. It is the result of the lack of flexibility and sustainability, and they are caused by the unidirectional development of the level of application. It is not without reason that the word “autarky” originates from “self-sufficiency” that was desired by the level of the Greek “polis”. The polis concerned a flexible reciprocal relation between city and hinterland, centralized and decentralized structures, culture and agriculture. When the balance was broken, new ‘polis’ were founded.

An additional advantage of the use of decentralized clusters is that it offers good possibilities to enhance the necessary transition of product supply to provision of services within the essential flows of energy and sanitation. This is also called: the change from “scale economy” to “economy of scope”. As a result of globalization and individualization, the consumers’ demands are less predictable and less unambiguous, and this is why many companies develop flexible structures of organization and direct-marketing tools. In such an “economy of scope”, clusters of specialized companies collaborate closely in synergistically attuning inputs and outputs and in exchanging knowledge. Because of privatization in the markets of energy processing and waste-disposal, the principle more and more applies to these essential utilities.

Technique influences social life, although this does not go so far as technician sometimes think: we would be able to solve social problems with technical solutions. The problem is that this technology-focused (“techno-fix”) thinking takes too little account of the fact that its introduction almost always involves several unforeseen side effects. In a relative way, our limited knowledge and organization is a problem for the current solutions. The theory has been developed with its basis on yesterday’s challenges, whereas the context has changed substantially. Society is characterized by constant change and transformation.

With respect to this, Röling (2000) claims that survival of mankind is connected with man's talent to change paradigms and to deal with that change effectively (adapted from Kuhn, 1970). This implies the creation of a new dynamic efficiency, an open-end condition as a start rather than a fixed end to work up to. As do Todd (1994) and other ecologists, biologists, urbanists and sociologists (Holling, 1995; Maturana & Varela, 1992; Harper, 2000; Capra, 1996; Tjallingii, 1996), Röling states that "cognition" (perception, emotion/affection and acting) should have a more central role in the current systems and their structures. This goes beyond just "adaptation". It should be taken into account form the moment of the initiative and design. This is also called a "resource-based view", as opposed to the usual "market-based view". Within such a process, the parties relevant to the area can focus on the future, any uncertainties and unexpected incidents, so that they may find alternative possibilities for the design and/or the arrangement, may reveal or promote subconscious strategies and gain experience with the aspect of joint actions. In a way, the process can be compared to the working of a metabolism. Because of an interweaving of sources as well as parties involved at present, advantage can be taken of the chances in a specific living area in a more effective way. The focus is on the incorporation of communities and the principle of "improvisation". Improvisation is "the concertino of action as it unfolds, drawing on available material, cognitive, affective and social resources" (Cunha, 2000).

The issue is how sustainable technology can be promoted within the focus of infrastructures, who is responsible, and how it can optimally fit in with the five phases of cognition. Should it be governed by the authorities or should it be left to the industry and the free-market system? In practice, it appears that the efficiency and competence of organizations to learn from the market or to adapt to it suffer from a lack of "social capital". In the development of buildings or districts and their infrastructures and technical systems and subsystems, parties involved often lack a concrete definition of the abstract notion of "society" and its "social needs" or "suprastructure" (Max Neef, 1991). Various approaches have been developed for this. The most important one within the scope of this paper, is the approach of "niche management" (Kemp et al., 1998). The basis is to realize that "niches" can be created. Niches often generate a set of instruments for setting up a new paradigm or system of techniques. The creation of niches can also take place in a planned way. This is called strategic niche management : "the creation, development and controlled phasing-out of protected spaces for the development and use of promising technologies by means of experimentation, with the aim of (1) learning about the desirability of the new technology, and (2) enhancing the further development and the rate of application of the new technology" (Schot & Rip, 1996). The difference with the more familiar principle of "pilot projects" is that a shelter is built around the new technology in the case of strategic niche management, through which the technology can develop from prototype to an actually applicable technology. Eventually, the technology should work without any protective measures at all.

It is essential to find a strategy and a method for a successful introduction of innovations to the market, even in the case of strategic niche management. It is of importance to find a strategy and a method that support such a process without relying on central authorities too heavily. Support may lie in modernizing the views on the (economic) value of products and services. This is also called the "Eco-efficient Services" strategy (Meijkamp, 2000). In the present "services economy", products and services should only be considered as instruments for the production of what people need. One of the potential advantages is that there will be more emphasis on system-oriented optimizations, rather than purely product- or process-oriented measures.

Critical to the implementation of this option of an approach based on the urban metabolism, or better: of integrated resource management, is knowledge dissemination of low exergy solutions (for all flows considered) including strong feedback systems between the different physical scales (site, neighbourhood, district, city-region). At all times alternatives should be offered. Meanwhile, "reflexibility", the use of the users' critical intelligence and commitment (in an environmental-technical, aesthetic and political or socio-political way) for the design of environmental-technical and spatial processes, can be achieved through the participation of users in the design, the construction and even the management of the built environment (including infrastructures), or parts of it. This goes beyond just social control. The other, often dominant parties involved should realize that the involvement of occupants/ users goes further than just the change itself (design, construction). It is a balanced concept which is interconnected with surrounding projects, in a structure that supports flexible and continuous change processes, is open, and is continuously capable of absorbing corrections through permanent reflection (and learning). A development of an area focused on sustainability had better not follow the ready-made plan, but should be embedded into a structure of flexible and continuous processes of change. This is also called "place making" (Healey, 1998). It should be based on regenerative systems, open to corrections and capable of continuously absorbing changes.

In the increasingly complex interaction of regenerative systems and integration processes it is crucial to appoint a so-called "leading actor". As there is often a lack of creativity, and the leading actor is too far away from the concept for the system to be able to play a good integrating role in the further development and building process, it is a natural decision to appoint the designer in this role. The designer's role, however, is quite different from what they have experienced or interpreted from times immemorial. The difference mainly lies in the type of the co-ordination and the manner of working, which is more like a following way (detailing various alternatives on the basis of, for example, maximization studies), where solutions are highlighted only at a later stage after checking with the various parties/participants; this as opposed to the (conventional) advancing of solutions. In addition to this, instruments focused on decision-making are necessary, so that people will not be stuck in endless discussion or design phases.

When started as a niche, it can be taken as a method of allowing innovations to grow for the purpose of a more structural and large-scale use. The starting points of the restructuring processes from the industry, known as “empowerment” and “business process re-engineering”, are of interest. On the one hand a more market-oriented attitude should be taken as its starting point, on the other a more local, bio-climatical or surroundings-oriented way of organizing. The background for this is the global transformation of economies from being focused on “mass production” to a focus on “tailor-made for the masses” (economy of scope). Particularly inspired by liberalization processes, there is now almost only attention for the first aspect within the essential flows in the built-up environment and their infrastructures. The second aspect (surroundings-oriented attitude) implies a larger and a more structural change, and offers better opportunities for innovation and further-reaching sustainability (at several scale levels) based more on the actual specific urban metabolism. It also addresses to the increasing demand for user-specific, “on-site” solutions.

6. Conclusions

One could state that the infrastructure of the essential (or critical) flows, due to its ‘path-dependent’, long term character, importance of network geometry and the existence of a limited number of dominant actors per network or flow, is determinative to what degree a project -varying in scale from a (part of a) building to a city or region- will or can be sustainable. Especially the wastewater infrastructure and the energy infrastructure can be characterised by transported flows that are not drawn up out of ongoing ‘ecologisation’ and dematerialisation but out of efficiency in central management and other economical factors. There is rising concern for the complexity of structures, aging of existing (technical) infrastructures and, within the increasingly heterogeneous networks, even several places of congestion. The development can be qualified for being ‘path-dependent’: as for the essential flows this means a ‘centralisation paradigm’, resulting most of the times in solutions that still include mixing of different (sub) qualities; i.e. are not based on the sustainable approach of cascading- and exergy principles. From the point of view of sustainability the technical infrastructure and with it urban development therefore seems to be insufficiently efficient. Within this process of path-dependent development, the existing infrastructures therefore can be considered as a growing restriction for sustainable interventions on lower scales, and therefore sustainable development.

In current central infrastructures of energy as well as wastewater flows, the possibilities of an alternative network layout are not or not sufficiently taken into account. More and more connections are made between the various networks and sub networks in gas and electricity networks, but this occurs because of considerations of capacity and economic (business) perspectives, rather than on the basis of the principle of network geometry. Consequently, there is a direct interest for large-scale central networks to have subsystems as a decentralized clusters included into the complex network. Because of the principle of self-organization, the latter also offers the possibility and the guarantees for being able to make local decisions with respect to, for example, further-reaching sustainability without abandoning the principle of scale size (“economies of scale”). Systems within decentralized planning concepts may lead to networks, complex or not, with a more strongly decentralized network structure with part of the networks performing relatively autonomously. These may support flexible planning concepts in town and country planning.

Differentiation and urban flexibility (i.e. for buildings and infrastructures) are pre-conditions for anticipating long-term uncertainties, due to liberalisation processes, rising complexities and mis-use or even sabotage. Sustainable starting-points are suppressed more and more by these changes. However, at the same time especially the intermediate scales can start up the necessary process of transformation towards real sustainable development, for it takes the best of two worlds. At present however, technical infrastructures still are leading to urban development, often even to the suprastructure of society. The strategically or even random integration of decentralised clusters (which preferably approach sustainable generated autonomy) in interconnected centralised networks will help to improve the resilience, flexibility, security and sustainability of the overall network. At present mostly only the dependence of decentralized systems on centralized systems -in general for reasons of storage and/or backup- have been put forward. However, especially in case of ongoing interconnection, centralization and liberalization, both future paths for sustainable development, the ‘economies of scale’ and the ‘scale economy’, or “autonomy” and “heteronomy” need one another mutually. Apart from that, the issue of a more precise attribution of costs to specific customers or transactions (which becomes more and more important as complexity decreases with ongoing liberalization) may be solved or may easier be solved. The postulated changed urban planning and related network philosophy in this is the cascading use of resources, where high-grade flows are used in high-grade processes and residual waste flows are used in lower-grade processes, thus making the most efficient use of the initial value of a resource. This so called low exergy approach taken here is inspired by the urban metabolism based on natural ecosystems, where processes run on the available (usually low exergy) resource flows. This approach is thus in line with the Industrial Ecology and regenerative design thinking of taking nature as a role model. Low exergy design and ecological approaches can strengthen the systems, methods and tools used for organizing, operating and supervising the urban environment and will minimize the negative impacts of urban areas on ecological cycles at all levels, creating efficient urban systems and livable cities. A life-cycle approach and planning based on ‘place-making’ is mandatory here in order to capture all relevant environmental effects to ensure an overall optimisation of resource use at all times.

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A STUDY OF SOCIAL ASPECTS WITHIN AN ENVIRONMENTAL ETHIC IN ARCHITECTURE

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Summary

Sustainability is the joint consideration of environmental, economic and social factors. While there is already a methodological *corpus* on environmental and economic aspects, research on social aspects is still lacking, especially in the field of construction.

These social matters as applied to the world of sustainable construction need to be specified: the group of social issues is too vague. Therefore, a basis on which to act is to be found and needs to be defined. This involves an understanding of the aspects which must be specifically treated within the framework of social relations and behaviours in sustainable architecture.

In order to achieve this, we have begun by compiling all the already existent basic definitions that hold the theoretical base of a sustainable building. For example, what the social aspects are, strictly speaking, and what their positions are, if any, in the field of environmental ethics. These basic definitions are then developed in more specific aims, framing the field of study and marking out fields on which to act as the basis for defining indicators.

Secondly, the fields of study within a social understanding have been extracted from the different existing evaluation methods for buildings environmental behaviour (for example, analysing in what general fields the applicable indicators are defined: those relative to user's health, mobility, etc.).

These indicators have then been studied in terms of their range, universal scope and field of action, and later compared with the basic definitions. This has helped to determine if the indicators are adequate, sufficient, and adjusted to ensure compliance with the social aspects that conform a sustainable building.

With the observation and analysis of these criteria, the empty fields, lacks and deficiencies that must be overcome in environmental evaluation methods, in order to holistically understand sustainable buildings have been stated: this holistic understanding is one of the necessary steps for obtaining an environmental ethic.

1. Present status. Sustainability as a concept

The term "sustainable" has reached a wide spreading in later years in different fields, with practical results in the construction sector and mainly in the architectural field. Nevertheless, for the consolidation and development of the process, it is necessary to search the meaning and specify the concept of "green" buildings and the benefits these buildings can bring. This particular task should be orientated, not only towards the general public but also and more specially so, towards the professionals implied as agents and from whom the development and fulfilment of these plans depend.

The first issue is to define what building sustainability is. There are several initiatives, social movements, organizations and working groups which have the mark of sustainable building and indeed, a great number of different approaches can be identified.

The reality offered to the architectural professional is drawn from too many alternatives which have created a confusing situation. This unclear and imprecise state adds up to the one created in other spheres but also with a great influence in the construction field: that is, the frequent outrageous architectural construction presence in the media and the overwhelming use of the "sustainable" adjective in non-scientific environments such as publicity, marketing, or in general in the mass media. Therefore, the difficulty to come up with an appropriate, precise definition of "sustainable building" has become an international problem and its scope is thus global.

The first initiatives and organized groups working on the issue of a "green" building (see the following sources identified later) started to join together efforts a decade ago. At the beginning, several studies on energetic topics were carried out, directed towards a consumption reduction and an energetic efficiency. (Gay et all, 1997), (Banham, 1997) Later, some economic and different factors and categories were also considered (Graham 1997) (Beetstra, 1997) and finally sustainability was defined as the integration of environmental, economic and social factors, according to Takemasa (2005) and Ulrich von Weizsäcker (2005). As a result of this, there have been a prolific number of surveys approaching environmental and economic aspects, whereas studies concerning the social studies in sustainability present a confusing state (Guy et all, 2007).

2. Difficulty in establishing indicators

The unclear situation of sustainability conformed by the three aspects –environmental, economic and social--, is further increased by the difficult situation originated by the information spreading and the lack of accuracy in the terms being used. An objective perspective for selecting the sustainable buildings needs to unavoidably focus on these three indicators. A quite clear agreement exists over the environmental and economic indicators, supported by technical surveys based on the building environmental assessment methods. An indicator is a parameter capable of providing relevant information regarding a specific phenomenon. It has to be simple so as to be easily used; it needs to be able of quantifying in order to establish comparisons, and it should be capable of communicating the needed information. Therefore, the indexes used are a combination of the values obtained by the element on the precise indicator so as to measure the variable.

Regarding the environmental and economic aspects there is quite an agreement. As an example, we can take the indicator of the energy used for a building maintenance in a geographic location and with a specific building typology. The 15 kw/m2 indicator obtained for passive houses (Passivhaus Project, 2007) in the district of Kronsberg in Hannover, Germany, indicates results higher than 50 kwm2 per year obtained by other buildings in the same sector. At the same time these results can be compared with the ones obtained in Spanish typological constructions. The period of economic return of the investment used for the improvement of the building thermal insulation is in fact an economic indicator. There is clearly an agreement in the appraisal of the benefits obtained by these indicators. The CO_2 emission produced by the manufacture of the materials employed in constructing a building of a specific type can also be another indicator. The potable water supply per inhabitant per day can become also an indicator regarding the scarce water resources of our societies. The application of these indicators is direct, rational and comparable. Nevertheless, it is very difficult to come up with a definition for an equivalent of these quantifications in the social aspects. Indeed, the questions remain clearly unanswered: what are the social indicators? What do they have to measure? On which concepts should they be applied to, or studied? And even more; is it possible to reflect, in a comparable way, the object to be measured, the scope and the results of these "social" criteria? What criteria can be taken as a common base so as to establish those criteria?

3. Aims of the indicators establishment

The primary aim of this proposal is to establish a common base among all these multiple approaches of the so called "sustainable architecture" in order to create a ground on which to specify, analyze and define the indicators integrating the aspects, and paying special attention to social determiners.

For this reason, in this study the following operations have been established:

- A selection of main resources, keeping in mind the broad spreading in the different fields.
- A compilation of definitions, their analysis, selection and systematized comparison of the gathered information.
- Establishing unifying criteria proposed for the completion and methodology to use the new indicators (system).

The working hypotheses stated at the beginning are the following:

- The assumption of the variety of points of view in sustainable architecture; the complexity of architecture allows several approaches.
- The difficulty a field such as building encompasses, with multiple and varied users.

- The variables, probable qualitative rather than quantitative, that social aspects include and which are fairly difficult to express in objective terms or with a certain degree of subjectivity implied in the process.

4. Basis and sources of knowledge

To reach an integral interpretation of the phenomenon, the different sources of knowledge should be clearly known and analyzed in detail. In the present state, sustainable architecture is a term used and even adapted in many different areas. Some of the sectors in which this term has become a landmark are commented hereafter. At the same time these sources define, in a direct or indirect way, their own idea of what sustainable architecture represents where the social indicators defining the concept are implicit.

4.1. HABITAT program of United Nations

The HABITAT program of United Nations and the International Community periodically organizes the Contest of Good practices. It has, as the main goal, to strengthen society and political awareness toward the improvement of the citizens' life conditions from a perspective of sustainable development. It works in agreement with the principles stated at the Second UN Conference on Human Settlements, Habitat 1, and the Dubai Declaration, ratified at the Special Session of the UN General Assembly , Istambul+5, celebrated in June 2001. Probably, this is the organization which more directly analyzes and awards initiatives with a clear "social" approach applied both to constructive and urban practices, developing a system on objective indicators of social issues within the integral concept of sustainability.

Regarding this, the Habitat Committee recognizes as Good Practices the following requirements, also drawn at the previously referred Dubai Declaration:

- To have a demonstrable and real improvement in the life conditions of the people.
- To be the result of a joint work among different sectors acting and living in the city: administration, citizens through their associations, and the private sector in general.
- To be socially, culturally, economically and environmentally sustainable and durable.
- To contribute to the strengthening of the community and its organization capacity.
- To specially consider the resolution of social exclusion problems, due to gender, cultural, ethic or economic reasons.

In the last of these callings, for 2008, the following areas of studies are stated; all of them strongly supported on socially bounded criteria:

- Housing area, in which concepts such as ecological dwellings, energetic saving and rehabilitations are included. Special attention is paid to problems such as rent problems, physical, economic and social accessibility for disadvantaged groups.

- Area of sustainable land and urban planning development. This section values improvements in the urban, physical, economic and social environments for all sorts of collective medium such as neighbourhoods, cities, tourist locations as well as their rehabilitations. It includes the land and urban planning which considers the accessibility and the design for all communities, the functional balance and the improvement of amenities.

- Specific area of gender and fight against social exclusion. It studies and values the initiatives which reduce specific problems of gender, migration and cultural diversity.

- Specific area of sustainable management of natural resources. It studies solutions and initiatives which promote a more efficient energy production, consumption reduction, renewable energies, and recycling. It also deals with the recuperation of contaminated grounds and the study of the water cycle.

- Area of the city and its natural environment; focusing on present and specific problems, such as ecotourism and new enterprise initiatives.

- Area of transport and accessibility, studying the specific problems of gender and disabled.

- Area of urban governs, insisting on issues of management and valuing solutions for gender specific problems.

4.2. Consolidated international private initiatives of scientific character: iiSBE

The iiSBE, acronym for *International Initiative for a Sustainable Built Environment,* has a recognized international acclaim. Among the great quantity of technical information found within it, the research referring to social aspects in the sustainable construction has not yet reached enough development, and specially not so in the case of health and air quality inside buildings. In the academic program of the International Conference SB05 held in Tokyo, areas normally related to sustainable construction (such as environmental assessment, building evaluation, case studies, urban and regional context and construction agents), were analyzed and for the first time ethical aspects regarding sustainable construction were also included. This shows how the scope of the different areas affected by the term sustainability in building are being enlarged and go beyond the merely technical aspects, moving towards a more complete, integrated concept of architecture. These ethical aspects focus in the relation between human beings and nature, and within it, the impact of the architectural professional in its surroundings. The need for ethical codes in relation to the performance of all the actors involved in the constructive process through learnt lessons and education aims was also highlighted.

4.3. Methods for building environmental assessment

These methods allow to establish objective comparisons between different buildings, in such a way that the ones with a “smaller environmental impact” can be chosen, and it will be possible then to give them the trademark of “sustainable building”. The different strategies of the environmental impact studies are well known for all the phases of the life cycle building –design, construction, maintenance and demolition--, regarding energy and resources use and specific environmental impacts.

The main methods or those which have been widely used are further described (Sangster, W. 2006.) All of them recognize, in their declaration of intentions, the economic, social and environmental benefits of a way of constructing which causes smaller impact to the environment. This leads to considering these practices as key factor for the upkeeping of the planet’s health, and a clear improvement of the products themselves together with the profits for the users.

These methods are the LEED (USA), BREAM (UK) , Green Globe (Canada y USA), Green Star (Australia), CASBEE (Japan), SBTool (originally from Canada using tools which have been regionalized and adapted in many countries such as Spain, Italy, Argentina, etc).

These systems assess environmental impacts through study fields or categories. As an example, the CASBEE method presents the following four areas: energetic efficiency, resource efficiency, as well as local and interior environment. Other methods include up to 9 areas of study, as in the case of the BREEAM: management, use of energy, health and user’s wellbeing, pollution, transport, use of solar energy, materials and use of water.

The fields of study refer mainly to environmental issues. None of these methods includes a study area specifically oriented towards social themes with concrete social indicators. However, they also include topics which clearly surpass the environmental issues, and they are related to more subjective issues: LEED includes design innovation and quality in the process; BREAM includes health and wellbeing; Green Globe, Green Star and CASBEE assess the quality of interior air as a study category; SBtool also refers to the quality in service, and transport indicators as well as distance to points of social relevance.

An important issue not to be forgotten due to its great transcendence is the new orientation these methods are undergoing; more precisely, SBTool of iiSBE which is going through a conceptual change where basically the impacts are measured and the reduction is assessed. The values given to each of the impacts are assigned regarding the priorities of each country and the local and global importance each one of them has. This new orientation is technically supported by the standardization efforts of CEN and ISO, and is also considered by the national norms (in the case of Spain, CTE and CALENDER)

Therefore the scientific precision of the process is enlarged, since it is not any longer based on the addition of the means from areas, criteria and categories but it needs a consensus on a more subjective basis. At the same time, it will allow for the self assessment by any of the implied agents in the construction and exploitation processes.

4.4. Reknown and highly qualified architecture

The spreading of “sustainability” in the field of architecture is done in the media through several sources. Since it is not a traditional or fixed subject in any educational cycle, and it is of quite recent development, and it appears in an area where a great ignorance prevails, the way it shows in the media and way this appearance is done has a great influence. Some architects known by their brilliant works and by their support to sustainable architecture have been of great importance for the wide spreading of sustainable architecture. Their opinions, including the contrary or opposed, have also contributed to the raise of the concept of sustainability.

These architectures, called by their authors “sustainable”, are represented as models for the public who accepts them as such without questioning this issue or posing any criticism. In fact, this would not have happened regarding other more technical aspects or other disciplines more studied by architecture. The works and even the opinions of architects such as Norman Foster, Renzo Piano, Richard Rogers, Shigeru Ban, Ken-Yeang, as well as other Spanish architects have a great impact on the general public, but even greater one on the younger generation of architects. A similar situation can be observed with well known international competition or contests, such as the Holcim Awards, or the Aga Khan Awards among others, in which sustainability and the solution to social and integration problems are part of their value. However, it is necessary to extract from this discourse the concept of sustainability, especially when the term is applied to these types of buildings in which their iconic character surpasses any kind of critical architectural analysis.

In relation to this, it is necessary to comment the different approaches these architectures hold regarding the social content. Guy and Farmer (2001) identify six different positions in where the social interest is a predominant idea when this specific context is considered as one of them. The logical premises of sustainable architecture, according to these authors are the eco-technique, eco-centric, eco-aesthetic, eco-cultural, eco-health and eco-social.

In the opposite side of the professional prestige, but also with an important incidence is the excessive marketing of some commercial products –included not only in buildings, but also within urban units and complex tourist complexes—which use the term “sustainable” as a commercial call in order to capture environmentally conscious clients, although with a great technical lack of knowledge. There is not yet an objective way or recognized mark to identify these initiatives as “sustainable”, which can be internalized by all the members, in a similar way to what has been done with other evaluation systems of scientific research.

4.5. Non-state spontaneous initiatives of collective participation character

A different vision in sustainable architecture, much more committed with the practical daily life and the social compromise, is the one developed by some organizations, associations, foundations, non-governmental and independent groups. Some of them have been founded by spontaneous efforts of people in the rural environment and are based on the agriculture practice, removed from any conventional commercial circuits. This is for example the case of the “ecoaldeas” (ecovillages), (RIE, Iberian Web of ecovillages) which have organized sustainable dwellings, considering ecological aspects apart from social, economic and cultural ones, and where green architecture is developed. They promote a horizontal development of strong social content opposed to the commercial structures.

Other initiatives have based their efforts in the recuperation of the heritage and the conservation of almost abandoned traditional techniques. As an example, the use of the soil as constructive material has been recuperated due to social, environmental reason, and because it represents a tradition and it is compatible with the surroundings where the constructions are inserted. Examples of this practice are: Centroterra, Arquiterra, Proterra, Interacción (Navapalos Foundation), Craterre (France), Terra Cruda (Italy), Modern Lehmbau (Germany) etc, which have brought up discussion forums, studies, documentation groups or research in different countries. These initiatives are not completely strange to the legacy of those American alternative movements from the 60’s, with the self-sufficient, imaginative, self-accomplished and isolated proposals such as the ones described in the film “Counter Communities”. The work of sustainable architecture performed within these initiatives has a strong social, practical character, and is self-sufficient to a great extend, far from the conventional industrialized systems.

4.6. Grouped Standardized Organizations

The main organizations are:

- International Standard Organization ISO and its committee devoted to sustainable construction (ISO/TC59/SC17 *“Building construction/ Sustainability in building construction”*)

- In a European setting, the committee CEN/TC350 *“Sustainability in construction works”* as a result of Mandate of the European Commission to CEN (*Standardisation Mandate to CEN “Development of horizontal standardized methods for the assessment of the integrated environmental performance of buildings”*).

- In Spain, the organization responsible for standardization, AENOR (Spanish Association for Standardization and Certification) created at the end of 2003, a working group on Sustainable Construction, within the AEN/CTN41 “Construction” committee, which later changed into AEN/CTN41/SC9 “Sustainable Construction” and has recently become an independent standardization committee by the name of AEN/CTN198 “Sustainability in Construction”. Other normalization groups are AEC (Spanish Association for quality) and ENAC (Notional Entity for Standardization).

As can be seen, the interest in developing standardizing projects is increasing. In this sense, the European program LENSE (Methodology Development towards a Label for Environmental, Social and Economic Building), is working in this direction on the three categories mentioned. These categories --environment, social and economic-- present a whole range of main subtopics including: safety, health, comfort, user’s wellbeing, functionality, social values (equality, accessibility, privacy, working conditions, and boundary properties), cultural heritage (architecture, image and history) and ethical values (orientated towards an honest purchase, punctual payment and acquisition criteria). Therefore, the field of valuable criteria has been noticeably broadened with more complete new concepts.

5. Conclusions

It is obvious that those sources of knowledge provide, each one, with a different face of the architectural fact. One general view of all those sources is necessary. HABITAT program of United Nations offers a merely social structure; Private initiatives of scientific character, such as iiSBE, have a technical and numeral approach to subjective items; Methods for building environmental assessment show a whole view, but have a great difficulty in catching the design parameters; Highly qualified architecture is not very environmentally rigorous, shows a scarcity of critics, and sometimes contains too much marketing; Non-state spontaneous initiatives of collective participation character are too poor artistically and technically; and Grouped Standardized Organizations have a particular items, not focused on the standard certification, and are very far away to catch the whole symbols and languages of the complexity of architecture. Nevertheless, all of them contribute to understand the whole concept, and to establish rules for more accurate definition of social aspects of sustainable architecture.

So, taking the working hypotheses stated at the beginning into account, that is, the variety of points of view of sustainable architecture, the complexity of architecture allows several approaches, and the difficulty to express in objective terms, it is possible to obtain some concept systematisation. Although what has previously been said is merely an approximation in which the indicators for an assessment are not clearly determined too, the social dimension of sustainability is suggested through the groupings in some performance fields such as:

- Social aspects of the built environment: urban mixture, mixed use of land, accessibility to basic means of transport including the transport in leisure and culture areas, availability of green areas and social segregation.

- Land use (for example, density since it contributes to the wellbeing of the inhabitant etc.).

- Impact of the building on the built heritage, cultural heritage or on the social structure of a specific environment (for example, the one related to Nimby, Not In My Back Yard which describes the adverse reactions of some of the neighbourhoods to certain type of constructions).

- Aspects referred to the process: user’s participation in the process, capacity to encourage a good relation among neighbours, quality to support social cohesion, consideration of the different social groups in the design of common areas, etc.

- Universality and integration of the human diversity, regarding capacities (psychic, functional, sensory disabled), ages, sexes, social status, religious and cultural situations etc.

- Health and comfort aspects of the users, referred to humidity conditions, temperature, interior air quality, and safety (home safety and safety in the workplace, fire, risk or dangerous situations, etc)

- Safety for the workers during the preparation and building construction, during the manufacture of the construction materials, etc. Although the normative is not directly treated, there are references towards it.

- Aspects referred to the circumstances of building acquisition, whether it is of contractual, economic, financial or of purchase capacity type.

- Aspects related to the environment from the point of view of the user: quality of architecture, relation with the traditional and artistic inherited heritage, etc.

It is quite clear that the study of the social aspects broadens and that it includes integral aspects of building. This wide field evidences the interrelation between primary environmental, economic and social aspects as a requirement for a sustainable valorisation and needs to be considered from a global perspective; a final holistic approach towards an integral project is necessary so that it shows the complete shelter and habitat of the human beings, that is, the essence of architecture.

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ANALYSIS OF PASSIVE COOLING EFFECT OF VEGETATION AND A CANOPY THROUGH FIELD OBSERVATIONS IN THE SUMMER

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Summary

In the last century or two, the increase in man's influence on the urban environment, such as the concentration of energy, and artificial factors, such as buildings and the heat characteristics of surface covering materials, has brought changes to city climates. Urban climate needs to be determined by many different factors, such as the use of various artificial buildings' surface materials on a building scale. The passive cooling effect has been recognized as the most effective alternative at natural cooling. This is a study of the passive cooling effects of three outdoor solar shading facilities: trees, a pergola with wisteria vine growing on it; and a steel framed canopy, all of which are expected to provide cool spots in the summer. Field observations of measuring the thermal environment of selected facilities are executed. The thermal environment measuring was categorized as short wave radiation, long wave radiation, net radiation, globe temperature, and surface temperature measured by an infrared camera. The heat transfer mechanism was analyzed with overall data from the field measurements. The results from this study are as follows; 1) The radiation balance measured on the shaded surface under the canopy was 17%(86 W/㎡) of the unshaded surface radiation balance(511 W/㎡). This clearly supports the theory of the natural passive cooling effect under the shade. 2) At 3 o'clock in the afternoon, a surface temperature comparison between the vegetation (the tree and the vine) and the canopy was performed. The surface temperature of the vegetation was same as the air temperature and that of the canopy was 5 ℃ higher than the air temperature. It is believed that the main factor that causes those differences in temperature is vegetation transpiration. 3) As the results from this study could be used as fundamental data for reducing the heat island, and continuous research on this subject is needed.

1. Introduction

As the city's overcrowding and centralizing is deepening, the increase in man-made arrangements, due to the concentration of energy, and artificial factors, such as buildings and the heat characteristics of surface covering materials, a decrease in vegetation, and wind directions affected by building structures, all act in concert to create a unique urban thermal environment. This urban environment is highly affected by the heat characteristics of building exteriors. Other factors, such as the characteristics of the buildings' exterior materials, planning the vegetation in the outdoor spaces, the planning of the building arrangement in consideration of the wind environment—all directly affect the urban thermal environment.

In consideration of the natural heat convection function, applying the passive cooling environment controlling method is the best possible alternative for a building's exterior space.

In this study, the outdoor solar shading facilities (trees, pergola with wisteria vine and canopy) are selected and analyzed for their passive cooling effects in the cool spots in the summer by observing the experimental objects' thermal environments, while focusing mainly on radiant environment and temperature.

The observations of the experimental object's thermal environment measuring were categorized as: short wave radiation, long wave radiation, net radiation, globe temperature, and surface temperature measured by infrared camera. The experimental objects and their surrounding area's heat transfer mechanisms are analyzed with overall data from the field measurement.

The result of this study is ultimately for a moderation of the thermal environment around the outer space of the building structure and it could be used as fundamental data to evaluate quantitatively for trees and the shading structure's spot cooling effect.

2. The outline of experiment

2.1 Space for experiment and methods of measurement

The experiment spaces are shown in Figure 1. The three popular outdoor solar shading facilities such as trees, pergola with wisteria vine, and a steel frame canopy were chosen as experimental spaces. The tree located in the grass garden is a zelkova tree, 7 m in height and 8m in width. The pergola with the wisteria vine is covered the steel frame, which is 7 m (length) ×5 m (width) ×2.4 m (height). The size of the steel frame canopy is 4 m (length) ×4 m (width) ×2.7 m (height) and is made of white Teflon.

a) tree *b) pergola with wisteria vine* *c) canopy*

Figure 1 The experiment spaces

The location of the measurement points were selected on each experimental object as the shaded area and the unshaded area to measure air temperature, surface temperature, globe temperature, relative humidities, wind velocity, infrared radiation temperature, and both long and short wave radiation. Among the radiant environment measurements, long wave radiation is measured on each experimental object, one by one, due to the difficulties in supplying the measuring device.

2.2 Experiment conditions

The conditions set for the experiment and the measurements of the representative day are shown in Table 1. The experiment conditions were set up to measure the thermal environment and radiation balance of the each experimental object's lower part, including the shaded area and the unshaded area.

The experiment was conducted from the 12th to the 15th and the 27th to the 28th of August in 2005. During the fine weather conditions of August 12th to 15th, the 13th of August was chosen as the representative day and analyzed. In this study, the measurement of the thermal environment was taken at the height of 0.8 m. On both the27th and the 28th of August, a long wave radiation measurement was added to be observed and analyzed. To measure the shape factor of each experimental object, a fisheye lens was used. The calculated shape factors are as follows: trees, 0.73 (73%), Pergola with wisteria vine, 0.77 (77%), and canopy, 0.58 (58%). The shape factor of the pergola with wisteria vine measured the highest and the shape factor of the canopy measured the lowest.

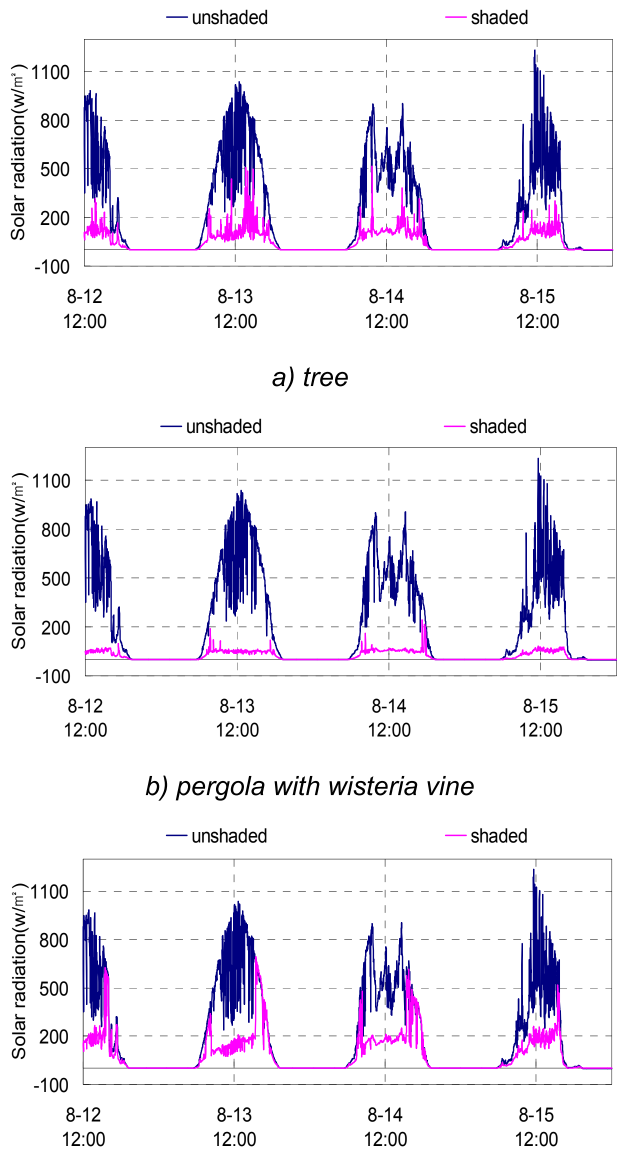
Table 1 The weather condition of the representative day

Experiment condition	Experiment day	Representative day	Temperature[℃]			Globe temperature[℃]			Relative humidity[%]		Wind speed[m/s]		
			Max	Min	Aver.	Max	Min	Aver.	Max	Min	Max	Min	Ave.
Tree (unshaded)	2005.08.12 ~08.15	2005. 08.13	35.9	22.6	27.9	50.8	21.7	32.4	95	47	3.4	0.0	0.7
Tree (shaded)			35.0	22.3	27.7	41.4	22.5	29.4	94	49	-	-	-
Pergola (unshaded)			37.3	23.5	29.2	50.5	23.0	33.6	-	-	-	-	-
Pergola (shaded)			34.2	23.6	28.6	40.1	23.7	29.7	-	-	-	-	-
Canopy (unshaded)			34.5	23.7	28.7	49.4	23.5	33.3	-	-	-	-	-
Canopy (shaded)			34.5	23.9	28.9	52.4	23.7	32.1	-	-	-	-	-

3. Analysis of experimental results and examinations

3.1 Solar radiation, relative humidity, wind velocity distribution

The distribution of solar radiation is shown in figure 2. The maximum value of solar radiation was 1,000 W/㎡ on the representative day. The value of solar radiation under the shaded area of the tree was about 60~120 W/㎡; under the pergola with wisteria vine was 40~60 W/㎡; and under the canopy was 80~200 W/㎡ (Figure 2). Around noon time, from 11:30 to 12:30, each experimental object's shaded area's solar radiation

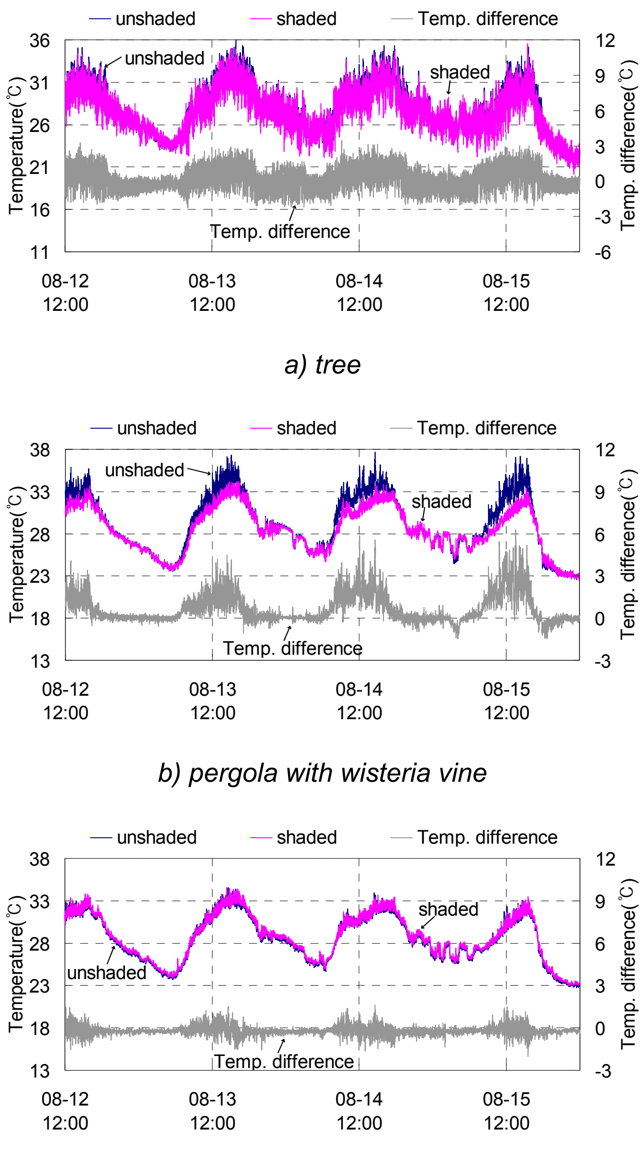


a) tree

b) pergola with wisteria vine

c) canopy

Figure 2 Distribution of solar radiation



a) tree

b) pergola with wisteria vine

c) canopy

Figure 3 Air temperature (Shaded and unshaded area)

was compared with their unshaded areas' solar radiation (1 hr average: 601 W/㎡) as follows: trees 15%(88 W/㎡), Pergola with wisteria vine 8%(48 W/㎡) and canopy 22%(129 W/㎡) (Figure 2).

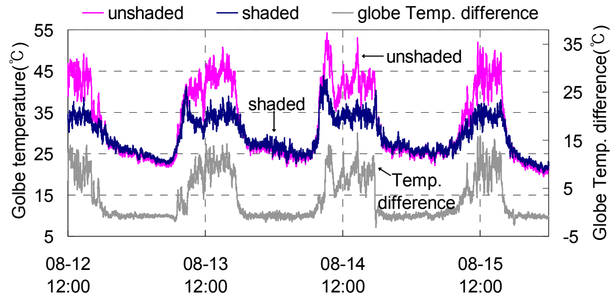
According to the result, the Pergola with the wisteria vine had the highest shading effect over the solar radiation, while the canopy had the lowest. These results were derived from the interaction of the multi vegetation structure (leaves) with the higher radiation shading rates, the canopy's shading structure (white), and the reflection effect of the solar radiation and the low shape factor.

The representative relative humidity was 47~95% and the humidity difference between the tree's shaded and unshaded areas was at most 8%. The maximum wind velocity on the representative day was 3.4 m/s, with an average of 0.7 m/s, the experiment had been conducted under a low wind velocity condition.

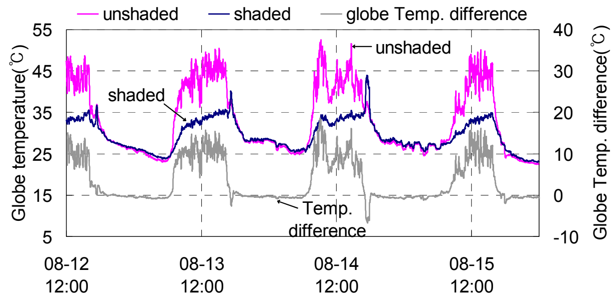
3.2 Temperature distribution

3.2.1 Outdoor temperature

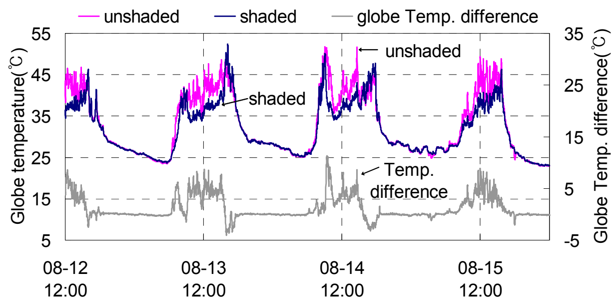
The experimental objects' shaded and unshaded areas' air temperatures are shown in figure 3. At around 05:40, the tree's unshaded area's air temperature on the representative day (13TH of August) had the lowest temperature of the day - (23.7 ℃) , while at around 15:50, it had the highest temperature of the day, at (35.2 ℃). The pergola with wisteria vine's unshaded area's air temperature was the lowest, at 23.9 ℃, at around 05:40, while its highest temperature (36.6 ℃) was measured at around 15:10. The canopy's



a) tree

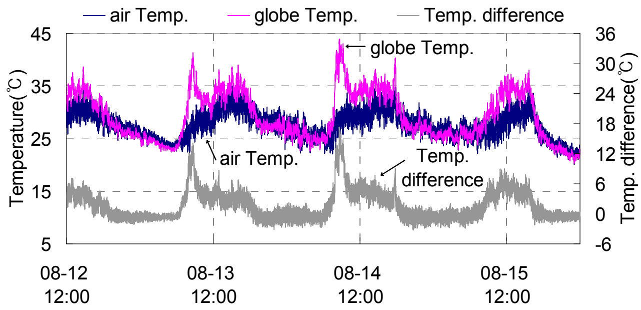


b) pergola with wisteria vine

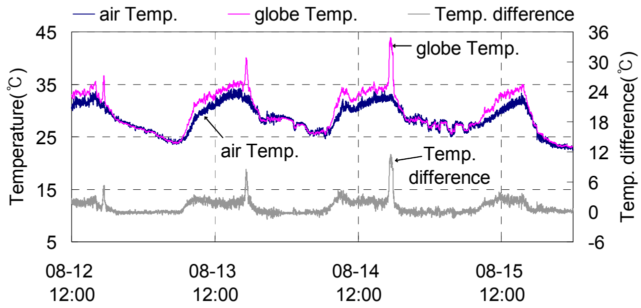


c) canopy

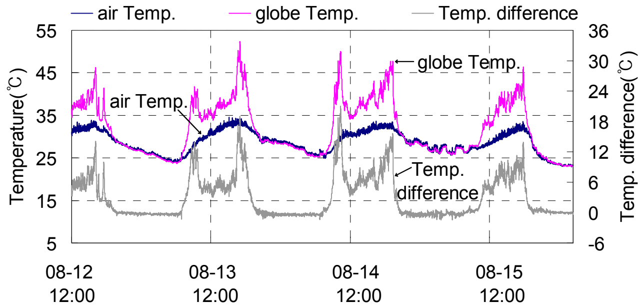
Figure 4 Globe temperature (shaded and unshaded area)



a) tree



b) pergola with wisteria vine



c) canopy

Figure 5 Globe and air temperature (unshaded area)

unshaded area's air temperature was measured at its lowest (23.8 ℃) at around 05:40 and its highest temperature (34.5 ℃) came at around 14:40. The pattern of the temperature changes was similar. The temperature difference between the shaded and unshaded areas in the Pergola with the wisteria vine was higher than between the tree's 2 areas. Compared to the tree and the canopy, the Pergola with the wisteria vine had the highest difference in air temperature, and the canopy had the least temperature differences (Figure 3). However, the air temperature measurement of each experimental object at 0.8 m high and 1.5 m high did not show any particular differences. Therefore, it is not mentioned in this study.

3.2.2 Globe temperature

The measurement of globe temperature, which is the incorporation of the radiant component around the experimental object's shaded and unshaded areas and the convection component in the surrounding air, is shown in Figure 4, 5 and table 2. To compare and analyze the experimental objects' shaded and unshaded areas' globe temperature changes under the equal conditions, the experiment was taken between 10:00 and 15:00, when the altitude of the sun is high and the shade is formed stably.

First of all, the globe temperature for the tree's unshaded area, where the solar radiation is directly affected, ranged from 33.2 to 50.2 ℃(average 42.6 ℃), while for the shaded area, it ranged from 28.7 to 38.5 ℃ (average 33.2 ℃). The tree's shaded area had little temperature variation as the temperature difference in the unshaded area was measured as 17 ℃ and the shaded area as 9.8 ℃. There was a temperature difference of 4.5~11.7 ℃ between the tree's shaded area and its unshaded area. The average temperature difference of 9.4 ℃ was measured (Table 2, Figure 4 a)).

The temperature of the Pergola with wisteria vine's unshaded area ranged from 36.6~50.1 ℃ (average 44.5 ℃) while in the shaded area, it ranged from 31.6~35.5 ℃ (average 33.4 ℃). Compared to the tree, its

Table 2 Temperature of representative day

Experimental object	Experimental areas	Globe temperature changes [℃]	Average[℃]		
			Globe temp.	Air temp.	Temp. difference
Tree	unshaded	33.2~50.2	42.6	-	-
	shaded	28.7~38.5	33.2	30.2	3.0
	difference	4.5~11.7	9.4	-	-
Pergola with wisteria vine	unshaded	36.6~50.1	44.5	-	-
	shaded	31.6~35.5	33.4	31.7	1.7
	difference	5.0~14.6	11.1	-	-
Canopy	unshaded	35.4~48.2	41.4	-	-
	shaded	34.1~40.8	36.6	31.8	4.8
	difference	1.3~7.4	4.8	-	-

unshaded area's average globe temperature was 2 ℃ higher, while the shaded area was only 0.2 ℃ higher (Table 2, Figure 5 b)). Finally, the canopy's unshaded area ranged from 35.4~48.2 ℃ (average 41.4 ℃), while in the shaded area it ranged from 34.1~40.8 ℃ (average 36.6 ℃). Unlike the other experimental objects, the canopy's unshaded area's average globe temperature difference was 3 ℃ lower but its temperature in the shaded area was more than 3 ℃ higher. The difference in globe temperature verified that the passive cooling effect of the shading structure (the canopy) was not effective (Table 2, Figure 4 c)).

In the comparison of the air temperature and the globe temperature, the little temperature differences both in the shaded area of the tree and the Pergola with wisteria vine were measured at 3.0 ℃ and 1.7 ℃ respectively. On the other hand, there was a relatively big difference of 4.8 ℃ in the canopy's shaded area compared to the vegetation (tree and Pergola) (Figure 5). This is a result of the reflection of the radiation energy of canopy.

3.2.3 The surface temperature of the objects

The experimental objects' surface temperatures were measured using an infrared radiation camera at the hours of 06:00, 11:00, 13:00, 15:00, and 22:00. The surface temperature reached its highest at 15:00. The surface temperatures of the vegetation (trees and Pergola with wisteria vine) were the same as the air temperatures, while the canopy's surface temperature was 5 ℃ higher than the air temperature. The temperature difference is a result of the differences in heat characteristics between artificial materials and vegetation. This can be explained as the cooling effect of the transpiration of the vegetation. On the other hand, the surface temperature of the canopy measured at dawn (06:00) was lower than that for the vegetation. The surface temperature after sunset (22:00) was similar to that measured at 06:00. The surface temperature of the canopy showed that it was high during the days and low at night.

3.3 Radiation environment

The graph of the short wave radiation and the net radiation of the experimental object's unshaded area measured on 28th of August. On this day, the radiation balance (short wave radiation, long wave radiation, net radiation) of each experimental object's shaded and unshaded areas were measured and analyzed and are shown in Table 3.

3.3.1 Short wave radiation

In observing the value of the downward short wave radiation of each object, the canopy had a value of 154 W/㎡, ahead of all the other objects' values. The upward component of the shortwave radiation was 82 W/㎡, the highest value of all the other objects. Its difference was 72 W/㎡ and it was verified that the canopy observed the most of the short wave radiation. The albedo in the tree's unshaded area was calculated as 0.30(=249÷838), as shown in table 3. The value of the albedo in the canopy was high, as its reflection rate affected influentially as it was in white color unlike the vegetation which was in green color.

3.3.2 Long wave radiation and net radiation

In the same manner as the short wave radiation analysis in the previous section of 3.3.1, the long wave radiation radiated by the surface temperature of the object measured highest in the canopy, as the result of the fact that the surface temperature of the canopy was higher than the other experimental objects.

On the contrary, the vegetation (trees and Pergola with wisteria vine) had a relatively low surface temperature compared to the canopy; therefore, the long wave radiation measurement was also low.

In the section on the overall radiation rate in table 3, "▼mark" represents the direction of the overall radiation balance according to the results of the calculations. As above, the value of the overall radiation balance (net radiation) implies the surrounding area of the objects' radiation energy value. As a result, the calculated radiation in the unshaded area of the tree, at 511 W/㎡, was much higher than that in the canopy, at 86 W/㎡. The reason for the low radiation value of the canopy's shaded area of 86 W/㎡ was because the downward short wave radiation (154 W/㎡) was lower than the tree's unshaded area's radiation (838 W/㎡). Moreover,

Table 3 The result of radiation environment

Experimental object	Direction	Short wave radiation [W/㎡]	Long wave radiation [W/㎡]	Net radiation [W/㎡]
Tree (shaded)	downward	84	459	543
	upward	32	460	492
	difference	▼ 52	▲ 1	▼ 51
	total	116	919	1,035
Pergola with wisteria vine (shaded)	downward	25	476	501
	upward	22	463	485
	difference	▼ 3	▼ 13	▼ 16
	total	47	939	986
Canopy (shaded)	downward	154	500	654
	upward	82	486	568
	difference	▼ 72	▼ 14	▼ 86
	total	236	986	1,222
Unshaded	downward	838	431	1,269
	upward	249	509	758
	difference	▼ 589	▲ 78	▼ 511
	total	1,087	940	2,027

"▲,▼" represents the direction of the radiation

as to the total value of the short wave radiation, the tree's unshaded area measured at 1,087 W/㎡, while the Pergola with wisteria vine's shaded area was 47 W/㎡; therefore, the variation difference was 1,040 W/㎡. On the other hand, in the long wave radiation, the canopy's shaded area was measured at 986 W/㎡, the tree's shaded area was measured as 919 W/㎡, showing a difference of only 67 W/㎡; therefore, the measurements of the long wave radiation showed that, it was not depends on the objects.

The overall value of the long wave radiation of the canopy measured the highest, at 986 W/㎡, as its surface temperature was relatively higher than the other objects (vegetation). This because there was no transpiration in the canopy, like there was with the vegetation, and also because it is made of artificial materials.

4. Results

1. In comparing the air temperatures and the globe temperatures under the objects' shaded areas, the canopy, which has a higher reflection rate than the vegetation, showed the biggest difference in temperature values. It is believed that the main reason for this was that there is a higher reflection rate in white than in vegetation, which is green.

2. The surface temperature reached the highest at 15:00. The surface temperature of the vegetation (trees and Pergola with wisteria vine) was approximately same as the air temperature while the canopy's surface temperature was 5℃ higher than the air temperature. The temperature difference results from the differences in heat characteristics between artificial materials and vegetation. This cooling effect can be explained by the transpiration of the vegetation.

3. The radiation balance measured on the shaded surface under the canopy was 17%(86 W/㎡) of the unshaded surface radiation balance(511 W/㎡). This clearly supports the theory of the natural passive cooling effect under the shade

4. The overall value of the long wave radiation of the canopy measured the highest, at 986 W/㎡, as its surface temperature was relatively higher than that of the other objects (vegetation). This, and the fact that it's made of artificial materials, is the reason there was no transpiration in the canopy, unlike in the stratified vegetation, and therefore less of a passive cooling effect from the canopy.

Acknowledgement

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A STUDY OF PUBLIC HOUSING LIVING ENVIRONMENTS FOR THE ELDERLY IN TAIWAN

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Keywords：the elderly, living environment, public housing

Summary

Regardless of developed or newly industrialized countries, the phenomenon of “old age less offspring” has become a trend for future population development. According to relevant studies in Taiwan, living style and living intentions of the elderly are aimed at “aging in place”. Hence, the current living environment of the elderly has become an important issue. In addition, residents of public housing in Taiwan are mostly veterans. Initially, community planning of public housing and design regulations in Taiwan emphasized “cross-generation life demands”. However, whether this intended design was actually implemented is yet to be confirmed. Therefore, we used six public housing developments as research subjects to examine the current conditions for the living environments of the elderly.

1. Introduction

Currently, the aging population is higher than 15% in West European countries, compared with Japan at 20% in June 2006. In July 1993, the aging population in Taiwan exceeded over 7%, and Taiwan formally became an “aging society”. At the end of 2006, it reached 10% with an aging index of 55.2%, indicating Taiwan is facing an unavoidable aging problem. Furthermore, according to the survey, the aging population will reach 14% by 2017, only 24 years to go from 7% to 14%, which is equivalent with the pace in Japan. Compared with other developed countries, it is obvious that Taiwan has less time for preparation; hence, living arrangements for an aging society is a topic that demands active confrontation.

Studies conducted in Taiwan show that, living style and living intentions for the elderly are mainly based on “aging in place”. Therefore, from this perspective, we selected six public housing buildings in Taiwan as research subjects to examine living environment usage and functional requirements. The purpose of this study includes; 1) establish “review framework of living environments for the elderly; 2) review living environments for the existing elderly in public housing; 3) suggest methods to improve living environments of public housing for the elderly.

2. Research method

According to literature review, this study divided the living environments into: “indoor environment”, “building environment”, “community environment”, and “urban environment” for discussion. Based on the data concerning the aging phenomenon and corresponding living environment designs for the elderly, functional requirements for elderly living environments include: 1) safety, 2) health, 3) convenience, 4) comfort, and 5) assessment of welfare, as shown in Fig. 1. Referring to regulation standards and data information for elderly housing, we established evaluation factors and criteria for each item of the “Questionnaire on current situations for elderly living environments”, and conducted survey with the objective “Questionnaire on current situations for elderly living environments” and subjective ”Questionnaire on elderly living environments”. We also compared and analyzed survey results of all public housing communities in order to understand facility differences in different stages. From the perspective of the elderly, suggestions on points of attention and improvement regarding public buildings and living environments were proposed for use as reference in future planning, design, and improvements.

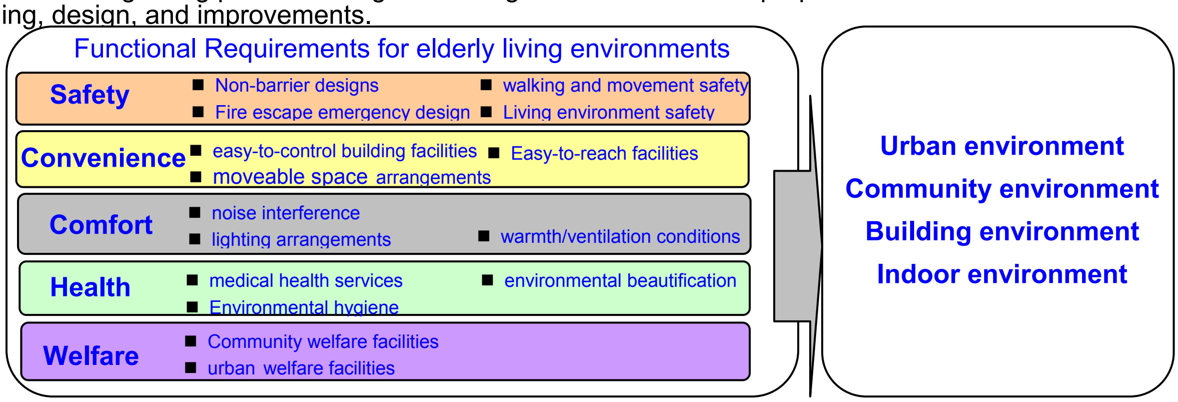

Fig. 1 Review Framework for elderly living environments

3. Research Subjects

3.1 Case study

Existing public housing in Taiwan can be roughly divided into three stages based on the date of its construction: Initial stage(stage1), Development stage(stage2), and Transition stage(stage3). Two public housing developments, in three stages were chosen for this study, and analyzed from aspects of indoor environment, building environment, community environment, and urban environment. The case profiles are shown in Table 1.

Table 1 Basic Data of Survey Cases

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6
Periods	Initial stage(stage1) (1975--1981)		Development stage(stage2) (1982--1991)		Transition stage(stage3) (1992~2008)	
Location	East District, Tainan City	East District, Tainan City	North District, Tainan City	Anping District, Tainan City	East District, Tainan City	North District, Tainan City
Construction date	1978~1980	1980~1982	1982~1984	1991~1995	1996~1999	1998~2003
Number of units	532	1,530	902	226	506	1,222
Number of floors	4F, 7F apartment	5F apartment	5F, 7F~12F apartment	5F apartment	5F, 12F apartment	11~14F apartment
Number of questionnaire	32	80	52	34	34	63
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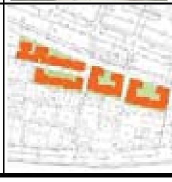
Layout						

3.2 Basic information of the interviewees

This study conducted in-person interview with community residents over the age of 65, and a total of 295 effective questionnaires were rendered. In addition, five households were chosen for an indoor environmental survey for every case. The surveyed interviewees included 51.21% female, 48.79% male, 30.31% with elementary education background, uneducated was 25.09%. The following statistics indicate the general living styles of the elderly in Taiwan with source of living expenses including: self-support (41.78%), followed by from children (33.56%); most elderly (and spouse) are living with their children (59.85%), and a low percentage is living alone. It reflects the common living style of elderly in Taiwan. The ideal living style considered by elderly is “living with children”, which highlights the importance of “at-home living environments for the elderly”.

4. Results Analysis

4.1 Satisfaction with entire living environment

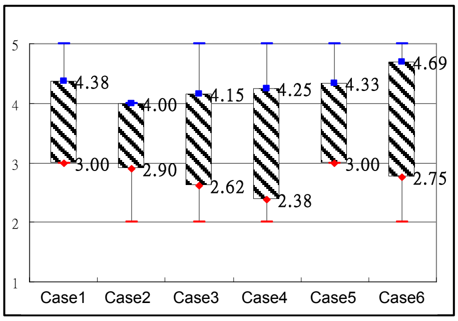
In terms of overall indoor environment satisfaction, the average community satisfaction is as follows: the average satisfaction in Case 1 has an increasing trend, indicating that living environment design is more concerned in buildings built in recent years. The building environment showed no significant trend, and the satisfaction varies according to the public housing community planning, among which, Case 4 ranked the lowest. Community environment satisfaction is affected by entire community planning, arrangement, and size of public facilities/space; among which,,community satisfaction in the transition stage(stage3) is higher. There is little difference of urban environment satisfaction among all cases, as shown in Figs. 2~5.

4-2 Review for the elderly living environment functions

4.2.1 Safety review

(a) Review of no-barrier designs

The width of indoor living room entrance is smaller than the width of the average wheelchair, there are 2cm or higher doorsills at the entrances of living room, kitchen, bathroom, and balcony in most cases. Only cases since early transition stage(stage3) are design with sloping path for disabled; and the self-built sloping path have not met the needs of elderly in terms of slope, height of armrests, and extensions. For building less than five stories, all five cases have not equipped with elevator facility, which causes daily inconvenience of vertical movement for the elderly.



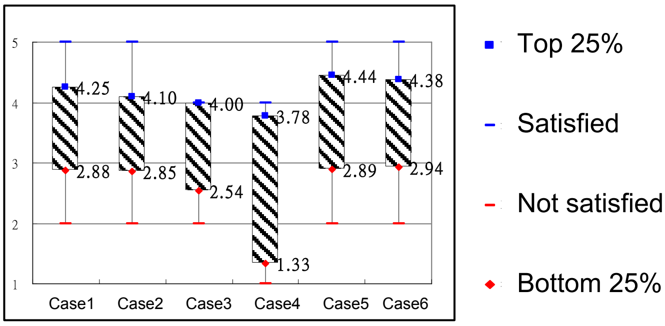
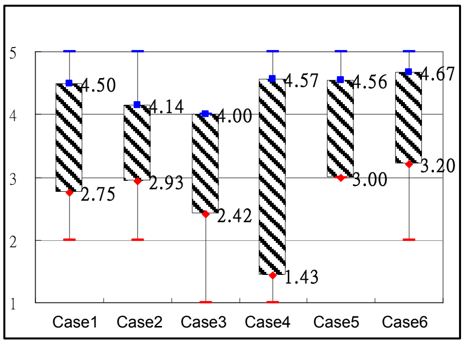


Fig. 2 Indoor environment satisfaction *Fig. 3 Building environment satisfaction*



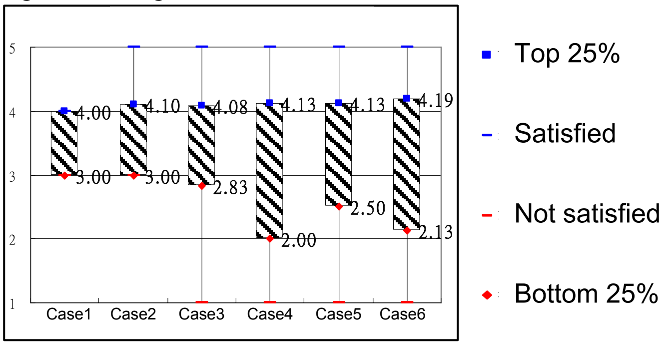


Fig. 4 Community environment satisfaction *Fig. 5 Urban environment satisfaction*

(b) Review of fire escapes and emergency designs

Fire alarms and automatic sprinklers must be added in kitchens and bedrooms to ensure the safety of the elderly. In addition, the survey found that the most needed facility is “automatic gas disconnection device” in elderly homes, as shown in Figure 6. It shows the importance and need for household fire safety for the elderly.

The building fire safety survey indicated that following the progress and practice of new regulations, fire safety facilities such as fire distinguishers and fire alarms have already been improved and installed. Emergency lighting equipments have been installed since the development stage(stage2); since the transition stage(stage3), emergency broadcasting system has been installed.

(c) Review of walking and movement safety

The survey results showed that there are no handrails installed in front porch and bedroom for elderly at home The elderly consider the bathroom to be the most accident-prone indoor space, but only 4 elderly households (13.33%) have installed handrails by the side of the toilet and bathtub. Regarding flooring and tiles, slip-proof porcelain tiles are largely used in bathroom and kitchen in all cases. In addition, a local survey of indoor accident rates showed that the bathroom (38.28%) is the highest, followed by the living room (21.09%), the bedroom (17.19%), and the dining room (9.38%).

(d) Review of living environment safety

Regarding safety facilities, there was no emergency call device in any of the cases. For the cases in the initial stage (Cases 1 and 2), there are no cold/hot labels on bathroom faucets, which is a cause of danger to the elderly.

For achieving safety in elderly living environments, survey results showed that the three areas that require the most indoor improvements are bathroom (27.6%), living room (20.36%), and bedroom (17.65%), as shown in Figure 7. Individual items needed for improvement include: (1) living room: size of space, slip-proof materials, doorsills removed; (2) dining room: size of space, slip-proof materials, improved lighting; (3) kitchen: gas leakage detectors, size of space, slip-proof materials; (4) bedroom: size of space, handrails added, air conditioner heater added; (5) bathroom: size of space, slip-proof materials, handrail added. Regarding the buildings that have the greatest need of improvements, all buildings that were built in earlier days or seldom repaired have higher demands for improvements.

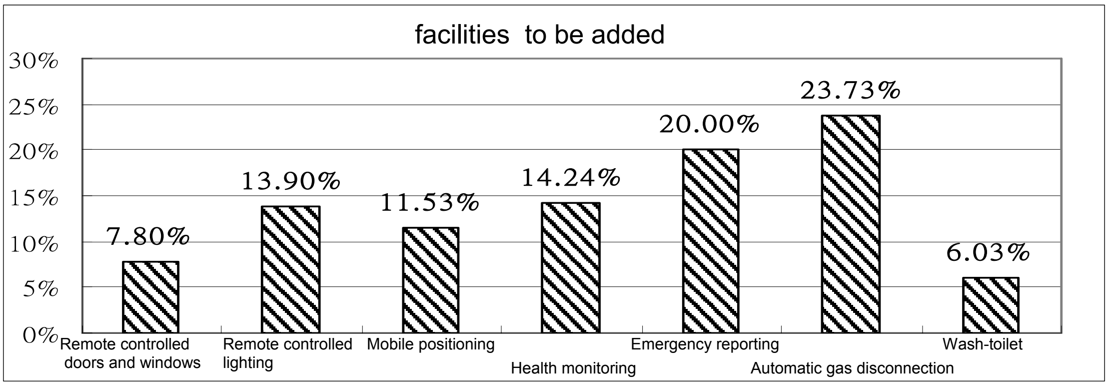


Fig.6 The most-needed indoor facility

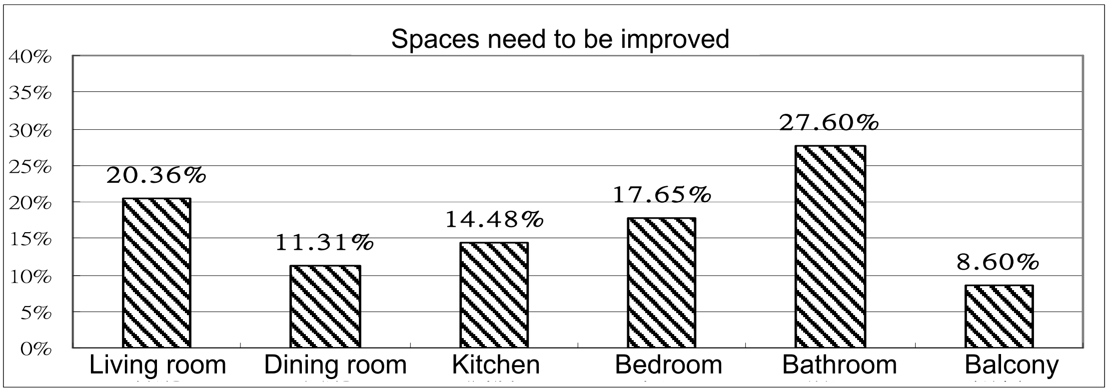


Fig. 7 Necessary renovations of indoor spaces

4.2.2 Convenience Review

(a) Review of easy-to-control building facilities

In all cases, bathrooms have horizontal pull-style windows with a higher-than-average windowsill standard (>140cm). Doors and screens are inward/outward open style with higher than the standard of 85~90cm distance measuring between the floor and handle. Handle style is a rotary lock, which causes inconvenience for the elderly. Regarding the height of light switches, the ideal height is 90~105cm from the floor; yet in the survey, we found the height of most indoor switches in community building is 110~125cm. The ideal height between floor and switch is 70~90cm. This survey found that the average height for switches in living rooms and bedrooms is 30~35cm, 100~140cm for kitchen, and 110~135cm for the bathroom.

Regarding facility cleaning and maintenance, as shown in Figure 8, there is a very high percentage of self-maintenance addressing water pipe blockages for elderly residents. In Cases 3~6, nearly 60% elderly residents would replace light bulbs on their own, and among the self-cleaning items, cleaning air conditioner filters is the highest because the cleaning frequency is rather low.

(b) Review of moveable space arrangements

In terms of indoor master bedroom space, 50% of the cases have less than the ideal standard of 12 ㎡ (Case 1:11.34 ㎡; Case 3: 11.70 ㎡; Case 5:10.88 ㎡) of floor space. For indoor bathrooms, 60.38% of the elderly do not have a bathroom because the master bedroom is used by children or grandchildren.

In shared stairs and halls, all cases meet the standard of over 140cm (radius for wheelchair rotation) to ensure a convenient entrance for elderly in wheelchairs. Regarding separate lanes for pedestrians and cars, all cases adopt separate lane design. In terms of satisfaction on community outdoor hallways, Case 4 has the lowest satisfaction level due to its poor hallway design and motorbike parking, which have caused problems for other residents and serious access problems for the elderly.

(c) Review of easy-to-reach living facilities

"Usage frequency" and "convenience" for urban facilities are the main topics for review. In terms of usage frequency, these are generally categorized as "economical living facilities", "medical health facilities", and "cultural recreational facilities". The detailed classifications are as follows: 1) park/green space, 2) traditional/supermarkets, 3) hospital/clinic, 4) dining facilities, and 5) post office/financial institutions. The uses of cultural recreation and social welfare facilities are comparatively lower.

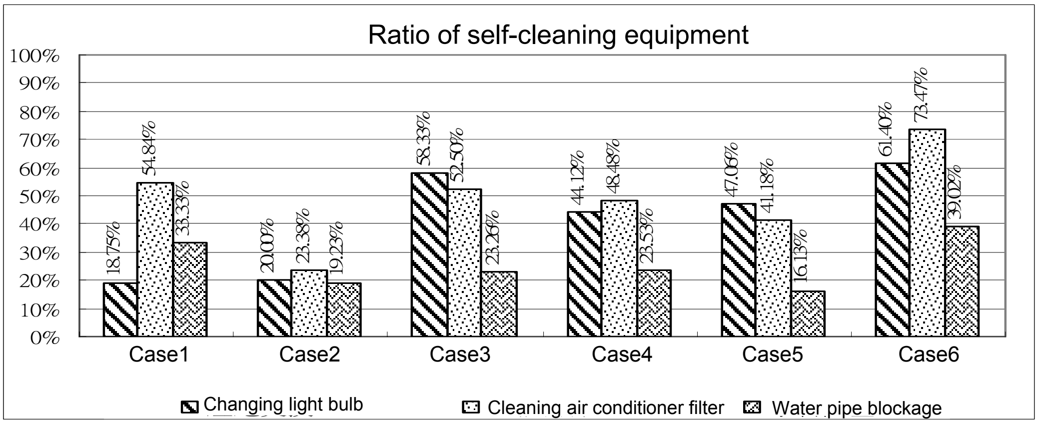


Fig. 8 Percentages for case facility self maintenance

4.2.3 Review of comfort

(a) Review of noise interference

Dissatisfaction on noise interference is much higher than any other items in every case. The effect of outdoor traffic noise is apparent in all cases, as shown in Fig. 9.

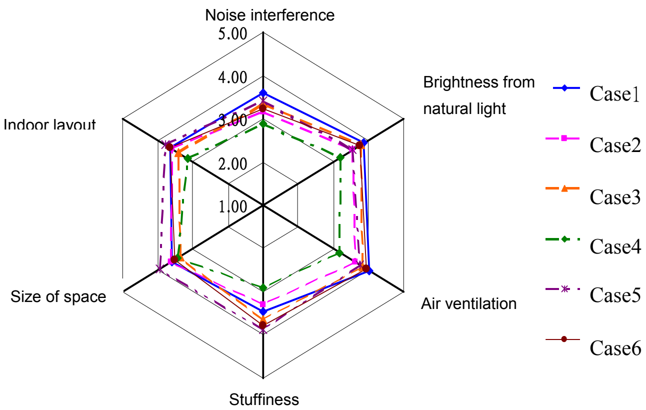
(b) Review of lighting arrangements

The satisfaction on indoor lighting is affected by the overall layout of the community and surface planning and design. Among all surveyed cases, Case 4 has the worst satisfaction due to its closed architectural design.

(c) Review of warmth/ventilation conditions

For building cases in our survey, most buildings face south and north, except for Case 3. Residents are generally satisfied with indoor muggy conditions. In Case 4, the satisfaction is lower because the community has no separation of buildings and open ground like other communities, and is located in an alley surrounded by crowded and narrow building structures, which lead to muggy conditions. In the survey of air conditioning facility installations, no heating facilities are installed in elderly households, the need for heating facilities is lower for the elderly living in southern Taiwan. Regarding air conditioning, there are 67.86% elderly having air conditioning installed in the bedroom.

The satisfaction on air circulation in each case is above average. Among them, there is higher satisfaction on indoor ventilation in Case 6 and Case 1. Although there is over 20 years of gap the construction period of the two building cases, the architectural designs adopted individual building-plan layout, which created better indoor ventilation. Case 4 has the lowest satisfaction due to its enclosed architectural style, which causes ventilation problems. This shows the importance of “planning and design” for residential physical environments, as shown in Fig. 10.



5:Very satisfied 4：Satisfied 3：Fair 2：Not satisfied
1： Very dissatisfied

Fig. 9 Satisfaction survey of case study for indoor environment satisfaction

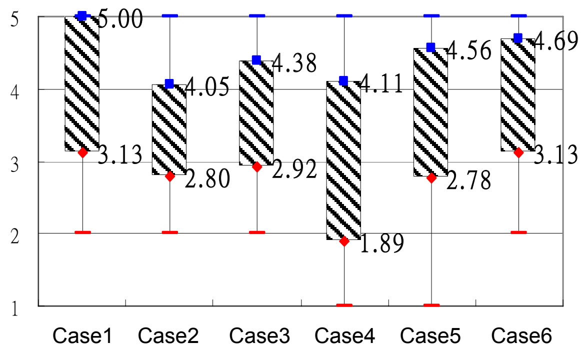


Fig. 10 Satisfaction on indoor air circulation

4.2.4 Health review

(a) Review of medical health services

The survey found health issues ranking the second highest, only after safety issues, for the elderly. Facilities expected by the elderly include health-monitoring equipment (14.24%), as shown in Figure 11. As to community environment, most elderly consider medical stations as the most needed (26.80%) in public spaces of the community. Currently, three community cases are providing simple blood pressure measuring services. In urban environment, hospital/clinic usage for the elderly is higher, with an average of 1~2 visits per month, it also includes 70% elderly who visit 3~4 times per month, indicating the importance of medical facilities for the elderly. The transportation time needed to reach hospitals and clinics is approximately 5~15 minutes, with over 80% of the elderly able to reach hospitals within 30 minutes, showing it is commonly used in the area.

(b) Review of environmental hygiene

The survey showed that waste and garbage disposal in all communities, for all building cases, are collected by garbage truck, except for the garbage disposal services in Case 6. Survey results indicated that 30.38% of the elderly think garbage disposal service is necessary and should be provided, as shown in Fig. 12. In addition, 12% of the elderly think stores in the community affect community living and cause environmental problems.

(c) Review of environmental beautification

In terms of satisfaction on outdoor recreational space, the elderly generally expressed satisfaction. Case 4 showed the lowest satisfaction because the community has very limited outdoor recreational space and green plantation, and is floored with tiles, as shown in Fig. 13. For other cases, centralized open recreational space is provided, indicating that proper community layout design and sufficient outdoor recreational space are essential to meet the needs of the elderly.

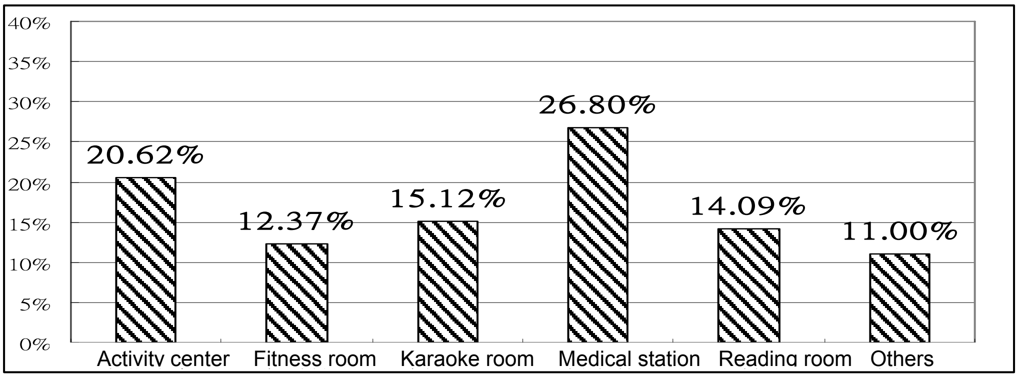
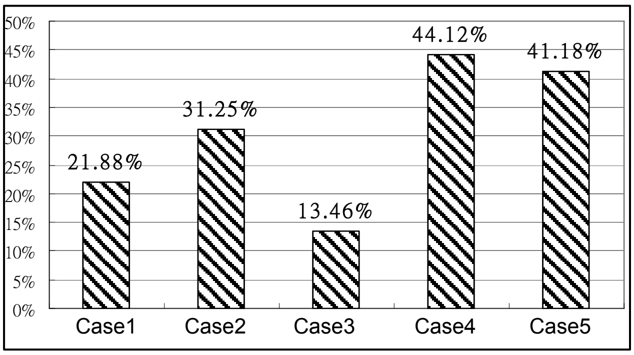


Fig. 11 Public spaces desired to be added



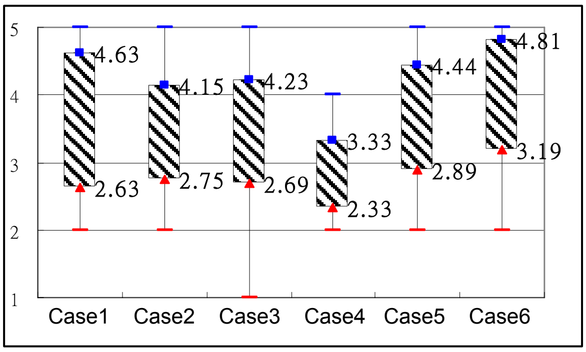


Fig. 12 Percentage of the demand of waste disposal services

Fig. 13 Outdoor recreational services

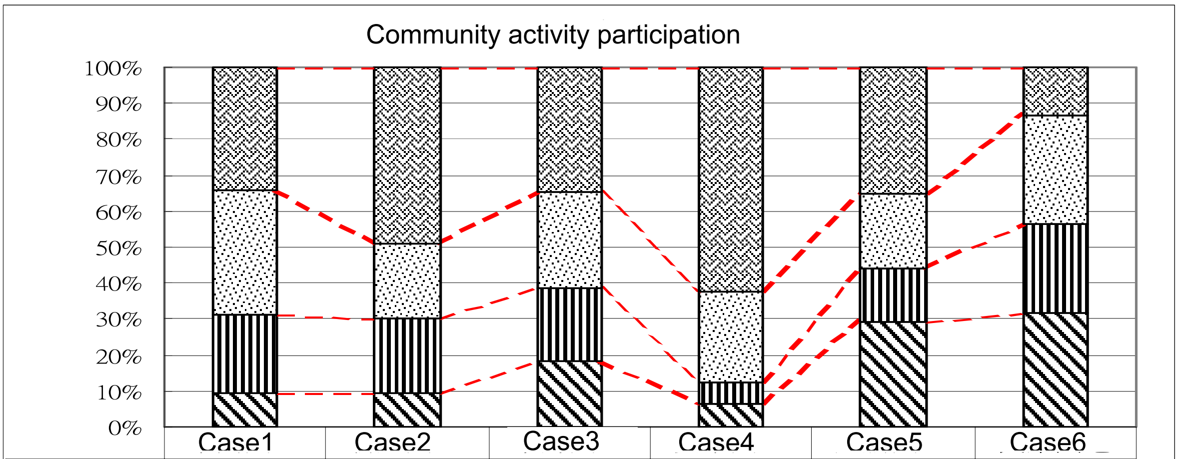
4.2.5 Review of welfare

(a) Review of community welfare facility participation

The survey showed that only Case 6 has provided community meal delivery services. Using space in community centers to provide the elderly with less expensive and convenient meals have resulted in a positive feedback. Among other cases, there are 20.12% hoping to have meal services in the community. In terms of community activity participation, besides personal preference, promotion by the community committees is an important factor. In the transition stage(stage3), the community committee is more active, and organizes more activities, thus, the activity satisfaction and participation levels are higher, as shown in Fig. 14.

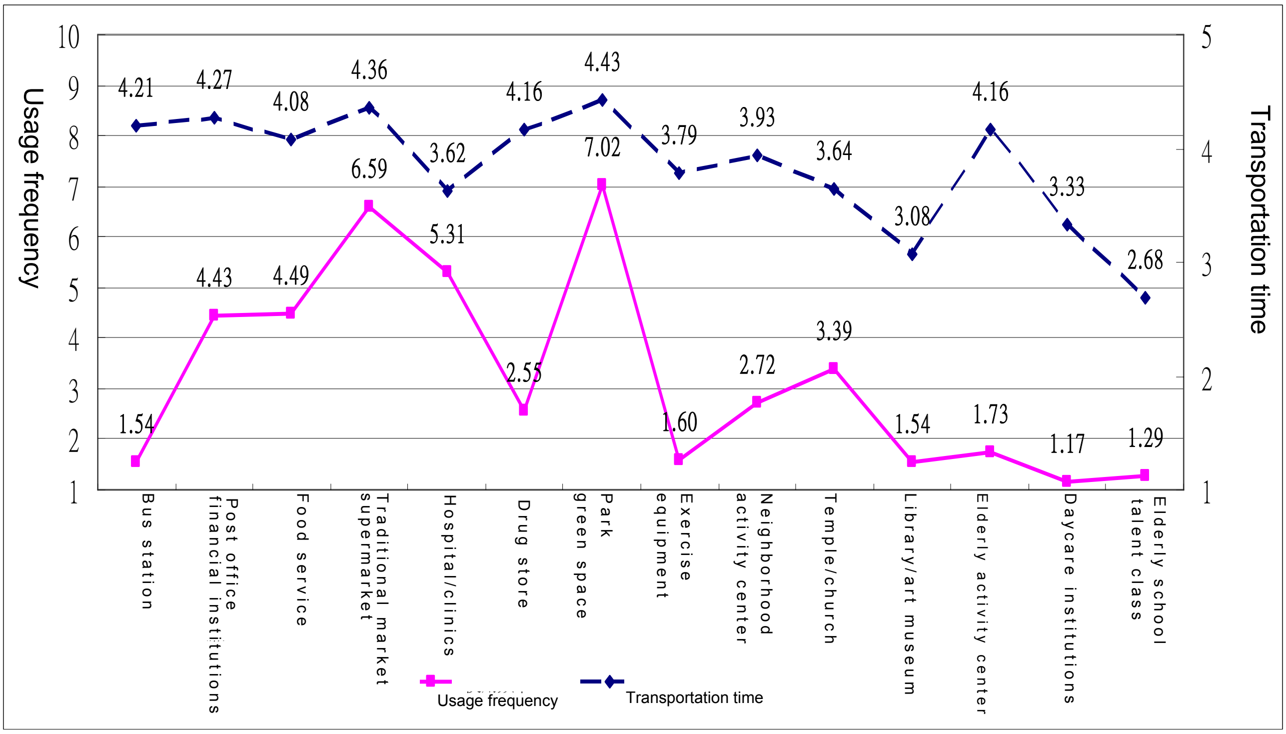
(b) Review of urban welfare facilities

As shown in the survey, the elder usage of urban cultural and welfare facilities is limited, among which, about 80% elderly never visited library, art museum or elder activity center. The usage rage of daycare institutions and art class/elder school is very low, as high as over 90% elder living in public housing never visited these facilities. The usage of urban facilities is as shown in Fig. 15.



	Case1	Case2	Case3	Case4	Case5	Case6
Never	34.38%	66.20%	34.69%	62.50%	35.29%	13.33%
Seldom	34.38%	28.17%	26.53%	25.00%	20.59%	30.00%
Occasionally	21.88%	28.17%	20.41%	6.25%	14.71%	25.00%
Frequently	9.38%	12.68%	18.37%	6.25%	29.41%	31.67%

Figure 14 Participation in public housing community activity



Usage frequency 1:Never 2:1-2 times per year 3:3-4 times per year 4:5-8 times per year 5:Over 8 times per year 6:1-2 times per month 7:3-4 times per month 8:5-8 times per month 9:Over 8 times per month 10:Everyday

Transportation time 5:Within 5 min 4:5-15 min 3:15-30 min 2:30-60 min 1:Over 60 min

Fig. 15 Frequency/transportation times for metropolitan case facilities use

5. Conclusions

5-1 Establish "Review Framework for the elderly living environments"

Based on literature reviews, this study focused on living environment function requirements for the elderly to establish a review framework. This framework is divided into five aspects: 1) safety, 2) health, 3) convenience, 4) comfort, and 5) welfare. Then, it focused on "indoor environment", "building environment", "community environment" and "urban environment" for assessment.

5-2 Review the living environments for the elderly in current public housing

According to the survey of "Review framework for the elderly living environments", six existing public housing developments in different stages were surveyed, in order to understand the current usage and demands on the five function in elderly living environments.

5-3 Recommended improvements of living environments for public housing for the elderly

According to the survey results, safety functions for the current public housing living environments should be recommended. In terms of space, bathroom renovation should be considered; followed by living room. As to facilities, emergency call equipment and fire alarms should be added to provide a safe living environment for the elderly.

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STUDY ON THE FLOATING FIELD SYSTEM

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Keywords: climate change, water resources, agricultural production, floating vegetation.

Summary

After the Industrial Revolution, the Earth's greenhouse gases continue to grow denser. In recent years, all parts of the world are experiencing high temperature, serious flood and drought disaster. The climate change becomes drastically faster and threatens human's survival and evolution. This research focuses on these points and proposes a concrete operation for "□-field planning" and "floating field farming" plans. These attempt to penetrate the agricultural fields in order to improve the existing irrigation system, increase the land ability for flood detention and rain buffer enhances, increase the area of evapotranspiration in square measure to reduce the environmental temperature, preserve the retention time of the fresh water on land, advance the water self-supplying ratio in farming land for agriculture, as well as decrease the influence of climate change on the agricultural production and overcome the challenge of hot climate and flood in the future. This study designed a "floating field system" to proceed with the experiment using the pool of the Symbiosphere 1 Center of Archilife Research Foundation. The elementary experiment provides a feasible method for planting vegetation on water through floating fields, which need neither good weather condition nor irrigation but still grow plants as well. In conclusion, this study believes that in order to overcome the damages brought by climate change, the floating-field system of planting vegetation is a feasible method.

1. Introduction

Recently, the global climate change has been very sudden. Many meteorological data consistently break record. Different places in the world continuously encounter surprisingly high temperature and serious water drought. The greenhouse gasses continue to become denser. The climate change has become more and more drastic. Therefore, there is a need to consider adjustments for the living system of the future generation due to climate change, whereby the relationship of water resources processing and constructions is aligned. This will influence the regional disaster prevention and the resource recycling efficiency. Agricultural production is becoming more and more inseparable to the global natural resource, water. Therefore, this paper attempts to discuss the possible problems caused by climate change, and proposes a corresponding strategy to sustain the continuity of a better living system.

In the recent 100 years, Taiwan has a tendency to become warmer. Also, the average increase warmth is the double the world's average. Taiwan has consistently encounter days without rain. Since 50 years, the average

4 days has also increased to 10 days. The threat of drought has become more evident. We can already anticipate that the future climate and the change of water resources strongly endanger our existence. Facing these challenges – water preservation, agricultural production guarantee, with the inclusion of increasing micro culture adjustment – are unavoidable. How to solve the problems will influence Taiwan's future. We believe that in order to contest the challenges of hot climate and flood prevention in the future, we need to increase regional transpiration. We use this transpiration to lower the region's environment temperature, increase fresh water maintenance in the land, increase the land's flood detention and water preservation capabilities, increase self-sufficient rate of the irrigation water and decrease the water pressure. Thus, we propose change in land utilization and agricultural methods. This is to change the originally fixed agricultural thinking towards land. We use water's floating system to decrease the climate change influence to agricultural production. We also propose "[illegible]-field planning" agricultural plan and "floating field farming" plans agriculture cultivation concept to reach a stable regional micro climate and water resources. Also, when tackling this environmental climate change, we will be able to sustain the agriculture production ability to reduce the loss and disaster. But, to concretely execute the concept above, we first need to consider how to execute the floating field cultivation. Hence, this study tried designing numerous floating fields to experiment. Undergoing related experimental observation experience, we unceasingly find design economic efficiency which would ease the plants on the floating field system. While facing the problem of climate change, we design a new agricultural system that pursues a set that confer to efficiency, safety, technology-adequate, convenience and economically sustainable.

2. Climate Change Challenge

Base on the 2007 Intergovernmental Panel on Climate Change (IPCC) United Nations annual report, the carbon dioxide density in our atmosphere has increased from the pre-1750 Industrial Revolution of 280ppm to 379ppm in 2005. Analysis of carbon dioxide in the ancient Antarctic ice showed that at no point in the past 650,000 years did levels approach today's carbon dioxide concentrations of around 380 parts per million (ppm). If the discharge of greenhouse gases is to maintain at the present standard, the whole world will be warmer and even create a bigger climate system change. According to the report, this will initiate drought, famine, sea level increase and more frequent poor weather. From this, we can see that the pressure on mankind brought by global climate changes will increase and not decrease and moreover will be harder to prevent. Facing the problems of global warming doesn't only involve the lessening of greenhouse gases but more importantly the possible frequenting of climate change and decreasing of future disaster loss and survival/development of mankind under the circumstances.

2. 1 Main Issue on Climate Change

This ponders on facing the warming trend and believed that the way to achieve the regional temperature and microclimate modulations considerations are essential in the future. In addition, the surface evaporation hastens as the temperature increases. This leads to the problems of drought, extreme rainfall, flood and agricultural production problems simultaneously brought about by the insufficiency of water resources. Also, this study believes that the countermeasures are "water" related; hence agricultural development strategies are vital. The evapotranspiration of water can modulate microclimate change temperature. Water also provides for the growth of all things on earth, maintains the ecosystem and biodiversity. Plants and animals also rely on water for their cultivation and growth. The growth of plants also provides carbon dioxide which is a good thing. Therefore, the maintenance of nature requires an abundant supply of water. Naturally, water is still an essential part of mankind. Food, which is brought by agricultural development, also needs water abundance. All in all, the role of water can't be fully explained by words.

However, since agriculture cultivation accounts for over seven-tenths of Taiwan's water usage; once a shortage of water supply occurs, it will have the first effect on irrigation needs. Thus, to analyze the problem of water resources in the future, diverting sufficient water for irrigation must first be considered. As a result of Taiwan's various agriculture property divisions and of course, "water ownership" is debatable and complicated, it is necessary to first establish a proper irrigation system in order to face the challenges of water shortage. In addition, we must also consider that under extreme tendency of rainfall can we maintain agriculture production and lessen agriculture losses. Integrating the above considerations, this research proposes a concrete countermeasure and method of agriculture developments.

3. Concrete Methods and Strategies

In the future, mankind must face the serious climate change that gets worse every day and the potential problems brought by water preservation and agricultural development. Thus, we must consider how to improve land utilization and agriculture methods, increase regional ability to face extreme climate condition, efficiently use the limited agriculture lands and water resources. On this, this study proposed a concrete strategy of "回-field planning" and "floating field farming" plans. Although the floating field system is still in the experiment stage in a small pool, but it is believed that the future floating system development will move with the accumulated experimental results. We can start from a small ecological circular system and expand to a bigger system. From the small experimental pool, we can develop the results to a bigger region's agriculture developments, increase the region's production and resource utilization, decrease the natural environmental burden, face a more efficient symbiotic cycle development.

3.1 Agricultural Planning Strategy

This research proposes using the square-field as a unit and having a 4-shape water storage hole like in Figure (see Figure 1). Therefore the planned land shows the Chinese character "回" which means return. Thus, it complements the idea of naturally returning the water to the land for storage. Hence, we call this plan as the "回" or "return" to field plan. For water storage area, depth for rainstorm, runoff, flood amount, needed flood detention pond and evapotranspiration and seepage, we pushed through with planning the design where on can either choose double, triple or quadruple layer. The more layers, the more flexible the water storage can be. The channel between the fields can serve as water detention ponds during rainy seasons. This will decrease the burden of the regional drainage system, decrease the tendency of river overflow and at the same time, this can provide the necessary water amount for irrigation ahead of time and prevent possible water shortage. Also, because the water quality needed for agriculture is relatively lower than for domestic needs, the usual grey water and the rainwater system's collected water can be asked to be collected and would lessen the pressure given to the reservoir dam and lower the risk of water shortage for agriculture purposes. In addition, the growing plants and vegetation would help absorb the water nutrients, lessen environment burden, decrease water pollution, increase regional cycle efficiency and increase the regional environmental self-clean capabilities.

However if water will not flow for a long time, there is a chance for it to become stagnant. Therefore, in order to include the use of aeration, we consider using the solar energy and learning how to use the machine in breeding fishes to dissolve the oxygen and thus avoid water being stagnant. In addition for the water pond to become a floating field, it can also be a place to raise ducks, geese and fishes and thus increase the land's usage and products. The above layer of floating field can be used to raise herbs and the lower layer can be used as a place to raise animals such as geese, ducks and fishes. This will initiate a food chain system. With regards to the problems of culicid, fishes feeding on worms can be raised in the pond or plants feeding on worms can be raised on the floating fields.

Moreover, on the borders of the field, windbreaks can be planted to lessen the possible effects of strong winds to the fields and floating fields. Usually, the stored water of [illegible]-fields are used on floating fields and for those other fields, they can use the reservoir's water during dry season. Most of the time, the increase of water level can be used on the cultivation of floating fields. Hence, this will help prevent flood and problems caused by monstrous rain. Naturally, the floating fields must also consider their own distinction; because of their arrangement, management and convenience of harvest must all be taken into their consideration.

The establishment of this system must anticipate increasing the ability to retain water, reduce the burden on water conservation, flood retention on rainy seasons, enough water for agriculture during dry seasons, maintain the usual evapotranspiration capabilities, increase the microclimate modulation ability and lower the regional warming. This must also be able to make sure of the land's production, reduce the after-effect of natural calamities and reduce the usual burden on farmers to worry about water. This must be a multi-functional system.

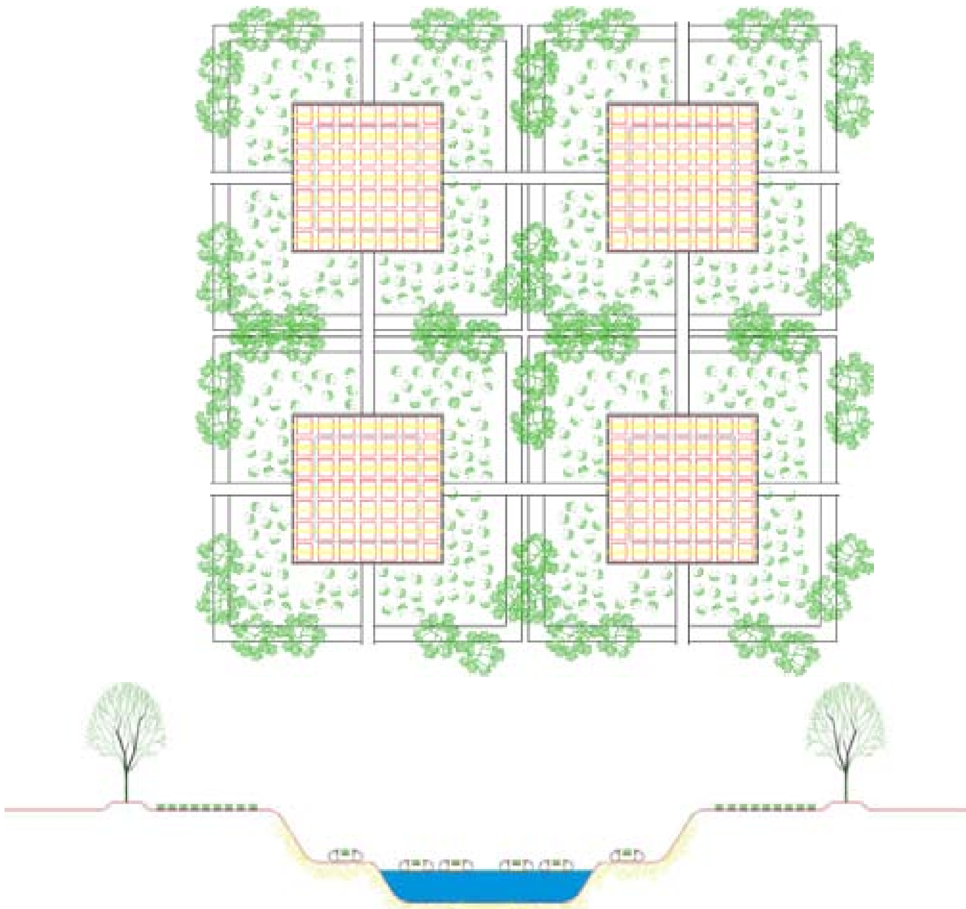

Figure 1 「□-field」 surface and sections

3.2 A Discussion on the Floating Fields Method and Initial Experimental Results

Because of the agricultural cultivation system nowadays, only a few possess aquatic cultivation experience and therefore does not fully satisfy the needs of this research. Therefore, this study tried to design a floating fields system. Before designing, we tried harder to have an understanding of each floating island all over the world. While reviewing the past literatures, observation includes that the functions of floating islands include ecology functions, embankment abilities, water purification abilities, landscape functions and at the least agricultural production abilities. (Will, 1970; Fager, 1975; Hoeger, 1988; Nunnally, 1987; Nakamura, 1997). And since most of the plants' nutrients originate mostly from water, aquatic plants must be more cultivated. This study also hopes that the floating fields can be used as a grain production and system and would also be able to suit the growth of different land and aquatic plants. Therefore, the designed floating field of this paper primarily uses soil and partly uses water as the origin of plant nutrients. In addition, the past floating islands' usage concern very minimal regional warming or microclimate modulation considerations. The less it is on the issues of water shortage concerns and grain production considerations.

Because of the different usage and challenges, this research proposes an aquatic floating fields system so as to have a segment for floating islands development. This therefore clarifies the taken agriculture challenge of floating field system development. Based on the reasons above, this study tried designing different forms of floating field units to experiment (see Figure 2). After two years of being in the water pool of Archilife Symbiosphere I Center, the preliminary experimental results showed that flexibility must be present in the floating fields used on plants. (Chen, 2006; Chen, 2007) Even though winter and summer seasons, rainfall and typhoon were experienced during the plating time, the plants were able to grow well and were able to even avoid watering service.

In order to face the future challenges of natural disasters, lessen agricultural losses and maintain the agricultural production abilities, floating fields cultivation is a feasible agricultural production method. However, because of the limitation of researchers and budget insufficiency in this present research, the results of small regional experimental grounds may be applied to a bigger ground in the future. This way, the development will be more evident.

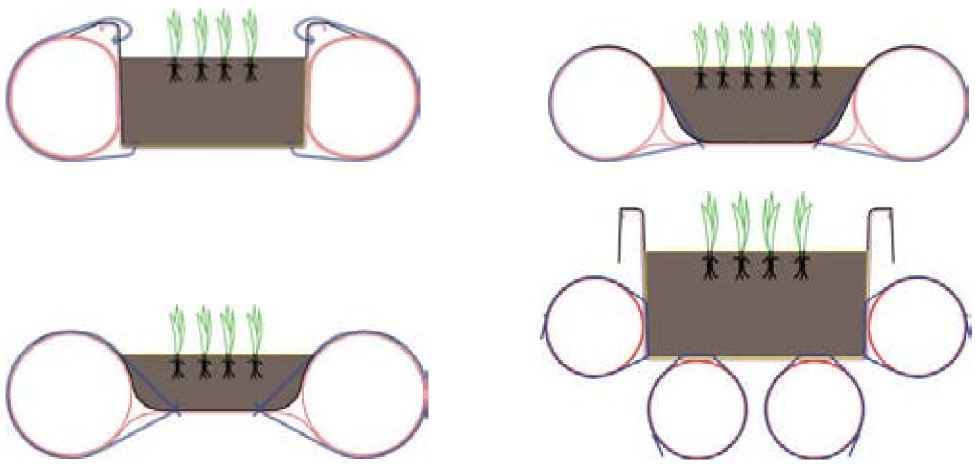

Figure 2 Different Floating Fields Sections

3.3 Floating Field System Design Unitization and Future Developments

After long-term experimentation, this research proposes uniting the floating field system design (see Figure 3). It is mainly to focus on the plants' convenience. Because they are planted on the water surface, if the unit is too big, the transportation and soil change will be of serious work. Using unitization and standardization, most of the labor work can be substituted by automated machines. No matter it is to fill the soil, change soil or ease the soil and so on, the automated machine will be able to handle these. Also, unitization can make its own adjustment basing on different plant demand, seasonal/climactic conditions. It can also change the plant box materials, shape of opening side (see figure 4), permeability, soil fertility, waterlogged depth and carry on with modifying the control to the suitable physiochemical conditions for a living organisms. It will also be providing multi-plant growth condition, preventing the system to plant unitize. Naturally, multi-plant has another advantage in preventing the problems of pests. Another, aside from eluding the necessary watering, the aquatic plants can also lower the need for agricultural cultivation processed water. The result nutrients therefore will be hastily dissolved and loss. Also, when the habitat humidity of microorganisms always changes, it might create problems. When the soil fertility can be prolonged, especially the habitat stability of microorganism, it can multiply the microorganism and help with the plant's growth. In addition, because the system can anytime support the water needs of plants, even the moisture content and absorption content can be contained. Also, undergoing evaporation, the water temperature would adjust, creating a more steady temperature that will benefit plant growth. Therefore, the anticipated unit time and unit area must be able to compare with the natural ones. Only the above particular problem should indeed go for a further experimentation.

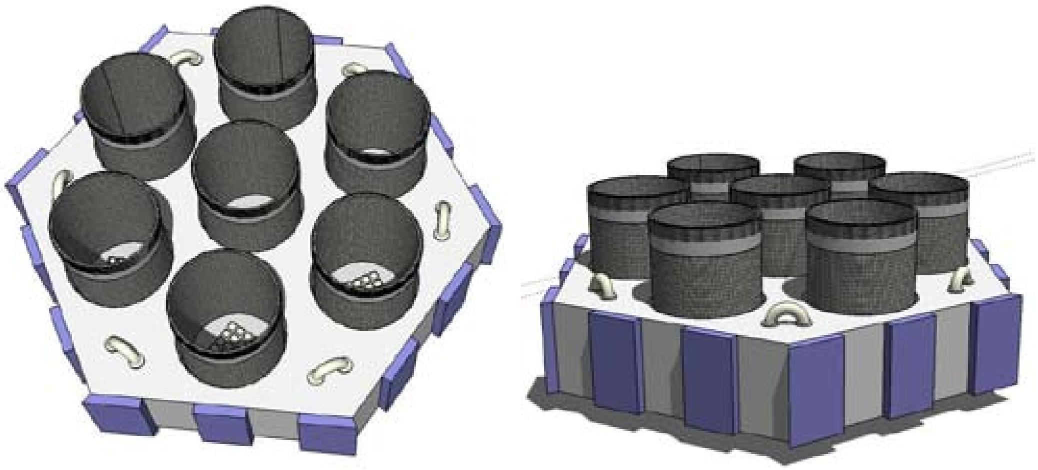

Figure 3 Single floating field unit and plenty planting-boxes assembly figure

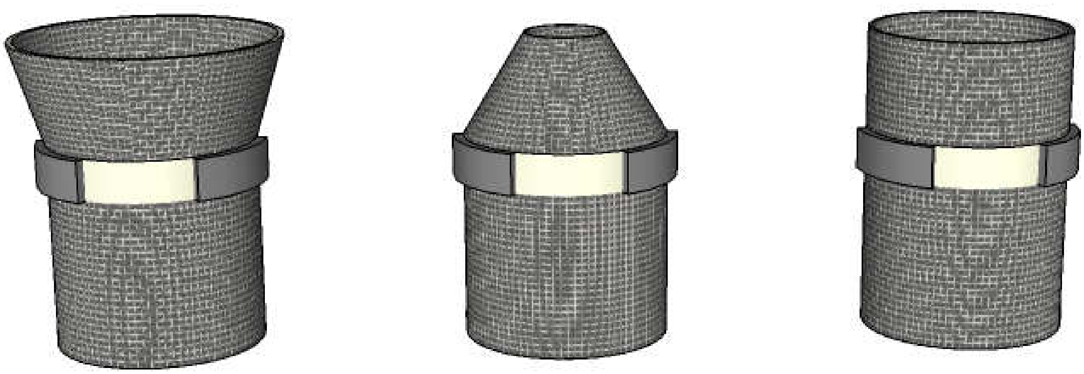

Figure 4 Planting boxes with different design in shape of opening side

4. Conclusions

Along with global warming, the future mankind will face the threat of climate change trend that becomes worse everyday. This study proposes "□-field planning" and "floating field farming" plans attempts to have changes in land utilization and agricultural methods to reach a stabilized regional micro climate water resource and under the environmental climate change, the agricultural production ability can be maintained and lower the losses and disasters. The study responds to this and tries to design various floating field system and proceed with experiment. Different crops are planted for long-term observation. Going through the preliminary experiments, the aquatic plants will be able to show feasibility and elude the need for manual watering. The growing of plants and climate looks to be good and in fact, it has undergone experimentation in four different seasons. Another, the study designed a new floating field unit that attempts to be the future floating agriculture, change soil, harvest, integrate industrial production, lower the need for manual work, lower production cost and will be able to provide an efficient and convenient agriculture system. These experiments have undergone preliminary tests and have shown feasibility. Although related designs still have rooms for improvement, but we believe that from the accumulation of the experimental results, the floating field system will be able to expand different agriculture fields in the future and establish a more efficient symbiotic cycle.

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NEUTRALISING A FACULTY: VICTORIA UNIVERSITY'S CARBON NEUTRAL FACULTY OF ARCHITECTURE AND DESIGN

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Keywords: green house gas, carbon neutral, education, tertiary, emissions reduction.

Summary

International research suggests that the built environment may be responsible for approximately a third of global carbon emissions. It is therefore particularly appropriate that Victoria University's Faculty of Architecture and Design, in Wellington, New Zealand has taken the significant step of becoming the Southern Hemisphere's first carbon neutral campus, and the world's first carbon neutral Faculty of Architecture and Design. This is part of the Faculty's long term commitment to sustainability in the built environment and is consistent with a growing international movement calling for Architecture Schools to be carbon neutral by 2010.

The process and opportunities that enabled the Faculty to become carbon neutral in May 2008 are outlined, including the preparation of a greenhouse gas emissions inventory, an emissions reduction and management plan and the audit and accreditation process. The successes and difficulties inherent in the approach taken are examined.

As well as reduced environmental impact, this paper analyses further significant anticipated benefits of the Faculty of Architecture and Design's carbon neutral status, including opportunities to publish research and enhance the reputation of the Faculty and the significant opportunities arising for the development of new teaching tools and methods. Involvement and participation by students in reduction plans and the facilitation of a forum for debate and discussion about the future of carbon trading markets are also elaborated on.

It is anticipated that the process undertaken by Victoria University of Wellington's Faculty of Architecture and Design could be used as an example by other educational institutions moving towards becoming carbon neutral. It is posited that reducing and offsetting carbon emissions in academic institutions, particularly those responsible for the education of new generations of built environment professionals, could become an important part of the creation of a built environment that is better able to address mitigating the causes of climate change.

1. Introduction

Climate change will affect many aspects of life and has well documented social, economic and environmental impacts (Stern 2006; Chapman, Boston, and Schwass 2006). Public awareness of this and with it Government directives to address climate change issues, have increased significantly in the last two years in New Zealand and in many other countries. Coupled with this is the growing realisation that the global built environment contributes significantly to the causes of climate change through construction and demolition practices, but most significantly through operational and embodied energy (O'Connell 2003; Alcorn 2003; Lend Lease Corporation, et al, 2007). Built environment professionals and designers will have to address reducing greenhouse gas emissions in the future as well as find solutions to adapting to many of the changes that will come about through climate change (Camilleri, Jaques, and Isaacs 2001). O'Connell (2003) points out that *'current projections indicate New Zealand buildings will potentially suffer significant impacts this century.., the direct and indirect costs of which may be very high*'.

Many of the negative human impacts on climate and ecosystems have been described as a failure in design rather than available technology (Orr 2002; McDonough and Braungart 2002). Lowe (2000) estimates for example that reductions of 80% in carbon emissions form the built environment are possible using current technologies. It is appropriate then that Victoria University of Wellington's Faculty of Architecture and Design is addressing climate change issues in part by reducing and offsetting greenhouse gas emissions. This is consistent with a growing international movement calling for Architecture Schools to be carbon neutral by 2010 (Architecture 2030 2008). The Faculty will be a pilot for the rest of Victoria University of Wellington (VUW) in assessing the feasibility of ongoing and future greenhouse gas (GHG) offsetting and emissions reduction planning for the university's other four campuses.

The Faculty of Architecture and Design participated in Landcare Research's carboNZero programme to achieve certification, and obtained international Gold Standard carbon credits through a sponsorship agreement, to offset GHG emissions. These credits are sourced from Meridian Energy's wind farm projects in New Zealand[1].

2. The Carbon Neutrality Debate

It is acknowledged that voluntary carbon offsetting and trading is still in its infancy in New Zealand but that this is growing rapidly internationally (Bellassen and Leguet 2007). The difficulties with 'carbon neutrality' achieved through offsets are acknowledged in their role as a potential green washing mechanism. Harris (2007) points out that *'despite its positive attributes… the role of offsetting should be only temporary, creating much needed early emissions reductions and generating awareness, whilst being only a small part of a much wider and longer term global effort to tackle climate change*.'

For this reason the Faculty consider it prudent to use participation in the carboNZero programme primarily as a platform to plan for and instigate significant GHG emission reductions. Offsetting is considered to be the final step in a plan that seeks to avoid, then reduce and finally offset emissions. 'Carbon neutrality' also provides a valuable forum to discuss and raise awareness of the issues of climate change that effect in the case of the Faculty of Architecture and Design: the built environment; tertiary education and research; and New Zealand. It is the intention of the Faculty of Architecture and Design to combine carboNZero certification with a range of additional sustainability initiatives and research already existing and proposed for the Faculty. This is in line wide a wider strategy to move towards becoming a leading educational institution for environmentally sustainable design.

3. Opportunity for Engagement in Climate Change Issues

The Faculty deciding to become carbon neutral and then making this a reality was a long and somewhat complicated process. This is briefly described below in chronological order.

3.1 Initial Steps: A Carbon Neutral Course

Since 1997, the School of Architecture has offered a specialist elective course in Sustainable Architecture. More than a third of the second year cohort of architecture students elected to take this course in 2007. This course is open to all students in the University beyond first year and is designed to give an introduction to the philosophy, concepts and ideas of sustainable and regenerative architecture. The objective is to enable students to incorporate these ideas into further study and into their practice of architecture, design, building science and related fields.

In late 2006, the course coordinator began to investigate opportunities to engage the students in debate on carbon trading and carbon neutrality as part of the educational programme concerned with climate change. The decision was made to explore the possibility of the course becoming carbon neutral through both emissions reduction and offset.

Initial calculations for the course were made by sourcing university records for energy use (gas and electricity) and estimating the proportion of these figures that the course was responsible for. Assumptions were also made for commuting by establishing distances of student and staff residences from the campus. Paper use and field trip emissions were calculated from the previous year's course.

New Zealand based online carbon calculators and emissions multipliers were used[2] and compared to come up with an estimated carbon emissions amount for the course. These online calculators use different factors and methods, and are not consistent with each other or with international calculators (Bottrill 2007). In light of this, the highest estimate was used. A figure of just under 2 tones of carbon equivalent emissions was reached for the course of 50 students.

3.1.1 Determining Offset Options

Several avenues were explored in determining an appropriate method for reducing and offsetting GHG emissions. Because making the course carbon neutral was intended to be an educational exercise for the students involved, it was thought that involving them in the offsetting part of carbon neutrality might be appropriate. For this reason, carbon sequestration through tree planting was initially investigated. Both the Greater Wellington Regional Council, which offers a corporate volunteer programme to plant trees in community group planting areas, and a local non-governmental forest regeneration scheme [3] were approached for tree planting possibilities. While both were willing to have students plant trees for them, the framework for measuring the carbon sequestration potential and ensuring the continuation of the planted areas was not in place. Although research has been done in New Zealand and internationally defining methods for calculating carbon stored in trees and forests (Landcare Research 2006; Brown 2002), it was thought that tree planting in projects not specifically dedicated to carbon sequestration would be problematic and would not be a robust method of carbon offset. It was also difficult to calculate how many trees and of which species would be suitable in a local context.

[1] For a full description see http://www.meridianenergy.co.nz/AboutUs/Emissions+trading.htm and Appleyard (2004).
[2] CarboNZero, NIWA, BRANZ.
[3] Manawa Karioi Trust

A search was made for other Tertiary institutions that had attempted a similar project to ascertain best international practice. Newcastle University launched their first carbon neutral degree course in 2006 (Newcastle University Press Office 2006). Personal correspondence between the two institutions helped to define the best way to progress with carbon neutrality. The potential problems with tree planting were discussed and the need for engagement with recognised carbon offset and certification programs established (Broderick 2006). A recommendation to source credits from Gold Standard projects was made.

The Gold Standard is a certification scheme that registers projects in the Clean Development Mechanism (CDM), Joint Implementation (JI) and voluntary offset markets and is endorsed and supported by 51 non-governmental and charitable organisations. The projects accepted by the Gold Standard Foundation for registration must be *'clearly additional, involve local stakeholders in their design and show transparently how they will contribute to sustainable development'* (The Gold Standard 2006). Independent validation and verification of the projects also takes place. Being *'clearly additional'* refers to a project could not take place without the sale of its carbon emissions reduction credit in a carbon market (Bellassen and Leguet 2007). Gold Standard accepts only energy efficiency or renewable energy projects and is not open to forestry projects, due mostly to the problem of the impermanence of forests (Bellassen and Leguet 2007). Few projects have achieved the grade for Gold Standard to date, but the number is increasing rapidly (Harris 2007). The Gold Standard (2006) point out that Gold Standard verified projects are selected because they provide additional benefits (social, economic or environmental) beyond just emissions reduction *'lest offsetting become a zero sum game where emissions are reduced in one place while they continue in another'.*

In New Zealand, Meridian Energy supplies Gold Standard third party verified emission reductions (VERs) carbon credits from their wind farms in Te Apiti and White Hill. These projects were among the first registered with the Gold Standard, and are the only New Zealand source of Gold Standard credits. The decision was made that using these credits would mean that some of the uncertainty with forest offsets would be avoided and importantly that the highest standard of international carbon credits would be met (Bumpus 2007). It was decided this method of offset was more relevant to students of architecture and design, who will in part be responsible for the energy performance of the built environment and will be making decisions about energy sources and energy efficient design and technologies in the future. It was also thought that approaching a local New Zealand carbon credit provider would be more desirable that sourcing credits from another country.

3.1.2 Securing Carbon Credits – A Sponsorship Agreement

Meridian Energy were approached in March 2007 to explore sponsorship potentials, and were positive about providing their Gold Standard carbon credits to offset the course's emissions. To increase the educational and research collaboration potential of the sponsorship agreement for both parties, it was agreed that a Memorandum of Understanding (MoU) would be drawn up between the Faculty of Architecture and Design and new Meridian Energy subsidiary Right House. Right House specialises in energy conservation and energy efficiency in the residential sector[4]. This relationship began in 2007 with Meridian and Right House participating in various courses in the Faculty on critique panels and offering guest lectures where appropriate. The MoU was formally signed in on the 31st of March 2008.

3.2 Expanding the Scope: A Carbon Neutral Faculty

Senior Faculty management and academic staff were involved during sponsorship negotiations with Meridian Energy. After learning that a sponsorship agreement was possible, the decision was made to try to expand the project to include not only one course, but the entire Faculty. Several initiatives to strengthen and expand the capacity of the Faculty to deliver a high standard of education in sustainable architecture and design had already begun, including development and expansion of compulsory and senior aspects of the sustainability programme, and significantly increasing staff numbers with specialties in aspects of sustainability. Addressing the problems of climate change, through engaging in the carboNZero programme was seen as being a suitable addition to these set of initiatives. Between April and September of 2007, the sponsorship agreement with Meridian Energy was expanded and agreed to in principle.

Victoria University's Faculty of Architecture and Design is made up of the School of Architecture (architecture, building science, landscape architecture and interior architecture programmes) and the School of Design (digital media and industrial design programmes). The Faculty is housed separately from the rest of Victoria University on the Te Aro Campus, located in central Wellington, New Zealand. Two connected building facilities make up the campus, which houses lecture theatres, design studios and computer suites, a workshop, library, offices, and exhibition space. Approximately 1200 students are enrolled in courses in the Faculty and more than 100 academic, general and technical staff are employed.

3.2.1 Calculating the Faculty's Emissions

Faculty wide emissions were calculated by analysing external records and internal accounting records. Direct emissions sources (termed scope one) were identified as gas (used for boilers) and vehicle fleet (consisting of one diesel van). Indirect emissions (scope two and three) included the hiring of vehicles (buses

[4] http://www.righthouse.co.nz/

for field trips), flights (both international and national), and waste. Electricity for the Faculty is supplied by Meridian Energy, 100% of which is generated by wind and hydro sources[5]. Meridian Energy themselves went through the carboNZero programme in 2007 and were New Zealand's first certified carboNZero energy company (Meridian Energy 2007). Electricity use was measured therefore for the Faculty, but was not recorded as requiring offset. This was a requirement by Meridian Energy in the sponsorship agreement and was agreed to by carboNZero to avoid double counting of emissions. Increasing energy effieciency was however included in the GHG Emissions Reduction Plan. Because the Faculty began GHG calculations in 2007, 2006 was initially used as the base line year. Total emissions for the Faculty were calculated to be equivalent to 192 tones of carbon.

3.2.2 Certifying the Faculty's Carbon Neutral Status

To ensure the most robust and transparent process of reducing and offsetting GHG emissions, it became apparent that the Faculty would have to obtain certification of carbon neutrality from an independent organisation. This was a requirement of the Meridian Energy sponsorship agreement to ensure that the process had integrity, and would be robust under scrutiny. Certification would also ensure that calculations were correct and that procedures in planning for reductions and offsets met international best practice based upon a rigorous, third party verified process.

There is currently only one organisation that is able to certify individuals, organisations or events as carbon neutral in New Zealand. The carboNZero programme was established by Landcare Research, a Crown Research Institution in 2001, after more than a decade of climate change and GHG reduction research[6]. Initial quotes were obtained from the carboNZero programme and from Pricewaterhouse Coopers for a third party audit in March and April of 2007.

3.3 Final Goal: A Carbon Neutral University?

During the negotiation and recalculation period to enable to whole Faculty to become carbon neutral, funding was sought from the central university. At this time however, the university's Environmental Committee also submitted a proposal for central university funding for the entire university to become carbon neutral. While this initially held up the process for the Faculty, valuable research into emissions across the university was conducted by URS consulting (commissioned by the Environmental Committee), which was then able to be used by the Faculty. The proposal for the whole University to engage with carboNZero was unsuccessful; however a decision was made to grant funding to the Faculty, so they could act as a test pilot for going through the carboNZero process, and committing to GHG reductions, on the condition that going through the carboNZero process be run as a research project.

4. Time delays and unexpected issues

Initial timelines for the project anticipated that by September of 2007, the Faculty would have completed all requirements for certification and would be able to claim carboNZero status. Several delays in the process made this impossible. Final quotes and contract agreements for the Faculty from the carboNZero programme were held up due to the possibility of the entire University becoming carbon neutral. If this proposal had been successful, this would have included the Faculty of Architecture and Design, making the process of the Faculty becoming carbon neutral redundant. Once it was established that funding for the entire university to become carbon neutral was not obtainable, progress on the Faculty going through the carboNZero process resumed.

The six month period between the initial quote for Faculty participation in the carboNZero programme and the final quote meant that a substantial increase occurred in projected costs. This required further funding to be sought from central university funds, which added to the length of the process. Because of these delays, it became apparent that certification would not be achieved in 2007, but rather 2008. The 2006 base line year for emissions measurement had to be changed therefore to 2007.

In January of 2008 after all of the major issues had been rectified, the Faculty was in a position to engage with all parties in the carboNZero programme. A three month time period to redo the inventory for the 2007 year and draw up the Emissions Reduction Plan and Greenhouse Gas Emissions Inventory Report was agreed to by all parties (as illustrated in Figure 1).

After a re-calculation of emissions for 2007 a new figure 341 tonnes was arrived at. Additional emissions sources that were included in the 2007 inventory were the use of taxis, rental cars and industrial gases used in the workshop. The increase from 2006 figures was accounted for by increases in the scope of the inventory, changes in emissions factors, changes in calculation methods, and actual increases in emissions. This meant that the sponsorship agreement of providing carbon credits to offset 200 tones of carbon emissions had to be expanded once more, leading to further time delays.

[5] In 2007, 68% of all electricity available for purchase by consumers in New Zealand was generated from renewable sources including hydro, wind, geothermal, and biomass. This figure was 65% in 2006 (Statistics New Zealand 2008).
[6] http://www.carbonzero.co.nz/index.asp

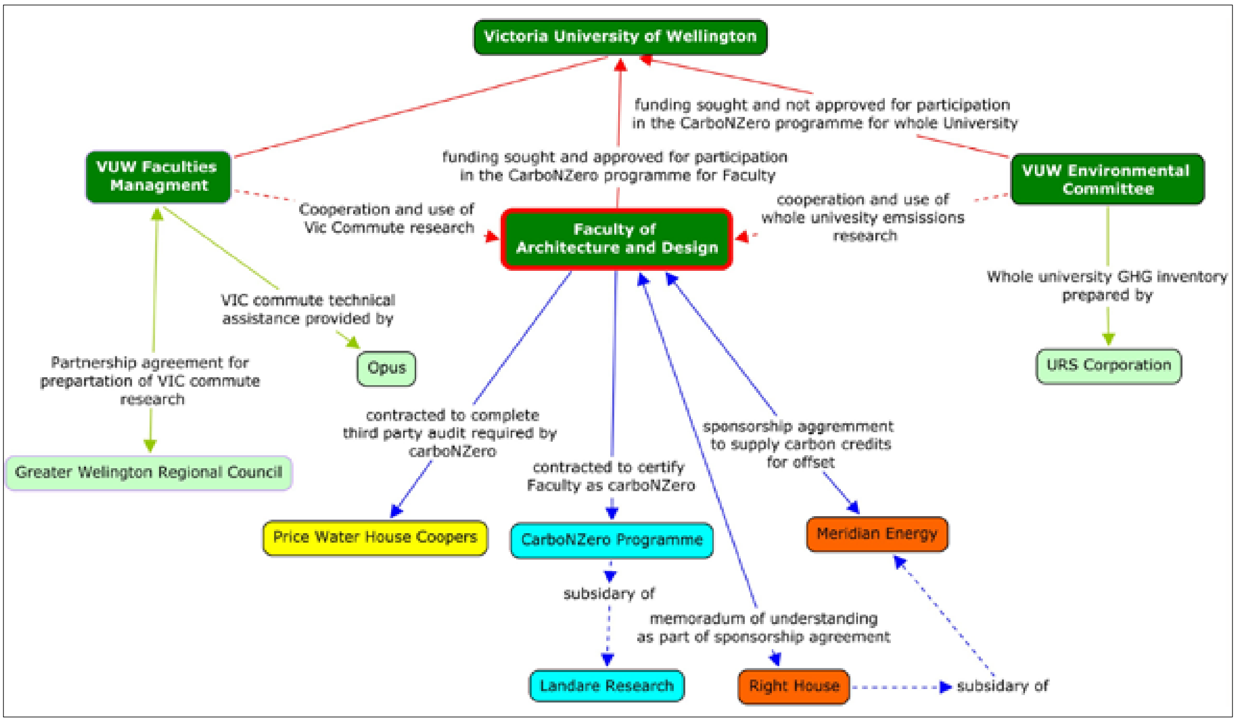

Figure 1 Participants in VUW Faculty of Architecture and Design's carboNZero Process.

5. The carboNZero Process

The carboNZero process involved six steps:

5.1 Measure - understand and measure GHG emissions

The Faculty prepared a 2007 Greenhouse Gas Inventory in February of 2008. The process of sourcing data for the GHG inventory was at times difficult, exacerbated by a lack of reporting and record keeping structure for GHG emissions. Most external records such as those for gas and electricity consumed, diesel purchased for the van and flights purchased from the university's travel agent were easy to obtain. Records of hiring cars and buses for field trips were more difficult to obtain. Calculating waste was also difficult and several qualified assumptions were made by Landcare Research.

Research commissioned by the university's Environmental Committee on university wide emissions contributed to the Faculty's inventory. The inventory was handed to carboNZero, who produced the emissions calculations based on most recent emissions factors and checked all the data for accuracy and made sure no emissions were left out. A Greenhouse Gas Emissions Inventory Report was completed in mid April 2008[7]. The purpose of the report was to document direct and indirect greenhouse gas emissions from the Faculty of Architecture and Design and was prepared in accordance to International Standard ISO 14064-1:2006, (Technical Committee ISO/TC 207 2006) and the GHG Protocol for Corporate Accounting and Reporting (WRI-WBCSD, 2004) in order to meet carboNZero certification procedures.

5.2 Manage - make a commitment to manage and reduce emissions

The Faculty prepared a Greenhouse Gas Emissions Reduction Plan in April 2008[7]. This incorporated comments and suggestions by interested staff, included several student initiatives to reduce GHG emissions in the Faculty, and involved negotiations and advice from the university Facilities Management Team. The objectives of the plan were to: demonstrate management commitment to reducing GHG emissions; maintain and introduce effective GHG emissions accounting procedures; target both the most significant and the easiest to address emissions; and to target reduction of emissions that are significant, but considered to be outside the scope of the Faculty's operations.

Major emissions were identified as the burning of gas which is used in boilers (41% of total emissions requiring offset); GHG emissions from decomposition and transportation of waste (32% of total emissions requiring offset); and the burning of fossil fuels used in international flights (26% of total emissions requiring offset). Student and staff commuting, although not included in the inventory, due to the difficulties in accurately measuring the emissions from this source (Buttazzoni and Zyla 2005), were targeted in several ways in the management reduction plan. A Victoria University of Wellington travel plan (Vic Commute) was

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[7] GHG Emissions Inventory Report and GHG Emissions Reduction Plan are available from the author upon request.

prepared as an internal university document[8]. It estimated commuting emissions by conducting a survey in 2007. Faculties Management used these same results to estimate that student and staff commuting could be responsible for an additional 130 tonnes of emissions for the Faculty of Architecture and Design. This would equate to approximately 28% of total emissions if it were included.

5.3 External Audit - conducted by an approved qualified auditor
The third party audit of the GHG Emissions Inventory Report was carried out by Pricewaterhouse Coopers in June of 2008. Several suggestions were made to ensure that the report was accurate and adhered to international best practice.

5.4 Mitigate - offset or mitigate remaining or unavoidable emissions
Meridian Energy organised the retirement of carbon credits though the M-co company to meet the requirements of the carboNZero process. This ensured that the credits were cancelled in a maintained independent register and that they could not be on sold in the future. The credits supplied to the Faculty were a combination of 2006 and 2007 Gold Standard credits.

5.5 Certification - verify mitigation step and issue certificate
Landcare Research provided the certification of the Faculty's carboNZero status after the first four steps were completed in June 2008.

5.6 Marketing - communicate achieving carboNZero certification
Public announcements of the Faculty's carbon neutral status were made in June 2008, to coincide with Internation World Environment Day. Meridian Energy and the Faculty co-operated in media announcements. Case studies and further information about the Faculty's carboNZero status were posted onto the university and carboNZero websites[9].

6. Benefits of a Carbon Neutral status

It is the intention of the Faculty to quantify benefits of becoming carbon neutral, where possible, after a year period. There are a number of anticipated benefits that can be discussed here that ultimately made the project more attractive for allocation of funding by central university, and allowed it to proceed.

6.1 Environmental Benefits

The primary benefit and justification of the Faculty participating in the carboNZero programme is the reduction of GHG emissions in mitigating the causes of climate change. Through the carboNZero certification progress, a detailed GHG Emissions Reduction Plan must be put into action. It is anticipated that this will result in tangible GHG emissions reductions in the Faculty that could have environmental benefits that go beyond Faculty boundaries.

If a university wide commitment is made to reduce and offset carbon emissions, after a successful trial period conducted by the Faculty of Architecture and Design, significant emissions reduction may occur across the entire university. The carboNZero programme has acknowledged that the Faculty is the first educational institution to go through the programme in New Zealand and as such sets a benchmark.

6.2 Social and Cultural Benefits

As the Faculty of Architecture and Design embarks on strengthening its capability to deliver sustainable design education, it is important that its own conduct is bought into line with what it teaches. By being an early adopter of voluntary carbon offset and GHG emissions reduction measures, the university is able to take a leadership role on climate change in a New Zealand context. This provides a platform to bring attention to climate change issues in a positive forum, to debate or normalise the idea of voluntary GHG emissions reduction planning, and potentially to enhance the reputation of both the University and Meridian energy.

The potential to involve students in projects to reduce emissions further and to facilitate debate and discussion about carbon trading and climate change in general has been taken, and will be developed further during the year trial period. The main building on the campus is already set up to be an educational tool and is studied in depth by building science students in particular. Students in the Sustainable Architecture course devised GHG emissions reduction schemes for the Faculty and implemented them where possible in 2007. Some of these ideas and projects were included in the Faculty GHG Emissions Reduction Plan. The potential to involve more students will be developed in 2008 and 2009. This may include: involvement in projects to reduce emissions further; participation in monitoring and measurement

[8] Available from http://www.victoria.ac.nz/fm/services/vic-commute.aspx
[9] Available from http://www.carbonzero.co.nz/members/organisations_certified.asp#VUW and http://www.victoria.ac.nz/architecture/

associated with such projects; participation in GHG inventory data collection and management; and participation in debate and discussion about carbon trading.

6.3 Economic Benefits

The reduction of gas use, paper use, international flights, and waste produced in accordance with the Faculty's GHG Emissions Reduction Plan is expected to have tangible economic benefits for the Faculty and University alongside the anticipated environmental benefits. Preparing for managing GHG emissions while it is still voluntary will likely be less costly than leaving it until institutions such as universities are regulated to take account of their GHG emissions.

It is expected that unique research opportunities will arise from a carbon neutral status. With increased monitoring and more accurate records it is anticipated that students and academic staff alike will be able to analyse results and carry out additional research projects. It is possible that academic research papers would subsequently be published in international journals or conference proceedings. The Memorandum of Understanding between the Faculty and Right House, a subsidiary of Meridian Energy is also expected to herald research opportunities for both parties. Improving and cementing the Faculty's reputation as a leader in sustainable design and architectural education and research may bring further economic benefits by attracting high achieving students and staff.

7. Recommendations and Findings

The conclusion to be drawn from the experience of the author is that although all parties in the process were willing to make a carbon neutral Faculty of Architecture and Design a reality, it took substantial time and effort for all groups to be clear about the process involved and to fulfil their parts. This is due in part to steep learning curves for the Victoria University and for the Faculty of Architecture and Design, and rapid changes in the carboNZero programme, and carbon trading in general during the time period. It is clear that it is important to carefully define the scope of the project first to avoid delays caused by recalculation of emissions and sourcing funding. Other significant delays were caused by rapid changes in how GHG emissions are measured and offset, and the costs of certification.

The commitment of senior management to the process was important in the Faculty obtaining carboNZero certification. In larger organisations, having a dedicated and resourced team to source required data, write the necessary reports and coordinate communication and record keeping is seen to be a crucial part of an efficient process. Although a number of parties are necessarily involved in the process, making the coordination of the project more complex, several beneficial relationships have been formed and a success of the process has been using participation in the carboNZero programme as both and educational and research opportunity for students and staff.

The efforts of the Faculty of Architecture and Design to move towards carboNZero certification were not made public for some time while negotiations were taking place. Once the plans were discussed with a wider group of staff and students, opportunities for wider engagement were taken. In inviting staff in particular to participate in the GHG Emissions Reduction Planning, greater 'buy in' was thought to have occurred. Students that participated in designing and implementing initiatives to reduce GHG emissions in the Faculty in late 2007 also commented on the positive experience of practical engagement in reducing the causes of climate change.

8. Conclusion

The process of becoming certified carbon neutral was longer than initially planned for and significant delays occurred during the process for Victoria University's Faculty of Architecture and Design. By clarifying the decisions that were made and outlining the process that was undertaken, it is anticipated that other intuitions or organisations may avoid some if the same time delays.

Along with the environmental benefits of reducing GHG emissions, it is clear that engaging in carbon reduction and offset measures will have significant additional benefits for the Faculty in terms of educational, research and marketing potentials. Economically, the benefits are expected to be longer term.

It remains to be seen if the significant efforts that the Faculty have and will go to in reducing GHG emissions will result in a net reduction, or reduction in intensity (per student), of GHG emissions. The opportunity to be leaders in addressing climate change in the built environment however, sends a clear signal to students, staff and the public alike that working towards mitigating the causes of climate change is considered to be important by Victoria's Faculty of Architecture and Design as a design and built environment educational institution.

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NUMERICAL ANALYSIS OF THERMAL ENVIRONMENT ACROSS TYPES OF AIR CONDITIONING SYSTEM IN RESIDENTIAL BUILDINGS IN KOREA

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Keywords: residential building, cooling, package air-conditioner, indoor-unit type, thermal environment

Summary

This study was conducted as a preliminary study to establish energy-efficient installment standards for individual-unit air conditioning system in residential buildings in Korea. Therefore, this study examined current air conditioning status and related problems in residential buildings, and selected currently the most common package air-conditioner type, the indoor-unit type of package air-conditioner. Based on this, this study performed a numerical analysis to compare and analyze the thermal environment across each type of indoor-unit package air-conditioners.

1. Introduction

As worldwide discussion for sustainable development is actively in motion in these days, variety of effort on environmental protection is also in motion around developed countries. Keeping pace with this effort, Korea is also searching for various solutions. Among the buildings that consume near the two thirds of energy, however, residential buildings explosively increase energy consumption for heating and cooling as living standard arises, which causes many problems.

Korea has considered only heating system in design and construction of residential building with the consideration of air-conditioning system almost excluded due to the temperature characteristics of short cooling season and the Korean life style. Therefore, the resident individually installs a package air-conditioner for their own depending on their affordability and need after construction is completed. For this reason, there are no standards for energy consumption and design in case of air-conditioning system.

In addition, many construction companies were competitively looking for ‘brand’ and ‘luxury’ buildings in their business, constructing many high-rise residential buildings. The increased load from heating and cooling due to the trend of tall buildings and air-tightness in residential buildings accelerated energy consumption in residential buildings. For this, the number of house that installs air-conditioned cooling system increased abruptly raising various individual and national problems.

Hence, this study is a preliminary study to establish energy-efficient installment standards for individual-unit air-conditioning system in residential buildings, and intends to compare and analyze the indoor thermal environment across the different types of indoor-unit package air-conditioner. For this purpose, this study examines the current status of air-conditioning and its related problems in residential buildings in Korea, and selected a most common indoor-unit type of package air-conditioner. Based on this, this study performed a numerical analysis to compare and analyze the thermal environment across each type of indoor-unit package air-conditioners.

2. Air-Conditioning System in Residential Buildings in Korea

2.1 Current Status of Air-Conditioning in Residential Buildings

Korea is geographically located to the east of Europe-Asia continent, between 33.6°~43.1°N latitude, middle range, and in temperate climate zone. The CDD (cooling degree-day) and the HDD (heating degree-day) in Korea in 2006 was 721 degree-days and 2525 degree-days, respectively, which indicates that the portion of air-conditioning in buildings is relatively low by 30% compared to that of heating. Because of this and Korean life style, only heating system has been considered with cooling system excluded since past in designing and constructing residential buildings in Korea. Hence, the resident individually installs and uses individual-unit air-conditioning system depending on his/her ability and needs.

2.2 Problems in Individual-Unit Air-Conditioning by Package Air-Conditioner

2.2.1 National problem

In the past, when the residents needed air-conditioning in the residential building, they did natural ventilation and put up with some unpleasant feelings. However, the ratio of apartment house increased more and more, and recently many high-rise buildings were constructed, as the results of which the heating and cooling load in the residential building increased. Moreover, as the need for pleasant and comfortable residential environment increases due to increased living standards, air-conditioner occupies the position of living necessity.

Korea power exchange (2006) was reported that the penetration rate of air-conditioner was 0.02 per house in 1985 and kept increasing year by year to 0.48 per house in 2006, which is 14.29% of increase to 0.42 in 2004 showing steep increase rate

Air-conditioning system using package air-conditioner uses electricity for the power for the compressor. Therefore, the penetration increase of highly electric energy-dependent air-conditioner leads to the increase of electricity consumption. In addition, it leads to the increase of maximum power demand and the decrease of power reserve rate in summer season, which becomes a social issue. Moreover, it causes high increase of power demand in summer season that induces increase in investment expense for expansion of power generation plant and decrease in the usage rate of power supply facilities, which becomes a factor that decrease the effectiveness of national power supply system. These increase in power demand and decrease in effectiveness in power supply system result in increase of CO_2 emission due to the increase of primary energy to produce electrical energy.

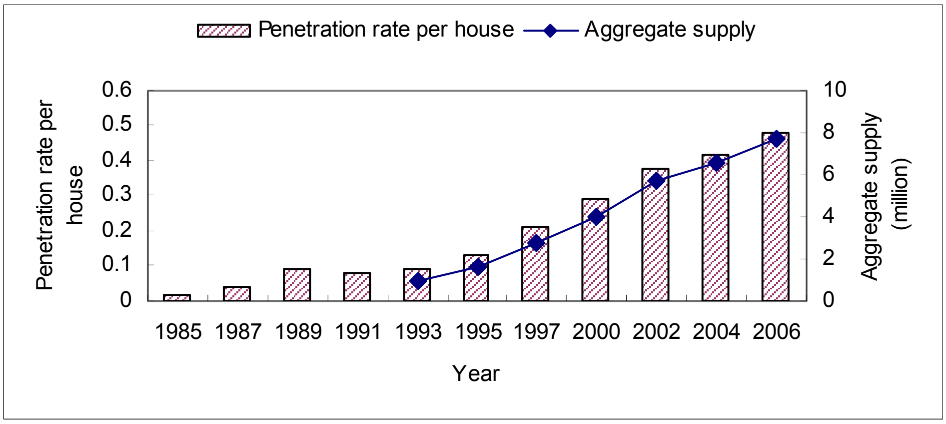


Figure 1 Annual changes of aggregate supply and holding rate of package air-conditioner in Korea

2.2.2 Personal problem

Progressive tax is applied to the electric charge for household in Korea in which the charge is weighted as the amount of use increases. Therefore, when a household operates a package air-conditioner during cooling season, it should pay the weighted charge in which the electric charge for the package air-conditioner is added to the ordinary electric charge. For example, if a house hold consumes 300KW per a month on average, the electric charge for it is 39 960 won (about 42 USD) calculated by the usual method as of February, 2008. However, if the household uses a package air-conditioner that consumes 2KWh for 8 hours per a day and 30 days per a month during summer air-conditioning period, the total amount of electricity consumed for a month is 780KWh, and the household should pay 326 600 won (about 344 USD), 286 640 won (about 302 USD) more than when it does not use a package air-conditioner. Consequently, it charges 8.2 times more despite it is weighted charge for only 2.6 times of actual amount of electricity consumed.

Such burden of energy expense acts as a negative factor for the users to operate air-conditioning system although it is equipped when they need it. While the penetration of air-conditioner increases at high rate year by year, the increase rate of electricity consumption for air-conditioner in 2006 was only 0.6% compared to that of 2004. However, during the same period, the increase rate of electricity consumption for electric fan was 9.54%. This results from the fact that although requirements for cooling increased due to seasonal factors, they used more electric fans alternatively to air-conditioner for the burden of energy expense.

The phenomenon caused by the burden of air-conditioning energy expense also influenced on the installation location and operation time of air-conditioner. The installation location of air-conditioner in Korea is mostly limited to the living room in which all family members gathers. As for the operation time, the ratio of the households that restrictively operates air-conditioner between 7 p.m. to 9 p.m. when all family members gathers together is very high.

Another problem caused by the burden of energy expense is the indoor air quality. Users tend not to ventilate while package air-conditioner is on operation in order to prevent temperature rise due to the induction of warmer outside air. This operation pattern causes many negative problems such as contamination of indoor air and air-conditioning it is due to no ventilation during air-conditioner operation.

2.3 Change in the Types of Indoor-Unit of Air-Conditioning System

The fist air-conditioner mass production began in late 1960s. Since ever, air-conditioning system has developed in a variety way according to consumers' need for bigger cooling capacity, premium, and multi-function product. The types of indoor-unit of air-conditioning system can be divided into the window type of 1st generation, wall mounted type of 2nd generation, Floor standing type of 3rd generation, and the ceiling cassette type of 4th generation, and the characteristics of each type are as such in the table 1. In recent, most of houses use a package air-conditioner with one of wall mounted type, Floor standing type, and ceiling cassette type.

Table 1 Changes in the types of indoor-unit of air-conditioning system

Period	Indoor-unit type	Characteristics
1st generation (Late 1960s)	Window type	Attached to window as indoor unit and our door unit are combined as one unit
2nd generation (Late 1970s)	Wall mounted type	Embellished outlook and began to be used as an interior design factor
3rd generation (Mid 1980s)	Floor standing Type	Most commonly used and large cooling capacity
4th generation (Late 1990s)	Ceiling cassette type	Improved design and space usability by installing on ceiling

3 Brief Overview of CFD Analysis for Thermal Environment Analysis

3.1 Target Space for Analysis

The common size and shape of Korean house was selected as the target space for CFD numerical analysis as shown in figure 2. The target space was also limited to living room area considering the fact that the most common installation place is living room. In addition, since living room area is generally connected to the kitchen and other adjacent rooms through aisle spaciously, the adjacent open area was also included in the target space to examine the interaction effect of the other adjacent open area with the living room. The target space was 7.1m(W) × 8.1m(D) × 2.3m(H), the total floor area of 36.6m^2.

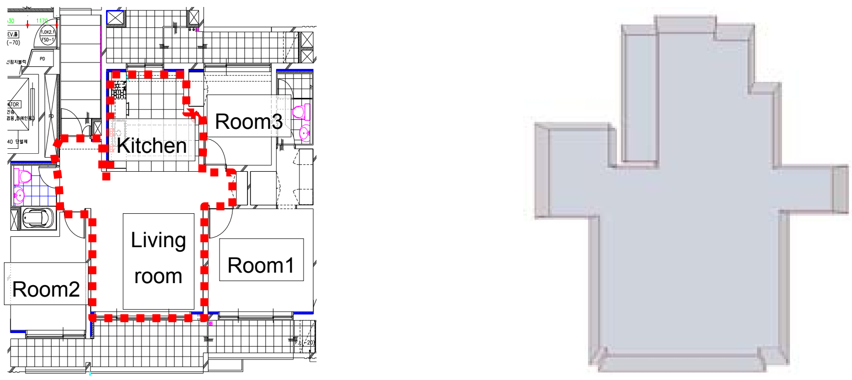
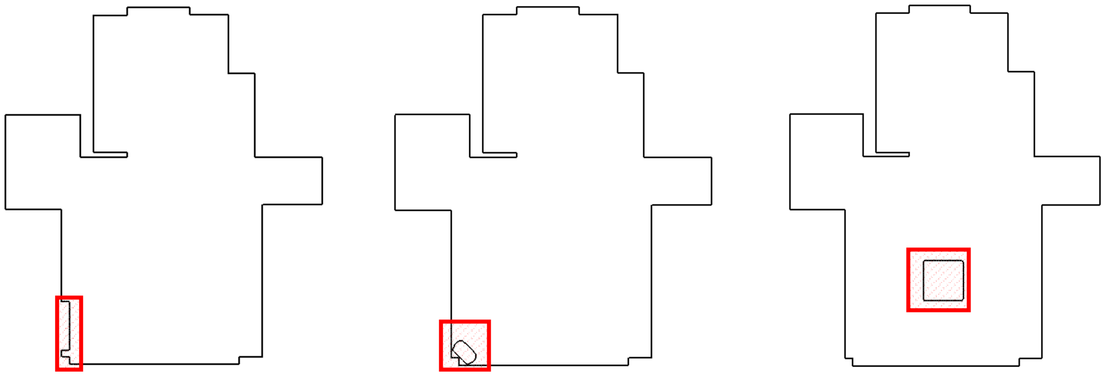


Figure 2 CFD Floor plan and modeling of the target space for analysis

3.2 Case for Analysis

The analysis was performed by making figural copies of wall mounted type, floor standing type, and the ceiling cassette type installed. An individual package air-conditioner consists of indoor-unit and out-door unit. As for the arrangement of the indoor-unit and outdoor unit, the outdoor-unit is generally installed at terrace and the indoor-unit is installed in the living room near the terrace in order to increase the effectiveness of installation and the efficiency of air-conditioning by shortening the length of refrigerants pipe. The installation place for indoor-unit and outdoor-unit for each case is as following in figure 3.

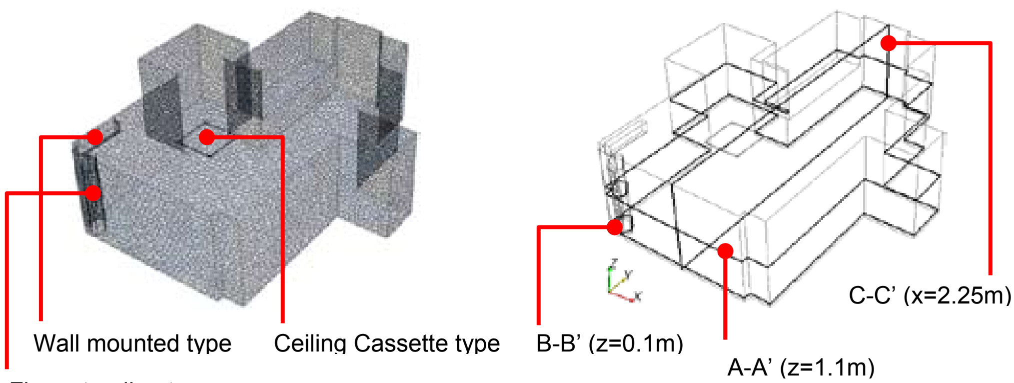


(a) Case1: Wall mounted type (b) Case2: Floor standing type (c) Case3: Ceiling cassette type

Figure 3 Case for CFD numerical analysis

3.3 Mesh for CFD Analysis

Polyhedral mesh was used for the space division for CFD numerical analysis. Different depending on case, the total volume was divided by 60 000 elements, and the surface was divided by 400 000 elements.



(a) Mesh for CFD analysis (b) Analysis section

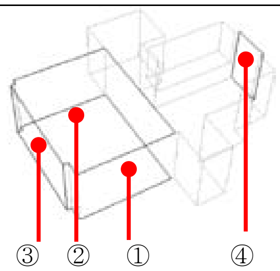
Figure 4 Mesh for CFD analysis and the analysis section

3.4 Numerical Analysis Model for CFD & Boundary Conditions

Standard k-ε turbulence model of STAR-CCM+ was used for the CFD numerical analysis, and the boundary conditions of the CFD numerical analysis are shown in table 2.

Indoor thermal environment according to the changes of indoor-unit types for all cases was examined at equivalent supply air temperature and volume condition by fixing the volume and the temperature at equivalent level. Assuming that the target space was located in the middle floor, and the adjacent rooms were also air-conditioned by the equivalent temperature condition to the target space, the wall was set as adiabatic. The windows of the living room and the kitchen were the areas in contact with outside air and set as 309.3K for the outside temperature and 3W/m^{2}K for the heat transfer coefficient. The heat transfer of human body was set based on the 70W (sensible heat) for 1.1met for an adult man to make the total 234.5W of a foursome family, one male adult, one female adult, and two children. In addition, assuming the heating rate from basic electric home appliances was 100W, total of 334.5W of heating was evenly distributed on about 15.7m^2 of the living room floor on plane figure. Heating from lights was set as 15W/m^2 from the ceiling.

Table 2 Boundary conditions of CFD

Wall		Body and equipments load (①)	• Body convective heat transfer: 234.5W 1) Male: 70.0W (100%) 2) Female: 59.5W (85%) 3) Childs: 52.5W (75%)×2(person) • Equipments: 100W
		Lighting load (②)	• 15W/m^2
		Convection (③, ④)	• Outdoor temperature: 309.3K • Heat transfer coefficient: 3W/m^{2}K

		Case1	Case2	Case3
Air-conditioning	Supply air	• Volume: 0.2m^3/s • Temperature: 291K • Velocity: 2.4m/s • Size: 0.98m×0.085m • Direction: Downward 15° • Turbulence intensity: 10%	• Volume: 0.2m^3/s • Temperature: 291K • Velocity: 1.9m/s • Size: 0.44m×0.24m • Direction: Upward 30° • Turbulence intensity: 10%	• Volume: 0.2m^3/s • Temperature: 291K • Velocity: 1.7m/s • Size: 0.42m×0.07m×4 • Direction: Downward 30° • Turbulence intensity: 10%
	Return air	• Size: 1.09m×0.11m	• Size: 0.07m×0.86m×2	• Size: 0.46m×0.46m

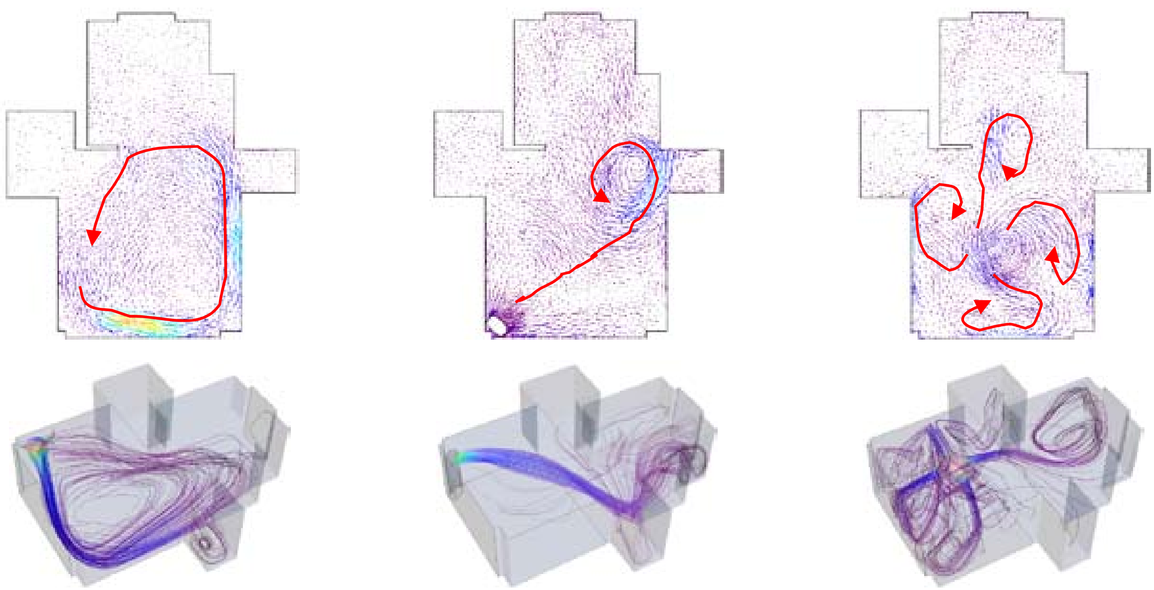
3.5 Analysis Method for Evaluation of Indoor Thermal Environment

The efficiency of indoor air-conditioning was comparatively analyzed for the indoor thermal environment factors in air current field, temperature distribution, and velocity distribution formed between 0.1m and 1.1m from the floor when equivalent supply of volume and temperature was extracted. The evaluation target range was limited to living room area.

4 Analysis of the CFD Numerical Analysis Results

4.1 Air Current Field

For Case1 to which the wall mounted type was applied, the air extracted from the distributor descended right after extraction due to extraction angle and density difference from around-air, and moved through the left-side living room window. The descending air progressed to the direction of the distributor and moved to the kitchen, an open space, through the surface of the walls opposed to the distributor. For Case1, current air field which circulated around the whole kitchen and the living room through the floor was formed.



(a) Case1 : Wall mounted type (b) Case2 : Floor standing type (c) Case3 : Ceiling cassette type

Figure 5 Velocity vectors of A-A' (z=1.1m) section across each case and streamline of the chilled air extracted from the distributor

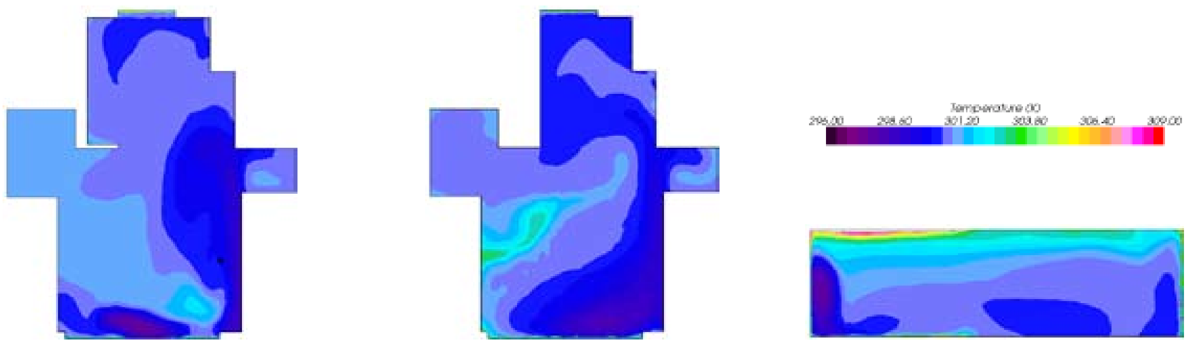
For Case2 to which the floor standing type was applied, the extracted air moved relatively far away through the ceiling and hit the walls of the aisle connecting to the adjacent rooms to form current air field spiraling and scattering around.

For Case3 to which the ceiling cassette type was applied, the four-way extracted air flowed through ceiling toward the distributor and hit the opposed walls to form abruptly descending air current field. Case3 shows the formation of living room-limited air current field due to the fact that cooled air was extracted from various directions with lower wind speed compared to other cases.

4.2 Temperature Distribution

4.2.1 Case1 (wall mounted type)

For the wall mounted type, the chilled air extracted from the distributor was distributed centered on the opposed walls to the direction of the distributor. The pattern for temperature distribution area between 0.1m and 1.1m was formed in a similar fashion. In addition, due to the cool air distribution grounded on the floor, the low temperature zone at 0.1m was formed relatively broad. The temperature at the living room window and the opposed walls at which the cool air arrived earlier was formed low. However, the temperature for the air current that came into the return circulating throughout the kitchen was formed higher than adjacent areas because it was mixed with the air in the around area. The average temperature for living area at the height of 1.1m, breathing height on seat, was 300.5K. The average temperature of 0.1m was 300.2K formed similar to 1.1m because while the range of relatively lower temperature than 1.1m was wide, the temperature for the area that the cool air did not directly reach was formed high.

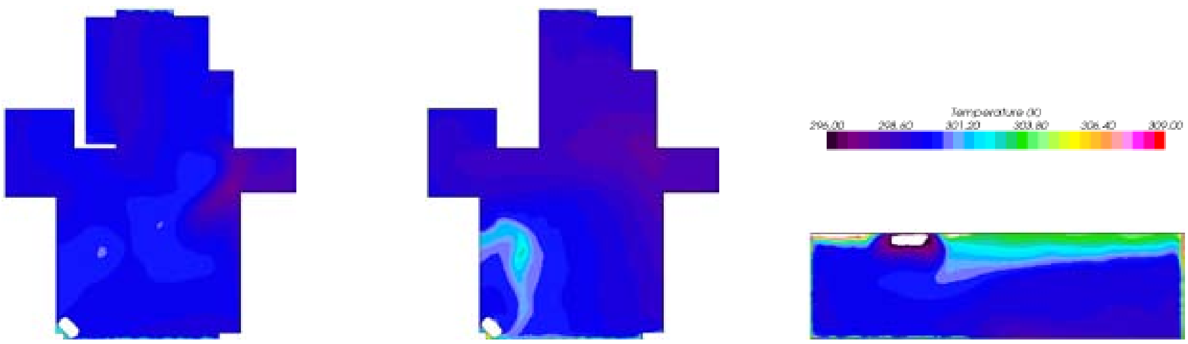


(a) A-A' section (z=1.1m) (b) B-B' section (z=0.1m) (c) C-C' section (x=2.25m)

Figure 6 Temperature distribution of Case1

4.2.2 Case2 (floor standing type)

For the floor standing type, the temperature distribution for the section of 1.1m and 0.1m was evenly distributed across the whole area. Only the area around the air-conditioner formed a zone that showed higher temperature by 2K than surrounding area. The average living room at 1.1m and 0.1m was 299.8K and 299.7K, respectively, which was relatively lower than case1 by 0.6~0.7K. In addition, Case2 showed lower and even temperature distribution than case 1. It is judged to result from the fact the first air unmixed with surrounding second air reached more at the occupied zone since the location of the distributor was closer to the occupied zone than Case1.

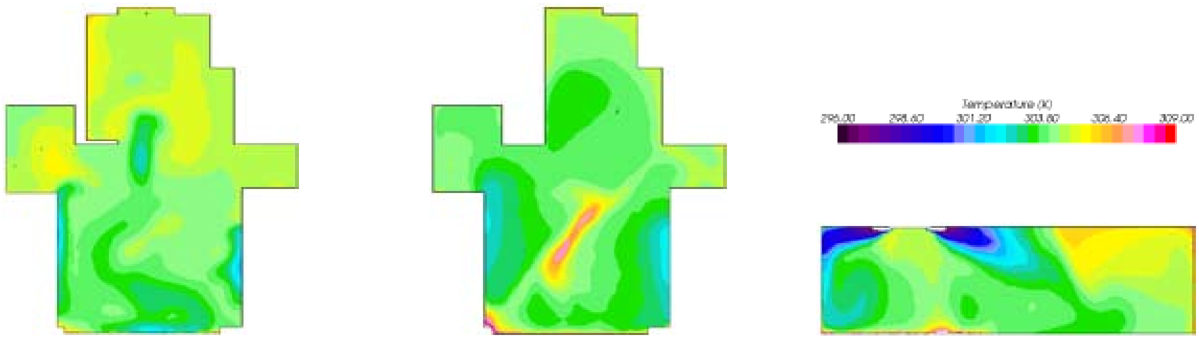


(a) A-A' section (z=1.1m) (b) B-B' section (z=0.1m) (c) C-C' section (x=2.25m)

Figure 7 Temperature distribution of Case2

4.2.3 Case3 (ceiling cassette type)

For the ceiling cassette type, the average living room temperature for 1.1m and 0.1m was 303.9K and 303.7K, respectively. These were the temperature above Case1 and Case2 by about 4K. Case3 had narrower distributor and lower extraction velocity than Case1 and case2 since it had many distributors. In addition, the distributor was located on the ceiling so that it was located farthest from the occupied zone. Therefore, before the extracted chilled air from the distributor was mixed with surrounding hot air before it reached the lower part of the occupied zone, it did not effectively remove the air-conditioning load in the occupied zone.



(a) A-A' section (z=1.1m) (b) B-B' section (z=0.1m) (c) C-C' section (x=2.25m)

Figure 8 Temperature distribution of Case 3

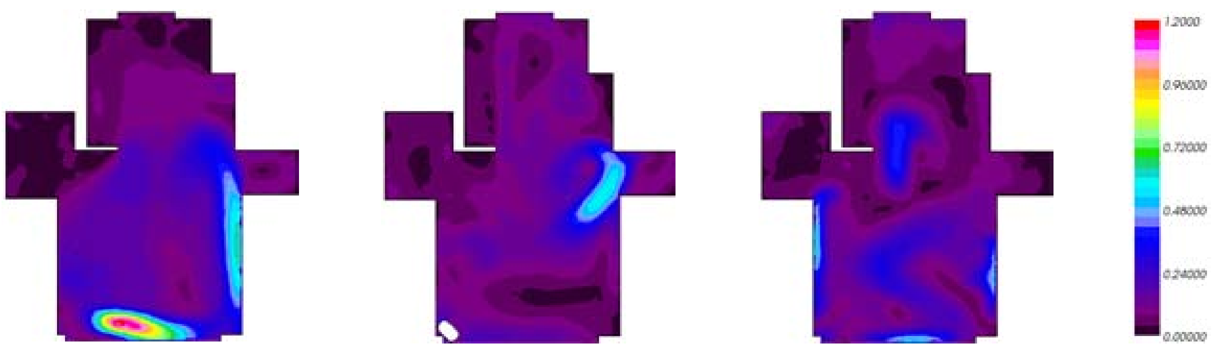
4.3 Distribution of Velocity

The velocity scalar of 1.1m across each Case was shown in figure 9. For the wall mounted type, the velocity of the extracted air current was formed relatively high at 1.2m/s. The velocity around the walls forming air current was formed high as well. The average velocity in the living room was 0.25m/s

For the floor standing type, the velocity around the corner opposed to the living room at which the extracted air current reached first was formed high, and generally the current velocity at the location diagonal to the distributor was formed high. The average velocity in the living room area was 0.13m/s, lowest among the three cases.

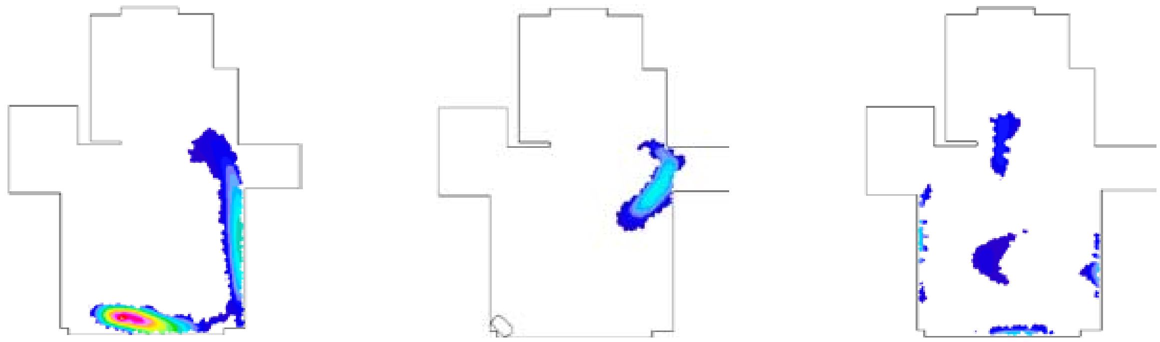
For the ceiling cassette type, the velocity was formed evenly and actively around the living room in which the indoor-unit was installed as extracted to various directions from the distributor. Therefore, the air current in the living room area was most even and finest among all the three cases. The average velocity in the living room area was 0.18m/s.

Figure 10 shows the velocity area beyond 0.25m/s of the A-A' section (z=1.1m). For the ceiling cassette type, the velocity area beyond 0.25m/s was formed broadly around the walls in the living room. On the contrary, the velocity in the living room for the floor standing type remained under 0.25m/s except the corner of the living room opposed to the distributor. For the ceiling cassette type, the four-way extraction directions from the distributors and the vertical below the indoor-unit installation place formed the velocity area beyond 0.25m/s. The area beyond velocity 0.25m/s is very likely to cause partial unpleasant feelings due to draft.



(a) Case1: Wall mounted type (b) Case2: Floor standing type (c) Case3: Ceiling cassette type

Figure 9 Velocity scalar of A-A' (z=1.1m) section across each case



(a) Case1: Wall mounted type (b) Case2: Floor standing type (c) Case3: Ceiling cassette type

Figure 10 Area beyond velocity 0.25m/s of A-A' (z=1.1m) section across each case

5 Conclusion

As a preliminary study to establish the standards for energy-efficient installation of individual air-conditioning system, this study comparatively examined the thermal environment across the types of indoor-unit through CFD analysis. The results are as following:

1) Examining the average temperature formed in the occupied zone around the living room, the ceiling cassette type formed higher than other types by 4K, which indicates that it does not effectively remove the cooling load in the indoor occupied zone. For the wall mounted type and the floor standing type, the average temperature for the occupied zone was formed lower by 0.6~0.7K for the floor standing type. In addition, the floor standing type was relatively better in the evenness of temperature distribution.

2) The average velocity in the occupied zone around the living room was 0.25m/s for the wall mounted type, 0.13m/s for the floor standing type, and 0.18m/s for the ceiling cassette type. As for the evenness of velocity distribution, the ceiling cassette type showed even distribution in the living room area due to the variously directed extraction from the distributor. Examining the area in which the velocity went beyond 0.25m/s to be likely to show partial unpleasant feelings, the floor standing type was the best among all the types.

3) The reason that the package air-conditioner consumes high amount of energy is that the compressor consumes a great amount of electric power. Therefore, the compressor would not be operated as much as possible to reduce the electricity consumption. For this, the indoor temperature should be set higher. From this perspective, the worst energy-efficient type is the ceiling cassette type, and the best is the floor standing type.

Acknowledgement

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Managing the Built Environment – The Facilities Management Industry's role in delivering connected, viable, liveable Built Environments.

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Summary

The role of the Facilities Management Industry in managing the Built Environment is not widely understood or appreciated. There is very little recognition of the possible contribution the Industry can make in making the built environment more sustainable, particular in respect of the existing built environment. The focus of many government and corporate policies is on new buildings and refurbishment. This is supported, using energy efficiency as an example, in the OECD's Environmentally Sustainable Buildings; Challenges and Policies document which states "This concentration of policy implementation on the new building sector can be justified, to some extent by the fact that energy performance of buildings is largely fixed at the time of new construction." There is a fundamental flaw in this argument as it assumes that all new buildings will be operated at the optimum design level (which is indeed, somewhat fixed at the time of new construction). However, evidence suggests that a majority of buildings (both old and new) do not currently operate at their optimum design levels. There are a number of possible contributing factors to this sub-optimal performance, but a key contributing factor is the standard of facilities management.

Consequently, the anecdotal evidence also suggests that improvements of in excess of 20% could be achieved in the sustainability performance of much of the existing built environment through better facilities management practices with little or no requirement for capital expenditure. Again using energy efficiency as the example, a 20% improvement across the non-residential component of the built environment alone could generate up to a 2% reduction in Australia's total contribution to greenhouse gas emissions.

As an industry, Facilities Managers must promote their role in sustainability to a wider audience and hence improve this audience's understanding of the facilities manager's role. Facilities Managers must improve their understanding of sustainability through better education and training and deliver demonstrable improvements in environmental sustainability across the built environment.

This is the challenge that must be taken up by the Facilities Management Industry to deliver connected, viable, liveable Built Environments.

1. Managing the Built Environment

"Managing the Built Environment" was the title given to the Facilities Management Action Agenda (FMAA) sponsored by the Australian Federal Government and supported by industry over the period from August 2005 until April 2008. Its vision for the Australian facilities management industry was "to be the foremost contributor to a productive and sustainable built environment through excellent and innovative management of facilities services" [1]. Twenty actions were developed including four specifically relating to sustainability;

Action 14 Promote the role of facilities management in responding to increased demand for corporate accountability associated with sustainability performance.

Action 15 Promote the role of the facilities management industry in key industry and government forums addressing sustainability.

Action 15 Use the data portal [FMAA] proposed to disseminate sustainability information.

Action 17 Develop a 'business case' model that highlights the costs and benefits of embracing sustainable practices in the use and management of materials; energy; water; waste and indoor environmental quality with a particular focus on workplace productivity.

In addressing the above 4 actions as part of the FMAA Sustainability Working Group it became very apparent there was little understanding of the facilities management industry and the role it must play in delivering sustainable built environments.

At the holistic level, Governments can legislate and Corporations and individuals can adopt sustainable policies. Architects, engineers and builders can design and build new 'green' buildings or refurbish existing buildings to enable better sustainable performance but this does **not** deliver sustainable performance in the built environment. It provides the tools for improved performance, but it is the facilities manager who must used these tools effectively to deliver optimum sustainable performance.

In Paul Bannister's 2003 review of energy use benchmarks for class 5 commercial buildings (offices)[2] a key finding as to why computer simulations results differed significantly from actual building data was that "real buildings suffer from a range of operational issues that impact upon building efficiency above and beyond the impact of design". It is these operational issues that are in a large part the responsibility of the facilities manager of either the owner and/or user of the building. The impact of these operational issues was not quantified, but a telling statistic is that less than 25% of buildings designed to a specific ABGR (Australian Building Greenhouse Rating) level were not operating at that level at the time of the report. This is even more concerning given that these new 'green' buildings had generally been given the necessary tools to perform. What about the existing built environment? How well is it currently performing against its original design intent given that it makes up in excess of 98% of stock, with the other 2 % being currently under construction or refurbished?

Various other reports have identified the opportunity of improving the existing built environment sustainability performance, but very few have focussed and quantified the impact that facilities management has in this area. For example the Parramatta CBD Greenhouse Leaders Project[3] (2005) acknowledges the contribution from "improved housekeeping" (a euphemism for better facilities management) but does not quantify the improvement and generally focuses on technical solution improvements. This is also evident in the more recent CIE Report[4] (2007) which addresses "Capitalising on the building sector's potential to lessen the costs of broad based GHG emissions cut". It reports that "the building sector as a whole could reduce its share of CHG emissions by 30-35% per cent whilst accommodating growth in the overall number of buildings by 2050". Again the focus is on investment in energy efficiency technology and does not address the potential risk of not having an industry skilled enough to manage effectively that technology nor does it address the even greater opportunity of combining improved management with this greater investment in technology.

On the other hand, Orjan Lundberg[5] (2008) has attempted to link the management of buildings to environmental impacts and concludes that "there is a relationship between the environmental performance of a building and the way it is managed. However, to be able to quantify and qualify that relationship, some modifications to the research design are necessary", which neatly sums up the general understanding of the impact the Facilities Management Industry has on the delivering sustainable built environments.

2. Barriers to delivering Sustainable Built Environments in the Facilities Management Industry

There are numerous barriers to delivering sustainable built environments in the Facilities Management Industry including;

1. Facilities management is not currently recognised by the Federal Government as a profession;
2. There have not been undergraduate degrees available in Facilities Management until recently in Australia and hence most people entering the profession do so as a "second career";
3. There is still little or no understanding of the Industry at the school leavers level, but the Industry's ability to deliver real sustainability improvements could be used to attract younger people into the Industry;
4. The remuneration paid to most facilities managers is not commensurate with the skill level required to deliver sustainable outcomes;
5. The property sector's continued focus on design attributes as opposed to actual performance. There needs to be a significant paradigm shift in the industry where stakeholders are rewarded for actual performance of the built environment not just its design potential;
6. Accredited designs need to be correlated with actual performance data, and the root cause of any gap analysed and addressed; and
7. Lack of basic sustainability education for practicing facilities managers.

It is the strong belief of the Author of this paper that in relation to Point 7 above, if one hundredth of the investment in any building refurbishment is made in providing basic sustainability education to practicing facilities managers, you will see a ten fold improvement in sustainable building outcomes over and above what is delivered by the actual refurbishment alone. Taking energy efficiency as an example, the return on investment in education and training can be significantly higher than that provided by investment in refurbishment of technology.

3. Industry Initiatives to deliver Sustainable Built Environments

As part of the FMAA, there are a number of specific initiatives been undertaken to address a number of the barriers highlighted above. Generally, the FMAA Sustainability Working Group has been actively promoting the role of the facilities management industry across many government and industry forums over the past three years.

The industry has supported the emergence of a number of undergraduate degrees in Facilities Management and in tandem has developed a strategy to "market" the industry to school leavers.

Specifically "Sustainable Operations Guidelines for Facilities Management" [6] have been developed by the FMAA Sustainability Working Group to provide operational facilities managers with a simple and relevant reference document on "how to" deliver sustainable built environments.

In conjunction with the University of Sydney and UNE Partnership, an innovative, industry led, education and training programme is being developed specifically for operational facilities managers with defined work related sustainability improvements as part of the key deliverables.

The industry continues to engage with the Federal Government in relation to the proposed Green Building Fund to ensure taxpayers funds are spent proportionately on what will provide a lasting legacy through improved education and training rather than a "one off" technological fix (which is unlikely to provide the expected benefits for all the reasons outlined in Section 2).

Conclusion

The Facilities Management Industry clearly has a role to play in delivering connected viable liveable built environments. What is needed is greater recognition and clear understanding of this role by all stakeholders so that the Industry can be developed to realise the full potential of its ability to deliver improved performance across the entire built environment.

Relying on design and technological improvements ***alone*** does not equate to delivering sustainable performance in the built environment.

Australia must invest in education for the facilities management industry as this is clearly the "lowest hanging fruit" available to produce material improvements to the sustainability performance of the built environment.

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MAINSTREAMING SUSTAINABLE HOUSING: POLICIES AND PROGRAMS THAT WORK

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Keywords: sustainable housing, policy, consumers, industry, home buyers, social research

Summary

This paper draws on the findings of research by the Institute for Sustainable Futures (ISF) for the Queensland Environment Protection Agency (QEPA) into attitudes towards sustainable housing. The aim of the research was to examine what drives housing provision and choice from both the housing industry and consumer perspectives, and how sustainability fits within this picture. The research also aimed to demonstrate how this understanding can better inform sustainable housing policy. The research found that for consumers, cost and lifestyle are the most powerful drivers of housing choice. For industry the drivers for action (from product supply and service delivery to building practices) are profit and market edge, both of which are largely driven by perceived consumer demand. There is a significant mismatch between the perceptions of consumers and industry in that each group perceives the other as lacking commitment to advancing sustainability in the housing sector. The study underlined the value of social research in informing sustainable housing policy in the mainstream housing market in order to ensure that these drivers and conflicts are addressed.

1. Introduction – the importance of social research for sustainable housing policy

Governments around the world have implemented a wide range of policies to encourage and underpin the uptake of sustainable housing, covering the full complement of regulatory, fiscal and educational measures. These have had varying degrees of success, and sometimes unexpected and even undesired outcomes.

Currently, much of the research undertaken prior to policy implementation focuses on technical and financial analysis, with little effort put into finding out and understanding what motivates consumers and industry. However, when it comes to what drives action, it is as likely – if not more likely – to be structural or attitudinal factors as technical or financial ones.

If sustainable housing policies are to be effective and supported by both consumers and industry in the mainstream housing sector, there is a need to research and respond to the perceptions and attitudes of the intended recipients. Policy is more robust and effective if it aligns with people's existing drivers for change, while anticipating and addressing barriers to uptake. Even the apparently more predictable regulatory measures can fail to achieve desired outcomes if they are not grounded in an understanding of these drivers.

This paper presents the results of research conducted by the Institute for Sustainable Futures (ISF) for the Queensland Environment Protection Agency (QEPA) on consumer and industry perceptions of sustainable housing. A review of previous research on perceptions of sustainable housing establishes common themes and key questions for investigation. The results of new research conducted in Brisbane for the QEPA are then described, building on themes and issues evident in the literature. The research findings are then used to create a framework for policy to progress sustainable housing.

2. The QEPA project

The project that the Institute for Sustainable Futures (ISF) undertook for the Queensland Environment Protection Agency (QEPA) consisted of two main components; a research element, using primary and secondary research to investigate building industry and consumer perceptions of sustainable housing; and a policy development component, using the findings of the research to inform the development and analysis of a series of policy options. The research included some examination of the social aspects of sustainable housing such as accessibility and health, however the main focus of the research was the environmental aspects of sustainable housing. The research component of this work consisted of three parts:

- A literature review (described in section 2 below)
- Empirical social reseach, comprising:
  - A series of telephone and face-to-face interviews with key stakeholders
  - Two surveys conducted with visitors to the *HIA Home & Building Expo 2006,* held at the Brisbane Convention & Exhibition Centre from 4 – 7 May 2006 (hereafter referred to as the 'Brisbane Expo survey'). One survey targeted consumers (382 responses), while a smaller survey was aimed at building industry members (142 responses)

The policy development component consisted of three stages:

- Development of a suite of potential policy measures and instruments (informed by the research)

- A stakeholder workshop to present and seek feedback on the research findings and the potential policy measures and their likely impacts
- Refinement of the policy proposals using the workshop outcomes and including an analysis of the costs, benefits and risks associated with each option

These were focused on new housing, but many of the findings would be equally applicable to the home renovation market.

The results of the literature review are discussed in section 2 below, and the findings of the emprical social research summarised in section 3. Section 4 then goes on to explain how the research phases of this work were used to inform policy development.

2. Previous research on consumer and industry perceptions

Previous research into awareness of sustainable housing has produced conflicted results, with literature divided on the extent to which consumers are aware of and interested in sustainability in the residential sector. A number of studies indicate a general lack of awareness and resistance to sustainable housing based on a perception that sustainable housing is less aesthetically attractive and has a lower resale value than traditional housing (see for example, Minnery et al. 2003 cited in Buys et al. 2005; Buys et al. 2004; Clark 2001). A Queensland Department of Housing study identified a relatively low consumer awareness of sustainable housing issues and found that there was little education or information provided to them (Colmar Brunton 2004). Interviews with 421 consumers from Melbourne and Sydney found that only 47% had even heard of ‘green’ buildings (Trilogy Property Pulse 2005 cited in Iyer-Raniga et al. 2007). Gold Coast water identified lack of awareness as a barrier to the successful uptake of its water efficiency program, evidenced by questions from consumers such as “Will this really save water?” “What does the rating system mean?” and “Which appliance do I buy?” (GHD 2005).

However many Australian and international studies contradict these analyses and there is evidence that consumers are becoming not only more aware of sustainable housing, but more interested and convinced of its value. A US study of consumer approaches to green home buying found that half the market were interested in sustainable buildings, with energy efficiency, indoor air quality and water efficiency the most valued features (Johnston 2001, cited in Iyer-Raniga et al. 2007). Similarly, research undertaken in Melbourne by Trilogy Property Pulse (cited in Iyer-Raniga et al. 2007) found that 85% of 421 survey respondents believed that future developments should be ‘environmentally friendly’ or ‘green’. A survey conducted for the Sustainable Energy Authority Victoria (SEAV) found that of a group of display home visitors interested in a household energy rating, 25% indicated energy use would significantly influence their choice of home (Allen Consulting Group 2002, cited in Kam 2005).

Despite increasing awareness of and support for sustainable housing, much of the literature reports that action is lagging behind expressed intentions. While consumers feel positively about sustainability, these positive attitudes often do not translate into action. This is because consumers do not consider sustainable features in isolation, but in relation to other more significant and often conflicting drivers. As a result, actual uptake of sustainable housing elements – unless regulation mandates implementation – does not match people’s expressed support for sustainability as a principle.

The relatively low voluntary uptake of sustainable housing is reported anecdotally and supported by a number of studies. Ambrose et al. (2005) note that uptake of energy efficient design in the residential sector has rarely been voluntary and has primarily followed advances in regulation including amendments to the Building Code of Australia. This is reinforced by Buys et al. (2005), who note that despite increasing consumer awareness about the importance of reducing energy consumption, the uptake of sustainable housing designs and smart technologies remains relatively low. Of 50 homes surveyed by Brisbane City Council about energy efficiency (Brisbane City Council 2002), over half did not consider natural ventilation and more than a third did not consider eaves or window shading. A survey of 3,304 Queensland householders in 2005 found that only 7% use solar hot water systems, with 85.5% using electricity for hot water (OESR 2005).

Cost is the most commonly cited reason for low uptake of sustainable housing (for example Iyer-Raniga 2007; Yudelson 2004 cited in Kam 2005). This is interesting in light of apparent increasing support for sustainable housing. Sibley (2004) suggests that cost is not so much a *motivator* as a *barrier*. Rather than driving consumer choices, cost is a limiting factor for those consumers unable to afford particular initiatives. This implies that cost is a secondary – albeit important – consideration: consumers identify preferred sustainability initiatives first and consider affordability (and consequently rule out particular options) second.

Lack of industry support is also cited as an important barrier to consumer uptake of sustainable housing and a perception exists amongst consumers that the urban development industry generally lacks awareness of sustainable housing. Of 421 Melbourne and Sydney consumers interviewed, 60-70% believed that developers are not interested in the environment (Trilogy Property Pulse 2005 cited in Iyer-Raniga et al. 2007). A Melbourne study of environmentally conscious buyers found that only 3% of 300 people surveyed had received information on environmentally friendly housing from their builder or architect (Sibley 2004).

This forms a significant barrier to wide uptake of sustainable design features, as consumers naturally tend to rely on advice from industry when making choices about house design and construction.

Interestingly, while consumers believe industry has little interest in sustainable housing, the perception from industry is that it is lack of consumer demand that is preventing mainstream adoption of innovative design. In a survey of housing industry representatives in South East Queensland, respondents believed that consumer expectations centre on comfort, lifestyle and resale (HIA 2005). They perceived a general consumer ignorance regarding sustainability issues, and said that whilst they had a role in educating consumers they could only take this up to a point. There was also the perception that consumers would not pay more for sustainable housing (which conflicts to some extent with the consumer literature). The consensus was that without consumer demand industry is not in a position to deliver sustainable housing.

3. Results of new social research on attitudes to sustainable housing in Queensland

The new social research undertaken by ISF for the QEPA explores perceptions of sustainable housing among consumers and industry, and builds on themes and issues evident in the literature described above. Results from this research provide insights into both consumer and industry perceptions of issues relating to sustainable housing. The study also helps understand some of the behaviours and choices that both groups display in response to these issues. The findings of this research are summarised below.

3.1 Consumers

Consumers have a range of perceptions about sustainable housing, some of which support and some of which inhibit the uptake of sustainable housing features, products and services. The study suggests that people feel positive about sustainability and sustainable housing at a conceptual level, as something they aspire to. For example, almost 80 per cent of survey respondents agreed that 'it's important to do the right thing' in the context of sustainable housing. Respondents were also convinced that sustainable housing has the potential to offer them a number of different personal benefits. Almost 65 per cent thought that it could improve their lifestyle, over half thought it could save them money and half thought it could improve the value of their house. Respondents also ranked sustainability highly compared to other factors. In response to the survey question *what is most important to you when buying, building or renovating a home?* respondents ranked environmentally friendliness third overall (below comfort/lifestyle and resale value) when given a list of eight criteria. These results suggest that consumers are predisposed to view sustainable housing positively – at least at the conceptual level. They also have high levels of intent to implement sustainability features. The survey asked whether people had, or intended to, implement a range of specific features (such as rainwater tanks, energy or water efficient fixtures and passive/low energy heating and cooling and so on), and among those who had not already implemented these features the proportion who intended to do so in the future was at least 40 per cent for each of the features. The elements that the highest numbers of people intended to include in the future were rainwater tanks (69 per cent) and energy efficient fixtures (60 per cent).

However, despite positive general perceptions and good intentions, there are also barriers for consumers that may prevent them from translating intent into action, behaviour and purchasing choices. Overall, the biggest barrier to implementing sustainability elements is cost. Perceptions about the cost of sustainable housing tend to be negative – that is, the belief that 'sustainability costs more' is fairly common. This can be seen in two aspects of the research findings. In the survey, when consumers were asked about implementation barriers in relation to a diverse range of sustainability aspects, 'added cost' was consistently named as the biggest barrier. In the stakeholder interviews, the perception that consumers are largely driven by cost was very common. As one interviewee put it, "*Consumers want [sustainability] as a bonus but they don't want to pay for it".* Many interviewees noted that not only are consumers driven by cost, but they also tend to have a narrow, or short-term view of what constitutes 'cost'. It was thought that many were only interested in comparing up-front costs – few considered running costs, or the savings that could be made over time by using more sustainable features. As one person said, "*most consumers base their decisions on "what can I afford right now?"*

The ISF survey found that many people do see sustainability as something that has the potential to save them money over time. For example over half the consumers surveyed thought sustainability could potentially save them money or add value to their home. Further, when offered a choice of factors that might encourage them to implement elements of sustainable housing, 'savings on energy and water bills' was overwhelmingly the highest ranked answer.

It is worth policy makers noting this positive cost-related perception, and where possible building on it, by stressing the potential for cost savings over time (for example, through lower bills) and for added asset value. However, while worth pursuing, the potential for this approach may be somewhat limited. Stakeholder interviewees suggested that most consumers still consider cost predominantly in relation to upfront costs and asset/resale value, and that ongoing or running costs are secondary and much less important considerations for most consumers.

Insufficient knowledge is also a barrier, with one in five survey respondents stating that they did not know enough about sustainable housing. However, interviewees generally thought that consumers have become more aware in recent years, particularly in relation to environmental issues:

In general, people are more concerned and smarter about the issues

The consumer base is more educated and more wanting of a greater intersection with sustainability.

Awareness is across a broader cross-section of the population now.

One interviewee suggested that younger people in particular are showing higher levels of awareness, and that their views may be quite influential in the future:

The generations coming through are far more educated about this whole process than their parents were.

However, many of the interviewees suggested that there is a marked difference between what consumers say about sustainability, and what they actually do when it comes to housing choice.

If I just did a general survey of the public out there, you'd get an overwhelming response that, 'yep this [sustainable housing] *is good'. But you target the people who are about to build and spend the money; you'll get a totally different answer.*

This apparent gap between general attitudes and actions was a key theme of the research, and it is perhaps explained by the fact that consumers are motivated by other important drivers. These certainly include cost, as just discussed, but also important are what might be referred to as 'lifestyle' factors. When asked what was most important to them in their home, 'comfort and lifestyle' was by far the most highly ranked criteria overall, and was also the most popular criteria, with far more respondents ranking it first than any other.

'Lifestyle' is a loose term, used here to refer to a range of factors that are commonly expressed by consumers. 'Lifestyle' factors are most often expressed in terms of comfort and convenience, and can also relate to other aspects like aesthetics, status and the size of the home. The desire to be sustainable can be easily overridden by these considerations. On the face of it, consumer perceptions linking sustainability and the lifestyle driver tend to be largely positive. For example, 65% of consumers surveyed in this research believed that sustainability could improve their lifestyle, and almost none saw sustainability as a lifestyle compromise. However these attitudinal results (particularly the latter) should be interpreted with some caution. The link between this 'lifestyle' driver and cost is difficult to measure, particularly because consumers are less likely to admit to attitudes that conflict with their stated desire to 'do the right thing'. Nevertheless, translating those positive attitudes into action, particularly when it means compromising on comfort or lifestyle, proves challenging for many.

However, while it is true that actions do not always live up to attitudes, and consumers are not keen to 'compromise' comfort or lifestyle, it appears that consumers do at least have a positive perception of sustainability in relation to lifestyle. This indicates the potential for a greater emphasis on the lifestyle benefits of sustainable housing to be used as a policy lever.

3.2 Industry

What emerged from the research as the key drivers for industry when it comes to decisions about sustainable housing were the need to make a profit and the desire to develop or retain a 'market edge' over competitors. These drivers are strongly influenced by perceptions about two things, firstly consumer demand, and secondly the cost and risk of any given action. Perceptions of how sustainability relates to these two drivers are predominantly quite negative, particularly in the mainstream of the housing industry.

Some aspects of industry perceptions and drivers are best understood with reference to certain characteristics of the mainstream housing industry, for it is the particular nature of the industry that appears to influence industry perceptions about the possibilities of sustainable housing. Firstly, the industry is relatively segmented, with different segments playing different and well-defined roles. This means that many industry players are focused fairly narrowly on their own role in the building process, rather than on the 'bigger picture' and their relationships with other segments of the industry. This is illustrated by the fact that 40 per cent of industry respondents to the ISF survey said that the main barrier to implementation of sustainability is that it is often not specified 'upstream' in the process. This appears to mean that individual players 'downstream' feel they have little control or influence over it. The second relevant characteristic of the housing industry, in particular the project home sector, is that it is highly standardised and relies on certain designs, processes, relationships and supply chains that have been gradually developed and refined over time. There are large perceived (and possibly actual) costs and risks in changing these standard ways of working in order to incorporate more sustainability initiatives. Further, in a buoyant market, this is seen as an unnecessary 'experiment'.

Changing housing designs and product supply chains is seen as a significant financial investment, with no guarantee of a financial return. Even if the will to show leadership and change current practice exists on an individual level, it can be constrained by other factors including organisational reluctance, lack of knowledge, insufficient skills or lack of access to training

Another significant finding is that the housing industry is heavily influenced by perceptions of consumer demand. A message that came through very strongly in the interviews was that the industry is highly consumer driven. Many people noted that industry members will only act on sustainability if they see a consumer demand for them to do so:

Our industry is driven by what people ask for, rather than what we give them.

Furthermore, it seems to be a common perception amongst industry members that there is little consumer demand for sustainability, and without such demand, the industry cannot respond. There was a feeling among some people however, that this perception was quite limited, and that if the industry were more proactive on sustainability issues then perhaps consumers would respond:

It's definitely in the hands of the developer or the builder [to stimulate demand]

They [the industry] *don't actually realise that it's a chicken and egg argument.*

However, others thought that change in industry ultimately must be driven by consumer demand, and that it is the responsibility of governments to educate consumers and create a demand (and hence a market) for sustainability in the housing industry. In this sense, the high degree to which the industry sees itself as demand driven can potentially be positive:

If the public can create the demand, change within the industry tends to flow on very, very quickly.

In general however, and particularly in the 'mainstream' project home market, levels of consumer interest in and demand for sustainability are thought by industry to be low, or even in some cases, non-existent:

Nobody comes into our office and says, "I want the most environmentally friendly house that you've got". Nobody does that. The environment for our customers is way off their radar.

The consumers aren't asking us for choices.

Customers come to us and say, "I want the most amount of house I can get for the least amount of money, and I want it to be big, and I want it to be functional; I want the kids to have big bedrooms".

The main reason for the lack of consumer demand is perceived to be cost of sustainable housing, and the fact that consumers do not see it as an immediate benefit:

Would [consumers] *pay an extra thousand dollars knowing that it's going to take them ten years to get that thousand dollars back? No.*

If you want people to be environmentally friendly you have to make it instant and you have to make it not cost any more.

Industry perceives cost to be a major driver for consumers, and sees the challenge with sustainable housing to be marketing it in a way that addresses this:

We've got to find a way to target the sustainable housing at the hip pocket because that's where you're going to get the people in.

Further, many interviewees thought that most consumers have not yet reached the point where the issues of sustainability is personally relevant and important to them.

The industry perception of limited consumer demand relates strongly to the profit and market edge drivers. Clearly many industry members are aware of the consumer 'attitude-action gap' discussed above. They feel that while consumers have positive intentions about sustainability, when it comes to implementation their behaviour may not reflect this, and it is their behaviour that industry pays attention to. As a result while the industry is aware of increasing consumer interest in sustainability it is seen as fairly marginal, and certainly not as a key factor that drives decision making. In particular, industry does not believe that consumers are willing to pay more for sustainability. For these reasons, sustainability is not generally seen as a useful differentiator for business. It can even be seen as having the potential to compromise profit and market edge in cost sensitive markets such as the project home market.

The perception that sustainability adds cost was a predominant industry view among the survey respondents. Cost was the most commonly identified barrier to implementing sustainability features, with between 14 and 34 per cent of respondents naming cost as a barrier, depending on the feature.

This perception may be compounded by the typical tendency to treat sustainability as an 'add on' rather than as integral to the house, and therefore to view the costs as additional to the cost of a 'standard' house. It is also affected by levels of knowledge – some industry members, like some consumers, may only be aware of the larger more costly features (such as rainwater tanks and solar cells), and not immediately think of the range of low or no-extra-cost features (such as solar passive design and orientation, or water efficient tapware). Lastly the perception that sustainability adds cost may be related to the lack of experience and skill in incorporating sustainability elements, and the view that 'skilling up' to do things differently will be a time consuming and costly process.

Finally, it is also important to acknowledge that there is a perception predominant in mainstream industry that there is no *need* to change practice. This can be the result of individual lack of interest in sustainability, inertia or attachment to the status quo, or of people not feeling a sense of personal responsibility for change.

There are however, some sectors of industry that hold a more positive view about sustainability. In the ISF survey, almost half the industry respondents thought that sustainability was a way of 'adding value' for their clients, and over a third saw it as potentially adding value to their business. Others are beginning to see sustainability as a marketing tool, or a means of giving their business a 'market edge', particularly if they can target consumers who are both more aware of the issues and capable of making more sustainable choices (although there is a perception that these are likely to be the more educated and wealthier consumers rather than those in the 'mainstream', or project housing markets). Some also suggest that sustainability has the potential to improve efficiency and risk management in the industry, by promoting better integration and cooperation between currently fragmented players. Finally, there are industry members, although they are in a minority, who are highly committed to the principle of sustainable housing and are 'leading the way' by actively seeking information, exploring options, and developing and trialing new ways of working. The positive examples being set by these motivated individuals can be highly influential within the industry, as they have the potential to inspire others to start moving in a new direction. Building on these more positive perceptions may be a useful approach to the development of sustainable housing policy that seeks to get larger numbers of industry members 'on board'.

There may also be a need to focus on particular segments of the industry. It was notable that builders were viewed by other industry respondents as being less open to change and in some cases playing a 'change resistor' role. Builders tended to be viewed as quite resistant to addressing sustainability issues, particularly where doing so is optional – in other words, where it means taking action beyond compliance with building code requirements. As one interviewee said:

> *The builders, as a general rule, will only be compliant. They'll do the minimum they have to, and they'll fight tooth and nail against anything that's likely to add any more effort and more challenges for them, or more money to the job.*

Part of the reason for this may be that builders are already working to narrow margins, particularly in the first home buyer market. This means that any additional costs of sustainable elements may be seen as difficult to absorb.

It seems that many builders may see themselves as having a limited role in sustainability innovation because they are mainly implementers of other people's designs and requests, and 'change followers' (responding to new directions set by customers, architects and developers). However, there is some evidence to suggest that this is not the case, and that builders can actually exercise a high degree of influence over whether or not sustainable features are chosen (for example Brisbane City Council, 2005). This suggests that if builders were to change their standard offerings to include more sustainable options, consumers may well just accept the new and different inclusions. Product suppliers, subcontractors and sales people were also identified as change followers rather than leaders. It appears that there is substantial scope to work with these various industry groups to help them better understand the level of influence they have, and the potential role that they could play in the change process.

4. Implications of social research for sustainable housing policy

This section discusses the implications of the research findings discussed above for housing policy, and shows how the findings were translated into policy recommendations for the state of Queensland.

The research ISF conducted in this area is based on the firm belief that a 'technical solution' will never deliver sustainability on its own, rather there is a critical need to consider the social dimensions of the issue, and design policy in response. Social research is extremely valuable in identifying the key drivers and corresponding perceptions of the target audience for a given policy, and provides a knowledge base that can inform policy development. In the case of sustainable housing policy, strategies that are based on an appreciation of the target audience's existing drivers and perceptions, and that counter negative aspects and build on positive ones have the best chance of being supported and therefore effective.

4.1 Translating social research into policy

Figure 1 (right) shows the research and policy development process used in this project. The first step was a review of relevant local and international literature, from which research findings were collated and further questions were raised. These findings were tested specifically for Queensland through surveys conducted at the Brisbane Home Show, which collected mostly quantitative data from a statistically significant sample of consumers and industry practitioners. Survey questions were designed to test the previous findings, explore relationships between certain findings and examine some of the

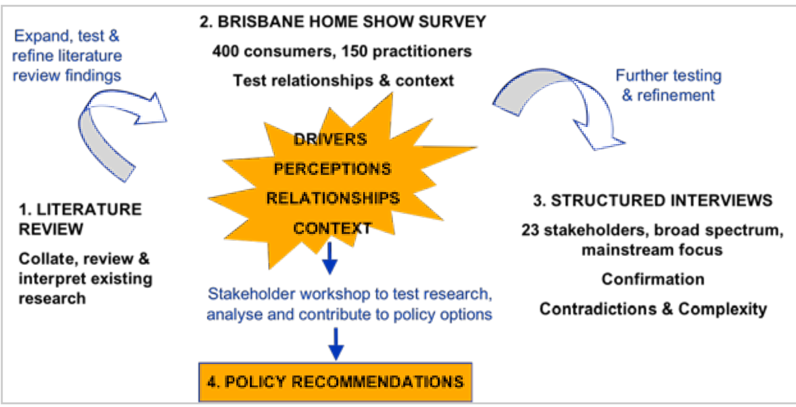

Figure 1 Process for social research and policy development

unanswered questions raised by the previous literature review, for example, "How do perceptions vary based on the specific aspect of sustainability being considered?" and "Is there indeed a gap between attitude and action?" The third and final stage in the social research involved structured interviews with a diverse and carefully selected sample of stakeholders to further test the findings and explore in more detail the complexity and contradictions raised in previous stages of the research.

Then, the drivers and perceptions identified in the research were mapped and translated into potential policy aims. A workshop with key stakeholders from government and the housing industry was held to discuss and further develop policy aims and potential instruments.

Figure 2 Translating drivers into policy (extract)

DRIVERS	PERCEPTIONS	POLICY AIMS	POTENTIAL POLICY INSTRUMENTS
Example drivers: Profit Market edge Cost Resale	Costs more upfront (consumer and industry perception) Limited consumer demand (industry perception)	Reduce upfront costs of sustainable housing	Low interest loan (specific items, or entire home/ renovation) Rebates for sustainable products Fast tracked approvals processes for sustainable developments Development bonuses/ concessions for sustainable developments
	Doesn't add value (consumer and industry perception)	Increase asset/ resale value of sustainable housing	Sustainability rating tool for homes Point of sale disclosure of sustainability performance Home valuation standards that incorporate sustainability
	Compromises market edge (industry perception) (Note: this is a particularly strong perception the in cost constrained project home market)	Improve industry practice in sustainability without compromising market edge (Note: project homes constitute approximately 80% of new housing in South East Queensland)	Voluntary partnership program with project home builders to review designs and supply chain

Figure 2 (above) is an extract of a larger table that shows how drivers and related perceptions were mapped and translated into potential policy aims and instruments. This extract uses money-related drivers (profit, market edge, cost and resale) as an example. For consumers, these money-related drivers primarily relate to capital costs and resale value, and are accompanied by perceptions that sustainable housing costs more upfront and doesn't add value to their property. For the housing industry, drivers relate to market edge and profit, and are accompanied by the perception that consumers aren't interested in sustainability and therefore any cost increase due to sustainability will diminish market edge and profit. This perception was particularly prevalent in the cost-constrained project home market, which attracts a significant proportion of first home buyers and constitutes around 80% of new home sales in the populous and rapidly developing South East Queensland region.

The policy aims were directly translated from drivers and perceptions. This alignment ensures that the policy aims leverage drivers and any positive perceptions, as well as addressing negative perceptions. The policy aims were then used to develop appropriate policy instruments, in collaboration with a number of key government and housing industry stakeholders.

5. Conclusion

Currently much of the research prior to policy implementation focuses on the technical and financial barriers, with little effort put into finding out what will motivate consumers and the industry to take the desired action. However, our research suggests that barriers and drivers are often as much structural or attitudinal as they are technical or financial, if not more so.

If policy is to be effective, there is a need to research and respond to the perceptions and attitudes of the range of intended recipients. Policy is more robust and effective if it aligns with the drivers for change while addressing the barriers. Social research is needed to identify the drivers that can be used to support policy development and implementation, and is a way of indirectly involving recipients (in this case, consumers and the housing industry) in the policy development process.

Furthermore, the intent and implications of policy measures, especially regulatory measures, must be communicated to both consumers and industry. That way technical and fiscal solutions chosen will be well received, which is essential to facilitate implementation and ensure acceptance and uptake.

Until issues related to consumer and industry attitudes and perceptions are addressed by the development of policy that is informed by in-depth social research, the implementation of sustainable housing policies is likely to be difficult, uptake may be lower than expected, and policy may even have undesired outcomes.

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SUSTAINABLE DESIGN LABORATORY: THE HARMONY OF NATURE AND TECHNOLOGY

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Keywords: Sustainable house, Passive House, CASBEE

Summary

"Sustainable Design Laboratory" (SDL), is a unique research facility that was established by Sekisui House Ltd. in 2006 to propose a more environmentally friendly lifestyle through houses that coexist with nature instead of challenging it. SDL has built an experimental house that is suitable for an urban environment. It was designed with consideration for the environment by utilizing natural energy, and it incorporates ancient practices and modern technology at the same time.

There are two fundamental concepts of the SDL research; The first one is "Learn from the trees"; We want to create houses that depend on, and use, the sustainable energy of nature, as trees do. The second concept is "Learn from traditional Japanese houses"; Use natural energy to mitigate the effects of heat and cold as people did in earlier times. People can feel and enjoy the four seasons.

1. Concept & Planning

The building is located in Kunitachi City, in Tokyo Japan (Figure 1). Figure 2 is the floor plan and Figure 3 is an elevation view of the building. Table 1 shows an outline of the building. It is a heavy steel-frame structure with a 2story *engawa* (Japanese sunroom) of wooden construction attached on its south side, forming a doubleskin structure made of glass and *shoji (sliding doors made of a wood frame and Japanese paper)*.

The environmental concept of this building is the reduction of energy consumption and comfortable living through a hybrid-technology house (Fig. 4). In Japan, four distinct seasons bring hot, humid summers and cold, dry winters. In the summer, this building reduces the cooling load with well-controlled ventilation. In the winter it lowers the heating load by incorporating solar heat. The balance of utilizing nature and modern technology is thus called a hybrid-technology. The keys to achieving this balance are the "*engawa* space" and "ventilation skylights".

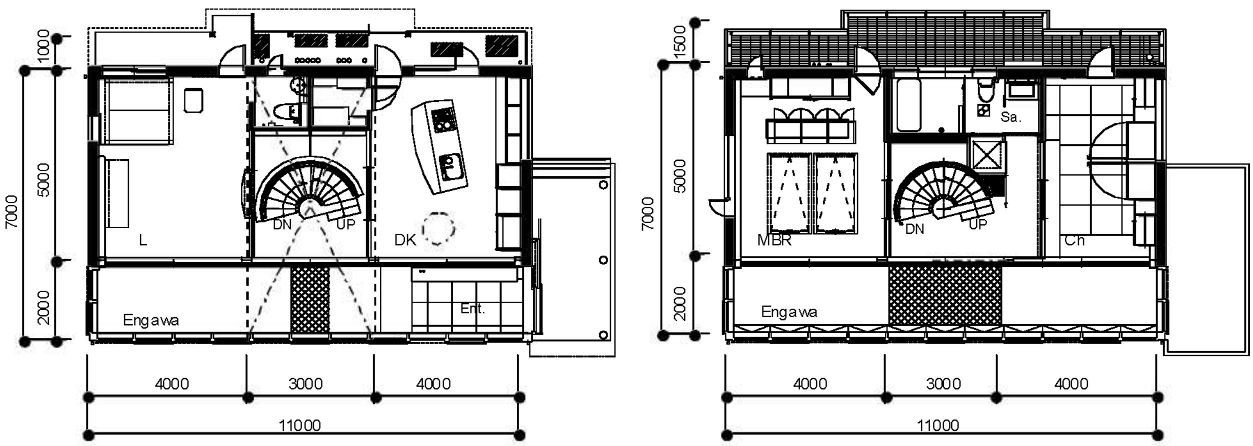
The Japanese house should be suited to the climate and environment of Japan. The concept guiding this design was a desire for it to be a home where people can feel the changing of all four seasons.

Table 1

Building outline		
Address		Kunitachi City, Tokyo, Japan
Completed		June 2006
Building area		99.79m^2
Floor area	Basement	23.1m^2
	1st floor	88.7 m^2
	2nd floor	79.9m^2
	Penthouse	6.0m^2
Total floor area		197.85m^2
Construction		Heavy steel-frame 2-story building

Photo 1 Sustainable Design Laboratory

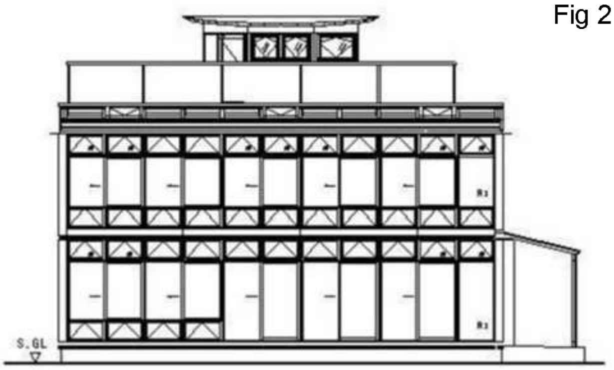
Fig 1 Kunitachi City
Tokyo JAPAN



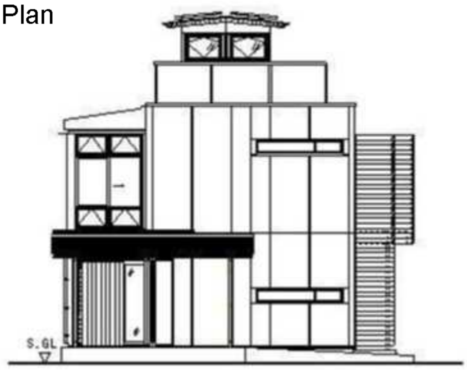
1F PLAN

2F PLAN

Fig 2 Plan

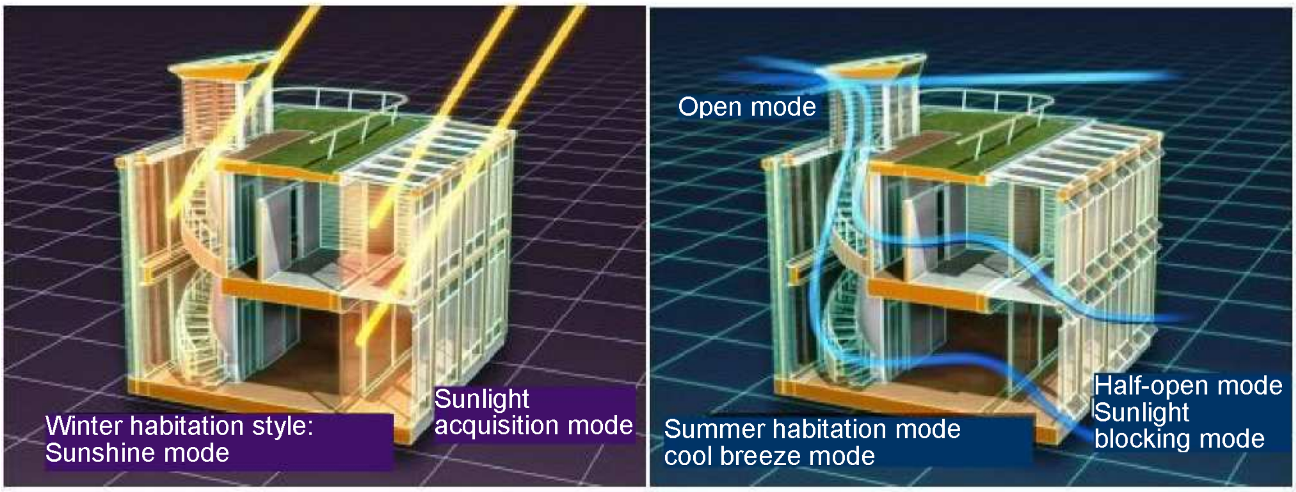


1) South



2) East

Fig 3 Elevation



Winter

Allows sunlight to enter, reducing heating load

Summer

Instead of air conditioning, allowing natural airflow from the outside to pass through

Fig 4 Hybrid Function Plan

2. ELEMENTS

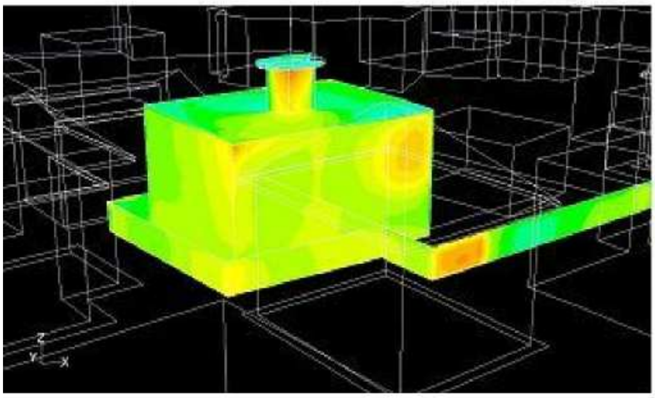
2.1 PENTHOUSE

The planning of the house included a simulation of a three-dimensional airflow (Figure 5). In Kunitachi, in the summer, south winds blow frequently during the daytime. The pressure distribution map provided a hint on where to locate the windows in the design.

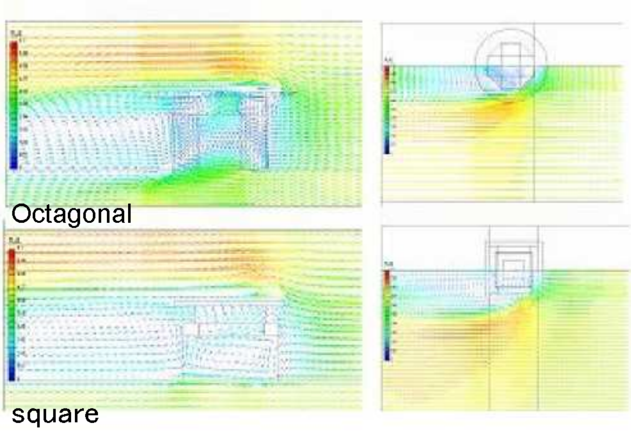
Ventilation skylights equipped with a SWINDOW were installed in the penthouse. A simulation showed that the wind speed on the roof was high. It was designed to take advantage of the wake effect, which exhausts heat from inside the building. Square, octagonal and other shapes were studied (Fig. 6), with a hexagonal shape finally being selected.

Photos 2 and 3 show the SWINDOWs. The SWINDOWs on the windward side are closed so that negative pressure forms, on the leeward side, thus drawing out the wind; Opening the downstairs windows creates a natural upward airflow through the SWINDOWs.

Figure 7 shows how air is exhausted from the penthouse during the summer. The figure shows the wind speed inside the penthouse, the outside wind speed and the temperature difference between the first story and the penthouse. It shows that during the daytime the outside wind produces negative pressure just outside of the SWINDOW, which in turn causes the inside air to be exhausted. The ventilation is also facilitated by the temperature difference. It shows that during the night, only negative pressure causes ventilation because there is no temperature difference inside the building.



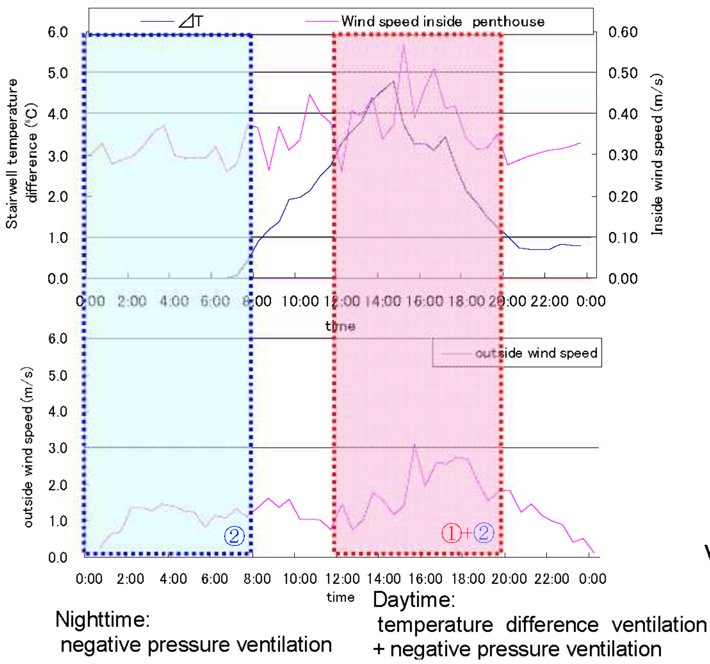
Fig–5 Pressure distribution map

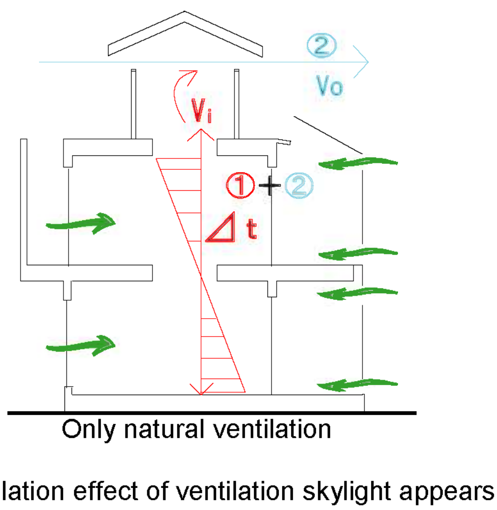


Fig– 6 Airflow System

Photo –2 Stairwell

Photo –3 SWINDOW





Fig–7 Penthouse Ventilation

2.2 Double Skin

The *shoji* is the inner skin of a double skinned structure in this house. The space between the windows and the *shoji* is called “*engawa*” in Japanese. The *engawa* can be used to enlarge room space by opening the *shoji*. To give people in this space a feeling of being outdoors, it is completely enclosed by a glass ceiling and glass walls (Fig. 17).

Because the *engawa* faces south, shade must be provided to block the sunlight during the summer, but during the winter the *engawa* helps warm the inside air. Figure 9 shows the temperature in the second floor bedroom during the winter. For the first day, the temperature is shown for when the *shoji* was closed. For the second day, the air in the *engawa* warmed up and the *shoji* was opened at 10 o’clock. The warm air in the *engawa* is allowed to move into the bedrooms, keeping the temperature at 20ºC for five hours. This saves heating energy.

Photo 4 Engawa
.

Photo 5 Opening Shoji to Expand Usable Space

Photo 6 Blocking Sunlight (summer)

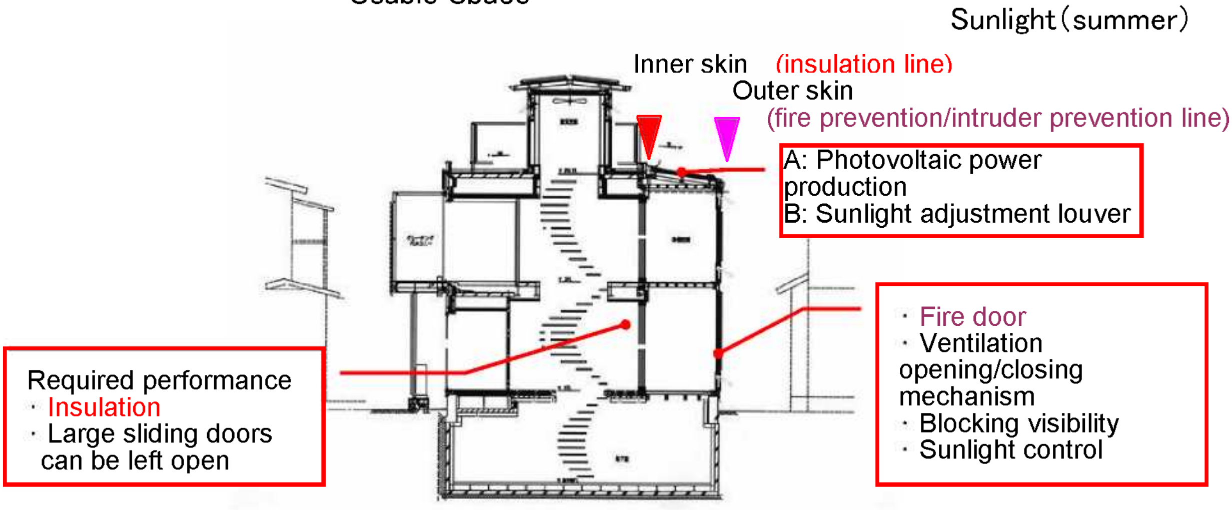


Fig 8 Schematic Diagram of Double Skin Mechanism

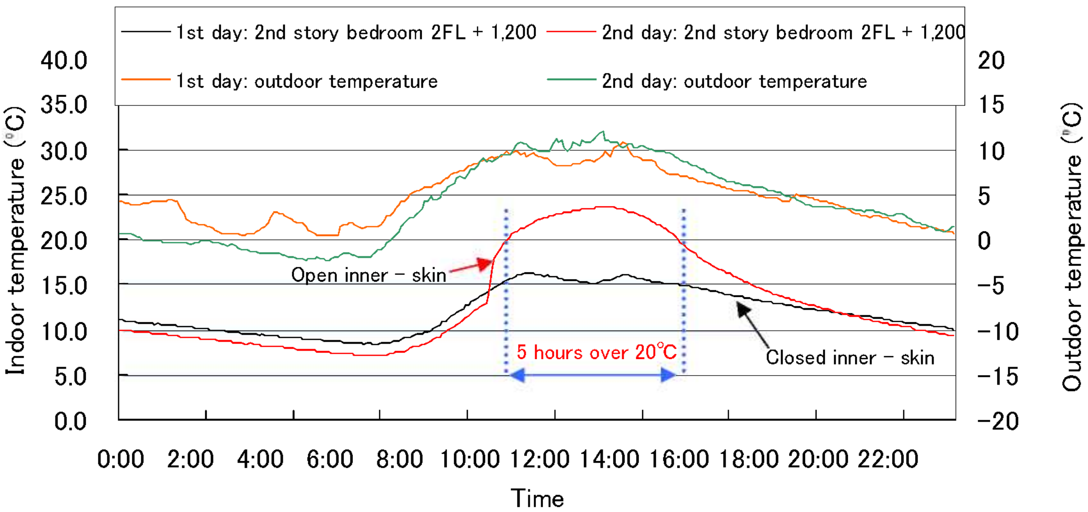


Fig 9 Intake of Warm Air During the Winter

2.3 Sunlight blocking screen

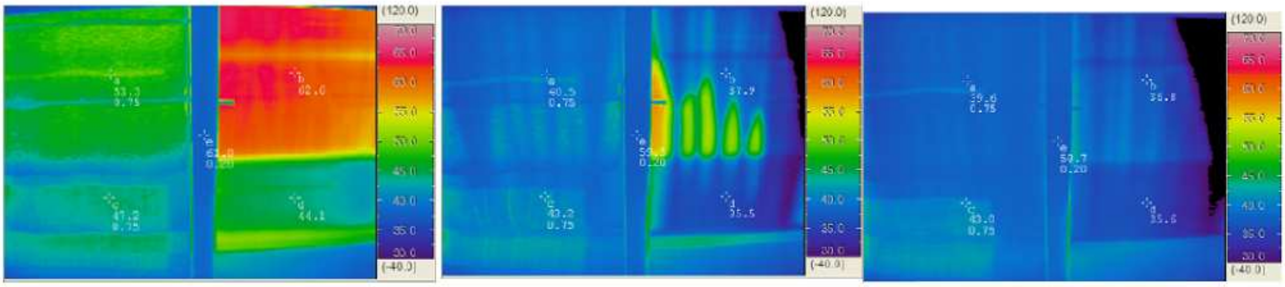
Photo 7 shows how this screen is both a thin membrane solar panel as well as a sunlight blocker. The skylight opens as shown in Photo 8. It opens from the top rather than the bottom, which is normal for a rainwater barrier. It is meant to exhaust heat without allowing hot wind to enter from the south side. It is designed so that warm air can be purged at night.

Photo 9 shows well water being sprayed on the top of the skylight to cool it down (5L/min). Figure 10 shows the temperature when water is sprayed on the skylight. Before spraying, its surface temperature was about 60ºC. Within one hour of spraying it, the surface temperature was down to about 40ºC. It lowers the surface temperature while the sound of the water makes the residents feel cool, allowing them to enjoy a pleasant daily life.


Photo 7 Skylight


Photo 8 Heat Exhaust from the Skylight


Photo 9 Opening the Skylight


1. Before spraying 2. 30 minutes of spraying 3. 60 minutes of spraying

Fig–10 Spraying Time and Temperature

2.4 Control technologies

This house was not consciously designed as an IT home; The sensing technologies were added as a supplementary feature. They measure the inside/outside temperature, humidity, and ppm of CO_2 (Photos 10&11). They monitor the condition of the air and allow for both manual and automatic opening/closing of the windows as needed.

The airflow through the open windows was simulated in the design stage, verifying that when the upper windows are open, air is discharged. Even when it is hot and the air conditioner must be on so that people can fall asleep, after the outside air cools down late at night, the air conditioner shuts off and outside air is taken in. The operation of the windows can be set to several different modes, depending on the daily life patterns of residents. For example, a mode to provide comfort in the second-floor bedrooms at night is called "the night air mode". Figure 11 shows a PMV evaluation of the night air mode in the summer. This reveals that conditions are comfortable, even when dawn approaches and the air conditioning is off.

Photo 12 is a view of a bed pushed out into the *engawa* space during the day. This allows the bed to absorb the sunlight and dry out so that residents can sleep in warm beds in the winter. The beds are also equipped to accurately measure people's respiration and pulse.


Photo 10 Home Navigation


Photo 11 Sensor Display


Photo 12 Movable Beds

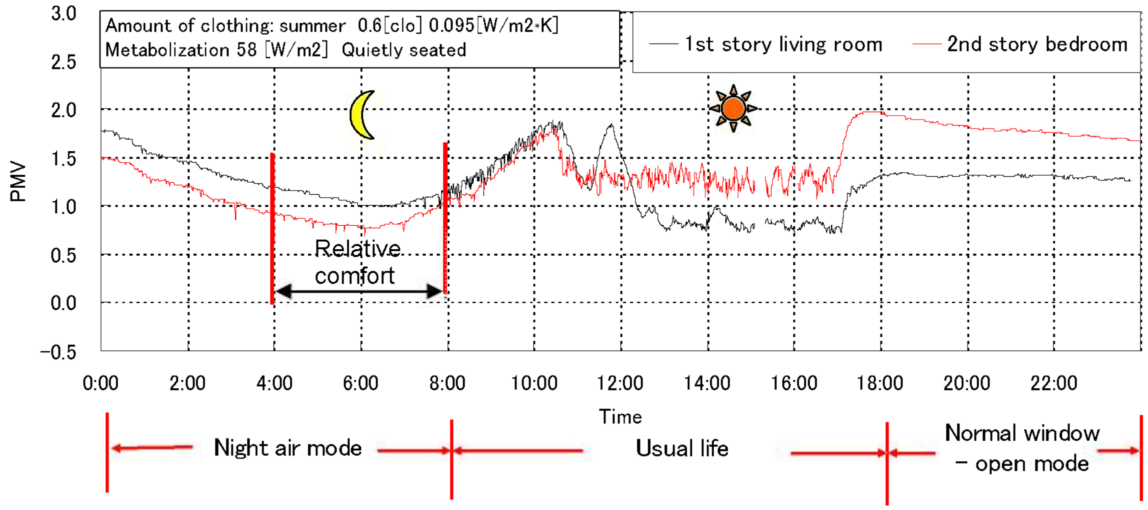


Fig −11 Interior Room PMV in Night Air Mode

2.5 Environmental performance evaluation, *CASBEE for homes* (detached single family) (Comprehensive Assessment System for Building Environmental Efficiency)

CASBEE is a tool developed by industry and government to be used to comprehensively evaluate the environmental performance of a building. This single-family home edition of CASBEE was completed in September 2007.
CASBEE for home is used to evaluate 54 points of the house and its environment. It provides an overall score, and the house is rated in one of five different levels based on that score (Table 2).
The results of using it to evaluate the Sustainable Design Laboratory are reported (Fig.12). This building achieved a 5.6-point score, and is ranked “S”, the highest rank.

Table 2 Five evaluations levels

Rank code	Evaluation	Rank
S	Excellent	★★★★★
A	Very good	★★★★
B+	Good	★★★
B-	Fainx	★★
C	Poor	★

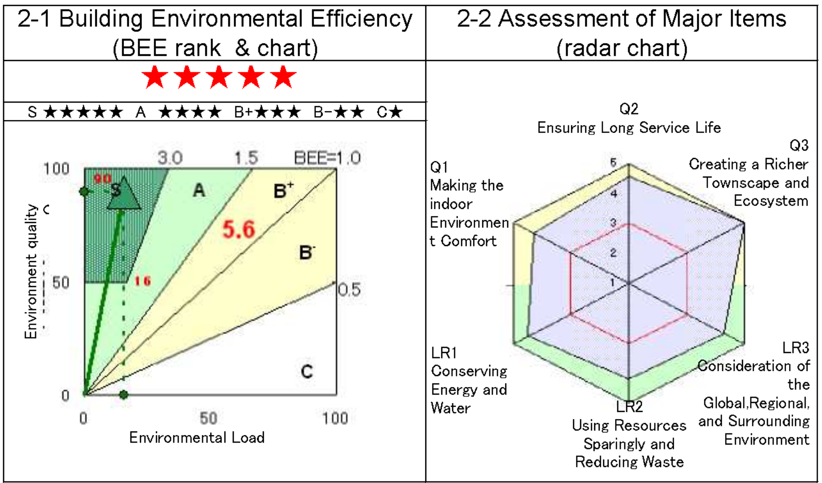


Fig 12 Evaluation Rank

3. Summing up

Guided by the ideas, “Learn from traditional Japanese houses” and “Learn from trees”, we have developed a house suited to modern lifestyles.

The following points have been discovered through experiments carried out on this project:
1. An increase in comfort of interior room environments is realized by the ventilation effect of a penthouse
2. The effectiveness of *engawa* (blocking sunlight, drawing in warm air, conserving energy)
3. Interior temperature is reduced by spraying water on skylights
4. The effectiveness of “opening mode”
5. Achievement of the highest rank of CASBEE.

The following points are considered to be future challenges:
1. Trial occupancy testing
2. Measurement of the effectiveness of night purges
3. Installation of cool tubes in basements
4. Evaluation of the contribution to comfort by extremely low-speed air movement

WHAT IS A "GREEN" BUILDING ACCORDING TO DIFFERENT ASSESSMENT TOOLS?

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Summary

Environmental assessment tools for buildings are rapidly developing in many countries. All of them claim that they measure "greenness" or "sustainability" of buildings, i.e. if maximum scores are awarded a building is sustainable in some respect. But so far there is no consensus on the interpretation of "green" or "sustainable" in terms of criteria and indicators.

This article explores if different tools point in different directions regarding "green" building design. It also investigates characteristics of assessment tools and consequences of different approaches.

Three distinctly different assessment tools, LEED-NC, Code for Sustainable Homes (CSH) and EcoEffect have been selected. They have three core assessment areas in common, namely Energy, Indoor Environment and Materials & Waste. The content however is different.

The tools have been compared with respect to aim, content and aggregation. They have been tested on a new multi storey residential building. Assessments within the core areas were compared. Measures to improve the overall judgement were explored. The diverging result raises the question how to design environmentally relevant and practically useful assessment tools for buildings.

1. Introduction

Building environmental assessment tools, have emerged to provide an objective evaluation of resource use, ecological loadings and indoor environmental quality (Cole, 2005). Much work has been done to develop a tool that predicts, calculates and estimates one or more environmental performance characteristics of a building (Sundkvist et al, 2006). These tools present different ways to define criteria for "green" building" They bring together a large number of environmental issues and aggregate them into overall judgments. What issues the tools address and give priority to indirect or direct might influence environmental building policies, design and building practices. Assessment methodologies play multiple roles; understanding the impact of buildings on natural systems, marketing "green" buildings, addressing sustainability (Cole, 2005), help decision makers and politicians, and being tools for environmental management primarily in architectural projects. What picture the tools mediate to their users influences "green" building designs. This may contribute to setting the agenda in a similar way as trade magazines and mass media (Gluch and Stenberg, 2006).

Environmental assessment tools consist of a number of indicators and criteria. Some also include life-cycle assessment (LCA) methodology (Assefa et al, 2007). Important for the outcome of the assessment are choice of indicators, measurement scales, aggregation and classification criteria. However the basis for these choices, which always are a balance between theoretical and practical aspects, is seldom presented in tool descriptions (Malmqvist, Glaumann, 2006). A lack of theoretic and systematic approach and a mix of different kinds of indicators make tool comparisons difficult as well as understanding what a final award means in terms of environmental impact.

2. Objective and delimitation

The objective with this paper is to compare different methodologies for environmental assessment of buildings and to explore in which direction they push new "green" building designs.

3. Methodology

Three completely different environmental assessments tools have been select to illustrate fundamental differences. These tools have been compared with respect to a limited number of aspects, namely; *aim, content* and *aggregation.* At last they have been applied on a new multi storey residential building to illustrate the differences between the tools.

The tools chosen for comparison are LEED®-NC, Leadership in Energy and Environmental Design for New Construction version 2.2, (USBC, 2005), Code for Sustainable Homes (DCLG, 2007) and EcoEffect (Assefa et al, 2007). The tools differ, in a number of ways, for example regarding where they are developed, for home they are developed, the methodology they use and the way they are used. The two first tools are internationally well-known and well documented. Besides being different EcoEffect is chosen because it is the one that we have the greatest experience from.

4. Method comparison

4.1 Different Aims

LEED is developed by U.S. Green Building Council (USGBC) committees with the aim to promote "green" design. It is argued that "Green design not only makes a positive impact on public health and the environment, it also reduces operating costs, enhances building and organizational marketability, potentially increases occupant productivity, and helps create a sustainable community" (USGBC, 2005). USGBC (2005) claims that LEED is "consensus-based, market-driven, based on accepted energy and environmental principles, balancing between established practices and emerging concepts."

Code for Sustainable Homes (CSH) is the first tool in the process of becoming a code (DCLG, 2008). It is a further development of the BRE's EcoHomes© scheme. "Adoption of the Code is intended to encourage continuous improvement in sustainable home building." The driving force behind establishing a code for sustainable building seems to be the wish of the British Government to act on climate change in combination with the fact that BRE (Building Research Establishment), has extensive experience with voluntary schemes in this field.

EcoEffect is an assessment tool developed by a group of researchers in Sweden. The task was to develop an holistic environmental evaluation method not a national classification system: The formulated objective was twofold: "1) to quantitatively describe environmental and health impact from real estate and the built environment 2) to provide a basis for comparison and decision making that can lead to reduced environmental impact. The method primarily target decision makers within the planning, designing and management of the built environment". (Sundkvist et al, 2006; Glaumann, Malmqvist, 2004)

LEED is voluntary and very market oriented. CHS involves the authorities and intends to integrate environmental assessment into the building code. EcoEffect is neither commercial as LEED, nor institutionalised as CSH. Focus is on methodology and understanding the significance of different types of environmental impacts.

4.2 Different content

All the tools have the areas Energy, Materials and Indoor Environment in common, but the content still vary a lot. Besides assessing issues related to these core areas LEED gives credits related to the issues: Water, Design Innovation and Site. CSH also specifically assess Water, Waste, Management and Ecology. EcoEffect includes Site assessment and calculation of Life Cycle Costs. The tools also measures issues differently. To be able to compare them we have ranged similar criteria and indicators under common areas (Table 1.). Only the issues within the core areas are presented in this paper.

4.2.1 Energy

About ¼ of the assessments in all the tools are devoted to energy. LEED (Table 1.) assesses energy performance, green power and management. CSH assesses CO_2 emissions for energy use and specific energy saving technical solutions. EcoEffect takes only the detrimental side of energy use into account assessing its associated negative emissions and depletion of resources. EcoEffect then uses a linear scale without a defined endpoint, which cannot be easily transferred to scores. Another difference between the tools is that CSH also assess the energy performance of white goods.

Table 1. Addressed issues and available scores or scale within the three areas; Energy, Indoor Environment and Material & Waste.

AREA		ASSESSED ISSUE	ASSESSMENT METHOD		
			LEED	CSH	EcoEffect
ENERGY	Energy use	Minimum Energy Performance	Mandatory		
		Optimize Energy Performance/ Energy cost savings	10		
	Kind of energy	On-Site Renewable Energy	3		
		Green Electrical Power	1		
		Resource depletion			Calculated
	Emissions	Low or Zero Carbon Technologies		2	
		Dwelling emission rate (CO_2)		15 /Mand.	
		Life cycle emissions from energy use			Calculated
	Technical solutions	Internal lighting		2	
		Drying space		1	
		Energy labelled white goods		2	
		External lighting		2	
		Home Office		1	
		Building fabric (Heat Loss Parameter)		2	
		Cycle storage		2	
	Management	Commissioning of the Building Energy Systems	1/ Mand		
		Measurement and verification	1		
		Available scores for this area	**16**	**29**	-
		Fraction of totally available scores	**23%**	**25%**	-
INDOOR ENVIRONMENT	Air quality	Air quality in general			0-3
		Minimum IAQ Performance	Mandatory		
		Environmental Tobacco Smoke (ETS) Control	Mandatory		
		Outdoor Air Delivery Monitoring	1		
		Increased Ventilation	1		
		Low-Emitting Materials	4		
		Radon			Assessed
	Thermal comfort	Design & Verification	2		
		Thermal Comfort in general			0-3
	Noise	Sound Insulation / Noise		4	0-3
	Daylight	Daylighting, views and sunlight	2	3	0-3
	Else	Electric environment			0-3
		Private space		1	
		Lifetime Homes		4	
		Legionaires diseas			Assessed
	Management & control	Construction IAQ Management Plan	2		
		Controllability of Systems, Lighting/Thermal comfort	2		
		Indoor Chemical & Pollutant Source Control	1		
		Home user guide		3	
		Available scores in this area	**15**	**15**	**0-15**
		Fraction of totally available scores	**22%**	**16%**	-
MATERIAL & WASTE	Recycling of materials	Building Reuse	3		
		Materials Reuse	2		
		Recycled Content	2		
	Household waste	Household Waste Storage & Collection of Recyclables	Mandatory	4 /Mand.	
		Composting		1	
	Construction waste	Site Waste Management		2 /Mand.	
		Construction Activity Pollution Prevention	Mandatory		
		Waste Management	2		
	Environmental Impacts	Environmental Impact of materials		15 /Mand.	
		Global Warming Potential - GWP of insulants		1	
		Emissions from material production			Calculated
		Resource depletions from mater. prod.			Calculated
		NOx emissions		3	
		Fundamental Refrigerant Management	Mandatory		
		Enhanced Refrigerant Management	1		
	Sourcing of materials	Certified Wood	1		
		Responsible sourcing of materials		9	
	Other	Regional Materials	2		
		Rapidly Renewable Materials	1		
		Available scores in this area	**14**	**35**	-
		Fraction of totally available scores	**20%**	**34%**	-

4.2.2 Indoor Environment

LEED covers Air Quality, Thermal Comfort, Daylight and Management of Indoor Air Quality but surprisingly not Noise. CSH addresses Noise, Daylight and the three features; Privacy, “Lifetime homes” and “Home user guide” measured in terms of accessibility, adaptability and information. EcoEffect assesses; Air Quality, Thermal Comfort, Noise, Solar Access and Daylight, Radon Legionella and Electric and Magnetic fields. EcoEffect has an inverted scale, i.e. high scores here mean risk for inconvenience.

4.2.3 Material and waste

LEED is very much focused on reuse and recycling. Typically credits are given for reuse and recycling without taking into account that the reduction of environmental impact vary with material, (for example between recovery of aluminium and wood). Other LEED issues are; Household Waste, Local Materials and Rapidly Renewable Materials.

CSH is concentrated to environmental impact from production of building materials and responsible sourcing but do also cover household waste. Material is about 1/3 of all assessed issues in CSH, compared to 1/5 in LEED. Concerning material EcoEffect evaluate negative environmental impacts from the production phase of used building materials. Reuse and recycling is rewarded by decreased emission, from processing, and material depletion.

Hazardous Substances is not addressed in LEED. In CSH and EcoEffect primarily toxic emissions from the materials and their production are covered by the LCA of the materials. Thus none of the tools assess the issue embedded hazardous substances. Even though hazardous substances are one of the most prominent sub-themes of "environmental impact" according to the building sector in Sweden (e.g. Swedish Environmental Advisory Council, 2000; The Ecocycle Council, 2007). The Swedish focus on hazardous substances has also been observed in other studies (e.g. Stenberg and Räisänen, 2004).

4.3 Differences in weighting and aggregation

All environmental assessment tools weight and aggregate results differently. According to Lee et al. (2002) weighting is the heart of all assessment schemes since it will dominate the final valuation of an assessed building. However, according to Grace K.C. Ding, (2008) there is at present neither a consensus-based approach nor a satisfactory method to guide the assignment of weightings. There are a number of techniques to set weights in a systematic way (Andresen, 1999).

Within LEED 69 points are available within 58 assessed issues organized in six assessment categories. Some indicator are of a *procedural nature*, rewarding procedures and behaviour, like following a certain control plan, in contrast to *performance indicators*, which directly measure performance like amount of energy used for heating. Often there are optional ways to receive a point. Normally one point is available per issue except for two energy indicators, where more points can be gained (10 for "Optimization of Energy Performance" and 3 for "On Site Renewable Energy", Table 1). This means that the points have the same "environmental" value and are tradable, with the exception of a few mandatory aspects. The awarded points are added and the total score tells which of four final rewards the building get (certified, silver, gold, platinum). The basis for assigning a certain number of points to an issue is not described. This aggregation system is simple and easily understood, but the environmental meaning of the final score is hazy (Humbert, 2007).

In CHS 104 credits can be awarded within 9 categories (Table 1). A total of 34 issues are assessed and the value of each issue varies between 1-15 credits (per issue), some mandatory while most tradable. Most assessed issues gives at maximum 1-4 credits, except the issues Dwelling Emission Rate and Environmental Impact of Materials, which can give up to 15 credits (Table 1). Each category has a weighting factor, which emanates from a survey among international "experts" and a consultation with industry representatives. Energy has a category weight of 1,26 while Materials only have 0, 33, which in reality says that the environmental value of energy scores are almost four times larger than those for materials. The sum of the credits results in a character represented by 1-6 stars. Since the aggregation is done by varying the credits per issue and by weighting the categories the meaning of the result is difficult to perceive. Special for CSH is that it evaluates dwellings and not buildings. A rating of a building is composed of the ratings for its dwellings. The final rating is achieved when the building has been erected and used to make sure that the performance complies with the intentions and the points received at the design stage.

The final rating in EcoEffect consists of results regarding external impacts and internal impacts. External impacts include energy and materials use. The basis is a life-cycle approach and equivalents for seven impact categories are calculated mainly using internationally well-known calculation algorithms. The external impact is measured per designed number of building users and divided by the corresponding value per capita in the country, i.e. in the end showing a percentage. This favours efficient space use, which is important from an environmental point of view (Wilson and Boehland, 2005). For each impact category weights have been established by estimating the potential harm the endpoint problems within each category might cause people. (Assefa et al, 2007). The assessment is based on the total amount of energy and materials used per resident or user.

Internal impacts cover indoor and outdoor problems on the property. Targets are categorized in 5 categories and assessed through risk assessment at the design stage considering 54 issues. The final assessment is completed at earliest one year after building completion. It is then based on a couple of measurements in the building along with a user questionnaire. A scale with four steps (0-3) is applied, punishing poor measurement results and discomfort. Originally there was an expert weighting system in three levels which is now being exchanged to disability/discomfort scale developed as an extension of the DALY (Disability Adjusted Life Years) system (Malmqvist, Glaumann, 2006).

EcoEffect is quite comprehensive and the aggregated values, although systematically applied, may be difficult to understand for a layman.

5. Case study

To illustrate differences in practical use and assessment result the three tools have been tested on a new residential building under construction, Gronskar, Stockholm, i.e. complete drawings and descriptions are available but no real performance data. No environmental assessment tools were used during the design. The results in the areas; Energy, Indoor environment and Material & Waste are presented. The EcoEffect results, which not are received in points or credits, are shown in relation to a reference building, built in 1990 in the same region. LEED and CSH scores are presented in relation to the maximum possible score.

General information about the test building, GRONSKAR,
Gross area: 2893 m^2, 32 apartments, 8 storeys, Energy use for heating and hot water 80 kWh/m^2,yr. Energy supply: District heating and a heat pump on exhaust air.
Structure: Prefabricated concrete elements with an insulation of polystyrene.
Average U-value is 0,46 W/m^2,K, (window U-value is 1,3 W/m^2,K)

5.1 Energy use

With LEED Gronskar receive 9 of 16 points on energy (i.e. corresponding to 56%). 6 of 10 available points are gained for energy optimization. Primarily due to the heat pump on exhaust air since the envelope is not exceptionally well insulated. No points are gained for on site renewable energy which corresponds to ~20% of the available points. Measures needed to gain all the 10 available points correspond to about 150m^2 solar collectors for 50% of the hot water or lowering the average U-value by ~20%, i.e. from 0,46 to 0, 37 W/m^3K. The first option also gives maximal points for renewables. Since LEED uses *cost indicators* for energy the solar collectors don't give any credits since they are more expensive than district heating for hot water. The option left is to lower the U-value, which would influence the construction of the building.

In CSH 16 credits are given out of 29 for energy, (i.e. corresponding to 55%). The CO_2 emissions per year are compared with emissions from a reference dwelling which has the same size, fixed U-values and is heated by gas. Gronskar uses 80 kWh/m^2,yr. while the reference building uses 146 kWh/m^2,yr mainly because it lacks the heat pump. Gronskar emits about twenty times less CO_2 compared to the reference building because district heating fed by bio fuel emits very little CO_2.

The remaining 3 points Gronskar gained for energy saving fittings and "home office" which implies certain space and support of electricity and telecommunication. More energy points are available for improved envelope, labelled white goods, drying space, bicycle storage etc. The last two and "home office" can be called *potential indicators* since they award possibilities to reduce the environmental impact, which may not happen. Energy saving technical solutions are credited at the same time as low overall energy use, which might lead to *double counting*, i.e. crediting both energy saving measures and overall energy use. Normally Gronskar could also receive two additional points for the heat pump which is considered as a low carbon energy technology. But in this case the heat pump gives no CO_2, reduction according to our calculations, because the Swedish electricity mix emits much more CO_2 than the district heat. To improve the scores it would be better to exchange the heat pump with district heating and receiving more scores for low CO_2 emissions.

In EcoEffect, energy use is evaluated by measuring resource depletion and emissions influencing a number of effect categories. Although Gronskar uses 70% more electricity pr m^2 (the heat pump) than the reference building the overall energy use is 40% less than for the reference building which is also heated with district heating. The result is that the impact from emissions is only slightly larger for Gronskar. The largest impacts come from nutrification and radioactivity (nuclear waste from nuclear power). Contribution to nutrification origins to 70% from Swedish electricity mix and to 30% from the Stockholm district heating. Changing the heat pump here would only give a small reduction of environmental impact so the signal from EcoEffect is primarily to reduce the heat losses, i.e. improve insulation of the building envelop.

5.2 Indoor environment

Gronskar receives 12 out of 15 points (corresponding to 80%) in LEED, 6 credits out of 12 credits (corresponding to 71%) in CSH and is 30% better than reference values in EcoEffect, i.e. is good on indoor environment in all methods. The indoor indicators are different in all methods except from daylight, which still is calculated differently.

In LEED ventilation is the most dominant issue with 6 of the 15 points and two mandatory requirements: Air Quality in general and Minimum IAQ Performance. To receive a higher score Gronskar would have to meet the criteria for emissions from adhesives, sealants, paints and coatings. Low content of hazardous substances in building materials has been an important goal in the design, but emissions have not been measured. LEED is the only method, which uses indicators for management and control systems. Here Gronskar receives 4 out of 5 points because of the used management and control system. More documentation of specific measures and procedures would be needed to be able to gain the fifth point.

Air quality, ventilation and thermal comfort are not included in CSH. The tool uses a wider definition of sustainable building and includes social issues like “Private Space” and “Lifetime Home”. Lifetime Home contains a number of criteria, which all have to be met. Gronskar misses 4 lifetime home points because the buildings electric sockets are not placed at the right height. CSH also gives 3 credits for a “home user guide”, which is a specific document that is missing. Further more sound insulation is included in the assessment. To get the 4 available credits better sound insulation would be necessary.

EcoEffect addresses Air Quality, Ventilation, Thermal Comfort and Sound Environment. In EcoEffect Gronskar gets a rather high score in all these areas. The indoor environmental issues that are linked to comfort and health are included in the indoor environment area and Electric environment and Legionnaires disease are also included here. The scores for solar access and daylight are low because many dwellings face north. Directing balconies and some rooms in other directions would be needed to attain better scores.

5.3 Material and waste

Gronskar receives low scores in all the tools. In the category Material and Waste there was a wide variation in the type of indicators and criteria used. With LEED Gronskar received 4 out of 14 points (39%), with CSH it was estimated that it would receive 18 out of 35 credits (54%). The latest version of “Green Guide” and the Mat 1 and Mat 2 calculator tool, all necessary for the rating, were not available to other than approved CHS and BREEAM assessors.

With LEED the project doesn’t earn many credits because the lack of reused or recycled content. 7 points out of 14 can be gained in this category. There are also three mandatory criteria - Storage & Collection of Recyclables, Construction Activity Pollution Prevention and Fundamental Refrigerant Management. Using FSC, (Forest Stewardship Council) certified wood and local and rapidly renewable materials would also be needed to get the maximum scores.

The main targets in CSH are using materials with low environmental impact that are responsibly sourced.The low score with CSH primarily depends on the estimated high environmental impact from the used materials. The criteria for the indicator “Responsible Sourcing” was not met exactly as the method demanded EMS Certification and a third party control. Moreover the wood used was not FSC certified. For Household Waste Storage and Construction Waste Gronskar received high scores. The industrialized building processes applied minimize construction waste.

With EcoEffect the indicator for emissions from production of building materials was eight times higher than for the reference building and the indicator for resource use was twice as large as for the reference building. These high values are explained by the comparatively high use of concrete, steel and polystyrene, which demands a lot of energy for production and thus giving emissions. EcoEffect doesn’t assess means to recover household waste during operation as in LEED and CSH.

6. Concluding discussion

A “green” building according to LEED has a commissioned and cost optimized energy system and on site renewable energy. Low-emitting materials are used and management and control systems applied to secure a good indoor environment. Building materials are preferably reused, recycled and regional. Schemes for waste and pollution prevention are used.

CSH’s “green” building has low CO_2 emissions from energy use and specific technical solutions to reduce the households energy use. The walls and slabs are sound insulated and rooms daylit. The building is adopted for disabled and home office. Responsibly sourced building materials with low environmental impact are used and constructions and household waste is taken care of.

“Green” building according to EcoEffect has low energy use produced with low environmental impact. The indoor environment is designed to have good air quality, thermal comfort, daylight, sunlight and sound isolation and to prevent, electromagnetic fields, radon and legionnaires’ disease. Building materials with low environmental impact from production and transport are used and measures are taken for simplifying future recovery. The layout plan is designed for efficient use of space.

Further characteristics of the tools are summarised in Table 2. The differences in aim may influence the market penetration, Table 2. Official back up probably will become a strong incentive to use CHS for residential buildings, LEED is used by “green” forerunners and EcoEffect is mostly used for educational purposes. The dissemination is not a consequence of the content of the tools or their applicability but rather which forces push them into the market.

Table 2. Summary of significant characteristics of the tools

		LEED	CSH	EcoEffect
Aim	*Practical use*	Commercial tool	Policy tool	Analytical tool
	Environmental focus	Environmental sustainability	Climate change, (CO2)	Decreased emissions and depletion.
Content	*Energy*	Quantity and cost of energy use. Technical solutions	Quantity and quality of energy use. Technical solutions	Quantity and quality of energy use.
	Materials and waste	Quality and cost of materials use Recycling	Quality of materials used. Waste management	Quantity and quality of materials used
	Indoor environment	Air quality, Thermal comfort Daylight. Management	Noise, Daylight Management	Air quality, Noise, Daylight, Thermal comfort.,
Assessment & Aggregation	*Energy & materials*	Indicators, criteria	Indicators, criteria	Calculations
	Indoor environment	Indicators, criteria	Indicators, criteria	Indicators, criteria
	Within categories	Scores added	Scores added	Calculated equivalents for energy and materials, Indoor environment weighted
	Between categories	Scores added	Weighted	Weighted and added
	No of assessed issues	58	34	18
	No of final scores	1	1	2

The tools use different methods for measuring and different methodology for aggregating. For example regarding indoor environment both LEED and CSH awards good management for the building in operation while EcoEffect for this purpose relies on questionnaires. The basis for assigning scores for different issues and setting weights seems quite arbitrary in all three tools apart from the damage based weights in EcoEffect. The more issues involved in the weighting procedure the less influence is given to each indicator. A higher weight of one indicator means a lower of another. Finally, adding scores and weighting categories makes the meaning of the result difficult to understand. In this respect LEED, which is purely additive, is easier to understand.

The case study of Gronskar shows that the tools push the design of “green building” in different directions. CSH signals that the heat pump should be exchanged for district heating, since the tool concentrates on CO_2 emissions. Bicycle sheds and laundry lines and other technical solutions could be used to gain more scores for Energy in CSH. In LEED use of local and renewable energy sources are awarded, but since energy cost is decisive in this case solar collectors would probably mean too expensive scores. EcoEffect advocates better U-values and low emission fuels for heating, like the district heating in Stockholm. The huge quantity of concrete and expanded polystyrene insulation would have been avoided with EcoEffect and CSH. Applying LEED it would have been more important to use recycled concrete and insulation. Being a commercial tool may be the reason why LEED puts relatively more weight on the indoor environment and consequently might have produced a better indoor environment than CSH. EcoEffect would have influenced the architect to orientate the north facing balconies to a sunny direction. This exemplifies cultural and geographic differences between the places where the methods have been developed.

It is obvious that a technique encouraged by one tool is not always the best way to reduce environmental impacts according to another. A complete environmental assessment of a building ought to consider the whole life cycle, just like environmental assessments of products or services (Finnveden, 2000). The result of this comparison shows that the concept of “green building” is far from universal. The diverging result raises the question how to design environmentally relevant and practically useful assessment tools for buildings.

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A Discourse of Micro Wind Environment and Indoor Temperature and Humidity adapted on the Building Openings of Taiwan in Subtropical Zone

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Summary

This research is to improve, Taiwan's high temperature and high humidity climate environment located at the subtropics area. This study proposes an appropriate opening design and implementation method for buildings in Taiwan, with the aim to improve such environment. The subject of this study was a three-floor atrium-style building, and 8 residential units were investigated. The two-sided openings were formed by shutters and glass, and could be categorized into 4 models. The research method was numerical simulation and field measurement. The numerical simulation divides into three criteria field ranges of three scales, in order to understand the wind flow situation surrounding the buildings. The simulation results and measurements were approximate. Also, the measuring results on temperatures and relative humidity inside the units showed that two-sided shutters are more effective to dissipate heat at night in summer than two-sided glass windows are. In winter, full-closed openings with small gaps could make the indoor temperature 2°C higher than the outdoor temperature, and the relative humidity could reduce by 10%. If there are furniture and heat source inside, the indoor temperature can be 1~2°C higher, and relative humidity can be 3~8% lower. Based on the results, this study proposed the window-opening ways are suitable for summer and winter, and discussed the wind guide effect after installing vertical deflector outside of the opening to improve the natural ventilation effect. In accordance with simulated results, after installing the vertical deflector, its average ACH can increase approximately 260% when the wind direction is parallel to the external windows. Also when the wind direction with the building stand the surface becomes 45°, and the angle of vertical wind deflectors (P=0° ~ 22.5°) is advantageous to the indoor airflow field evenly, however, with the vertical wind deflectors at 67.5°, there is a reduction in DR (draft rating).

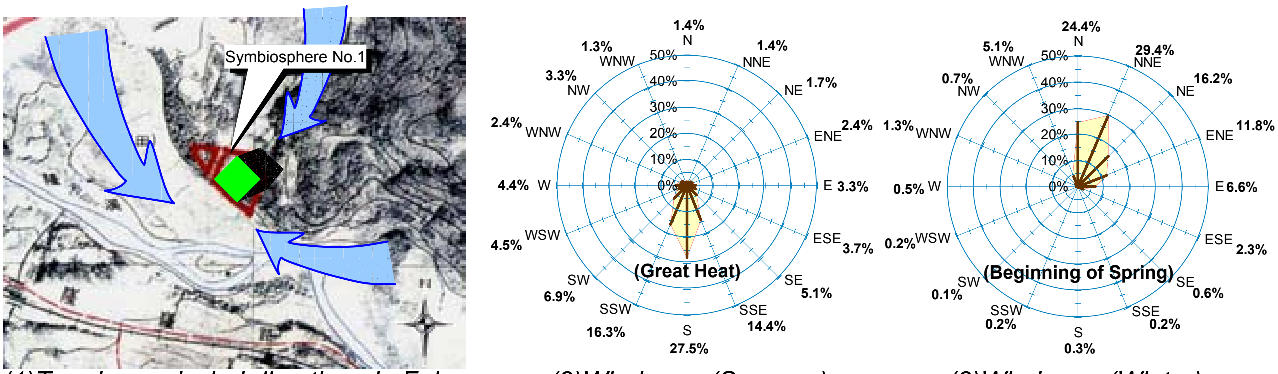
1. Introduction

Many studies in the past pointed out that the indoor temperature and humidity significantly affects people's health and their working efficiency. The outer layers of a building, like the cells on the surfaces of foliages, have the functions of adjusting the air flows, temperature and humidity. The Opening Design of a building greatly impacts the indoor environment conditions in this high temperature and high humidity weather climate of Taiwan. Based on the premise of energy conservation, many studies investigating on the ways to improve the efficiency of natural ventilation are very popular in Taiwan. The objective of these studies is to maintain a healthy and comfortable indoor environment.

Based on the theory of ventilation, Cross ventilation has very good ventilation performance. Some studies (Chiang, 1999, Chiang et al, 2005) pointed out that one-sided opening space is very effective in ventilation by changing window opening patterns and by utilizing the thermal buoyancy principle. However, the use of natural ventilation is still not easy because factors such as the outside winds, building distribution and height in the practical environment. Therefore, in order to understand the effects of natural ventilation on indoor environment, we must understand the external environment conditions such as wind direction, wind speed, wind temperature, etc. However, data such as these are difficult to obtain. The majority of data are obtained from the weather station of the Central Weather Bureau located in the vicinity of the base building. But these data do not represent the actual wind situations around the base building.

In this study, a three-floor atrium-style building (Symbiosphere No.1) located at Fulong, a city in the northeast corner of Taiwan, was used as the research target. A long-term climate monitoring stations was set up at this base building. From data obtained from 1999 to 2001, it is shown that the general weather around the base is as follows: It is hot in summer and cold in winter, and it has distinct different temperatures for the four seasons. The highest temperature in summer is on the “Solar Term” called "DaShu- Great Heat ", the lowest temperature is on the “Solar Term” called “LiChun- Beginning Spring”. The temperature difference between these two is 17.3 °C. There are 25% of the 24 Solar Terms in a year with high temperature over 28 °C (from late June to early September). There are 37.5% of the 24 Solar Terms in a year with low temperature lower than 20 °C (from early December to early April next year). Since Taiwan is an island, its climate is generally humid. Fulong has high humidity (relative humidity is above 70%) all year long, especially in spring and winter. Its relative humidity is over 80% for 2/3 of a year (early October to early May next year). Mainly influenced by the monsoon wind, terrain and the sea-land wind, the local wind roughly is Northwest, North or Northeast in winter and mainly Southeast wind in summer as shown in Figure 1.

In summary, the main objective of this study is to propose the building opening designs to maintain a healthy and comfortable living environment according to the wind characteristics around the base.



(1)Terrains and wind directions in Fulong *(2)Wind rose (Summer)* *(3)Wind rose (Winter)*

Figure 1 The terrains and wind directions analysis in Fulong area.

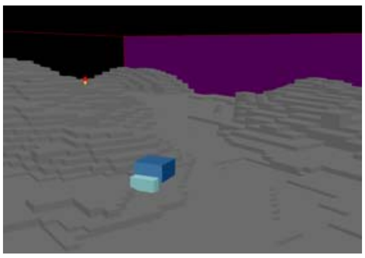
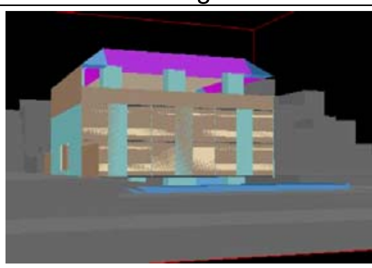
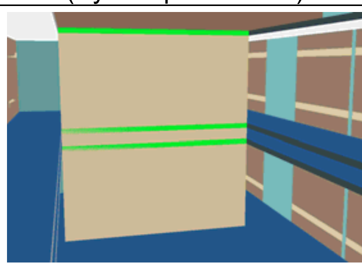
2. Steps and Method

This study is divided into the following three stages:

2.1 Study of the wind environment around the base

Numerical simulations and field measurements of the wind environments around the base were used to explore the difficulties in using natural ventilation. In order to thoroughly understand the airflow changes around the base building, simulations of three field ranges of different scales were performed in the study, as shown in Table 1. These three are: simulation of wide range valley terrain (large range), simulation of field range around the base building (medium range), and simulation of air flows inside the building (small range).

Table 1 The descriptions of the numerical simulations of the three field ranges of different scales.

Field Range	Large Range	Medium Range	Small Range
Definition	The whole valley terrain in Fulong area	Terrains and buildings around the base building	The base building (Symbiophere No.1)
Model Picture			
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2.2 Study of the temperature and humidity conditions in the resident units

The field measurement method was used to measure temperature and relative humidity in eight resident units in the base building. Based on daylight utilization and ventilation, four two-sided opening models were created by mixing the shutters and openable windows, as shown in Figure 2 and 3, in order to understand the indoor temperature and relative humidity conditions under the extreme weather (extreme cold or extreme hot).

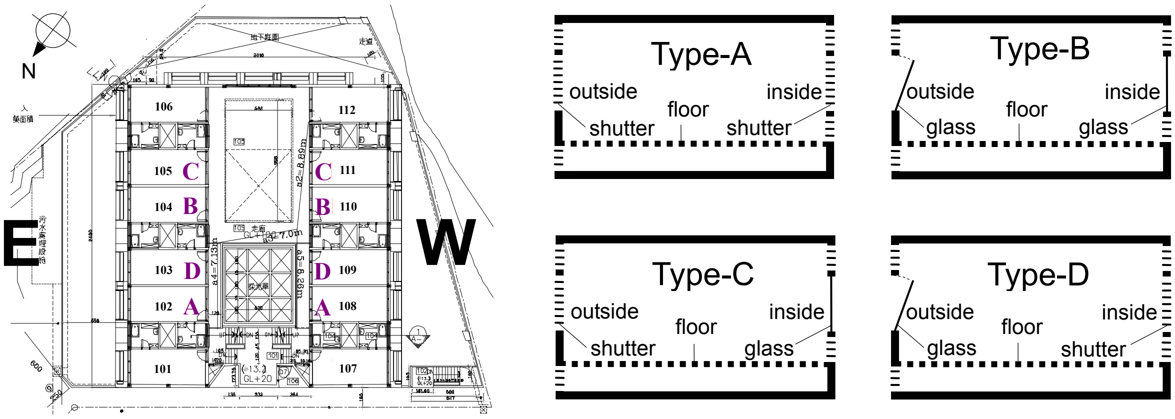


Figure 2 The positions of the eight resident units and the four two-sided opening *models in Symbiosphere No.1.*

(1) Outside shutter *(2) Outside transparent glass* *(3) Inside shutter* *(4) Inside foggy glass*

Figure 3 The types of shutters and glass at the openings.

2.3 The improved design of the opening model

The numerical simulation methods were used to further analyze the situation of the base and resident units to identify the solutions of increasing the efficiency of natural ventilation. The numerical simulation used in this study is the Reynolds-Averaged Navier-Stokes (RANS) simulation method. It analyzed the flow fields inside and outside of the building, and established basic assumptions for the computational domain, as shown in table 2.

Table 2 The basic assumptions for the numerical simulation in this study.

Basic Assumptions	
1. Steady State flow (wind speed, pressure)	5. Do not consider the roughness of the wall
2. Turbulence Flow	6. Use Wall Function
3. Do not consider the influence of Gravity	7. 3D Cartesian Coordinate
4. The speed field on the wall is assumed to be zero	8. Incompressible Flow

The turbulent transfer model selected is the widely used standard k-ε model. This model has good predictability for the mean velocity of the natural convection, and the required calculation time is also shorter (Chen, 1995). The average governing equation about the continuous, momentum and turbulence scale k and ε is shown in equation (1).

$$\underbrace{\frac{\partial(\rho\phi)}{\partial t}}_{transient}+\underbrace{\nabla\cdot\left(\rho\vec{V}\phi\right)}_{convection}=\underbrace{\nabla\cdot\left(\Gamma_{\phi}\nabla\phi\right)}_{diffusion}+\underbrace{S_{\phi}}_{source} \quad (1)$$

In equation (1), ϕ represents 1, u, v, w, k, ε, and source, S_{ϕ} has different descriptions for different equations. Convection and diffusion are the same in all motion equations. Γ_{ϕ} represents diffusion coefficient for quantity variables and the effective viscous coefficient for velocity variables.

In order to understand the ventilation effects, this study evaluates the ventilation rate (air changes per hour). The air changes per hour (ACH) is defined as the number of times a volume equivalent to the room volume are replaced per hour as shown in equation (2), where *Q* is the ventilation volume (m^3); *V* is the room volume (m^3), *T* is the ventilation time (hr).

$$ACH = \frac{Q}{V \times T} \qquad (2)$$

Since under natural ventilations, the ventilation rates are influenced by external environmental factors such as the outdoor wind speed and wind directions, therefore by merely looking at the magnitudes of the measurements provides no common basis for evaluation. Hence, in this study, the ACH was converted under different conditions to dimensionless air change increase rates and compared them. The calculation equation is shown in equation (3) where $Q_{normalize}$ is the air change increase rate (%); Q_e is for ACH with vertical deflectors; Q_c is ACH without vertical deflector.

$$Q_{normalize} = \frac{Q_e - Q_c}{Q_c} \qquad (3)$$

3. Results

3.1 Analysis of the simulation results of the wind environment around the base

Figure 4, 5 depict the numerical simulation results for the summer and winter wind fields of large range. From the flow structure it can be found that in summer, wind mostly comes from the Southeast, and in winter, it comes from the North as predicted. However, the simulation results also show very detailed changes in the flow field. The wind speed is significantly lower on the Eastern side of the building in summer (Figure 4), on the contrary, its wind speed is higher in winter. The wind speed on the North side is also high because of the air compression (Figure 5). The South side is the main static area both in summer and winter.

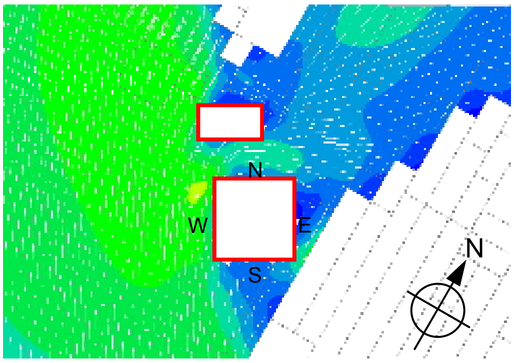


Figure 4 Simulation results for wind fields in summer (Large range model).

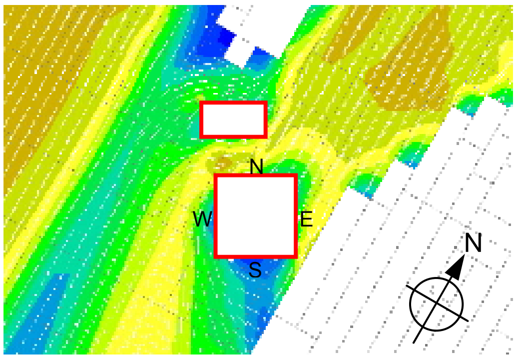


Figure 5 Simulation results for wind fields in winter (Large range model).

To exam the accuracy of the simulation results, the simulated values of wind speeds were compared with the field measurements of those. From the simulation results of the wind field around Symbiosphere No.1, five (A~E) places that have dramatic changes of wind speed, and some places surrounding the Symbiosphere No.1 were selected to measure wind speeds. Those places surrounding the Symbiosphere No.1 include five measurement points E1~E5, on the East side because the wind on that side is stronger affecting by the terrain, and three measuring points individually on the remaining three sides W, S, N.

The results of the comparisons on the A~E points are shown in Figure 6. On places A and B, there are larger differences where measured wind speeds are lower than the simulated values. But on the others (C, D, E), the simulation results and the field measurements are consistent. The results of the comparisons of the wind speeds on the places around the Symbiosphere No.1 are shown in Figure 7. The results from the large-scale simulation have larger differences than those from the medium-scale simulation, especially shown on the points (E1~E4) on the East side. The correlation coefficient between the medium-scale simulations and measurements can reach to 0.89. It demonstrates that the medium-scale simulation can more approach the real situations.

In addition, the accuracies of the simulation results are different on locations with different heights. The comparison of large-scale simulation results from the height of 5m and 13m show that the latter has higher correlation as shown in Figure 8.

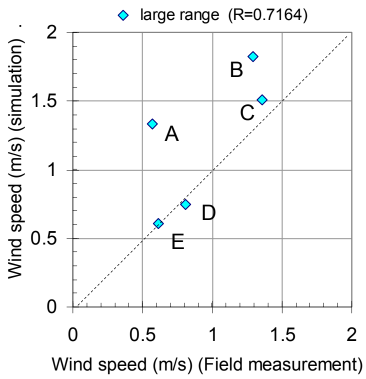


Figure 6
Comparison of the simulation results and the field measurements (A~E).

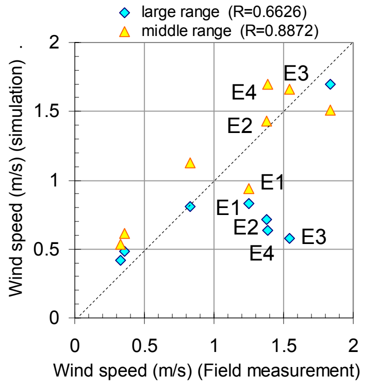


Figure 7
Comparison of the simulation results and the field measurements, large range vs. medium range (E1~E5,S,W,N).

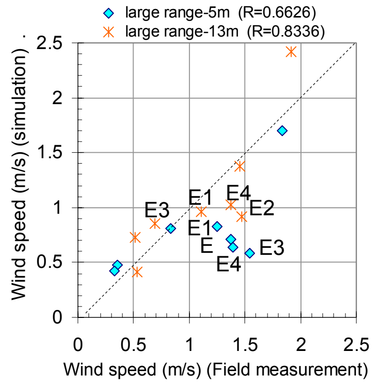


Figure 8
Comparison of the simulation results and the field measurements at different heights (E1~E5,S,W,N).

The medium-scale simulation can also model the very small air flow changes surrounding the base building. Figure 9 and 10 are the simulation results for the air flows in summer and winter respectively. It shows that in both summer and winter, the air flows are closely in parallel to the window surface. With respect to the ventilation needs for different seasons, we extremely need indoor natural ventilation to dissipate the heat for summer. However, Figure 9 shows that, in summer, there are some small air flows getting indoor in resident units on the West side and the air flows are not noticeable in the resident units on the East side. Hence the effects of heat dissipation are limited. In order to let air get indoor more effectively, installing the some deflector at opening is necessary to change wind direction. For the analysis of the impacts of installing vertical wind deflectors to natural ventilation using small-scale simulation, please see 3.3.

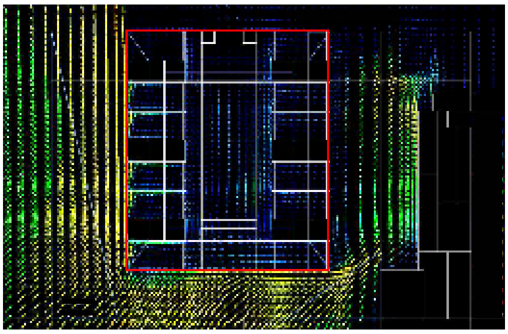


Figure 9 The simulation results for wind fields in summer using medium range.

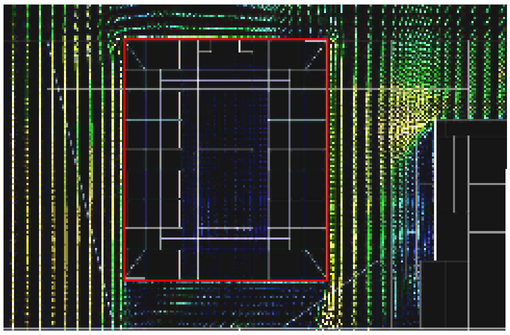


Figure 10 The simulation results for wind fields in winter using medium range.

3.2. Measurement results of the temperature and relative humidity in resident units

3.2.1 Measurements of the temperature and relative humidity in summer

The temperature and relative humidity were measured in summer at the Solar Term: Great Heat and in winter at the Solar Term: Beginning Spring - the extreme climates of these two seasons (extreme cold or extreme hot). Whether the windows are open or closed depends on the need of the season, it is open for summer, closed for winter.

In the area of temperature, due to the fact that sometimes the ventilation during the higher temperatures in the day time not only has no benefit to reduce the indoor temperature, but also cause a great deal of heat to get into the interior of a building, hence ventilation cooling is mainly performed at night time. Figure 11 is the changes of the indoor temperatures in the resident unit, Type-A, during Great Heat. It shows that when the outdoor temperature plunged at night, the indoor temperature of the Type-A will also droop sharply. The indoor temperature is only higher than the outdoor temperature by an average of 0.81 °C. However, the effects of other types of night time ventilation for heat dissipation are less significant. The temperatures of Type-B, Type-C, and Type-D are higher than the outdoor temperature by 0.87, 0.98, 1.08 °C respectively.

In the area of relative humidity, the relative humidity decreases because of the higher temperature for the day, so to prevent high humidity at night is our main goal. Figure 12 shows that the difference is larger between indoor and outdoor relative humidity for Type-A. The indoor relative humidity is lower than that of the outdoor by an average of 6.53%. The differences between indoor and outdoor humidity for Type-D also can reach an average of 5.53%. Type-B and Type-C are less effective in lowering the humidity than Type-A and Type-D. The differences between indoor and outdoor humidity for Type-B and Type-C are only 3.38% and 4.02% respectively.

The test results during Beginning Spring show that every opening model is somehow effective for thermal and humidity insulation, with the indoor temperature higher than that of the outdoor by about 2 to 3°C and the indoor relative humidity less than that of the outdoor by about 10%. Take Type-C for example, the impacts of the indoor furniture and heat source are shown in Figure 13 and 14. The indoor temperature for the unit with furniture and heat sources is higher for about 1 to 2°C. In other words, it is maintained at 17 to 18°C, about 4°C higher than the outdoor temperature (13 ~ 14°C). The relative humidity of the unit with furniture and heat sources is maintained at 65 ~ 70%, about 3 to 8% lower, or approximately 15% lower than that of the outdoor humidity of 80 ~ 85%.

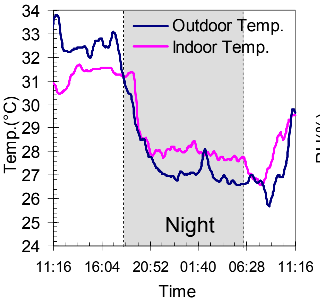


Figure 11
The temp. changes in the resident unit, Type-A (Great Heat).

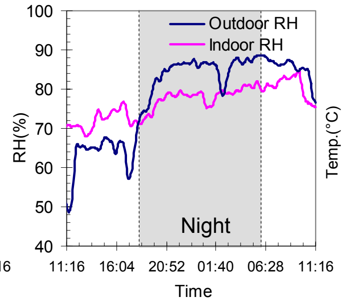


Figure 12
The RH changes in the resident unit, Type-A (Great Heat).

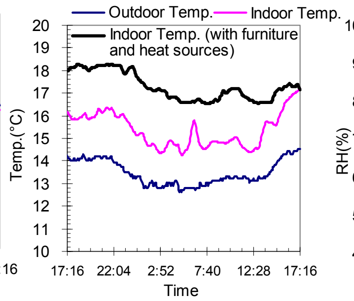


Figure 13
The temp. changes in the resident unit, Type-C (Begi nning Spring).

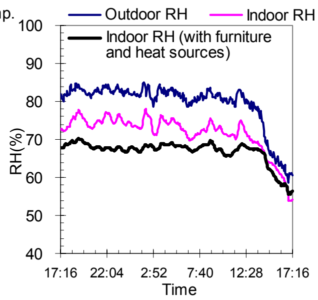


Figure 14
The RH changes in the resident unit, Type-C (Beginning Spring).

3.3 Simulation results for the improved opening model

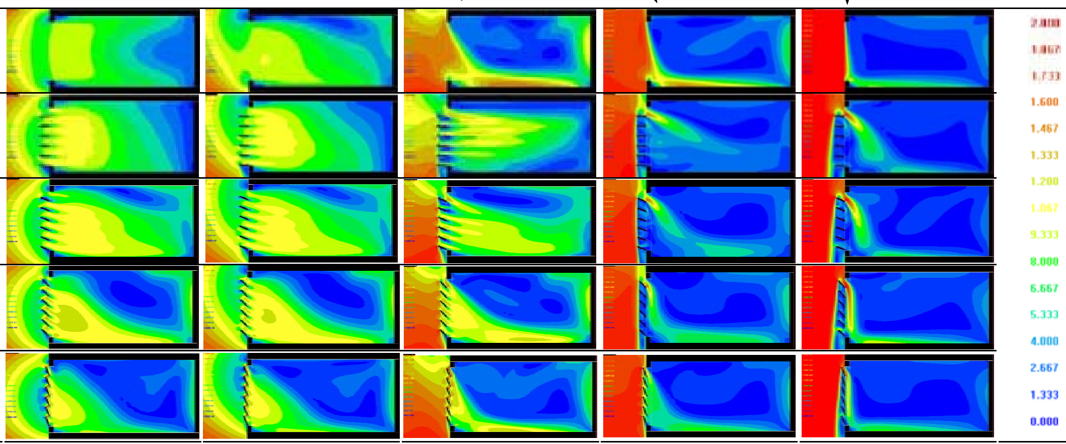
3.3.1 Numerical simulation results

From the small-scale simulation (as shown in Table 3), we can see that when the wind direction S is 45 ~ 90 degrees, the outside air entering the room would cause the higher speed air flow concentrate on the edge of the walls. This will make the wind speed lower in the middle of the room because the airs can not be distributed uniformly in the room. As a result, large areas of "Dead Zones" tend to develop in the room.

Table 3 also shows that if the angel P of the vertical wind deflectors is set to 0 or 22.5 degrees, air flow can spread more evenly to the living space through the wind deflectors to improve the problem of uneven distribution of flow velocity. The improvement is the most significant when the wind direction S is 45 degrees. The improvement is less effective when the angel P of the vertical wind deflectors is larger than 45 degrees. But at these angles, the wind deflectors have the ability to reduce the wind speed. Especially the wind speed was reduced significantly when the angle P of the vertical wind deflectors is 67.5 degrees, the indoor draft rating DR is thus lower.

Table 3 The comparison of the indoor air flows.

Opening Model		Wind Direction (S) 0°	22.5°	45°	67.5°	90°	Unit m/s
Without Vertical Deflector							
Angle of Vertical Deflector (P)	0°						
	22.5°						
	45°						
	67.5°						



3.3.2 The analysis of the Air Changes per Hour (ACH)

In addition, installing vertical wind deflectors improve indoor ventilation when the wind direction is parallel to the external windows. It can be seen from Table 4 that when the outdoor wind speed is 0.5 m/s, after installing the vertical wind deflectors of 0 degrees, ACH increased from 2.9 to 9.2. The greater the wind speed, the more increase in the ACH. When the wind speed is 2.0 m/s, the ACH increased from 10 to 38. The difference in ACH is not significant with different wind deflector angles, especially when the wind speeds are low.

Table 4 The comparison of the ACHs with and without the vertical wind deflectors.

V	0.5 m/s					1.0 m/s					1.5 m/s					2.0 m/s				
P(°)	Non	0	22.5	45	67.5	Non	0	22.5	45	67.5	Non	0	22.5	45	67.5	Non	0	22.5	45	67.5
S = 90° (ACH)	2.9	9.2	10	10	9.0	5.1	19	19	20	18	7.7	28	29	31	26	10	38	38	41	35

Annotation: V: Wind speed, P: Wind deflector angle, S: Wind direction, Non: Without vertical deflector, ACH (Unit:h^{-1})

Following the discussion above, the equation (3) was used to calculate the air change increase rate ($Q_{normalize}$) at various wind deflector angles under different wind speeds as shown in Figure 15. The ACHs of the rooms with installed different wind deflector angles has an average increase of about 260 percent than those without the deflector.

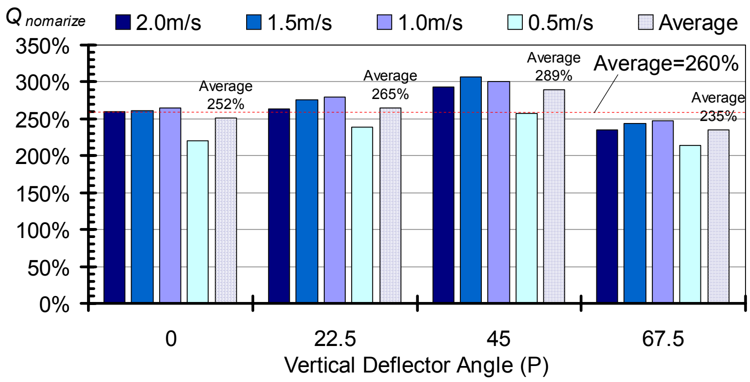


Figure 15 The air change increase rate for vertical wind deflectors with different angles (S = 90°).

4. Discussions

4.1 The necessity and the difficulties of the numerical simulation of different scales

Large-scale simulations help us understand the wind environment change in the area. However, since this model is rough so it affects the accuracy of the simulation. Like some objects including trees, bushes on the ground were not built in the model could cause the simulation values higher than the real values. Furthermore, as shown in Figure 8, that the errors are larger at heights closer to the ground maybe is impacted by the terrain because the complete landscape could not be modeled. These problem can solved either by setting more roughness on the ground in the model, but the values of the settings may vary for difference cases, or by narrowing the domain of simulation, and increasing the details in the model. In the second case of medium-scale simulations, the model gradually approaches the true situation and can show micro-environment wind changes in the base to achieve a more accurate simulation results. However, the impact could be significant if the transformations of the boundary conditions of simulations of different scales in the numerical simulation are not performed correctly.

4.2 Comparison of four opening models

4.2.1 Reductions of the temperature and humidity in summer

With respect to indoor cooling, Type-A has the advantages. The main reason is that inside and outside openings of Type-A are all shutters. Cross-ventilation can be formed to reduce the temperature rapidly. Especially when the temperature rises in the afternoon, a lot of ventilation makes people feel more comfortable. Other types of cooling effect are less significant because the open area is not large enough so the ventilation is not adequate.

With respect to indoor humidity reduction, Type-A can remove moisture by ventilation because of the larger open areas. The indoor relative humidity of Type-D is lower because its glass outside prevents external moisture from getting into the room. On the other hand, Type-B and Type-C are less effective than Type-A and Type-D for removing moisture because their ventilations are inadequate and they allow more external moistures to enter inside.

4.2.2 Maintain temperature and reduce humidity in winter

In winter, even the resident units with shutters on both sides are effective in maintaining temperature and reducing humidity mainly because the window frames are hermetically treated which block the majority of heat loss and moistures entering. The ventilation relies on the gaps on the floor alone. In addition, rooms with furniture and heat sources are more effective in maintaining temperature and reducing humidity. The heat sources (such as computers, people, lights, etc.) provide heat to raise the indoor temperature and lower relative humidity. Other factors of influence are the ability of the furniture to absorb moisture and the shutters to block the transfer of heats to outside. The proper and simple window-opening ways for summer and winter is suggested as shown in Table 5 based on the above analysis.

Table 5 Suggestions on the window-opening ways in summer and winter for Symbiosphere No.1.

Season	Time	East Side		West Side	
		Outside	Inside	Outside	Inside
Summer	Day	All Open or Half Open, All Open in the afternoon	All Open	All Open or Half Open, All Open in the afternoon	All Open
	Night	All Open	All Open	All Open	All Open
Winter	Day	All Closed	All Closed	All Closed	All Closed
	Night	All Closed	All Closed	All Closed	All Closed

4.3 Discussion on the angles of the vertical wind deflectors

We can see from the cross-section of the flow field shown in Table 3 that although the vertical wind deflectors can deflect the air indoor, but air flows accelerated when it passed through the shrunk openings and may cause greater wind draft to the staff indoors. Hence, the adjustable vertical wind deflectors are more suitable both for indoor ventilation and comfort. It can be adjusted according to the wind changes in the external environment.

Because feeling of the wind draft for humans is inversely proportional to the temperature, proportional to the wind speed, so improving ventilation should be more considered when the temperature is high or wind speed is low. The angle P of the vertical wind deflectors should be smaller in these situations. When the temperature is low or the wind speed is high, the impact of the wind draft needs to be more considered, so the angle P of the vertical wind deflectors should be larger.

Furthermore, when this study investigate the impacts of the vertical wind deflectors on natural ventilations, it sets limits on the five kinds of designated wind directions, four kinds of wind speeds (0 to 2 m/s) and four kinds of wind deflector angles (separated by 22.5 degrees). We will conduct more in-depth researches in the future with other conditions.

5. Conclusions

In this study, micro-environment wind field and indoor temperature of the real room are used to investigate which opening models benefit natural ventilation. By using numerical simulations of different scales, the monitored data obtained from the weather stations are converted to more detailed wind flow situations around the base buildings. Assisted by the investigation on the indoor temperature and humidity, the conclusion is that, the two-side shutters is more effective than the two-side glass windows in using night time ventilation to dissipate heat in summer. When they are all closed except some small gaps, the indoor temperature is higher than the outdoor temperature by about 2 °C, the relative humidity is reduced by 10%. With furniture and heat sources, indoor temperature can be further raised by 1 to 2 °C and relative humidity dropped by another 3 to 8%. This study also proposed the window-opening way suitable for summer and winter. When the wind direction is parallel to the external windows, the average ACH increases about 260% with the installation of vertical wind deflectors. When the wind direction with the building becomes 45 degrees, the wind deflector angel set between 0° to 22.5° (P = 0° to 22.5°) is advantageous to the indoor airflow field evenly. When wind deflector angle is 67.5° (P = 67.5°), it can reduce wind speed and help lower the draft rate DR. Therefore, respect to the Taiwan's subtropical climate, installing vertical wind deflectors with the appropriate angles at openings of the building has noticeable improvement in natural ventilation.

Acknowledgement

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A CRITICAL EVALUATION OF THE GREEN MARK SCHEME FOR NON AIR-CONDITIONED BUILDINGS IN SINGAPORE

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Keywords: Green Mark scheme, Sustainability, Green Building, architect, Performance specifications

Summary

Green Building Design has been interlaced in to the larger agenda of sustainability and it has already been shown that working with the idea of Green Design is closely related to issues involving environmentalism, energy efficiency and economy. Buildings can no longer be seen as independent entities with architects as the master control, without adequately factoring the symbiotic contribution they have with the surrounding environment. Green Building Rating Systems such as LEED and BREEAM have been developed in the past and are constantly being reviewed and refined over the years in order to assess the performance of buildings. Studies show that the buildings that have achieved awards under these systems generally perform in a much more efficient way than others. In line with its European and American counterparts, the Building and Construction Authority of Singapore introduced Green Mark Assessment for air-conditioned buildings in 2005, in an attempt to draw the attention of the construction industry towards developing an awareness on develop pay more attention to its impact on the environment. Green Mark assessment scheme went through its first revision in the year 2006 and its modified version for residential buildings has also been released at the same time. This paper attempts to compare the newly developed Green Mark Scheme with respect to other major green building rating schemes with the aim of critically discussing the role of an architect in contributing to the design of a true green building as emphasized through these rating systems. It is necessary to approach the topic with an universal bias towards sustainability and energy efficiency in order to highlight the critical need from the profession to be aware of the potential directions of progress in to a future green society.

1. Background

Sustainable architecture is not a style to be blindly followed or replicated without meaningful interventions. It is a holistic design approach which takes into account all aspects of the building that will affect and be affected by the environment. It is the harmonious integration of technology and natural habitat, with minimum negative impact on the living environment. As the number of buildings bearing the tag of sustainability increases, it is essential for the building industry to understand how well or poorly they perform, in order to access the degree of implementation. This information would also allow cross communications between the regulators, architects, engineers, contractors, clients and end users, and benchmark progress in improving performance. Green building rating systems are thus developed as a way to evaluate the performance of buildings across a board range of environmental considerations against an explicit set of criteria. Rating systems such as Leadership in Energy and Environmental Design (LEED, http://www.usgbc.org/DisplayPage.aspx?CategoryID=19) in US, British Research Establishment Environmental Assessment Method (BREEAM, http://www.breeam.org/) in UK, though established only in the 1990s, have been responsible for the surging number of buildings that are more environmentally friendly. Throughout the world, countries have shown great interest in learning, adopting and developing their own set of rating systems, which would be unique to the local climate, environment and economic context. There are about 21 countries using various types of rating systems throughout the world currently. The increase in the awareness of the building rating systems towards reducing the negative impacts on the environment and the dependence on the finite availability of non-renewable resources, is thus gaining importance in influencing the building industry to play a major role in creating a sustainable city.

2. A prelude to existing green building rating systems

BREEAM, British Research Establishment Environmental Assessment Method, was developed by the British Research Establishment and introduced in 1990. It was the first building rating system to assess the environmental performance and impact of buildings with the longest track record. It is also responsible for the certification of many environmental buildings both locally and abroad. BREEM has a wide coverage of buildings such as offices, homes, industrial units, retail units and schools. BREEAM Offices 2005 generally focuses on the following categories of building design and life cycle performance including management, health and well-being, energy, transport, water, materials, land use, ecology and pollution.

U.S. Green Building Council (USGBC) was formed in 1993 and launched the first version of Leadership in Energy and Environment Design (LEED) after five years of intense research work on existing building matrix and rating systems. It is a voluntary, consensus-based, market driven building rating system based on existing proven technology. It evaluates the total performance of buildings from an overall environmental perspective over a building's life cycle. For each category, a number of pre-requisites and credits with specific design performance criteria exist. Design Projects and buildings need to fulfill the pre-requisites in the respective categories in order to qualify for assessment. Although pre-requisites do not award points, it is essential that they are met first, irrespective of whether other credits requirements are fulfilled, to enable the whole design process to be properly addressed.

Green Building Council of Australia (GBCA), formed in 2002, is a non-profit, national organization that has major support from both the government and industry players. Green Star environmental rating system (http://www.gbca.org.au/green-star/) was launched in 2003 with aims to reduce the environmental impact of buildings, improve occupant health and productivity and archive real cost-saving, while showcasing the innovation in sustainable practice. Green Star has tapped on the rich experiences of the other two and has been fast in developing different Green Star Rating Tools catering to specific types of buildings. And like USGBC and BRE, GBCA also offer courses for interested individuals and organizations to be a registered Green Star Accredited Professional upon passing.

The point distribution profile of BREEAM evidently shows that the percentage of the number of points available in BREEAM is relatively evenly distributed with the highest being the Management category at 16%. However, only for the categories of Land Use and Water, the percentages are much lower at 3% and 9.8% respectively.

3. Introduction to the Green Mark assessment scheme

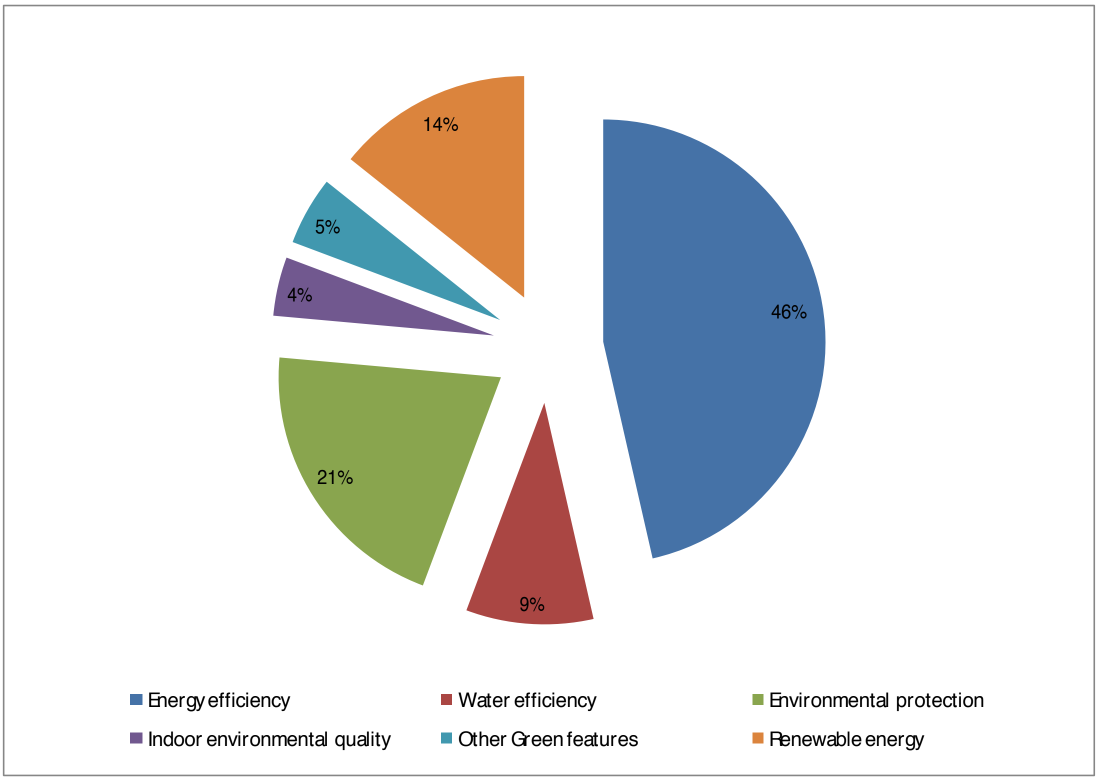

Figure 1 Schematic distribution of different green aspects of a design in the Green mark labeling scheme, Singapore

Green Mark Scheme (http://www.greenmark.sg/public/greenmark/en.html) was introduced in the lines of its western rating systems in the year 2005. The current version 3.0 has been just released in April 2008 and has developed leaps from where it originated. For typical residential as well as a non-residential building, there are five categories in Green Mark namely, Energy Efficiency, Water Efficiency, Environmental Protection, Indoor Environmental quality and Other green features. Figure 1 clearly identifies the structural decomposition of the Green mark evaluation criteria. 35% of the point allocation has been made to the aspect of "Energy efficiency". Green Mark encourages designers to take into account essential factors such as site ecology, local culture and infrastructure and integrate them with the building design. This would optimize the use of existing or/and natural features and minimize the negative impact on the environment. In terms of material selection, besides the conventional aspects like costs, performance and aesthetics, environmental friendliness and health issues are also being assessed in a Green Design. The revised version of Green mark has an additional set of criteria including conservation and restoration ideas, CONQUAS score that impinges on overall quality of the construction and public transport accessibility that would in turn encourage the public to use bus and MRT services compared to the use of private cars. With such comprehensive considerations, the particular site can be potentially deployed in a more environmental responsible manner while promoting sustainable utilization of resources.

In terms of energy efficiency, optimization of the performance of each of the building's components and systems both individually and in interaction with other energy consuming systems has been the prime objective. Such design integration, together with energy efficient technologies, can provide significant returns for building owners. Efficient facade design and the use of energy efficient features are the two key scoring elements in the revised Green Mark assessment criteria. Energy efficiency also includes the use of renewable resource technology that helps to reduce the reliance on non-renewable energy, and the pollution involved in consumption. Use of gardens and landscaping in building designs helps to reduce the cooling load and the urban heat island effect and this aspect has been insisted through the addition of "Green Plot ratio" in the revised version. Besides the control of quality of water, the level of consumption also needs to be monitored as it contributes significantly to a building operation cost. Suitable choices of water efficient equipments, fittings and fixtures can help to minimize water wastage. Proper storage and use of recycled water for non-potable usage could be encouraged to further reduce the consumption of water in a building. Innovative rainwater harvesting systems could also be integrated into the building design to provide additional source of water.

Green Design not only aims to reduce the amount of resources consumed by buildings and the negative impact generated, it also pays attention to improving the total quality of the indoor environment. Components in indoor environment quality consist of thermal comfort, acceptable air quality, visual comfort and appropriate acoustical level. Increase the overall quality of indoor environment would improve the quality of the workspace and boost the productivity of the occupants. Green Mark encourages the incorporation of innovative design strategies, technologies and construction methods for building projects. Such innovations which exceed the current benchmark set by the authority could bring about significant impact on improving the performance of buildings and promote the concept of sustainability. In order to aid the process of familiarizing the industry to the concept of green building design, a guide to supplement the assessment criteria of the building has also been developed.

4. Architect's contribution in aiding green building Design – A Green Mark perspective

Although the contribution of a particular profession in designing, developing and constructing a green building is debatable from a conceptual perspective, it is equally important to understand that architects play the first cut, key role in developing a green society. Hence, it is necessary to motivate the professionals to take up their role in achieving a truly efficient and green building design. A number of prescriptive requirements under Green Mark scheme currently have very high involvement from the architect's side. The following are the key components under which architects can play a vital role in obtaining a Green Mark certification for a residential building

4.1 Energy efficiency category under Green mark scheme

1. RB 1-1: Residential Envelope Transmittance Value (RETV) calculations

   Calculation and Optimization of Residential Envelope Transmittance Value (RETV)

   a. RETV depends on five parameters:
      i. Building Geometry and facade orientation
      ii. Window to wall ratio
      iii. Material of the wall
      iv. Glass type and thermal properties
      v. External Shading provided on the facade

   b. The value of RETV is evidently dependent on an architect's decision as an engineer has very little control over these listed parameters. However, in Singapore's current practice, these technical numbers are computed and optimized through engineers and this process is often resulting in either thickening of walls (to decrease U-value of the wall, by increasing the resistance offered by the thermal mass) or by darkening the glass (to reduce the Shading coefficient of glass).

   c. The computation and optimization of RETV values could result in up to **15 points** in both residential and non-residential buildings.

2. RB 1-2: Dwelling Unit Indoor comfort:

   This clause controls the selection of air conditioning system and gives a choice to an architect to opt for natural ventilation. The points awarded for a naturally ventilated building against an air conditioned building depends on the following three aspects:

   a. Building layout design: this is primarily decided by the architect and the decision of orienting the building right as well as providing fenestrations in the right facade orientations would give a building up to 6 maximum points.

   b. Achieving true cross ventilation is the second aspect that could provide the building with another 6 points. Cross ventilation in the building depends on the orientation of the openings to the prevailing wind direction, prevailing wind speed, depth of the floor plate and the size and position of the inlet and outlets for the air flow.

c. These factors clearly are either completely external or contingent upon the decision made by architects. Hence, an architect could be considered as solely responsible for these 6 points.

d. The third requirement on calculating and optimizing ventilation potential is currently handled by consultants in the field, although the inputs are primarily from an architect.

e. On a whole, it could be assumed that an architect actively contributes to about **12 points** of the total 16 points under this clause.

3. RB 1-3: Natural Ventilation in Common Areas:

   Provision of natural ventilation in common areas of a buildings is another decision made jointly often by the architects in terms of their spatial requirements in consultation with the client's requirements. The attempt to make such a naturally ventilated space also lies in the hands of an architect. Considering the architect plays a significant role in deciding the type of space (Air-conditioned vs. Naturally ventilated), the points resulting from the same (RB1-3) are to be shared equally between the clients and the architects (i.e. **1 point each**).

4. RB 1- 4: Lighting

   Computation and optimization of artificial lighting is usually not attempted by architects. However, optimization of artificial lighting through implementation of day lighting has a significant architect's role. In Singapore's condition, where the direct sunlight is not desirable and only diffused lighting is to be harvested, it is only feasible to achieve a 3 m deep penetration through the spaces and this in turn has a definite impact when we decide on the floor plate size and depth. In addition, perimeter glare is another pertinent problem in Singapore and hence, the treatment of the facade to curtail perimeter glare and to redirect natural lighting to deeper interiors could be a possible strategy that would save on the artificial lighting demand required. In all cases, an architect plays an equal role as that of an electrical engineer to optimize lighting budget and hence could be considered vital for gaining up to **6 points** under this clause.

5. RB 1-5: Ventilation in Car parking
   Car parks designed with natural ventilation is again a joint decision process between four different parties namely the client, the architect, M&E engineer and fire consultant. Apart at times, safety consultants also play a vital role in deciding the same when there are possible threats to lives (terrorism, etc.). Hence, the maximum point of 8 is to be apportioned amidst 4 key consultants including the client. An architect is able to contribute through this design (12 m from an opening maximum is the required regulation for naturally ventilating the car park, if the car park is in the basement) to a maximum of **2 points**.

6. RB 1-6: Lifts

   The architect has no control over the mechanical specifications and selection of a lift. Hence, he plays a negligible role in deciding the energy saving parameters of the lift.

7. RB 1-7: Energy efficient features

   Feature based points was considered as an ineffective means of rating a scheme. However, In the current version of the Green mark, energy efficiency features have been further classified in to high impact items and low impact items. Some of these features are designed and incorporated by an architect. For instance, implementation of light redirecting devices, wind directional devices, new technology test bedding (cool paints, phase change materials, etc.) are driven by the designers. However, domain experts handle the design and incorporation with due collaboration from designers. Hence, the architects could have a 10 – 20% role in effectively implementing these systems in place. The apportionment of points is also based on the same figures above and hence, of the total 7 points under this clause, an architect can be considered vital in scoring a maximum of **2 points**.

8. RB 1-8: Renewable energy

   Solar energy is the prime source of renewable energy in Singapore. Singapore's island wide average wind speed is around 3 m/s (www.nea.gov.sg) and hence, harvesting wind at low heights is almost impossible. Hence, mostly Solar cells and BIPV systems are the commonly considered renewable strategies. Although these strategies are commonly considered, there is reluctance because of the prices from the client's side. The client plays a vital role in deciding the use of solar energy and an architect supports its implementation in to the design. Thus, an architect's intention of incorporating the system in to his design brings a contribution from his side. This could be considered as contributing to about 25% of the total bonus points which is **5 points.**

Thus, under the domain of energy efficiency, an architect plays a confident contribution in scoring the maximum allowed score of **38 points** and a bonus of about **5 points**, giving the signal towards the basic green mark certification to the building.

4.2 Water Efficiency

The role of an architect under this topic only comes under the clause RB 2-3 where the concept of rain water harvesting systems come in to picture. Rain water harvesting has been very little practiced in Singapore as the country had no real demands of conserving water until recent days. Today, Singapore consumes about 300 million gallons of water per day, which is equivalent to about 500 Olympic-sized swimming pools of water. By 2011, we will consume about one-third more. To meet this growing demand for water, PUB will expand our water catchment and continue to develop other water sources such as NEWater and desalinated water (http://www.pub.gov.sg/Marina/about.htm). This awareness to conserve water is only in the recent times and attempts are only happening at the macro level. Hence, bringing in to rainwater harvesting in to the individual building design is considered a good starting strategy for designers to adopt. This **carries 2 points** when the architects make provisions for an effective rainwater harvesting system and utilize the water for irrigation purposes.

4.3 Environmental protection

1. **RB 3-1 Sustainable Construction**

   Efficient regulation of concrete as a key building material with the use of Concrete Usage Index (CUI, which is defined as the volume of concrete used per unit area) is a key factor that would require an architect's participation. The designer needs to decide on the material composition in order to realize their design intention. Concrete has conventionally provided an architect a dream platform to realize unimaginable spans, unsupported lengths and structural integrity. Restricting the use of concrete truly requires an architect understands and support and this parameter would very much determine the resulting design solution. The computation and optimization of CUI provides 4 points and this is jointly contributed both by a structural designer and an architect. Hence, there is an equal share to an architect resulting in **2 points.**

2. RB 3-2: Greenery

   Greenery Provision (GnP) is calculated by considering the 3D volume of spaces covered by the plants. The provision of greenery in a building is decided by an architect to match his design intentions and is jointly executed by architects in conjunction with landscape specialists. Hence, of the maximum allowed 6 points, an architect's spatial provision carries a 30% weightage to be further designed, developed and detailed by landscape specialists who hold 70% of the total score. Hence, in terms of an architect's contribution**, 2 points** could be claimed.

The other categories of the Green mark scheme do have contributions from an architect, however, not extensively. Provision of bicycle parking lots (1 point), Appropriate location of refuse areas to reduce airborne contamination (1 point), Provision of natural ventilation in wet areas (1 point), reduction of noise levels (0.5 point), provisions for other green features (3 points) have roles played by an architect. However, there are specialist consultants involved in the same and hence the role of an architect is diluted a lot.

5. Key findings

The exploration of a single rating scheme at this micro-level is extremely necessary with the global concern on sustainable built environment from the following scenario:

The building industry is headed and lead by the creative group of professionals, the architects and in most cases, the design related decisions are taken and executed in line with the architect's thoughts. Hence, in order to drive the industry towards a green building practice, the concept of going green is to be assimilated in the minds of these designers. If the understanding of how they could participate does not strike their minds, it would be difficult for them to play their parts in creating a green built environment. There is also a definite misconception amidst industry players that green building design is a lot of additional work and it involves expert simulations and computer programs. The presented rating tools are simplifying the requirements as start-up incentives and hence it is necessary for the industry to understand and appreciate the same.

The study exploration on analyzing green mark scheme clearly reveals that approximately 50% of the total green mark score is dependent upon an architect's decision and this clearly elucidates the importance of the role of this team player in building a green society.

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THE DIALETIC CREATIVE PROCESS FOR A SUSTAINABLE IN THE CONSTRUCTED ENVIRONMENT

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Keywords: sustainable, constructed environment, building.

Summary

In this work, the historical dialectic method is used to analyze the creative process in the constructed environment. The paper relates that creative process with the historical moment starting from the period of the beginning of century XX. This period is marked by the rational thought, where the man believes in the man believes in its capacity to control whole the causes. The researches and great progresses of engineering allow that the technology culture can be used in the creative process of the constructed environment in the levels of materials, buildings and cities. The perception of the consequences of this model of development promotes the discussion of the technological paradigm. In the contemporary reality the conscientious thought indicates our incapacity to control the consequences of the development of the current model. We have the uncertainty of the future and we search for a model of sustainable development. In some countries, the influence for the new cultural context and new paradigm of sustainable development does that the actual creative process of the environment constructed be object of experimentations for sustainability. The article believes that is necessary to make a synthesis in the sustainable construction theories. One way for it is to consider a theory of selection of five points in some levels of the constructed environment. The five points would be: correct conception; correct consumption of energy; correct water consumption; correct constituent and correct end. The levels of the constructed environment would be related to the correct constituent: cities are constituted by buildings; buildings are constituted by construction materials; and materials of construction are constituted by substances cousins. The theory of selection of five points believes in a virtuous chain in process for sustainable construction.

1. The historical dialectic.

The theory of the historical change (MARX) considers that each moment of progress is the synthesis of two preceding and conflicting trends. This theory of historical change is based on a method of thought developed for Hegel that is named dialectic method. The principles of this method are the thesis and the antithesis. The thesis is an affirmation or a situation initially given. The antithesis is an opposition to the thesis. The synthesis appears like a consequence of the conflict between thesis and antithesis. The synthesis is a new situation that have inside of itself resultant elements of this shock. Then, the synthesis becomes a new thesis that contrasts with a new antithesis generating a new synthesis, in a continuous process.

The historical moment of the search for the sustainable development can be interpreted under the optics of the historical dialectic. The current model of development of our civilization, characterized by the consumerism, increasing consumption of energy and natural resources and increase of the generation of residues, clearly presents a conflict with the antithesis of the ambient reality of climatic changes and exhaustion of the energy and natural resources. Of the conflict of these two situations, it is necessary to search a synthesis that would contain elements of the thesis and antithesis.

Our current model of development is an affirmative thesis that is denied for the antithesis of the exhaustion of the natural resources and climatic changes. The negation (ambient situation) of the affirmation (consumerism) implies in stopping the consumption of resources and energy, and the emission pollutant. The transformation of the negation in a affirmation is inadequate for solution of the problem. Our society cannot simply to stop of consuming. Moreover, the consequenc of the current model can have it become irreversible, fact that science calls of “point of in return”.

New actions are necessary, a dialectic change, where through the negation of the negation, let us reach a new situation, that it suppresses and it contains, at the same time, elements of the thesis and antithesis. The negation of the thesis and antithesis, or doble negation, becomes a superior positive proposal, a new thesis. Thesis that is not simply the addition of the characteristics of the consumerism and the ambient situation, but a new model of development, that changes the current paradigm.

The dialectic also considers that a situation is as part of another one. To understand synthesis of the conflict, the whole X+Y, it is necessary to understand subject X that it is part of subject Y, and subject Y. Therefore, the search for the agreement of the new model of sustainable development passes for the understanding of the model of current consumption and our ambient situation.

2. Actual historical moment - Thesis and antithesis

Our historical moment can be analyzed from the period of the beginning of century XX. This period is marked by the rational thought, where the man believes in its capacity to control whole the causes. This thought can be understood as a result of the industrial revolution of the half of century XIX. This introduces the machine and a technological certainty. The culture of the technology is used in the creative process of the constructed environment, with experimentations and research and great advance of engineering, in the levels of the materials, buildings and cities. New techniques, like reinforced concrete, and concepts, like functional archictecture, international style and cities gardens, appear. These techniques fed the technological culture. The technological certainty paradigm began to be questioned when the consequences of this model of development was noticed. In the contemporary reality we have a conscientious thought, in which the man perceives its incapacity to control the consequences of the development of the current model. We have the uncertainty of the future and we search of a model of sustainable development.

In this context, the term sustainable dominate great part of the speech of the most different subjects of the society. Many times the term is used to reinforce the old philosophical desire of a more human society. However, the sustainable must be understood as the welfare with the social, economic and ambient balance. The human vision of the society also worries about the welfare state and ambient. However, a differentiation is necessary for the constant relevance that sustainable has been reaching in this historical moment. Inside of this historical revision, our interest is to stand out the importance of the constructed environment in the process, that is, the sustainable construction.

In some countries, the actual creative process of the environment constructed, influenced for the new cultural context and new paradigm of sustainable development, presents, experimentations and researches for sustentability in the constructed environment. The development of the civil construction level is a indicator of economic development and social growth, and it varies of country for country. The sustainable in the constructed environment is also. Infrastructure, building, pavement, water and energy supply are products of the construction industry that reflect the degree of economic development of each country. A traditional process of construction worry about costs, quality and time. In the new paradigm of century XXI, the construction must consider the natural resources, the biodiversity and the pollutant emissions. This occurs because the construction generates a great ambient impact as consequence of the consume of tons of natural resources. It also pollutes the environment directly, when it generates residues due the mistakes and wastefulnesses, and indirectly, when it consumes products whose manufacture pollutes the environment. The contribution of the construction sector for the ambient impact still can be bigger if it is considered that during its useful life the construction consumes energy and water to remain itself, and that, after the use, it generate dump. The ambient impacts of the civil construction are for long stated period.

According to Kibert (Agenda 21, 2000) the sustainable construction would given for the creation and responsible administration of an environment of healthful construction, based on ecological principles and efficient resources. However, to reach the sustainable construction, is also necessary to approach social-cultural and economic dimensions (figure 1).

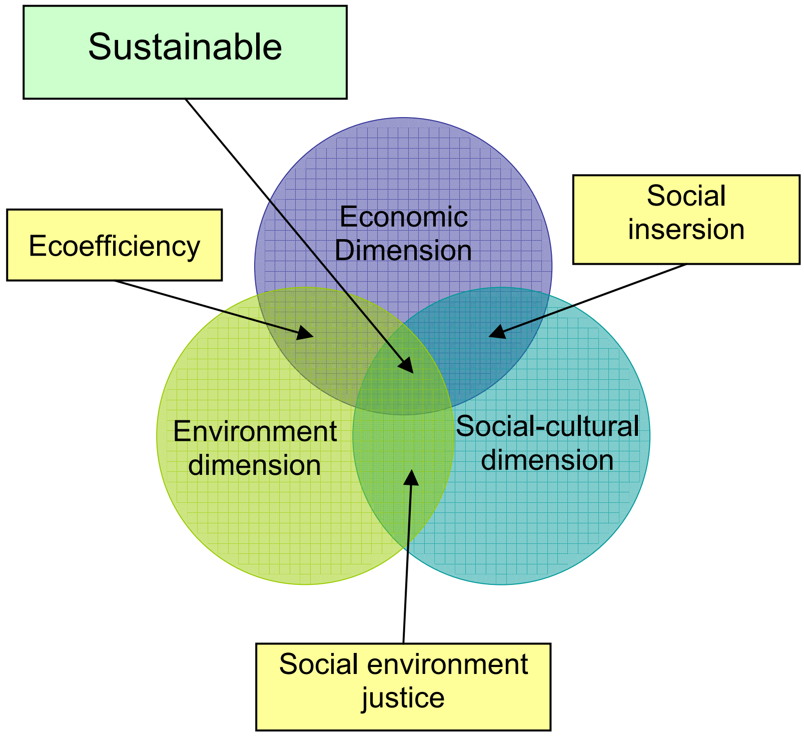

Figure 1 – Sustainable dimension

3. Prompt boarding of goals of sustainable in constructed environment – Synthesis.

The creation of a model of sustainable in the constructed environment is complex because involves action in different space levels and different sectors of the society. The complexity of the constructed environment takes the researchers to propose simplified models based on personal perceptions. In this way, they are induced only to notice the elements for interpretation that was chosen unconsciously. They not perceive other elements that would be important in the complex system. The relationships inside of the system are not noticed also, and the synthesis is harmed.

A prompt boarding facilitates the perception of the elements that the mind eventually are not considerate when it was exposed to the complex system whole. This prompt boarding can be defined as a reduction of the complexity of the system. The perception, interpretation prompt of the elements of the system allow to understand the relations and functions of it, and they allow the synthesis and the understanding the complex system in whole.

This prompt boarding must consider the concept of constructed environment in its totality and fluidity. The concept of the creative process for a sustainable construction does not have to be static. The synthesis of the creative process must allow that we have different and even contradictory perspectives as how to make a sustainable construction. A concept with flexible boarding allows to consider all the parts of the whole constructed environment. The parts of the constructed environment, as for example its scales, are parts one of the others. Therefore, we cannot conceive a sustainable building, as something separate of its construction materials or its locality. Some scales of the constructed environment are related. The synthesis of the creative process for a sustainable construction must consider this influence between some scales.

For the prompt boarding we can have goals for some scales of the constructed environment. These goals must have a positive influence. The goals must be flexible to allow adequate actions to some existing realities. The article suggests the following goals:

• Correct Conception, with social, cultural, economic and environment considerações.

• Correct consumption of energy, with the search of lesser consumption of energy and minor generation of residues for the existing necessity.

• Correct water consumption, with the search of lesser water consumption for the existing necessity and not water contamination.

• Correct constituent, with use component and constituent that searchs the five goals suggested.

• Correct end, with the search of the biggest durability for the existing necessity and destination with a correct conception when it will not be useful.

The positive influence in some levels of the constructed environment would be given by the goal of correct constituent. Cities are constituted by buildings, buildings constituted by construction materials, and construction materials constituted by cousins. The search for the correct constituent in these some levels, would bring a virtuous chain in the creative process for sustainable in the constructed environment (figure 2).

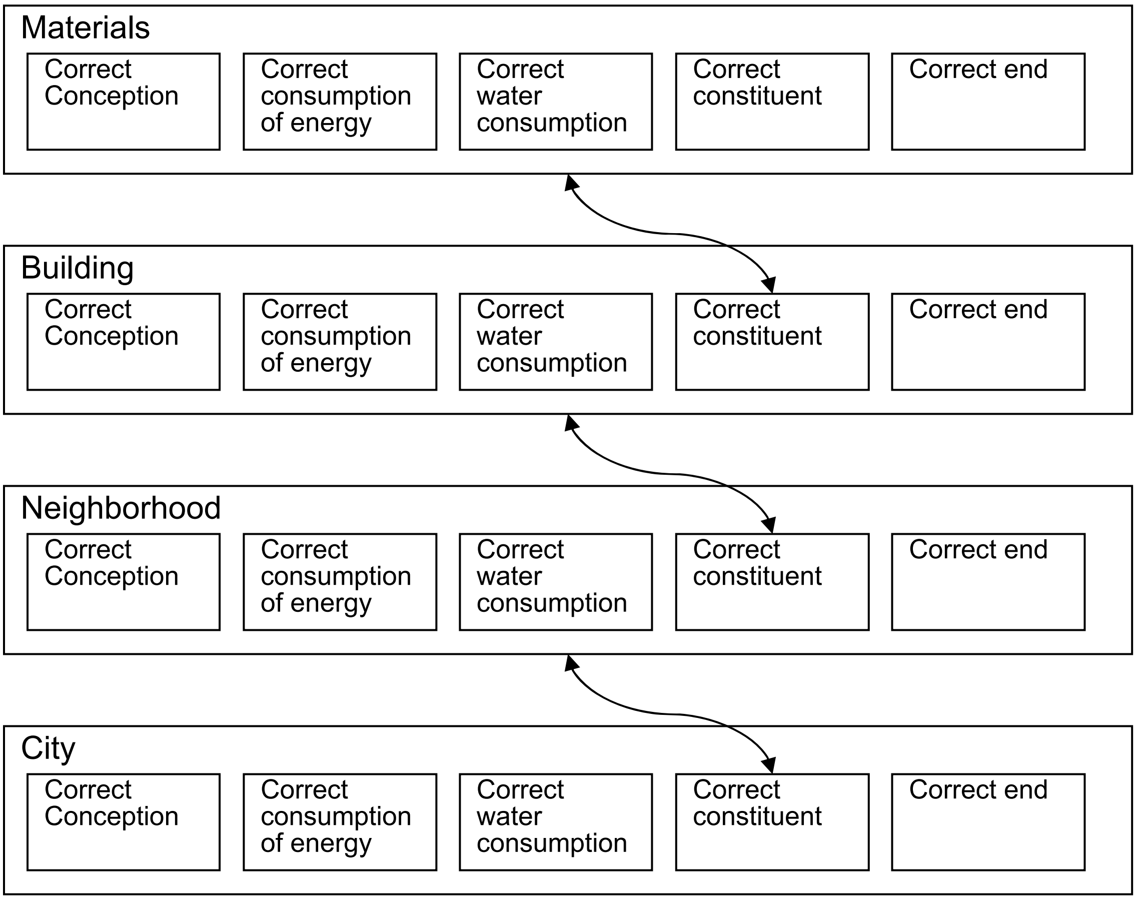

figure 2 - The positive influence in levels of the constructed environment.

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SOLAR HEATING – MORE THAN A TECHNICAL SYSTEM

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Summary

The solar collector technology is well developed and cost-effective. Why is then solar heating not more widely used? In this study a socio-technical system approach is applied to identify some of the obstacles to increased use of solar heating. The main focus is on the planning process of buildings and heating systems, the influence of user behaviour and different combined system solutions for large-scale and small-scale heating respectively. Parts of four different projects in the topic are presented to show the complexity of the issue, which has to be understood to reach wider implementation of solar heating. The importance of user-friendly and well-functioning planning tools as well as easily installed and operated system solutions are addressed. Increased knowledge and communication in all actor groups are also recurring concerns.

The solar heating development has to adjust the focus from only improving the technological properties of the components to also put effort on attracting the user. Not only energy output or investment cost is decisive for whether a solar heating system is installed or not. To overcome the obstacles and reach success solar heating has to be seen in the wider social context it is actually part of.

1. Introduction

Energy demand in buildings should always in the first place be minimized, but there will always remain a need of energy supply for appliances, space heating and hot water. To meet the requirement of being sustainable the energy supply must come from renewable energy sources. Solar energy is a vast resource of renewable energy that today is used only to a small extent for heating and electricity production. Thermal solar collectors for hot water production have been markedly developed since the 1970's and the technique to utilize solar radiation for heating is today well developed and has reached cost effectiveness. But if the systems are both technically well developed and cost-effective, why is solar heating not more widely used? The reasons are many and of different nature and in order to grasp the complexity we apply a socio-technical framework to solar heating in this study.

The following report is based on a PhD thesis work under completion that comprises a socio-technical evaluation of domestic solar heating using Sweden as a case study. The objective is to identify technical and social obstacles for a wide implementation of solar heating. The study focuses on problems that arise in the building planning process, installation and utilization of solar heating systems. The study does not cover all obstacles that can possibly appear in those stages, but more highlights a few important issues in each stage. We address the importance of good planning tools for dimensioning solar thermal systems, easy-to-install systems for solar collectors combined with an auxiliary heat source and heat storage issues that influences the final contribution of solar heat in the total heating system.

Below, the technical solar heating system and the present development of the systems are first discussed before introducing the extended system view, including both technical and social aspects of solar heating. Three main issues are then discussed; the importance of planning tools, the influence of hot water use on the dimensioning of a system and the auxiliary heating system. Finally, the importance of applying a socio-technical frame of references is argued.

2. The technical solar heating systems

Traditionally, when speaking of solar heating a pure technical system is considered; the solar collectors, storage tank, circulation pump, auxiliary heat source, heat exchangers and supply loops being the main components. One of the studies presented in this report is based on interviews with actors within the solar and pellet industries (see further in section 3.3.2). According to some of the informants solar heating systems are often presented in very *technical* and complex ways, showing detailed technical schemes. They even claim this to be a reason for low selling rates of solar collector systems. Development of solar heating systems has mostly been focused on increasing the solar yield in the collector or the efficiency of the system. Some solar collector retailers, however, argue that this is not what the costumers are interested in; that some few extra kilowatt hours over the year do not make a considerable difference when choosing a heating system. The costumers are rather interested in a well-functioning, aesthetically attractive and easily operated system. The development should therefore rather be directed to the issues that concern the potential costumer to achieve increased sale rates.

The development of solar collector technology has however moved in that direction; efforts are made to develop units that are both easy to install and easy to operate by the end-user. The number of components and operational options open to the end-user are reduced to secure optimal operational conditions. This is applied both to solar heating systems and combined system solutions, such as solar and wood pellet systems presented below. By this approach the manufacturers hope to offer easily operated and robust systems and thereby attract costumers to a larger extent. This shows the importance of including a social dimension in the system and we will in the following define the solar heating system as a socio-technical system when analysing implementation of such systems.

3. Extended solar heating system – a socio-technical system approach

Figure 1 shows additional social components connected to the technical system, which altogether constitutes the socio-technical system. A system is in this case considered comprising a set of components interacting with each other through connections. What is not influenced by the system is considered belonging to the environment (not shown in the figure), but the environment still influences the system (Churchman, 1968). Consequently, by this system view users and other actors, which were previously regarded as belonging to the surroundings and not being influenced by the technical system, are now considered parts of the system and intimately interacting with the technology.

In this study four main sub-issues have been studied; the planning process through building simulation tools (including components such as *architects* and *constructors*), the utilization of the solar heating system by modelling hot water profiles from people's statements about their activities (*user*), system solutions with different auxiliary systems by evaluation of a large solar heating pilot plant as well as investigation of the present Swedish market for small-scale solar and pellet heating systems (*installers, building companies, user, market, government, industry*).

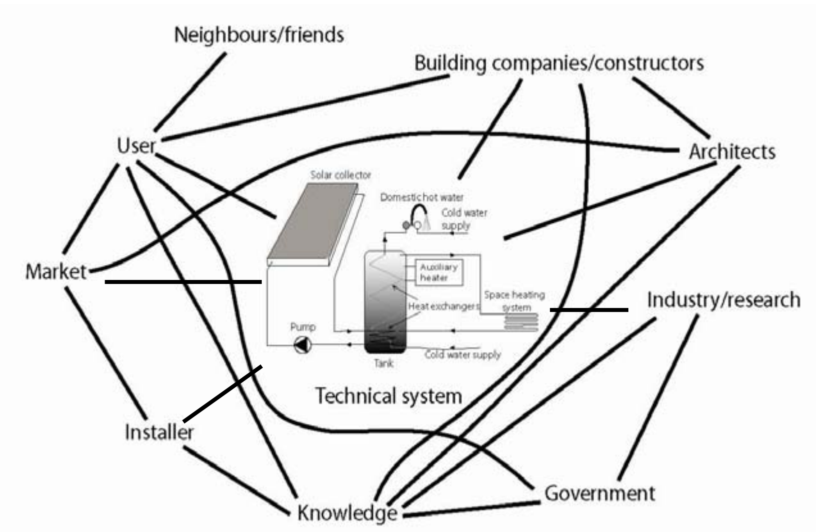

Figure 1 A socio-technical system view of solar heating, including both technical and social components.

3.1 The planning process – simulation tools for solar system dimensioning

Numerical models for calculating energy demand of a building are often used in the planning of new buildings or retrofitting of existing ones. Similarly, for dimensioning a solar heating system, models are used before erecting a solar collector plant. Such system simulations are of high importance to the architect, the builder, the entrepreneurs and other actors taking part in the planning process. The prerequisite for simulations being valuable in the planning is however that they deliver reliable results. This in turns requires simulation tools based on validated system models.

The need of well-functioning and user-friendly simulation tools for buildings has even increased the last years due to a directive on energy use in buildings from the European Parliament and Council from 2002 (Cox et al, 2002). It claims that energy certificates for buildings should be introduced in all member countries. The certificates shall show the energy performance of a building, but also supply proposals for cost-effective measures to improve the present performance. To serve this purpose several simulation tools have been developed to estimate the energy balance of buildings.

At present, planning buildings with solar heating often requires two different simulation tools, one that simulates the energy balance of the building and one simulating the performance of the solar collector system. That puts a lot of responsibility on the planners, to be able to handle different simulation tools, but also to compare and use the results from both programs in relation to each other. This makes the planning both complicated and cumbersome. A more easily managed alternative would be one simulation tool handling both different types of buildings and various installation systems.

Very few building simulation tools offer the choice to include solar heating systems in the model for calculation of energy supply. When investigating the market of commercial building simulation tools frequently used by planners in Sweden, it was found that only one of them (at that time, since 2007 there is at least one more similar simulation tool available) had an option to include solar heating. This simulation program was used to calculate the monthly solar energy contribution to space heating and hot tap water for an average new-built single-family house with a solar collector system of 12 m^2 and a water heat storage of 1 000 litres. The result was compared with results obtained with simulation tools that are specialized on solar collector systems, but also with experimental measurements on a real system. The solar heating systems and heat loads were comparable in size in all system models as well as in the real system. The results showed that the commercial building simulation tool severely underestimated the solar energy contribution as shown in Figure 2.

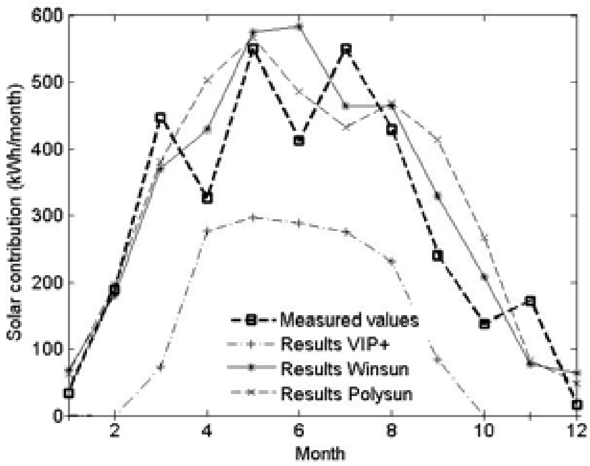

Figure 2 Simulation results from three different simulation tools as well as measured solar heating contribution for a solar combi-system in Sweden. The results from the building simulation tool VIP+ 4.0 deviate significantly from the others.

The deviating result for solar gain obtained in the building simulation originated from the tank model used in the program. The model only accounts heat of the set temperature in the tank, but in storage tanks used in solar heating systems heat of lower temperature is also accumulated for pre-heating (Lundh et al, 2007c). The results, however, show the importance of correct system models that are also validated against real operating systems. If this type of simulation tools is used in the planning process, resulting in extremely low solar energy contributions, solar collector systems will probably not be chosen because of low cost effectiveness. Building simulation tools with supply system models must be easy to use by the planner, not requiring professional competence in each area, but they also have to generate realistic estimations. The results must be reliable to thereby constitute the base for rational decision-making during the planning process.

3.2 User behaviour – hot water profiles

The planning and dimensioning of small solar heating systems (i.e. for single-family houses) is performed by the installer, mainly based on experience and rules of thumb. When planning for larger systems simulations are often used for determining system sizes. In both cases, the daily hot water demand is crucial in order to obtain the proper system sizes. Simulation tools for solar heating systems are often equipped with default daily pattern of hot water use, which can be adjusted to a chosen total daily consumption level, but which can not be changed in the time-resolved pattern. This section presents results from a study where hot water use was modelled for individual households based on time use data. This enables use of significantly diverse behaviours as time-resolved hot water loads and thereby also investigation on how different behaviour influences the solar contribution through the hot water use.

It has been shown in Krause (2003) that the heating cost of a large solar collector system can be considerably underestimated if it is dimensioned for too high hot water consumptions, while the difference in cost is small if the hot water use is underestimated. However, not only the total load, but also the distribution of the daily load has been shown to influence the solar utilization. In Jordan et al (2000) hot water profiles were constructed from statistical means on hot water, based on empirical studies from Germany and Switzerland. System simulations with the statistical load profiles showed a reduction in solar fraction (the fraction of the total heating demand covered by solar energy) by more than three percentage units compared to the default hot water draw-off pattern often used in simulation tools. Jordan's profiles were also used in Frei et al (2000) to investigate the influence on solar tap water systems. The difference in performance due to the type of draw-off pattern shows that solar heating does not only depend on the technology but also on how it is used; that the hot water user pattern actually influences the solar heating system.

In this study a model for translating time use data from so called time diaries into hot water demand was developed, which is jointly reported with a model for generating electricity load profiles in Widén et al (2008). The model is based on a pilot study on time use, which was performed by Statistics Sweden in autumn 1996. It comprises 464 persons living in 179 different households in apartments and detached houses. All family members older than ten years wrote time diaries, where they recorded all activities and the time spent on them, for one weekday and one weekend day. The time resolution in the time diaries are mainly five minutes intervals, which therefore serves as the basic resolution in the load profiles as well.

The model can generate load profiles with different time resolution, for single persons, single households or groups of households, for different types of dwellings as well as for different taps. The generated average load profile for a person living in a detached house and an apartment is found in Figure 3a and 3b respectively, while Figure 3c shows the significant deviation in hot water use between different individual households on a weekday. The hypothesis is that the time and amount of hot water use influence the ability to utilize solar heat. By introducing the modelled hot water profiles in dynamic simulations of solar collector systems a more realistic interaction between users and technology can be achieved.

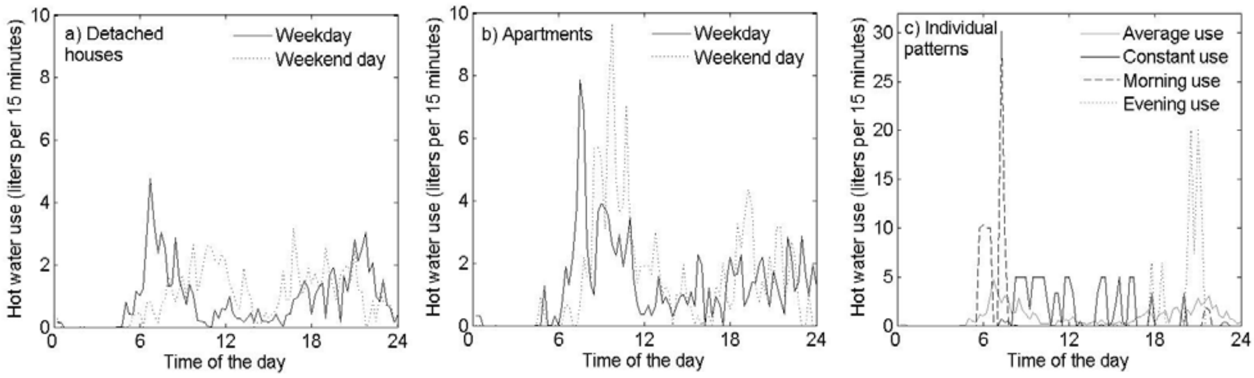

Figure 3 In figure a) the hot water profiles for weekdays and weekend days are shown for an average person living in detached houses. In figure b) the profiles for an average person living in an apartment is shown, while c) presents individual patterns of an average person from three different households showing completely divergent behaviour. (Lundh et al, 2008b)

The generated profiles need not be representative for all households, but constitute improved descriptions of hot water loads compared to the schematic draw-off patterns normally used in simulations. By generating load profiles from time diaries, they are based on people's statements about their activities. That means an order of activities that makes sense to the person that performs them, but it also puts energy use in a larger context of activities.

The main lesson to be learnt from this study so far is that the distribution, but also the amount of hot water use over the day, looks very different between different households. Can the load then be generalised with a certain, significantly simplified, hot water profile and a stereotyped total demand for all households when dimensioning solar heating systems? This is the question at issue in an ongoing continuation of this project which will be reported later.

3.3 Auxiliary system solutions – demonstration and market development

Solar heating systems are mainly of two different types, tap water systems or combi-systems. The tap water system, which only supplies hot water, dominates the world market having a share of more or less 90-100 percent in most countries (Weiss et al, 2002). Combi-systems, on the other hand, supply both hot water and space heating, and constitute 75 percent of the total installed solar systems in Sweden. A solar heating system can however not cover all heating demand in a building, but has to be operated together with an auxiliary system. For example, a combi-system is often dimensioned for a 20-25 percent solar fraction, while a tap water system covers about half of the total hot water demand over a year. To achieve considerably higher solar fractions seasonal storages have to be used. Storage of heat over long periods of time and to a reasonable cost is however not trivial, especially for small systems such as for single-family houses, since long-term storage is associated with high thermal losses. This means that proper system solutions have to be developed. There are several appropriate combinations of heating systems with solar collectors, and two different solutions are presented below; one large-scale solar heating plant with a seasonal storage and one small-scale solution combining solar collectors with another type of renewable energy, biomass in form of wood pellets.

3.3.1 Large-scale solar heating with seasonal storage in rock – 70 percent solar fraction

In 2000 to 2001 a new residential area, Anneberg, was built outside Stockholm in Sweden. It comprises 50 semi-detached and terraced houses, but what makes the area special is the heating system. A total of 2 400 square meters roof-integrated solar collectors have been installed on all south-facing roofs, see Figure 4. This yields an over-production of heat during summer, which is used to heat a 60 000 m^3 rock volume, by leading the heat through 100 boreholes penetrating the ground. The temperature increase can then be utilized for heating buildings and pre-heating hot water during the winter without use of heat pumps, due to the low-temperature floor heating system. Both solar collectors and borehole storages are well-known techniques, but the combination was unique. Previously, mainly large water storages have been used as seasonal storages for solar heat.

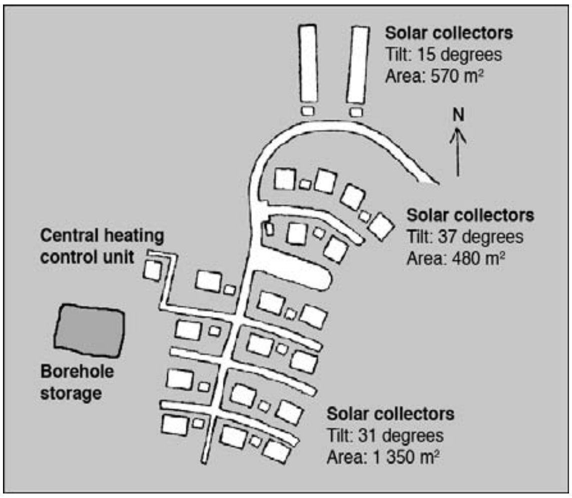

Figure 4 Example of the semi-detached houses in the area Anneberg outside Stockholm is seen to the left (Photo: M. Lundh). The south-facing roofs are covered by flat plate solar collectors. The right figure shows the distribution of buildings, solar collector areas and tilts as well as the location of the storage.

The initial thermal losses from the borehole storage will be large and full capacity will therefore be reached first after three to five years of operation. By utilizing the two techniques of solar collectors and borehole storage the heat demand will be supplied by solar heat to 70 percent under designed steady state conditions. The remaining required heat is supplied by electrical heaters in the floor heating system and in the water heater respectively. An electrical back-up system was chosen due to its simplicity and the small space requirements.

The solar heating system was put into operation in spring 2002, but due to problems both in the collector loop and in the storage loop, equilibrium has not yet been reached. When the solar collector system was tested, some of the pipes in the collector loop were found to be made of plastic, which resulted in an exploding pipe and a water leakage in one of the heating sub-units. The pipes therefore had to be replaced by copper pipes. This caused a delay in operation until autumn 2002. The system was then running without major problems for two years, until a leakage was discovered in the borehole storage. The U-tubes in the boreholes were found to have an inappropriate construction, causing cracking and thereby leakage, and all pipes in the storage loop had to be replaced as well. The system was put back into operation in autumn 2005 and has been running since then.

A first evaluation of the system was performed in 2005. Detailed information about the evaluation is found in Lundh (2007a) and Lundh et al (2008a). An evident supply of solar heat to the households both directly and indirectly via the borehole storage was shown. The system is designed to supply about 9 000 kWh heat per household and year at full capacity. From measurements of the storage discharge during 2003 it was found that an average of about 1 700 kWh heat had been used per residential unit. Moreover, the direct use of solar heat was assumed to be about ten percent of the total collected solar energy, which means another 1 800 kWh per residential unit. In total this means that the solar heating system already the first year contributed with more than one third of the designed heat supply at full capacity. (Lundh et al, 2008a)

What lessons can then be learned from a demonstration project like this? The two major incidents with leakages in the heating system have resulted in the electrical back-up system being the main heat supplier. This, in turn, has caused higher electricity bills than expected by the residents and thereby complaints, since several residents expected reduced costs already after one year of operation. These problems have in some cases led to reduced confidence in the heating system, but also in the property developer. When the indoor temperature, in addition, has been experienced as being too low, the negative attitude has been reinforced. On the other hand, there is an overall positive attitude towards the solar heating system, shown by interviews with residents (Lundh et al 2007b). The understanding of the system being a pilot plant, and thereby acceptance of some initial problems, is wide-spread.

Both technical and social issues connected to knowledge and understanding, have occurred in Anneberg. It is of high importance to engage, inform and discuss the system performance and what to expect from the system with the residents both before and during the operation. By clearer communication, the frustration experienced by the residents in Anneberg, and the speculations caused by lack of information, would probably have been reduced. On the other hand, some of the technical problems in Anneberg were unavoidable, but there are a lot to be learned from the building process (which was not followed at the time). Several problems seem to be a result of lack of global means of control during the building process. For example, diverging instructions for the piping in the heating system resulted in the exploding pipe and the leakage in the solar collector loop. Although many problems have arisen during the project, new system solutions have to be installed and evaluated in reality to show actual potentials as well as difficulties. Computer models can never replace actual demonstration projects if solutions for future energy supply are to be found. Systems have to be built and used by people to achieve knowledge about the actual interaction and performance.

3.3.2 Solar and pellets – an increasing small-scale solution

Seasonal storages are not economically feasible for small-scale solar heating systems for single-family houses, due to the large volume required and the high losses from the relatively small storage. For single-family houses other solutions therefore have to be applied. One system solution that has been introduced on the market recently and that is getting more frequently used is the combined system with solar collectors and a wood pellet boiler.

Both solar heating and heating systems with biomass are sustainable energy suppliers based on renewable energy sources. By combining the two systems even more advantages appear; the solar collector system and the wood pellet boiler complement each other well. A pellets boiler normally operates with a low efficiency and frequent starts and stops during the summer when the load is low (only hot water), while a solar heating system can not supply all heat during the winter. By introducing solar collectors in a pellet heating system the pellet boiler can be turned off completely during summer, while it can operate at a high efficiency in the winter when the load is high, which in total increases the system efficiency. Furthermore, wood pellet is an economically reasonable solution that is easily handled by the user. It may however mainly suit countries with domestic wood assets. Combined systems have been used for some years, but during the last years more and more efforts have been made to develop integrated systems that are easy to install and easy to operate by the user. To study the development of the *concept* of combined solar and pellet heating systems, as well as trying to identify obstacles to increased use, an interview study was performed with ten actors such as manufacturers, retailers, installers and representatives for interest organizations within this business in Sweden during autumn 2007. The material will be further analyzed and reported in detail in future papers.

During the interviews the installers were pointed out as key actors for guiding the consumers in their choice of heating systems. Today, lack of installers willing to install combined systems with solar and pellet is experienced both by installers themselves and by manufacturers. Many installers lack in knowledge, mainly about the solar heating systems, and as one of the informants expressed it “plumbers do not want to climb roofs”; they are unwilling to make this kind of businesses. To make the systems attractive they must however be easily accessed by the consumer. One solution could be to develop standardized systems that are easily and quickly installed, and thereby also changing the attitude among the installers.

On the other hand, very few suppliers are able to deliver complete system solutions. Instead the potential costumer is directed to purchase different components from different companies, which probably discourage many people. An important issue is therefore co-operation. At present, the different actors delivering the different system components often meet first at the installation, which could be too late to enable well-performing heating systems. Collaboration already at the stage of planning would be an important progress. The present system development is however focused on adapting the components to the combined systems, for example by introducing small boilers suitable for an accumulator tank with solar, but also on packaging the systems nicely, offering the costumer (and installer) a simple system with less units and simple operational conditions; systems that the user can understand. The comfort is also highly stressed, not demanding daily commitment from the operator, but also to offer system solutions compatible to other heating systems that are already nicely packed and easily operated.

Identified obstacles to solar and pellet heating were mainly the lack of user focus in the system development; comfort and design have not been the main issues for the manufacturers so far. When no complete combined systems are offered on the market, the consumer is forced to consider an *additional* system. The cost could also constitute an obstacle, while no technical problems were recognized. Due to previous governmental subsidies for converting heating systems, causing a fluctuating Swedish market mainly for pellet boilers, a stable market with long-term governmental decisions and well-established governmental viewpoints in energy supply issues were also pointed out as necessities for success.

Most informants agreed on that combined solar and pellet systems have entered the market during the last two or three years, and that the market share will grow significantly; “it is just a matter of time”. Comfortable standardized, but also cheaper, combined systems, enough number of good and engaged installers to meet the increasing demand, as well as more and better marketing are necessary prerequisites for solar and pellet systems to reach success.

4. Main advantages with an interdisciplinary approach

What are the advantages of extending the system view on solar heating from the traditional view of being purely technical to a *socio-technical* view? Foremost, a solar heating system will always be part of a social context; (developed in the industry or at an academic institution due to decisions taken by a board, financiers or a group of researchers) it will be available on the market, which is governed by several different actors (manufacturers, importers, installers, interest organizations), it is planned by an installer, architect or a construction company and finally it is operated by the users (household members or technical staff). All those stages include *people*. Thus, the solar heating system, or any heating system, can not be considered purely technical. If one of these stages fails, solar heating will not work in a satisfactory way, or in the worst case it will not be installed at all. This in turn can result in bad reputation and in the long run a vicious circle of decreasing number of installations.

By applying a socio-technical approach the technical system is seen in a wider context and connections not only between components within the technical system, but also between components inside and outside the technical systems, can be identified. When applying a research question such as “How can the use of solar thermal systems be increased?” the studied object can not be limited to the devices. To enable identification of obstacles as well as possibilities with solar thermal the wider socio-technical system, that the solar heating system is actually part of, has to be considered. Both advantages and obstacles tend to appear in the connections between the social and technical components, meaning that the issues can often be related to *people* and their knowledge; people’s expectations on the technology and the planners’ expectations on people. Those do not always match. But to understand *why* they do not match the interaction between technology and people have to be investigated.

6. Conclusions

There is not *one* universal solution to reach increased use of solar collector systems. Different obstacles towards the establishment of solar heating have been pointed out, all by applying a socio-technical approach, where the hindrances are traced to the interaction between technology and actors. The importance of well-functioning planning tools for dimensioning solar thermal systems integrated in a model for energy use in buildings is stressed. Furthermore, easy-to-install systems for solar collectors combined with an auxiliary heat source are crucial to attract both the potential user and the installer.

The divergence in hot water use between different households is significant. There may even be a greater potential in energy savings and profitability of a solar heating system in *how* it is used, than in technological improvements of system components such as the collector or the tank. Solar heating is in the middle of its breakthrough. By widen the perspectives from the pure technical it is possible to attend the existing lack of knowledge, and put the effort in the direction necessary to attract the costumer, since interested and satisfied users are essential for solar heating to reach success.

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CLIMATIC DESIGN STRATEGIES FOR SYDNEY, ADELAIDE AND PERTH: A STUDY OF BUILDING CODE OF AUSTRALIA'S CLIMATE ZONE 5

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Keywords: Climate, climate classification, climate analysis, building design, design strategies

Summary

Building Code of Australia (BCA) has been developed and maintained by the Australian Building Codes Board (ABCB) on behalf of the Commonwealth, States and Territory Governments. BCA has identified eight different climate zones within Australia. This paper discusses climate conditions of the state capital cities of Sydney, Adelaide and Perth that belong to the same climate zone 5 of the BCA. This comparative study aims to identify the similarities and the differences in climate conditions in these cities, as a result of microclimatic features. Temperature, humidity, sky conditions and, wind intensity and directions are different in Sydney, Adelaide and Perth. Perth experiences higher summer maximum temperature than Sydney and Adelaide. Sydney is warm and humid in summer while Adelaide and Perth are hot and arid. Winter sky condition is clear in Sydney while it is overcast in Perth and Adelaide. Wind intensity and directions are varied during the day and seasons in all the three cities.

This paper outlines a few design strategies; some are same for all the cities while others are different. Street and building orientation, outdoor space planning are specific to the locations while winter heating requirement and necessity of thermal mass are prerequisite to all the cities.

1. Introduction

Global climate classifications basically use prominent climate data to form climate zones of similarity especially useful in agricultural study. Climate zone classifications to describe appropriate building design should be different from those invented for agriculture (Cook 1996). In the context of building regulations, climate zones are regions which are of sufficient similar climate such that, a common solution for energy efficiency measures is possible and justifiable (AGO, 2000).

Climate across Australia is very diverse. Diversity is huge such that even in a metropolitan scale, one can experience differences in the climate (Upadhyay 2008). However, there still is a need to generalise climate to define climate zones using variety of criteria depending on the purpose. Various organisations have classified the whole of Australia into number of climatic zones. The Bureau of Meteorology has six zones while Building Code of Australia (BCA) has eight zones and NatHERS (Nationwide House Energy Rating Scheme) has 69 climate zones for the Australian continent (NatHERS 2008). The six climatic zones developed by Bureau of Meteorology are based on dry-bulb temperature and humidity. Other climate determining elements such as, the wind and solar radiation are not considered because of the complexity arising with the inclusion of those parameters. However, the effect of wind, sky condition and rainfall pattern can not be ignored when considering climate for building design purposes.

This study has considered three state capital cities of Sydney, Adelaide and Perth which belong to the same climate zone 5 of BCA. Sydney Metropolitan has diverse climate conditions. This study has considered only the eastern part of Sydney and has used climate data from the Sydney airport. Climate zone 5 resembles the temperate climate zone of Bureau of Meteorology (BOM 2008). This study has summarised climate information from the three locations; and detailed climate analysis is carried out to understand the prevailing climate characteristics in these cities. Climate analysis is then used to come up with practical design recommendations for the three state capitals Sydney, Adelaide and Perth.

2. Methodology

This paper is a part of a larger study, which aims to develop design guidelines for planners, designers/ builders to help them in selecting the planning/ design options and building elements that are climatically suitable, as well as, energy efficient. The study will cover the major population locations within Australia, such that, it covers all the states and major cities, which are distinctly different in climate conditions. The study is carried out in two steps: climate analysis, and formulating recommendations for planning and building design. In climate analysis, climate data from the Bureau of Meteorology, Australia for each of the locations is summarised in a graphical format. Comfort condition for each location is investigated using Building Bioclimatic charts; and wind roses are prepared to understand the wind flow at different times across different seasons. Final design guidelines are based on preliminary recommendations from Mahoney tables, which formulate design strategies using temperature, humidity and rainfall; and detailed climatic analysis. This paper undertakes the same process of climate analysis and will provide location specific recommendations.

3. Climate study

3.1. Sydney

Climate data over a period of 78 years (1929 – 2007) from **Sydney airport** has been used for this study.

Sydney experiences a hot and humid summers and mild winters. Autumn and spring months are transitional periods between the two main seasons. Mean monthly air temperature ranges from 26°C in February to 18°C in July. The average minimum temperature ranges from 7°C in July to 17°C in December. Humidity in Sydney is high for two months in summer; otherwise it remains within a comfortable range. Requirements of heating or cooling are best described by heating/ cooling degree hours. Cooling threshold temperature is determined by the neutral temperature (Szokolay, 1982) for each month. Heating threshold temperature has been taken as 18°C for the year round (Hart and de Dear, 2004). In Sydney, summer requires cooling, but from mid autumn to spring, heating is required. In total, 3% of the time has cooling demand and 97% of time has heating requirements. Summer and autumn months get substantial rain; the sky is overcast in summer and autumn. In winter, the sky is clearer. The annual mean rainfall of 90 mm, which is approximately 95 days of rainfall, is distributed fairly across all the seasons. It rains more frequently during autumn while least during spring months. Wind changes its direction in each season. Generally, the morning wind comes from the north-west. The afternoon wind blows from the east to the south and the evening wind from the north and south. In summer and spring, wind comes from the north-east to the south directions. Autumn and winter morning wind comes from the west and north-west and afternoon wind comes from the south.

3.2. Adelaide

Climate data from **Kent town, Adelaide** over a period of 30 years (1977 – 2007) has been accessed for this study.

Adelaide experiences hot, dry summers and mild, wet winters. Mean monthly air temperature ranges from 29°C in February to 17°C in August. The highest temperature ever recorded is 44.3°C in February 2004. The average minimum temperature ranges from just 7°C in July to 17°C in January. The lowest temperature ever recorded is –0.4°C in June. The morning and afternoon humidity levels in Perth are within the comfort zone. Summer months are hot and winter months are cold but humidity levels are always in the acceptable range across seasons. Of the annual mean rainfall of 550 mm, which is approximately 84 days of rainfall, about 60% usually fall between May and September. It rains more frequently during winter with 75 mm rainfall in an average of 12 rainy days in a month. In contrast, the total summer rainfall is just 61 mm with an average of 3 rainy days in a month. As winter months get substantial rain, the sky in winter is overcast for about 15 days in a month. Summer months require cooling; but from autumn to spring, heating demand is very high in Adelaide. In total, 93% of the time has heating demand and 7% of cooling demand. The wind is mainly from the south west and west in the afternoon. Prevailing wind in summer is from the south. In winter, morning wind is primarily from the north.

3.3. Perth

Climate data from **Perth Airport** is accessed which is averaged for a period of 63 years (1944 – 2007).

Perth experiences a Mediterranean climate, characterized by hot, dry summers and mild, wet winters. Mean monthly air temperature ranges from 32°C in February to 18°C in July. The highest temperature ever recorded is 46.7°C in February 1991; however, the temperature exceeds 40°C only three days per year on an average. The average minimum temperature ranges from just 8°C in July and August to 17°C in January and February. The lowest temperature ever recorded is –1.3°C in June. The morning and afternoon humidity levels in Perth are found within the comfort zone. Summer months are hot and winter months are cold but humidity levels are always in the acceptable range across seasons. Of the annual mean rainfall of 767 mm, which is approximately 87 days of rainfall, about 70% usually fall between May and September. It rains more frequently during winter with 150 mm rainfall in an average of 14 rainy days in a month. In contrast, the total summer rainfall is just 35 mm with an average of 2 rainy days in a month. Hence, it is not unusual in Perth to have extended dry periods during summer. Perth is one of the sunniest Australian cities and enjoys an annual average of 8.8 hours of sunshine per day. In predominantly clear days of summer, the average daily sunshine duration exceeds 11 hours. As winter months get substantial rain, the sky in winter is cloudy for about 12 days in a month. Summer and early autumn months require cooling; from mid autumn to spring, heating demand is very high in Perth. In total, 85% of the time has heating demand and 15% of time has cooling requirements. The wind is mainly easterly in the morning due to the effect of land mass; and south westerly in the afternoon due to afternoon sea breezes. Winter morning wind comes from the north and changes its course towards the west and south-west in the afternoon. The westerlies are associated with the bulk of the annual rainfall in Perth. The average wind speed in winter is considerably lower than in summer.

Table1: Climate comparison between the three locations

Climatic parameters	Sydney	Adelaide	Perth
Air Temperature			
Extreme maximum	45.2^{0}C	44.3^{0}C	46.7^{0}C
Mean daily maximum			
summer	26.4^{0}C	29.3^{0}C	31.8^{0}C
winter	18.2^{0}C	16.7^{0}C	18.9^{0}C
Mean daily minimum			
summer	17.4^{0}C	15.5^{0}C	14.8^{0}C
winter	7.0^{0}C	7.4^{0}C	8.0^{0}C
Extremely minimum	-0.1^{0}C	-0.4^{0}C	-1.3^{0}C
Mean diurnal range	7.3 – 10.2 degC	7.9 – 12.2 degC	9.7 – 14.7 degC
Heating degree hours *(base 18^{0}C)*	97%	93%	85%
Cooling degree hours *(base neutral temperature)*	3%	7%	15%
Humidity	Humid for two months (Jan and Feb)	Always within comfort range of 4-12g/kg	
Sky Condition	Winter months have clearer days while rest of the seasons are prevalently cloudy	Summer months have more clear days while rest of the year is prevalently cloudy	Summer months have clear sky while winter months have the cloudy conditions.
Rainfall	Summer and autumn months receive substantial rainfall and winter receives the lowest rainfall	Winter and spring months receive substantial rainfall and summer receive the lowest	Winter months receive the highest rainfall and summer months receive the lowest
Wind	In summer, southerly wind is prevalent while in winter, wind comes from the west except wind from the south in the afternoon.	Wind is mainly from the south west and west in the afternoon. Summer wind is predominantly from the south while winter morning wind is primarily from the north.	Perth experiences three distinct wind patterns. Morning wind comes from the east, afternoon wind comes from the south-west and evening wind comes from the south.

4. Climate comparison

The table above illustrates the differences in climate of these three locations, although, they are in the same climate zone in BCA. The differences of the parameters are discussed in detail below.

4.1. Temperature

Temperature profile of Sydney, Adelaide and Perth looks similar at first. Temperature usually surpasses the comfort zone in summer while it drops below the comfort zone in winter. These locations experience very similar extreme maximum temperature, within the range of 2.5 degC. The striking difference however is observed in mean daily maximum temperature in summer, which increases from the east coast to the west. The difference between Sydney to Adelaide is around 3 degC and from Adelaide to Perth, is around 2.5 degC. Winter maximum temperature in Adelaide is the lowest. Perth has got the lowest mean daily minimum temperature among the three. As a result, mean diurnal temperature in Perth is the largest which is in the range of 9.7 to 14.7 degC while it is the lowest of 10 degC for Sydney. The daily temperature fluctuation also increases moving from the east coast to the west. The requirement for heating is the highest in Sydney while Perth needs more cooling than rest of the locations.

4.2. Humidity

Sydney experiences humid condition for two months during summer, while Adelaide and Perth do not experience humid conditions. In general, humidity is not a problem for all the three locations.

4.3. Sky conditions and rainfall

Sydney enjoys winter sunshine while Adelaide and Perth have overcast sky in winter months. Consequently, winter months receive the lowest rainfall in Sydney but other two locations receive the highest in winter months.

4.4. Wind

Wind pattern is completely different from one location to the other. Sydney experiences wind coming from the south and north-east. Adelaide and Perth have three distinct wind directions for the morning, afternoon and the evening. Adelaide and Perth both have afternoon wind from south-west and the evening wind from south while the morning wind in Adelaide is from north and in Perth, it is from the east.

5. Climate analysis

Climate Analysis has been done using Building Bioclimatic Chart and Mahoney tables.

5.1. Building Bioclimatic chart

The Building Bioclimatic chart derived by Givoni (1976) provides suggestions for building design considering the local climatic conditions. Various control strategies, which ultimately lead to a climate-sensitive design, are suggested. Szokolay (1986) defined control- potential zone to describe the range of outdoor atmospheric conditions within which indoor comfort could be achieved by the various passive control techniques. In the Psychrometric chart, different zones are plotted to indicate different strategies depending upon the monthly temperature–humidity relationships. To identify the comfort conditions, the climatic data of all the months are plotted in Building Bioclimatic chart, as shown in Figures 1-3. Two points of each line represent mean minimum temperature with the 9 AM relative humidity and the mean maximum temperature with the 3 PM relative humidity.

Temperature – humidity relationships for Sydney suggest having thermal mass and ventilation arrangement to counteract the summer hot conditions. Adelaide and Perth experience hot but arid conditions, so thermal mass is required to moderate the climate in summer. For the majority of the time, temperature drops below the comfort range for all the locations, making recommendations for passive solar heating strategies.

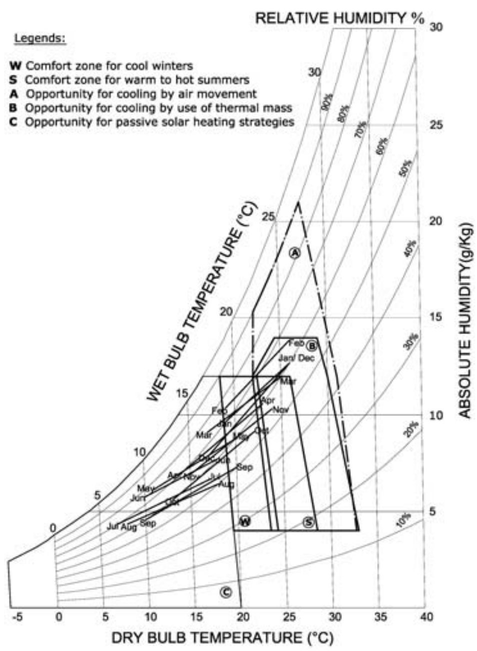


Figure 1. Building Bioclimatic chart (Sydney)

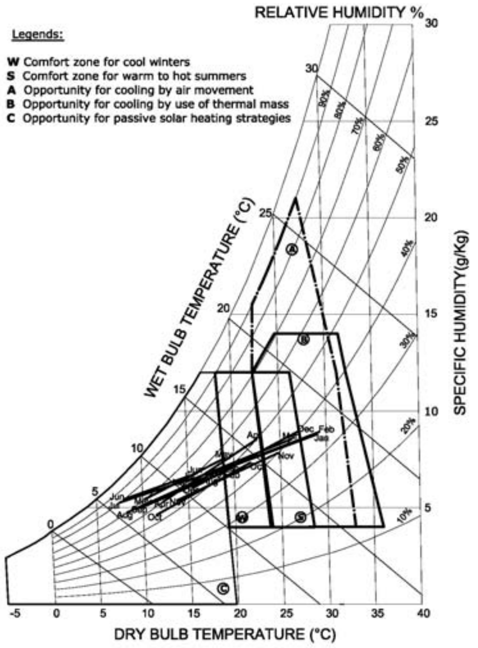


Figure 2. Building Bioclimatic chart (Adelaide)

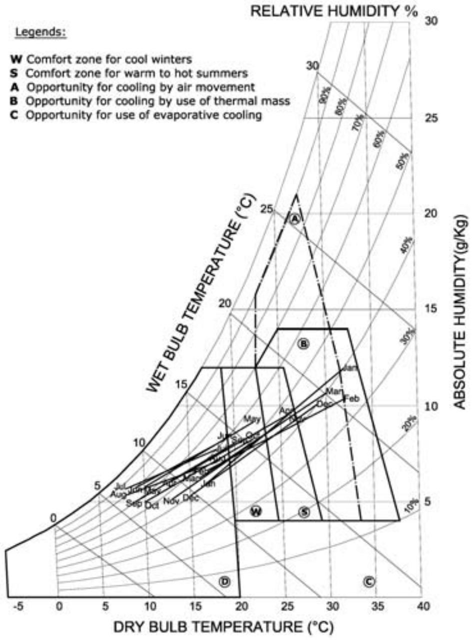


Figure 3. Building Bioclimatic chart (Perth)

5.2. Mahoney tables

The Mahoney tables (Koenigsberger, et al., 1973) provide results of thermal comfort analysis using primarily the temperature and humidity data, and make recommendations for pre-design guidelines.

These pre-design conditions are classified under certain climatic groups or indicators. The Mahoney tables have six indicators (i.e. three ‘humidity indicators’, H1- H3, and three ‘arid indicators’, A1 –A3). The Mahoney tables indicate remedial action involving air movements for humid conditions in H1 and H2. Excess downpours may affect the building structure, so adequate rain protection is advised in H3. Similarly, for hot and arid conditions, thermal capacity (A1) is one of the options for making the indoor space comfortable. When the temperature range is more than 10 degC with relative humidity up to 70%, thermal mass is recommended. Climatic zones with night time temperature above the comfort limit and relative humidity less than 50%, are advised to make provisions for outdoor sleeping (A2). A building with the temperature below comfortable range needs protection from cold wind (A3). Indicators and recommendations from Mahoney tables for Sydney, Adelaide and Perth are presented in table 2.

Table2: Indicators and recommendations from Mahoney tables

	Sydney	**Adelaide**	**Perth**
Indicators	A1, 2 months and A3, 5 months	A1, 7 months and A3, 5 months	A1, 10 months; A2, 2 months and A3, 4 months
Recommendations on			
1. Layout	North and south (long axis east – west)		
2. Spacing	Compact layout of estates		
3. Air movement	No air movement requirement		
4. Openings	Medium openings 20-40 %	Small openings 15-25 %	
5. Protection of openings	Exclude direct sunlight		
6. Walls and floors	Light walls, short time lag	Heavy external and internal walls	
7. Roof	Light, insulated roof	Heavy roofs, over 8 h time lag	
8. Outdoor sleeping	N/A		Space for outdoor sleeping required

Building layout with long axis towards east and west is best suitable for all the three locations and favours compact layout of estates without mandatory air movement across buildings. Recommendation for Sydney is larger opening area than Adelaide and Perth. Openings need to be protected from the direct sunlight. Mahoney tables suggest having heavy walls, floors and roof for Adelaide and Perth while light structures for Sydney. The arid indicator (A1) recommends use of thermal mass. Building in Perth should have outdoor sleeping space for summer

Mahoney tables do not consider night time wind movement to cool the thermal mass, which has been already proved effective in different climate conditions (Givoni, 1994). Even if compact layouts of estates are recommended due to arid characteristics of the places, the need of breeze penetration across buildings are still necessary to cool off the thermal mass in the evenings and at nights. Provision of securing afternoon wind movement can not be overruled as the daytime cooling can be met with the afternoon breezes.

6. Formulating the design strategies

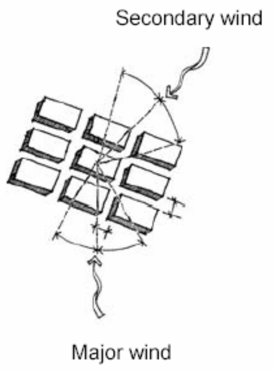
These climatic differences do have implications in building design and planning. The large diurnal temperature range with higher summer mean temperature in Perth needs special care, in comparison to Sydney. Requirement of thermal mass is significant when the diurnal temperature range is more than 10 degC. Sydney needs design response to address humid conditions in summer months, while Perth and Adelaide need different strategies for the arid conditions. Free flow of air through interior is important in Sydney while water bodies in and around the building is advantageous to balance humidity level in Adelaide and Perth. There is an opportunity for passive solar heating strategies for all the three locations. Winter clear sky in Sydney is the most favourable for the use of passive solar heating techniques while it is not the same for Adelaide and Perth due to prolonged overcast conditions in winter. In the local level, wind needs to be attended to, and it has a great influence in street layout, building orientation and the window placement in the buildings. In Perth, rooms that can be extended in covered semi open space are advantageous, as the outdoor sleeping condition is favourable for some months. Some of the design strategies are elaborated to make a clear understanding of the differences.

The design strategies are formulated based on the climate analysis. Design strategies are meant to be comprehensive and schematic to be helpful in the design process so that no major opportunities are missed. At the same time, they have to be few such that they can be easily memorized to be used effectively.

6.1. Building orientation and Street layout

Building orientation and layout of streets have significant effect on accessing sun and wind in the buildings. To maximize solar access and air movement in streets, primary avenues in Sydney, Adelaide and Perth should be oriented some angles west of south. To be more precise, this angle is 20 degree for Sydney, 25 degree for Perth and 30 degree for Adelaide. It helps to secure both prevailing afternoon wind and night breezes in summer; and winter solar exposure on the north facade. Major street orientation within the angle of approximately 20-30 degree on either direction of the prevailing breezes is highly recommended (Brown and DeKay, 2001). The figures below show the preferred wind direction along with the street layout at different locations.

Table3: Building orientation and Street layout considering sun and wind movement

<table>
<tr><th>Sydney</th><th>Adelaide</th><th>Perth</th></tr>
<tr>
<td>
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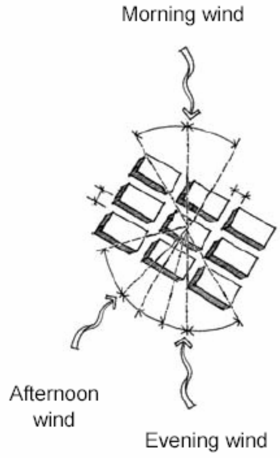
<td>
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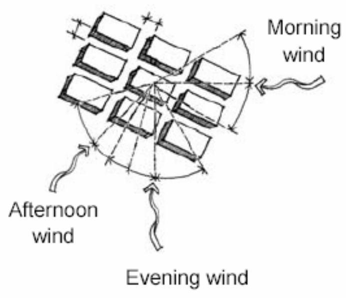
<td>
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6.2. Securing neighbourhood sunshine

Buildings in Sydney, Adelaide and Perth require solar radiation in the winter months. An ideal organization of streets, open spaces, and building for solar utilization is to elongate buildings in the east – west direction and spacing in the north – south direction. This placement allows buildings facing north to collect sun, and at the same time they are far enough apart not to shade each other. However, because of the topography or pre-existing conditions, many streets do not have an east west orientation so the figures 4-6 show several possible options of buildings and open space layout, along with opportunities for solar access. The previous strategy already recommended non –cardinal street arrangement for all the three locations considering the summer wind movement along with winter solar access.

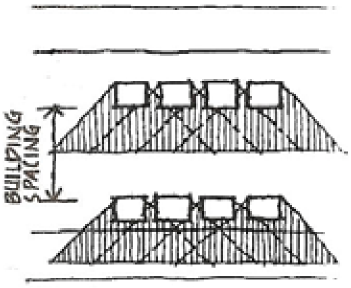


Figure 4. East –west lot arrangements

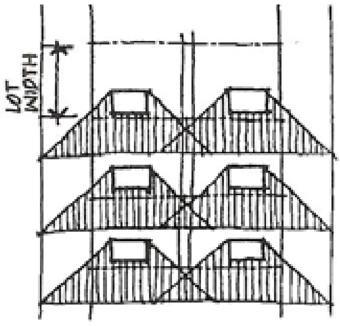


Figure 5. North –south lot arrangements

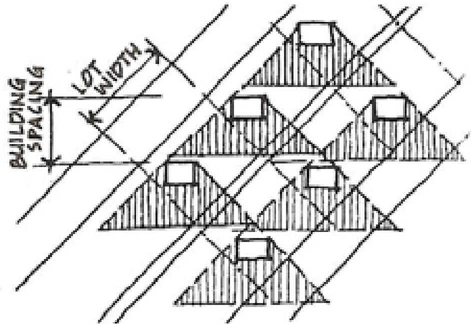


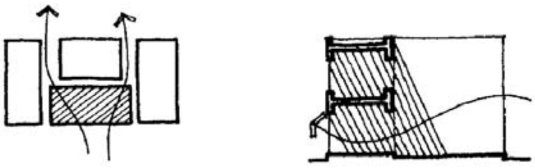
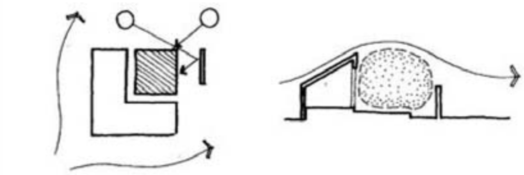
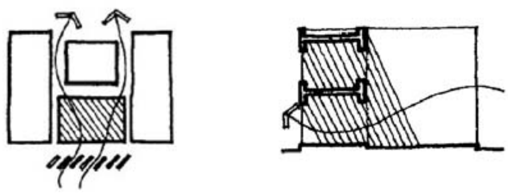
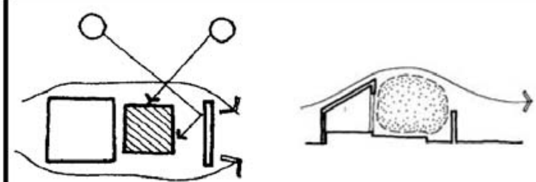
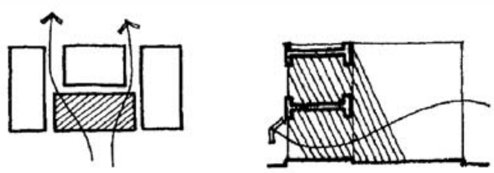
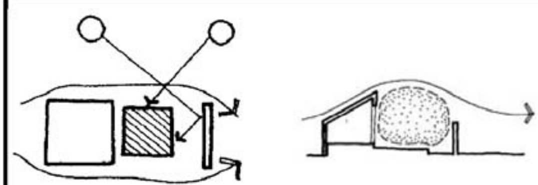
Figure 6. Non cardinal streets, lot arrangements

(Source: Brown and Dekay, 2001, modified)

6.3. Outdoor spaces

In summer months, outdoor spaces towards south are very useful as prevailing evening breeze comes from the south west in Perth. Outdoor sleeping is recommended in Perth for two months in summer. Winter months require sun tempering, as daytime temperature remains below the comfort range. Outdoor space towards the eastern part of a building, securing solar access from north and protecting it with westerly breezes is very useful.

Table4: Probable location of outdoor space for summer and winter in Sydney, Adelaide and Perth

	Plan ↓ **Summer outdoor space arrangements** Section ↓	Plan ↓ **Winter outdoor space arrangements** Section ↓
Sydney	 Summer wind comes from south	 Winter wind comes from west and south
Adelaide	 Summer wind comes from south-west and west	 Winter wind comes from west
Perth	 Summer wind comes from south	 Winter wind comes from west

6.4. Building structure

Sydney, Adelaide and Perth require cooling in summer months and heating in winter months. The large range of thermal conditions requires utilization of both radiation and wind effects, as well as, protection from them. Hence, dual role is required of the structure. Thermal mass helps to store daytime heat during the day and releases it at night to balance room temperature in winter months. Thermal mass can be used to absorb heat from a room during the day and to cool off the radiated heat at night with ventilation in summer months. For this, there must be enough mass in the building to absorb the heat gain, and the mass must be distributed over enough surface area so that it can absorb the heat quickly and keep the interior air temperature comfortably low. The opening must be large enough to allow cool outside air to flow past the mass to remove the heat accumulated during the day and carry it outside the building.

The diurnal temperature range, and summer mean maximum temperature, is higher in Perth than other two locations indicating the requirement of greater area of thermal mass for Perth. Similarly, evening wind movement to cool the thermal mass is also equally important for Perth.

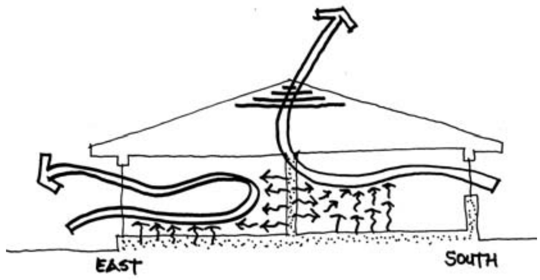


Figure 7. Effective ventilation helps to cool off thermal mass in summer

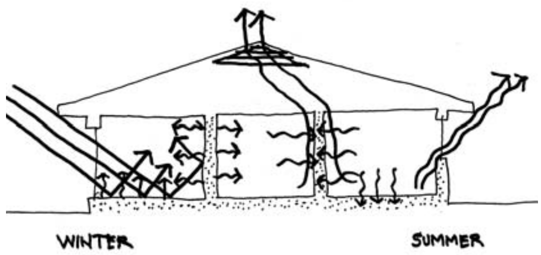


Figure 8. Use of thermal mass in winter and summer months

7. Conclusion

The climate of a place is influenced by various micro-climatic features. The climate classification of Bureau of Meteorology Australia has Sydney, Adelaide and Perth in the same temperate climate zone. Similarly, Building Code of Australia has them together in zone 5. However, the rigorous climate analysis of these locations revealed differences in climate conditions among these locations. This study identified differences in temperature, humidity, sky condition and wind intensity and its directions. All these features are major, considering the climate as an integral parameter in urban planning and building design.

Winter heating and summer cooling requirements together with available solar radiation and wind suggest for different orientations of building and streets in all the three locations. High heating degree hours for all the locations suggest securing sunshine in site and lot planning. Wind directions in different seasons and time are crucial to plan the outdoor open space for summer and winter months. Thus, the variation in summer and winter open space is observed in all the cities. The higher summer mean temperature along with higher diurnal temperature range in Perth require special attention in comparison to Sydney and Adelaide. Sydney has got warm and humid summer while it is hot and dry in Perth and Adelaide. Larger area of thermal mass in building is required in Perth and Adelaide along with evening or night ventilation which can ensure comfortable condition indoors. The winter clear sky condition in Sydney encourages the use of passive solar heating techniques while it is not so in Adelaide and Perth due to overcast conditions.

Acknowledgement

This paper is an outcome of ongoing research on “Climate and design guidelines for major locations in Australia”. I would like to thank Think Brick Australia for funding this research.

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THE ESTIMATION OF GLARE INFLUENCE DUE TO SPECULAR REFLECTION OF DIRECT SUNLIGHT FROM CURTAIN WALL OF A HIGH-RISE BUILDING

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Keywords: specular reflection, glare, radiance

Summary

With the advent of high-rise building and clustering of the building, range of influence by the new establishment of large-scale building to the surrounding environment is being reinterpreted. Namely, range of estimation is expanding from previous direct or physical elements such as traffic, noise, vibration or structural aspect to sunlight, view, glare influence, energy load and personal psychological elements as well. In case of high-rise building in downtown, most of buildings are finishing the exterior envelopes of the building with glass, the specular material, for the landmark image and securing the view of residents as of now. However, in case the front of building finished with specular reflection material is designed as broad plane, specular reflection of direct sunlight may occur due to exterior envelopes of the building at certain time period and it may bring about danger inducing the discomfort glare or disability glare to drivers and pedestrians on adjacent road. the purpose of this study is analyzing and estimating the influence of direct sunlight reflection of building exterior materials on glare on the road as newly established building Y is constructed near the interchange where big roads are close to one another.

1. Introduction

With the advent of high-rise building and clustering of the building, range of influence by the new establishment of large-scale building to the surrounding environment is being reinterpreted. Namely, range of estimation is expanding from previous direct or physical elements such as traffic, noise, vibration or structural aspect to sunlight, view, glare influence, energy load and personal psychological elements as well. In case of high-rise building in downtown, most of buildings are finishing the exterior envelopes of the building with glass, the specular material, for the landmark image and securing the view of residents as of now. However, in case the front of building finished with specular reflection material is designed as broad plane, specular reflection of direct sunlight may occur due to exterior envelopes of the building at certain time period and it may bring about danger inducing the discomfort glare or disability glare to drivers and pedestrians on adjacent road.

Accordingly, when constructing building, especially high-rise building, in downtown, design considering not only the visual environment of residents in adjacent area but also the specular reflection to prevent the damage on road shall be devised and it is necessary to establish standard and method to determine the likelihood of damage by glare in designing process.

Therefore, the purpose of this study is analyzing and estimating the influence of direct sunlight reflection of building exterior materials on glare on the road as newly established building Y is constructed near the interchange where big roads are close to one another.

1.1 Method and Range

This study was carried out in following orders.

1) To estimate the glare influence on adjacent road, trait of reflection angle based on incident angle of newly established building's exterior materials was measured using self-manufactured Gonioreflectometer (BRDF meter).

2) Spatial relationship was accurately implemented by analyzing the horizontal and vertical location of the building using the drawings first and then drawing up 3-D AutoCAD drawing.

3) Considering the placement of sun's location and the building, etc, estimated location for glare occurrence was set after drawing a reflection map from sunrise to sunset on 21st of Jan. ~ Dec., the representing days of year.

4) Basic data was collected for the computer simulation of glare influence using Radiance program.

5) Analysis and evaluation of image was carried after the simulation using Radiance program.

2. Preparation of Manuscripts

2.1 Discomfort Glare and Disability Glare

Although discomfort glare inflicts pain and discomfort in vision, it does not dramatically decrease the visual capacity and it is influenced by the light condition in overall field of vision. Disability glare decreases the perceptual capacity for visual information and it is influenced by the light of the object - direct light shed on desk from above or headlight of car from the opposite direction at night, etc.

Since average luminance of sun reaches about 2 x 109 cd/m2, be cautious in that disability glare may be induced at angle where specular reflection occurs with reflection of sun on object with lucid surface.

2.2 Bi-directional Reflection Distribution Function (BRDF)

BRDF presents the reflection rate for each wavelength of surface material as function in two directions, namely the direction of incident light and reflection light as illustrated in Fig. 1 and it is the ratio of reflection light intensity to incident light intensity. On the premise that most of construction surface material is either Lambertian surface or specular surface, reflection rate of surface is expressed as a single constant. However, in most cases, construction material is not Lambertian surface thus intensity and direction of reflection light differs according to the incident direction of incident light.

Formula 1 (Karner) expresses the reflection rate for each wavelength on surface of material as function of normal angle θ_r and azimuth angle ϕ_r of reflection light and normal angle θ_i and azimuth angle ϕ_i of incident light. When Item λ is removed from the Formula 1, it is becomes BRDF ignorant of reflection properties for each wavelength and it can be simplified as Formula 2.

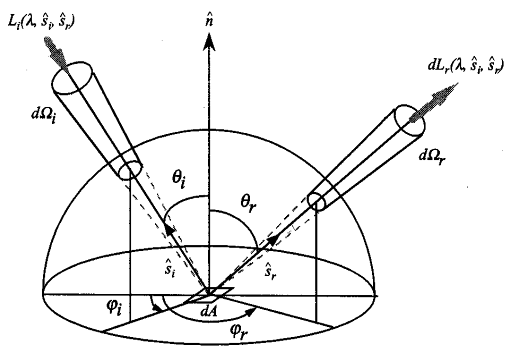


Figure 1 Concept Map of BRDF

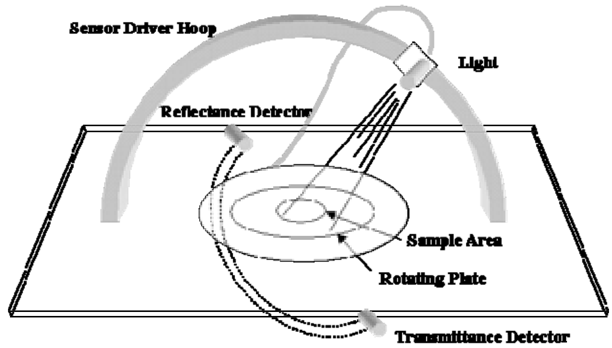


Figure 2 BRDF Meter by Murray-Coleman

$$\rho(\lambda;\theta_r,\phi_r;\vartheta_i,\phi_i) = \frac{L_{\lambda r}(\lambda;\theta_r,\phi_r;\vartheta_i,\phi_i)}{L_{\lambda i}(\lambda;\theta_i,\phi_i)\cos\vartheta_i dw_i} \quad (1)$$

$$\rho(\theta_r,\phi_r;\vartheta_i,\phi_i) = \frac{L_r(\theta_r,\phi_r;\vartheta_i,\phi_i)}{L_i(\theta_i,\phi_i)\cos\vartheta_i dw_i} \quad (2)$$

In here,

$L_{\lambda r}$: Intensity for each Wavelength of Reflection Light [W/sr/㎡]

$L_{\lambda i}$: Intensity for each Wavelength of Incident Light [W/sr/㎡]

(θ_r, ϕ_r) : Angle of Reflection Light[°]

(θ_i, ϕ_i) : Angle of Incident Light[°]

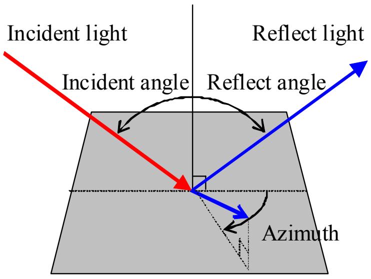
dw_i : Steradian of Incident Light[sr]

As a method to acquire BRDF of material, there are mathematical modeling or experiment (Foo, 1997). Method to acquire BRDF of material through mathematical modeling is to theoretically interpret and apply physical behavior of light on surface of material. Although it is accurate, it is difficult to calculate. Method to acquire BRDF of material through experiment is simple since it actually measures the behavior of light on surface of material and error in measurement can be narrowed down with several measurements with application of Monte Carlo method.

3. Measurement of the Reflection Rate of Exterior Materials

3.1 Outline of Experiment

Definition of incident angle of incident light and vertical (reflection angle) & horizontal (azimuth angle) angle of reflection angle in measurement of BRDF for exterior material sample is as Fig. 3. Define the angle between normal line on sample area of exterior material and incident direction of light as incident angle. In case, incident light is projected vertically on sample area of exterior material, condition is met where incident angle is 0°. Also, define the angle between direction of incident light reflecting on and out of the sample area and normal line of sample area as reflection angle. Direction of incident light going out with specular reflection was set as horizontal angle 0° and direction till 360° was defined as azimuth angle.



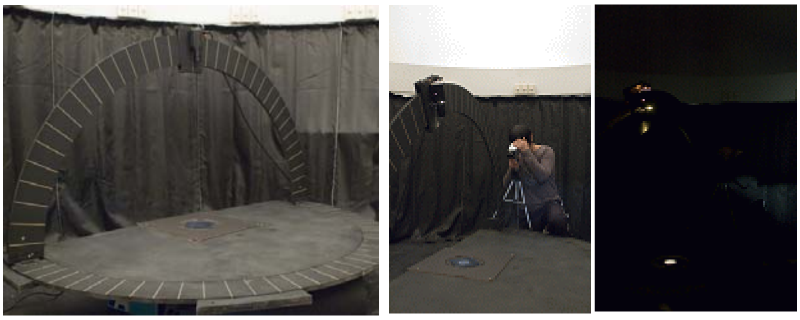


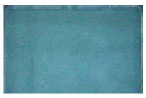
Figure 3 Definition for Location of Incident light and Reflection Light(L)

Figure 4 Form and Actual Measurement of Gonioreflectometer(R)

3.2 Experiment Material

As illustrated in Table 1, measurement of BRDF was carried out with exterior material sample of the building.

Table 1. Specification of Sample for Measurement of BRDF

Section	Sample
Image	
Trait	Transparent
Color	Dark Blue

3.3 Experiment Method

Gonioreflectometer (BRDF meter) as illustrated in Fig. 4 was used in the study to measure the BRDF pattern of the sample scheduled to be used as exterior material of the building. The experiment was carried out in artificial sky laboratory that does not receive external influence and equipment used in experiment was painted in flat black to exclude the reflection rate. BRDF meter used in the experiment was self-manufactured to measure the sensitivity for each direction. MR-16 halogen light bulb (50W) was used as standard light source and device that can control the illumination angle of light to make horizontal light as direct sunlight was installed to the bottom of flood lighting. BRDF meter can project light on target from any angle between vertical angle of 0~180° and horizontal angle of 0~360°. Measurement of luminance at certain location is available when placing exterior material for BRDF measurement on the center and changing the vertical and horizontal angle of flood lighting by using BRDF meter.

BRDF measuring reflection rate of reflection angle(0°, 15°, 30°, 45°, 60°, 75°) and azimuth angle(0°~360°, in unit of 30° of reflection light based on change in incident angle (0°, 15°, 30°, 45°, 60°, 75°) of incident light regarding the sample was measured.

3.4 Result of Experiment

As a result of analysis, maximum reflection rate of 88.86% was presented when incident angle of incident light is 75° and reflection angle and azimuth angle of reflection light is 75° and 0° respectively. Also, it was analyzed that trait of propagation and expansion was presented in general. Table 2 illustrates the reflection rate(%) for each reflection angle of sample in case incident angle is 75°.

Table 2. Reflection Rate(%) of Sample when Azimuth Angle is 75°

Azimuth angle / Reflect angle	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
75°	88.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60°	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45°	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30°	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15°	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0°	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

3.5 Discussion on Result

Fig. 4 illustrates the reflection rate for each reflection angle in case Azimuth angle of reflection light is 0° when incident angle of incident light of the sample changes. As illustrated in 3.4, the reflection rate was presented to be biggest in most of samples when incident angle of incident light changes and incident angle is same as reflection angle when azimuth angle of reflection light is 0°

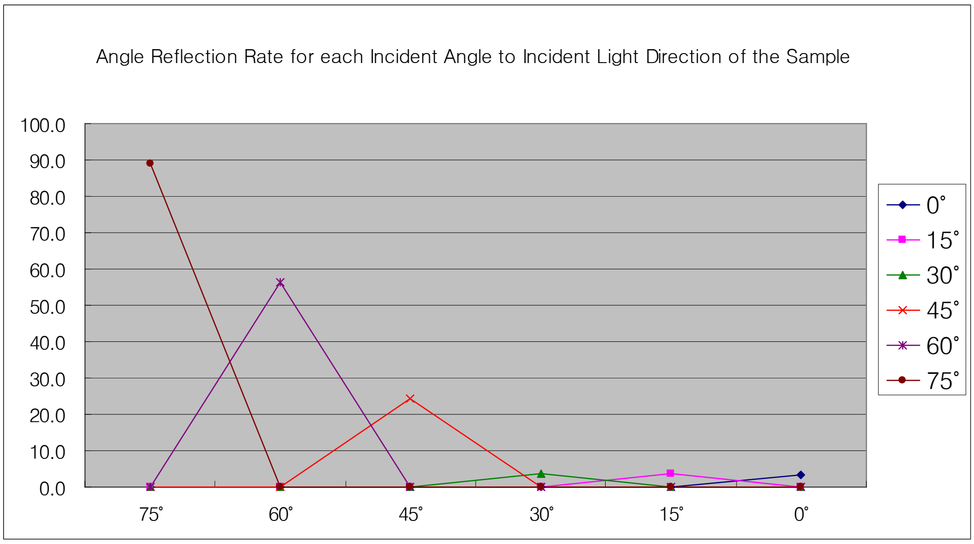


Figure 4 Reflection rate for each reflection angle based on incident angle when azimuth angle is 0°

4. Reflection Area Simulation using Radiance Program

4.1 Location of the Area

Fig. 5 illustrates the horizontal location of the building and the vertical location. Azimuth was set based on true north.

Table 3. Outline of Newly Established Building Y

Classification	Azimuth	No. of Floors	Height of Building	
			34th Floor	Max. Height
Office Building	Southeast 47°	34 Above-Ground Floors	147.2m	160.6m

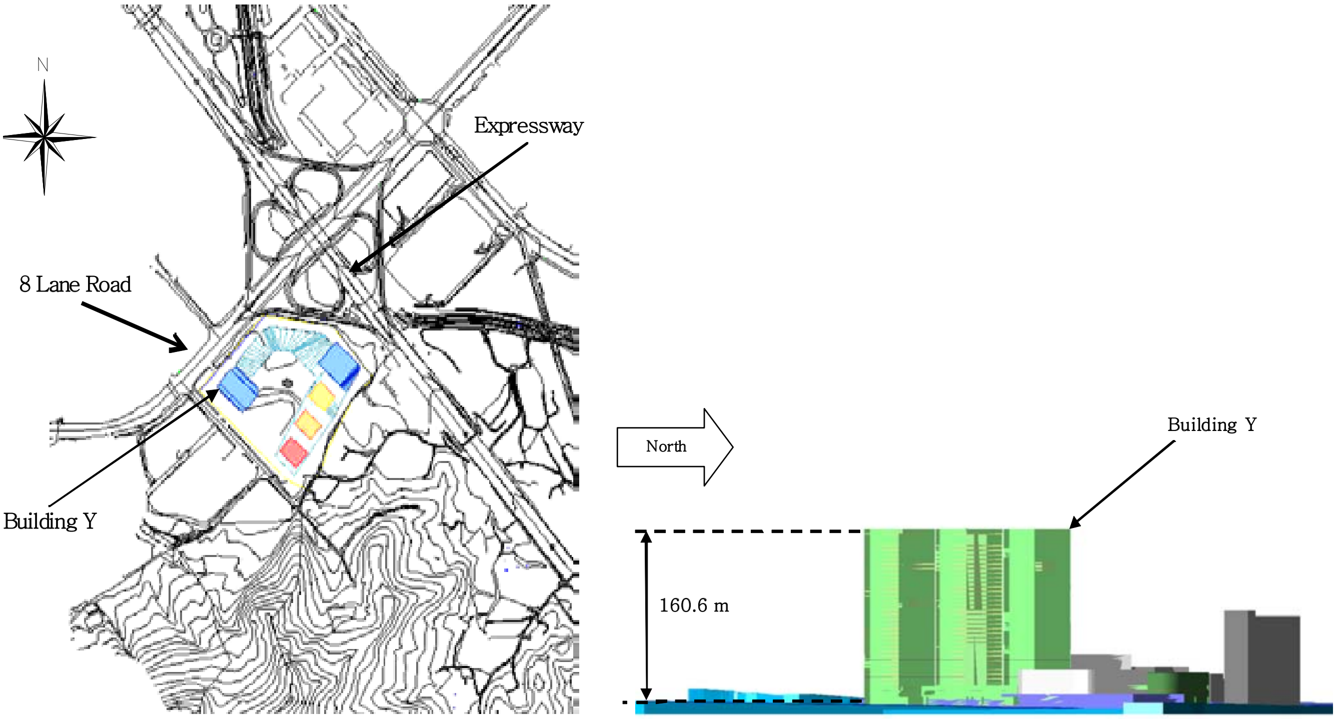


Figure 5 Horizontal Location and Azimuth of the Area (L) and Vertical Location of the Area(R)

4.2 Analysis on Reflection Area for each Month & Glare Visualization Image

Reflection area on representing day (21st) from Jan. to Dec. was drawn up considering the altitude and azimuth angle of sun and glare occurrence observation point was set limiting the range as on road considering the surroundings of the building. 70 estimated glare occurrence points by the reflection light of sun reflected on exterior materials of newly established building for each hour from sunrise to sunset in representing day (21st) of each month from Jan. to Dec were set. These observation points were set within range including the expressway, main road and interchange for access and entrance. A location where the reflection area are within field of vision from the observation point based on the reflection area map was designated as a observation point. To compare the difference in use of exterior materials for the building and high-reflection glass (reflection rate 28%), rendering image of two materials were created through RADIANCE. 4.3 illustrates the reflection area map of Mar. 21st (vernal equinox), Jun. 21st (summer solstice) and Dec. 21st (winter solstice) from Jan. to Dec. Images of estimated glare occurrence points representing each month from 70 points and total 74 instances was inserted. No. of each observation point was set based on order of specular reflection occurrence from Jan.

Table 4. Altitude of Sun & Azimuth Angle on Mar. 21st

Day.	Solar Time	Altitude(α)	Azimuth Angle ϕ)
Mar. 21st	07:00	11.85°	80.74°
	08:00	23.37°	70.64°
	09:00	34.12°	58.67°
	10:00	43.40°	43.48°
	11:00	50.02°	23.76°
	12:00	52.50°	0.00°
	13:00	50.02°	-23.76°
	14:00	43.40°	-43.48°
	15:00	34.12°	-58.67°
	16:00	23.37°	-70.64°
	17:00	11.85°	-80.74°

4.2.1 Vernal Equinox (on Mar. 21st)

It is revealed that the reflection at 10:00~14:00 from the reflection area map of vernal equinox (Mar. 21st) does not have influence on road similar to other season except winter.

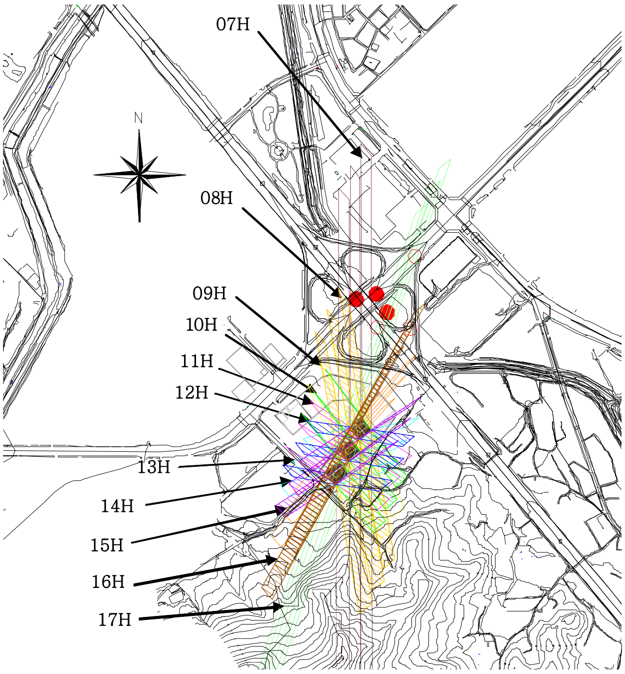
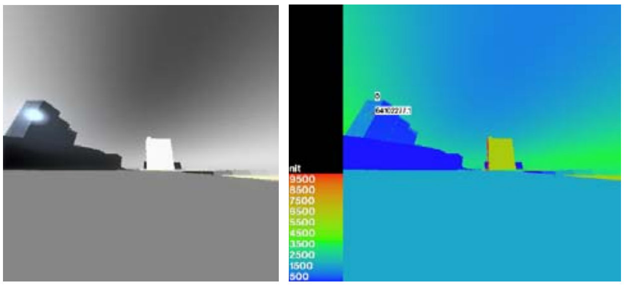
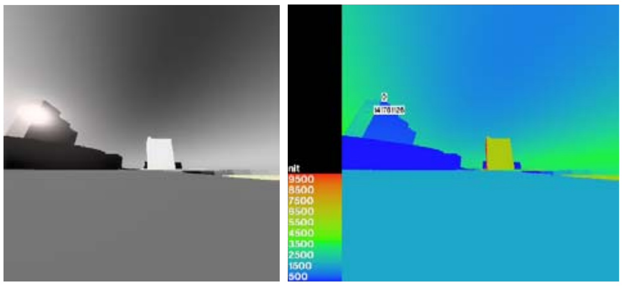


Figure 6 Reflection Area & Observation Point at each Hour on Mar. 21st



(a) Reflection Rate of 6%



(b) Reflection Rate of 28%

Figure 7 Visualization (L) and Luminance (R) Image at Observation Point 1 (Mar. 21st 07:00)

4.2.2 Summer Solstice (on Jun. 21st)

Glare occurrence point was estimated second most as length of sunrise to sunset is increasing, width of overall reflection area is narrowing down and length of overall reflection area is increasing for the reflection area map of summer solstice (Jun. 21st).

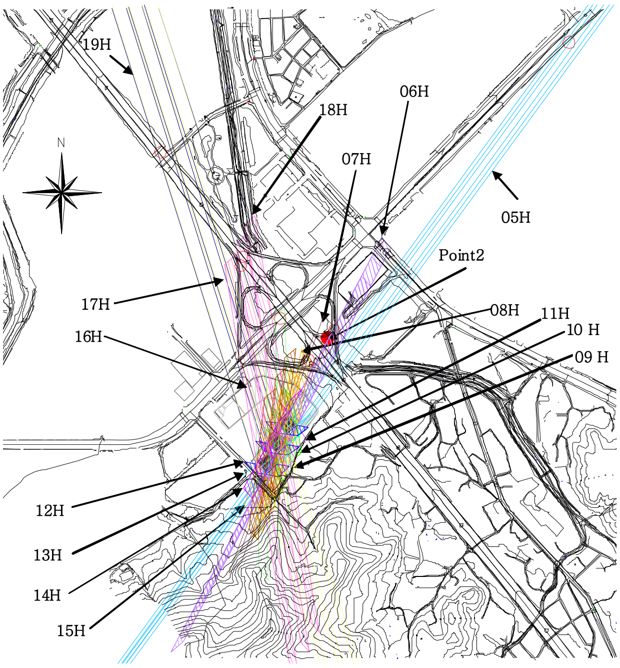
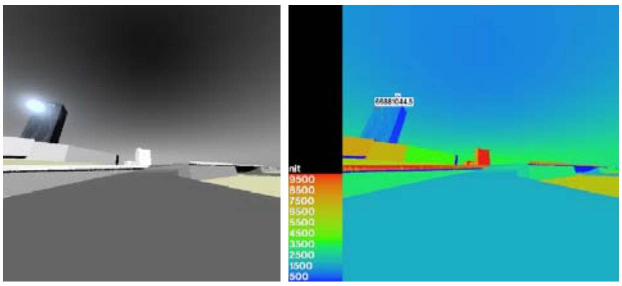
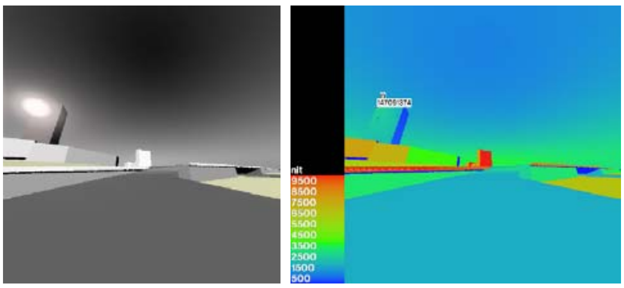


Figure 8 Reflection Area & Observation Point at each Hour on Jun. 21st



(a) Reflection Rate of 6%



(b) Reflection Rate of 28%

Figure 9 Visualization (L) and Luminance (R) Image at Observation Point 2 (Jun. 21st 07:00)

4.2.3 Winter Solstice (on Dec. 21st)

Direct sunlight reflection of winter solstice (Dec. 21st) was estimated to have influence on expressway and main road at 12:00~15:00. However, it is estimated not to have great influence on driving vehicle since reflected light is projected almost vertical with driving direction except the Observation Point 3 at 13:00.

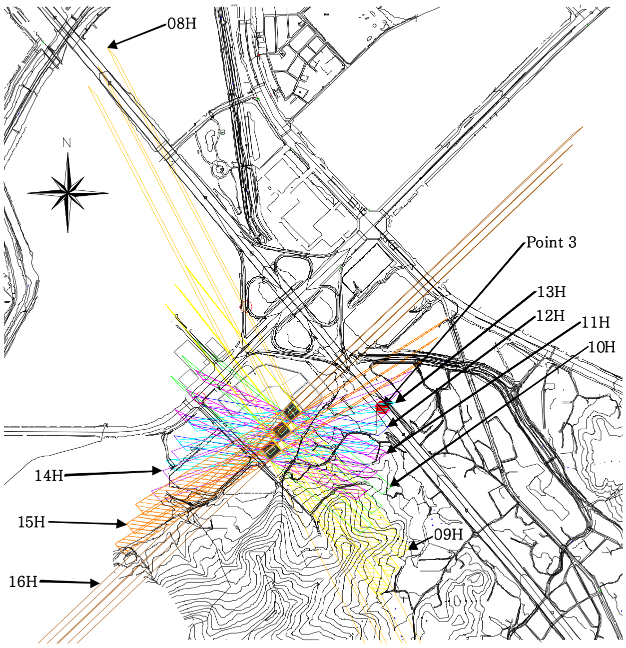
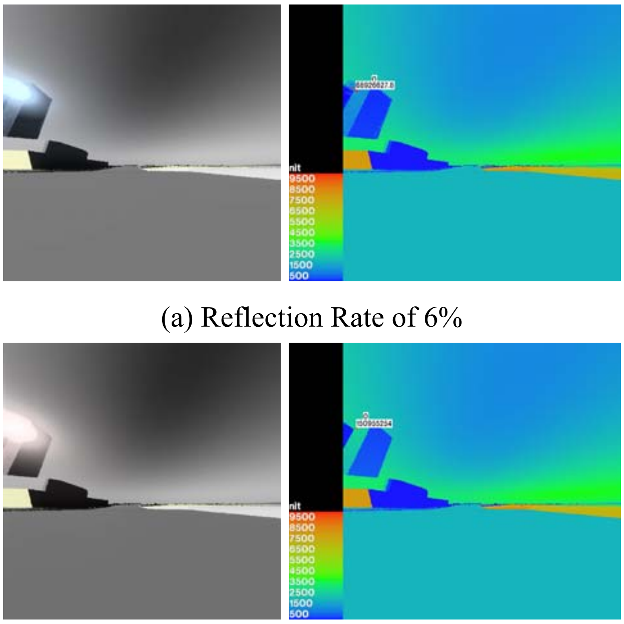


Figure 10 Reflection Area & Observation Point at each Hour on Dec. 21st



(a) Reflection Rate of 6%

(b) Reflection Rate of 28%

Figure 11 Visualization (L) and Luminance (R) Image at Observation Point 3 (Dec. 21st 13:00)

4.3 Result

As a result of analyzing the glare occurrence by reflection light of sun reflected on exterior materials of the newly established building for each time from sunrise to sunset on representing day (21st) of each month from Jan. to Dec., influence by direct sunlight reflection was estimated for total 70 points and 74 instances. Actual glare occurrence by direct sunlight reflection on exterior materials of newly established building presented to be total 26 points and 26 instances. Since cases where reflection light of sun is directly exposed to field of vision among remaining 44 points and 48 instances is the glare occurred with direct exposure to direct sunlight rather than reflection of direct sunlight on exterior materials of newly established building, it was excluded from the influence of direct sunlight reflection of exterior materials of the newly established building. Also, parts where reflection light is screened by the surrounding buildings and low floors of the newly established building are excluded. As a result of analyzing the month, hour, reflection area, driving direction, etc of glare occurrence with observation point of glare occurrence, it was revealed that glare by the direct sunlight reflection of exterior materials of newly established building mainly occur at 5~6PM in summer on expressway (southeast) and main road (southwest) by the northeastern area of the newly established building.

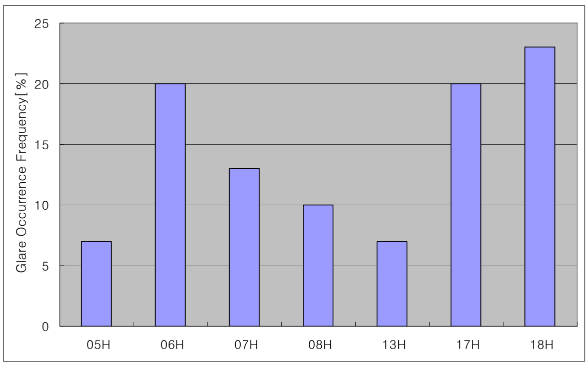


Figure 12 Comparison on Glare Occurrence Frequency for each Hour(%)

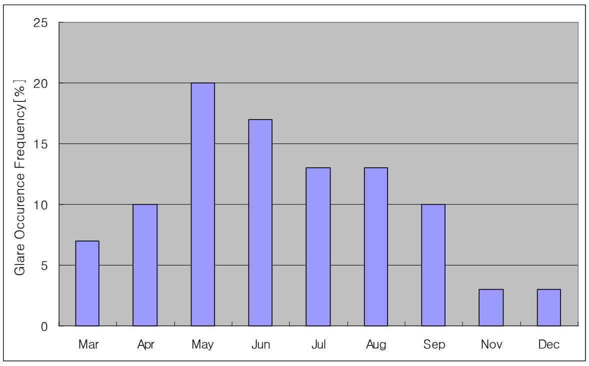


Figure 13 Comparison on Glare Occurrence Frequency for each Month(%)

5. Conclusion

BRDF pattern of sample scheduled to be used as exterior materials of newly established building were measured and analyzed to estimate the visual environment elements that may have influence on surrounding area and adjacent main road as the building is constructed. Total 70 observation points were set with reflection area map and simulation was carried out using RADIANCE to analyze the occurrence of glare by exterior materials of the building in surrounding areas. For the cases where glare is occurred by the direct sunlight reflection of exterior materials of the newly established building, degree of glare influence by low reflection exterior materials (reflection rate 6%) and high reflection exterior materials (reflection rate 28%) was compared and analyzed through simulation.

1) As a result of BRDF measurement of exterior material scheduled to be used in the building, reflection rate was presented high in direction of specular reflection regarding the incident light. Also, reflection rate increased with the increase in incident angle just like general traits of glass. Reflection toward the normal direction of material that presents the reflection rate of glass was 3.32%.

2) Comparing the simulation result of exterior materials scheduled to be used in the building and high reflection (reflection rate 28%) glass, no dramatic difference was presented on image. However, in case of max. luminance value observed at same location, there was huge difference up to 85,958,492cd/m2 on Nov. 21st 13:00 based on the exterior materials of the building.

3) Glare occurrence of estimated glare occurrence observation points projected using reflection area map was determined through simulation using RADIANCE. Simulation analysis/evaluation using RADIANCE based on the analysis on reflection area map is necessary since cases where sun is directly exposed to the field of vision at observation point, glare is blocked by the low floors due to distance between the buildings, etc occur.

4) With the result of RADIANCE simulation based on grasping the reflection traits of the material and reflection area map, it was possible to carry out analysis and estimation on influence of building's exterior materials on surrounding areas. It is expected that in-advance consideration on influence of glare to surrounding areas may be carried out in designing the buildings through above analysis/estimation process.

Acknowledgement

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A STUDY ON THE DEVELOPMENT OF BIM BASED AUTOMATED BUILDING EQUIPMENT DESIGN SYSTEM USING CAD BUILDING INFORMATION

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Keywords: 3D CAD, Automated Building Equipment Design System, Object Information, Building Information Modeling, Industry Foundation Classes

Summary

Recently domestic construction industry, the needs of construction standardization, construction engineering globalization, and construction informatization are desired for advancing performance system, improving productivity, shortening construction period and reducing cost. Therefore, the development of 3D CAD information's building services design automation system through 3D visualization and informatization of building services design processes is essential in the building services field.

This study is an initial stage for development of BIM based building facility design automation system. The objectives of this study are to understand existing facility design processes, check the feasibility of applying 3D onto major parts, and suggest the direction of system development while considering the analysis of 3D program and BIM.

1. Introduction

1.1 Research Background and Necessity

In recent domestic construction industry, the needs of construction standardization, construction engineering globalization, and construction informatization are desired for advancing performance system, improving productivity, shortening construction period and reducing cost. Therefore, introduction of 3D CAD in building services and computerizations are actively in progress. For building services design, more accurate engineering calculations and simulations are highly requested. Moreover, by computer databasing the collected data during the lifecycle including design, construction, maintenance, and remodeling, its desire to use consistently by steps has increased as well. Due to continuous development of computer technology, calculation capacity has improved greatly while the data processing time has reduced which made it easier for visualizing 3D of the building design plan. Also, development of the Internet allowed no restriction on space limitation which also made real-time cooperation possible. It's because of the realization of practical development due to the improvement of computer processing speed and expression ability with reliability of 3D CAD software and application of building project's lifecycle from the stage where CAD system was just used for existing drawing figures.

As object oriented CAD systems are being introduced, it became applicable to the stages after the building facility design's initial design development such as basic design, detail design, and shop drawing. Also, in order to detect of design problems at the early stage and to reduce the facility design's construction period through virtual simulation, the needs are increasing as an importance of various CAE based simulation. Therefore, the development of 3D CAD information's building services design automation system through 3D visualization and informatization of building services design processes is essential in the building services field.

In advanced countries, researches on the development of new conceptual computer aided design (CAD) tools have been very active based on the above architectural necessities and the development of computer technology. Similar concept applied new generation CAD tools are already being introduced.

This study is an initial stage for development of BIM based building facility design automation system. The objectives of this study are to understand existing facility design processes, check the feasibility of applying 3D onto major parts, and suggest the direction of system development while considering the analysis of 3D program and BIM.

1.2 Research Scope and Methodology

In order to develop BIM based building facility design automation system, reviews on concept of the BIM based building facility automation system and currently used programs are needed. Development of the BIM based building facility design automation system should provide productivity improvement, construction period shortening, and cost reduction through simple building facility design processes of existing mechanical (heat source, air ventilation, sanitary, and fire fighting, etc) and electrical (illumination, electric heat, power, and telecommunication, etc) systems. Therefore, the purposes of this study are to find out the requirements on the development of 3D building facility design automation system and to suggest the direction of research development through analysis of existing building facility design processes and application programs.

Below are the steps for this study.

(1) Study of BIM based building facility design automation system's necessities through theoretical research

(2) Review of BIM based building facility design automation system's concepts through theoretical research

(3) Analysis and study of current BIM based 3D building facility design programs

(4) Review of BIM based building facility design automation system's applicability through analysis of 3D building facility design programs

(5) Derive problems and improved plans during above steps and to suggest direction of the future research developments

2. Theoretical Study

2.1 Necessities of BIM Based Building Facility Design Automation System

The basic concept of BIM based 3D CAD building facility design automation system is to draw 3D drawings by using 3D program based on line and face, 2D drawings, by using 2D programs. These 3D drawings contain object information of machines, materials and, equipments used for building facility. Also through the virtual construction simulation, it allows to check errors and interferences during the facility construction for revision through preview which supports to estimate the facility design processes. The saved object information makes it possible to estimate the cost automatically by calculating the amount of materials through information sharing of each process.

BIM based building facility design automation system reduces the design changes from planning to construction stages and increase its work efficiency by checking the work progress of each process steps. Moreover, increase in work efficiency reduces construction period, increases productivity, and reduce cost as well as increase the quality. However, there are some problems for constructing BIM based building facility design automation system at the moment. In order to solve these problems, review of BIM based building facility design process model's applicability through analysis of 2D building facility design processes. Also, construction of 3D based building facility library, construction of DB by equipment capacity based on equipment capacity estimation and role analysis for building's load calculation automation, review of applicability on automation system for estimated construction cost calculation and improvement of real-time cooperation environment between different parts through network are desired.

By solving these problems through the development of building facility automation system, it can improve the construction project's lifecycle efficiency including facility processes. Therefore, it's highly required for development and competitiveness of domestic building and construction industry.

2.2 BIM and 3D Based Building Facility Design Automation System

Existing 2D programs expressed objects simply as graphical components. These drawings required a lot of time for generating drawings due to change of building designs. Also, there were lots of problems to solve errors due to change in object information. In order to overcome these problems, BIM(Building Information Modeling) solution uses parametric method which reflects all the amendments occurred during work processes which also prevents from omissions and errors from amendments in advance.

By using BIM, the building objects (wall, sleeve, window, door, roof, stairs, etc) contain each property (function, structure, use, material characteristics, etc), recognize its relationship, and reflect building's changes. Based on these, IBM emphasizes that it can construct high quality and low cost buildings with prompt processes including design, construction and maintenance and there are cases regarding to it.

Not just graphical components but also providing information management environment is the major advantages of BIM that includes building facility.

BIM automatically generates and provides various information such as material quantity, cost, schedule, and material list as well as the analyzed data of structure and environment. Through these, it enablers accurate and prompt decision making. Moreover, management environment through BIM provides effective sharing of all the information of building's lifecycle while supporting to solve problems such as data loss, data re-entry, and data redundancy which makes it efficient to manage all the information.

Figure 1 shows some functions of Bentley's BIM solution. During designing stage, all the data of architectural, mechanical, structural, electrical parts can be shared through Internet on the ProjectWise server. Also, during this stage, it can visualize 3D design plan through Navigator as well as check the interference of the parts. For generating duct drawing of mechanical parts, Trane's or Bentley's duct calculating program can be used and enable shop fabrication of duct using CAM(Computer Aided Manufacturing). After the design plan is completed, 3D visualization simulation of construction processes based on the schedule can be executed. BIM data firstly constructed in design stage and added or amended in construction stage can be used at the maintenance stage through facilities server.

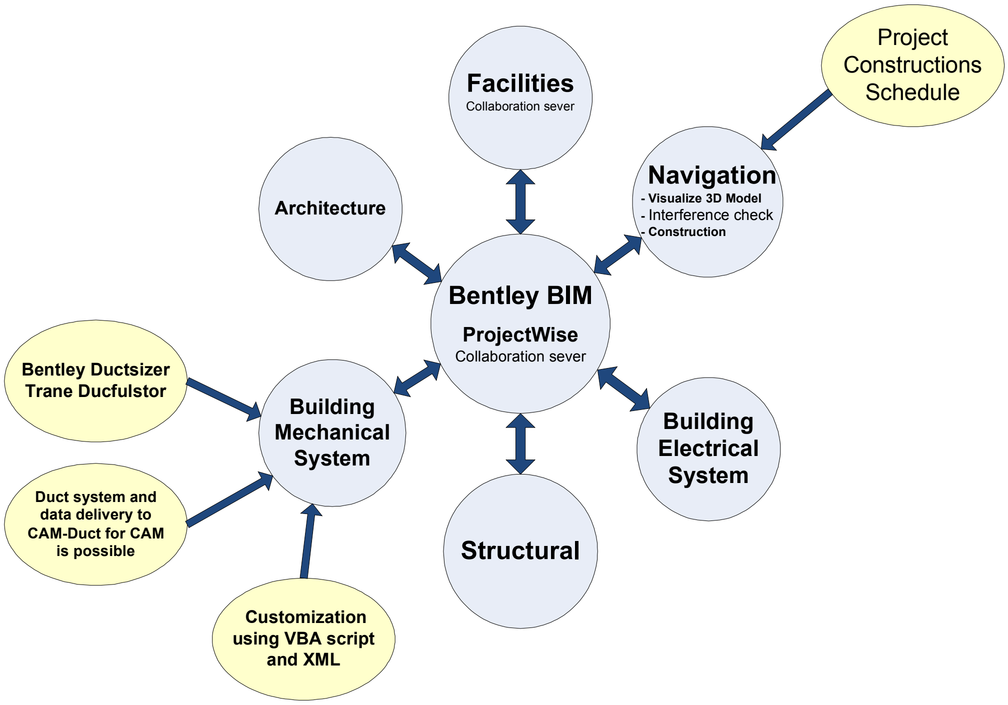


Figure 1 Example of Bentley BIM's Functions

Figure 2 explains the BIM's various application fields and shows that the entered data in BIM can be used consistently and constantly through the building's entire lifecycle from building project's planning stages to regulation review, planning, simulation, specification and statement generation, material purchase, construction management, facility management after construction completion, and building demolition.

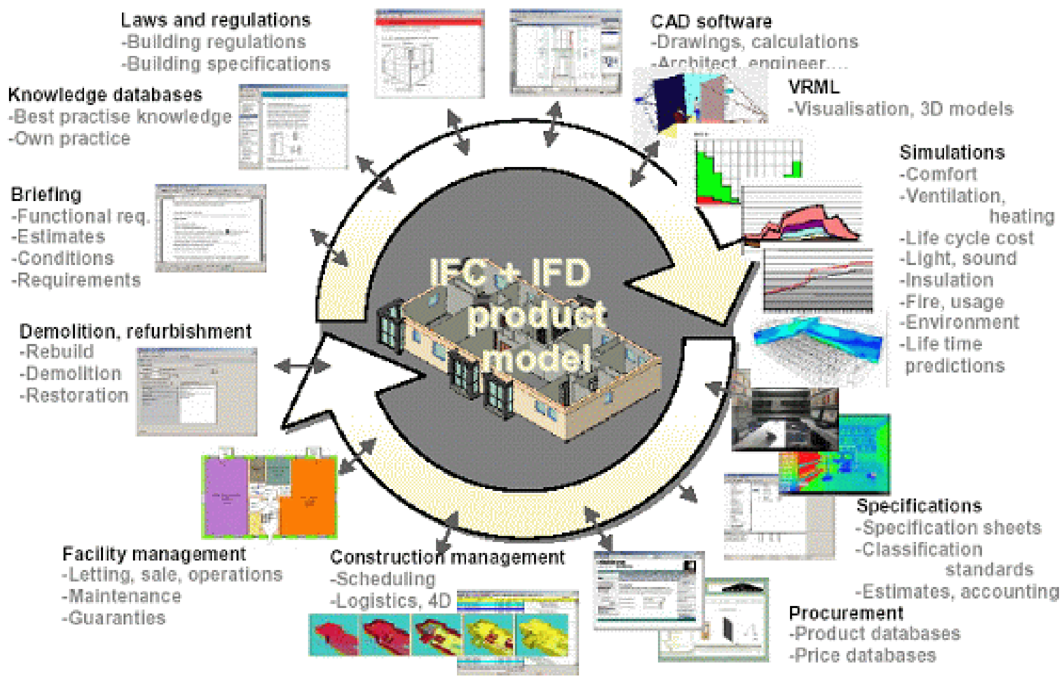


Figure 2 BIM's Application Fields

2.3 Analysis and Study of Currently Used BIM Based 3D Building Facility Design System

This is a CAD tool with BIM concept. Programs that are introduced and on sale in domestic market are ArchiCAD, Revit, and Microstation and for building facilities, there are DDS-CAD, RevitMEP, and Bentley Building Mechanical/Electrical System.

Table 1 shows the summary of program major features and functions indicated in PR brochure. While considering that the required functions in the building facilities field are more standardized than other design fields, it seems that there are similar functions in three different programs even though they are not indicated here. Moreover, as the BIM's standard is not positioned yet and all of the three programs contain too many functions to be used for building facilities in domestic market, it's difficult to discuss and make discrimination between the programs.

Figure 3 and 4 shows the building facility work processes in 3D using GFAPHSOFT's 'ArchiCAD'.

Figure 3 is the drawing of redevelopment complex new building site in Mapo area. Left drawing is the 2D(AutoCAD) drawing of 77py, B type electric/telecommunication PVC which is difficult to check the interference to distribution panel board between electrical pipe. The right drawing, on the other hand, through the virtual construction of 3D modeling, it is easy to check the interferences of piping and easy to select the location of PVC Box location based on the piping interferences.

Figure 4 is the case which mechanical/electrical parts are virtually constructed in 3D and checked and amended the electrical tray interferences in advance. Samsung Corporation's Seocho project, Space in Sajik-dong, and Korea Chamber of Commerce & Industry are the cases using ABS(Autodesk Building System) and mostly applied in design review, interference check, virtual construction simulation of mechanical room, basement floor, and AHU. Likewise, through virtual construction of building facility related duct piping, spring cooler, telecommunication tools arrangement, mechanical/electrical room equipment arrangement, it can not only increase the construction efficiency but also check design error and interference between processes in advance which prevents from reconstruction and minimizes the delay time as well as save cost and shorten the construction period. However, while using the 3D programs on the site, some problems were found.

First of all, there was a lack of 3D based building facility related tools and material's library. Also, there was a compatibility problem on parametric information between 3D programs. In order to solve this kind of problems, design guideline and standard on model construction through study of 3D based library modeling and tools and models on materials are suggested and for most of libraries in future, it can be manufactured in-house and distributed by tool and material producing companies. Moreover, there's a need for research on detail parametric information of IFC(Industry Foundation Classes) based facility materials and tools.

Table 1 Integrated 3D CAD Program Review Table Considering BIM

Classification	Program	Features
Revit	Revit MEP	- Auto 3D model generation - Parametric modeling selection - Engineering calculation of mechanic and electric facilities - Revit building and Revit structure
ArchiCAD	DDS-CAD	- Auto 3D model generation - Mostly used in Europe - Engineering calculation of mechanic and electric facilities - Database construction on Europen maker's machine and equipment
Microstation	Bentley Building Mechanical /Electrical Systems	- Auto 3D model generation - Existence of other part programs (Architecture, Structural, Facilities) and compatible with each other and includes design, construction, maintenance, etc - Customization using VBA script and XML - Construction simulation using project management tool such as Microsoft Project - For mechanical part, sizing and analysis on pipe and duct system and data delivery to CAM-Duct for CAM is possible

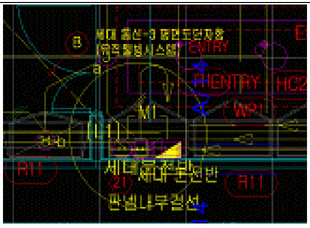
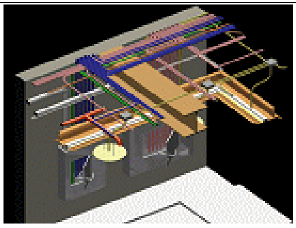
Electric/Telecommunication Rooms 2D Drawing	Electric/Telecommunication Rooms 3D Drawing
	

Figure 3. Electric/Telecommunication PVC 3D Virtual Construction and Review

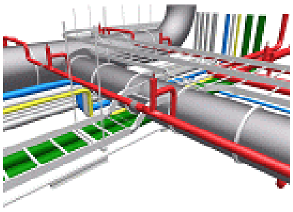
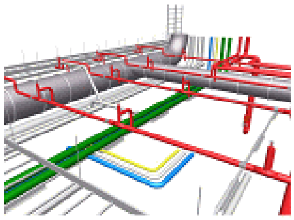
Mechanical Room Interference Check (Before)	Mechanical Room Interference Check (After)
	
Electric Tray Interference	Solve by Electric Tray Root Change

Figure 4. Interference Check of Mechanical/Electrical Room's Major Parts

Building facility design related 3D based program's application field and functions are as below.

(1) 3D Modeling
- Building facility visualization: Pipe and duct, machine and equipment
- Advance checking of drawing error and interference of processes

(2) BOM Computation

(3) Engineering Calculation using Object Property Information and Location Information
- Pipe sizing & analysis
- Duct sizing & analysis
- Air-conditioning load calculation

(4) CAM
- Duct manufacturing

(5) Construction Simulation
- Connection with construction schedule

(6) Just In Time Delivery
- Machine and equipment

(7) Facility Management

3. Applicability Review of BIM Based Building Facility Design Automation System

At the moment, design office has the most interest in CAD and by setting up the BIM based 3D CAD program review items based on design works, it can be classified into 3D visualization using BIM data, engineering analysis/simulation, statement automatic generation and code check functions.

Evaluation of BIM based building facility design program functions is as Table 2. In table 2, the mid generation, AutoCAD MEP was also included and compared. It was to relatively reduce its unfamiliarity of existing AutoCAD users changing to other CAD tools. For program's applicability review, there were three classifications including classification on 2D and 3D modeling, analysis through engineering calculation, and construction cost estimation. Also, realization of requirements on required data was review using 'AutoCAD MEP', 'ArchiCAD', and 'Revit MEP' program.

(1) 3D Visualization

3D visualization using computer existed even in the past but it was just for visualization instead of building objects (e.g. wall, window, boiler, AHU). On the other hand, the difference of visualization using BIM based 3D CAD program is that building object itself can be visualized instantly. For building facility field's case, piping, duct, machines and tools can be visualized which allow to check the interference and it's easier to make the manager understand the design plan by showing the complicated drawings in to 3D.

(2) Engineering Analysis and Simulation

By using object property information and geometrical information entered in BIM data, energy analysis, equipment capacity calculation, indoor air simulation, air environment simulation, fire safety evaluation simulation through equipment's (air conditioning load calculation, piping system analysis, duct system analysis, freezer inside the building, cooling tower, boiler, AHU) organic relationship analysis is possible. Some parts of these analysis functions would be directly made by the CAD tool developing companies but it's assumed that most of the parts are created by related professional companies. It's because BIM data can be easily extracted with professional company's program by IFC.

(3) Details Automatic Generation

Details automatic generation function existed in past but due to BIM's existence, it can be generated easier and more accurate.

(4) Regulation Review

It's not applied in domestic system yet and it's very difficult to use as developed in foreign countries. However, if this function can be used properly in the domestic system, it's assumed that the building related various permission works can be simplified and transparent.

Table 2 Program Review for 3D Based Building Facility Design Automation

Requirement		Required Data	Support of Existing Program			Improvement Required Part for Domestic Application
Classification	Sub-classification		AutoCAD MEP	DDS-CAD (ArchiCAD)	Revit MEP	
2D Drawing and 3D Modeling	Tool/Equipment 2D drawing/view	Tool, equipment 2D library	○	○	○	○
	Tool/Equipment 3D modeling	Tool, equipment 3D library	△	△	△	◎
	Pipe 2D drawing/view	Pipe, valve 2D library	○	○	○	
	Pipe 3D modeling	Pipe, valve 3D library	△	○	○	△
	Duct 2D drawing/view	Duct, damper 2D library	○	○	○	
	Duct 3D modeling	Duct, damper 3D library	△	○	○	△
	Tool, pipe, duct interference check	Tool, equipment 3D library	○	○	◎	
	Pipe, wire 2D drawing/view	Pipe, wire 2D library	○	○	○	
	Pipe, wire 3D modeling	Pipe, wire 3D library	△	○	○	△
	Equipment, tool, pipe interference check	Equipment, tool, pipe, 3D library	○	○	◎	
Engineering Calculation, Analysis	Air conditioning load calculation	Space geometrical information, structure component, material heat conductivity	×	○	○	
	Equipment capacity calculation	Equipment role and relationship, equipment capacity DB	×	×	×	△
	Pipe measurement calculation and system analysis	Flux, piping system component	△	○	○	
	Duct measurement calculation and system analysis	Flux, piping system component	△	○	○	

	Building energy analysis	Facility system component, building management plan	×	△	△	
	Indoor heat environment analysis	Outdoor heat environment, structure component, material heat conductivity, air ventilation system management plan	×	△	△	
	Indoor air environment analysis	Air condition, ventilation amount, indoor pollutant emission amount	×	×	×	△
	Indoor voice environment analysis	Outdoor voice environment, structure component, material acoustic absorptivity and noise reduction coefficient	×	×	×	
	Fire safety analysis	Space geometrical information, material heat, smoke amount, occupant features	×	△	△	△
	Illumination intensity calculation	Space geometrical information, internal finishing material's reflexibility, illuminator DB	×	○	○	△
	Power system calculation and analysis	Electric line and water edge equipment DB	×	△	△	△
	Telecommunication system calculation and analysis	Telecommunication line and telecommunication equipment DB	×	△	△	△
	Indoor light environment analysis	Space geometrical information, natural lighting, illuminator DB	×	△	△	
Cost Calculation	Details automation	BOM, materials unit price	○	○	○	△
Code Check	Regulation satisfaction review	Regulation related information	×	×	×	△

* ◎ : Fully Supported ○: Supported, △: Partially Supported, ×: Not Supported

4. Suggestion on Development Direction of BIM Based Building Facility Design Process Automation System

For system development, understanding of current 3D based facility design system, development trend analysis, existing facility design process analysis, and analysis of required functions for system development are required. Moreover, in order to construct BIM based 3D object library on 3D based facility machines and materials that fits into domestic situation, guide on construction plan with suggestion on standard model should be along with the IFC model standard.

Through library construction on building facility design process automation system's modeling and pilot test, application of system based on the development and its evaluation should be accomplished. Also, system R&D that allows prediction and analysis on building facility environment should be accomplished.

In order to suggest system development direction, the research directions on the 3D building facility design automation system modeling through analysis of existing building facility design process are established as below.

Firstly, select the 3D program that allows programming and user setup function that can add required function between facility design processes for using BIM which enables information sharing of construction project's entire lifecycle. Moreover, construction method for functions on building facility related tools and materials' detail parametric information data saving and information data on 3D based object properties (density, heat conductivity, emissivity, etc) of wall, roof, glass are suggested. Furthermore, by using these object property detail information, automation on equipment capacity selection through building's air conditioning load calculation, programming development after review the relationship with equipment roles and equipment capacity DB construction plan that fits into domestic situation are also suggested.

Secondly, consideration on the applicability of automation system for construction cost estimation and compatibility with estimation related automation system should be developed. Applicability of the automatic cost estimation generating program on details should be reviewed through various data analysis and derive of estimated construction cost's major influencing factors. Currently, construction cost standard is being preparing by analyzing the construction cost detail data based on direct construction cost standard data. Also, linkage to quantity calculation and estimation related automation system is in review.

Thirdly, in order to use BIM based program in mechanical and electrical field, real-time work through information sharing of each processes is required and therefore, the need for real-time cooperation using the network is required. For smooth information sharing of processes with other fields, compatibility of data became the problem. This can be done through construction of IFC based 3D object library. Currently, development on compatibility between IFC related various programs are actively in progress domestically and internationally. It's assumed that the development of IFC module which is compatible with 3D object's property information can solve this problem.

5. Conclusion

This study is a basic research for the development of BIM based building facility design automation system and was accomplished for the purpose of suggesting the development direction. Therefore in this study, concept and necessity of development through theoretical study for BIM based building facility design automation system development was studied. Based on the analysis and study on the BIM based building facility design program, BIM based building facility design automation system's development directions based on derived problems of applicability review were suggested. Summary on the developments are as below.

(1) Analysis of building facility design related BIM based program application field and required functions

(2) Review and selection of integrated 3D CAD program considering BIM

(3) Select additional functions of applicable filed considering selected 3D program

(4) Development review of engineering analysis/simulation using BIM data

(5) Development and review of details automatic generation and regulation review function

(6) Analysis and construction of library that fits into domestic system

At the same time, development of building facility design module system through analysis of building energy consumption using building facility environment's (heat environment, voice environment, air environment, light environment) computer simulation should be reviewed. Moreover, in order to survive in domestic and international construction industry in future, development of the essential technology should be also progressed.

Acknowledgement

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STUDY ON CURRENT ISSUE OF OPERATION AND MANAGEMENT OF CONDOMINIUMS IN TAIWAN—CONDUCTED IN COMPARATIVE STUDY BETWEEN TAIWAN AND JAPAN

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Keywords: condominiums, operation and management, Taiwan

Summary

For existing houses in Taiwan, condominiums are a very important building type and the number is increasing. To ensure the living environment quality and value of existing building stock, sound operation and management is the basic requirement to be met. Therefore, this study adopts comparative study to compare the operation and management of condominiums in Taiwan and Japan in order to clarify the issues of operation and management of condominiums in Taiwan as reference of ensuing solutions of improvement. The issues discussed in this study include: keeping management organization, community empowerment, general administrative affairs, financial management, and built environment management. The basic data of condominiums in the part of Taiwan is acquired from an empirical survey conducted by this study, and the part of Japan is acquired from references. The findings show that, overall, the condominium operation and management in Taiwan is poorer than that in Japan. Particularly in capital improvement program, collecting funds and recordkeeping of operation and management documents, one can see a significant lag. Moreover, the researcher also finds that residents in the condominiums in two countries have encountered similar problems in condominium living.

1. Introduction

In accordance with Taiwan Agenda 21: Vision and Strategies for National Sustainable Development (Council for Economic Planning and Development, 2004), sustainable development is a major policy that Taiwanese government is progressively promoting. From Housing Condition Survey 2006 (Construction and Planning Agency [CPA]), 2006, number of the total houses in Taiwan is 6.38 million in which condominiums account for 32.1%, the only type of houses is continuing growth. Condominiums are, as a result, a major type of houses in Taiwan. In light of condominiums operation and management, this study believes that, to have sustainable development of living environment quality and value of existing building stock, the main strategies are "to conducting appropriate daily operation and management provides deserved service quality of condominiums. At major refurbishment and replacement, sustainable building concept is introduced to make decisions in order to enhance the sustainability and use value of condominiums". Based on the preceding concepts, this study considers appropriate operation and management of condominiums is the basis of sustainable development of condominiums and also greatly affects the sustainability of overall living environment in Taiwan.

On the basis of preceding viewpoints, this study conducts an empirical survey of current status of condominium operation and management in Taipei and Kaohsiung, two major urban areas of Taiwan. The findings are then compared with those in Japan to clarify the issues of operation and management of condominiums in Taiwan. The findings of this study will serve as reference for the government competent authority in making the decisions of proposed improvement and as the fundamental data of sustainable refurbishment and replacement of condominiums in Taiwan.

In regards of work fields of operation and management of condominiums, based on the articles of Condominium Act (2006), this study divides them into two major fields—keeping management organization and community empowerment related to operation of condominiums with general administrative affairs, financial management, and built environment management (including building maintenance, security management and cleanliness management) related to management of condominiums. These five are the major works of survey and statements in this study.

2. Investigating the current status of condominium operation and management in Taiwan

This study conducted a questionnaire survey to investigate the current status of condominium operation and management in Taiwan. From the statistics of Construction and Planning Agency in June 2004, the total number of registered condominiums in Taiwan is 12,819 with 7,972, or 62%, in Taipei and Kaohsiung urban areas. The samples of this study were taken from condominiums with registered management organization in these two areas. Due to without distinctive different in the modes of operation and management of condominiums in Taiwan and limited study resources, effective size of samples in this study is no less than 30 condominiums in each area for random survey. Each condominium chosen for the survey received one questionnaire for the management committees and three questionnaires for the occupants.

Questionnaires for management organizations include current status of condominium operation and management, satisfaction level with the operation and management of condominiums and satisfaction level with and expectations of the assistance from the government. Those for occupants include satisfaction level with the operation and management of condominiums, troubles encountered in condominium living, satisfaction level with and expectations of the government's assistance, and long-term desire to live in the condominiums.

The questionnaire survey was administered between January and May 2006. A total of 92 effective samples for management organizations (51 from Taipei and 41 from Kaohsiung) and 176 effective samples for occupants (98 from Taipei and 78 from Kaohsiung) were collected.

Regarding the characteristics of condominiums, the condominiums were constructed between 2 to 30 years ago, the average being 12 years. Most of the condominiums were between 9 and 14 years old. Further, most of the condominiums are above 15 stories (48%), followed by 6–14 stories (40%).

Regarding operation and management modes, 16% are owner management mode; 70% are partial company management mode and 14% are complete company management mode. In partial company management mode, the most contracted works is building maintenance account at 80%, followed by security services at 55%, cleaning services at 50%, general administrative affairs at 16% and financial affairs at 15%. Moreover, 71% of the management committees have tenure of one year per term. In addition, 63% of the management committees have a limited number of renewable terms; of these, 77% are renewable for one term.

Regarding the characteristics of the 176 effective occupant samples, the effective occupant samples are primarily nuclear families (86%) and comprise 3.62 members on average. The average dwelling area of a unit is 41.0 m^2/ person.

3. Comparisons of current status of condominium operation and management in Taiwan and Japan

Taiwan is close to Japan geographically, and frequent exchanges of information take place between these two countries. Development of legal frameworks of condominiums operation and management in Japan is much earlier than that in Taiwan.

However, the legal frameworks of condominiums in Taiwan and Japan are both in continental European legal systems and are very similar. Comparisons of current status of condominium operation and management in the two countries will help identifying issues of condominium operation and management in Taiwan. From the analysis construct in this study, differences between the two countries can concluded in Table 1. The sources for facts in Taiwan are the findings of this study and that in Japan are references from the government of Japan.

A. Operation of condominiums

Close to 90% of condominiums in Japan are in complete company management mode, proving high professional development of operation and management of condominiums in Japan. Holding meetings of the owners in two countries are quite the same, although management committee meetings are more frequently held in Taiwan. The reason is that less than 14% of condominiums in Taiwan are in complete company management mode, forcing management committees spend more time to the condominium operations. Also, promotion of condominium bylaws in Japan is better than that in Taiwan. Most of condominiums in Japan have already established their own condominium bylaws.

In community empowerment, Japan has less community activities. However, occupants have stronger long-term intension to live in the condominiums. Condominiums in Japan also coordinated activities related to the prevention of disasters more frequently than did those in Taiwan.

B. Management of condominiums

Overall, condominiums in Japan perform better in general administrative affairs, financial management and built environment management than those in Taiwan do. The most distinctive different between the two countries is capital improvement programs in Japan far exceeds those in Taiwan in the program establishment and financial preparation, which can be proven from over 80% of condominiums in Japan had established capital improvement programs and ratio of sufficient collecting funds close to 70%. Moreover, keeping of drawings and specifications of buildings in Japan is much better than that in Taiwan.

C. Others

Japan had a higher number of occupants satisfied with the overall operation and management of condominiums than do Taiwan. This corresponds to the results of comparisons of current status of condominium operation and management between the two countries. Moreover, the three major things bother the occupants in the two countries include residents owning pets, parking against regulations and neighborhood noises. However, the rankings in two countries are different. The serious one in Taiwan is residents owning pets and that in Japan is parking against regulations.

Based on the survey of this study, only around 15% of the occupants are satisfied with the assistance from the government in operation and management of condominiums. They think the government should adopt measures to improve its assistance toward the condominiums to promote the development of condominium operation and management. The highest priority is offering related information on the current status of operation and management of other condominiums and then subsidizing. What the government has been paying most attention to, improvements in legislation, ranks the bottom.

Even though Japan has better current status of condominium operation and management, to ensure living quality and value of existing building stock, Japan still has made reforms in recent years. In the improvement of legislation, Japan has reviewed and amended relevant legislation on the issues of operation and management of condominiums under social development such as keeping building maintenance records, community empowerment, and occupants failing to pay common expenses as well as troubles encountered in condominium living. In addition, on information policy tools improvement, the government of Japan also offers required information, consultation service and education training through government institutes and NGOs. In economic policy instruments, the government of Japan offers fund subsidizing through banking institutions and programs to major refurbishment and replacement of condominiums. Based on the preceding, Taiwan performs more poorly in preparation of information and economic policy instruments than does Japan, which can be proved from the fact the occupants of condominiums request the government to enhance works of promoting the development of operation and management of condominiums.

Table 1 Comparisons of Current Status of Condominium Operation and Management between Taiwan and Japan

Issues of condominium operation and management		**Taiwan**	**Japan**
Operation of condominiums			
Keeping management organizations	Complete company management mode	14%	89%[*1]
	Holding meetings of the owners in one year	98%	99%[*1]
	Holding more than one management committee meetings in one month	86%	41%[*1]
	Establishment of Condominium Bylaws	86%	≒100[*2]
Community empowerment	Held community activities in one year	84%	55%[*1]
	Fire drills held in one year	36%	38%[*1]
	Intention of moving by occupants	48%	27%[*2]
Management of condominiums			
General administrative affairs	No keeping of drawings and specifications of building	22%	3%[*2]
Financial management	Condominiums have more than 5% of the total occupants paying common expenses behind the due date	8%	6%[*2]
	Collecting funds meeting future demand	Almost none	78%[*2]
Built environment management	Establishment of capital improvement programs	Almost none	83%[*2]
Others			
Satisfaction of operation and management	Satisfaction of occupants of current operation and management	48%	61%[*2]
Troubles encountered in condominium living	Residents owning pets	43%	49%[*2]
	Parking against regulations	31%	56%[*2]
	Neighborhood noises	27%	52%[*2]
Source: [*1] from MLIT (2005); [*2] from MLIT (2003).			

4. Conclusions

In the issues of condominium operation and management in Taiwan, composition of management organizations basically conforms to the legislation of Taiwan. However, the promotion of condominium bylaws is not thorough. In community empowerment, occupants do not have long-term intention to live in the condominiums and they have weaker community awareness. As for general administrative affairs, poor recordkeeping of condominium operation and management documents will fail to support condominiums to do maintenance, refurbishment and replacement. In built environment management, maintenance of buildings is not duly made and almost all condominiums lack of capital improvement programs. In financial management, balance of common expenses is basically acceptable. In light of long-term operation and management of condominiums, insufficiency of collecting funds will not sustain the future refurbishment and replacement in the future. On the other hand, only less than 15% of occupants are satisfied with the assistance from the government in condominium operation and management. They desperately hope to obtain the information of operation and management of other condominiums for their reference and subsidy of funds.

Based on the results of this study, we propose following improvements for operation and management of condominiums. First, for management organizations of condominiums, they must duly establish and execute the operation programs and enhance promotion of community activities in order to strengthen the community awareness. Secondly, they must have proper daily maintenance of condominiums to ensure the sound service quality and public security. Thirdly, they are required to establish long-term improvement program and have sufficient collecting funds to meet the needs of refurbishment and replacement of condominiums, and then enhance use value and sustainability of condominiums. Finally, the government, in addition to enhancing preparation of information and economic policy instruments of condominium operation and management, must aggressively help condominiums without management organizations to expedite establishing management organizations, and subsequently, promotion of the overall development of condominiums to achieve sustainable development of the living environment.

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SB340
THE RATIONAL FOR TENANT CENTRIC BUILDING MANAGEMENT TOOLS

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Keywords: behavior, commissioning, guide, building, green,

Summary

Cultural change is a key component of the development of a sustainable society. The social environment, physical surroundings and innate behavior affect people's behavior. The combination of these aspects plays an important role in the evolution of the human species to a sustainable behavior. Social marketing, behavior of influential members of society, the cultural upbringing and advertising form much our social environment. The design of buildings, urban communities and cities affects the individual in their ability to act sustainably. The genetic character of our brain affects our wants and needs based on the evolution of the brain that made us into a successful species.

This paper explores the influence of these three components on our behavior and the rational for a Tenant Centric Building Management Tools. Surveys have shown that employees are not inclined to participate in sustainable activities if their bosses don't visibly participate. Studies of children have shown that they are influenced more by their peers than parents. Advertising is researching the neurological character of the brain and tests ads out using MRI scans to determine whether an ad is effective or not. We already know that the participation of tenants in the design of green building changes the design as well as behavior. The brain has a high level of plasticity. In addition, much of our most complex problem solving happens in our subconscious. Both the physical and social environment can have a dramatic effect on our subconscious thought processes.

1. Introduction

The foundation of human behavior is the subject of great debate. The role of nature vs nurture vs god in forming the way we act will always be controversial. None the less, it is our species behavior that has created a great civilization and is also the key to eliminating our species over exploitation of Earth. In "Occupant Participation in Green Building, 2005" I provided a brief outline as to why and how tenants could be integrated into the design and management of a building. At SB07 Toronto, Anthony Hillard, Chris Caners and I participated in a plenary session discussing "Developing a Sustainability Culture". In "Rewire: Changing Habits, Changing Minds" (Caners) looks at the University of Toronto's "Rewire" program aimed at changing the behavior of U of T students through Social Marketing. In "Can Human Factor Methods Help Design Sustainable Buildings? (Hillard) looks at how the physical design of space affects human behavior. The presentation "Neuroscience and Sustainability" (Jalkotzy) investigates the role of the evolution of our brain on our behavior. "The Blank Slate" (Pinker) also suggests that our behavior is a function of the social environment of our upbringing, the social and physical environment we are currently immersed in and the physiology of our brain.

Commercial buildings are designed so that people can accomplish a task efficiently and effectively. Most manuals that provide advice for Building Managers are centered on the optimal management of the building from the owners and/or managers perspective. However, it is the tenants at we want to satisfy, so it would be logical to manage the building from the tenants' perspective. This report outlines the basic requirements for a tenant centric building operational manual. It includes the broad management principles and techniques that that will enable a building manager to operate a "green" building in a "green" way. This includes recommendations on how to develop green stewardship in the building; conduct assessments of the building's sustainability and design renovations. All of the recommendations are based on the authors understanding of human behavior and incorporates all three human behavior drivers; the physical environment, the social environment and the physiology of the brain.

This outline of a "tenant centric building management manual" is divided into four parts. Part one provides a description of the people in the building and their general roles. Part two outlines the physical environment of the building. Part three describes the general social environment. Part four provides recommendations on how to manage the building from a tenant centric perspective. The operation of the facility is reviewed during the two basic stages of a building; conception and operation. It takes the perspective of the tenant.

2. People in the Building

2.1 Groupings

A commercial building is built to house people to produce a good and/or service. A building goes through three basic stages in its life. Stage one is the design and construction of the building (conception stage). Stage two is the productive life of the building (operating stage). Stage three is the eventual its eventual death (demolition stage). The demolition stage of the building will not be discussed. There are three groups of people involved and /or resident in a commercial building. In each stage, the three basic groups of people remain the same, their composition changes somewhat. These three groups can broadly be characterized as the following: a) the people for whom the building is designed built and is being operated; b) the people that assist the first group in organizing themselves as a functional unit and c) the people that design, maintain and operate the building. The tenants are usually thought of as group a) and b). The building owners, operators and designers are group c). The tenants are divided into a) and b) because their role in the building is quite different.

Group a) directly produce the good and service that the building was designed to produce. In the case of a car factory they are the individuals that make the cars or in the case of a bank building they people who manage and administer bank accounts.

Group b), even though they are also tenants, are the people that ensure that group a) can operate efficiently and effectively from a governance perspective. They are the managers, human resources personnel, planners, strategic thinkers and policy makers that ensure that group a) can achieve the organization's production goals, whether these are reports or cars.

Group c) are the people who create the building, ensure that the building protects the occupants from the weather, possible feed at nourish the occupants and plan the continual operation and maintenance of the building.

For simplicity group a) is referred to as the "tenants", group b) is referred to as "managers" and group c) as "operators".

2.2 Current Roles

During the two stages in the life of the building there are different roles for each group. Only the "tenants" are made up of the same people during all stages. The "operators" and "managers" groups have slightly different people involved at the three stages. Current roles are divided into two approaches. The first description is when a building is built for a specific organization which would include "tenants" and "managers". The second description is when a building is built "on spec" or the organization that intends to lease the building comes on board during the construction.

2.2.1 Building for a Specific Organization

2.2.1.1 Conception Stage: The "managers" are made up of senior directors in the organization and the people specifically responsible for accommodation. Depending on the size of the organization an individual or group may be responsible. The "operators" are made up of the designers such as architects and engineers, constructors and people financing the building where an organization will lease the building. Where the building will be owned by the organization there are no financers

The "managers" of the organization work directly with the "operators" to design and construct the building. The "tenants" work with the "managers" to develop the functional program.

2.2.1.2 Operation Stage: The "managers" are made up of the of senior directors, human resources department, the organization's planners and strategic thinkers, trainers and any other personnel involved in ensuring that the "tenants" are able to produce the good and service the building is intended to for. The "operators" include the building's maintenance personnel, services within the building such as food preparation, the owners of the building where the organization is leasing the building and any personnel directly related to ensuring the building functions for its intended purpose.

The "operators" operate the building in such a fashion that the "tenants" are able to function to produce the goods and services intended. The "managers" ensure that the corporate governance (social environment) for the organization is such that the "tenants" function.

2.2.2 Building on Speculation (in this case there is no specific tenant only prospective tenants):

2.2.2.1 Conception Stage: The "managers" are made up of the "operators" sales and senior personnel. The "managers" may also be an independent real-estate sales organization. The "operators" are made up of the designers such as architects and engineers, constructors and people financing the building where an organization will lease the building. Where the building will be owned by the organization there are no financers

The "managers" of the organization work directly with the "operators" to design and construct the building for a specific market segment.

2.2.2.2 Operation Stage: The operation stage is the same as 2.2.1.2 once there are organizations that lease the building.

3. The Physical Building Environment

3.1 The Parts

A commercial building has several major components. The main and first part of the building is where the "tenants" conduct their activities for which the building was built. This also includes the space that the "managers" use. This is the space that is primarily used to produce the good and service that the building intended for. This will be referred to as the "usable space". The second part of the building consists of the mechanical, electrical and plumbing systems as well as stairs, elevators and other means of egress. This will be referred to as the "systems" of the building. The third part of the building is the parts that protect the building from the outside elements such as windows, walls and doors. This part also includes the structure of the building. This will be referred to as the "envelope" of the building. The fourth part of the building is the site and outside environment in which the building is located. This will be referred to as the "outside".

3.2 The Role of the Parts

The design of each part of the building has specific effects on how the "tenants", "managers" and "operators" will behave. The physical design of a part will lend itself to specific "affordances" (Hillard). The height of a ledge, the character of a handle and the location of a stair will suggest a specific use and may also suggest untended uses (Hillard). In each part of the building there are opportunities to affect behavior either by channelizing unsustainable behavior into sustainable behavior or by taking advantage of innate behavior to foster sustainable activities (Jalkotzy). In addition, the governance structure of an organization may suggest some specific design elements that will make it easier for an organization to operate and produce goods and services sustainably. Most sustainable design assist and assessment tools such as LEED ™ already suggest solutions such as individual control of the environmental conditions, access to natural light, noise control, the use of non hazardous material, access to recycling, bicycle racks, showers, access to transit, natural landscaping, etc. This will not be repeated. There are more things that could be done with a better understanding of how humans behave. Some of the aspects that make common sense are listed here. In addition, the way some parts are designed will provide clear messages to "tenants" on what an organization and "managers" value most. As well, the involvement of the "tenants" in the design and management of the building and its' parts will have a direct affect on "tenants" behavior relative to the sustainability features, the sustainability elements to be included, their design and the future operation of the building.

3.2.1 Usable Space: Real-time displays of resource use accessible to all "tenants" and "managers"; location of light switches in a logical location and order; used resource center; location of "managers" offices relative "tenants" cubicles;

3.2.2 Systems: Location of stairs, windows in stairs, music and art in stairs, location of bicycle racks and car pooling relative to car parking

3.2.3 Envelope: Operable windows; ease of use of blinds;

3.2.4 Outside: Right of way for pedestrian and bicyclists over cars, location of senior "managers" parking;

4. The Social Environment

4.1 Background

As noted previously our behavior is affected by the way our brain evolved, the social environment we are a part of and the physical environment we have created. We like sugar and fat a lot, not because we need them now, but because we needed them when we were a hunter-gatherer society. If you didn't like sugar and fat you did not survive to a child rearing age and you had no offspring. Only the people that liked these high value foods had children and their genes were passed on. The "Blank Slate" (Pinker) outlines in detail where much of our behavior likely comes from. "The Blind Watchmaker" (Dawkins) also describes how complex organisms may have evolved. The evolution of language and social structures such as religion came about because they increased the survival rate of the human species. In the same way walking is hardwired evolutionarily into the brain of a new born calf our brain is hardwired for language and some social behaviors. These are behaviors that are very difficult to change. We may be able to channelize such destructive behavior, but we likely cannot change it (Jalkotzy).

The social environment can support sustainable behavior. We already realize that many of our economic models and governance structures do not encourage sustainable behavior. We simply reward ourselves for doing the wrong things. The way that the "tenants", "managers" and "operators" organize the operation of a building will have an affect on how sustainably the building is managed.

4.2 Elements of the Social Environment

There are three social environments within a building. The organization made up of the "tenants" and the "managers" constitute the first social environment. This will be referred to as the "company". The relationship between the "tenants" and the "operators" is also forms a social environment. This will be referred to as the "team". The organization made up of the "operators" is also a social environment. This will be referred to as the "maintainers". Generally these social environments work independently, however one social environment does have an effect on the individuals within another social environment. For example, if the social environment within the "company" is not conducive to recycling, then there will be an effect on the ability of the "maintainers" social environment to encourage recycling. Current and potential social environment characteristics are described.

4.2.1. Current Social Environment Characteristics: These are generalized social environment characteristics of organizations that exhibit unsustainable behavior.

4.2.1.1 Company: Typically this is a hieratical structure with vertical reporting structures. Usually there are more than four levels going from the employee to the senior executive. The departments of the organization are organized around specific activities such as finance, human resources, production, etc. There is little interaction between departments except at the senior executive level.

4.2.1.2 Team: This social environment has no structure in most buildings. This environment is the informal relationship between "tenants"/"managers" and building "operators". Generally the operators maintain a "tenants" complaints system. The only formal interaction is through a health and safety committee that is mandated in some jurisdictions (countries, states). There may be some accounting of how complaints are handled back to the "managers" of the organization. There usually is similar accounting back to the "tenants".

4.2.1.3 Maintainers: This social environment is usually structured around contracts between the building owners and the individuals maintaining the facility. In some cases the individuals maintaining the facility are employees of the owner. There is generally little interaction between the cleaners, mechanical system operators, physical building maintainers and any services within the building such as food preparation, dry-cleaning and other services.

4.2.2. Suggested Social Environment Characteristics: These are generalized social environment characteristics of organizations that exhibit sustainable behavior.

4.2.2.1 Company: Typically this is a non-hieratical structure without vertical reporting structures. Usually there are fewer than four levels going from the employee to the senior executive. Work groups are developed made up of individuals from many departments or directorates. Instead of each employee continuing to report to their immediate supervisor, they would report to one manager. The "managers" group is seen as a team. The departments of the organization are organized around specific production tasks. There is interaction between departments at all levels.

There is an important culture change within organizations that is fundamentally necessary to have a successful sustainable behavior change occur. For the most part the executive class of the "managers" group believe that the "tenants" (employees) are there to serve "them". This is clearly not the case. In an enlightened and progressive organization there is a fundamental understanding and belief that the executive class of the "managers" serves the "tenants" (employees). The executives would not exist if it is not for the work that the "tenants" do.

4.2.2.2 Team: There is a building management team made up of "tenants", "managers" and "operators". This would function similar to a health and safety committee. They play a formal role in the building and asset management plan for the building. They review and analyze the complaints data for the building. They provide advice to the "operators". This is where a Green Stewardship Committee could be formed.

4.2.2.3 Maintainers: Similar to the "company" this governance model would encourage interaction between the various "operators". From a governance perspective they could be a sub committee of the building management team.

5. The Tenant Centric Building Management Guide

5.1 Background

A tenant centric building management manual would incorporate a governance model that takes the concept of an integrated design process in the design of new building or major renovations into the formal management of a building and then takes it a step further. Unfortunately, the integrated design process currently pays only lip service to the role that "tenants" could play in the design of a building. There still is a fear that "tenants" will complicate the work of the "operators". Architects and engineers are always concerned about "scoping" the "tenants" involvement for fears that their involvement will unnecessarily raise expectations. Where "tenants" have been involved in the design process the reverse is generally the case. "Tenants" actually enhance the creative process. They bring new perspectives and solutions to the design process. It also develops a sense ownership in the building and its operation. For "green" buildings this is particularly important. "Tenants" can and do negate some of the "green" features designed into buildings. This model is proposed for the management of a building. However, "operators" in designing new buildings or conducting major renovations can use it.

As the title indicates, management of the physical environment and social environment of the building is taken from the point of view of the "tenant". There are several steps that set a foundation for managing a building from this perspective. There are many buildings that use some of the following principles. Most do not use all of these principles. Buildings that are owned and occupied by the same organization, particularly if it is an environmental "organization sometimes combine all these principles. However there is almost always a gap between the "operators" and the "tenants"/"managers".

5.2 Steps and Principles

The steps suggested are divided into two parts. Part one requires a governance model for the building that produces the social environment outlined in 4.2.2. An outline of such a model and the interrelationships is provided. Part two follows a typical pattern of finding out where you are, "base-lining"; developing goals, objectives, an action plan and setting targets, "planning"; implementing the action plan, "implementation"; measuring results against the targets and base-line, "measuring"; then back to "base-line". This list of principles can be applied to the management of a building. It can also be applied to the design of a new building or major renovation.

5.2.1 Part One, Governance Model: The principles to good governance model are as follows:

5.2.1.1 Rational for Building Management Team: There is a direct relationship been "tenants" involvement in the management of a building and the level of complaints about a building. In addition, by involving the "tenants" in the asset management plan, the "tenants" buy-in to the solutions proposed for the building. If this is combined with providing real-time feedback on performance measurements of the building significant reductions in resource use have been observed. In addition, complaints about the building decrease. After the cost of operating a building, answering complaint calls is the next highest cost center in operating a building.

5.2.1.2 Development of a Building Management Team:

- Inclusive,
- Must have a charter,
- Must have a formal role in the building and asset management plan,
- Should incorporate a green stewardship committee,
- Needs to be funded,

5.2.1.3 Roles of a Building Management Team:

- Review building "tenants" satisfaction data for the building and asset management planning process
- Manage "tenants" events in the building such as environment week
- Develop sustainability targets for the building

5.2.2 Part Two, Process

5.2.2.1 Base-lining:

Indicators:

- Must be measurable,
- Must be understandable by the "tenants",
- Must reflect what the "tenants" values,
- Must be useful for making decisions and
- Indicators need not be directly measurable if there are other measurable values that vary in direct relationship with the proposed indicator,

The building management team develops a narrative describing the sustainability performance of the building using the base-line indicators of the building and the "tenants" satisfaction data for the building.

5.2.2.2 Planning: When developing plans for new roads, subdivisions and other municipal infrastructure planners use as system that is useful for planning the operation of a building. Planners rely on two groups of people. Technical Advisory Committees (TAC) are made up of engineers, architects and planners. TACs advise the process from a technical perspective. Planners also form Public Advisor Committees (PAC). PACs are made up of people from community associations and other public advisory groups such as cycling associations. PACs advise the process from a community perspective. Planning the management of a building can be approached in the same way. The Building Management Committee would be similar to the PAC. Their role will assist the "operators" in understanding building issues from a "tenants" perspective.

5.2.2.3 Implementation: As outlined in the roles of the Building Management Committee, the "tenants" can play the most substantial role in ensuring that the targets set in the "planning' step are met. As previously stated they can also ensure that targets are not met. There are many ways that "tenants" can interact with the "operators" to successfully meet sustainability targets. The following is a list of methods that can be organized and used by the "tenants":

- Press and media communications
- Television documentary
- Website
- Signage and posters
- Lunch and learn
- Kiosks
- Add on buttons on programs on personal workstations
- Move in package developed by "tenants"
- Green Stewardship Teams
- Green Building Champion
- Training and orientation sessions
- Challenges and recognition

5.2.2.4 Measuring: The key to "tenants" ability to assist "operators" in meeting a building's sustainability targets is real-time indicator measurement. Human behavior is such that "only what gets measured done" and as individuals if we are able to access real-time information on utility resource consumption we reduce our consumption by 10 to 15%. Self reported sustainability behavior has been shown to be reasonably accurate. Where this can be cross referenced with actual data it is highly reliable.

- Sustainability footprint calculators,
- Metering of building utilities accessible to "tenants" at desktop computers

6. Proposed Public Works and Government Services of Canada Tenant Involvement Program

How can building occupants participate in operating green facilities

There are four activities that occupants could take part in to increase the effectiveness of green building features.

Participate in Building Survey (National Tenant Satisfaction Survey)[1].Appendix 1 provides a link to resources relating to the use of surveys in the development of sustainable buildings.

Focus groups made up of building occupants then could review optional Lists of Projects developed assessing each to see how they addressed issues identified in the National Tenant Satisfaction Survey. This review would be conducted during of the Asset Management Plan (AMP) cycle and form part of the deliberation leading to a preferred List of Projects for the AMP.

Some of the kinds of areas where employees can help increase the effectiveness of energy reduction strategies and green features are listed below. It is important that these areas be assessed in detail for how occupants' involvement can improve the sustainability of the asset cost effectively[2]:

<u>Base Building</u>

- Control strategies for:
- Lighting; switches and levels
- Heating and Cooling; switches, temperature levels and ventilation rates
- Monitoring strategies for electrical, water, paper, waste and fuel consumption[3]
- Location of bicycle, transit and car pool parking allocations, decreasing use of single occupant cars
- The character of stairwells and their attractiveness for use, decreasing use of elevators
- Fit-up
- Design of business centres; reuse storage and new material storage cabinets,
- Location of recycling facilities
- Kitchenette facilities that reduce the use of non-refillable or reusable products

Building occupants could review building operations procedures manual and modify it to incorporate green features. The manual will be downloadable on Buildings Online Site and distributed to staff in paper or electronic form

Building occupants could develop their sustainability objectives using PWGSC's SDS targets as a baseline, particularly energy reduction targets for the five year AMP cycle through a "consensus building" process.

<u>Methodology</u>

The proposed process for each asset would have to go through a three-step approval at the Service Integration Team (SIT) and asset levels. Approval will be required from:

- Director General or Director of the SIT
- Building management team, Asset and/or Building Manager
- Client Management, Assistant Deputy Minister, Director General and Director levels

The final check of the occupants' willingness to participate will come from the number of volunteers that indicate their interest in the program. The invitation to participate will come from their respective Assistant Deputy Minister and/or Director General.

The draft outline of the process follows the four areas previously outlined. Each area will have a detailed process and goals.

Participate in Building Survey (National Tenant Satisfaction Survey)[4]

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[1] The National Tenant Satisfaction Survey # provides an excellent mechanism for communication between the tenants and the building management; documents the perceived quality of PWGSC services; allows PWGSC to ensure tenants receive the best service possible

[2] This is a draft list of ideas based on current sustainability design assist and assessment tools such as Green Globe and LEED. It may be possible to do some things at low cost during regular fitups and maintenance of the asset, others may only be cost effectively done during a major refit of the building.

[3] If employees do end up setting some GHG emission reduction or waste reduction targets, then there needs to be ways of reporting on achieving the targets. This is a critical motivational strategy.

[4] This survey could be reviewed using the work done by Adrian Leaman and Bill Bordass in Britain in the Probe Study of existing building.

Focus groups made up of building occupants could review optional List of Projects during the Asset Management Plan (AMP) cycle relative to issues identified in the National Tenant Satisfaction Survey. (see previous list of areas where occupants could assist)

We propose to hold a 1/2-day brainstorming session with 15 to 20 people (for example if the building population is 1000, 4 to 5 focus groups would be optimal, this would provide a demographical representative sample as well as provide the seed individuals necessary to continue the program). These employees would be invited to participate on a first come basis by the Director Generals and Directors of the respective client departments.

Building occupants could review building operations procedures manual and modify it to incorporate green features. The manual will be downloadable on Buildings Online Site and distributed to staff in paper or electronic form

(We would seek the assistance of Environmental Citizenship Initiative Support Centre.)

Building occupants could develop their sustainability objectives using PWGSC's SDS targets as a baseline, particularly energy reduction targets for the five year AMP cycle through a "consensus building" process.

We would develop option energy reduction targets and scenario's using the Existing Building Sustainability Assessment and the Environmental Citizenship Initiative Support Centre work on developing baseline occupant energy and products use. The occupants would then modify and adopt a five-year target with year-to-year goals

SURFACE TREATMENT IN BUILDINGS: A SUSTAINABLE PRODUCT SERVICE SYSTEM

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Summary

Product service systems (PSS) can be an innovative solution in the material intensive building industry. PSS are packaged system solutions of products and services that fulfill specific consumer needs. If immaterial services are efficiently combined with material products, overall resource and energy consumption of the system can be significantly reduced.

In this paper, a PSS strategy is described for the surface treatment segment in the building industry. Throughout a series of system analyses and idea generation processes, the idea of ‘contract-based service for surface management’ is suggested. The basic concept is that the company and/or its partners provide(s) a complete result of treated surfaces, instead of selling treatment agents. A professional painter or carpenter treats certain surfaces, and visits the customer on a regular basis, or on request, to maintain the surface quality. The PSS concept has several advantages. Through the high quality product application and tailorised professional services, the amount of material consumption can be reduced. Furthermore, it can create new opportunities of employment. This service model is adaptive for private households, public buildings, and even restoration and maintenance of historic buildings. As a result of the feasibility investigation and user group surveys, a number of practical requirements for the successful implementation of the idea are defined.

1. Introduction to Product Service Systems

Product Service Systems (PSS) are commonly defined as the result of ‘an innovation strategy, shifting the business focus from designing and selling physical products only, to selling a system of products and services which are jointly capable of fulfilling specific client demands’ (Manzini and Vezzoli, 2002). The main goal of PSS is to satisfy users not only by means of material artifacts, but more by immaterial services. In order to deliver the expected values, and even beyond the expectation, suitable products and services need to be assembled in the most efficient way. In doing so, both functional (e.g. food, mobility) and non-functional (e.g. satisfaction, social status) aspects of customer demands need to be considered.

Primarily, the concept of PSS was introduced in the market as one of product marketing approaches. Companies began to provide additional services in order to attract customers to their products and increase their satisfaction. Therefore, PSS are often perceived as ordinary ‘business proposition’ or ‘product promotion’. Since the concept began to be discussed in the sustainable development field, however, the role of services has been highlighted, the role of which is no longer increase of sales volume, but the direct fulfillment of customer demands.

Our society is always changing, and accordingly, our market is changing. To be outstanding among numerous business entities, it is necessary for enterprises to capture and fulfill the changing demands of customers and market trends in a new and different way. Many researchers and business developers inspired by the concept try to further understand the intrinsic nature of PSS and to implement the idea in the market.

1.1 Product Service Systems Corresponding Socio-Economic Changes

PSS are in concert with emerging socio-economic transitions in the society. There are economic, environmental, and social trends underpinning the adoption of PSS strategies in business units. Not surprisingly, PSS have been already implemented in many industries. In the building sector, however, PSS are fairly new and rarely existing (Ness, et al. 2005). One of the reasons is that the building industry has been classified as a *manufacturing* sector for a long time, concerning its inherent material-intensive aspects. However, when we consider the actual values we get from buildings, such as safety, comfort, coziness, and relaxing moments, will it be impossible to reorient the industry as a *service* sector, by providing those needs behind the needs?

1.1.1 Economic trends

It is obvious that the economic paradigm has shifted from the traditional mass material market to the post-industrial market. One of the indicators is the remarkable growth of service industries among all industrial activities in the last half century (Statistik Austria, 2006; Statistics Bureau, 2005; U.S. Census Bureau, 2008). Business activities increasingly rely upon immaterial values in tertiary industries (e.g. consulting, information technology) instead of relying only on the material values in primary and secondary industries (e.g. mining, manufacturing goods). It is partly because margins from product sales are getting smaller in the severe competition among global producers. Many of European and North American countries have witnessed that a great part of production facilities were moved to those countries with growing production capability, due to the relatively low costs for natural resources and labour. In terms of technical functions and prices, the difference between brands is no longer clearly distinguishable. Therefore, as one of marketing means, companies provide services such as delivery, guarantee, repair and take-back. The scope of services can be further expanded.

1.1.2 Environmental trend

From an environmental point of view, PSS solutions contribute to decoupling amount of natural resource consumption and value creation. It is primarily because services can create values out of immaterial sources such as knowledge, information, ideas, labour, and time. Service-based solutions show, in general, higher resource productivity compared to pure product solutions, as well as increased efficiency in product use (Kang and Wimmer, 2008). For example, repair and maintenance services prolong the useful life time of products, and take-back and recycling services impose a new useful life to certain materials and products. Also, the success of information and communication technology has dramatically increased the possibility of immaterialized answers to many customer needs for knowledge and information.

1.1.3 Social trend

The beliefs of citizens are changing. In most of early industrialized countries, issues related to the quality of life, such as well-being, work-life balance, and emotional satisfaction arise. The old perception that ‘the more, the better’ is being replaced by new common sense, ‘the less, the better’ or ‘the better, the better’. These quality-oriented criteria are already recognised in the food production industry and consumption behaviour (Kang and Wimmer, 2007). Such convergence of values can be valid in other production and consumption areas as well. Additionally, the shift in social attitudes toward moral responsibility has made the ethics of personal decision become a major professional concern. There lies a great potential of creating new services or improving current services in order to address these high-level needs/demands, which are hardly able to be fulfilled by mere products.

1.2 PSS in the Building Industry

Innovative PSS are created from questioning ‘what are the real needs?’ With this new way of looking at our everyday needs and material artifacts, more radical solutions can be found in many sub-segments in the building and building-related industries. If this transformation is combined with the sustainable deliberation, a new perception on our living and working places can be established.

The potential of the innovative change can be seen in a number of PSS examples in the building sector: the remanufacturing service for unit houses by Sekisui Chemical (Iwahara and Suzuki, 2005), co-housing systems in Europe and America which facilitate space sharing, the ‘office space rental service’ by Regus (2008), the carpet leasing and take-back service by Interface (Ness, et al. 2005), and so on. Those PSS examples currently running on the market can help enterprises understand PSS in a more practical way. We can also learn how to design, implement and operate the systems successfully.

One of the common characteristics of the PSS models above is that the companies regard a building not as a last destined object of their business, but as an intermediate medium to deliver customers’ various needs. Here, the customer needs about buildings are not only physical and spatial places to live or work in, but also sources of refreshment, intimacy, self-esteem, and convenience. Therefore, their design approaches lie on a system level beyond a product or material level.

2. New PSS Development for Building Surfaces

A new PSS model for the building surface treatment sector has been developed. Surfaces include most of building elements such as façade, floor, window, walls, etc. and other consumer products (e.g. furniture). This branch involves chemical-based materials including paint, polish, lacquer, etc. and services for the application of those materials. In such a material dominant conventional market, the relationship between the provider and the customer simply ends up at the point of product sales.

From an environmental perspective, the product segment – as an overlapping field of building and chemistry -shows high natural resource consumption, while creating relatively low economic values compared with other industrial branches (Fig.1). A new approach has been taken in order to reduce the material consumption amount and to increase economic and other values, in surface treatment for buildings.

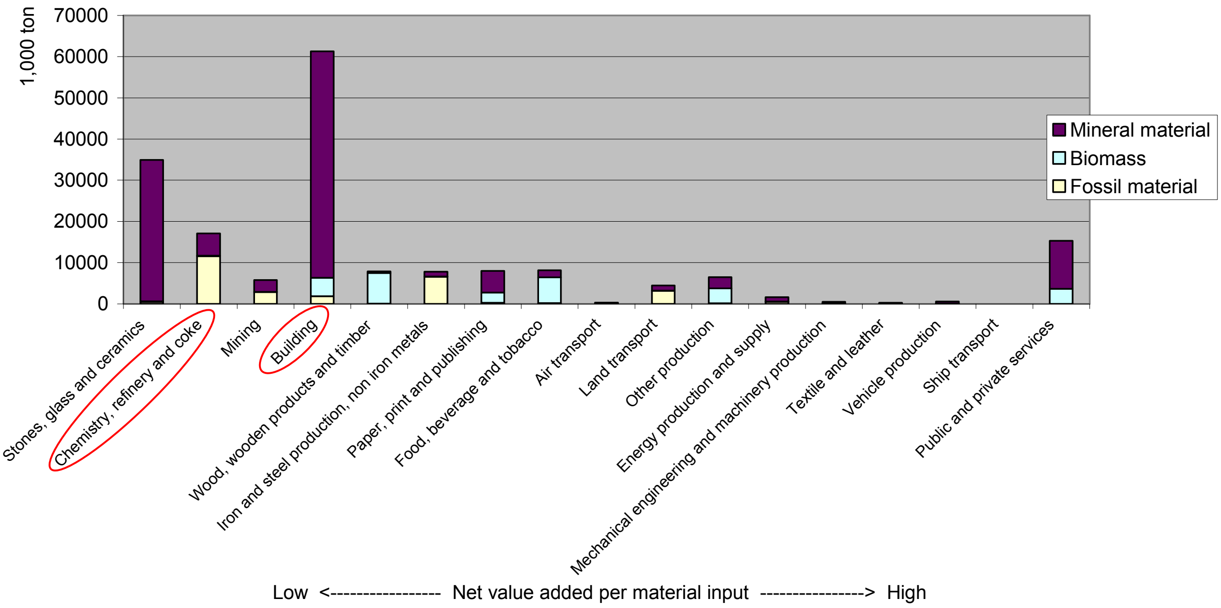

Figure 1 Material consumption and net value added in different business sectors (Wimmer, et al. 2007 based on Statistik Austria, 2003)

The project was carried out in collaboration with the natural paint producer, AURO Austria. The company is specialised in producing natural paint, oil, and other surface treatment products. As a part of mid-term strategies, they plan to engage service elements into their business to be more competitive in the saturated market. In advance to actual tryout, beneficial and risky potentials need to be clearly grasped. With the help of systematical methodologies and tools, a new PSS model has been built up.

2.1 Processes and Tools Used for the Development

2.1.1. Simplified PSS development handbook for small- and medium-sized enterprises (SMEs)

The 'simplified PSS development handbook for SMEs (Wimmer et al, 2007)' was employed. The handbook consists of a series of analytic and strategic tools selected and/or refined from the tools in 'Methodology for Product Service Systems Innovation (MEPSS) (Van Halen, et al. 2005)'. The 5 phase-step-process structure of MEPSS has been trimmed down into 3 phases, to respond to the demands of SMEs for easy use. The basic flow of system development and the sequence of tools used in the each phase are shown in Figure 2.

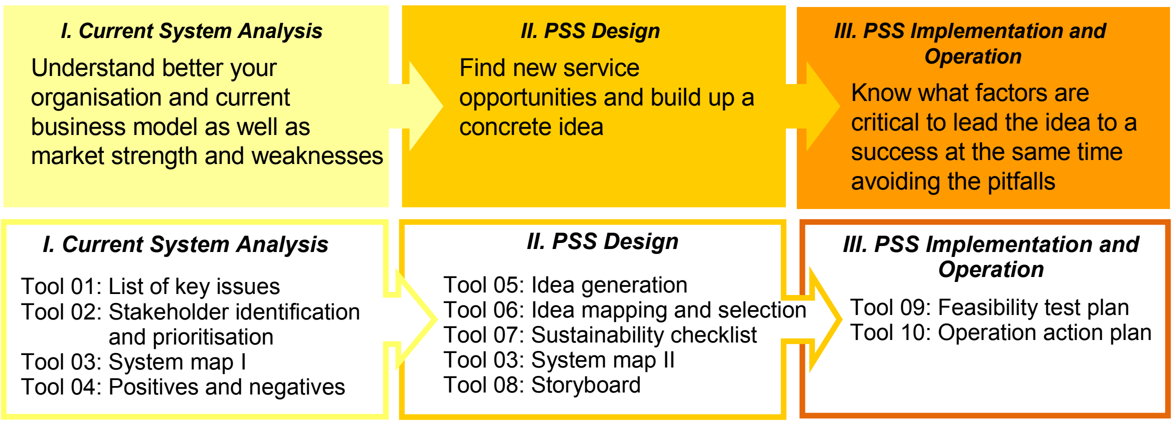

Figure 2 Three phase model of PSS development and tools used in each phase (Wimmer et al, 2007)

2.1.2. Key processes and results

Among the tools applied, a few key tools and the respective results are summarised.

1) Current system analysis - stakeholder identification and prioritisation

Instead of the linear relationships between stakeholders along the supply chain (e.g. material provider–producer–retailer–customer), PSS require a network of vertical and horizontal relationships among them. The following tools enable to identify all relevant actors who already have stakes in the business, or who could have a relationship with the company in the future. They are categorized according to their interest in and influence on the system. Each stakeholder category is defined as follows:

-Primary stakeholders are those who have a direct stake in the organisation and its success
-Secondary stakeholders may be influential, but their stake is more representational
-Social stakeholders can be directly communicated with
-Non-social stakeholder cannot be directly communicated with

Table 1 Stakeholder identification

	Direct stakeholder	Indirect stakeholder
Primary stakeholder	• Mother company • Employees and managers • Customers • Regional dealers • Construction managers • Regional painters • Shareholders and investors	• Competitors • Environmental pressure groups
Secondary stakeholder	• Raw material providers • Governmental institutions • Social interest groups (e.g. labour union) • Media	• Natural environment • Future generation • Non-human species

The stakeholders are mapped along the value chain (Fig.3). The map is sectioned into internal-/external-entities and former-/next-value chains. The dotted line in the middle shows the boundary of possible PSS partnership. The boundary and the location of individual stakeholders can be updated as the strategy of the company changes as well as system solutions develop.

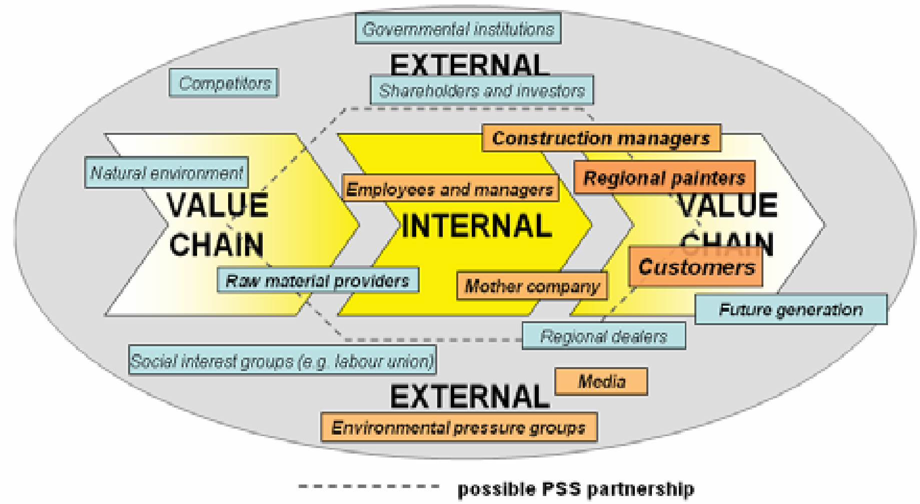

Figure 3 Stakeholders along the value chain and possible PSS partnership

The involvement of stakeholders in the early design phase is one of the requirements for successful development and implementation of PSS. Therefore, the prioritized stakeholders were invited to a workshop for the system analysis and idea generation.

2) Current system analysis - system map

The 'system map' is a codified and progressive representation tool. Its main purpose is to facilitate conversations among partners. This drawing helps viewers to understand the overall system structure and major stakeholders in the system (Jégou, et al. 2004). A system map consists of graphic elements symbolising the stakeholders and the three flows between them: material-, information-, and financial-flows. The following system map (Fig.4) visualises the primary system of AURO, which focuses on selling natural paint to private or business clients through regional dealers or painters.

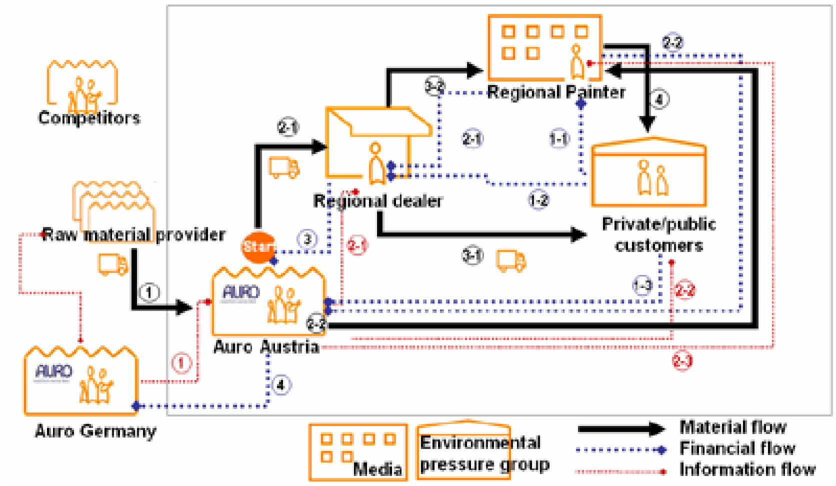

Figure 4 System map of current business

3) Current system analysis - positives and negatives (SWOT analysis for the product and the system)

Based on the factual understanding of the current system, positive and negative aspects are discussed. The widely used SWOT analysis was used with regard to the target product (Tab. 2), and key strategies were derived from the analysis results (Tab.3).

Table 2 Product and market SWOT analysis

Strength	Weakness
• No negative impacts on health • Durability of the treated surface • Easy maintenance • Comfortable smell and atmosphere • The raw material does not have to be extensively modified → Possibility of individual formation/variation	• Perceived to be expensive ('kg' measure) • Long drying time • Know-how required for correct application • Improvement of environmental performance of synthetic materials • Lack of access by large number of customers (available only via special retailers) • Environmental performance as a weak unique sales proposition
Opportunity	**Threat**
• Interest from customers with environmental consciousness • Regulations for occupational health care have been tightened for professional users • Disposal regulations have been intensified • Simple compositions/ simple production • Volatile Organic Compounds (VOC) regulations come into force • Professional maintenance is getting more and more popular • Growth of 'do it yourself' market • Wellness trend (modern, well-being)	• Improvement of synthetic products (competitors) • Easy availability of synthetic products through conventional trade (e.g. home merchandise retailer) • New competitors appear in the market • Conventional paint producers discover the opportunities of the ecological market trend

Table 3 Strategies derived from combinations of SWOT analysis

	Strength	Weakness
Opportunity	• Emphasis on the compliance with health-related regulations • Patents with the VOC control	• PSS offers can compensate the price difference • Emphasis on the cost saving over surface lifetime • Educational programmes for the proper application of this product
Threat	• Visible differentiation from conventional products • Emphasising accompanying benefits (e.g. texture, smell)	• Exploring new marketing channels • Emphasising the lower life cycle costs especially in comparison to conventional products

A characteristic of this process is that a 'system' SWOT analysis was added to the conventional SWOT analysis. The analytic method often focuses on a target product/service and its market situation only. The system SWOT analysis is newly suggested to enhance the subject of consideration up to a system level. In stakeholder workshops the system map (Fig.4) is used to scan all the flows as well as to aid the communication among stakeholders. The advantages and disadvantages in the flows and the relationships among stakeholders have been figured out. The results are utilised in the next processes in order to construct promising strategies that smartly strengthen the advantages, and compensate the disadvantages.

4) Idea generation and mapping

From the previous analyses and liberated brain storming sessions, a pool of PSS ideas was generated. The ideas were, then, mapped according to a set of criteria. The following figures show the actual ideas and its simplified mapping.

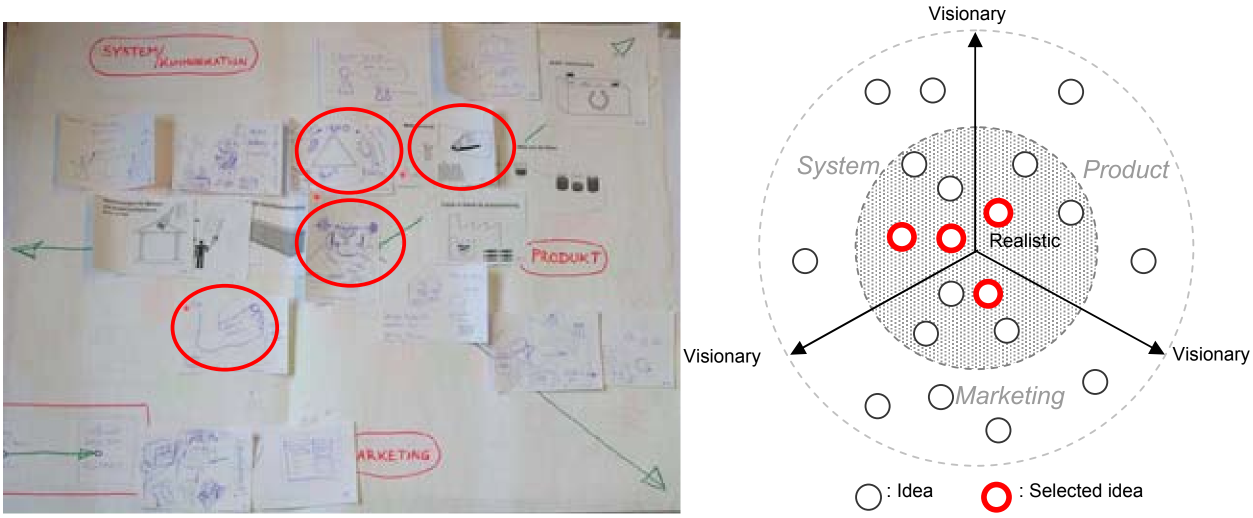

Figure 5 Actual ideas (left) and simplified mapping (right)

The ideas for surface treatment are divided into three groups: products, marketing strategies, and system (organisational) communication. The other mapping dimension is the feasibility of ideas. According to the technical, administrative, and financial feasibility assessment, individual ideas were placed along the axis: visionary and realistic. Four alternatives were chosen for further analysis and development.

1) Professional surface treatment service
2) Painting course for DIY customers
3) PR activities in wellness-related branches
4) Emphases on healthy and comfort aspects of AURO products

With regard to the selected four ideas, their sustainability performances were assessed by using a qualitative sustainability checklist. Among the ideas, the 'professional surface treatment service' was evaluated to hold the largest potential for environmental, economic and social benefits. On the other hand, this idea is most challenging, because it requires a customers' different perception on the traditional product purchase model. The remaining three ideas can be taken as supportive means of launching the selected idea.

3. Contract Based Surface Treatment Service

3.1. Description

The basic concept is that the company and/or its partner provide(s) a complete result of treated surfaces, instead of products only. A professional painter or carpenter treats surfaces, and visits the customer on a regular basis or on request to maintain the surface quality. The quality level of the treatment and service performance are ensured by a contract which is agreed upon at the beginning of the offer and renewed periodically. The basic structure of this service contract is elaborated through benchmarking the general standards of Service Level Agreements (SLAs) and the 'energy contracting service' model (Oegut, 2008). The contents can be further supplemented by discussions and interviews with representative stakeholder groups, as well as through investigation of legal contract components. The contract draft includes an escalation management plan* and a fixed rate of payment, thus, the customer can foresee the cost in advance.

* Escalation management plan arranges alternative solutions in case that the primary specialist cannot deliver defined service performance within the indicated time periods.

3.2. Benefits

The benefits of this PSS model are manifold. First, resource consumption can be reduced owing to the expanded lifetime of the surface and efficient material application. Second, professional painting and maintenance services can keep the quality of results at best status, and thereby, satisfy customers. Other benefits are also anticipated from the interview with a professional surface treatment technician who is specialized in restoration of historic buildings in Austria, such as Schönbrunn Castle and Belvedere Museum. According to the expert, normally surfaces need to be maintained partially, rather than in whole. To sustain the precious floors and fragile surfaces of historic buildings, he carefully examines the current status of the surface, and treats only some parts that call for maintenance (e.g. worn-out visitors' paths). This partial renovation can not only save materials, but also preserve the original surface in a better condition. Further, he mostly uses natural materials that are similar to the original application materials. Through the contract based PSS model, this type of high-quality professional services with valuable knowledge and experiences can be provided to other customers.

In this model, the profit arises from certain dimensions (m²) of treated surface, rather than weight of products (kg). Consequently, the service takes preventive care of the surfaces to avoid a major application, and consumes materials as efficiently as possible. In this concept, the fact that this natural paint can apply a larger surface, compared to a synthetic paint, has been taken as an advantage.

Users no longer buy and own tines of paint material, but simply pay for well-treated surfaces. They do not need to be concerned about organisation of treatment service themselves, maintenance of the surface over a long period, storage of leftover materials, and disposal.

For successful PSS implementation, intelligent networking among companies in different industrial branches is important. Emerging socio-economic trends of today do not necessarily require competitions against each other. Instead, competences of each of the partners can be taken to constitute new and advanced industrial solutions. The company can decide whether they will expand their business scope by integrating the service factors (i.e. in-house provision of professional painters and customer services), or they can outsource the service. Alternatively, an umbrella organisation could be founded as a supervisory management institution and an information centre for customers. Such a control and consultation unit can recruit a number of technicians and train them with technical knowledge and know-how's. In either scenario, there is a possibility of new job creation.

4. Consumer Attitude

For refinement of the idea, its market acceptance was investigated by means of questionnaires and interviews. The primary target groups were divided into three groups: regular users (who purchase materials and hire technicians for private buildings), Do It Yourself (DIY) users (who purchase and apply materials themselves for private buildings), and public bodies (who purchase materials and hire technicians for public buildings).

In general, the regular users are interested in the service offer for some building elements, for example, façade, windows and wood preservation. They suppose the proper duration of a service contract between 5 and 10 years. In terms of the price, they seem willing to pay about 20% more than the material cost, over a defined period. The most appreciated advantage of the offer is the competence of professional technicians for high quality treatment.

The survey of DIY users shows that they highly appreciate the environmental benefits of the natural paint and reduction of transportation energy, etc. Nevertheless, it is not only technical functions that influence customers' decision, but also non-technical values. In this case, the DIY users voluntarily go through the self-application procedures and enjoy own labour. Therefore, they seem to be not keen on giving this 'experience' to other professionals.

Generally speaking, business-to–business (b2b) PSS offers are more successful than business-to-consumer (b2c) offers in the market. One of the reasons is that companies make a decision based upon rational evaluation of options, while household customers are often emotionally biased (Wimmer, et al. 2006). The effect of demonstrations in a b2b field is often far stronger than that in a b2c market, due to the capability to win public credit. If a new business model works successfully in a public organisation, the idea can be more widely talked than when it was adopted at a private household.

Considering all conditions above, public organisations were selected as the first trial target group, and the municipal school building administration of Vienna was interviewed as a prospective customer. Through verbal explanations and visualized scenarios, the PSS offer was able to be clearly understood, and the new method of public building management was perceived to be captivating. In advance to real application, however, some institutional and financial hurdles were recognized, such as extensive administrative decision making process and more concrete financial benefits over a long term.

As an alternative target within the public building sector, kindergartens, hotels, hospitals, and sports complexes are suggested. These branches are supposed to be more concerned about the issues such as health and air quality as well as brand images. With regard to the maintenance aspect, the PSS offer suits the treatment of historically valuable buildings and restoration work. Churches, museums and other heritages that are under protection regulation can be implementation subjects.

5. Conclusion

Along the systematic approaches, a PSS strategy for surface treatment has been elaborated. The result is an advanced solution for quality improvement, new profit generation, reduction of material consumption and opportunities for job creation. This practice may show the potential of market transformation in the building industry. In many industrial places, we see the product-dominant age is ending. Larger and powerful values are originated from immaterial services, knowledge, information, and experiences. While some industries have quickly adapted themselves to fit this new stream, some segments have adhered to the conventional material-oriented business models. As one of the latter, the building industry has been ranked as the most material intensive industrial branch. However, not exceptionally, creative and clever PSS strategies can be created in this sector as well.

The value position in our economy is changing, from production of material goods to service offers. This transposition requires that firms should develop corresponding business strategies. By caring about the true needs behind material needs, building enterprises and institutions can discover more diverse options of value propositions, and consequently achieve the system level innovation. The answer to ‘what is the real need?’ and ‘how can we address this need?’ would not always require enormous amounts of resources and energy. Customers’ comfort, welfare and happiness can be directly served.

Consumer mindset is diverted gradually. In the innovation process, therefore, companies may face several challenges such as a change of the organisational mindset and new financial schemes. To accelerate the market change into more sustainable solutions, more success stories in the same industrial sector are needed. One of the substantial tasks in promoting PSS in marketplace is to disseminate their benefits and to improve the information flows between providers and possible target groups. At the same time, methodological, financial, and institutional support of governments is required to facilitate the implementation of public organisations and enterprises.

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INVESTIGATION OF MEASURED THERMAL ENVIRONMENT IN 41 OFFICES

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Keywords: office, thermal environment, Japan, cool biz

Summary

Recently, the Japanese Government recommends 28 °C as the room temperature of the office for cooling and 20 °C for heating. But, it is a well-known fact to get behind in the work in the hot office. Therefore, the authors investigated indoor thermal environment of the actual office rooms of 41 buildings simultaneously. This investigation was carried out by mailing a super-miniature temperature and humidity logger to 41 people working in the different office. The authors asked to set a logger on the edge of each person's desk and send it back by mail to the authors again after one week. This measurement was repeated from summer until winter, and the authors could collect indoor environment data of the actual offices for the long term. Furthermore, it was proved that the indoor thermal environment of the offices which equipped the central air conditioning system was different from that of unitary air conditioning system. This knowledge is very precious information to predict the amount of energy consumption and carbon dioxide discharge of air conditioning system.

1. Background

Japan previously laid down regulations concerning the indoor thermal environment of offices and other buildings with total floor areas of 3,000 m2 or more. The law allows for a great range of thermal conditions, with dry bulb temperature permitted within the range of 17 °C to 28 °C and relative humidity between 40% and 70%. The law is intended for the prevention of health hazards, rather than for securing comfort. Meanwhile, in the actual design of air-conditioning systems, a long-standing common practice is to try to keep the dry bulb temperature in offices at 26 °C and the relative humidity at 50% while cooling, and at 22 °C and 50% humidity while warming. These temperatures are considered to strike a balance between comfort and economy, two factors that usually conflict with each other, and this balance has been learned through experience.

Recently, with the aim of reducing the effects of greenhouse gas emissions originating from air-conditioning systems, the Japanese government announced a program to set air-conditioning temperatures at 28 °C for cooling and 20 °C for warming. This suggests that the government added a new criterion of eco-friendliness to the two existing evaluation criteria for air-conditioning systems; namely, comfort and economy. Since 2005 the government has been carrying out a large-scale campaign titled “Team Minus 6%” in order to encourage people to follow specific action plans. To help people adjust more easily to this relatively high government-recommended temperature for cooling systems, the government introduced a dress code called “Cool Biz,” and has been promoting its widespread use.

Although “Cool Biz” did not meet with any serious resistance from the people, the recommended temperature of 28 °C for cooling systems in summer encountered harsh opposition from many office workers. The authors hear that many offices are still refusing to introduce this government-recommended temperature setting.

2. Objectives of the study

Against the background described above, the authors of this paper measured the indoor thermal environment of many offices to conduct a survey of actual temperature and humidity in offices and confirm how closely the Japanese government’s recommended temperature settings are being followed. Although a great number of survey reports on the indoor thermal environment of offices have already been published, most of these cover only a single building, and they vary considerably in terms of dates of survey, measurement methods, etc.. Consequently, comparing the results of the survey reports has been difficult. To solve these problems, in this survey, the authors simultaneously measured the indoor temperature and humidity in many offices over a long, continuous period of time, using consistent measuring methods. This helped us understand the general trends among many offices. In addition, the authors conducted a questionnaire survey of people working in those offices to find out about their clothing styles at work and their perceptions of their thermal environment.

3. Methodology

The authors chose 41 offices, all in Japan and listed in Table 1, and sent miniature data logger that could measure temperature and humidity and questionnaires on thermal environment directly to people working in those offices.

The miniature temperature and humidity data logger measures 17 mm in diameter, 6 mm in thickness, and 3.3 g in weight. It has built-in sensors, a battery, and a memory. Its resolution is 0.1 K for temperature and 0.1% for humidity (Fig. 1). The measuring interval was set to 10 minutes. The authors asked each cooperating office worker to attach the data logger onto the front edge of his/her desk, at least 50 cm away from his/her body (Fig. 2). Each recipient was asked to fill out the questionnaire at their convenience, and send it back to the authors one week later, together with the data logger. Table 2 lists the survey items of the questionnaire. The authors collected the information recorded in the data loggers, sent them back to the respective offices, and repeated this procedure several times.

Table 1: List of the offices covered

Name	Location	Line of business	Kind of work	Name	Location	Line of business	Kind of work
A01	Kanagawa	Corporate body	Engineering	B01	Tokyo	Corporate body	Clerical
A02	Chiba	Construction subcontractor	Research	B02	Tokyo	Energy	Clerical
A03	Tokyo	General Contractor	Engineering	B04	Hokkaido	Energy	Sales
A04	Tokyo	Public agency	Engineering	B05	Tokyo	Real estate	Engineering
A05	Kanagawa	Stationery	Research	B06	Tokyo	Insurance	Sales
A06	Tokyo	Service industry	Research	B07	Tokyo	Energy	Engineering
A07	Tokyo	General Contractor	Engineering	B08	Tokyo	Public agency	Clerical
A08	Tokyo	Construction subcontractor	Engineering	B09	Tokyo	Information technology	Sales
A09	Tokyo	Construction subcontractor	Engineering	B10	Tokyo	Equipment	Clerical
A10	Tokyo	General Contractor	Engineering	B11	Tokyo	Publication	Reporting
A11	Tokyo	Electric power	Sales	B12	Aichi	Energy	Sales
A12	Tokyo	Equipment design	Engineering	B13	Tokyo	Machinery	ales engineerin
A13	Tokyo	Equipment design	Engineering	B14	Tokyo	Electric power	Engineering
A14	Tokyo	Design	Engineering	C01	Kanagawa	Electric power	Research
A15	Osaka	Machinery	Clerical	C02	Tokyo	Railroad	Clerical
A16	Tokyo	General Contractor	Engineering	C03	Tokyo	Energy	Research
A17	Tokyo	General Contractor	Engineering	C06	Aichi	Electric power	Sales
A18	Ibaraki	Information technology	Engineering	C07	Tokyo	Gas	Sales
A19	Tokyo	Equipment	Management	D01	Chiba	Public agency	Clerical
A20	Tokyo	General Contractor	Engineering	D02	Tokyo	Building management	Engineering
				D03	Tokyo	Machinery	Engineering

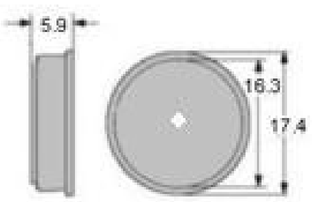

Figure 1 Miniature temperature and humidity data logger

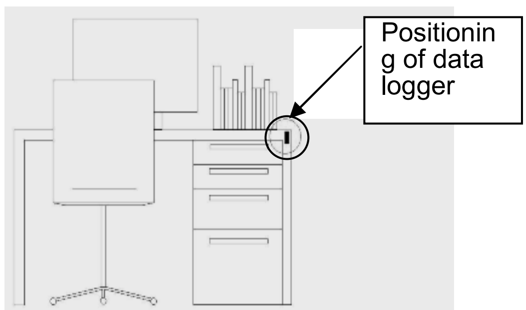

Figure 2 Positioning of data logger

Table 2: Survey items of the questionnaire

Location	Sensitive to heat	Radiated heat	Region where the respondent spent his/her childhood
Weather	Sensitive to cold	Predicted room temperature	Distance to the entrance
Date and Time	Work	Ideal room temperature	Air-conditioning system
Sex	Clothing	Predicted humidity	Current subjective warmth/coldness
Age	Physical fitness	Ideal humidity	Work efficiency under the current thermal environment
Kind of work	Air current as sensed by the respondent	Distance to the window	Remarks

4. Survey results

4.1 Business hour temperature and humidity at all of the offices surveyed

Figure 3 shows the daily mean indoor dry bulb temperatures measured in all of the offices during the business hours. From summer throughout winter, the authors see that temperature varies considerably from one office to another. The mean temperature distribution is roughly around 24 °C to 28 °C during summer, and 21 °C to 26 °C during winter. Mean room temperature gradually declines as the season changes from summer to winter.

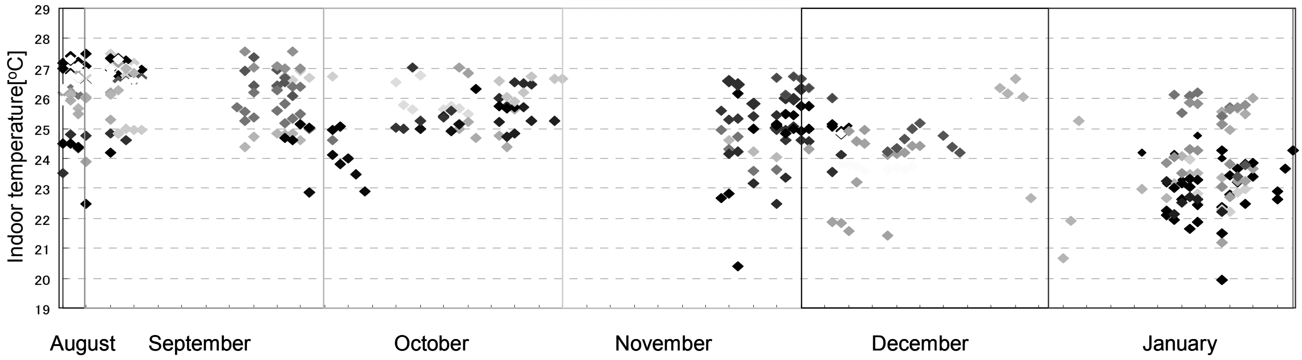

Figure 3 Daily mean indoor dry bulb temperatures during business hours

Figure 4 shows the daily mean indoor relative humidity during business hours in all of the offices measured. As with the dry bulb temperatures, the authors also see a great diversity here. The distribution is around 40% to 65% during summer, and 20% to 55% during winter.

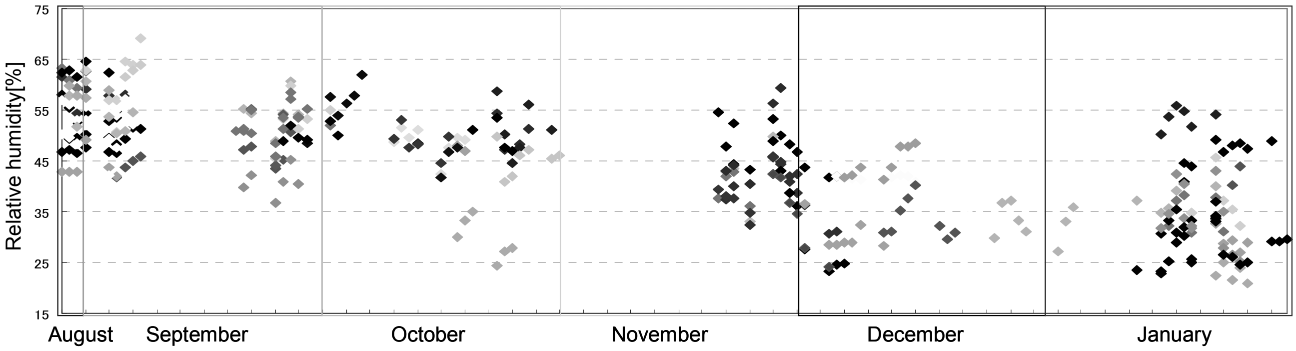

Figure 4 Daily mean indoor relative humidity during business hours

Many of the offices covered by this survey performed clerical or design work. Still, as the results show, the thermal environment differed greatly from one office to another.

Figure 5 shows the frequencies in different temperatures that were measured each month. Here the authors see a wide range in the lower temperature in each month surveyed. Figure 6 displays chronological changes in mean room temperature across all the offices on a weekday, in different months. During summer, the room temperature dropped when the air-conditioning began to work in the morning. During winter, temperature rose in the morning. Typically, the cooling system was in operation from summer to November, and the heating system from November.

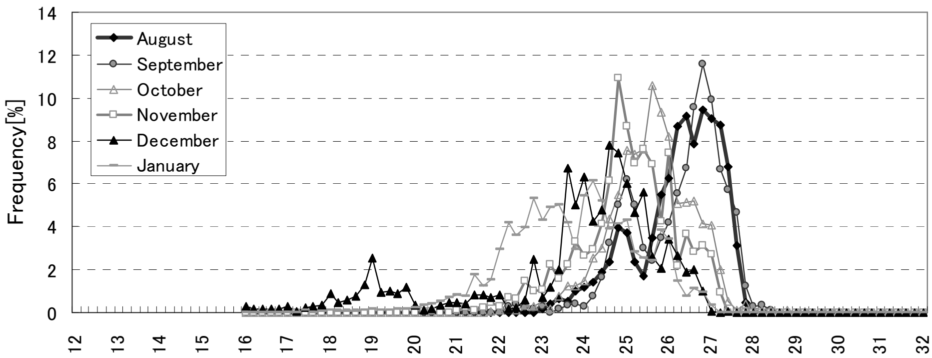

Figure 5 Frequencies in different temperatures measured during business hours

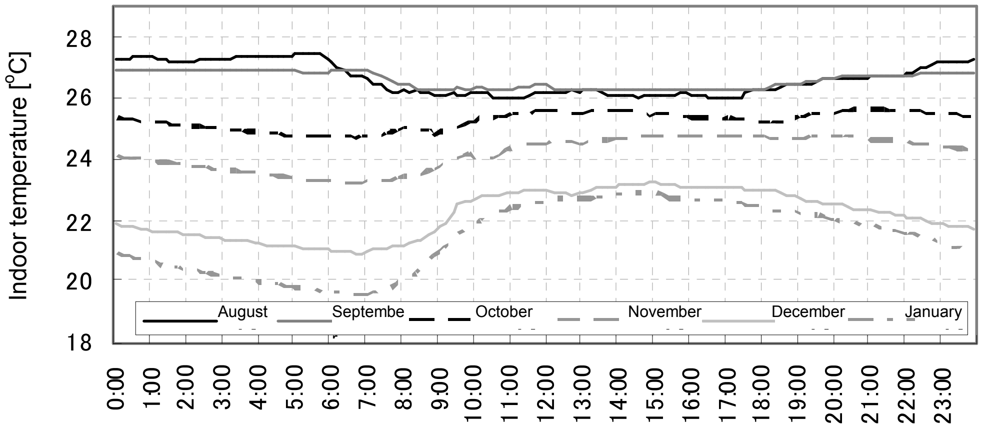

Figure 6 Chronological changes in mean room temperature in different months

4.2 Room temperature outside business hours

The typical business hours in Japan are, roughly, 9 a.m. to 5 p.m. In reality, however, many people also work overtime on weekdays and on weekends and holidays. The office air-conditioning system works intermittently, usually only during business hours. During overtime and on weekends and holidays, air-conditioning is usually provided in response to workers' requests.

Figure 7 shows the frequencies in different room temperatures that were measured outside regular business hours. As compared with Figure 5, the distributions cover an even broader range. Especially in winter, the distributions spread very broadly in the lower temperature range. Still, a typical air-conditioning system in Japan is capable of warming/cooling specified zones or floors only. Thus, when an office worker finds his/her thermal environment unbearable during overtime or on a weekend, he/she requests air-conditioning of the zone where he/she works alone.

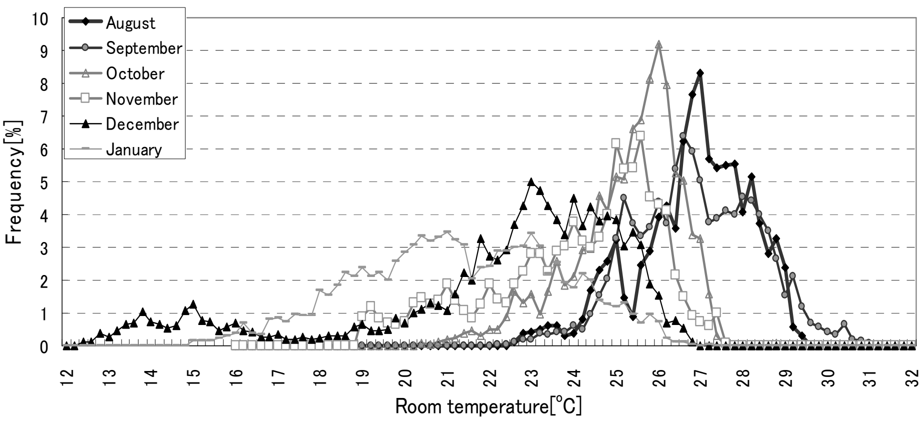

Figure 7 Frequencies in different room temperatures measured outside regular business hours

4.3 Differences between different methods of air-conditioning

Currently, two major methods of air-conditioning are in common use in Japan. One of the two, a central system, combines a central heat source unit and many air-conditioners. The other, a unitary system, consists of package air-conditioners as represented by the VRV system. Although the former is capable of providing relatively good quality of air-conditioning, it does not leave many choices to users. The

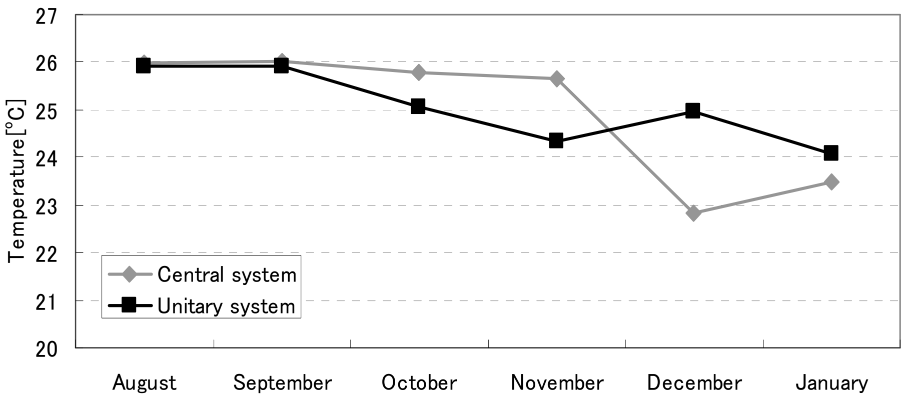

Figure 8 Mean room temperature during regular business hours for the different methods of air-conditioning

latter, on the contrary, allows users to choose from many choices of operation. Users can turn the respective air-conditioners ON/OFF and change their pre-set temperatures by remote control. Of the 41 offices covered by this survey, 24 employed a central system and the remaining 17 a unitary system.

Figure 8 shows mean room temperature during regular business hours of each month, for the two different air-conditioning systems. Although during summer the two didn't show much difference, the difference grew larger in fall and winter. With central systems, mean room temperature remained almost constant until November and then suddenly plunged in December. In contrast, with unitary systems the transition was much smoother, with no sudden ups or downs

4.4 Amount of clothing worn by workers

This survey covered 38 male and 3 female workers. Figure 9 shows month-by-month changes in the amounts of clothing the workers wore in their offices. Although many respondents replied with 0.6 clo as the amount they wore in summer, the amounts changed greatly from October to December.

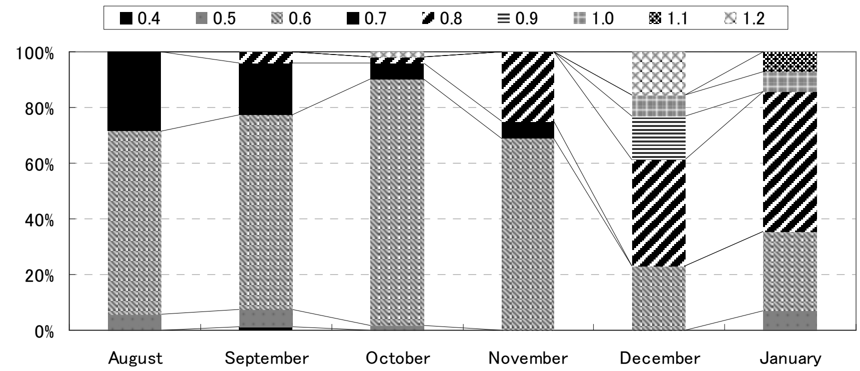

Figure 9 Amounts of clothing worn in offices

Figure 10 displays the correlation between temperature within the offices and the amount of clothing worn. Although a negative correlation is evident between the two, the authors see some workers who are heavily clothed in the range of lower office temperature.

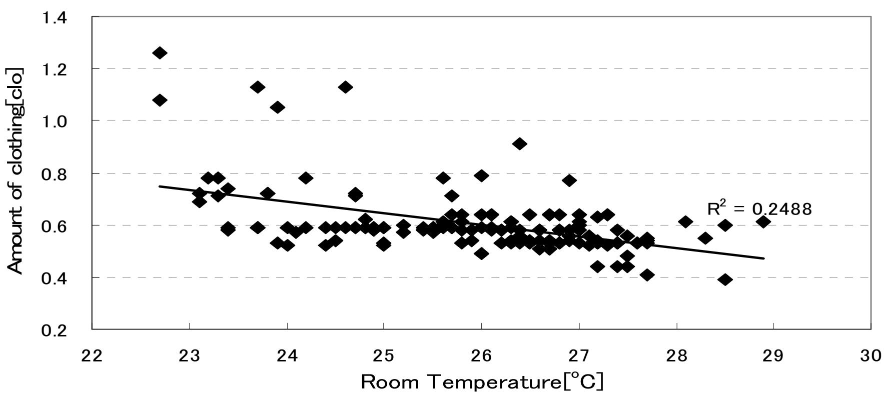

Figure 10 Office air temperature and amounts of clothing worn by workers

4.5 Thermal sensation felt by the workers

Figure 11 shows how many of the workers surveyed felt cold or hot in their offices. Synchronous with the major changes in amounts of clothing they wore from October to December shown in Figure 9, the authors see changes in the subjective warmth / coldness they felt during the same period.

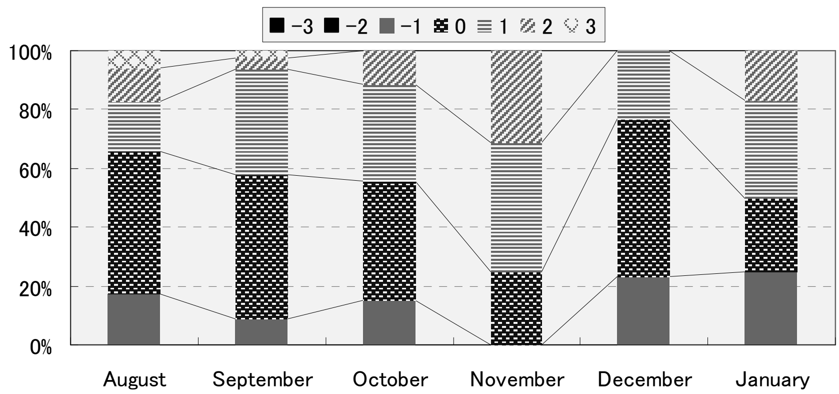

Figure 11 Coldness / warmth felt by workers in their offices

4.6 Effects of office thermal environment on work

The questionnaire asked the workers how their offices' thermal environment affected their work. Please note that this question asked for the workers' subjective impressions and was not intended to quantify their productivity. Figure 12 shows the replies. This same question was asked of the same person multiple times, and the vertical axis indicates a total of replies.

While "Seldom affects" and "Somewhat affects" are roughly equal in number, a considerable number of workers replied with "Does not affect at all." None of them said "Seriously affects."

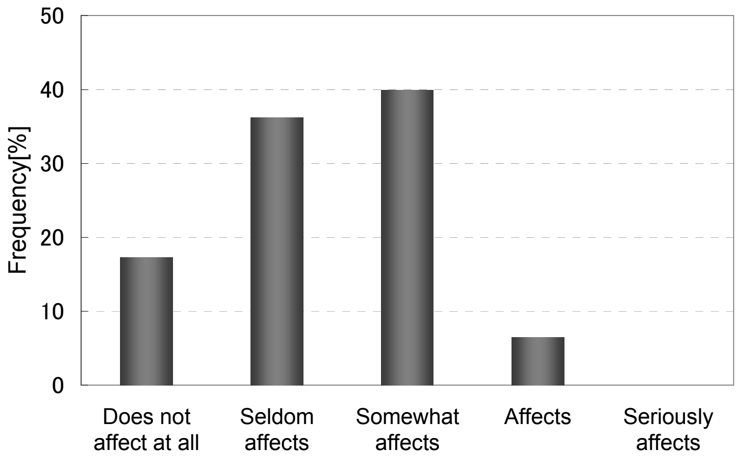

Figure 12 Effects of office thermal environment on work

5. Discussion

The survey results show that, even in offices performing similar work, indoor thermal environment can differ considerably from one office to another. Now, how do workers working in offices perceive their indoor thermal environments?

Figure 13 displays the relationship between room temperatures predicted by the workers surveyed and those recorded by the data loggers, for the same points in time. Although some positive correlation does exist between the two, the authors can hardly claim that the office workers correctly know the temperatures in their offices. The predicted temperatures carry prediction errors, on both the positive and negative sides, off the actual temperatures.

Judging from those survey results, the authors can infer that workers may illogically ascribe any change in subjective coldness/warmth to room temperature, disregarding disturbances to their senses brought about by changes in their own metabolism, amounts of clothing they wear, etc. Furthermore, the survey results also give us a concern that the temperature for cooling recommended by the Japanese government, 28 °C, might actually be seen as a very vague standard, in that people have different perceptions of what this temperature feels like.

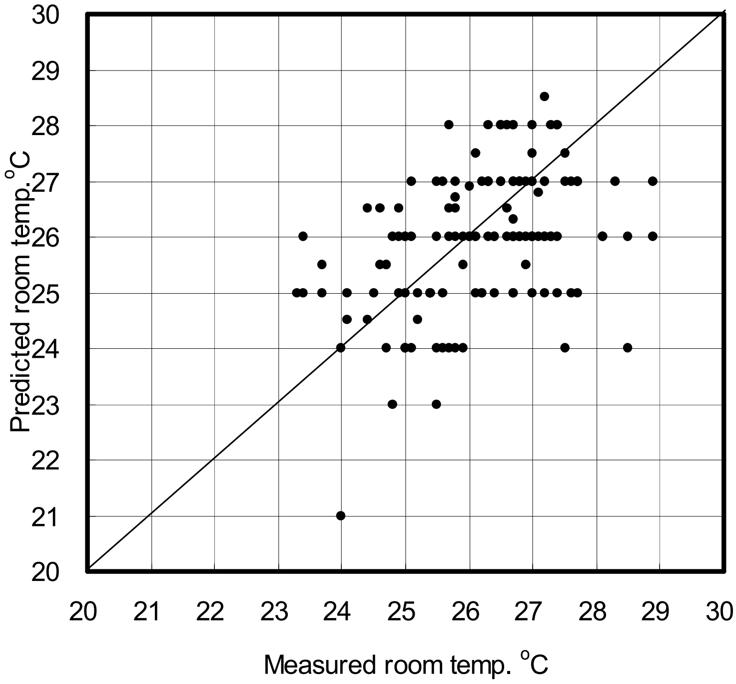

Figure 13 Room temperature measured and predicted by workers

6. Conclusion

The authors conducted a survey of indoor thermal environment in 41 offices in Japan. The results show considerably broad distributions of room temperature and relative humidity during regular business hours with each office as well as during each season. The authors also found that the Japanese government's recommended room temperature for cooling of 28 °C was not followed by a lot of offices surveyed but some of them kept their room temperatures rather higher. The government's call for fewer emissions was met with acceptance by some offices. Still, there is a concern that the physical quantity of "room temperature" might not be correctly recognized by some workers. To persuade more offices to follow its call for a temperature setting of 28 °C, therefore, the authors believe that the government needs to consider and take further measures in the years to come.

Acknowledgments

The authors hereby express our gratitude to all the people who kindly collaborated with us in conducting the office environment measurement and completing the questionnaire.

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INTEGRATING THE NATURAL AND BUILT ENVIRONMENT IN EDUCATION FOR SUSTAINABILITY AT THE BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY

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Keywords: education, natural environment, construction, sustainability, building, technology, trades

Summary

The British Columbia Institute of Technology (BCIT) is an innovative polytechnic specializing in advanced technology training in Western Canada. The largest of six schools at BCIT, the School of Construction and the Environment (SoCE) is concerned with the built environment, the natural environment and the relationship between them. The School integrates sustainability concepts, processes and technologies over the entire spectrum of programming and applied research. The belief is that in order to be effective, sustainability education needs to be embedded within each conventional trade, technology, and engineering sector and not be a stand alone endeavour. A Sustainability Framework has been established to guide research, curricula adaptation, and operations. Six themes spanning ecological, social and economic interests give focus to reflecting sustainability in action. The Framework underpins three foundational notions: i) ecological carrying capacity, ii) global equity, and iii) full-cost accounting. The School has also formalized a working partnership with BCIT's Administrative Services Department to reduce the Institute's ecological footprint and transform BCIT campuses into living laboratories of sustainability. The partnership approach has proven instrumental in accelerating sustainability as a focus for action across the institute.

1. Combining Construction and Environment Programs in One School

The BCIT School of Construction and the Environment (SOCE) represents a unique approach to interdisciplinary education. Whereas many schools adopt a "Built Environment" focus, concerned predominantly with buildings and their interactions with ecosystems, the approach at SOCE has been to pursue the integration of a full spectrum of natural resources programs within a School that simultaneously offers a suite of building design and construction-related programs. The intent in offering multiple disciplines housed within a single school is to encourage opportunities for interdisciplinary learning and research across the widest possible interface of natural and built environment systems.

This combination of programs offers a platform for the parity of value of both construction and environmental education. The School of Construction and the Environment espouses to be: "concerned with the natural environment, the built environment and the relationship between them." The direction of the School's evolution towards sustainability in all aspects of its curricula, operations and research activities, and its multi-disciplinary format, boasts a rich diversity of educational opportunities. Programs in natural resource management range from Mining to Fish, Wildlife and Recreation. Technology programs include: Civil Engineering, Environmental Engineering, Architectural Building Sciences, and Interior Design. Trade programs encompass: Steel Fabrication, Piping, Saw trades, Joinery, Carpentry and Electrical.

1.1 Targeting Curricula and Aligning Administrative Practices to Reach New Horizons

In 2006, observing the links between changes in global ecosystems due to anthropogenic activities and the implication that the building sector accounts for two-thirds of global energy and materials consumption (Worldwatch 1995), the School's management team embarked on a "sustainability agenda" that targeted four strategic areas:

i) creating new and emerging disciplines;
ii) morphing of existing disciplines;
iii) embedding the practices of sustainability into existing disciplines;
iv) integrating operations with academic programs.

The objective of the SOCE is to accelerate a transformation in the state of practice of natural and built environment sectors towards the embodiment of sustainable development and environmental stewardship.

To institutionalize this strategy, the SOCE embarked on a three year initiative that commenced with the creation of a full time director position in the School. This significant role is dedicated to incorporating progressive environmental management and rapidly emerging sustainability themes into the education programs and applied research activities of the School. Since mid 2006, the Director, Sustainable Development and Environmental Stewardship has been working with the School's Associate Deans and Program Heads to transform academic programs and to proactively embed environmental and sustainability concepts, technologies and processes within the mandate of the SOCE. The state of practice for commercialization of new and emerging technologies, their applications and industry standards are explicitly considered through lenses of sustainability: social and environmental impacts, efficiencies, conservation opportunities, and restoration of potential natural resources. The Director is a resource to the SOCE and builds research capabilities in sustainability while addressing the general needs for transformation of academic portfolios. However, in order to gain rapid traction, the Director's priority has focused on the immediate needs of the Natural Resources Portfolio of programs. This area of the School is already engaged in formative thinking about sustainability issues. Several programs within this portfolio are in the process of being adapted and/or introduced. The intent is to focus preliminary efforts in this area of the School as a strategy to lodge the initiative and build a base of confidence for implementation approaches.

The formal transformation towards a pervasive sustainability culture within SOCE began by development of a Sustainability Framework (http://www.bcit.ca/construction/sustainability) to guide thinking and practice within the School. The Framework was developed by the School's management team in consultation with the Department Program Heads. An incremental approach was developed whereby the Dean stipulated that all departments would have to clearly and specifically demonstrate how their portfolio was moving towards sustainability in curricula, operations or research activities. BCIT's status as a Polytechnic facilitated this level of leadership since faculty are predominantly in educational roles that are not tenured, and research activities are linked to programs. Ultimately, program funding could be tied to the performance of departments to respond to the sustainability agenda.

The School's annual operations planning process was amended to include a focus on "Sustainable Development and Environmental Stewardship" whereby each department is asked to reflect their program changes accordingly. As an annual planning tool that is used for both performance assessment and budgeting purposes, the incorporation of sustainability as a focal point in the Operations Plan enables the School to both monitor its progress towards sustainability goals as well as align its administrative decisions and resource allocations accordingly.

1.2 Developing an Interdisciplinary Research Agenda

As a polytechnic institute, BCIT has a mandate to pursue technological development in applied research. For the School of Construction and the Environment, a research agenda that pursues interdisciplinary innovation in technology is a "natural" fit. Within the School, several research portfolios were initiated to reflect both a need and desire to use applied research to both: a) apply technology that integrates the natural and built environment towards more sustainable outcomes, and b) inform the evolution of educational programming toward sustainability goals. Examples of "Centres" developed by the School to meet these dual objectives include: the Centre for the Advancement of Green Roof Technology, the Building Science Centre, the Canadian Housing and Construction Centre, the Centre for Infrastructure Management and the Centre for Energy Systems Applications (www.bcit.ca/construction/research/areas.shtml).

2. Incorporating Sustainability Concepts, Processes and Technologies

2.1 Adopting a Sustainability Framework

To begin the process of transforming SOCE towards an organizational culture of sustainability, the management team consulted with the School's Program Heads to develop a Sustainability Framework with six guiding themes. The Sustainability Framework is based on a systems perspective that links the natural and built environment through a global cycle of resource flows, see Figure 1. It recognizes that production starts with ecosystems from which natural resources are derived, as a function of economic activity aimed at meeting societal aspirations for improved quality of life. Natural resources are then turned into the commodities used to construct and operate built environments with the help of engineered systems. The wastes from these activities are, ultimately, absorbed by ecosystems to re-produce natural resources, and so on (www.bcit.ca/construction/sustainability). The integration of environment, society and economy can be conceived as a circular flow where economic activity bridges the relationship between the environment and society – it is the vehicle for extraction of resources and deposition of wastes through the process of manufacturing and consumption. The implication is that an imbalance in the rate of resource harvesting or pollution production that exceeds an ecosystem's reproductive or assimilative capacities creates an unsustainable condition. A nested hierarchy of systems is also implied whereby ecosystems are viewed as the foundation for societal activities that are implemented through economic activities. The economy exists because of and is dependent on society, which exists because of and is dependent on the environment. However, the economy, despite its ultimate dependency on people and the planet, exercises an "organizing" capability – it can control the rate of extraction, distribution and consumption of resources. Through globalization, the economy brokers relationships between society and the environment: directing both the flow of resources and the location of labour. It has the power to both serve as well as dis-serve society. Similarly, society can serve as well as dis-serve the environment – to its peril.

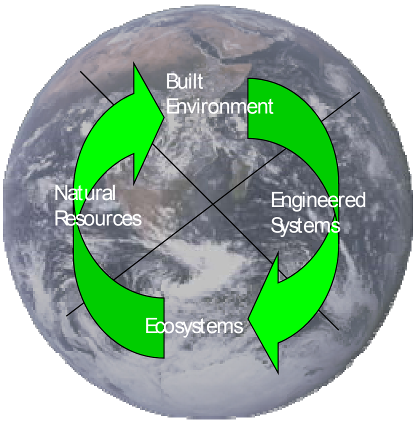

Figure 1 Sustainability Framework: systems perspective of resource flow.

The Sustainability Framework underpins three foundational notions:

i) ecological carrying capacity,

ii) global equity, and

iii) full-cost accounting.

To give meaning to these foundational notions within the Sustainability Framework, six themes spanning ecological, social and economic interests were developed to give focus to departmental programs and the work of individual faculty and staff. The intent is that the themes be used to guide thinking and inform adaptations to curricula, education delivery, applied research, and School operations.

The six sustainability themes are:

- Strengthen and protect assets
- Balance use with renewal of resources
- Account for all costs and benefits
- Reduce waste and eliminate toxics
- Ensure safety and access to services
- Support opportunities for improvement and enjoyment

2.2 Pedagogy and Practice: Incorporating Sustainability Across the Curricula

Sustainability within the context of urban development is becoming an industry standard in British Columbia. All industry sectors are undergoing rapid transformation. Global issues such as livability, climate change and shifting economics are seen to need new approaches by practitioners. Entry level and mature students have an expectation that programs address these issues. There is also a general trend towards integrated consideration of health, sustainability, ecological principles, and community-based solutions as the basis for “sustainable” industrial and social development. SOCE strives to drive this industry agenda into its program delivery as quickly and as seamlessly as possible to meet the mandate for job-ready graduates. Alignment of existing and emerging programs and applied research focused on core sustainability themes is intended to ensure that all existing and future engineering, trades and technology programs in SOCE produce graduates that are at the cutting edge of sustainability practice within their fields.

A broad, progressive, innovative and consistent strategy has been designed to manage the incorporation of sustainability across the curriculum of the School. Given that programs range from trades to Master’s level, the unique approach at SOCE consists of encouraging integrated systems thinking and trans-disciplinary solutions.

2.2.1 Creating new and emerging disciplines

To immediately implement the sustainability agenda, the School has developed the new Bachelor of Technology in Ecological Restoration program. It aims to provide students with a strong foundation in the methods available to restore a broad range of ecosystems impacted by human influence. Graduates will obtain skills to assist in the recovery of degraded ecosystems. They will also be encouraged to develop leadership and innovation skills to enable cross-disciplinary work with other professions in a pre-emptive approach to avoid or mitigate impacts to ecosystems from human activities (BCIT, 2008, 2).

SOCE is also pursuing a new Sustainable Urban Development Bachelor of Technology. The goal of this degree is to prepare graduates with the technical, valuation, managerial, and capacity-building skills relevant to all industry sectors that are transitioning to a sustainability-focused economy. Through community-based experiential learning, students will be exposed to dimensions of sustainability and "integrated practices." Although originating in the SOCE, this program will be open to diploma graduates from all Schools within BCIT and will extend opportunities for students to pursue integrated, or trans-disciplinary studies, and to study sustainability in-depth in order to fill the needs of industry for human resources at the operational levels, and entry management levels (BCIT, 2007a).

2.2.2 Morphing of existing disciplines

Existing disciplines are continually changing. Therefore, striving to keep the curriculum as current as possible is an imperative. SOCE, for example, is meeting this need through its Civil Engineer distributed learning courses that provide a variety of training to the municipal utilities' sector. Municipalities in Canada are facing fiscal and human resource constraints. Meanwhile civil infrastructure is aging and new technologies are usually expensive. This predicament prompted the SOCE to create the Centre for Infrastructure Management (CIM) (http://commons.bcit.ca/infrastructure). The CIM promotes improved infrastructure management, develops and supports best practices through workshops and distributed learning and is formulating programs to provide professional development and training opportunities in an integrated and sustainability focused fashion. This is an example where new programs are created to enable multi-disciplinary and flexible education to existing students and to industry practitioners who need to update their knowledge. The opportunity for morphing of existing disciplines is, therefore, not squandered on traditional education silos. Instead, modern, integrated and sustainability-focused concepts (for example promotion of trench-less technologies) are included at the onset of program formulation. As such, sustainability is not an add-on, but rather an integral consideration to the morphing of traditional sectors such as public works management.

The CIM also intends to target its programs to suit a matrix of learning requirements at the functional, working, and detailed knowledge levels. For example, an elected official may only need a functional understanding of infrastructure management topics, whereas a public works manager will need a combination of functional understanding, working knowledge, and detailed knowledge depending on the topic. The scope of the education program is being given extensive breadth even at the entry level of delivery. This approach is much more robust in terms of keeping student's and practitioner's options as open as possible, while allowing for staged consolidation of certificates, diplomas and Bachelor programs.

Adapting existing curricula is being addressed through a School-wide approach. Recognizing that the work load for educational faculty impedes opportunities for reflection and research that might commonly accompany a research/teaching appointment, the School has launched "The Pacific Spirit Project." This initiative is modeled on the Ponderosa Project (http://www2.nau.edu/~ponder-p/) that was pioneered at Northern Arizona State University and subsequently adapted as the Piedmont Project (http://www.scienceandsociety.emory.edu/piedmont/) by Emory University in Atlanta, Georgia, USA. Both initiatives focus predominantly on the environmental aspects of sustainability and place an emphasis on inter-disciplinary faculty engagement and empowerment.

The Pacific Spirit Project represents a unique adaptation to a polytechnic context. Like its predecessors, the project enables faculty who are interested in incorporating sustainability concepts and practices into their curriculum. The project commences with a two day workshop followed by a commitment over the following six weeks to reflect on how to use what was learned to adapt curriculum so that it includes sustainability content. The project reconvenes with a one day meeting at the end of the six week period where faculty share their plan for next steps as well as reflect on experiences and lessons learned through the process. Usually, the workshop is held in May and the reconvening meeting occurs in late August. However, because the Pacific Spirit Project aims to meet the needs of faculty in both technology and trades programs, there is an additional layer of complexity that must be addressed regarding the timing of the project. This is because trades instructors seldom enjoy the "break" in teaching responsibilities that traditionally occurs over the summer months. This poses a challenge to the structure of the project that assumes the built-in reflective period.

To address some of these challenges, the Pacific Spirit Project is being undertaken in cooperation with the BCIT Learning and Teaching Centre (LTC). Faculty who wish to pursue significant changes to their curriculum will be offered advice and guidance by the LTC on how best to proceed, and what incentives or other resources are available to assist. These incentives, in the form of paid leave from teaching duties for example, are critical to enabling faculty with full and continuous teaching loads to succeed in securing the time needed to revise curricula. Additional resources are also being provided by the SOCE for discretionary use by the Steering Committee that have been appointed to oversee the initiative. These funds will be provided on an as-needed basis to faculty that are engaged in the Pacific Spirit Project and who are embarking on or are in a process of adapting their curriculum.

2.3 Administrative Change: Sustainability in Education Delivery and Departmental Operations

Technology enabled learning is an institute-wide priority at BCIT. Within SOCE this is reflected and modified to technology enabled learning that also achieves sustainability objectives. An example is distributed learning. An emphasis on e-learning and other forms of distributed learning is a strategic focus within the School. This is partly in response to the fact that a significant portion of SOCE students are commuting long distances to attend classes. A large percentage of the student body also comprises part-time studies enrollment, meaning that students who are commuting usually do so to attend only one class per day.

Different educational programs lend themselves to different approaches. While e-learning can work as a delivery vehicle for portions of or indeed whole courses in some program areas, skills training such as those prevalent in trades programs require hands-on, supervised instruction. Administratively, the educational content requirement for trades programs is far more prescribed by industry and government certification bodies than are the technology programs. This means that adapting the delivery or substantive content in trades training becomes extremely difficult. This remains an ongoing challenge.

2.3.1 Embedding the practices of sustainability into existing disciplines

Recall the four strategic areas adopted by SOCE's management team that were introduced in section 1.1 above. The third strategic area: embedding the practices of sustainability into existing disciplines is perhaps the entry point for many trades training programs to respond to the challenge of incorporating sustainability.

Embedding the practices of sustainability into existing disciplines is a way to demonstrate the values of full-cost accounting, social equity and environmental stewardship without necessarily having to revise the substantive content of curricula. An example of this approach is demonstrated in the School's Joinery program. A criteria-based point system to evaluate the department's operations is being developed. The point system aims to reflect the themes of the Sustainability Framework and will be used to evaluate product purchases for the program. A range of materials will be assessed for use in the production of office furniture ranging from Forest Stewardship Council certified wood to alternative fibers such as bamboo and straw. Continuous application of the point system will be used to:

- Review commonly used materials and identify those considered to be toxic,
- Assess opportunities to substitute non-toxic materials,
- Reduce waste and identify options that divert wood fiber from the waste stream,
- Upgrade furniture production to meet LEED^{TM} minimum requirements.

2.4 Transforming the Campuses to become "Living Laboratories" of Sustainability

BCIT has five campuses scattered across the Vancouver Metropolitan area, one of which is shared with several other universities and institutes. Each campus is unique and several cater specifically to the needs of individual technology areas. Examples include the Aerospace Campus, or the Marine Campus. However, what all campuses share is a commitment to embodying the best in state of the art technology. More recently, this vision is being complemented by an aspiration to become "Living Laboratories" of sustainability.

2.4.1 Integrating operations with academic programs

The fourth and final strategic area of the SOCE's management team approach is: Integrating Operations with Academic Programs. This requires a collaborative effort with BCIT's Administrative Services Department that oversees institutional responsibilities for campus planning, facilities management, purchasing, safety and security, among others. In March of 2007, the Dean of the SOCE signed a Memorandum of Understanding (MOU) with the Executive Director of the Department of Administrative Services pertaining to: Environmental Stewardship and Sustainability Practices. The signing took place during BCIT's biannual "Eco-Fair" event and was witnessed by the VP Education and Student Services who then gave a public address in support of sustainability as both a value in education and opportunity for campus-wide engagement. The MOU enables students, faculty and staff to work collaboratively towards environmental stewardship and sustainability practices on BCIT campuses. Ten activities are articulated that include the annunciation of the commitment to "developing and promoting the concept of the campuses as living laboratories to further the evolution of environmental stewardship and sustainable development practices" (BCIT, 2007b). Other activities include:

- Involving faculty and students in creating examples of new technologies, methods, and approaches and demonstrating and documenting those as part of the educational and research interests of the Institute.
- Providing input to master planning of the Burnaby campus and to specific development activities related to the plan's implementation.
- Promoting BCIT's activities in environmental stewardship and sustainability practices within the Institute and to external audiences.
- Developing a "green" plan for the campuses belonging to the Institute and those managed in partnership with other institutions.
- Disseminating information throughout BCIT campuses to inform, educate, promote and encourage best practices in sustainability and environmental stewardship by staff, faculty and students.
- Assessing the ecological footprint of the Institute and developing the means and methods to minimize and/or repair that impact while achieving economies and adding value to the Institute and industry clients.

2.4.2 Reducing the ecological footprint of campus

A Greening Campuses Strategic Plan is being drafted by the Director Sustainable Development and Environmental Stewardship and the Director of Campus Planning. The document is intended to complement the Institute's Campus Master Plan (http://www.bcit.ca/planning/masterplan), which cites sustainability as a planning principle. The strategic plan utilizes the Sustainability Framework that was developed by the SOCE and introduces an overarching, aspiration to reduce the Institute's ecological footprint sufficiently to "model sustainability by achieving a four-fold decrease in the amount of energy and materials throughput on campus" (Moore and Wong, 2007, 6). In effect, this is similar to the concept of a "Factor Four Economy"

(Weizsacher et al., 1998) or the 80 per cent reduction in the level of greenhouse gas emissions that scientists claim would be required to stabilize global climate (UCSUSA). Seven sub-goals are articulated to guide the initiative in support of the proposed objective:

i) Greenhouse gas neutral
ii) Net energy producer
iii) Zero Waste
iv) Water Balanced
v) Ecologically Restored
vi) Equitable and Socially Responsible
vii) Accessible to All Students and Faculty

Given the ambitious nature of this effort, the goals and overarching objective will be applied and tested at the BCIT main campus in Burnaby. A faculty researcher has been retained on a part-time basis to investigate the Burnaby Campus ecological footprint using a comprehensive material flow analysis approach. The findings will be used as a baseline. The method will be documented for purposes of informing new curriculum development for SOCE's Environmental Engineering Program and the proposed Sustainable Urban Development Program, mentioned above. The initiative is building momentum slowly as service units within various departments recognize the opportunity to meet multiple objectives through the initiative. For example, the Institute's waste management and energy management programs are benefitting from the increased communication and awareness that is building around the campus "Ecological Footprint" initiative. People want to be involved in solutions and there is a keen interest to learn about how to reduce one's own footprint. When that overlaps with energy conserving activities on campus, for example, there is a dual benefit: to the Institute and the individual.

2.4.3 Engaging other schools and departments

The Living Laboratories concept was initiated at BCIT through the School of Health and the related research that was being undertaken within BCIT's Technology Centre. The concept has tremendous appeal as an overarching banner for the relationship that the administrative and services arms of the institute can have in collaboration with the academic and applied research areas. The engagement of SOCE with the Administrative Services Department forms one of potentially many similar initiatives that aim towards further integration of operations with academic programs. It may also serve as a spring-board for increasing inter-disciplinary activity across the schools of the Institute. For example, in forming the steering committee to oversee effective implementation of the MOU referenced above, the Administrative Services Department and SOCE invited the Institute's Information Technology Services unit to participate permanently in steering committee meetings. The rationale was based on a shared interest in sustainability and interest in learning about what embracing sustainability would mean for each of the operations and academic units. The steering committee also agreed to adopt a working-group model whereby different groups of individuals could work on specific projects related to the overall implementation of the MOU, regardless of their home department affiliation. The longer-term, shared objective is to find initiatives and opportunities to engage a broader cross section of the Institute's operational and academic business units within the activities of the steering committee and under the banner of creating Living Laboratories of sustainability on BCIT campuses.

3. Reflections on Lessons Learned and Challenges to Overcome

SOCE's transformation to a culture of sustainability is a broad and multi-faceted endeavor. It is, therefore, essential to hire dedicated staff whose responsibility it is to nurture, inspire and constantly attend to the various initiatives and opportunities that such a process engenders. It cannot be done on the side of one's desk. By the same token, one person alone cannot bring about a complete organizational transformation. Building relationships and opportunities to demonstrate leadership across the organization is also important.

It is noteworthy that the interest in sustainability is now so prevalent amongst students, faculty and staff, that the initial intended focus on the Natural Resources program portfolio has very rapidly spread to many other parts of SOCE and indeed the BCIT Institute simultaneously. This has happened in a much more accelerated manner than was originally envisaged. By the same token, while this is an exciting evolution, managing expectations is important. Success in many regards, like the road to partnership, is a journey of many steps. Some feel like giant leaps and some feel like steps backwards. Nevertheless, being clear about roles and responsibilities, what can be reasonably accomplished within a given time period and with available resources are all important management skills that equally come to bear here. An important insight for gaining momentum is to identify clear goals that meet the interests of multiple parties and to begin working on their implementation right away. For example, BCIT holds a biannual event called "Open House." This is the Institute's most significant student recruitment activity. In 2008, the organizers of Open House developed a theme that aimed to demonstrate how being a part of BCIT enables opportunities to make a positive contribution to society. Environmental stewardship was chosen as a concept to help illustrate the theme. Simultaneously, the Director of Sustainable Development and Environmental Stewardship and a handful of BCIT employees were organizing an employee volunteer committee called the Green Team. Some members of the Green Team were also part of the Open House organizing committee. Once the theme was announced, the synergy created between the Institute-wide focus on Open House and its concomitant themes and the actions of the Green Team created a tremendous momentum that seemed to feed itself through a year-long "buzz of activity" culminating in a very successful Open House that featured a tent display dedicated to the Green Team's activities as well as local media coverage. This type of excitement could probably not have been achieved by either initiative acting alone.

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WASTE PREVENTION POLICIES, ITS REDUCTION POTENTIAL AND ECONOMIC IMPACTS

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Keywords: Integrated Solid Waste Management, Waste Prevention, Life Cycle Assessment and Life Cycle Cost Assessment.

Summary

The quantities of municipal solid waste in the world are increasing each year, fast growth as GDP. This presents a challenge for metropolitan cities in developed and developing countries. Waste prevention encompasses activities of waste avoidance, reduction and reuse. These activities are considered to be preventative as they contribute to decrease the amount of household waste entering the collected waste stream. Previous researches identified many approaches across a wide range of waste prevention policies to be implemented in metropolitan cities. To gain a better understanding of which effort should be focused on this study, an analysis of current activities of all stakeholders at the study field was conducted. For each program, it was identified the component of household waste that the approach was likely to impact upon. Based on that, reduction potentials were calculated as well as its economic impacts using life cycle cost assessment. The results demonstrated that costs decreased as a result of waste prevention policies implementation combined with recycling and composting. In setting the context for this study, it was possible to notice that this type of solid waste requires action at all levels in the production chain. Understanding the social and institutional performance of environmental policies is an area of significant and growing concern. Thus, the assessment of activities that influence consumption patterns is highly relevant. While waste prevention is certainly not easy, the rewards are potentially very significant in terms of cost savings, social inclusion and the local and global environment. In the long term, these activities should continue to decrease solid waste in absolute quantities and hopefully also the underlying growth rates.

1. Introduction

In early times, the disposal of human and other wastes did not pose a significant problem because the population was small and the amount of land available for the assimilation of solid waste was large. However problems with disposal of wastes can be traced from the 14th century, littering of food and other solid wastes in medieval towns led to the breeding of rats and the outbreak of the plague epidemic killed half of the Europeans and caused many subsequent epidemics and high death tolls.

Nowadays, limited space for new landfill sites and social acceptance of solid waste management policies are the majors concerns related to solid waste issue. All policies in this area must be environmentally friendly, economically sound and socially acceptable to guarantee their success, since social movements and conflicts between residents and authorities sometimes lead to closure of an existing facility or to fail an applied policy. Therefore, in dealing with solid waste, there are two fundamental requirements: reduce the amount of solid waste generated and then an effective system to manage the waste still produced.

Solid waste management must be sustainable. In other words, it must consider the whole life cycle of waste from the cradle to the grave. An integrated solid waste management – ISWM system combines solid waste streams, collection, treatment, and disposal methods, within a life cycle approach [White, 2002]. Using a range of management options in an integrated system gives the flexibility to channel waste via different treatments as economic, environmental and social conditions change.

Nevertheless, for an ISWM system to reduce solid waste effectively waste prevention is necessary. In other words, waste prevention is an alternative to avoid solid waste generation. Waste prevention, “waste reduction” or “source reduction” refers to any change in the design, manufacture, purchase, or use of materials or products (including packaging) to reduce their amount, toxicity and fugitive emissions before they enter into solid waste stream.

Recently, new studies have been developed in order to understand how waste prevention helps to reduce solid waste generation. Most of them are based on the conventional solid waste management, which do not include all the activities in urban cleansing. Although, all these studies have presented trusty data, no absolute results have been achieved. Economic and environmental aspects must be included simultaneously to improve the decision-making tool.

Hence, this study will address the lack of comprehension about waste prevention inside ISWM system subject, based on the evaluation of environmental and economic impacts. And, to achieve this it will introduce the unique system adopted in Porto Alegre, presenting how this system works in the local context and also as a potential model for adaptation elsewhere.

2. Study Case

According to the National Survey of Basic Sanitation [IBGE, 2000], about 69% of the solid waste produced in Brazil is disposed in adequate landfills but the remaining part has being still disposed in waste dumps. The 13 biggest cities are responsible for 32% of the waste collected in urban centers and almost 100% of them has adequate final disposal.

In addiction, 236 out of the 5507 Brazilian municipalities have a selective collection implemented as an alternative to resolve the environmental, economic and social problems consequents of informal solid waste collection in wastes dumps [CEMPRE, 2004].

The research was delimited to Porto Alegre considering the previous elements and the fact that its ISWM system is internationally recognized as a good example of the municipal urban cleansing management in developing countries.

2.1 Porto Alegre City

Porto Alegre City is located in the southern part of Brazil and has a population of approximately 1.5million [Fig.1]. Since 1996, Porto Alegre has consistently had the highest standard of living of all Brazilian metropolitan areas, with a human development index of 0.865 and a gross domestic product per capita of US$4697 per year, according to IBGE (2000a, b). Its progress is primarily linked to the way in which the city has been managed since 1989, with the adoption of the participatory budget, in which citizens and local government divide the responsibility to designate the municipal budget.

Figure 1 Porto Alegre's location in Brazil's Map, (CIA, 2005).

As a direct consequence of the high level of citizen involvement in allocating the municipal budget, the proportion of investment serving public environmental management policies, as well as solid waste management, and the regeneration of public spaces has increased in recent years [Carrion, 2005].

These results represent an important advance in prioritizing social issues and an improved political relationship between government and society. However, an emergency situation that Porto Alegre faced in 1989 also contributed to the increase of these investments. At that time, the dumpsite had already reached its capacity; its soil was contaminated and pollution levels were increasing in environmentally protected areas. In addition, a large number of people were making a living by searching for and collecting recyclable waste from inside the dumpsite and consequently spreading the diseases associated with waste among the population.

In 1990, the Municipal Department of Urban Cleansing, with objectives that not only included sustainable development but also a strategy to fight poverty with income generation, implemented an ISWM system. This system was based on four interrelated components: (a) citizen participation, (b) public environmental management programs, (c) comprehensive knowledge of Porto Alegre's natural and built environment and, (d) environmental education [Menegat R., 2002].

As shown at Figure 2, the ISWM in Porto Alegre uses a combination of four methods:

a. Source separation into domestic, industrial, commercial and hospital solid wastes;
b. Selective Collection;
c. Different treatment, re-use, disposal for each type of solid waste, and;
d. Promotion of environmental education.

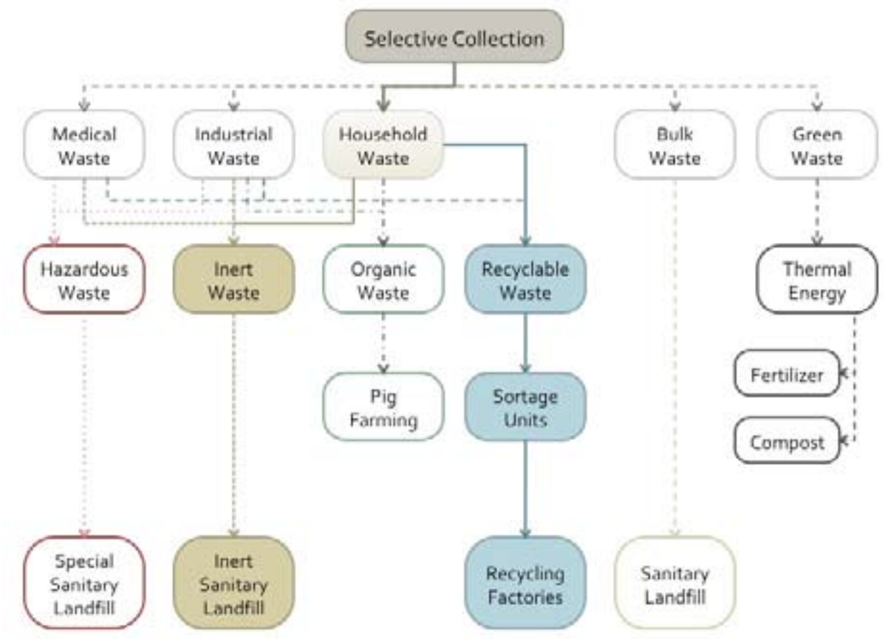

Figure 2 Porto Alegre's integrated solid waste management system flowchart.
**Highlighted processes in grey correspond to the boundary system adopted in this study.*

Consequently, to promote the inclusion of poor communities, the first action was to create an organization for those who were living by collecting recyclable wastes (the Former Scavengers Association), and after that a partnership to intro-duce selective collection in the city. Based on a mutual agreement, it was established that the local government would be responsible for collection and delivery of recyclable waste to the so-called unidades de triagem (sorting units), where former scavengers would separate, store and sell them to recycling factories. Through this partnership, the former scavengers man- aged to obtain higher prices for their recyclable materials and a larger quantity of such material has been sold directly to the formal recycling industries, thus avoiding the middlemen.

Construction and demolition debris, considered as inert waste, are recycled and disposed in a different site. Waste concrete and brick is usually crushed, screened and used as road-base and paving pieces, this process is accomplished by the local government but paid by the waste generators. Vegetation removed during clearing of the site is also collected by the local government and used in the composting of organic waste. In case of steel, glass and plastic wastes, they are usually sold to recycling factories in the region. The entire process consists in: (a) on-site source separation; (b) concrete and brick recycling; (c) green waste composting and, (d) disposal at the inert sanitary landfill.

Environmental education is also one of the important elements inside Porto Alegre's ISWM system. In 1998, the environmental atlas of Porto Alegre was published, providing the basic knowledge that citizens need in order to participate in an informed way. Hence, public participation as a part of the ISWM system was established in Porto Alegre through a participatory budget, the former scavengers associations and an environmental education programme.

At the present day, the selective collection has 80 employees, 29 trucks and collects around 40t/day of solid waste. According to DMLU, the cost of the selective collection is US$42 per ton, being one of lowest cost in Brazil. It is estimated that independent collectors (not members of the scavengers association) collect 150 tons of solid waste out of which 70% is potentially recyclable [Tab.1].

3. Waste Prevention

Realizing the limits of downstream, end-of-pipe approaches, during the early of 1990's many environment administrations fully embraced "source reduction" and "pollution prevention" as general, overarching goals.

This meant, among other things, that as little solid waste as possible was to be finally disposed of, and this objective was to be achieved with priorities focus on preventive efforts, generally followed by recycling.

In most of previous studies, both waste prevention and waste minimization usually have the same meaning. However, according to terminological definition at OECD report [OECD, 2000], waste minimization is a broader term than prevention in that it includes recycling and incineration with energy recovery. As discrete activities, both recycling and incineration are distinct from waste prevention.

Table 1 – Porto Alegre's ISWM System Data [DMLU, 2005].

Population	1,448,322 inhabit
Total solid waste collected	296,140.33 t/year
Local population attended	100%
Household solid waste production	0.62 Kg/ inhabit.day
System's cost	US$ 3,575,320/year
System's self-sufficiency	51.3 %
Recycling efficiency	20 %

Therefore, waste prevention is fundamentally different from the waste minimization. Recycling and disposal options all come into play after goods have been used. In contrast, prevention takes place before materials have been identified as solid waste. To implement waste prevention, managers need to promote practices that reduce solid waste before it is generated.

The consensus understanding of waste prevention achieved by OECD in 1998 can be broken into three types of action:

a. Strict Avoidance, involving the complete prevention of solid waste generation by reducing material or energy intensity in production, consumption and distribution;
b. Reduction at Source, with minimization of materials or energy consumption;
c. Product Re-use, considering the multiple use of a product in its original form or purpose for an alternative with or without reconditioning.

It is important to highlight that the potential contribution of prevention to overall waste minimization has not been realized. While waste prevention will never make recycling obsolete, the application of both will generally have a greater influence on overall solid waste reduction than the singular application of one or the other. For example, there are numerous applications of source-reduced packaging, made with recycled materials, which can also be recycled.

At the municipal level, waste prevention avoids unnecessary solid waste collection, processing, storage and final disposal. It also offers significant potential for diverting materials from landfill, as well as contributes to greenhouse gas mitigation. Secondary materials market development can also be avoided and, consequently, it saves money and conserves natural resources. However, experience at the municipal level is still limited as well as the difficult to access its contribution to solid waste diversion relative to recycling.

Waste prevention also includes a sustainable design of products, including buildings. It consists in using all resources efficiently while creating healthier buildings with cost savings through improved human productivity, lower cost building operations and resource efficiency. In other words, is a structure that is designed, built, renovated, operated or reused preventing unnecessary waste from construction until its demolition. It is also designed to improve employee productivity, using energy, water and other resources more efficiently and reducing the overall impact to the environment.

4. Methodology

A large number of methods, approaches and modeling tools that can be used for supporting solid waste management decisions at different levels in society have been developed in the past years. Life-cycle thinking and life cycle assessment – LCA have become important methods for solid waste management and policy, and have been successfully applied to ISWM systems in a number of case studies.

Based on the methodology of life cycle assessment, as introduced by White et.al (2002), the ISWM system of Porto Alegre was investigated, focused on solid waste materials from households and small shops, only. Environmental loadings were analyzed through life cycle assessment and economic costs were estimated through life cycle cost assessment – LCCA. The activities of ISWM inside each process, collection, transport, treatment, recycling, landfilling were determine as well as the corresponding costs and savings.

Quantitative analysis was performed through LCA and LCCA to determine environmental and economic aspects, respectively. In both methods, two different scenarios of the system were applied, namely the current (scenario 1) and the improved (scenario 2) situations, for comparison.

Scenario 1 consisted of ordinary solid waste collection and selective collection with source separation. After selective collection, recyclable waste materials were delivered to sorting units separated into four categories (paper, glass, plastic, metal) and then sold to recycling factories. Solid waste that was collected through ordinary collection was delivered directly to a landfill site.

Based on the status quo (Scenario 1), the following scenario 2 for improving ISWM practice in Porto Alegre was analyzed: (a) full coverage of ordinary, selective and organic waste collection; (b) composting of collected organic waste; (c) increasing of existing recycling rates; (d) implementation of waste prevention programs; and, (e) upgrading of existing disposal practice to sanitary landfill with energy recovery.

At this study, five waste prevention programs were adopted at the scenario 2. Home composting and clothing reuse as residential waste prevention programs, while office paper prevention (duplex copping initiative and reducing waste) and paper towel reduction as commercial programs.

5. Discussion

The purpose of this study was to investigate on a general and approximate level, how waste prevention influences solid waste generation and its integrated management in Porto Alegre. First, waste prevention programs were determined and applied. Next, a future scenario with the improvement of current collection, recycling, landfilling, treatment and source separation was analyzed in view of their impacts on environment and on network costs. This study's findings provided a quantitative understanding of waste prevention inside solid waste management and revealed consistent approaches to improve its environmental and economic performances.

Life cycle thinking are becoming the principal decision support tool of solid waste management systems and, in this study, it illustrated the benefits of different waste management methods and waste prevention programs applied in the improved scenario, mainly with the reduction of solid waste disposed at the landfill and with the production of new raw materials that could replace production from virgin materials.

Here, waste prevention has been showed to have considerable environmental impacts, particularly decreasing greenhouse gas emissions and, water and soil contamination. However, no single solid waste management process or technology produced the overall lowest environmental impacts. Tradeoffs among management options were needed in both scenarios, indicating that society will have to make choices regarding the type of environmental impact that is least desirable in a certain place.

Applying waste prevention as a part of integrated solid waste management system in Porto Alegre has led to a reduction in the quantity of solid waste at the landfill and has also decreased unnecessary collection, processing, storage and final disposal.

Another important fact identified by this study concerned the relationship between industry and the former scavengers' association in Porto Alegre. Nowadays, the association's employees only earn enough to maintain their own survival but not to improve their living conditions; usually middlemen and industry receives most profit. A well-organized market for the recyclable waste trade is needed to structure this relationship in a fair manner for all parties. Increasing prices do not mean decreases in industry savings; in fact it might increase the availability of recyclable waste in the market.

The main objectives of solid waste management are to protect human health and the environment, and to conserve resources. In Porto Alegre, this study presented that direct impacts of solid wastes on human and the environment may be eliminated by introducing extended recycling strategies and waste prevention policies such as reuse.

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DEVELOPMENT OF COMPREHENSIVE ASSESSMENT SYSTEM FOR BUILDING ENVIRONMENTAL EFFICIENCY (CASBEE) FOR HOME

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Keywords: CASBEE, detached house, environmental quality, load reduction

Summary

The Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) is an environmental assessment tool for buildings built in Japan. New CASBEE tools have already been developed for new buildings, old buildings, buildings in urban districts, etc. In Japan, approximately 500,000 detached houses are constructed every year. In order to improve the quality of houses, “CASBEE for Home” was introduced in 2007.

In this paper, we present the main features of the CASBEE for Home. Since the CASBEE for Home is expected to be used by various stakeholders in the housing construction industry, such as clients, designers, contractors, and builders, it is designed to be easy to use. The structure of the CASBEE for Home is similar to that of other CASBEE tools, and it can be used to evaluate both quality and environmental loads. The evaluation criteria are divided into 6 categories— Q1: comfortable, healthy, and safe indoor environment; Q2: sustainability to service life; Q3: regional contribution for view and ecology; LR1: energy and water conservation; LR2: resource conservation and reduction in construction waste generation; and LR3: contribution to improvement in regional and global environment. The assessment also includes 54 evaluation criteria that are based on the standards established in Japan. The comprehensive assessment considers not only the features of houses but the environment outside the houses, home appliances, information provided to the occupants by the house owners, and the techniques used in the building material production and the house construction.

1. Introduction

We have developed the “Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) for Home (Detached House)” (hereafter called as the CASBEE for Home below.) to improve the quality of detached houses in Japan. Approximately 500,000 houses are built in Japan every year. The CASBEE is an environmental assessment method for buildings built in Japan. CASBEE tools for new buildings, old buildings, buildings in urban districts, etc. have already been developed. The CASBEE for Home was introduced in 2007. In this report, we mainly present the outline of the evaluation system used in the CASBEE for Home. Since the CASBEE for Home is expected to be used by various stakeholders in the housing construction industry, such as clients, designers, contractors, and builders, it is designed to be easy for use.

2. Structure of Evaluation

The CASBEE for Home evaluates general environmental condition on the basis of two indices Q and L. Index Q indicates the environmental quality of a detached house, and index L indicates the environmental load of the detached house. BEE is evaluated as shown in Figure 1.

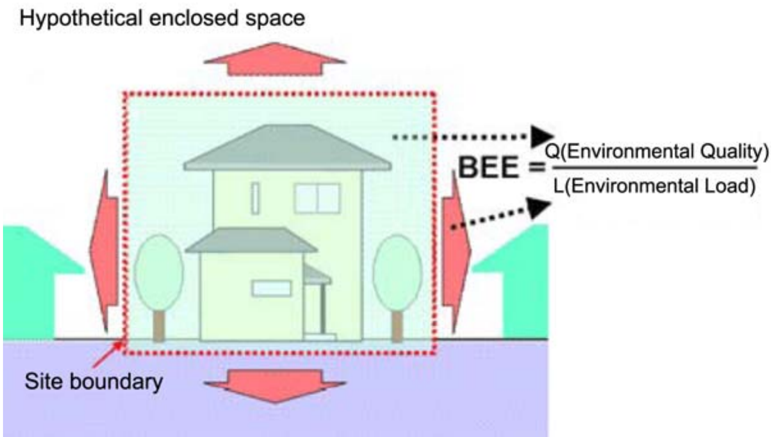


Figure 1 Hypothetical Enclosure for Estimation in CASBEE for Home

The structure of the CASBEE for Home is similar to that of other CASBEE tools, and it can be used to evaluate both quality and environmental loads. The environmental load is evaluated by the load reduction (LR) parameter. The evaluation criteria are divided into 6 categories—Q1: comfortable, healthy, and safe indoor environment; Q2: sustainability to service life; Q3: regional contribution for view and ecology; LR1: energy and water conservation; LR2: resource conservation and reduction in construction waste generation; and LR3: contribution to improvement of regional and global environment. The assessment also includes 54 evaluation criteria that are based on the standards established in Japan.

Because the CASBEE for Home evaluates the overall environmental quality of detached houses, the 54 evaluation criteria include not only the features of the houses but also the features of their surroundings, home appliances used by the occupants, information provided to the occupants by the house owners, and the techniques used in the building material production and house construction. There are some evaluation criteria that builders cannot fulfill; however, we have decided to evaluate basically everything that affects the environment considerably.

The evaluation of Q and LR in the CASBEE for Home is based on the CASBEE for new buildings, although the criteria for the former have been slightly modified.

In the CASBEE for new buildings, the evaluation of water resources is included in the LR2 category. However, in CASBEE for Home, we have shifted the evaluation of water resources to the LR1 category. This is appropriate for the $LCCO_2$ estimation since resource conservation is considered in the LR1 category.

The 54 evaluation criteria are listed in Tables 1 and 2.

Table 1 Criteria for Evaluation in CASBEE for Home (Quality)

Q1 Comfortable, Healthy, and Safe Indoor Environment		
Additional Criteria	Minor Criteria	Merits
1. Hotness and Coldness	1.1 Basic Performance	1.1.1 Efficient Thermal Insulation and Airtightness Performance
		1.1.2 Sunlight Control Settings
	1.2 Control of Temperature in Summer	1.2.1 Natural Ventilation
		1.2.2 Proper Cooling
	1.3 Control of Temperature in Winter	1.3.1 Proper Heating
2. Health, Security, and Safety	2.1 Countermeasures against Chemical Contamination	
	2.2 Proper Ventilation	
	2.3 Prevention of House break-ins	
3. Brightness	3.1 Use of Sunlight	
4. Peaceful Atmosphere		
Q2 Sustainability to Service Life		
Additional Criteria	Minor Criteria	Merits
1. Basic Life Performance	1.1 Building Frame	
	1.2 Exterior Wall Material	
	1.3 Roof Material	
	1.4 Resistance against Natural Disaster	
	1.5 Fire Detection System	1.5.1 Fire-proof Structure (Excluding Windows)
		1.5.2 Fire Detection System
2. Maintenance	2.1 Ease of maintenance	
	2.2 Maintenance System	
3. Functionality	3.1 Floor Area and Room Layout	
	3.2 Barrier-free Housing Design	
Q3 Regional Contribution for View and Ecology		
Additional Criteria	Minor Criteria	Merits
1. Consideration of Townscape and Scenery		
2. Creation of Biological Environment	2.1 Tree Plantation	
	2.2 Creation of Biological Environment	
3. Safety and Security in Region		
4. Use of Regional Resources and Assimilation of Regional Culture		

Table 2 Criteria for Evaluation in CASBEE for Home (Load Reduction)

LR1 Energy and Water Conservation		
Additional Criteria	Minor Criteria	Merits
1. Energy-saving Design of Building	1.1 Thermal Load Restriction for Buildings	
	1.2 Natural Energy Use	
2. Energy Saving with Equipment Performance	2.1 Air-conditioning System	2.1.1 Heating System
		2.1.2 Cooling System
	2.2 Hot-water System	2.2.1 Hot-water Supply Equipment
		2.2.2 Heat Insulation of Bathtub
		2.2.3 Hot-water Plumbing
	2.3 Lighting/Electric Home Appliance	
	2.4 Ventilation System	
	2.5 Energy-efficient Equipment	2.5.1 Household Cogeneration System
		2.5.2 Photovoltaic Power Generation System
3. Water Saving	3.1 Water-saving System	
	3.2 Rainwater harvesting	
4. Devices of Maintenance and Management	4.1 Presentation of Lifestyle	
	4.2 Energy Conservation	
LR2 Resource Conservation and Reduction in Construction Waste Generation		
Additional Criteria	Minor Criteria	Merits
1. Use of Materials that are Useful for Resource Conservation and Reduction in Waste Generation	1.1 Building Frames	1.1.1 Wooden Structure
		1.1.2 Steel-framed Structure
		1.1.3 Concrete Structure
	1.2 Reinforcement Materials for Construction of Foundation Ground and Foundation	
	1.3 Armoring Materials	
	1.4 Interior Finishing Materials	
	1.5 Materials for Outdoor Facilities	
2. Reduction in Waste Generation in Production and Construction Stages	2.1 Production Stage (Parts of Building Frames)	
	2.2 Production Stage (Excluding Building Frames)	
	2.3 Construction Stage	
3. Promotion of Recycling	3.1 Dissemination of Information on Material Usage	
LR3 Contribution for Improvement of Regional and Global Environment		
Additional Criteria	Minor Criteria	Merits
1. Consideration of Global Warming		
2. Consideration of Regional Environment	2.1 Control Load on Local Infrastructure	
	2.2 Preservation of Existing Natural Environment	
3. Consideration of Surrounding Environment	3.1 Reduction in Noise, Vibration, Exhaust, and Exhaust Heat	
	3.2 Improvement in Warm Environment of Surroundings	

3. Method of Evaluation

The houses are given grades 1 to 5 according to the abovementioned criteria. The criteria are adjusted by the weighting factor on the basis of their importance. The score is calculated at every stage, additional criteria, and main criteria for Q and L. Finally, the BEE of houses can be determined.

The criteria are set such that normal houses built these days can get grade 3. However, we have given grade 3 to the relatively good efforts which especially need to be promoted in the future.

The CASBEE for Home is not meant for a specific purpose. We are developing it so that it can be used by various people who are involved with house construction. Our aim is to make the assessment as simple as possible. In fact, the evaluation method does not involve investigation, measurement, and complicated numerical analysis and basically involves simple calculations; the number of steps involved in the evaluation depends on the environment.

We have already presented proposals for "Housing Performance Indication System in Japan," "Authorization and Supporting System of Environmentally Symbiotic Housing in Japan," and an environment-friendly design titled "Design Guideline for Low-Energy Housing with Validated Effectiveness." We have developed the CASBEE for Home on the basis of systems and methods that are widely used and are well known to reduce the time taken for evaluations. We have used the proposed housing performance indication system without making any changes to it and have taken care to prevent contradictions or double standards in the evaluation.

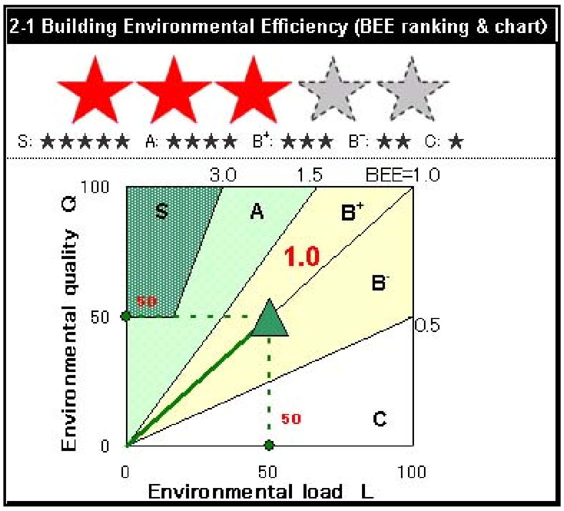
4. Presentation of Results

Special software transforms BEE from the final result and Q and L for each process into graphical form. BEE is shown in the form of a BEE chart in Figure 2.

Houses are ranked by BEE and given grades 1–5, indicated by the number of stars. The BEE values are represented in a graph by plotting L versus Q on the x- and y-axes, respectively. The BEE value is expressed as the gradient of the straight line passing through the origin (0, 0). The higher the Q value and the lower the L value, the steeper is the gradient and more sustainable is the house. Using this approach, the results of BEE can be presented graphically. Figure 2 shows a BEE chart for buildings ranked on the basis of class C (poor), class B^-, class B^+, class A, and class S (excellent), in ascending order the BEE value. The result of BEE is presented in such a manner with ★ to be easily understood.

Figures 2–4 show three charts of the evaluation of the CASBEE for Home.

The radar chart shows the equilibrium between the 6 major criteria, Q1–Q3 and LR1–LR3 (Figure 3).



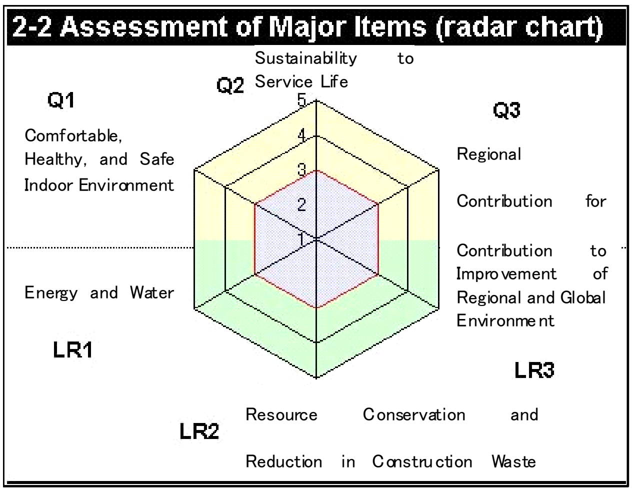


Figure 2 BEE Chart of CASBEE for Home

Figure 3 Radar chart of CASBEE for Home

The warming effect chart presents the $LCCO_2$ of a simple detached house and shows the reduction rate comparing to referenced general houses (Figure 4). Using these tools, detached houses can be evaluated precisely.

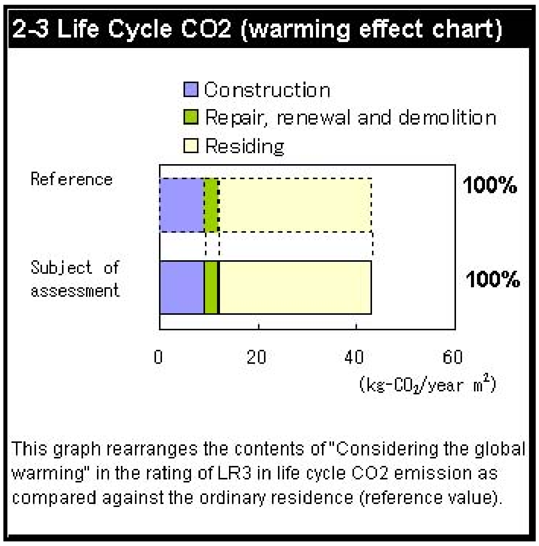


Figure 4 Warming Effect Chart of CASBEE for Home

It is assumed that the CASBEE for Home is used at an advertising stage and a tool of communication between a client and an architect at planning and designing stages. At these stages, the requirements for the evaluation are not usually determined yet, so you could only get an interim result. Special software classifies the results obtained from the evaluation on the basis of location, structure, area, number of houses, specifications, electrical appliances used, surrounding, etc. and shows if the parameters have been determined, partially determined, or assumed.

5. Conclusions

We have developed the CASBEE for Home, which includes 54 evaluation criteria and gives output in the form of charts showing grades assigned to houses. The CASBEE for Home can be used to evaluate detached houses. It is expected to develop assessment tools for existing houses and renovation. We plan to disseminate the information on this system to clients, designers, and constructors, which will contribute to the improvement in the quality of detached houses in Japan.

TIMBER LCI CASE STUDY: THE PRACTICALITIES OF REPRESENTING AUSTRALIAN VENEER, PLYWOOD & LVL PRODUCTS

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Keywords: LCI, forest and wood products, veneer, plywood, LVL, LCA

Summary

A Life Cycle Inventory (LCI) of veneer, plywood and laminated veneer lumber (LVL) was undertaken as part of an initiative to assess the environmental impacts of Australian wood products for a comprehensive Timber LCI. CSIRO conducted the investigation for the FWPA to create a rigorous LCI of representative Australian forest and wood products and processes. The LCI included in separate unit processes all cradleto-gate inputs and outputs for a product's creation including raw material extraction, transport to mill, and manufacturing.

The focus of this paper is the production of the LCI for veneer, plywood and LVL products. 80% of Australian plywood and LVL mills were included in the project making it the most comprehensive analysis of these products undertaken. The paper addresses the requirements of assessing these wood product industries and the issues arising.

The differences from international LCI research and the differences between varying wood products are investigated. The practicalities and realities of mill sampling, data collection, quality assurance and other methodological considerations are focused on. Problems encountered and lessons learned are also detailed. The paper is set out as guidance to future LCI data collectors who intend using results in a national LCI database.

1. Background

A life cycle inventory (LCI) of timber, LCI Timber, has been undertaken by CSIRO for the Forest and Wood Products Association (FWPA) to create a rigorous Australian LCI of representative forest and wood products and processes. The assessment includes all energy and materials associated with manufacturing wood products in separate unit processes. Main raw material extraction and transport, secondary input materials' production and transport, energy inputs, all outputs, emissions and wastes have been analysed. The in-use and end-of-life phases are not however included in this project.

The key output is a forest and wood product LCI database covering categories including Forestry, Sawn Timber, Veneer, Plywood, Laminated Veneer Lumber (LVL), Particleboard, Medium Density Fibreboard (MDF), Glulam and Engineered I-beams. The significance of this study is that all environmental impacts from gate-to-gate and the transportation of materials to manufacture are detailed providing an objective overview of timber products in terms of their environmental profiles. This study adheres to the ISO 14040 guidelines (ISO 2006a, 2006b, 2002) and LCI Timber's stringent Quality Assurance (QA) requirements. (Tharamarajah, 2007)

The specific interests of this paper are the practicalities, realities and the issues arising in collecting and assessing the required data for the LCI of veneer, plywood and LVL within the Timber LCI project (see Figure 1) and reported in Mitchell and McFallan, 2008. The primary data incorporates site-specific data collected from eight Australian mills using methods such as survey, mill inspections and discussion with mill personnel. The data was collected using records spanning from 2004 – 2007. Secondary data sourced from LCI Timber's SimaPro database includes the manufacture of energy, fuels, CO_2, emissions, production of resins and preservatives. The main log inputs are detailed in Module B: Forestry (Tucker, 2008).

1.1 System Boundary

In LCI Timber the system boundaries provide a gate-to-gate assessment of timber products used in the building industry. The project does not include transportation after manufacture, use, or end-of-life scenarios. The raw materials are the materials obtained directly from the environment. The inputs between the Life Cycle Inventory boundary and the module boundary are common or pre-defined processes which can be called upon by any module model. The common processes include logs from forests, glues, imported products and materials, energy, transport modes and equipment. The output products include the main product, co-products, and wastes.

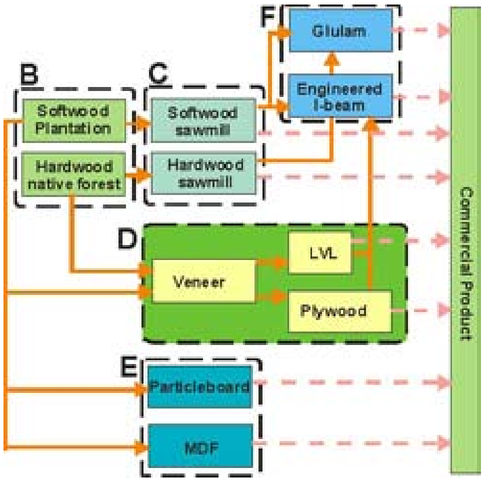

Figure 1 Veneer, plywood and LVL within the forestry and wood products LCI project.

1.2 Unit Processes

The unit processes for veneer, plywood and LVL form the complete 'gate-to-gate' processes. Each unit process consists of one or more sub-system and is determined to have identifiable inputs, outputs or separable processes. Aggregating the subsystems into unit processes creates identifiable data collection points and reduces the complexity of the system. If a co-product is produced and used within the unit process it is considered within the internal recycling loop and thus not included in the inventory, as the co-product does not cross the unit process boundaries. The veneer process has four unit processes within the system boundary (Preparation, Conditioning, Green Veneer, Dry and Finish). The plywood and LVL processes both have three unit processes (Manufacture, Finish, and Packaging). There is also a separate boiler process and a glue-mixing unit process which have been detailed as separate unit processes, but secondary data created for LCI Timber is currently used.

2. Review of existing studies and Australian industry

Initial reviews of existing veneer plywood and LVL studies, and in depth analysis of the Australian industry, provided a background which informed the project methodology.

2.1 International and Australian studies

International LCI studies and reports of veneer, plywood and LVL were reviewed to determine ways forward with the Australian LCI Timber. Pinpointing major impacts, for example, allowed reduction of scope and data collection focus. In Australia there is a lack of published LCI information relating to the engineered wood products however the project had access to some confidential in-mill studies. Examination of the ISO 14040 LCA series was also necessary to be accepted in the International LCI field (ISO, 2006a, 2006b, 2002).

The Consortium for Research on Renewable Industrial Materials (CORRIM) was of particular interest, as they had recently (Wilson, 2005) undertaken a similar timber LCI study in the US. CORRIM underwent an external critical review ensuring compliance with ISO14040 protocols. Their support of LCI Timber was beneficial to the methodology development and allowed the project to learn from experiences, processes, models and methods.

2.1.1 Methodological issues

CORRIM undertook a gate-to-gate analysis considering all inputs, outputs and impacts associated with plywood and LVL manufacture (Wilson & Sakimoto, 2004, Wilson & Dancer, 2004). CORRIM used different analysis methods dividing plywood manufacture into six unit processes but using a black-box approach for LVL. Due to similarities between plywood and LVL, veneer was taken directly from plywood system LCI data for LVL.

CORRIM's experience was read in context as the US produces 80 times more plywood and 20 times more LVL than Australia. CORRIM's data sampling size was selected based mainly on production capacity, surveying the least number of mills to cover the largest product volume. Five plywood manufacturing plants in the Pacific North West (PNW) accounted for 26% production and five in the South East (SE) accounted for 14%. CORRIM based their assessment on single plywood and LVL types: one thousand square metres (MSM) 9mm thick basis for plywood; and, 1 ¾ inch thick, 4ft wide and 60ft length basis for LVL.

Survey of manufacturers was used to collect primary data and existing sources were utilised to obtain secondary data such as energy, CO2 and press emissions, and resin production. The growth and harvesting of trees was undertaken as a separate study in the project, and the boiler was considered as a separate operation within the system boundary. The data collected was averaged and weighted and modelled using SimaPro (Pre Consultants, 2007).

2.1.2 Inputs and assumptions

CORRIM did not include inputs that contributed to less than 2% of total input. Energy was considered particularly significant and CORRIM used state profiles to specify percentage shares of fuel source. Hydro for example attracts no impact in SimaPro. Published data sources as opposed to survey data were used to determine distribution of energy amongst unit processes. Hogged fuel was given a green weight average (as per industry practice) and assumed to be at 50% moisture content.

CORRIM's assumptions relating to transport, wood densities, data issues, weighting and averaging, assigning burdens, unaccounted wood mass, etc. were analysed. Sensitivities were undertaken to examine effects of using different fuel sources for heat generation. Carbon balances and cost analyses were used for checks. The LCI results were generated in SimaPro5.0.9 version 5 using the survey results and the secondary data.

2.2 Australian Plywood and LVL Industry

In 2007 there were eight plywood production facilities and two LVL manufacturing plants. Many small operators had exited the market and two organisations controlled over 60% of the plywood market. Despite this domination, the majority of plywood mills are small to medium sized. With the newer and larger mills has come a change in technology and investment in plant and equipment modernization. The small and medium mills have also invested in computerized technology to make production more efficient.

Manufacture of plywood and LVL consists of turning high quality logs into thin veneers which are then transformed into plywood using adhesives. Softwood and hardwood veneers are used to produce plywood and LVL and softwood accounts for 70%. There are many variations of interior, exterior, flooring, formwork and structural plywoods. LVL is also available in a range of sizes making it difficult to specify a single product for assessment.

2.3 Lessons learned

The decisions made by CORRIM and issues detailed in LCI studies have been useful to examine in relation to the industry as guidance for determining a methodology for the Australian context. An energy coefficient study (Hall and Janssen, 1997) shows that international data can be considerably different to Australian data. Thus most of the information obtained was used strategically to analyse potential issues of importance to Australian industry; consolidate research to efficiently utilise time; and check data and results. The review of the industry provided information on existing mill structures, existing in-house systems for information collection, processes, supply chain, mill operations, environmental management strategies, current understanding of LCI/ LCA in mills. These contextual issues, alongside the review of international studies, informed the LCI Timber methodology.

3 Methodology for LCI Timber veneer, plywood and LVL

The initial methodological processes, which were determined using the reviews as well as the Timber LCI Guidelines (Tharumarajah et al, 2007), included:

- Mill Sampling – determining mill types to concentrate on; (Planning)

- Engaging Mills – to participate in project; (Planning)
- Data requirements – determining what data to be collected; (Data Needs)
- Product Sampling – establishing relevant products for analysis; (Data Needs)
- Data Collection strategy – collecting and mapping data methods; (Data Collection)
- Data Quality/ Evaluation – data analysis (Validation, Documentation, Communication)
- Assumptions – identification and treatment of data gaps (Identification)

The basic methodological processes were not followed in a lineal order rather they became iterative processes, whereby information ascertained from one step would inform another step which could be further modified to better reflect the project and mill requirements.

3.1 Mill Sampling and engaging mills

In contrast to the CORRIM experience, where sampling size was statistically representative, Australia has only a small number of mills. If the two largest plywood mills and one LVL mill are included, the sample is statistically representative at over 50% market share. CORRIM noted however that their samples had to be adjusted when, for example, kiln drying was found to be a significant contributor to the results. Thus the sample group for LCI Timber needed to be relevant in terms of representation of factors which may vary the results. It was decided that, as there were only ten mills, to undertake an initial analysis of them all to determine the differences and similarities which might make a difference to the inventory results. This was not onerous given the small range of mills, but set the project up to have a strategic focus based on factors which might be of significance in the results, as follows:

- Production capability: mills surveyed had to produce a representative amount of plywood i.e. it is no use surveying six mills, if the other two produce 60% of total.
- Product range: representative products with significant market share to be included. Small mills often have greater product range or niche market products and large mills produce commodity products, such as structural or formwork plywood.
- Mill location: geographical cross-representation of mills analysed to consider the variety of regional issues and test whether issues make a difference to LCI results.
- Proximity to forests: considered as log inputs are significant to plywood production and transportation is therefore an important impact issue.
- Technology types: technology differences need investigation as processes may be similar, but efficiencies, recoveries, waste reduction etc. may be improved with modern technology. The labour intensive processes utilised with older technology may make little difference. (Note: Labour is not considered an input in this project)
- Energy Sources: CORRIM report that energy has the potential to make significant impact on LCI. It is necessary to investigate different energy types and cross-representation of energy use. Wood waste is the most predominant fuel for drying furnaces and hot pressing but gas and co-generation are also used.
- Log Types: many log types are used in production and significance of these differences (whether relating to issues of region, transportation, waste etc.) need addressing. Hardwood versus softwood also requires further investigation.

In addition, willingness to participate in the project and availability were of vital importance as any mill surveyed would be critical to data quality given the small range of mills. The mills had to commit to both collecting and providing data which is an onerous task, particularly in smaller mills where day-to-day operation is the focus (Mitchell, 2004). Other potential issues, such as water supply, co-products, preservative treatments and wastes and emissions, were also noted at this point, but they were issues that would need further investigation using mill data, so were not part of the initial sampling investigation.

It was decided to collect data from all but two mills initially as these two duplicated two other mills in details such as size, locality, output, etc. It was deemed necessary to have at least one mill that could be used to test results or check methodology validity. The mills selected for inclusion contributed to more than 90% of plywood production and 100% of LVL production. It was considered important to have the variety mills involved as differences could be investigated and the implications of the differences, in terms of LCI results, analysed.

The sample mills selected were members of the Engineered Wood Products Association of Australasia (EWPAA). The EWPAA's support and involvement allowed entry to discussion with mill executives and helped disseminate the significance of the project to the industry. Letters seeking involvement in the project were sent to mills and on participation agreement the executives of each mill were contacted to discuss involvement requirements, as follows:

- Collection and delivery of required data;
- Allowing mill inspections and discussions with executives and employees, which was quite different to CORRIMs survey only approach;
- Confirmation of process map and data;
- Allowing data to be used in the Timber LCI database, in an industry averaged form.

Once the level of involvement was ascertained to be appropriate for the project requirements, the mills were engaged to collect data.

3.2 Data requirements and product sampling

Data collection is usually based on the purpose for use of data, but since LCI Timber will be a publicly available database, the objectives for use are not known. Data collection is a time consuming process, as documented in many LCI reports, and all data cannot be collected. It was therefore pertinent to be quite specific about data requirements based on data transparency, quality, and completeness, for example, and on specific industry processes.

Given the necessary understanding of industry processes, determining data required was an iterative process. The knowledge obtained during initial data collection processes, such as mill visits led to the refinement of data requirements. CORRIM's and other data surveys, as well as data considered relevant for our own knowledge of the industry, informed the initial survey, which included information on: inputs and outputs; energy and water; waste and emissions; transport; plant and equipment; and personnel

Part of this analysis consisted of determining product types manufactured by each mill. CORRIM based their report on a single plywood and LVL product. The LCI Timber project required a more comprehensive analysis of products based on market share. Product sampling however proved difficult despite the common range of products (see *Table 1*). Within this range there are many descriptors used to determine specific plywood products (including, grades, thicknesses, bond types, panel sizes, treatments, timber species, F-rating and finish) and LVL products, which are generally produced to customer specification (including thickness, bond, length, treatment, timber species and F-rating). Each range is made to many different specifications and even after data collection it was difficult to determine specific products with the greatest market share. One small plywood mill provided a detailed product breakdown for a year which consisted of over 400 distinct products.

A product list was therefore determined based on discussions with mill executives and other module leader's who required inputs of plywood or LVL as opposed to market share. The main purpose for analysing different products was to determine differences in LCI impact of different product types. It was therefore considered reasonable to generate a table of diverse, actual plywood types as shown in *Table 1*.

Table 1 Veneer, plywood and LVL product list for LCI Timber

Product	Details (Note: all panel sizes taken as 2400 x 1200)
Veneer	1mm & 3mm
Interior plywood	9mm & 12.5mm
Exterior plywood	6.5mm, 9mm & 19mm
Formply	17mm & 19mm
Structural plywood	12.5mm, 18mm & 19mm
T&G Flooring	12mm, 15mm & 17mm
LVL	90 x 36mm, 200 x 45mm & 240 x 63mm

3.3 Data collection strategy and data quality

A number of data collection strategies were analysed as CORRIM and Mitchell (Mitchell, 2004) both reported low level response to surveys by industry. Personal one-on-one discussions, information dissemination, and mill inspections, in conjunction with a survey, was deemed most appropriate. This more time intensive strategy could be implemented given the relatively small number of mills engaged.

An initial comprehensive survey was drafted and reviewed at a work-shop with EWPAA personnel. The survey was modified to better reflect Australian industry operations and be better understood by industry personnel. The survey was tested with one mill in a workshop to ensure understanding, determine the relevance of the questions, determine whether the information could be collected, and to establish any commercial in confidence requirements.

This initial survey was intensive requiring much time to complete to a satisfactory level. The test mill worked through this survey, but the survey was reduced into 'survey sets' which could be completed in short time slots. The 'survey sets' were based on impact which was determined using a basic model and running sensitivities. With each new piece of data received, the survey sets could be further refined and data collection streamlined. CORRIMS 2% rule was not utilised, and inputs contributing to less than 2% were still analysed to determine impact capabilities.

With the reduction of time required for each 'survey set', the completed form was often e-mailed back the same day as it was sent. The test mill with the full survey, and an LVL mill who received the full survey due to late inclusion, both struggled to return data. The survey sets were considered very successful allowing a set to be sent to the mills every week or fortnight depending on the mill. If the survey sets were not returned within two weeks a follow up e-mail was sent. Usually this prompt would see a return of the information, at which stage the next set would be sent out immediately. During this process other questions arose and questions were asked directly of mill personnel via telephone or e-mail.

Mill visits were simultaneously undertaken and in the first mill visited it was established how much of the required information could be collected on a site-visit (machinery details, waste points, etc) and processes were documented and process mapping was initiated. The mill walk-throughs were an excellent method of obtaining a reasonable understanding of mill operations allowing a lot of basic information to be documented including mill and process differences, and provided opportunity for mill personnel to ask project questions. The mill visits also assisted in the identification of unit processes and identification of inputs, outputs and separable processes (including energy, wastes, and emissions). It also allowed the process models to be refined, as the initial process maps detailed all actions within a mill. After several mill visits the process was reduced to key unit processes at a level which was manageable and took into consideration actions which would make a difference to the LCI.

The data provided by the mills was based on measurements, calculations, bills, records, mill statistics, as well as estimation and calculations where no other information was available. All data collected from the mills was time specific, and related to information from a period from 2005 – 2007. The iterative process of data collection, survey refining, mill inspections, etc. allowed for ongoing validation of data. Quality Assurance (QA) documentation of a high quality have been produced as part of the LCI Timber project to provide transparency to data uncertainty, distributions, subjective estimates, sources of variance, etc.

3.4 Data Evaluation and Assumptions

Evaluation of data was important to the process and several processes were undertaken to ensure data was of the highest quality. The data was verified with other data sources including international data and any available Australian data. Sensitivity analyses were undertaken to identify the areas of potential high impact. In particular where the data was not of a high quality, sensitivities were utilised to see whether variations would make a high degree of difference. The things which showed to be of significance to the overall impact included electricity, log input/ volume and resins. The data was varied based on minimum and maximum values to determine what difference the variation would make to results.

Data quality was continuously tested, and whenever variations appeared the original source was revisited and questioned. Where data precision was considered questionable or the sample size was restricted (i.e. in some cases all mills did not provide data for all issues, such as glue mixes) a triangular distribution was used. In the cases of all mills providing data which was considered high quality and reflective a normal distribution was used. Although not all mills provided data for all issues, the data used is considered representative as the similarities and differences between the mills were noted and data analysed accordingly. In the case of glue mixes, the mills were very hesitant to provide data due to the commercially sensitive nature of mixes. Only one mill provided decent data and although this was considered very high quality, could not be used in these results, and the common glue mix process had to be reverted to, despite the plywood glue mix being more specific.

There were limitation with not obtaining full data sets from all mills, and one LVL mill provided limited data, and the mill visit was used mainly to compare the two existing mills, to determine whether the results from one mill would be representative. The comparison of the plywood and LVL processes proved that the unit processes in most cases were interchangeable, so that LVL mill results could be adequately masked by combining plywood and LVL data for specific processes.

4. Results

The results were generated by a single server version of the SimaPro software using the FWPA data libraries updated on August 7th 2008. The results show average Australian veneer, plywood and LVL, although specific plywood and LVL products have also been detailed in the report (Mitchell and McFallan, 2008). Average Australian structural plywood is discussed here with veneer included in relation to plywood production.

The main inputs to manufacture 1m^3 structural plywood include: 58.8kg A-bond glue (which includes resins, flours, fillers, catalyst, etc.); 0.33m^3 hardwood veneer; 0.59m^3 softwood veneer; and 0.0034kg AACQ preservative. There are other inputs but in non-registering quantities. It takes 2.1m^3 of logs to produce 1m of veneer. The average preliminary results show that the yield of veneer from logs is approximately 47% compared to 50% estimated by CORRIM but varied between mills, with small labour intensive mills reporting higher recovery rates. The main source of energy is the boiler (7.7gJ) which is mainly used in the veneer drying process. The electricity input is 135.1kwm^{-3}; LPG is 3.1ltrs; and natural gas 0.734gJ. These energy sources are mainly used in the veneer drying process (40%). A large amount of water (344ltrs) is also consumed.

Preliminary results show that production of 1m structural plywood contributes 742kg CO2 emissions. Veneer drying accounts for about 10% of the CO2 emissions while glue production accounts for just over 25%. Forklift operation (predominately electrical) is responsible for a further 10%. Overall 66% of the CO2 emissions were attributable to electrical inputs and a further 20% to log production.

The initial results show that:

- Manufacture of adhesives are particularly intensive and emissions from adhesives is most significant during the manufacture and pressing processes;
- Energy for the production of veneer, plywood and LVL comes from several sources, including electricity, natural gas, LPG, diesel and hogged fuel, and is significant in LCI results.
- The use of high voltage electricity (within the pressing process in particular) is considered one of the significant impact factors
- Energy impact is higher than CORRIM as hydro electricity has no impact in SimaPro
- Main energy use is biomas as was the case with CORRIM
- Wood fuel is used for drying timber in all mills. The burning of wood is considered (along with use of high voltage electricity) to be one of the major impact areas.
- Water use in Australia particularly significant and the conditioning process accounts for a significant proportion of the 344ltrs used to produce 1m^3 plywood

5. Value to Australian LCI database

The LCI Timber project will be a very valuable resource for the Australian LCI project (AusLCI). The SimaPro models are highly detailed and complete. Data has been input in the system based on unit processes making the models highly flexible which will enable easy future modifications and updates. The associated Quality Assurance (QA) documents provide a comprehensive picture of the data quality and details data precision, completeness, collection and treatment methods, and representativeness. A pedigree matrix with a series of indicators which provides a scoring system to communicate the quality of each piece of data was utilised. Data evaluation was intensive and several validation and verification methods were utilised including comparisons with other sources, data checks and volume balances. Sensitivity analyses were also undertaken to identify the areas of potential high impact. In particular where the data was not of a high quality, sensitivities were utilised to see whether variations would make a high degree of difference.

The methodology for data collection, evaluation and quality has been thoroughly developed which resulted in excellent quality data being collected. This methodology will be beneficial for future LCI inputs and development. The methodology also led to excellent industry collaboration and cooperation which aided the data collection process, the dissemination of information and the support for Australian LCI developments. The data will be beneficial to future data collectors as areas of importance have been highlighted and future work can concentrate on the significant impact areas. The project has created a significant new benchmark for veneer, plywood and LVL products in Australia.

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DEVELOPMENT OF LCA-BASED BUILDING COMPONENT ASSESSMENT TOOLS

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Summary

Background: Although much is known about the building of houses in an environmentally-friendly way, very few tools have been developed to support the design of components/buildings. People involved in the building process (e.g. owners, builders, architects, civil engineers, product suppliers) find it very difficult to assess the effects of specific components and to compare alternatives. Several modules are currently being developed to calculate the environmental impact of components and technologies in a house. One of these modules is a calculator of the environmental impact of lightweight wall systems.

Benefits: These calculators allow comparisons to be made at the level of the smallest elements of the overall building system. These are based on properties common to all elements (e.g. structure, thermal resistance). It is, for example, possible to compare different designs of a wood-framed wall system, providing that the thermal resistance is the same.

Approach: The system calculators are based on analyses of designs that are currently used in New Zealand. The parameters of specific components (e.g. thickness, type of insulation, cladding etc.) are entered as inputs into the calculator. The calculation provides the thermal resistance (R-value) and lists the required materials. The material list is then linked to a list of Life Cycle Impact Indicators (e.g. Cumulative Energy Demand, Global Warming Potential). As the methodology is the same for all different calculators, only the lightweight wall calculator is presented here, as an illustration of the calculators. Furthermore, a case study comparing two different wall designs with the same R-value is presented and discussed.

Outlook: The overall aim of the project is the development of an LCA-based building assessment tool. This requires several additional system calculators (e.g. interior walls, windows, heating, etc.) as well as a connection of all tools with an overall building heat loss calculation tool. The results can then be allocated to the different components.

1. Introduction

A building assessment tool allowing comparisons on the basis of components with a specific function (functional unit) requires a virtual partition of the building into different systems or components/technologies (Kellenberger 2008). A possible structure is presented in Table 1.

Table 1 Systems/technologies/components related to the envelope of a building

System / Components	Example of Designs or Technologies	Possible Functional Unit
Exterior lightweight Wall	Heat insulated timber frame with fibre cement cladding	x m^2 of lightweight wall with specific R-value and specific load/wind etc. resistance
Exterior heavyweight Wall	Heat insulated concrete wall	x m^2 of heavyweight wall with specific R-value and specific load/wind etc. resistance
Groundfloor/Foundation	Concrete slab	x m^2 of floor with specific R-value and specific load resistance
Roof	Timber-framed roof with corrugated steel sheets	x m^2 of roof area with specific load/wind etc. resistance
External Door	Massive timber door	x m^2 of massive door with specific thermal and fire resistance
Window Glazing	Double glazing	x m^2 glazing with specific R-value
Window Framing	Insulated aluminium frame	x m framing with specific R-value
Heating/Cooling/Ventilation	Pellet heater	x MJ heat

The structure in Table 1 is based on an LCA study of the "Exemplar House" (Szalay, Z. et al. 2006). It compares different residential timber framed building designs made from different materials, located at different sites within New Zealand, with different heating systems and different heating schedules. Szalay's study showed a high contribution (up to approx. 50 %) from the materials to the overall environmental impact over 50 years including the operational energy for heating.. With a general improvement of the insulation level in future the impact from operation will be even more reduced and in relation the significance of "embodied" impact rises. This supports the idea of taking a closer look on the materials/components used in a building and to relate them to their heat, sound or other resistance (e.g. load, wind, etc,).

2. Structure of the Wall Calculator

Based on the "Exemplar House" study (Szalay, Z. et al. 2006) an exterior wall calculation tool has been developed which enables the user to calculate the thermal resistance and the environmental impact from different NZ wall designs in function of several parameters such as geometry of the wall and the openings, the location within the house (single storey, top of two storey), the type of wall (load bearing or not), the roof weight, the expected wind exposure etc. The calculator is structured as shown in Figure 1.

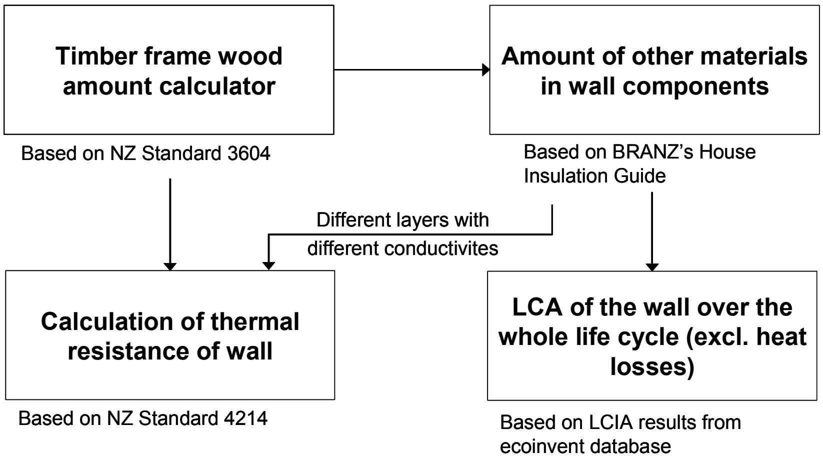

Figure 1 Structure of the LCA-based wall calculator

Most new housing in New Zealand (>90%) is constructed using a timber framed wall assembly. The timber frame wood amount calculator is based on the NZ Standard NZS 3604 (1990) for timber structures. This calculates the total area of wooden framing (m^2) on the main wall face and the corresponding volume (m^3). The wooden frame is a thermal bridge within the overall construction. As thermal bridges are taken into account when calculating the overall thermal resistance, it is essential to know the exact wood framing area. Together with other relevant sources of heat loss, the LCA calculator calculates the thermal resistance based on the NZ Standard NZS 4214 2006.

For all the different wall constructions listed in BRANZ House Insulation Guide (BRANZ 2005), a list of the included materials has been assembled. The tool enables the user to choose between different commonly used NZ insulation materials within the available wall cavity and define other parameters specific to the wall. After defining the overall wall a definitive list of materials is compiled and the corresponding thermal resistance is recalculated. The resistance is only needed when comparing different wall constructions.

As a result of the wall calculator, all the used materials required to produce a wall with a given thermal 'R' value are linked to corresponding LCIA (Life Cycle Impact Assessment) datasets (ecoinvent 2006). Together with the life-span of the products, and with a default disposal scenario at the end of life, the overall environmental impact is calculated and presented as a table and as a graph. The overall environmental impact does not include the impact from the heat generated and lost through the wall because the 'R' value is consistent between all wall designs being compared.

3 Goal and Scope

3.1 Goal

The main goal of the project is to provide independent tools which allow for comparisons of different designs of a specific component based on a specific functional unit. Furthermore, the tools should be implementable into an overall LCA-based building assessment tool that includes heat loss.

Sub-goals for the wall calculator are:

- To provide a comprehensive calculation of the overall wall thermal resistance (R-value) including a detailed material list
- To provide information on the influence of geometry and design (e.g. amount of wood) on the overall environmental impact

3.2 System and System Boundary

The system boundary used for the calculation of the different wall LCA's is illustrated in Figure 2.

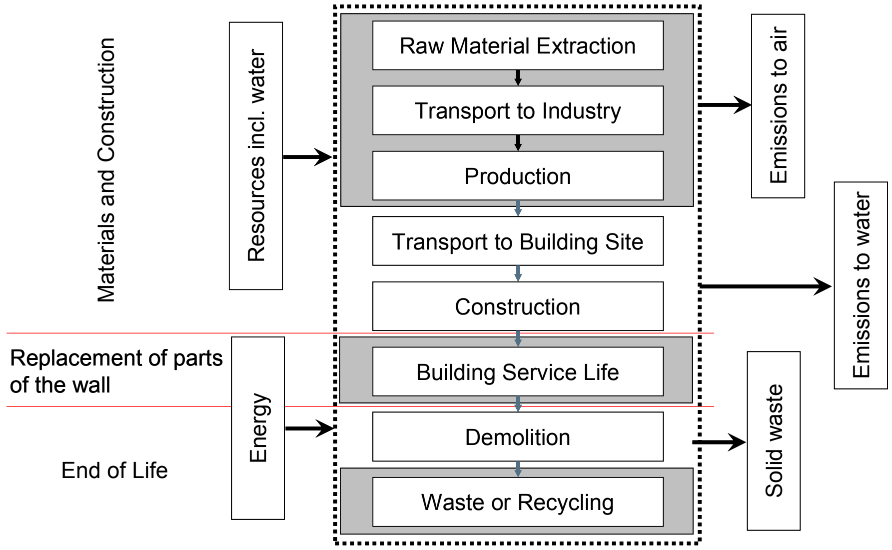

Fig. 2 System Boundary for the LCA-based wall calculator

Figure 2 shows the life cycle phases of a wall which are usually taken into account when doing an LCA. The grey boxes show the phases which have been taken into account within the wall calculator. The remaining boxes, transportation of the materials to the building site and the construction and demolition process, have not been taken into account as it is assumed that they are similar for all the wall systems. The building service life only includes materials that have to be replaced over the whole life cycle (e.g. Paint every 8 years). In addition to the used material amount, 10% cutting waste has been added.

3.3 Functional unit

The functional unit is a fully defined lightweight wall area (e.g. geometry, roof weight, wind exposure, etc.) with a certain thermal resistance (R-value in m^2°C/W) over an overall life span of 50 years.

3.4 Impact assessment categories

Based on the fact that the tool should be simple and comprehensible the chosen impact assessment categories are:

- Cumulative Energy Demand (CED) fossil, nuclear [MJ]
- CED water [MJ]
- CED biomass, wind, solar & geothermal [MJ]
- EcoIndicator 99 (H/A) [Points]
- Global Warming Potential (GWP) [CO_2-Equivalent]

Currently the LCIA data are taken from the European (and international) LCI database (ecoinvent 2006), as sufficient data for New Zealand and Australia is currently not available. The ecoinvent LCI database provides a transparent and consistent dataset for all relevant materials in this project. However, the calculators are designed in a way that allows the incorporation of country specific LCI data once it becomes available, e.g from the AUS LCI project or for the updated New Zealand data (update of Alcorn 2006).

4. Wood Amount Calculator

4.1 Introduction

Most of the lightweight wall constructions in the BRANZ' Insulation Guide (BRANZ 2005) are wooden frame based constructions. These wall designs are the most common constructions for residential houses in New Zealand. The calculation of the overall thermal resistance of insulated lightweight wall constructions takes into account the wooden frame as a thermal bridge. The BRANZ Insulation Guide (BRANZ 2005) calculates the thermal resistance based on the NZ Standard 4214 (NZS 4214 2006). The share of the area of wooden frame versus insulation area in the NZ Standard is based on an area between two studs (centre to centre) and assumes a wall height of 2.4m, including the dwangs and a top and bottom plate. In contrast, the calculator takes into account a real wall geometry which is planned to be built. The aim is to calculate the ratio between wooden frame and insulation in more detail. The wood amount calculator helps the user by providing a minimum of an input parameter to calculate these areas. Furthermore the calculator provides the total volume of wood needed for the specific wall system. This amount is also used for the calculation of the environmental impact from treated wood.

The calculator follows the main steps listed in the NZ Standard 3604 (NZS 3604 1990), 'Code of Practice for light timer frame buildings not requiring specific design'. Section 6 of this Standard goes through the wall design and supports decision making regarding the required timber parts. Bracing has not been taken into account as the influence on the required amount of wood and the visible frame area are minor. The input parameters in the next chapter concentrate therefore on the parameters which affect the wooden part of the framing most.

4.2 Input Parameters

The wall is defined as a rectangle with a specific length and height (between 2 and 5m). For other geometrical forms the tool should be used with care as it has not yet been tested for other forms. Furthermore, the geometry of up to three windows (rectangle) needs to be inputted. It is envisaged that the tool will be able to deal with more than three windows in the final version.

Besides the geometry, the function (load bearing or not) of the wall, the weight of the roof (heavy, light) and the location of the wall within the house are important parameters and are included in the calculator. The wall can either form the top storey of a multi storey house (same situation as in a single storey house), the lower of two storey house (same situation as the subfloor beneath one storey) or the subfloor beneath a two storey house. Another parameter is the wind exposure which is selected from the choices "very high wind exposure", "high wind exposure", "medium wind exposure" and "low wind exposure". The stud size is allocated to eight height categories depending on the wall height. The maximum span of member supported also plays an important role and is therefore a user input. For the stud spacing the user can choose between the most common ones; 400mm, 480mm, 600mm from centre to centre (ctr). For the dwang spacing the tool offers two default values: 600mm if the stud spacing is 400mm or 480mm and 800mm if the spacing is 600mm. The user can also manually input a value rather than using the default values. In future it is planned to connect the calculator to one of two existing main timber framing software systems currently used at prenailing factories in New Zealand (i.e. Pryda New Zealand and MiTec).

The following lightweight wall parts are calculated based on pre defined parameters:

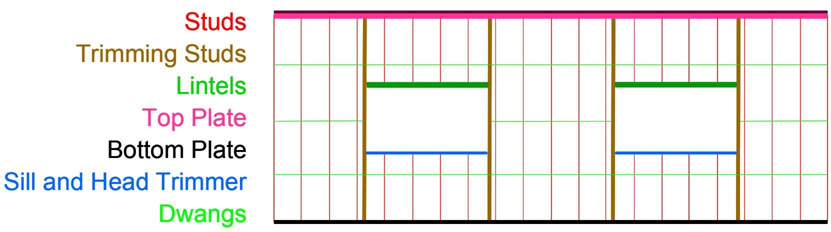

Fig. 3 Main elements of the timber frame taken into account in the calculator

The information from the timber calculation is the basis for the overall R-value calculation as well as for the calculation of the impact from different timber types (e.g. treated, untreated, etc.)

4.3 Output Parameters

The output parameters from the wood amount calculator are the view area in m^2 and the total volume in m^3 of wood needed for a specific framing. This area is then used to calculate the overall wall R-value and the volume is used to include the impact from timber production into the overall impact assessment.

5. Lightweight Wall Components

5.1 Introduction

The lightweight wall components which have been taken into account are mainly taken from the BRANZ Insulation Guide (BRANZ 2005), as they represent the common New Zealand building situation. The publication includes a raw sketch of the design and lists the most important material layers, including the type of framing, the thickness of the plasterboard, and whether or not it is directly fixed. The calculator includes this information, where possible, and adds missing information either from NZS 4214 2006 or in some cases from other sources, for example the ecoinvent LCI database documentation (e.g. Kellenberger, D. et al. 2004).

5.2 List of components

The tool will allow the uptake of other components based on existing or new materials. The calculator offers different options for the materials used (i.e different insulation and cladding materials).

The following list shows a choice of some of the included 16 wall components:

- Bevel-back Weatherboard, Timber frame – direct-fixed
- Bevel-back Weatherboard, Timber frame – cavity
- Fibre cement cladding, Timber frame – direct fixed
- EIFS (Exterior Insulation and Finish Systems), Timber frame – cavity

5.3 Parameters within Components

The LCA-based lightweight wall calculator allows a choice of different options within a certain design. For example, the tool offers the choice of different Insulation materials in different thicknesses and different R-values which are available in New Zealand (based on www.consumer.org.nz). These are, for example, polystyrene, glass wool, natural sheep wool and UF foam, from different producers with different thicknesses, different densities and therefore different thermal performances.

Furthermore the tool allows choosing between different plywood, fibre cement and brick cladding thicknesses, and many other options. When choosing a material all the connected information (density, conductivity, etc.) is adapted and the calculation of the overall R-value is updated.

An overall life span of the house of 50 years has been assumed, based on the New Zealand Building Code requirement. The life span of the materials is attached by default based on Szalay, Z. et al. (2006). To calculate the replacement rate it has been assumed that no replacement will be made in the last 5 years. The calculation routine therefore takes the number of replacements before the age of 45 into account and adds the first investment.

The calculation of the thermal resistance of the wall components are based on NZS 4214 (2006). The wall components are split into different layers (e.g. exterior sheet, interior surface). For each of these layers the corresponding R-value is calculated. For single materials the R-value [m^2K/W] is defined as the division of the thickness [m] by its conductivity (W/mK]. For insulated frame spaces it's important to calculate the ratio between the wooden (thermal bridge) and the insulation area.

5.4 Used LCIA data

The following table gives an example of the LCIA datasets used in the wall calculator. Due to a lack of transparent and consistent data in New Zealand, the lightweight wall calculator is currently connected to publicly available Swiss datasets. The design of the tool allows a replacement of these datasets as soon as new and consistent New Zealand datasets are available at end of this year.

Table 2 Choice of LCIA building material datasets (disposal not included in the values)

Name in ecoinvent v1.3	Default Disposal			cumulative energy demand, fossil & nuclear	cumulative energy demand, water	cumulative energy demand, biomass, wind, solar & geothermal	eco-indicator 99, (H,A), total	IPCC 2001, GWP 100a
		Unit	Density [kg/m3]	MJ-Eq	MJ-Eq	MJ-Eq	points	kg CO2-Eq
Brick, at plant, Europe	Disposal, building, brick, to final disposal, Switzerland	kg	1000	2.58E+00	4.03E-02	2.28E-01	1.11E-02	2.36E-01
Concrete block, at plant, Germany	Disposal, building, concrete, not reinforced, to final disposal, Switzerland	kg	2380	7.49E-01	4.86E-02	4.17E-02	3.84E-03	1.20E-01
Fibre cement facing tile, at plant, Switzerland	Disposal, building, cement-fibre slab, to final disposal, Switzerland	kg	1800	9.91E+00	9.96E-01	1.04E+00	3.83E-02	8.11E-01
Gypsum plaster board, at plant, Switzerland	Disposal, building, plaster-cardboard sandwich, to final disposal, Switzerland	kg	800	5.90E+00	1.53E-01	2.24E-01	2.79E-02	3.63E-01

The materials listed in the first column are an example of the materials used in the calculator. The second column indicates the datasets from a Swiss list called ecological building material list (version 1.0.2) (in

German: http://www.bbl.admin.ch/kbob/00493/00495/index.html?lang=de) which is based on the ecoinvent 2006 database. Each of the datasets is connected to a default disposal option. The impacts displayed in the last five columns do not include disposal. These datasets are additional datasets included in the calculator, but are not shown in the above example.

At the moment the default disposal scenarios are based on the Swiss/European situation. The mineral building materials are mainly disposed or recycled, the metals are mainly recycled and all the flammable products are incinerated as this is a law in Germany/Switzerland.

The LCIA datasets from the ecological building material list unfortunately only offer the following impact categories: Three types of cumulative energy demands (CED “fossil and nuclear”, “water” and “biomass, wind, solar & geothermal”), EcoIndicator 99 (H,A) (Goedkoop, M. et al. 1999) and GWP (global warming potential). The choice of impact categories??? is based on the publicly available datasets used.

The calculator is set up in way that Australian and New Zealand LCIA datasets can be easily added as soon as they are available.

6. Case Study (Comparison of two lightweight Wall Components)

6.1 Introduction

In order to show *how the tool can be used* and *how the results can be interpreted*, this publication concentrates on a comparison between two different lightweight wall systems. The results are *indicative* as they lack robust scientific information (e.g. life span) and are not based on New Zealand datasets.

Based on a pre-defined overall R-value of 1.56 m^2°C/W, the results for a timber frame construction with direct fixed bevel-backed weatherboard and polystyrene insulation has been compared with a timber frame construction with direct fixed fibre-cement weatherboard with mineral wool insulation (Pink Batts). The latest version of the tool does not offer the opportunity for the user to enter a specific R-value or to select from all possible options. At the moment the user has to choose different insulation materials (includes thicknesses) to come up with a specific overall R-value.

In general, the category CED fossil and nuclear is dominated by the fossil part. This is because the nuclear part mainly stems from electricity usage in Europe, which has a very small contribution to the production of the products used in the two wall components. However, a high amount of aluminum in the wall components would increase the nuclear energy component of the CED fossil & nuclear, mainly due to the large share of electricity produced from nuclear power in Europe.

6.2 Cumulative Energy Demand

Figure 4 shows the results for CED (Cumulative Energy Demand) (MJ) for the different sub categories and overall..

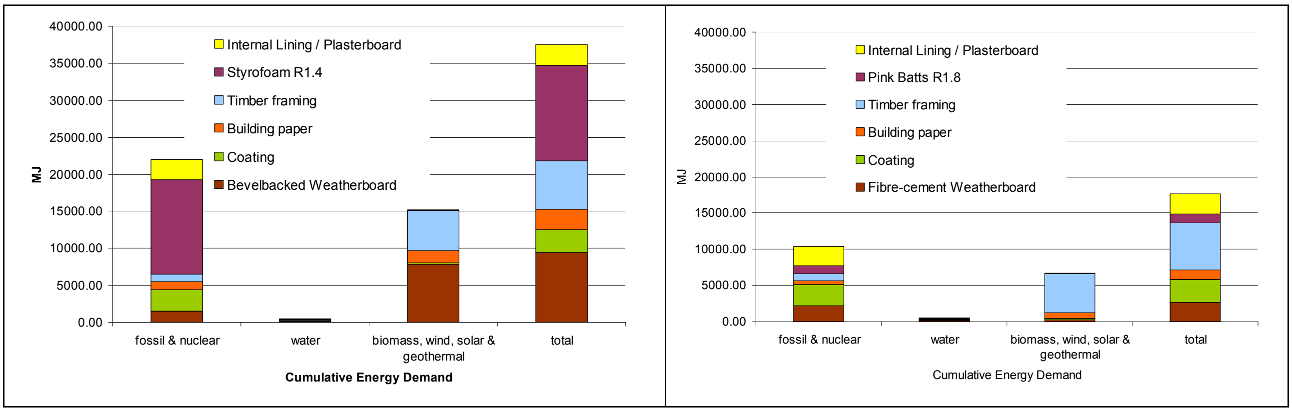

Fig. 4 Cumulative Energy Demand for timber frame wall system with bevel-backed weatherboard and Styrofoam insulation (left) and fibre cement weatherboard and mineral wool insulation (right)

The total CED for the timber frame construction insulated with mineral wool (right graph) is about half of the construction insulated with polystyrene. Analysing the CED from biomass, wind, solar and geothermal in the construction with bevel-backed weatherboard, the cladding and the frame have a high contribution (left graph). This is due to the energy stored in the wood which stays in the wood as long as there is no end-of-life treatment with energy recovery. The fibre-cement weatherboard has a much smaller contribution to the CED than the bevel-backed weatherboard due to the longer lifespan of the cladding. The insulation materials also have different CED results for each wall system. One reason is the different lifespan of the cladding systems which results in the replacement of the weatherboard once in 50 years whereas fibre-cement cladding is not replaced. The second reason is the higher energy demand in the production of polystyrene than in the production of mineral wool.

6.3 EcoIndicator 99 (H/A)

Figure 5 shows the results for the EcoIndicator 99 (H/A) impact assessment methodology.

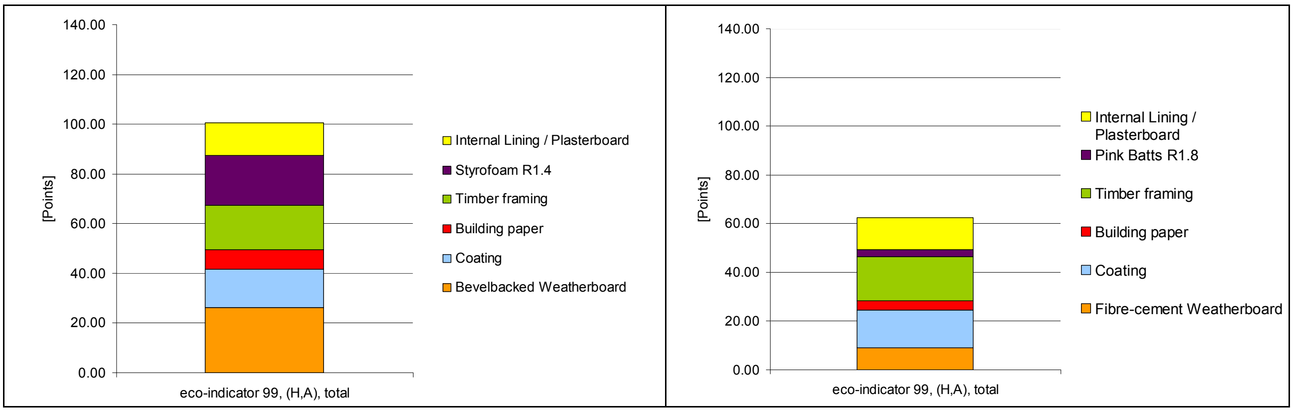

Fig. 5 Results for Eco-indicator 99 (H/A) for timber frame wall system with bevel-backed weatherboard and Styrofoam insulation (left) and fibre cement weatherboard and mineral wool insulation (right)

The results for the total EcoIndicator 99 (H/A) is similar to the results for Global Warming Potential. The impact from internal lining, timber framing and coating are the same comparing the two lightweight wall designs. The replacement of the bevel-backed weatherboard within 50 years lifespan is accompanied with a replacement of the building paper as well as the insulation. The high impact of bevel-backed weatherboard is on one hand due to this replacement and on the other hand due to the higher land-use of forestry products which is taken into account in Eco-indicator 99 (H/A).

6.4 Global Warming Potential

Figure 6 shows the results for the Global Warming Potential.

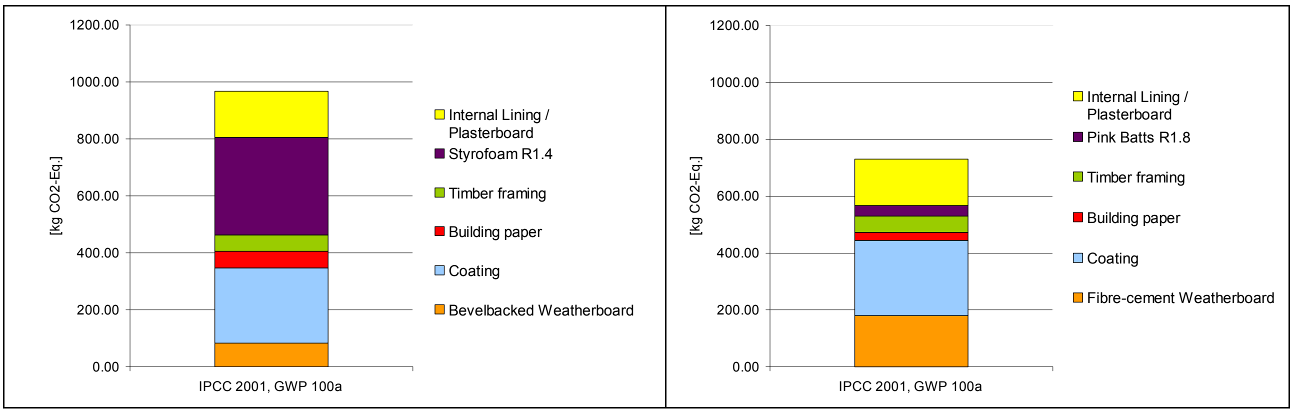

Fig. 6 Results for Global Warming Potential for timber frame wall system with bevel-backed weatherboard and Styrofoam insulation (left) and fibre cement weatherboard and mineral wool insulation (right)

The wooden parts in the wall are CO_2-neutral, i.e. the same amount of CO_2 which is taken up during the growing process is released when disposed (in this model it is burned). This is reflected in the low GWP for the timber products. However, this advantage is reduced by the high GWP from producing polystyrene insulation and its replacement during 50 years. It is also assumed that both type of claddings are repainted five times over its life-span which shows up in the high impact of coating in both wall designs.

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7. Conclusion

7.1 Lightweight Wall comparison

Although the used datasets are based on European data, the results clearly show the sensitivity of the lifespan of the materials on the results. The replacement of the bevel-backed weatherboard including insulation and wall paper, together with the bigger environmental impact of the polystyrene production, results in a much higher impact for all the studied indicators.

The assumption that the cladding is repainted 5 times over its lifespan results in a relative high contribution of the paint to the overall results, making the results highly sensitive to the quantity of paint in a system.

7.2 Lightweight Wall calculator

The key aspect of the lightweight wall calculator is that it is based on an actual wall design, including geometry (including window and door openings), and taking into account other design aspects. This offers the possibility to easily calculate the overall wood amount, and to study changes in the amount and the environmental impacts in relation to certain parameters (wind exposition, wall function, stud spacing, etc.).

If the user desires a comparison of different wall designs with the same thermal resistance, the tool currently does not offer a backward calculation starting with the definition of the R-value and giving a choice of possible comparable designs. This is an important requirement when bringing the calculator to a next stage.

The potential of the tool was demonstrated by conducting a case study. It has demonstrated the convenience of analysing results through changing parameters. To present the full strength and potential of the calculator more case studies are needed.

8. Next Steps

The lightweight wall calculator has now been converted from an existing MS Excel-based tool by using a more appropriate programming tool 'Microsoft Visual Studio 2008' and the programming language C# to design a user friendly interface and to be able to connect the results from and to other software. This will allow an update of some of the background information (e.g. densities of the insulation materials, adding new LCIA datasets from existing studies, an inclusion of cost as an "impact" indicator, etc.). In parallel a window calculator has been developed and will be transferred into the new software. The background information for further system/component/technology calculators will be developed (e.g. heating, floor, roof etc.) and the information converted into the chosen software. The overall product will be a connection of all the modules (calculators) to an existing heat loss calculation tool. This will allow a model of the full house, and, by choosing the functional unit "one inhabitant", even allows the inclusion of behavior related parameters (e.g. water consumption).

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TOOLS FOR ENVIRONMENT-BASED DECISION MAKING

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Summary

Existing assessment tools for the built environment have been designed for use in a reactive evaluation process rather than in a proactive decision process. Whereas current assessment tools generally catalog past decisions, the proposed decision-assistance [DA] tools focus on (1) guiding decisions when they are made and (2) directing relevant and timely information to specific decision makers. These proposed tools may be more able to support the implementation of environmental strategies in the building industry.

The authors advocate:

A. The identification of topics within existing assessment tools for use in applicable decision categories.
B. The development of new DA tools tailored to specific decision makers.
C. An overarching framework to coordinate DA tools, track past decisions, and collect public contributions.

1. Current Use of Assessment Tools

Existing assessment tools for the built environment have been designed for use in a reactive evaluation process rather than in a proactive decision process. Although professionals in the building industry have accepted the use of building rating systems during project development, the existing assessment tools are not well designed to function as design aids. The proposed DA tools would guide decisions as they are made rather than documenting the decisions after they are made. The current assessment tools do not fit this intended purpose for the following reasons:

1.1 Current assessment tools present achievements categorized by physical components or environmental aspects, missing the opportunity to highlight a process of decision-making over time. Commonly, tools relate to a particular building typology and then group individual assessment topics by project components or environmental resources or impacts. By presenting the individual assessment topics all at once, the current assessment tools deemphasize decisions made at various stages of a project in terms of its timeline.

1.2 Current assessment tools stress the integrated approach of sustainable initiatives, inviting several disciplines to provide input in a holistic process. The emphasis on integration denies the assessment tools the opportunity to present clear directives for each decision maker. Because they include information that is applicable to so many participating entities, the assessment tools become diluted overall, failing as specific and thorough guides.

1.3 Current assessment tools tend to be ignored in the earliest stages of project development and do not address changes in the building throughout its lifetime. Often the owner commences the assessment services during the design phase; thus the assessment tools are applied to a project only after the site has been selected and the building program established, decisions that may have been guided, if at all, by only a vague understanding of the assessment criteria. Also, many of the earliest decisions will have been made by entities other than the owner, such as local, state, and federal governments, or international commissions. Current assessment tools are closely linked to the design and construction phases of a project, and building operations and renovations are addressed in subsequent, non-integrated rating systems, if at all. As a result, the produced ratings tend to become quickly outdated since they fail to reflect building modifications or fluctuations in life-cycle operations and maintenance.

1.4 Current assessment tools do not provide for clear interaction between project team members. Preferences by one team member may not be apparent to another unless expressed outside of the system.

1.5 Current assessment tools, in general, focus on one project at a time and cannot demonstrate associations between several buildings in a complex or portfolio. Thus they do not educate users about the cumulative effect of several buildings that rate well in the certification process. Nor can the current assessment tools aid the design team in developing a sense of greater environmental responsibility, such as for a region or the planet, outside of their desire to reach a higher rating level when their perceivable scope and effect is limited to singular projects.

1.6 Current assessment tools also do not provide accumulated data from one project to another, or between rating systems. Because they fail to track and update information from the decision makers, assessment tools consider each project in isolation, and cannot be used to guide decisions in subsequent developments.

1.7 Current assessment tools can only indirectly affect the building industry. Through the advertising potential of positive ratings, they claim to affect the market at large by economically incentivizing environmentally responsible decision-making in the building industry. However, this market-driven approach appears somewhat circuitous and less effective than a direct method to affect change. Some of the current assessment tools do act as incentive programs, promising an award for a positive rating. A certification or plaque thus represents an opportunity to achieve broad market exposure, but requires very long feedback cycles to begin affecting the building industry's production methods. Furthermore, relying on entities like building product manufacturers, outside of the direct reach of building rating systems, to affect the market significantly weakens the argument that assessment tools assert pressure towards market-wide sustainability.

2. Proposed Objectives for Decision-Assistance (DA) Tools

Based on the above shortfalls in the current assessment tools, the authors propose the following objectives for DA tools:

2.1 Allow for a decision-making process over time

2.2 Provide clear guidance to each decision maker

2.3 Support the entire life-cycle of a building

2.4 Show input from project team members

2.5 Demonstrate the impact of decisions beyond a singular building

2.6 Track decisions in a public database

2.7 Affect direct change on the market

The proposed tools would each be directed at a particular decision maker, whether a developer, international commission, mechanical engineer or building operations vendor, and would be tailored to that entity's relationship to the project from inception throughout its lifetime. These tools would help guide the decision makers through their range of choices in the built environment, and would be called decision-assistance (DA) tools.

3. Proposed Framework for DA Tools

In order to establish DA tools with thorough access to relevant and timely information, an open-source framework based on wiki technology is hereby proposed. Such a framework will ensure that the DA tools are available for use as design guides and that they contain publicly shared knowledge on topics relevant to each decision maker. In detail, the DA tool framework will:

3.1 Allow for a decision-making process over time: The framework will be made up of a number of DA tools. Each of the DA tools will focus on how to positively affect decisions when they are made rather than after they are already in place, allowing decision makers to actively take environmental impact into account. Rather than a single assessment tool that catalogs decisions made by different entities at various points in the lifetime of a project, one can imagine a set of several DA tools that each focus on a single responsible team member. The DA tools may be linked to form a greater system, a framework, or they may stand as individual options to be used as needed.

3.2 Provide clear guidance to each decision maker: Because each DA tool will focus on a single decision maker, the information provided will be tailored to that entity's specialized knowledge-base. Introducing sustainable options directly to the relevant decision maker will allow issues to be addressed very early in a development's progress, facilitating integration of sustainable policies from a project's initial stages.

3.3 Support the entire life-cycle of a building: The DA tools, each directed at one decision maker, will give guidance to the decision maker throughout their relationship with the project. From international commissions to architects to facility managers and demolition contractors, the combined DA tools will reach out to everyone throughout the entire life-cycle of a project. A framework of DA tools will therefore resemble an overlapping group of timelines, each timeline representative of a particular entity's involvement in a development, in contrast to the approach of current assessment tools in which all the decision makers are required to participate in the assessment during one brief period in the project development.

3.4 Show input from project team members: Although each DA tool will emphasize the needs of a particular decision maker, it will also allow the other decision makers or project team members in supplementary roles to offer advice or information regarding their preferences. For example, within an owner's DA tool, the architect may stress the aesthetic desirability and environmental benefit of underground parking, although the owner will ultimately make the choice.

3.5 Demonstrate the impact of decisions beyond a singular building: Each of the DA tools will identify and describe the greater impacts of any potentially applied development strategy, on a region or the planet for example, based on past facts and future projections - including differing opinions and the surrounding debates between politicians, scientists, special interest groups and others. The open-source capability of the DA tools will keep information current and abundant as it facilitates a democratic dissemination of knowledge to the decision makers from all sides of the debates; and the participation of the public will keep the maintenance of DA tools manageable.

3.6 Track decisions in a public database: Each DA tool will inherently include more data capture and tracking than is common with current assessment tools. A historical record of environmental choices could become a powerful political instrument and prove useful to public interest groups or consumer advocates who value transparency in government. Such a database will also provide researchers the ability to track common disincentives towards certain environmentally responsible decisions and may lead to the development of economic incentives.

3.7 Affect direct change on the market: By being specific to decision makers, DA tools will have an immediate and fast opportunity to affect market change. Within the knowledge base associated with each tool, readily accessible information on incentives, such as financial benefits or marketing exposure, may directly influence decisions.

4. Content of DA Tools, as derived from Current Assessment Tools

The authors suggest thirteen DA tools, based on proposed major decision categories as shown in Table 1, where each category relates to decisions in the entire project development that can be assigned to a single type of decision maker. Current assessment tools were reviewed in order to determine what existing individual assessment criteria, "credits," may easily transfer into the proposed DA tools.

Table 1 Decision Categories

1. International Policies
2. National Policies
3. National Land Planning
4. Community Plan
5. Community Operations
6. Investment (ownership, location)
7. Building Property Design
8. Building Structure Design
9. Building Interior Design
10. Building Product Manufacturing & Distribution
11. Construction
12. Portfolio or Building Operations
13. Building Operations Vending

In order to identify which individual credits could become part of a DA tool based on an intended decision maker, the current assessment tools that were reviewed are: LEED-NC 2.2, Green Star NZ - Office Design v1.2, CASBEE-NC, 2006 NABERS Office, SBTool version SBT07, and BREAAM: Offices 2006.

Because these reviewed assessment tools sort their individual credits into groupings based on the building systems affected or resources used, commonly including groups for water use, air quality and recycled materials, no entire grouping from these assessment tools may be easily transferred into a single DA tool. For example, the current assessment tools typically include credits for general location and context; however, these credits may be mixed in with sustainable site design items and landscape design issues, requiring several decision makers to participate in the "Site" grouping of an assessment tool.

The focus of the research was on the most commonly used assessment tools; those not reviewed include rating systems specifically designed for building operations and community design. For example, the U.S. Green Building Council's Leadership in Energy and Environmental Design program includes a rating system called LEED for Existing Buildings: Operations & Maintenance, whose assessment topics could be extracted for use in decision categories like "Portfolio or Building Operations" or "Building Operations Vending." LEED for Neighborhood Development could also be useful for the DA tool, "Community Plan."

The following analysis of each proposed DA tool describes the intended decision maker involved and gives examples of relevant topics from some of the reviewed assessment tools.

4.1 International Policies

International Policies related to buildings are addressed by ongoing international forums, potentially leading to the ratification of internationally accepted protocols. Environmental issues like climate change affect the entire planet; thus the evolution of international policies in regard to the building industry is critically important. Decisions regarding these policies are implicitly addressed in several building rating tools, such as:

The use of alternate refrigerants that are less depleting to the ozone layer and that create lower amounts of greenhouse gases, as addressed in LEED-NC 2.2 EA Credit 3, Enhanced Refrigerant Management.

The practice of sustainable forestry, protecting against the destruction of forests including rainforests and old-growth forests, and the encouragement of reforestation for carbon sequestering, as touched on by LEED-NC 2.2 MR Credit 7, Certified Wood.

The Green Star Credit Ene-2: CO_2 Emissions encourages the reduction of carbon dioxide, a contributor to climate change, by requesting descriptions and comparisons of a building's energy sources in terms of predicted carbon dioxide emissions.

Recognizing the critical importance of reductions in harmful emissions from building energy use, BREEAM Credit P11 advocates the completion of a feasibility study in the use of local renewable energy. The credit further encourages the implementation of energy plans that incorporate a high percentage of the researched strategies.

4.2 National Policies

National policies related to the development of buildings are typically directed by national technical departments under the authority of a country's political leaders. These technical departments look into curbing pollution; the discharge of waste into water, land and air; limiting energy use per capita; and developing principles for the protection of ecosystems and wildlife throughout the country. Strategies researched by these teams may translate into laws and regulations, or they may provide the basis for environmental tax incentives. Examples for how these policies are addressed in building rating systems include:

The prevention of soil erosion and stream pollution, addressed in LEED-NC 2.2 SS Prerequisite 1, Erosion & Sedimentation Control, for temporary measures during construction, and in SS Credit 6.1, Stormwater Design: Quantity Control and SS Credit 6.2, Stormwater Design: Quality Control, for permanent measures during building operations.

Air pollution and energy use are affected by transportation to and from buildings by its occupants. LEED-NC 2.2 SS Credit 4.3, Alternative Transportation: Low-Emitting & Fuel Efficient Vehicles incentivizes the use of hybrid and alternative-fuel vehicles.

Green Star Credit Tra-2: Small Parking Spaces recognizes the tendency for smaller cars to be more energy efficient, and rewards the incorporation of parking spaces for very compact vehicles in the general parking plan.

4.3 Land Planning

Land planning on a national level is also conducted by national departments subordinate to political leadership. This large-scale planning frequently deals with land to be set aside for highway and train transportation or for the protection of natural or historic treasures; but it may also safeguard bodies of water or agricultural land. Government property may be allocated through these programs for military purposes and regional public transportation systems. Current assessment tools may likely address some of these planning criteria:

Sites should be selected to avoid prime land that may better serve other purposes and should be avoided as building sites. Previously developed land or brownfields may be more suitable for building sites. For example, LEED-NC 2.2 addresses some of these issues in SS Credit 1, Site Selection and SS Credit 2, Brownfield Redevelopment.

BREEAM Credit P11 requires that a project team hire an ecology professional to oversee the development and implementation of an ecological management plan, as well as to educate the relevant workforce on how to protect local biodiversity during the project works.

The net improvement of a building site's local ecology over its previous condition is addressed in Green Star Credit Eco-4.

Recognizing the often negative environmental impact of removing soil or adding fill to development sites, Green Star Credit Eco-5 encourages the balancing of cut and fill onsite requirements.

4.4 Community Operations

On a local level, community departments, sometimes in close relationship with private vendors, address operational services to the general public on a daily basis. These services include the routing and maintenance of public transportation and the management of landfill and/or recycling waste. Examples of how these operational policies are addressed by current assessment tools include:

LEED-NC 2.2 SS Credit 4.3, Alternative Transportation: Public Transportation Access encourages development within ½ mile from a commuter train station or within 1/4 mile of two stops for more than one roundtrip bus line.

BREEAM Credit T08 encourages the investigation of transportation issues at an early stage in the project. This credit addresses the development of a travel plan tailored to the specific needs of the building occupants and incorporating public transportation options where possible.

4.5 Community Planning

Community planning departments, frequently with public input, devise ordinances for the physical layout of both new and existing developments. The resulting zoning ordinances regulate lot coverage, building height, historic preservation, solar access, the protection and planting of trees, and the avoidance of exterior light trespass, for example. Individual credits that could become part of a Community Plan decision-assistance tool include:

Dense developments and mixed-use communities maximize opportunities for pedestrian circulation. For example, LEED-NC 2.2, SS Credit 2, Development Density & Community Connectivity provides some criteria for higher density and mixed-use areas.

An exterior light ordinance may regulate that no exterior light can fall on a neighbor's property. Such a requirement is addressed in LEED-NC 2.2 SS Credit 8, Light Pollution Reduction.

Achieving local continuity in desirable neighborhood character is addressed in Green Star Credit Mat-2: Re-use of Facades, in which building facades are preserved and reused.

4.6 Investment

A building venture is typically undertaken by a building owner or developer. The owner may be any combination of private (for profit or non-profit) and/or public entities, and may include a group of investors not directly linked to the design and building decisions. Thus, a bank or real estate investment trust, or several private investors may be linked to a project. Many decisions at the time of investment chart the course for the project, such as identifying the type of building, its intended use, its targeted tenants, tentative building area, and a general target location. Decisions at this level lock the project development into some crucial design parameters.

Decisions reflecting site selection are for example addressed in the earlier discussed LEED-NC 2.2 credits SSC1 Site Selection, SS C2 Development Density & Community Connectivity, SS C3 Brownfield

LEED-NC 2.2 MR Credit 1, Building Reuse addresses the choice between renovation and tearing down an existing structure.

4.7 Building Property

Site plans are designed by the architect and/or civil engineer with direction from the owner or developer, who often aim to maximize the building area on the site. Within the permissible ranges of zoning requirements and other regulations, the site plans address how much of the property is covered by structures and what areas are designated as open space. Environmental goals at the property level include the minimization of the building footprint and any hardscape, the use of light-colored/ shaded surfaces, the reduction and treatment of stormwater runoff, and the preservation, restoration or establishment of vegetated, wetland, and wildlife areas. Existing individual credits relating to these issues are addressed in several tools.

LEED-NC 2.2 SS Credit 5.1, Site Development: Protect or Restore Habitat and SS Credit 5.2, Site Development: Maximize Open Space reward the incorporation of designated open space on a development's site and the restoration of that open space to native vegetation.

Recognizing the participation of low-albedo materials on local temperature increases, LEED-NC 2.2 SS Credit 7.1, Heat Island Effect: Non-Roof describes alternative hardscape colors and materials to lessen the development's impact on local microclimates.

4.8 Building Structure

The design of the building structure is often the first phase in which an architect and a green building assessment consultant are involved. Many of the design issues at the structural stage are driven by the owner, who may draw on the recommendations of the architect and green building assessment consultant. A structural engineer also has an important role in the selection of materials and dimensions of the structural building elements. The design issues considered by all the players at this stage include: anticipated length of use and desired durability of the structure, available structural materials, building orientation, shape, configuration and height, floor-to-floor height, major vertical circulation elements, desirable views and solar access, floor plate size and depth, building envelope materials for the roof and walls, glazing, insulation, and air tightness. In this phase, decisions as to the building area and volume per occupant are solidified and the energy use per occupant will largely be determined.

LEED-NC 2.2, SS Credit 7.2, Heat Island Effect: Roof considers the incorporation of vegetated roofs or high-albedo coatings to reduce local heat gain and reduce building cooling loads.

LEED-NC 2.2 EA Credit 1, Optimize Energy Performance incorporates the building's shape, materiality, orientation, and operational systems to determine the building's net energy savings over a baseline building.

Natural daylighting strategies contribute to energy efficiency as well as to the well-being of occupants, as addressed in LEED-NC 2.2 EQ Credit 8.1, Daylight & Views: Daylight 75% of Spaces, and EQ Credit 8.2, Daylight & Views: Views 90% of Spaces. These individual credits use the building envelope configuration and materials to reward the inclusion of access to daylight and views for a high percentage of occupants.

BREEAM Credit HW02 encourages shallow floor plates in order to locate desks in an office setting within a reasonable distance from exterior windows.

SBT07 Credit A2.9 encourages the building orientation to suit local climates and aid in energy efficiency through the potential for passive solar systems.

4.9 Building Interior

Following or concurrently with the structural decisions, the architect and/or interior designer prepares documents for the building's interior environment, including the mechanical, electrical, and plumbing systems designed by engineers. Design issues related to the building's interior systems and materials contribute to energy efficiency, water conservation, indoor air quality, and controllability of the systems. Decisions could be more guided if specific disciplines were addressed; they could me more integrated if considered by a small team and alongside the building structure. Interior layouts and material selections may address the life-cycle of the building elements, and contribute to the healthfulness of the interiors, a major environmental consideration for this decision phase.

Controllability of system is addressed in LEED NC 2.2 EQ Credit 6.1 for Lighting and in EQ Credit 6.2 for Thermal Comfort.

Healthfulness of materials is addressed in LEED NC 2.2 EQ Credit 4: Low-Emitting Materials, which caps the VOC content of paints, composite wood products, and adhesives.

Interior noise pollution can contribute to negative impacts on the well-being of occupants and its avoidance is recognized in both BREEAM Credit HW17 and Green Star Credit IEQ-12: Internal Noise Levels.

4.10 Building Product Manufacturing & Distribution

Independently from the building development and design process, the building industry with its manufacturers, distributors, transportation providers, show rooms, sales representatives, and sales centers make many decisions contributing to the ratings reflected in green building assessment systems.

The decisions address recycled content, recyclability, and the sourcing of products (renewable sources, regional availability/manufacturing, harvesting, ecosystems endangerment through harvesting/extraction, and earthcrust exploitation may be considered, but may also be previously be addressed by governmental policies and regulations). For example, sustainable forest practices are addressed in LEED-NC 2.2 MR c7, Certified Wood.

4.11 Construction

The contractor or construction manager in charge of constructing a building project makes many building purchasing decisions and construction site management decisions, within the parameters defined by the owner and the designer team's documents and in cooperation with the subcontractors. Issues include the indoor air quality management of the building under construction, the management of construction waste, and the sourcing and delivery of purchased products. In the contractor's DA tool, the owner and designers could make their preferences visible regarding construction management.

Regionally manufactured and regionally extracted materials may be given preference, for example. In LEED-NC 2.2, this is addressed in MR C5 Regional Materials.

Construction site management issues as to waste and indoor air quality are addressed in several rating systems, for example in LEED-NC 2.2 MR C2 Construction Waste Management, or EQ C3, Construction IAQ Management.

4.12 Portfolio & Building Operations

Once the building is constructed, the facility managers will make many decisions for the building operations throughout its lifetime. Decisions are made for the single building or for a portfolio of several buildings, and may include the use of vendors for cleaning, landscape maintenance, pest management, consumer waste removal / minimum waste generation, and building consumables purchases. Building operations may address the maintenance of systems affecting indoor air quality, energy efficiency, and water use, and the measurement and verification of utility costs through submetering. This monitoring of energy uses and costs may inform the facility managers of what improvements make sense for the continued energy efficiency of the project, providing data regarding energy load per occupant or per unit area of the building.

These decisions are somewhat addressed in assessment tools for new design and construction, but usually in more detail in tools specifically geared toward the operations of existing buildings.

LEED-NC 2.2 EA Credit 5, Measurement & Verification establishes parameters for periodic measurement and verification programs.

Recognizing the varying limits of human comfort, LEED EQ Credit 7.2, Thermal Comfort: Verification addresses input from the building occupants regarding their satisfaction with the building's thermal characteristics.

4.13 Building Operations Vending

Each vendor for building operations makes decisions that affect the environment. If the DA tools for these entities described the preferred operations and maintenance methods of the facility managers, vendors could tailor their services accordingly. The maintenance vendors may offer more environmentally sound cleaning, landscape management, pest control, consumer waste removal, and building consumables purchasing. Providers of utility services like electricity, gas, water, or communications, could also use the DA tools to track decisions related to the building operations and may suggest how different decisions could positively affect energy efficiency and what incentives may be available.

Many of these issues are addressed in assessment systems more geared toward the operations of buildings, such as LEED for Existing Buildings: Operation & Maintenance.

NABERS, a building rating system developed in Australia, deals primarily with post-occupancy environmental performance. This assessment tool addresses the relationship between a property owner and the utility companies that serve the project.

5. Summary and Recommendations

No easy correlation between current assessment systems and the proposed DA Tools was found. Existing assessment systems do not provide clear decision making paths toward more environmentally conscious built environments. If the need for new decision tools should become recognized and widely acknowledged, a large undertaking would be necessary to rework the existing assessment tools into DA tools. While the individual credits from current assessment tools used in the examples above may be suitable for some DA tools, they would require extensive modification to become user-friendly in such a new application. Also, the existing credits do not have the capability to project the greater environmental impacts of applied building strategies in an interactive format, or to track decisions. For now, existing assessment tools are primarily framed to document the results for singular projects, results of decisions that have already been made. The authors recommend:

5.1 To those developing current assessment tools: Relate assessment topics to decision categories. Existing credits may be suitable for integration in future DA tools, specific to particular decision makers, and although they would need further development to be user-friendly in such an application, identifying their decision categories now will ease a future transition. More specialized assessment systems, such as those for neighborhood planning or those for building operations, appear to be a better basis for DA tools; thus entire systems or parts of systems could be converted to decision categories.

5.2 To those developing DA tools: Consider specific uses and tailor the tools to a specific type of decision maker identified by a major decision category. Tools should be available to decision makers over the length of their relationships with a project, and should be capable of maintaining user accounts for a long time period.

5.3 To those developing all tools: Add a framework that coordinates assessment methods and supports both data tracking and a searchable public-knowledge database. Current assessment tools rate project characteristics with differing methods, and there appears to be little dialogue between systems. Coordination would more easily allow for the development of DA tools by providing quick access to the topics in existing assessment tools. Synchronize decision topics related to a global scale across systems, and add data, opinions, and other public information that support decision making. Consider adding the capability to track decisions and maintain a database of such recorded information.

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THE SUSTAINABLE REFURBISHMENT OF EXISTING BUILDINGS: THE GREAT CHALLENGE FOR THE PROPERTY INDUSTRY

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Summary

The Australian Commercial Property Sector has fully embraced environmentally sustainable design for new commercial buildings. The challenge now is what can be done to improve the environmental performance of the existing stock without resorting to the environmentally damaging option of demolition and redevelopment of new buildings. Through a series of interviews with commercial building owners, the authors discussed some of the technical and management strategies that are being employed in Australia to improve the environmental performance of existing commercial buildings. The interviews discussed the financial aspects of these refurbishments and how major commercial property owners decide whether to refurbish their existing stock and to improve their environmental performance in an effort to retain their tenants, or to sell or demolish and redevelop their properties. Government can encourage the sustainable redevelopment of existing properties through legislation and incentives.

1. An Evolution for new buildings

The Australian Property Industry has fully embraced Environmentally Sustainable Design for new commercial buildings. This can be evidenced by the vast majority of developers seeking to have their new commercial buildings rated as four, five or six star buildings under the Greenstar Office Design rating scheme.

As of April 2008 there were 51 Green Star certified properties in Australia and many more have applied for certification. In recognition of this, the Property Council of Australia (PCA) acknowledged the green rating schemes in their May 2006 matrix which specified that new Premium and A Grade buildings are encouraged to be designed to achieve a 4 Star Greenstar rating and a 4.5 Star rating under the Australian Building Greenhouse Rating Scheme (ABGR).

It is fair to say that these minimum standards are generally being exceeded in most capital cities with most new PCA A Grade buildings seeking a 5 Green Star rating and Premium Buildings targeting a 6 Green star rating, in design. The next challenge for the developers of commercial offices will be to convert their "Design" Green Star ratings into "As Built" ratings. Educated tenants are now asking that the design promises are delivered as "As Built" GreenStar and ABGR ratings.

Developers and property owners are reluctant to agree to sign an ABGR Commitment Agreement which requires them to deliver a 4.5 Star ABGR rating to 18 months after occupation. Many are concerned that if the building does not achieve the ABGR rating specified that the tenants may be entitled to an unequitable rent abetment or require the lessor to pay for Green Power to deliver the contracted ABGR rating. It is with some justification as several recent commercial buildings which were built in recent years have yet to achieve the ABGR ratings which were promised when the building was designed. The NABERS web site pays testament to this in that in April 2008 there are no Melbourne commercial buildings listed as having achieved a 4.5 ABGR star rating.

Tenants commonly want the buildings which they occupy to achieve a 5 Star Green star tenancy rating and a 4.5 Star Tenancy ABGR rating whilst being unwilling to sign a requirement in their lease that they achieve any back to back tenancy rating. We believe that the industry has yet to evolve to accept that this is normal practice, where as the development cycle caters for majority of demand leaving sustainability behind as a point for negotiation. It is apparent that if the property industry is to achieve meaningful reductions in the Greenhouse emissions resulting from the occupation of its buildings, a partnership approach or back to back contractual arrangements will have to become commonplace with landlords and tenants working co-operatively together to assist each other in reducing their Greenhouse emissions.

2. The existing building dilemma

Approximately 2% to 4% of the available commercial office buildings are developed each year and new buildings retain their "new" status for approximately 5 years leaving about 90% of the existing stock which is largely not achieving high levels of Greenhouse and Environmental performance.

If the Australian Federal and State Governments wish to achieve reductions in Greenhouse emissions resulting from buildings, then much needs to be done in the next few years to improve the Greenhouse and Environmental performance of the existing commercial building stock albeit to an average below that of the energy ratings expected from new buildings.

Should the property industry wish to assist the Government to achieve reductions in Greenhouse gas emissions, is it willing to make the considerable investments in both capital improvement, education and better facilities management in order to improve the environmental rating of their existing buildings over and above the opportunities that are presented by developing new buildings?

3. The interviews

Through a series of interviews with commercial building owners, we discussed some of the technical and management strategies that are being employed in Australia to improve the environmental performance of existing commercial buildings. The interviews discussed the financial aspects of these refurbishments and how major commercial property owners decide whether to refurbish their existing stock and to improve their environmental performance in an effort to retain their tenants, or to sell or demolish and redevelop their properties.

The structured questions as summarised below were used to discuss the motivation of existing owners to improve the environmental performance of the existing buildings.

1. What are the important factors in commercial property investment decisions
2. What factors require cultural change to promote investment in sustainability through property
3. What are the key drives for retaining existing or old stock
4. What are the significant issues faced in retaining tenants
5. What incentives would assist in retaining tenants in existing buildings
6. What physical elements are paramount for the redevelopment of a financially successful building
7. Is upgrading existing buildings an appropriate way to develop a sustainable built environment
8. Is a focus on the quality and experience of building management necessary in delivering sustainable outcomes

4. The Findings

- *What are the important factors in commercial property investment decisions?*

The two most important factors were considered to be the investment horizon and "fit" within an existing or new portfolio and the capital costs of acquiring and /or refurbishing the property, but an underlying attribute that was sought was the inherent refurbishment potential.

Other factors discussed included compliance with industry standards, regulations and risk in development although these were also seen to be combined with the overall refurbishment appraisal where poorly performing buildings could be seen to be offering the greatest potential for capital improvement.

Green branding or specific tenant's requirements, at this point was not considered an overriding issue.

- *What factors require cultural change to promote investment in sustainability through property*

Interestingly there was no real move to change the cultural of their businesses, but there was an absolute need to have sustainable outcomes achieve investment parameters. (this leads to a greater motivation to invest in energy saving measures which generally have a greater return on investment that water saving measures).

- *What are the key drives for retaining existing or old stock*

The overriding factor to retaining existing assets is that the financial performance must be achieved within the investment criteria. Most felt that their asset management delivery systems needed to respond to this requirement once an asset was acquired.

- *What are the significant issues faced in retaining tenants*

Although over 50% of respondents felt that the green performance of the building played an important factor in attracting new or retaining existing tenants, it was also noted that perception and education were also important. Interestingly perception is not just green but relates also to perceived quality, function and design appeal.

- *What would assist in retaining tenants in existing buildings*

Improving the sustainability performance of the existing buildings was seen as an effective way of changing existing tenant's negative perceptions about the age of the buildings they occupy.

- *What physical elements are paramount for the redevelopment of a financially successful building*

The design of the entrance and Foyer has a great impact on tenants first impressions, equally building services that provide an enhance functionality and comfort (eg Lifts and air-conditioning).

Interestingly although aesthetics were important quality of finishes was not high on the list.

Facades and passive design features were desirable although generally felt to be cost prohibitive unless absolutely necessary.

- *Is upgrading existing buildings an appropriate way to develop a sustainable built environment*

All of the respondents agreed that the upgrading excising buildings was desirable

- *Is a focus on the quality and experience of building management necessary in delivering sustainable outcomes*

Again all of the respondents agreed that a focus on the quality and experience of building management was an absolute necessary in delivering sustainable outcomes and many were concerned about the apparent shortage of suitably skilled and experience building managers

5. What can Government do?

It was identified that the Government can provide an important role in directing coordinating and assisting with the delivery of sustainability through regulation, incentive and participation in the industry as a tenant, however the motivation for intervention was often queried. We note below some opportunities for government that were discussed.

- Tax incentives are often referred to an easily implemented incentive and one that is simply a deferred method of public investment; however the implementation needs to be carefully considered to ensure that the concessions granted are easily claimed, provide a reduction in emissions and water usage and drive innovation.
- Tax incentives should also be implemented allowing for the revaluation of existing buildings for tax concessions where a significant increase in environmental performance can be demonstrated.
- An innovative solution that was suggested by one of the interviewees was for the State Government or local authorities to refurbish a large commercial building which could be used by commercial building owners to relocate tenants while their buildings were being refurbished to improve their environmental performance. This would help overcome the problem that many landlords have when trying to schedule a major refurbishment, that of leases finishing at different times within the building.
- Government whether local, state or federal can encourage existing building owners to refurbish their properties by proactively leasing properties which have been upgraded to improve their

environmental performance. In this manner existing building owners can compete on an equal playing field with the developers of new buildings with high environmental ratings.

- One problem for investors wishing to buy an existing building or for tenants wishing to secure a lease is the lack of information on the amount of Green House Gases (GHG) generated by the buildings operations and their water usage. The introduction of mandatory reporting of the yearly GHG and water usage for commercial buildings may encourage existing building owners to improve their GHG and water performance. A league table of NABERS and energy and water ratings with positions this year and last year could be published to encourage building owners and tenants to maintain or improve their environmental performance.
- Government can play a more proactive role in the development and delivery of more efficient infrastructure such as for the water and power utilities that will in turn encourage innovative use and reuse of our scarce resources.

6. Conclusion

It is apparent from our research that age old investment criteria still stands for all property assets, in fact the investment models being implemented today scrutinise to a much grater detail than in the past, therefore any environmental initiative must deliver appropriate returns that suit the investment criteria of the developer or owner. However, this does not mean that every aspect of an environmental solution must achieve above market returns but it must contribute to the overall investment criteria. The term “future proofing” was often referred to in the interviews.

With over 90% of commercial building stock being over 5 years old, Existing Buildings are not discounted as being below investment grade any less than for new buildings, but rather provide an opportunity for repositioning and enhancing existing portfolios where their attributes suite an organisations investment criteria.

It was also apparent from various aspects of our interviews that it was believed that well educated and sound asset management practices from investment decisions through to the day to day management of buildings will pick up on sustainable opportunities. However it was also apparent that education was lacking in many areas of asset management.

It was identified that as tenants create demand their desire to occupy in a sustainable fashion must be backed up with not only their financial support but also their behaviour.

It was identified that the Government can provide an important role in directing coordinating and assisting with the delivery of sustainability through regulation, incentive and participation in the industry as a tenant.

There was a strong feeling that experience and quality of Building Management provides an important link in the delivery of sustainable outcomes and that the shortage of experienced building managers and engineers is a concern. It was also suggested that some tenants were equally concerned with the building management as they were with other aspects of buildings they seek to occupy.

PRO-ENVIRONMENTAL URBAN GRASSROOTS MOVEMENTS: COMMUNICATION THROUGH CULTURAL LANDSCAPES OF ENVIRONMENTALLY RESPONSIBLE CITIZENSHIP

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Summary

This paper focuses on pro-environmental urban grassroots movements that are pursuing their goals by transforming physical spaces in urban areas. Case studies, such as the creek mark on Center Street, Critical Mass, Park(ing), Save the Oaks, and "Stop (driving)," demonstrate the ways in which pro-environmental grassroots groups use and alter public and private spaces to communicate their desire for physical environments that will accommodate sustainable ecosystems and provide opportunities for healthier and environmentally-responsible lifestyles for their residents (e.g., bicycling instead of driving.) Through their interventions, they challenge the existing norms about cities and communicate messages about alternative urban forms to the rest of society.

Insurgent aspects of their movements portray the grassroots actors as active citizens who are also challenging conceptions of environmental rights and responsibilities. Their practices indicate that they consider living in a healthy and environmentally-friendly physical environment their fundamental right. They argue for and are committed to protecting the "environmental rights" of all members of the ecosystem (humans and non-human beings). Recognizing and understanding the needs and contributions of these grassroots actors is essential for environmental designers, planners, and governments in creating sustainable built environments, since it is a social challenge as much as a technical one.

1. Introduction

This paper focuses on pro-environmental urban grassroots movements that are pursuing their goals by transforming physical spaces in urban areas. The city of Berkeley, California is known as the home-town of liberals and environmentalists, both in historical perspective and in the present-day. In Berkeley, liberal, socially considerate, and pro-environmental groups have historically succeeded in manifesting their goals by reclaiming public spaces for the purposes they wanted and turning their social commitments into currently existing cultural landscapes (e.g. People's Park[1] and Sproul Plaza[2]). While historical examples are icons of civil rights and social justice movements, the movements discussed in this paper are emblematic of social responsibility for environmental problems. These grassroots actors transform the built environment in order to create sustainable urban environments, as well as to increase environmental awareness. Insurgent practices of these grassroots actors indicate that they consider living in a healthy and environmentally-friendly physical environment their fundamental right.

In this paper, "sustainable urban form" is used to mean urban form that encourages environmentally responsible behavior, such as bicycling instead of driving, and places where minimal environmental impact is the foremost principal in their design.

Participant observation, interviews, content analysis of mission statements of the various movements, and archival research are amongst the methods used to analyze the grassroots actors' motives and the messages they are willing to communicate to the audience around them who are not participating actively in the movements. The following case studies demonstrate the ways in which pro-environmental grassroots

[1] People's Park, created on university-owned land, was initially planned to be a site for student housing. Then, a decision was made to turn it into a parking lot. For the three weeks the site was vacant, people from the neighborhood started to build a garden, an action which eventually resulted in armed disputes between park volunteers and the university, which lead to many injuries. Nevertheless, after following negotiations, people in Berkeley succeeded in converting the site into People's Park, a space devoted to use by homeless people. Today it is still used that way. (http://www.afsc.org/about/hist/2002/peoples_park.htm, accessed in 12/10/2007).
[2] Sproul Plaza at the University of California, Berkeley Campus, became a symbol of 'free speech' during students' protests against a university ban on political activities on campus in the early 1960s.

groups use and alter public and private spaces, streets, and sidewalks for environmental campaigns and for communicating pro-environmental and sustainability-oriented messages:

- Creek mark on Center Street, by Friends of Strawberry Creek: a blue mark on the street indicating the portion of Strawberry Creek that is flowing underground;
- Critical Mass, anonymous: large groups (enough people to cut off traffic in a three lane avenue) meeting for bicycle rides on the streets once a month;
- Park(ing), by Rebar: creating temporary green spaces in parking lots or in spaces for car parking;
- Save the Oaks, anonymous: a tree-sit scene lasting for more than a year and sustaining itself with food donations from residents;
- "Stop (driving)" signs, anonymous: "stop" signs are converted to "stop driving" signs through the application of stenciled lettering.

These examples are important for the environmental design professionals, because they show a demand for change in urban environments. The movements, some of which were started in the San Francisco Bay Area, represent not only a local uprising for urban environmental change but a global demand, which is proven by finding supporters replicating the same movements (e.g., Park[ing] and Critical Mass) in cities in other parts of the world. Signs of permanent and temporal physical interventions in urban space demonstrate those communities' values regarding how they want to make use of the urban spaces in which they are living.

Case studies and interviews in particular show that those pro-environmental urban grassroots interventions are also a reaction to corporate capitalism and mass consumption culture, as much as they are about dissatisfaction with current urban forms, planning, and the uses imposed on society. Underneath the motives of these grassroots actors seems to be a desire for change towards more sustainable lifestyles (socially and environmentally) and a struggle of "rights" to sustain a healthy ecosystem, for people and for other living beings that are also part of the earth. The practices of these movements bring up several issues, including alienation from nature, healthy lifestyles, and lack of sense of community and public life. Some of the grassroots arguments stem from ecocentric values over anthropocentric values, i.e. prioritizing the ecosystem as a whole, rather than prioritizing human needs or any one individual organism in the ecosystem.

What is most intriguing about these environmental movements is the importance given to the physical environment itself. They aim for restructuring existing urban forms and current unsustainable lifestyles that are closely related to urban forms. Their actions do not consist solely of adapting urban spaces and enacting their goals about each particular space, but also of choosing space as a tool to communicate their pro-environmental messages to the public. Thus, their activities should not be overlooked as simple "tree-hugger" behavior; they are also agents/citizens structuring cultural landscapes of environmental responsibility.

These grassroots movements are also striking, because they do not limit their political environmental behavior to recycling their own garbage or closing their own tap when brushing their teeth, but instead they are interested in public behaviors and opinions that can be formulated and communicated in public spaces. They are interested in taking action and taking responsibility for public spaces and public behavior as active citizens. Therefore, after presenting the grassroots movements, this paper analyzes the pro-environmental urban grassroots movements from two angles: 1) construction of cultural landscapes of change for a sustainable future and the communication of social and environmental sustainability-oriented messages; and 2) environmentally responsible citizenship, environmental rights and duties, and ecological democracy.

2. Pro-environmental Urban Grassroots Interventions

The grassroots movements presented in this paper are chosen because of the ways in which they use and transform public space (and private space in the case of the Save the Oaks movement) in the city. Each of them demonstrates a claim, in different levels of intensity, about participating in decision-making for urban spaces. They share similar underlying pro-environmental intentions while using the space as an instrument to bring public attention and while enacting their will on the space.

The mission statement of Friends of Strawberry Creek presents their goals as protecting the quality of the creek, exposing it to sunlight wherever possible, and increasing the native vegetation and habitat around the creek. Their consequent goal is educating and involving the public in the pursuit of rehabilitation of the creek. Their way of executing this objective has been through bringing attention to the creek by painting a blue line on Center Street in Berkeley where the creek would be flowing openly if it was not flowing under the ground (Fig. 1). They choose to argue for their case where it exists. Moreover, they leave an actual mark of public will on the exact space they find problematic. Thus, the creek almost talks for itself, representing what would be healthy for the natural environment and pleasant for people.

Critical Mass is an event concerned more with sustainable behavior. It is a community bike-riding movement that takes place on streets designated for motor-vehicle traffic. Even though the city of Berkeley has been responsive to the needs of bicycle commuters by implementing various traffic calming measures, adding bicycle lanes, and creating bicycle-only streets, it seems that there is still a demand for more space for non-vehicle traffic. Critical Mass is a monthly bike-riding event first started in San Francisco in 1992 and now spread worldwide. Several websites about Critical Mass suggest that it is a self-organized social event with no leaders. The "unofficial" website of Berkeley Critical Mass describes the movement as a global non-authoritarian movement of celebration, street reclamation, and demonstration. The same website names the event also as “a rolling free speech stage and playground.” This association with the free speech movement hints at the political face of the movement.

Critical Mass may seem like people simply gathering for bicycling; however, for many participants, it means more. Besides riding bicycles, many participants also imply that they prefer seeing more space designated for pedestrians and bicycles rather than automobiles. Some participants communicate their reaction to oil dependency and automobile-dependent lifestyles and carry “Stop Global Warming, Stop Driving” campaign boards behind their bikes (Fig. 2). As local newspaper Modesto Bee suggests in one article, reasons for people’s participation are multiple: “Some want safe bike paths and more bike racks. Others want to show motorists that there is a healthier, cheaper, pollution-free mode of transportation. Some want to show that bikes are traffic too and should be respected. And some just want to be noticed -- not applauded, but seen, so they aren't hit by heavier modes of transportation (Hightower, 2007).”

Figure 1 *Creek mark on Center Street in Berkeley, CA indicating the portion of Strawberry Creek that is flowing underground (Morhayim, 2007)*

Figure 2 *One of the riders carrying a “stop driving” sign on the back of his bike during Critical Mass in Berkeley, (Morhayim, 2007)*

Having participated in the cycling event in Berkeley in 2007, my observation is that it is a temporary but empowering opportunity to have a voice in how people make use of a certain place in the city, instead of being contained by the existing physical, social, and political configurations of how to use the city. They take over control of the street and change its designated use, based on the motivation of biking freely in the city. They express their needs through simply acquiring what is needed. Furthermore, the riders are not the only celebrants of the bike rides; very often, I have seen drivers passing by and supporting the ride by honking. Hence, Critical Mass shows that both participants and several passersby share similar values regarding automobile dependency and, perhaps, regarding the amount of room it takes up in urban space and in urban life.

Park(ing) is an event that uses on-street car parking spaces as temporary public parks (Fig. 3). Park(ing) activists bring their lawn and furniture and lease a metered parking spot to transform it into a green space. It was initiated in November 2005 by Rebar, a San Francisco-based art collective, and has turned into an annual global event celebrated in 13 cities in 2006 and in over 50 cities in 2007. Their mission is “to rethink the way streets are used, call attention to the need for urban parks, and improve the quality of urban human habitat.” Their website also claims that, “[a] playful idea has become a lively and visible symbol of the desire to reprogram the street and increase public open space in cities all over the planet.” Park(ing) activists around the world manage to voice their needs for more green space by actually creating that space, for their own use and for the public. Even though it is a one-day event, it engages the public in the cause, as they sustain the event by public donations to the parking meter, and the public can use the randomly occurring temporary green spaces in the city.

Figure 3 Passersby enjoying one of the Park(ing) spots in San Francisco, CA (http://www.rebargroup.org/projects/parking/#, accessed in April, 2008)

Figure 4 'Stop Driving' signs on Milvia St. and Oregon St., Berkeley CA (Morhayim, 2007)

A rather radical and illegal activism in urban space is the production of "Stop Driving" signs: regular stop signs on poles stenciled with "driving" to read "Stop Driving." The same is also done for the stop sign markings on the roads at intersections (Fig. 4). This movement, of which the actors are unknown, communicates to many people not to drive and instead to choose walking, biking, and public transportation. This insurgent act, on the one hand, aims to provide an alternative perspective for street use; on the other hand, it transforms the exact element that is viewed as a problem and communicates a message of sustainable behavior and environmental protection.

Save the Oaks is another grassroots movement in the city depicting environmental sensitivity in an insurgent manner. The Memorial Oak Grove (containing a threatened native Coast Live Oak ecosystem) on the east side of the University of California at Berkeley campus, dedicated to Californians who died fighting in WWI and property of the University, has been fenced by UC Berkeley since August 2007. As of March 2008, a group of people have been tree-sitting for more than a year to protect the trees from UC Berkeley's plan to build an athletic facility on the site. They built wooden rope structures to sleep on, ladders to climb into the trees, and bridges to cross between the trees. Banners hanging around say "Home is where the trees live" (Fig. 5). The site has created a long controversial process between the university, environmental groups, students, and the city, given that some of the oak trees are 200 years old (older than the university itself), and that the proposed site is on a fault right next to the seismically challenged and aging UC Berkeley stadium. Tree-sitting has become widely known in the United States; a number of local and national newspapers have covered this issue since November 2006[3]. By February 15, 2007, the site attracted more than 80 people to support the cause; they have taken turns sitting in an oak tree (Bender, 2007). Tree-sitters sustain their movement through public support. They get donations of food and material from their supporters, especially from a group that call themselves "Berkeley Grandmothers."

The tree-sitters' argument is one of ecocentric values over anthropocentric values. The tree-sitters argue that a healthy functioning native oak ecosystem, supporting a whole network of other plants and animals, should not be lost for the sake of further development. Moreover, as it is stated on their website, the group also stresses the educational value of such a vital ecosystem existing in urban space.

Figure 5 Save the Oak Trees, tree-sitting site (NY Times, accessed in October, 2007)

Figure 6 Pro-environmental messages on the sidewalks around the Memorial Oak Grove (Morhayim, October, 2007)

Tree-sitters continue to organize events regularly to keep their case alive and to communicate other messages as well, one of which is creating an alternative community. The sidewalks in front of the site are painted with messages, such as: "A football team does not stop global warming, but trees do!" (Fig. 6). On October 28th, 2008, the tree-sit site was also used as a "free market" "to create a truly alternative economy" for "sharing," as stated in a flyer. Tree-sitters also announced the following in the flyer:

> "As globalized capitalism consumes more of the Earth every day, let's answer with creative resistance. This event is made by and for you/us. Bring anything you have that could be useful to others."

Analysis of these movements shows that all these grassroots groups perceive physical space as the center of environmental and social sustainability. They therefore choose to address their cases through physical interventions in these spaces in the city. Grassroots activists use the spaces as the locus of their action. This way, on one hand, they enact their agendas though transforming the spaces to more pro-environmental ones; on the other hand, they publicize their cases. As active citizens, they act as if it is their right or their responsibility to address the issues they perceive as unsustainable. Some grassroots actors show such a strong commitment that they take the risk of engaging in illegal behavior.

[3] According to a key word search of "Memorial Oak Grove" and Berkeley (in News Bank, www.newsbank.com, accessed, 10.11.2007)

3. Underlying Social and Pro-environmental Messages of the Movements

One of the active participants of these movements, who has given several speeches in the Memorial Grove and who has been reported on in several newspaper articles, describes the underlying messages of their activities as being beyond mere physical interventions. During my informal conversation with him, he refers to the overarching goal of stopping global warming, of which the tree-sit is part of, according to him. In order to reduce the risk of environmental deterioration such as global warming, he recommends a "paradigm of a lifestyle change; i.e., instead of thinking of green energy, [he calls forth for] thinking of reductions, [and] simplifying one's lifestyle." He also adds:

> "…[oil] economy, in basic terms, is a war on Mother Earth. It is use of resources quicker than you can replace them, and we can no longer afford it. By 2003, I find money hard to basically be justified…stop abusive lifestyle of capitalism!"

He extends this idea of "thinking reductions" and "lifestyle change" to physical interventions of private residential spaces, as well. He describes how the layout of residential buildings in a block needs to be transformed for social change:

> "How you could change society is you take inner city block, instead of having fences in the middle put one around the entire block and drop the inner one[s]. Then you would have an entire football field (excuse the term) inside that block, and you could become a community of one block…We don't think of community, we think of personal [in our current lifestyles today]."

> "There are so many resources…how many people have 2 or 3 bicycles in the garage, just sitting? We could, quite literally, and this is revolutionary thought, take all the bicycles we are not using and put them out on the street just leave them unlocked. Just have people whenever they wanted to go take a bike and go."

These rather utopian ideas show that grassroots activists' focus is more than environmental protection, and that they in fact long for social change. Such a configuration of dwelling units and shared private spaces proposes creation of a neighborhood community that will share their goods and their physical space, which suggests a very different social life than the existing one in many parts of the world.

Overall, the issues that came up in the interview are the problems of modern life, the isolation between people, isolation from nature, the fast pace of our lives, and increased consumption, which all are directly and indirectly related to and moderated by the way the physical environments are constructed. This explains why urban space becomes so central to the grassroots' activism to create change towards sustainability. While such attitudes need to be substantiated by a larger number of interviews, still at this point, this data provide important clues about values underlying the interventions of the grassroots actors. Grassroots actors strive to create sustainable urban forms that will encourage sustainable lifestyles and sustainability-oriented society. Through interventions, they communicate messages of an alternative form to the rest of the members of the city, including design professionals.

4. Pro-environmental Interventions as Cultural Landscapes

Urban space is important for these actors in multiple ways. Transformations in the urban space create opportunities for encountering like-minded people in the society and allow pro-environmental grassroots groups to experience the kind of city they want. Also, through their transformations in urban space, the grassroots actors bring attention to unsustainable parts of the city.

Dave Horton (2006), in his article "Demonstrating Environmental Citizenship," emphasizes the importance of "green spaces" and "green times" in constituting and strengthening green identities. He refers to places and times of social networking, like cafés that are renowned as places of green culture, green meetings like festivals, and environmental protest events (2006). One special thing about the "green spaces" in this paper is that the pro-environmental grassroots actors use the same urban spaces that they view problematic as the locus of their activities and for gathering. Choosing public space (or publicly visible private space, as in the case of the tree-sit) as the locus of their action allows grassroots actors to encounter their supporters. As in the case of Save the Oaks, Berkeley grandmothers regularly donate food to tree-sitters and help them to sustain their movements; likewise, drivers in traffic support Critical Mass bikers by honking even when bikers are cutting through traffic.

Lefebvre states that the "space of the city is said to embody a discourse, a language." Space represents the messages and intentions of the producers of the space (LeFebvre, 1961). When these grassroots groups appropriate the space, they also create cultural landscapes of "green identities." Cultural landscapes communicate environmental messages to the rest of society. Critical Mass and Park(ing) are prominent examples. These movements change the physical conditions of the space, and they change the use. They enact sustainable behaviors in public space. First, they create a pro-environmental spectacle, explicitly to create contrast with the modern, consumptive, and late capitalist spectacle. In a way, they act out a public show. Next, this act changes the meaning of the space, not only for that moment, but also for longer periods of time. Such a scene stimulates the viewer to question the taken-for-granted ways about how urban space is used and taken-for-granted public behaviors. Additionally, it reminds the viewer that there is not an adequate amount of space, such as adequate bike paths and other green space, designed for environmentally-friendly behaviors. Actors choose to show their need by using the existing space as they would like to see it being designed and used, even though it is not currently designed for their needs. Consequently, appropriated urban space becomes an instrument to raise awareness for creating sustainable urban spaces and to strengthen green identities.

Douglas Torgerson (1999) states that, "green movement provokes a reconsideration of the entire human/nature relationship." Practices of these grassroots activists challenge the current attitudes that society holds about physical and natural environments, such as how we live, how much we consume, how much we are connected or disconnected from nature, and problems like a loss of sense of community and spaces that will encourage sustainable behavior (e.g., bicycling).

As suggested by Pierre Bourdieu, active agents alter their actions based on their desires and needs, independently from the social structures (Stevens, 1998). Pro-environmental grassroots movements explicitly adopt and transform physical spaces, instead of being constricted by the existing physical, social, and political configurations. In turn, this adaptation becomes the usage of space as a tool of enculturation for environmental awareness, while they create the space they want. Grassroots activists bring attention to taken-for-granted uses of urban space as social problems as much as physical problems, in order to point to the kinds of unsustainable environments architects and planners choose to create and the role that these spaces play in a society trying to live sustainably. They question the ways in which our physical surroundings shape our lifestyles and the societal values and the worldviews people hold about nature. Grassroots activists transform the physical environments in an attempt to re-create the social structures towards a sustainable society. The illegal aspect of the movements, such as tree-sitting on private land and stop (driving) signs, show that constraints of existing structures can be challenged by the agents, to the extent of acting illegally[4].

When those actors alter physical spaces and use them for a different purpose than their conventional use, they exercise control over public space in addition to communicating their opinions. As Lefebvre states, that space produced "…also serves as a tool of thought and of action; that in addition to being a means of production, it is also a means of control, and hence of domination, of power…" Pro-environmental communities, whose needs haven't been addressed adequately through planning, take control and govern their spaces (Etzioni, 1968; Foucault, 1991).

By enacting their goals on the spaces they find unsustainable, grassroots actors address environmental and/or social problems occurring in those spaces. In time, places that pro-environmental movements create might become symbols of change towards environmentally responsible lifestyles. For instance, even if in the future oak trees might be replaced with an athletic facility, the tree-sit site will be remembered as a place of environmental struggle and a base of pro-environmental sub-culture, having been taken over for more than a year. A new image is already attached to the Memorial Oak Grove site, which is communicating messages for an alternative lifestyle and worldview that prioritizes ecological balance. This and other pro-environmental interventions in urban space become an instrument and embody an active role for raising awareness. Grassroots actors turn those spaces into cultural landscapes of pro-environmental change.

5. Environmentally Responsible Citizenship

As analysis of the movements show, some of the grassroots activists are so committed to their causes that they don't mind participating in illegal activities, as if it is their right or their responsibility to address and solve the urban matters that they perceive as unsustainable. This fact suggests that these grassroots actors are active citizens who are also challenging conceptions of environmental rights and responsibilities.

These pro-environmental urban grassroots movements claim the right to live in a healthy ecosystem, for themselves and for other living beings. Non-living elements are essential as well, since they are constituents of the natural environment that allow the existence of the living beings, just as the small creek ecosystem allows the plants and the animals that are its dependents to live.

Their everyday practices allow the grassroots actors to practice direct democracy and create a public sphere for decision making for the places in which they live. Pro-environmental grassroots movements make use of the public space as an "agora" to share their point of view and to create an "ecologically democratic" society. I use this term, ecological democracy, to point to a longstanding disregard of environmental problems and the need for compensation through a prioritization of the sustainability of ecological systems. Given that there is not an immediate platform to participate in decision-making for ecological justice in the city (socially and environmentally), the grassroots actors create their own political platform through physical interventions.

Derek Bell's concept of "liberal environmental citizenship" and Andrew Dobson's concept of "ecological citizenship" highlight different aspects of being an environmentally-considerate citizen (Dobson, 2003; Bell, 2005). Environmental citizenship proposes a rights-based approach: it "extends the liberal list of rights beyond civil, political and economic rights to include environmental rights, that is, rights to environmental goods or to protection from environmental bads" (Bell, 2003). Bell (2005) states that liberal environmental citizenship is based on the understanding of being a "citizen of the environment" and of a local environment. On the other hand, ecological citizenship is concerned more with behavioral duties and responsibilities, in order not to consume more than one's fair share of ecological space, so as to leave enough ecological space to other people (Dobson, 2003). Environmental citizenship is also concerned with others' right to a fair share of ecological space; however, this is mediated through supporting "institutional arrangements that [will] secure everyone's right," rather than securing it through a negative duty of not consuming more (Bell, 2003). In this light, ecological citizenship represents a rather active form of citizenship that is concerned with self-control of behavior, and environmental citizenship operates through liberal rights. Nevertheless, both formulations of environmentally considerate citizenship describe people that are interested in social change for sustainable future.

[4] In a similar way to how People's Park was used.

Each of the movements presented in this paper holds their own particularities in terms of rights and duty claims and in terms of their special interests in urban space. Some are illegal in their approach. Some are less active movements, like Friends of the Strawberry Creek, whose awaited contribution is influencing institutional arrangements as much as increasing public awareness. On the other hand, the tree-sit would be an example of the most rigorous activist citizenship amongst them all. While the Park(ing) movement is concerned with creating greener urban habitats for people, the tree-sitters in Memorial Oak Grove care about the rights of trees to exist and to sustain their ecosystem. The tree-sit shows that citizenship rights can be extended to protect rights of non-human beings (even if it might stem from self-interest), because all elements of the ecosystem are interdependent, and because living beings other than humans don't have means to fight for their existence. Nonetheless, even though all grassroots movements are slightly different from each other, they all claim rights and take responsibility for their environments. This suggests the existence of a political community of active, environmentally-responsible citizens who are aiming to achieve social and physical change in urban space.

Citizenship has always been a struggle for more rights. Given that, these pro-environmental grassroots movements, even the illegal ones, may be seen as part of an emerging form of citizenship. Illegal or not, grassroots movements may still be perceived as being "uncivilized;" however, their contribution to raising awareness and realizing their goals of creating sustainable lifestyles (even if it is for a temporal period) and creating a political platform for debating environmental and social problems of sustainability can not be ignored. As Dobson (2003) states, all of these movements aim to "re-moralize" the existing politics. According to Jamieson (2001), such insurgent attempts constitute a stronghold in democratic progress, and they are, as Carter (2001) states, "a significant political force, in the innovative repertories of protest and in the radical organizational forms and ideologies of ecological new social movements." Grassroots activists, through insurgent practices, negotiate for sustainable urban forms in order to promote sustainable lifestyles and to foster ecological democracy and an environmental community. Finally, they represent new identities of environmentally considerate citizens, whose needs have to be taken into account by designers, architects, planners, and policy makers.

6. Conclusions

Pro-environmental urban grassroots actors are active citizens who are arguing for and committed to protecting "environmental rights" of all members of the ecosystem (humans and non-human beings). Thus, the ecosystem can sustain its healthy balance, and we can all live in healthy environments. Moreover, analysis of the movements shows that these grassroots groups perceive physical urban space and urban social life as central to their goal of sustainability-oriented change, since sustainable places promote and allow sustainable behaviors.

These grassroots actors manifest their concerns about environmentally-unsustainable physical environments through physical interventions in those places. Insurgent practices of pro-environmental actors transform existing places into pro-environmental landscapes, and these places gain a new meaning. Hence, grassroots actors manage to bring attention to those places and promote a rethinking of the sustainability of existing urban forms and their uses.

Even though this paper covers grassroots groups in the San Francisco Bay Area, many similar local pro-environmental groups exist all around the globe. Grassroots actors strive for physical change in urban environments and for change in public behaviors and attitudes towards sustainability. They deliberately show their need for sustainable urban spaces with their practices. Creating better sustainable environments is a challenge ahead of us, not only consisting of inventing better building technologies, but also a challenge of increasing environmental awareness and increasing demand for more sustainable environments. Grassroots movements are important because of the effort and motivation they demonstrate to challenge existing conditions and to publicize the cases. They also show that there is a group of people in society who advocate design for a healthy ecosystem and whose needs ought to be recognized by designers, planners, and policy makers when making decisions for the built environments.

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OPTIMAL AIR TEMPERATURE AND AIR SPEED FOR BUILT ENVIRONMENT IN HONG KONG FROM THERMAL COMFORT AND ENERGY SAVING PERSPECTIVES

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Summary

In this study, 140 human subjects wearing typical summer clothing were invited to an environmental chamber to conduct a thermal comfort survey in sedentary position. The studying air temperatures were in the range of 25 to 30°C, air speeds 0.5 to 3 m/s at 50%RH. Their thermal sensations were collected by using the ASHRAE 7-point scale. Multiple regression analysis was carried out to study the effect of both indoor air temperature and air speed to the thermal sensation of Hong Kong people in the age group of 19 to 25. The difference in thermal sensation between male and female subjects was also studied. A comfort zone for different air speeds in the temperature range of 25 to 30°C was developed. The results of the thermal sensation of different combinations of air temperature and air speed were compared with the predicted mean vote (PMV).

1. Introduction

In the subtropical Hong Kong, air-conditioning is a norm for the built environment, it is a standard expectation of the occupants. The provision of air-conditioning is necessary, but the reality is the excessive cooling in many places, no matter due to the wrong settings or control problems. In fact, the primary objective of air-conditioning is to provide a thermally comfortable indoor environment instead of simply cooling. Human thermal comfort may be dependent to a number of physiological, cultural and habitual factors. For the people in the tropical or subtropical Asian cities, the thermal sensation would be different due to the effect of acclimatization (Givoni 1998). The thermal sensation at higher air temperature can be still neutral if appropriate air speed is involved without causing nuisance. Cheng and Ng (2006) conducted a study of comfort temperatures for naturally ventilated buildings for Hong Kong, they found that the comfort temperature could be elevated by increasing the air speed. Huda et al. (2006) had the same idea, and they conducted experiments to study the sensitivity of neck and ankle to higher air speed. In a working environment, it is important to prevent the occurrence of uncomfortable draft and annoying air speed. From both the thermal comfort and energy saving perspectives, it is essential to have an optimal setting of air temperature and air speed to provide a comfortable but not over-cooled built environment. On the other hand, Feriadi and Wong (2004) had a thermal comfort study in Indonesia, showing that there was discrepancy between their obtained results and the prediction by the conventional PMV. de Dear (2006) also argued the appropriateness of the PMV model to reflect the thermal comfort. In Hong Kong, application of PMV and PPD to assess a thermally comfortable indoor environment is common. It is necessary to review whether the thermal sensation derived by the PMV equations, particularly the involvement of air speed, would closely reflect the sensation of the Hong Kong people.

This paper presents the indoor thermal comfort study for the Hong Kong people in the age group of 19 to 25 at 50% RH. By varying the air speed from 0.5 to 3 m/s, the range of 90% comfort temperature was determined. The difference in thermal sensation between male and female subjects would be discussed. The conventional PMV was compared to the experimental results to understand the effectiveness of representation for the thermal sensation of people in Hong Kong.

2. Thermal Comfort Survey for Different Temperatures and Air Speeds

The thermal comfort survey was conducted in the summer (June) in 2007. In this survey, 140 volunteers were recruited and they were not paid. There were 102 males and 38 females in the age group of 19 to 25. All the subjects were requested to wear local typical summer clothing, including the polo shirt, long trousers, underwear, socks and shoes. This would have an expected clo-value of 0.55. Six temperature settings of

25, 26, 27, 28, 29 and 30°C and six air speed settings of 0.5, 1, 1.5, 2, 2.5 and 3 m/s were covered in this study, altogether thirty-six combinations at 50%RH.

2.1 Environmental Chamber and Equipment Arrangement

A thermally insulated environmental chamber (7.9 m × 5.9 m × 2.4 m H) was used for this thermal comfort survey in the City University of Hong Kong. Two existing fan coil units with room thermostats were installed for general air-conditioning purpose. There was a waiting area outside the environmental chamber, where the subjects could settle down themselves before the survey.

In each survey, four human subjects could be involved at the same time. Each subject had a working desk and sat comfortably to carry out light office works, such as reading and writing, during the survey period. There was a tower fan beside each subject, the fan speed could be changed according to the required setting from 0.5 to 3 m/s. The fan had a 500 mm-long slot outlet centred at 0.6 m above floor level, located at 30° from the longitudinal side of the desk and 1 m apart from the subject. The actual location of each fan was commissioned in the preparation stage. Four 2,000 W air heaters with thermostat control were installed evenly inside the environmental chamber, in order to provide the required temperature setting from 25 to 30°C. Eight ultrasonic humidifiers were also installed, in order to maintain the 50%RH at different temperature settings without contributing any space sensible heat gain.

A set of central measurement probes and data logger were used to monitor the air temperature, air speed, air humidity, operative temperature and radiant temperature asymmetry. Before starting the survey, a thermal tracer was used to make sure the surface temperatures at all the inside surfaces of the environmental chamber were close to the required setting of air temperature.

2.2 Questionnaire Design for Thermal Comfort Survey

There were two parts in the questionnaire. The first part covered the background information of the subject, and the second part was used to collect the thermal sensation and the related comments. With the linguistic consideration, the contents were in both English and Chinese to let the subjects understand this questionnaire precisely. In order to make sure the subjects had adapted themselves well in the Hong Kong climate, they should have continuously lived in Hong Kong at least for ten years.

Before implementing the actual thermal comfort survey, a number of trial runs were carried out to test the appropriateness of the survey questionnaire and the length of thermal response time. Comments were collected from the volunteers involved, and the questionnaire and surveying period were continually revised and verified.

2.3 Conduction of Survey

Each session of survey involved two air speed settings at a certain temperature and 50%RH. The whole session would last for about 1 hour and 15 minutes, including briefing and form filling. Initially, the human subjects were briefed about the objectives and procedures of the thermal comfort survey, and they were asked to fill up their general information on the questionnaire. Then the subjects were arranged to sit comfortably inside the environmental chamber so that they would perform a sedentary activity naturally. The survey for each air speed setting was conducted for 30 minutes, in order to achieve the steadiness of thermal sensation. Throughout this 30-minute period, the subjects were asked to give their thermal sensation based on the ASHRAE 7-point scale in a 5-minute interval. In the whole survey process, the air temperature, air velocity, air humidity, operative temperature and radiant temperature asymmetry were logged at 0.6-m level of the representative monitoring location inside the environmental chamber.

3. Results and Discussions

3.1 Comfort Air Speeds at Different Air Temperatures

From the last entries of the thermal sensation of the subjects, the results for each setting of air temperature and air speed were consolidated. Multiple regression analysis was applied to determine the relationships for thermal sensation in terms of air temperature and air speed. These mathematical relationships cover the cases of all the subjects, male subjects only, and female subject only.

3.1.1 Overall results: Through the regression analysis, the thermal sensation as a function of air temperature and air speed between the computed and observed data is expressed in Eq (1). The coefficient of determination was 0.7350, which showed good correlation of the data, as shown in Figure 1.

$$TS_o = 0.1574t - 0.2960v - 3.789 \quad (1)$$

where,

TS_o: overall thermal sensation

t: air temperature (°C)

v: air speed (m/s)

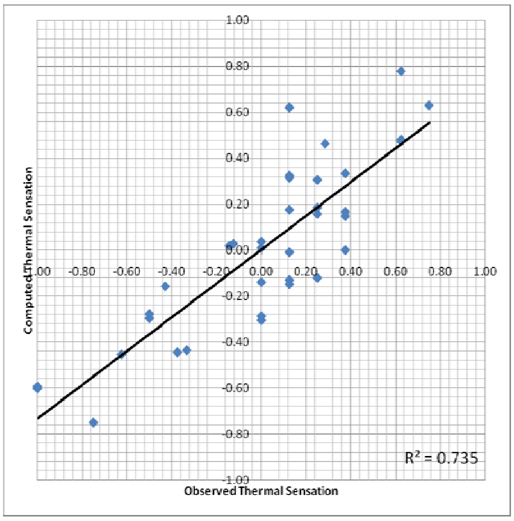

Figure 1 Computed thermal sensation vs. observed thermal sensation from survey.

Based on Eq (1), a band of 90% comfort zone was developed for comfort air speed as a function of air temperature in the range of 24 to 30°C at 50%RH. This band was developed by considering the bounds of thermal sensation between -0.5 to 0.5. From the energy perspective, the negative thermal sensation was not expected due to the tendency of over-cooling and energy-wasting. If looking at the band for thermal sensation between 0 and 0.5, the comfort air speed difference was 1.69 m/s at any temperature. For the neutral thermal sensation, the change of comfort air speed was in the range of 0 to 3.12 m/s for temperature from 24 to 30°C. The air speed was linearly lower with the decrease of indoor air temperature, or vice versa.

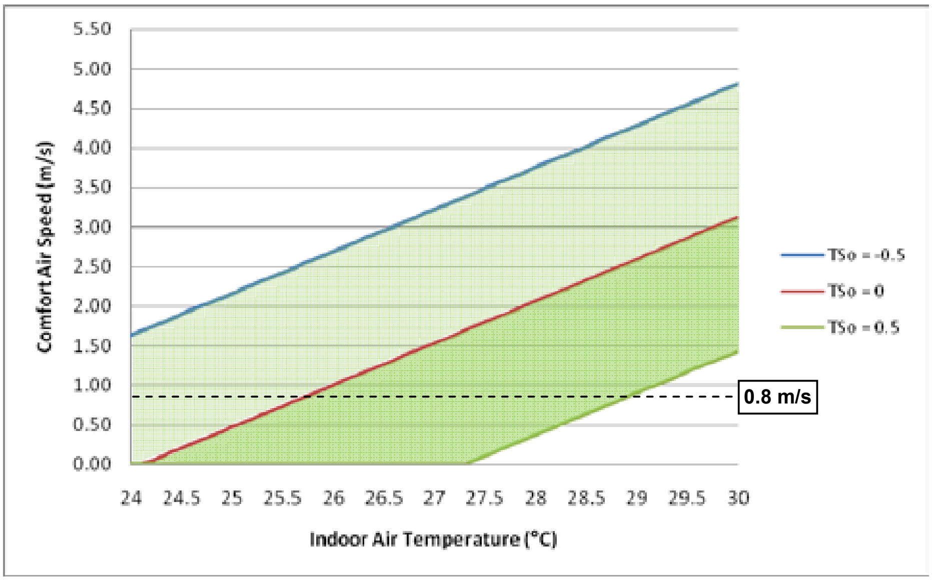

Figure 2 Comfort zone of general occupants based on comfort air speed vs. indoor air temperatures at 50%RH.

If the air speed limit of 0.8 m/s as recommended by ASHRAE was applied, the neutral air temperature could be up to 25.6°C. If the lower bound of this comfort zone was considered, the neutral air temperature would be up to 28.8°C. At the lower bound, the air speed in effect started its role in thermal comfort from 27.2°C, and up to 1.44 m/s at 30°C. Therefore it is possible to elevate the room air temperature by increasing the air speed up to a threshold according to the feature of room activity. Higher and suitable air speed would provide a sense of freshness, that may contribute to the psychological pleasure of thermal comfort.

3.1.2 Results of different genders: The regression analysis of the thermal sensation of male occupants TS_m and that of female occupants TS_f are consolidated in Eqs (2) and (3) as follows.

$$TS_m = 0.1535t - 0.3203v - 3.600 \quad (2)$$

$$TS_f = 0.1702t - 0.2328v - 4.366 \quad (3)$$

Based on these two regression equations, the 90% comfort zone of male occupants and that of female occupants are presented together in Figure 3. It was found that these two comfort zones were largely overlapped, showing that the thermal sensation of male and female occupants was generally the same. However, it was observed that the female occupants could withstand a higher temperature at a lower air speed as shown in the lower right non-overlapping region. On the other hand, the male occupants could withstand higher air speed at a lower temperature as shown in the left non-overlapping region, but this became opposite when the temperature was above 27.5°C.

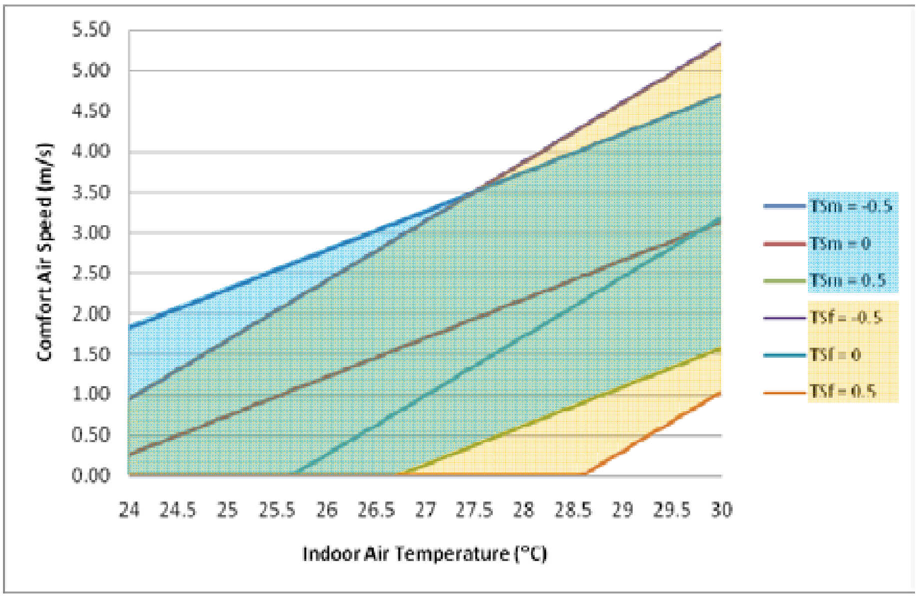

Figure 3 Comfort zones of male and female occupants based on comfort air speed vs. indoor air temperatures at 50%RH.

3.2 Comparison between Thermal Sensation from Survey and Conventional PMV

Based on each setting of air temperature and air speed, the conventional PMV was determined by using the ASHRAE Thermal Comfort Program (ASHRAE 1995). Then a 90% comfort zone of air speed against temperature was developed for the PMV between -0.5 to 0.5. This is plotted in Figure 4, together with the comfort zone based on the thermal sensation as developed in this survey in Section 3.1. It was found that the comfort zone from the PMV was narrower, steeper, and located at a higher temperature side in the range of 24 to 30°C. From the viewpoint of the comfort zone established from the survey, the local occupants had a wider range in thermal sensation. Appropriate air speed was required to achieve comfortable thermal sensation at the lower temperature, but the comfort air speed was not as high as that from PMV at the higher temperature. If the thermal sensation was determined by PMV, the involvement of air speed would be only necessary when the indoor air temperature was above 26.4°C, as indicated at the upper bound of the PMV comfort zone. In addition, a negative PMV would be expected due to air speed for temperature lower than 26.4°C. Therefore, the difference between these two comfort zones showed that the PMV had problem to represent the thermal sensation of the Hong Kong people in the summer time.

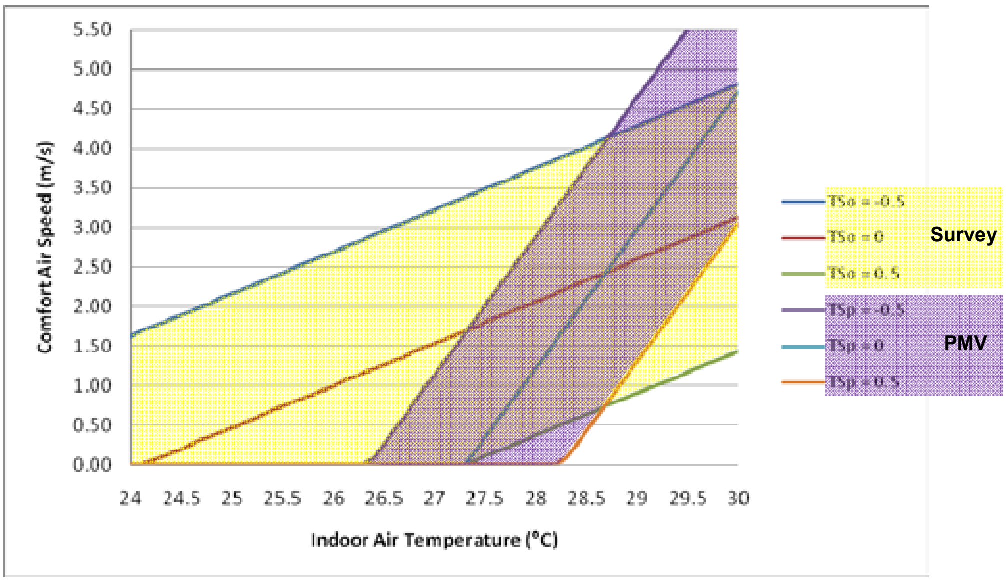

Figure 4 Comfort zones developed from PMV and thermal sensation in this survey.

Figure 5 also presents the difference between the survey results and those from PMV in another viewpoint. The survey results would generate the thermal sensation in the range of -1 to 1 for the air speeds from 0.5 to 3 m/s, while those from PMV would have the thermal sensation in the range of -3 to 1.5. It is obvious that the latter would be more sensitive to the air speed and feel cool or cold in the temperature range of 24 to 27°C. If the thermal sensation based on PMV was used, it would have a discrepancy between the predicted comfort and the actual thermal sensation of the Hong Kong people. This had a potential to underestimate the thermal sensation of occupants wearing typical summer clothing at sedentary position in the summer time. In addition, the PPD (predicted percent dissatisfied) as determined from the PMV would have problem accordingly.

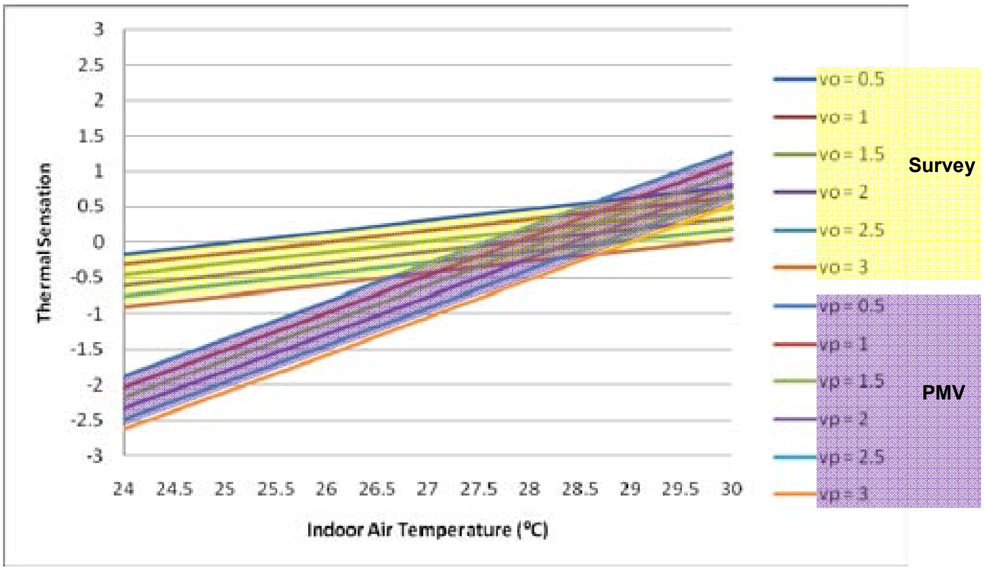

Figure 5 Thermal sensation vs. indoor air temperature for air speeds from 0.5 to 3 m/s at 50%RH.

4. Conclusion

This thermal comfort survey was conducted to study the acceptable comfort level as attained by suitable combination of air temperature and air speed in the summer in Hong Kong. For the people wearing typical summer clothing at sedentary position, a regression equation was developed for the thermal sensation as a function of indoor air temperature and air speed at 50%RH. It was found that the air speed could be up to 3.12 m/s for the indoor air temperature from 24 to 30°C, provided that it would not cause nuisance to the indoor activity. The air speed would be linearly lower with the decrease of indoor air temperature. The elevated indoor air temperature would save energy in refrigeration for air-conditioning, and outweigh the additional energy consumption incurred by the fans. The thermal sensation of male and female occupants was largely the same in the summer time, but the female occupants could withstand higher temperature at a lower air speed. About the representation of PMV for Hong Kong people, it was found that there was discrepancy to the actual thermal sensation in the survey. The PMV and PPD would have a potential to underestimate the thermal sensation of the occupants in the summer time. Another stage of thermal comfort survey will be carried out, and the study of humidity effect to thermal comfort will be included for the subtropical Hong Kong.

Acknowledgement

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TITLE : AN ECOLOGICAL APPROACH TO REGIONAL DEVELOPMENT : SOLUTIONS TO PUBLIC HOUSING COMMUNITY IN HONG KONG

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Keywords: health, comfort, livability, ecological, green ribbons, biodiversity, long life / loose fit technology, biotechnical research, greening coverage, water recycling, hybrid ventilation, community

Summary

High density cities carry undesirable effect of pollution and congestion which demands immediate attention. With a portfolio of high-rise building accommodating over 650,000 households, the Hong Kong Housing Authority (HA) is exploring new strategies and solutions to create healthy, comfortable and livable environment.

This paper looks at ecological planning focusing on possible solutions for completed and ongoing developments constrained by planning densities. The HA's pioneering attempt to bring transformation to the fabric of Yau Tong / Eastern Harbour Crossing Sites through an Ecological Master Plan featuring the following will be examined -

The compact urban fabric of metropolitan Hong Kong proliferates with its boundary abutting the country park which contains rich resources of greeneries and natural habitat. On the other hand, ecological planning inside the metropolitan area is depicted with a landscape plan of compromised quality. This paper offers a long term vision to realize green ribbons as a planning strategy for regenerating and linking the ecosystems from the country park into the built-up areas under the implementation of public housing redevelopment programme.

To nourish a harmonized urban habitat for the community, we recognize the intrinsic value of biodiversity / natural ecosystems, restore and replenish them to inject a new lifestyle and workstyle in the coexistence of the man made environment and nature.

Technology and innovations are means to empower the development of green living. We, in collaboration with the builder and research institute, innovate for the development of long life, loose fit greening technology and biotechnical research.

The compromised and piecemeal greening measures adopted in the past should be rectified. With the expanded provision of intensive and extensive green coverage in public housing estates, the demand for irrigation water is a growing burden. To capitalize on the operation of central air conditioning system for the regional shopping centre of Yau Tong Estate, collective use of A/C condensate will enable irrigation in a substantial scale. Furthermore, we also exploit the practice of rainwater harvesting with the prevail of rainy weathers in Hong Kong to promote sustainable and cost effective water supply for irrigation and cleansing purposes.

To cultivate a comfortable outdoor lifestyle surrounded with lush greeneries in the estate compound, we further innovate for the opportunity of reshaping tenants' shopping habit by using the hybrid ventilation system in the Yau Tong 4 and EHC 6 shopping centres. Natural ventilation will be resumed when the weather condition (humidity and temperature) is moderate and suitable to switch over from the air conditioning mode without compromising human comfort. Environmental design with the ecological concept of garden shopping will enlighten the shopping experience in lush greeneries and natural ventilation during the transitional seasons. Temporal operation of the system will promote energy saving and a green living habit in the long run.

To prepare for adaptive changes to a new ecological lifestyle, we will keep the local community abreast of the creative objectives in the development processes, from inception, design development to construction and occupation. In the course of community participation, the local community is enlightened and empowered to address their needs in a more effectively. Hence, self-recognition of their neigbourhood identity and further participation to enhance well-being could be fostered.

Not least, active and passive mitigation initiatives that are involved as part of the theories, strategies and solutions are presented holistically for appraisal and benchmarking.

1. Introduction

Extremities in density in the built-up environment brings along undesirable side effects of congestion, pollutions, heat island, and visual discomfort. Dominated by highrise buildings, Hong Kong is one of the cities with the highest density in the world. With a population at about 6.96 million and a total area of 1104 square kilometres, the city supports a density of 6410 people per square kilometre mostly concentrated in the built up area [1]. On a net site basis for some of our private or public residential development, it can be more than 5,000 persons per hectare [2].

At 2007, the Hong Kong Housing Authority has a portfolio of about 650,000 public rental flats housing one-third of the population in Hong Kong. The physical size, height and density of the built urban fabric contributed by public and private development poses strong physical impact on the environment which is irrevocable. The 21th century cities in the world demand a strong agenda to confront the challenges posed by rapid urban growth.

Whilst architects, planners, engineers and environmental specialists in the world are mapping out environmental strategies for virgin developments in various scales, equally important is the need to improve and transform the environmental conditions of completed and ongoing development constrained by planning densities. In the context of public housing development, design for comfort, health and livability [3] is the vision for enhanced functionality and efficiency as we migrate from the recovery of SARS (Severe Acute Respiratory Syndrome) in 2003. Solutions are many, this paper focuses on the goals and strategies to replenish and recreate the ecological balance and symbiotic existence between man and nature [4], human and other living systems, built form and bio-climate at a regional/community scale.

2. The Ecological Master Plan

The Yau Tong (YT) / Eastern Harbour Crossing (EHC) Sites is a major re-development occupying an urban site with overall site area of about 14 hectare housing over 80,000 persons featuring a high density Plot Ratio of 7.5 [5]. Enhanced mobility is provided by the mass transit railway extension line as a mechanism for urban regeneration. The west-bound linear configuration of the development rises above the waterfront along stepping terrain screening off the green mountain side at the back. This is atypical compared to the low density built-environment where rich greeneries from an intermingled landscape network exist. Rather, it is representative of the typical high density topographic development found in other metropolitan counterparts. Planned and built over a series of stages to serve the peak demand of public housing at the turn of the century [6], the existing high density built fabric has posed an antithesis to nature. Many opportunities were lost due to the need for rapid urban growth during which the bulk of redevelopment along the terrain has been constructed.

The Housing Authority is committed to transforming YT / EHC for ecological responsiveness. In the planning and design of subsequent phases of work from north to south, passive mitigation design features that optimize lighting and ventilation, sunshine, pedestrian comfort, pollution dispersion, energy conservation and water conservation have been adopted. Where applicable, active mitigation, including hybrid ventilation, motorized ventilators, water-cool air-conditioning, reclaimed water have also been employed, mostly at the commercial developments [7]. Most importantly, to tie these initiatives together holistically, and to positively address the impact of density; the associated heat island effect and to reconcile the gap between built environment and nature, an Ecological Master plan for the district has been created to achieve the following focus areas [8] -

a) Provide a long term vision to realize green ribbons linking the ecosystems between the development and the surrounding country park

b) Recognize the intrinsic value of biodiversity and natural ecosystems, protect, restore and replenish existing fabric

c) Enable development of long life, loose fit greening technology

d) Enable adaptation and sustainable growth through biotechnical research

e) Expand intensive / extensive green coverage

f) Expand a network for sustainable sources of recycled water

g) Promote ecological concepts in garden shopping/ hybrid ventilation

h) Engage the community, empower people and foster participation to promote awareness and ownership

Figure 1 High-rise high density developments at Yau Tong/ Eastern Harbour Crossing Sites

Figure 2 The Ecological Master Plan for Yau Tong / Eastern Harbour Crossing Sites

EHC 1	EHC 3	EHC 4	EHC 5	EHC 6	Spine/ Open Space	YT 4
Walled garden	Bridge Deck Greening	Vertical Greening	Greening Restoration	Garden Shopping	Roof greening (extensive)	Roof greening (intensive)
Roadside greening	Sunlight Penetration	Biotechnical studies	Roof Green	Reclaimed Water		Reclaimed Water
Slope Greening	Engagement	Maintenance Regime	Reclaimed Water	Hybrid Ventilation		Hybrid Ventilation
Transplant		Long Life, Loose fit				Engagement

Table 1 Environmental Greening features distributed amongst various phases of the Development

3. Green Ribbons

Green Ribbons have been instigated as a concept to link isolated systems and to form an ecological community in long term which will depict the central characteristic for consolidated urban development at the edge of city with the countryside. The development at YT / EHC stretches over 1 km in length. It is bordered by Wilson Trial of the country park at the northern rim. This serves as the 'secret garden' of YT / EHC, which apart from the historical reference of derelict quarry and ruin battery, there is also a rich habitat of biodiversity of flora and fauna.

Figure 2 Green Ribbons linking pocket greenery within the development to the country park along the hillside

Through intensive / extensive planting, restoration and replenishment of ground cover at slopes and retaining walls; comprehensive structural podium plaza planting; strategic carpet greening of open space, linkages and jump-boards between green pockets within the development and the mountain green are established.

Along the ribbon, pockets of greenery are strategically planned at about 100m apart to attract the migration of insects within short flying distance from their hillside habitat. The novel landscape strategy is an attempt to foster the biodiversity of nature in the residential setting, thereby bridging the physical and psychological gap between people and the natural habitat as a credit for enhancing mental health. More importantly, the proposed Green Ribbons allow for people exchange and interaction as the base of the urban design framework.

4. Restoration and Replenishment

Restoration and replenishment are key strategies that recognize and protect the intrinsic value of biodiversity and natural ecosystems at the disturbed landform. The major development at YT/EHC involved formation of 6 artificial platforms to accommodate over 50 residential towers of up to 30 to 40 stories. To mitigate the visual and heat island effect associated with man made slopes and retaining walls in between these platforms, every opportunity has been sought to maximize green coverage on the inclined surface. Slope greening using hydro-seeding on soil slope has been adopted comprehensively through out the site. Hard surface such as retaining walls are softened by creepers, colour treatment and introduction of planters. More innovative solutions of bio-engineering planting such as hydro mulching system for instant greening have been adopted to sustain round-the-year plant growth on the dry, rocky surface originally not suitable for plant growth.

5. Long Life Loose Fit Green Technology

Innovative concepts are underpinned by the enabling force of technology. The concept of long life, loose fit vertical green panels in the form of thin claddings is developed jointly with the contractor and applied in EHC Site Phases 4 and 5. Recognizing that truncated pocket greening at the ground level could not be reconciled by roof greening at 30-40stories above ground, the solution to meaningfully increase greening percentage for pedestrian comfort is to extend on-grade greening to the vertical dimension.

The vertical green panels compose of 1000 x 500mm aluminum trays with 40mm thick proprietary product as the growing media. Plant Species commonly used in HA projects, such as Parthenocissus himalayana, Zephyranthes grandiflora, Lantana montevidensis, Nephrolepis exaltata, etc, are selected for trial. Our landscape team has thoroughly searched the country park and a few wild plant species have been identified for further cultivation in the estate environment.

To facilitate ease of operation and water conservation, networks of automatic irrigation pipes have been introduced to form an integral part of the system. Trial panels have been set up to explore various possibilities of optimizing the design. They have been installed at the roof top of the site office to serve as green roof during construction stage. A total of around 240 nos. of the panels will be permanently erected at EHC Phase 4. Some of these green panels will be installed at the vertical walls of lift tower and rock slopes, others will be installed at roof areas with limited loading allowance.

Figure 3 Green Panels have been set up at the roof of the construction site to work out design optimization.

Continuous research is in place to test out the compatibility and maintainability of the proposed vertical landscape. The trial of vertical green panels at YT and EHC is unique for its modular, prefabricated clad-on character purposely designed for long life loose fit and reuse purposes. It is flexible in application, versatile and easily assembled on site and addresses the need for replacement and future maintenance. The thin profile addresses spatial constraints both for new construction and retrofit purpose.

Apart from the clad-on panels, EHC 4 has adopted self-standing vertical green panels to arrive at an integrative green hoarding. Similar to the trial panels installed at the roof of the site office, green hoarding enhances the site environment by providing dust and an element of noise screening. The long life, loose fit concept has been further extended as these large reusable panels are demountable and could be moved to other areas of the site as permanent green walls, or to other construction sites as green hoardings.

Figure 4 Vertical green panels designed to clad onto the external wall and laid flat on roofs of lift tower.

6. Biotechnical Research

To ensure long term performance of the vertical green panels, biotechnical research is being conducted, in collaboration with Hong Kong Chinese University, to -

a) test out the most optimal plant selection criteria in relation to their performance under different seasons and orientations

b) sustain vegetation growth relevant to water saving and the available management resources in housing estates

c) prepare guidelines for the future development and maintenance of the vertical green panel system.

A field site for the technical study has been set up in end July 2007 at the open space of EHC Site Phase1 with four light weight metal structures in north-south orientations to support the green panels. This is a 15-month research project due for completion in early 2009. The research comprises four studies exploring different aspects of the vertical green panel system including plant performance under different watering regimes for individual panels and panel clusters; Species selection; effect of soil thickness on plant growth; fertility persistence of the system and nutrient loss from the panels.

The research facilitates an optimum vertical green design in terms of technicalities and maintainability; evaluate the environmental effectiveness of vertical green panels at congested urban areas; and establish benchmarking performance based on the current design, for further improvement. The initial results have established the need for daily irrigation in an optimum amount to sustain healthy plant growth with the help of moisture sensors. Empirical studies of the daily thermal variance in a summer day also reaffirm the benefits of soft landscape in the mitigation of heat island effect.

Figure 5 Biotechnical research to test out the plant performance, species selection, soil thickness, fertility persistence and nutrient loss

7. Greening Coverage and Roof Greening

Expanding the targets of intensive / extensive green coverage is one of the fundamentals to materialize an ecological community [9]. Completed phases at YT/EHC developed over the last 10 years have a greening coverage at around 10%. Conscious of the need to enhance green coverage, HA has a standard since 2000 of planting a tree for every 15 built flats.

At YT / EHC, major breakthroughs in greening coverage have been made for projects in the pipeline. Podiums of low rise commercial developments and shopping spines have been fully maximized for intensive or extensive roof greening resulting in a greening coverage percentage of over 40% at YT Phase 4 and EHC Site Phase 6. Roof greening are also applied elsewhere on lift tower, ground floor canopy and intermediate floors of domestic blocks. A green tract [10] provides major enhancement to visual comfort. Roof greening could effectively reduce the surface temperature for 20 - 30°C as compared to hard roof surface. It reinforces building insulation and energy efficiency and lowers the overall heat island effect, greatly promotes community interaction and exchange in the pedestrian hubs.

Figure 6 Roof Greening commercial centre with strong improvement to green coverage percentage

Figure 7 Roof Greening at intermediate floors of residential tower brings enhancement to visual comfort

8. Reclaimed Water

Expanding the network for sustainable source of recycled water will support the expansion of vertical green coverage. The commercial centres at YT ph 4 and EHC Site Phase 6 will work as reservoirs of reclaimed water to irrigate both extensive and intensive greening over these sites. Rainwater will be harvested [11] from green roofs, concrete roofs, covered walkways and the main pedestrian plaza. Condensate from the commercial centres' central air-conditioning system will provide huge volume of sustainable water supply. Both sources of reclaimed water will initially pass through a set of break tanks and then stored for re-use. A set of filtration and disinfection treatments maintains the water quality to an international standard. By using the reclaimed water system, an annual reduction in water consumption of 9,263m3 is anticipated, which equates to 65% of the total irrigation amount required per year.

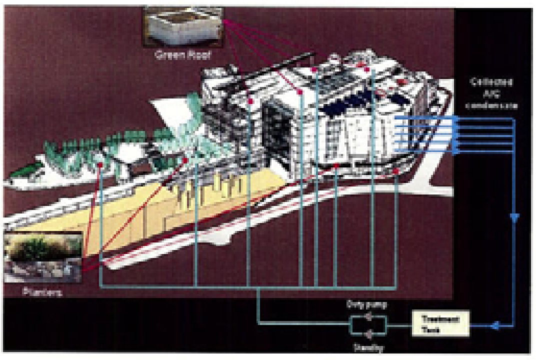

Figure 8 Reclaimed water system at commercial development collects condensate water for irrigation.

Recycling of reclaimed water is also introduced to the domestic development at EHC 5. Apart from collecting rainwater from roof gardens, and taking into consideration the requirement for regular cleansing of roof water cistern, waste water for cleansing of potable water cistern will also be collected for irrigation after filtration and sterilization. Subject to the outcome of the trial in EHC 5, the success of the scheme should contribute significantly to the agenda of water conservation at residential settings.

9. Garden Shopping and Hybrid Ventilation

Promoting garden shopping and hybrid ventilation will extend the ecological concept from external to internal environment. The shopping centre at EHC ph 6 is nestled in a luscious garden environment using greening strategies to reduce the centre's overall CO_2 emissions. Intensive greening is provided inside the commercial centre at various levels accessible to users. The garden shopping environment eventually leads to the roof with extensive greening provided to over 40% of the roofed over area of the centre.

Virtual greening is achieved by using a hybrid ventilation system alternating between natural ventilation, free cooling and full-scale air-conditioning. Temperature, humidity, wind and rain sensors would provide signal to activate intake and exhaust openings when the external environment matches the designed indoor comfort conditions. In YT Phase 4 and EHC Ph 6, with a predicted 10% of operating hours per year using natural ventilation, an annual reduction in air condition electricity consumption is approximately 82MWh, which equates to 35,260kg/yr CO2 emission, or the equivalent of planting 1,618 numbers of trees per year to absorb it.

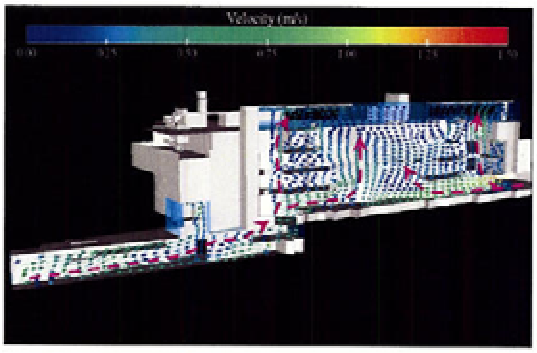

Figure 9 Hybrid Ventilation achieves reduction in CO_2 emission

10. Community Engagement

People of cities are key drivers for transforming cities towards sustainability [7]. We engage the community, empower people and foster participation so as to raise their environmental awareness and instill a culture of environmental protection. In EHC Ph 4, where the trial panels were installed at the roof top of the site office to serve as green roof during construction stage, the vertical green panels together with the growing medium and plants were delivered to the adjoining schools for initial establishment and care in April 2007. They have since been relocated to roof top of the site office in May 2007 after establishment.

As a long term programme, the Green Delight in Estate Programme has been launched with recruitment of public housing tenants as "Green Ambassadors" to spread the green message. Education and promotion programme by Green Groups on subjects such as estate greening; building up green infrastructure and promotion of green practices are continually cascaded to our tenants. The ultimate aim is to establish a volunteer core group which will gradually own the programme and guide other residents in the promotion of a green lifestyle. All the engagement programme is a people powered process to nurture ownership and hence a sustainable community in the long run.

Figure 10 Community engagement involving school student in promoting green culture

11. Conclusion

In embarking on the concepts, strategies and solutions towards an ecological community, we are conscious of the constraints and limits within the confines of a high density fabric that has been half established. This paper demonstrates however that the vision of the ecological master plan together with resolute actions towards restoration, innovation, research, passive and active mitigation, conservation and the active engagement of people are promising notes to nurture and replenish an ecological community. This requires, as illustrated in the paper, conscious review and communication of targets and benchmarks for monitoring and continuous improvements. This paper attempts to increase awareness, generate ideas, provides a framework for action without prescribed solutions. It encourages local and international efforts in creating sustainable high density living environments.

In all, we try harder to rupture the contrast and cultivate the meetings between building development and planting, between architecture and landscape – between culture and nature.

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PUTTING THE "ECO" IN TOURISM AND COMMUNITIES

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Keywords: sustainable, master planning, ecotourism, design, planning

Summary

With the current population growth in urban areas, developers are seeking permission to create new communities in previously undeveloped areas. Equally, tourism operators are seeking permission to develop "eco resorts" in pristine natural environments. Key stakeholders, such as Local, State and Federal governments and the community, want to ensure that these built areas are sensitively integrated into the natural environment and that they will provide for the needs of the region now and in the future.

This paper discusses the need to integrate sustainability principles into master plan and ecotourism developments and the opportunities for embedding sustainability into each phase of the development including planning, design, construction and operation and maintenance. In order to ensure sustainable outcomes for the development, it is vital that the process of integrating sustainability into the project phases is commenced from the early concept design phase with a framework is set up to deliver it.

1. Defining sustainable master planning and ecotourism

1.1 Sustainable Masterplanning

Sustainable master planning is the process undertaken in order to create a sustainable community. It is the process of embedding sustainability initiatives and mechanisms into each stage of the project lifecycle (i.e. planning, design, construction and management and operation) in order to ensure that sustainable outcomes are achieved and to ensure continual improvement of sustainability performance.

A sustainable community can consist of a collection of buildings and infrastructure, a planned development, suburb, town, city or region. It can also be a vertical community i.e. a single building comprising integrated mixed uses, such as commercial, residential, retail. Sustainable communities are planned with consideration for the future needs of the community and have the capability to adapt to changing modern needs. They have a high degree of self-sufficiency in terms of infrastructure, such as energy generation and water recycling and re-use systems, and a viable local economy supporting them. The culture, demographics and needs of sustainable communities are typically diverse resulting in the requirement for a broad range of land uses, activities and development densities. Well-designed public and green spaces and supporting facilities provide a high degree of amenity for residents, workers and visitors. The community has established transport links within it as well as strong connections to the wider region. There is active participation by stakeholders in planning the future of the community. Sustainable communities aim to minimise the impact of development on the environment through energy, water and resource conservation. A key priority of sustainable communities is the continued health, comfort, social amenity and safety of their residents.

Sustainable master planning initiatives and mechanisms that can be employed during the project lifecycle to ensure sustainable outcomes for the development can include: Development Control Plans that require sustainability features to be integrated into the development at the planning stage; computer modeling of options during design phase to ensure optimal façade design for energy performance; insertion of clauses into builders' contracts with waste recycling and minimisation targets, and the monitoring of utilities during the operational phase of the development.

1.2 Ecotourism

Ecotourism was initially defined by Mexican architect Hector Ceballos Lascurain in a campaign to conserve the Yucutan wetlands as a habitat for the American flamingo. The ecotourism program of the International Union for the Conservation of Nature (ICUN) adopted this in 1996 and defines ecotourism as:

"Environmentally responsible travel and visitation to relatively undisturbed natural areas, to enjoy and appreciate nature (and any accompanying cultural features - both past and present), that promotes

conservation, has low visitor impact, and provides for beneficially active socio-economic involvement of local populations."

Ecotourism developments represent a pinnacle of sustainable masterplanning due to their location, often being: remote, unconnected to mains facilities, and in an environmentally sensitive or culturally significant area. The restrictions of ecotourism development actually represent opportunities to create innovative solutions for the autonomy of a site that can serve as an example for mainstream development of what it is possible to achieve. Best practice requires an ongoing commitment to improvement an approach required in masterplanning if it is to provide for future generations

Ecotourist resorts are those that encourage guests to interact with natural areas adjacent to them. They are designed, constructed and operated using the principles of ecologically sustainable design. Ecotourism resorts are generally mixed use in nature and may comprise a number of distinct facilities and activities in the one precinct, including: hotel accommodation, cabins, retail, health centre, gymnasium, swimming pools, walking trails, day spas, interpretation and educational facilities, and natural features.

2. Defining the "greenness" of master plans and ecotourism developments

There is a plethora of rating tools in Australia. Some tools address a wide range of sustainability aspects and some address only one aspect, such as energy or water. There are tools for specific building types (e.g. commercial, residential, education). There are tools that predict the building's sustainability performance at the design stage and those that assess the building's actual performance in operation. There are very few tools in Australia and internationally that are capable of assessing the sustainability performance of a master plan or ecotourism development, which are typically mixed use by nature. The exception is EnviroDevelopment (Australia), Leadership in Energy and Environmental Design (LEED) for Neighbourhoods (US) and Green Globe 21 (international), which are outlined below.

2.1 EnviroDevelopment

The EnviroDevelopment tool was developed by the Queensland branch of the Urban Development Institute of Australia (UDIA). This rating scheme is the only tool so far in Australia that addresses sustainability at the master planning stage of a development. EnviroDevelopment is a voluntary best practice tool. Projects can be assessed under, and gain certification in, any or all six EnviroDevelopment categories; water, energy, ecosystems, community, materials and waste. Developers must demonstrate that their development satisfies the EnviroDevelopment requirements and standards for the target category. The developer's submission is then evaluated by the EnviroDevelopment Board of Management and certified if it meets compliance. The certified rating must be renewed annually.

The EnviroDevelopment tool is not a true indicator of a development's overall sustainability performance as not all categories need be addressed and a certain level of compliance in all six categories is not required. For example, a developer can certify a development in the EnviroDevelopment water category, but this does not mean that the development is energy or resource efficient. A true sustainability tool would require all aspects of sustainability to be addressed and certain standards achieved in all of these categories, as the very nature of sustainability requires a balance to be attained between social, economic and environmental aspects.

2.2 Leadership in Energy and Environmental Design (LEED) for Neighbourhoods

LEED is a voluntary good/best practice scheme in the United States managed by the US Green Building Council (GBC). LEED addresses a variety of sustainability issues at various stages of the development process, such as design, construction and operation. LEED applies to a range of building types, such as residential dwellings, commercial core and shell, commercial interiors, school, retail, healthcare and neighbourhood development.

LEED for Neighbourhood Development is currently in pilot phase and was developed by the US GBC in partnership with Congress for the New Urbanism (CNU) and the Natural Resources Defense Council (NRDC). The tool is aimed at new mixed use and regeneration projects developed by a single entity which then sells or leases components to numerous consumers. LEED for Neighbourhood Development focuses on communities and their connections to the region and to the landscape. The tool is applied at the design stage and consists of a number of credits under several categories, such as "smart location and linkage", "neighbourhood pattern and design" and "construction and technology". There are pre-requisite standards of sustainability performance for each of these categories that must be achieved in order to attain certification.

2.3 Green Globe 21

Green Globe is an international benchmarking and certification program providing a methodology to define and assess best practice sustainability integrated into travel and tourism operations. It was established by the World Travel and Tourism Council in 1993 specifically to recognise and promote sustainable travel and tourism globally. The program is based on Agenda 21 principles for sustainable development. The CRC for Sustainable Tourism Australia, with input from sixteen universities and over two hundred researchers, developed a benchmarking system (Earthcheck™) which was introduced to the program in May 2002 to inform the standards. Prior to this, the standards were based on process based initiatives. Benchmarking has provided a more powerful tool for comparing the environmental and social performance of ecotourism

operations internationally and establishing overall savings and achievements of the program.
Green Globe consists of a number of standards to inform and assess either, the design and construction phase or, the operational phase of a development. The standards applicable to inform the planning and construction of ecotourism developments are: the Design and Construct Standard for Infrastructure and the Precinct Planning and Design Standard (PPDS).

The PPDS is the most recently developed standard; it provides benchmarks for a range of key performance areas including: precinct location site and planning, energy efficiency and conservation, water conservation and management, solid and other waste management, resource conservation, chemical use, waste water management, stormwater management, social commitment and economic commitment.

Use of Green Globe standards provides for recognition of best practice through certification, the awarding of a logo, and promotion to the industry and market. Certification requires a commitment to on-going appraisal of operations to ensure the consistency and superior quality of the product to the industry, authorities and tourists. To receive certification, a project is first required to undergo benchmarking whereby various environmental measures are assessed against baseline figures and evidence that the design documentation details performance requirements and systems that meet them. This information is assessed by an independent assessor and if baseline or best practice is achieved in the majority of benchmarks, certification is granted (usually following planning approval to ensure essential elements are met.

3. The drivers for creating sustainable communities and ecotourism developments

The “big picture” drivers for sustainable master plan and ecotourism developments have arisen due to a wide range of global issues including climate change, finite fuel resources, population increase, rising sea levels, over-consumption of resources and social inequity. Aspects particularly relevant to Australia that are driving sustainable development include depletion of the ozone layer, scarcity of fresh water, increased incidence of bushfires, erosion, deforestation, salinity and expanding population in urban areas.

There are drivers for the sustainable development of master plans and ecotourism resorts at every level of government. The federal government is responding to international policies and treaties, such as the Kyoto Agreement. State governments are responding to issues, such as land releases and rezoning to accommodate the growing population and to the need to encourage employment generation to support it. Local councils are driven to demand sustainability be incorporated into developments through the need to plan for and ensure the future viability of their local community and region.

There is growing demand by the community for higher quality developments that consider the environment and the community’s economic and social needs. Developers of sustainable master plans and ecotourism developments are gaining market advantage by responding to this need. They may also gain planning permission sooner, and avoid extensive litigation, if it is demonstrated to the local planning authority that the development meets the needs of the region at the present time and in the future. Incentives such as tax deductions, grants and rebate schemes are encouraging developers to implement sustainable practices.

The desire to future-proof assets by planning for future rises in utility costs is driving owners of buildings and ecotourism developments to incorporate sustainability initiatives into their developments.

Building industry participants, such as architects and builders, are increasingly driven to address sustainability issues in their work in order to win more work and to differentiate themselves from other companies in the market. For example, it is common for tenders, especially for ecotourism projects, to require a project team or builder to demonstrate their environmental credentials and experience in sustainable design or construction in order to win work.

Stakeholders of companies are increasingly aware of environmental issues and growing pressure from them is driving companies to demonstrate their corporate social and environmental responsibility, to transparently report it and to continually improve performance.

4. The benefits associated with creating sustainable communities and ecotourism developments

Planned communities and tourism resorts are typically located on previously undeveloped sites and often, in the case of tourist resorts, are remote in location and have minimal existing connections to the region. Sustainable communities and ecotourism developments aim to minimise the impact of the development on the environment. For example, integrating Water Sensitive Urban Design initiatives can reduce the flow of potentially polluting surface water runoff into local natural watercourses during storm events.

For ecotourism projects there are often net gains in biodiversity of the site and surrounds through landscape conservation and enhancement programs. In the case of urban regeneration projects, the existing biodiversity on the site can actually be improved, for example, the rehabilitation of an industrial site to parkland.

Residents of the local region benefit from the creation of sustainable communities and ecotourism developments as they have the capability to attract investment to the area, generating employment and providing social amenities, such as health, education, recreation and leisure facilities. Owners and tenants of buildings within sustainable communities and owners and operators of tourism resorts benefit from the lower operating costs associated with sustainable design and technology.

5. The barriers to creating sustainable communities and ecotourism developments

A significant barrier to creating a sustainable community or ecotourism development is the traditional focus of the building industry on speculative development based on short term rewards. Developers are often not prepared to finance the sometimes additional cost of incorporating sustainability initiatives if their customers do not perceive a value in it and do not recognise that they will reap the long term benefits.

There is insufficient legislation enforcing sustainable development and planning controls can be inconsistent at the various levels of government. Insufficient stakeholder consultation and active engagement in the planning process can be a barrier to sustainable development if the needs of the local community are not adequately assessed and incorporated into the design.

The separation of responsibilities during the developmental phases of a project is a barrier to sustainable development. For example, designers and builders are not typically involved in the handover of a building or site to the users which could mean that it may not be operated as the designers intended. There is a risk that the sustainability principles and initiatives determined during the planning phase may not get carried through into the site's operation and management, leading to inefficiencies that could potentially result in a greater impact on the environment. Finally, there is a general lack of education amongst all those involved in masterplanning and ecotourism developments including developers, owners, operators, financiers, government, designers, builders, residents and visitors, as to what sustainability is, what the benefits are and how a sustainable community is defined and delivered.

6. The costs and savings associated with creating sustainable communities and ecotourism developments

There can be higher upfront capital costs associated with the creation of sustainable communities and ecotourism developments. These costs may be due to the installation of environmental technology, such as a photovoltaic array or due to an integrated design process. The capital cost of environmental technology is often offset over its lifetime by the savings in utility costs, such as the savings in energy costs as a result of using a photovoltaic array for energy generation instead of fossil fuels, which are predicted to increase dramatically in cost in the next decade.

There are other savings that are more difficult to quantify, such as the improved indoor air quality that may result from the selection of a low Volatile Organic Compound (VOC) floor covering or the social capital gained from engaging in community consultation. An integrated design process involving the early engagement of consultants and their participation in a collaborative planning and design process can result in higher upfront fees due to the extended time commitment. These costs can often be offset by the integrated design and services solutions and improved system efficiencies that result from closer collaboration and communication between the disciplines.

The certification of an ecotourism development will add minimal costs to the project in terms of the benefits gained. Going through the certification process will add to the workload of the consultant team to provide evidence that key performance measures have been met; this could include additional reports and computer modeling.

7. Sustainable Built Environments' Sustainability Process

Sustainable Built Environments' ultimate environmental design aim for our built environment is to create buildings and communities that are: comfortable and healthy; require no additional energy or water, other than that produced on site; produce no waste in operation or construction, and are made of materials that are derived from fully sustainable sources. Whilst this is very difficult to achieve in practice, this goal acts as a theoretical lighthouse for the opportunities that are considered in any of our projects.

7.1 Sustainability Matrix

Sustainable Built Environments (SBE) considers all of the sustainability aspects related to a building, site or community when undertaking a development project. Particular consideration is given to: energy conservation, water consumption, waste minimisation and reduced resource consumption, sustainable transport, emissions minimisation, enhanced biodiversity and land use efficiency, enhanced social issues and amenity, and viable management practices. For example, under the sustainable transport category, we would assess the opportunities for a site based on: reducing reliance on the private car, reducing the CO2 emissions due to transport, prioritising personal mobility networks, promoting safe transport connections and creating permeable links throughout the site and to neighbouring communities.

7.2 Embedding Sustainability into the Development of Sustainable Communities and Ecotourism Developments

SBE often acts as the sustainability champion of a development project on behalf of our client. We are responsible for advising the client and guiding the project team in integrating sustainability principles into the development and for developing a framework that will ensure that the sustainability vision for the site is not compromised and that sustainability targets and predicted outcomes for the development are carried through all of the developmental phases and successfully achieved. Outlined below are some mechanisms that can be applied in order to embed sustainability into each stage of the development of a sustainable community or ecotourism development.

7.3 Opportunities for integrating sustainability into the planning phase

Opportunities for integrating sustainability into the planning phase of a sustainable community or ecotourism development are as follows:

- Identify a site where development will result in the lowest impact on the environment
- Commence an integrated planning process involving the developer, planner, project manager and local planning authority
- Assess the opportunities, constraints and risks related to implementing sustainable initiatives on the site
- Engage stakeholders and the community actively in the planning process
- Research the needs of the local community and region
- Develop a sustainability vision for the project
- Develop sustainable design guidelines for the site
- Integrate sustainability into local planning controls
- Develop an integrated brief for the design team
- Undertake preliminary life cycle costing

7.4 Opportunities for integrating sustainability into the design phase

Opportunities for integrating sustainability into the design phase of a sustainable community or ecotourism development are as follows:

- Commence an integrated design process involving the developer, planner, project manager, design team and local planning authority
- Engage stakeholders and the community actively in the design process
- Develop a Sustainability Strategy consisting of broad objectives for the project, set preliminary targets and determine proposed actions to achieve the targets.
- Form alliances with relevant industry representatives, universities and non-government organisations (NGOs)
- Test the proposed masterplan or ecotourism development against the Sustainability Strategy to determine progress against targets
- Undertake a peer review or value management exercise to increase efficiencies
- Insert "green" clauses into the Specification
- Undertake further life cycle costing

7.5 Opportunities for integrating sustainability into the construction phase

Opportunities for integrating sustainability into the construction phase of a sustainable community or ecotourism development are as follows:

- Integrate sustainability requirements into the Request For Tender for builders
- Insert "green" clauses (incentives and/or penalties) into builders' contracts
- Facilitate education and training courses for builders in the installation of sustainable materials, products and technology
- Initiate a feedback loop between the builders and designers to ensure lessons are learned

7.6 Opportunities for integrating sustainability into the operation and maintenance phase

Opportunities for integrating sustainability into the operation and maintenance phase of a sustainable community or ecotourism development are as follows:

- Ensure adequate time and resources for commissioning of building services
- Develop a monitoring plan to ensure continual improvement
- Initiate a feedback loop between the builders, designers, operators and users to ensure that the buildings and site are managed as the design team envisioned
- Develop a Building User's Guide to explain the sustainability features and their optimal operation

- Carry out a Post Occupancy Evaluation to determine actual sustainability performance and user satisfaction

8. Case Study: Huntlee, Hunter Valley, New South Wales

Huntlee is located between the historic Hunter Valley towns of Branxton and North Rothbury at the northern gateway to the Hunter Valley, the oldest wine region in Australia.

The Huntlee site spans two Local Government Areas; Cessnock and Singleton. The site consists of cleared agricultural land previously used for stock grazing, timbered areas that are regrowth woodland following logging associated with the former colliery activities, land that has been previously used as a coal mining site and conservation land.

The Huntlee site was identified as a major urban release area in the Lower Hunter Regional Strategy. In 2007 a Concept Plan was prepared for the $1.8 billion development of this 1,748 hectare site. The Huntlee project will create a major new centre in the lower Hunter Valley over a period of around twenty years with a projected population of 18-21,000. The development will comprise approximately 7,500 residential lots, 160 hectares of commercial and employment lands, neighbourhood centres, education, healthcare and community facilities and associated infrastructure (including upgrades to local road and bus networks, sewerage and water infrastructure etc.). In addition, the project involves the dedication of 876 hectares of high conservation land on the site and a further 4,988 hectares of conservation land in other locations in the Lower Hunter Region. The Concept Plan was submitted to the NSW Government as a Part 3A Planning Application in late 2007.

Sustainable Built Environments Pty Ltd (SBE) was engaged by the client, Huntlee Holdings Pty Ltd, to develop a Sustainability Strategy with the aim of embedding sustainable development principles into the planning and early concept design process. The goal was to carry these principles through subsequent design and construction phases, ultimately ensuring the sustainable management and operation of the site. The Strategy was also developed to meet the Director General's Requirements for an assessment of the development's potential greenhouse gas emissions and a strategy outlining how they may be reduced.

The process began with a comprehensive background literature review of reports, studies and plans, a site visit and meeting with the project team and client. SBE discussed the sustainability vision for the scheme, outlined the opportunities on the site for integrating sustainability initiatives and obtained feedback. Building on information gathered during this process, SBE developed a draft Sustainability Strategy. The Strategy commences with a definition of sustainability and its context and role in the proposed Huntlee scheme, a definition of the nature of a sustainable community and the vision for the development in terms of principles. A number of sustainability objectives were nominated and opportunities for integrating ESD initiatives into the scheme to achieve these goals were outlined for a range of sustainability aspects (e.g. energy efficiency, water conservation, sustainable transport, resource use, biodiversity, social amenity, management). Finally, preliminary targets covering all of the sustainability aspects for the scheme were outlined with the intention of refining and further quantifying them in subsequent design stages. SBE presented the draft Sustainability Strategy with the aim of obtaining feedback. This was then integrated into the final Sustainability Strategy and technical report which formed part of the Part 3A Planning Application.

The planning process for Huntlee has not yet progressed to detailed design and engineering stages which will come later in Project Applications and/or Development Applications for subdivision, works and buildings. It is envisioned that the Sustainability Strategy will be reviewed, revised and refined over time to reflect the more detailed planning and design solutions associated with future stages of the development process as well as to reflect the outcomes and recommendations of specialist studies. Future tasks to embed sustainability in the development phases may included the development of sustainable design guidelines or Development Control Plans, use of sustainability rating tools to guide design and measure performance and "green clauses" in the site and building works Specifications and builders' contracts, the development of Building User Guides, monitoring, Post-Occupancy Evaluations etc.

The commencement of works is scheduled for February 2009 depending on relevant approvals being obtained.

9. Case Study: Alila Villas, Ulawatu, Bali, Indonesia

Alila Villas Ulawatu is a mixed-use tourism development currently under staged construction. The site is spectacularly located on a terraced plateau on limestone cliffs that edge the southern tip of Bali. The site is arid and subject to seasonal drought. This part of Bali is distinctively different from most of the island where vegetation is lush and spring water abounds; the site is arid and marked by a grand vista of the ocean and seasonal drought. It is valued traditionally as hunting and grazing ground.

The vision for the project was to develop a resort that was not only designed to be of luxury standard, but also to exhibit best practice environmental practice and management. The development includes a hotel with full leisure facilities including bar, restaurants, day spa, fitness centre, boutique, meeting facilities, library, and swimming pool. The 14.4 hectare development site also includes: 29 villas for private ownership but managed by the development; 36 hotel villas; a pool for each villa; a gallery; landscaping, paths, roads and infrastructure.

The project developers engaged a multi-disciplinary team with the vision and ability to create an environmentally sensitive and responsible project, that demonstrated best practice for Bali and internationally. Following sketch design stage, SBE was invited by the project architects (WOHA Designs) to provide ESD advice, with particular focus on gaining recognition for the project's achievements through certification.

SBE reviewed the project against the key performance indicators of the Green Globe Design and Construct Standard (GG D&C) to develop an ESD Opportunities Study detailing further opportunities and strategies to improve sustainable performance. One of the main things added to the project brief through this process was the development of targets for resource use so that the project could be benchmarked against baseline Earthcheck™ indicators. The GG D&C methodology provides a checklist of key performance areas for sustainable practices and design including: sustainability design approach, energy efficiency and conservation, potable water consumption, solid waste production, social commitment, resource conservation, site, and waste water management. The key areas for construction provide for a comprehensive construction environmental management plan that: encompasses the key performance areas of the design stage; requires targets for energy, water and waste reduction be developed and monitored, and that a social commitment to local employment is made.

The checklist of key performance indicators was used through design development as a sustainable quality management tool to record the strategies in place, and those to be investigated further, and to assign responsibilities to the project team.

Some of the challenges encountered were finding a sustainable timber supply and sourcing efficient hot water systems. One of the great achievements of the project has been to access renewable energy by supporting the development of a nearby wind farm. The built form of the project responds sensitively to the landscape and refers to local traditions and construction techniques while embracing a modern style. Degradation of biodiversity and loss of topsoil due to former grazing and periodical burning will be mitigated through reforestation from a developed list of indigenous plants and seed collected from the site, resulting in greater biodiversity. The intention is to regenerate a more complex gallery forest to connect to existing nature network, and to enhance and maintain topsoil by using local techniques of low terracing, living fences and conserving fodder plants. Local customs and culture have been considered in the approach to the site and initiation of construction works.

Lessons learnt from this project have included the difficulty of developing design targets for a complex precinct development and maintaining the project team's enthusiasm for providing evidence once tender documents had been completed. Nevertheless, the project's construction has included extensive environmental management with monitoring of resource use through construction.

Operational environmental management systems will provide the opportunity for the environmental impacts due to the operation of the Alila Uluwatu Villas to be reduced, monitored and improved over time. The project is at benchmarking stage of the certification process.

10.Case Study: Ythan Springs Resort & Spa, Warburton, Victoria

The Ythan Springs Resort and Spa is to be located on 19 hectares on the middle ranges of the south facing slopes elevation of Mount Victoria and Mount Donna Buang. The site is within an area of conservation and botanical significance and of regional zoological significance for the Upper Yarra Valley and Dandenong Ranges. Flora and Fauna Studies confirm a mixture of intact vegetation, regenerating native vegetation and exotic vegetation with four species of regional significance found on the site.

The resort developer has enthusiastically pursued the development of a deep green tourist facility that incorporates innovative systems to manage and conserve energy and water use. SBE prepared an ESD Opportunities Study in early 2003 to assist in developing: the sustainable vision for the project, targets for performance, and strategies by which to achieve the targets. As there was no formal methodology available at the time, SBE used our sustainability matrix and the core principles of *The Natural Step* to define best practice approaches to sustainable tourism development. Community consultation was undertaken in an endeavour to create community links with the project.

The design process included extensive environmental studies and assessments of the site, community consultation, and energy and water modeling. Passive solar design has been optimised to the hotel and villa type accommodation, however, the largely southern orientation of the site has focused the design on strategies to optimise building fabric and utilise thermal mass.

The project has been in a holding pattern for a number of years whilst proceeding through the planning process. SBE has recently applied the Green Globe Precinct Planning and Design Standard (PPDS) to provide an in depth master plan review by assessing the initiatives that have been integrated into the design and to determine the project's eligibility for certification.

The PPDS broad scale standard designed for use in the master planning and design of tourism infrastructure for medium to large mixed use precinct developments where stakeholders are seeking a measurable ecological performance outcome. The key performance areas addressed are: sustainable masterplanning approach, energy efficiency and conservation, water conservation and management, solid and other waste management, resource conservation (materials), chemical use, wastewater management, stormwater management, social commitment, 'Quality of Life' approach and economic commitment.

Some of the sustainable initiatives included in the development include: a consensus approach to design through consultation, comprehensive water conservation and reuse strategies to provide 74% of site's water needs with water harvested from the site, renewable energy using micro-hydro system, preservation of

Mountain Ash forest, water sensitive urban design, engagement with educational institutions, net gains for biodiversity. The development will provide economic gains to the community by acting as a drawcard for the area, providing job opportunities for an area with low employment, providing business opportunities and conserving the environment..

Due to the proactive approach taken to sustainability at masterplanning stage, Ythan Springs Resort & Spa has the potential to achieve baseline or best practice performance for all key area indicators with most of the strategies in place for certification.

Conclusion

Applying sustainable principles of integrated design at the initiation stage of masterplanning and ecotourism projects has the potential to reduce the environmental impact of the built environment while increasing its social capital and ability to meet future needs. An integrated design approach provides the opportunity for a more holistic built solution, as synergies between systems are more likely to be uncovered and utilised.

As best practice sustainable design principles include consideration of operational management and maintenance issues, it is ensured that systems to assess a development's performance against design predictions will be in place to allow for monitoring and on-going improvement. The information obtained through this process can be used to inform target setting for future sustainable developments and provide an example to industry of what can be achieved.

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Urban Development Institute of Australia's (Queensland branch) EnviroDevelopment tool http://www.udiaqld.com.au

EC3 Global Green Globe and Earthcheck http://www.ec3global.com/products-programs/green-globe/

THE EXECUTION AND PROMOTION OF THE TECHNOLOGY FOR IMPROVING INDOOR ENVIRONMENTAL QUALITY IN TAIWAN.

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Keywords: Health Building, Indoor Environment Quality (IEQ), Post-Occupancy Evaluating Method (POEM),

Summary

Entering into the 21st century, Taiwan is facing the problems of pollution to indoor environment and harmfulness to dwelling health. The dwelling environments of buildings must all face the ever worsening of “indoor environmental quality” day after day, regardless of new or old. Especially in Taiwan’s hot and humid weather, with the high ratio of 97% in existing buildings, sick buildings create harmfulness that affects the quality of health in the indoor environment including sound, light, thermal comfort and air. It could also lead to the break out of diseases including Sick Building Syndrome (SBS), Sick Home Syndrome (SHS) and Building Relative Illness (BRI). In this study, the improvement of indoor environment was split into three phases: self-inspection, initial investigation and advanced building health examination. The tested items include the diagnosis and investigation to indoor environment of sound, light, thermal comfort and air, plus the assessment to domestic and foreign indoor environmental criterions, for the purpose of finding indoor problems to improvement. The improvement includes target setting, designing and planning, constructing and re-inspecting, and finally ensuring the effectiveness of improvement. The entire operation procedure can be used as the reference for expanding the promotion in the future.

1. INTRODUCTION

According to the evaluation in ecological housing of World Health Organization (WHO), we find out that buildings are not only protecting people from invasions, but also effecting users’ lifestyles and indoor environment quality (IEQ) in our daily life Nowadays in Taiwan, the ratio of the new to old buildings is about 3:97. So the indoor environments of buildings have lots concern in human health. And the increase correlation between the output value and human comfortably shows the importance of the health and comfort in buildings. The increase of existing buildings’ service life causes a lot of questions For example, the aging of equipments , functions and materials in buildings, or the deteriorating indoor environment influence human health, and so on…

Many potential hazardous factors may appear in the indoor environment of buildings, which present many risks to the health of the habitants. In a broader definition, people spend 90% of their time staying in the indoor environment. Thus, the quality level of indoor environment will definitely cause impact to people’s health. Inferior indoor air quality may cause discomfort and harm. Moreover, it may spread the contaminated mass to more people and offer a media space for the diffusion of contamination source. The health of general public will be seriously influenced.

2. Environmental Characteristics

2.1 Overall Environment

The climate type in Taiwan is subtropics. The northern part of Taiwan has the subtropical monsoon climate and southern part of Taiwan has tropical monsoon climate. Climate of Taiwan Island is influenced by warm humid air current and ocean current. Therefore, the island also possesses maritime climate. However, being adjacent to the Mainland China where the weather system usually shifting from the west to the east, the island is inevitably influenced by the continental climate. Moreover, although the geographical area of Taiwan is small, the central and eastern terrains are mountainous. Forty-six percent of the total area on the island is mountain terrains, hills, and terraces with heights over five hundreds meters above sea level. Central Range of Taiwan (Zhong-Yang), Mount Snow Range, and Mount Jade Range (Yusan) lie longitudinally on the island are mountain regions with heights over three thousands meters. Mt. Ali locates in the western region has height between one to two hundreds meters. These mountains have great influences to the climate in Taiwan. They affect the rainfall patterns and temperature variation in the mountain regions and lowlands, in additional, they divide the climate patterns to the southern, northern, western and eastern areas.

2.2 Characteristics of Micro-environment

This study is to diagnose different types of surrounding micro-environmental climates of indoor environmental quality, with four categories including city, rural area, ventilated, and non-ventilated. Each diagnosed cases are distributed in Taiwan as indicated in Figure 1.

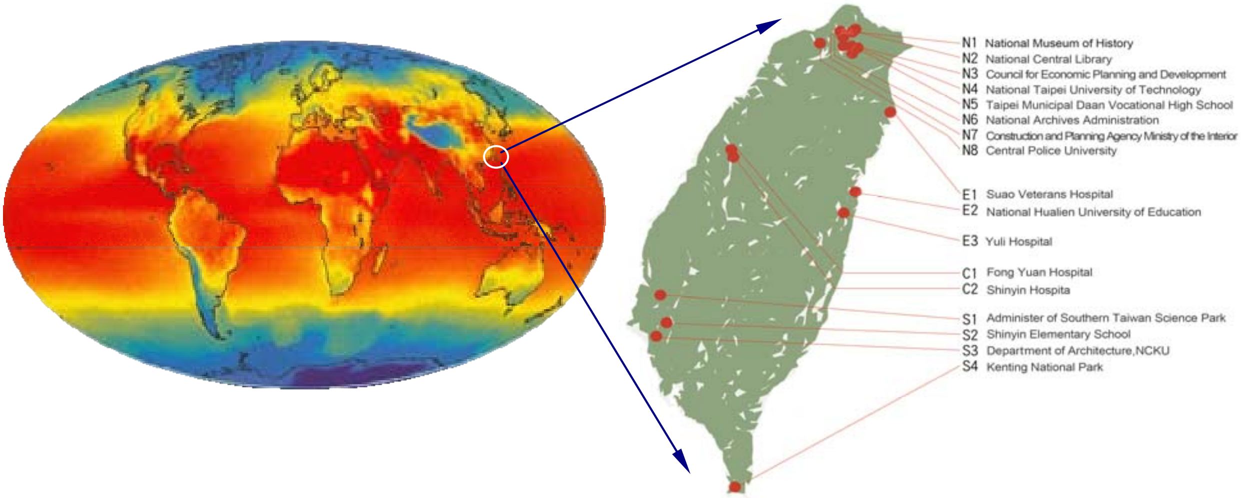


Figure1 Taiwan's location in the world & the diagnosed cases in Taiwan

3 Research Content

3.1 Diagnostic Procedure

Indoor environmental quality testing is divided into the following three levels: major issues and self-examination procedure, field inspection by building pathologist, and advance building health examination procedure. Working from the self-examination and field inspection to the final indoor health examination, this study scheme is initiated by individuals who have discovered environmental issues of their surrounding spaces and applied for an indoor environmental quality diagnosis. After completing field inspection and laying out the testing scheme, the building pathologist states the actions for improvements and goals in the final diagnostic reports (as in Figure 2).

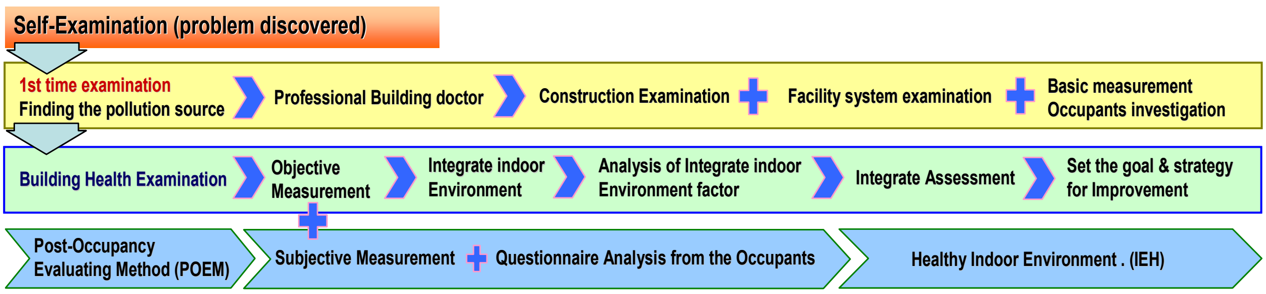


Figure2 Indoor Environment Examination Process

3.2 Selection and actual testing of indoor environmental items

This study adopted the standard operation process in improving the quality of indoor environment, which was created by previous studies. The actual quality of indoor environment was measured in order to understand the problems associated with the inferior quality, to draft measures of improvement and to undertake practical improvement work. Through confirming the goal of improvement, designing and planning, constructing and re-inspecting, it was concluded that the advancement of indoor environment quality was ultimately reached and the improved performance was assessed as well.

Prior to the indoor on-site comprehensive environmental test, an on-site test planning was drafted. The comprehensive environmental test items were roughly divided into five portions including sound, light, warmness, air and electric-magnetic. Tabular presentation of data is an easy way of condensing many items. Tables must carry numbers in the text (Table 1) and caption.

Table 1 This indoor environment of research assesses the datum.

Project	Factor	Unit	Datum					
1 Acoustics environment	Sound Level	dB(A)	Office		Museum		House	
			56 (IEI)		corridor 56	Show room 45	50 (IEI)	
					(EPA)			
2 Illumination environment	Illuminance	Lux	Office		Museum		Hospital	
			charting 750	Generally 500	Lobby 300~750	Show room 150~300	Therapy room 200~500	sickroom 100~200
			(CNS)		(CNS)		(CNS、JIS)	
	Uniformity ratio of illuminance	—	Office		Generally room		House	
			1/3 (IEI)		Both-side lighting 1/3	Uni-side lighting 1/10	0.6 (IEI)	
					(IEI)			
	disability glane	—	Whether there is glare of defending that is designed.					
3 Thermal environment	Temperature	℃	Machinery ventilation：22～27 Natural ventilation：23～28（Summer） 20～26（Winter）				(ASHRAE) (PMV-C) (PMV-C)	
	Relative humidity	%	40～70				(ASHARE)	
	Wind speed	m/s	Machinery：≦0.35 Naturally：≦0.5				(IEI) (TW-EPA)	
4 Air environment	PM_{10}	μg/m³	150				(TW-EPA)	
	CO	ppm	9				(TW-EPA)	
	CO_2	ppm	1000				(TW-EPA)	
	HCHO	ppm	0.1				(TW-EPA)	
	TVOC	ppm	3				(TW-EPA)	
5 Electronic environment	Electronic	V/m	10kHz～100kHz：87 50Hz～60Hz：4170～5000				(TW-EPA)	
	Magnetic	μT (1000nT)	12kHz～200kHz：4.6～6.25 50Hz～60Hz：83.3～100				(TW-EPA)	

3.3 Experiments and questionnaire

This work focuses on comparing the physical environment in different places around Taiwan, which could be observed to determine the differences causing by micro-climate in different places. A summary of the building ID numbers, test dates, locations, rates of occupancy, construction styles, and HVAC systems of the test buildings are given in Table 2.

Table 2 The details of 18 test buildings.

	Northern of Taiwan.							
ID number	N1	N2	N3	N4	N5	N6	N7	N8
Construction / Floor	RC/2F	RC/2F	RC/B1	RC/7F	RC/4F	RC/3F	RC/6F	RC/B1
HVAC type	MSAC	CACS	AHU	FCU	MSAC	CACS	CACS	FAN
Area(m²)/Height(m)	83.48 m² 3.5 m	29.4 m² 2.2 m	97.16 m² 2.4 m	277.3 m² 3.3 m	175.5 m² 2.6 m	132.3 m² 2.7 m	620 m² 3 m	710.2 m² 2.6 m
Density(person/m²)	0.23	0.17	0.31	0.12	0.28	0.121	0.048	0.071

	Eastern of Taiwan.			Middle of Taiwan.	
ID number	E1	E2	E3	C1	C2
Construction/Floor	RC/6F	RC/1F	RC/1F	RC/B1	RC/1F
HVAC type	CACS○	MSAC	MSAC	WTAC	CACS
Area(m²)/Height(m)	70 m² 2.2 m	80 m² 3.5 m	227.2 m² 3.2 m	71.12 m² 2.5 m	534.72 m² 3.4 m
Density(person/m²)	0.28	0.125	0.132	0.351	0.056

	Southern of Taiwan.				
ID number	N1	N2	N3	N3	N4
Construction/Floor	RC/6F	RC/3F	RC/7F	RC/2F	RC/1F
HVAC type	CACS	WTAC	MSAC	WTAC	MSAC
Area(m²)/Height(m)	620 m² 3 m	63 m² 3.8 m	68 m² 3.15 m	74.1 m² 3.2 m	435 m² 4.3 m
Density(person/m²)	0.104	0.634	0.29	0.539	0.137

Note.

This study included several space types as follows: office room, housing space, activity space, exhibition space and so on. We use long time (24hr) measurement to find out the status of indoor environment factors in different periods.

Codes of ventilation type:
MSAC: Multi-Split-A.C.
CACS: Central A.C system.
WTAC: Window type A.C.
AHU: Air Handling Unit.
FCU: Fan Coil Unit.
FAN: Fan.

In order to analyze effectively the relationship between the physical environment of different using type places, and the mental sensations of the occupants, the field-measurement'' and ``questionnaire'' were carried out simultaneously in this study. The measurements are composed of eight factors including carbon monoxide conc. (ppm), carbon dioxide conc. (ppm), air-borne dust conc. (mg/m^3), air velocity (m/s), air temperature (℃), relative humidity (%), noise level (dB(A)) and illuminance (lx). An automatically successive measurement was applied to sample eight physical factors in 24 hrs continuously, as shown in Fig. 3. The outdoor quantities are also monitored. The sensors were installed at the breathing zone (FL +90±120cm). In the questionnaire, the purpose is to investigate the level of satisfaction with the indoor physical environment during the sampling period. The satisfaction response was represented by a five-grade scale. The psychological response of occupants, working in the investigated spaces, was obtained by questionnaire as the field-measurement proceeds. The questionnaire was filled in by the researchers via the interviews with the occupants.

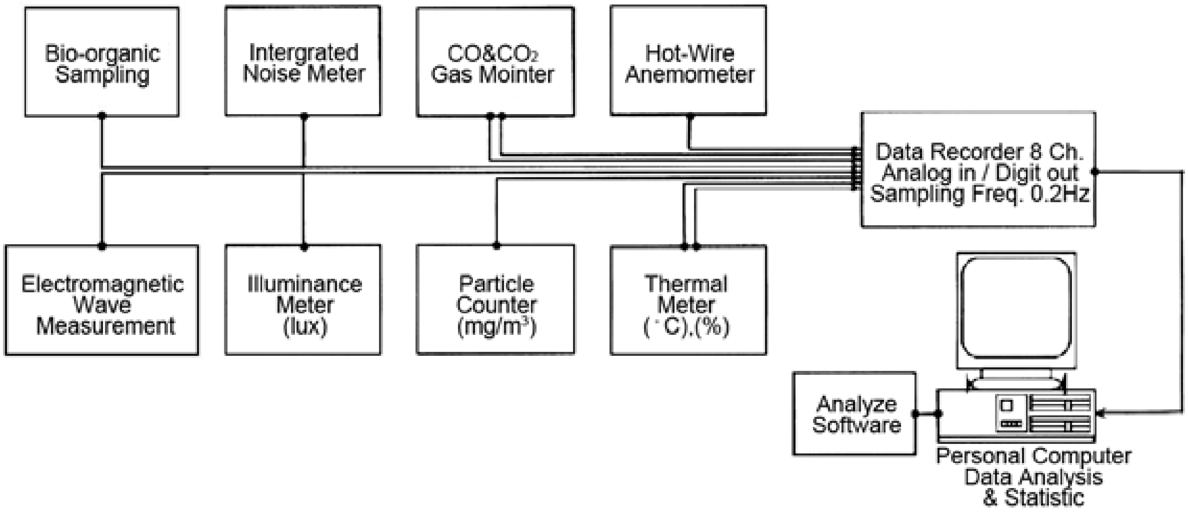


Figure.3. Schematic diagram of the field-measurement apparatus.

4 Research a result

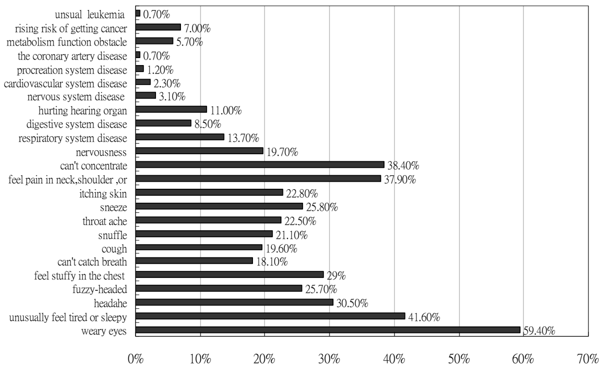
4.1 Case evaluation and user's feedback inquiry before improvement

The improvement to indoor environment must eventually aim at the assurance of user's health. Hence, it is necessary to collect the information on the indoor use status, the degree of complaints to indoor environment and the symptoms caused by indoor environment. As such, the questionnaires were drafted prior to initial inspection and the survey was conducted focusing on four key points.

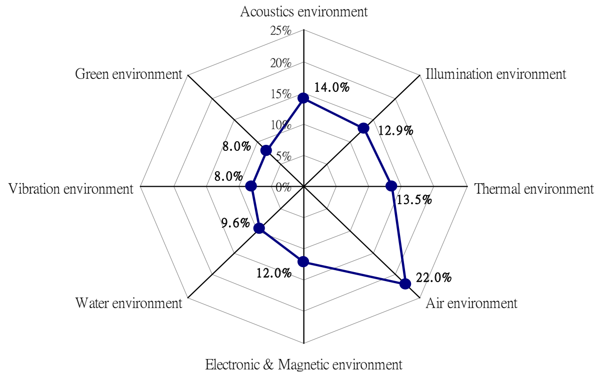
Examining the features of the samples, from the structure of sex, the percentage of male (40.34%)is lower than the female's (59.66%); from the structure of age, primarily in the range of 30 to 39(33.22%), followed by 40 to 49(31.56%), 20 to 29(17.94%), 50 to 59(12.96%), and the percentage of the age above 59(2.66%)and below 20(1.66%) are rather low; in the status of smoking, a high percentage up to 85.33% of the users do not smoke, current percentage of smokers is 8%, 6.67% of them already quit smoking; in addition, 85% of the users maintain normal living condition (85.02%) and balanced meals (84.23%). However, there are as high as 68.62% of the users under pressure. Probably take place in the indoor personnel's discomfort symptom. in figure 4(1).

Users' reaction to indoor environment problems is shown in figure 4. The project included the diagnosis and physical improvement of the indoor environment. For diagnosis, three different stages were implemented, including self inspection, the preliminary walk-through, and the detailed inspection of the building from a healthy environment standpoint. For environment measurement, there were components of indoor acoustics, illumination, thermal comfort, air quality and electromagnetic field. The process for conducting physical improvement started by setting the goals of improvement, and followed by planning, design, construction, and re-assessment after completion. It is also the purpose of this study to establish a reference manual for future projects.

Ranking the influence to human health by the items of indoor environment, the sensitivity to the air in the environment is the highest (22%), Acoustic (14%), Thermal (13.5%), Illumination (12.9%) and electric-magnetic (12%), these factors also draw a lot of attention, as shown in figure 4(2).



(1) Indoor personnel's discomfort symptom.



(2) Environmental factor.

Figure 4 Probability take place in the indoor personnel's discomfort symptom and the user counts every environmental factor attention degree.

Referring to this result, it can be concluded that while performing survey for cases, the visible environmental factors shall be specially watched or more items shall be added for inspection. Synthesize in its room the bad reason of environmental quality is counted. In figure 5.

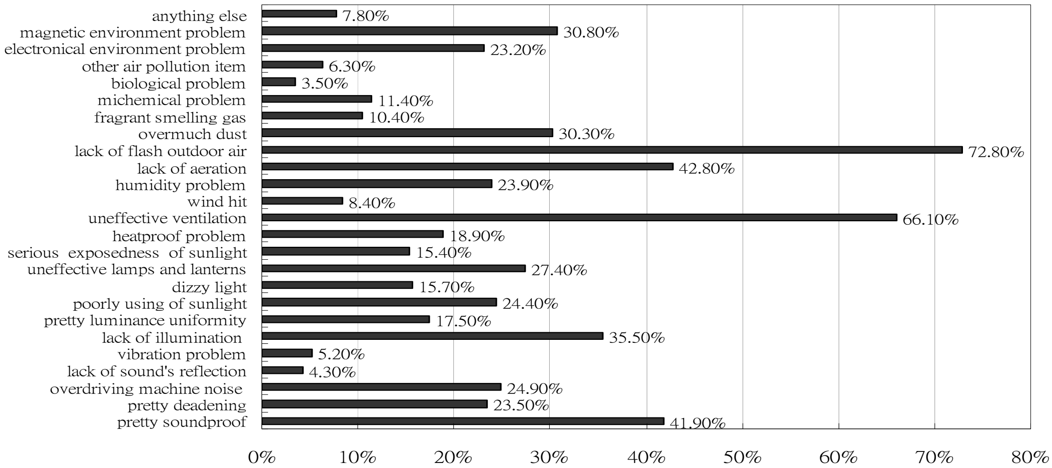
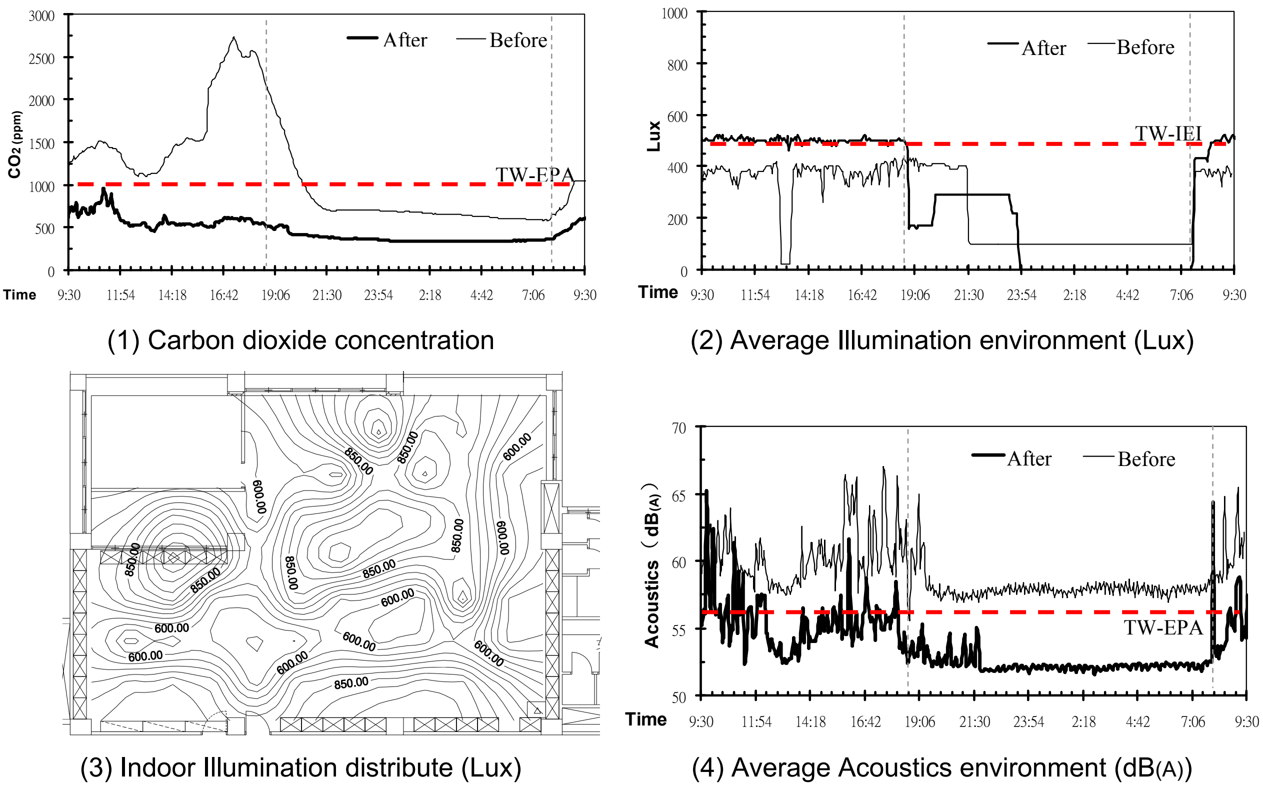


Figure 5 Synthesize in its room the bad reason of environmental quality is counted.

4.2 Diagnostics and user's feedback inquiry after improvement

Based on the climate differences in subtropical environment and in northern, central, and southern regions of Taiwan, this research investigates the environmental quality problems existed in different types of building and archive all the appropriate actions for improvement. The research then lists the localized construction items to be looked into in detail. The improvements should be discussed explicitly with the building management and pre-construction meetings should be held to reach an agreement prior to the construction. Things worth paying attention to such as the renovation to the interior environment should not destruct the existing building facilities itself. Instead, additional facilities or configuration should be added to achieve the improvement. In any event such that the improvement affects the building exterior or any regular usage, negotiation with the building management may be necessary. Part of the achievements after improvement are shown Figure6.

This research began from the viewpoint of health. Indoor environmental improvement is meant to ensure a healthy environment for the users. Hence, the user's usage behavior, degrees of complaint, and symptoms caused by surrounding environment are all essential information to be collected. Therefore, the users in the case studies are being inquired with questionnaire regarding usage purpose, health, and their emphasis in each interior environment after the improvement is implemented. The questionnaire is compiled to analyze the discomfort experienced with reference to the user's degree of emphasis on the interior environment. This analysis mainly focuses on the physiological discomfort and symptoms. It is discovered that user of the improved interior still experience illness such as dry eye or eyestrain, irregular fatigue or lethargy, dizziness, neck or shoulder muscle pains, and other symptoms. Greater percentages among the illnesses are headache, chest pain, dizziness, and neck or shoulder muscle pains. Occurrence of other discomforts is not as significant. The outcome with improvement is shown in Table 3:



(1) Carbon dioxide concentration

(2) Average Illumination environment (Lux)

(3) Indoor Illumination distribute (Lux)

(4) Average Acoustics environment (dB(A))

Figure 6 N7（Construction and Planning Agency）a model for improvement cases

5 Conclusion and Recommendations

Aiming at subtropical environment and the differences of climates in north, central and south Taiwan, this study discussed the indoor environment quality issues frequently occurred in each building features and planned appropriate improvement methods, further suggested items and content to be worked based on the individual condition.

The overall indoor environment quality in Taiwan's buildings was investigated and inspected, and the comprehensive conclusion is as follows: (1) Creating an IEQ efficiency zone of "green building design" for the existing private buildings. (2) Establishing indoor environment quality research and test process.(3) Drafting improvement techniques based on the specific conditions in each building.(4) The diagnostic result of indoor environment showed that the air environment was the primary problem.

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Table 3 Deficient points and contrast to before/after improvement

Case NO.	Problem causing	Before	After
N1	IAQ	ACH:2.62 ch^{-1}	ACH:4.25 ch^{-1}
	Illumination	Average:38 lux	Average:163.8 lux
	Thermal Comfort	Velocity:0.05m/s	Velocity:0.1m/s
N2	IAQ	ACH:3.7 ch^{-1} CO_2:845ppm	ACH:9.66 ch^{-1} CO_2:763ppm
	Illumination	1F:175.5 lux 2F:205.9 lux	1F:359 lux 2F:418 lux
	Acoustic	59 dB(A)	54.2 dB(A)
N3	IAQ	1.63ACH; CO2: 550ppm	4.07ACH; CO2: 360ppm
	Illumination	Uniformity：0.33	Uniformity：0.63
N4	IAQ	Room 1 ACH:1.27 ch^{-1} Room 2 ACH:2.7 ch^{-1}	Room 1 ACH:2.76 ch^{-1} Room 2 ACH:3.5 ch^{-1}
N5	IAQ	0.31ACH	0.57ACH
	Thermal Comfort	Wind striking occurs	velocity: <0.35m/s
	Acoustic & Noise	80dB(A)	55dB(A)
N6	IAQ	Office A HCHO: 0.19ppm ACH: 2.67 ch^{-1} Office B HCHO: 0.15ppm ACH: 11.4 ch^{-1}	Office A HCHO: 0.033ppm ACH: 4.79 ch^{-1} Office B HCHO: 0.031ppm ACH: 22.75 ch^{-1}
	Thermal Comfort	Office A 32.1℃ Office B 28.2℃	Office A 25℃ Office B 24.8℃
N7	IAQ	CO_2 : 1564.8ppm	CO_2: 603ppm
	Illumination	352.1(lux)	502.1(lux)
	Acoustic & Noise	60.1dB(A)	55.56dB(A)
	Thermal Comfort	ACH: 3 ch^{-1}	ACH: 25.06 ch^{-1}
N8	IAQ	ACH:7.45 ch^{-1}	ACH:12.72 ch^{-1}
	Thermal Comfort	Temp: 32.23℃ RH: 72%	Temp: 25.44℃ RH: 49.3%
	Illumination	391(lux)	420(lux)
	Acoustic & Noise	70.8 dB(A)	55.8dB(A)
E1	IAQ	ACH:1.6 ch^{-1}	ACH:6.2 ch^{-1}
	Illumination	296(lux)	471(lux)
	Acoustic	63.2 dB(A)	53.5 dB(A)
E2	IAQ	ACH: 2.3 HCHO: 0.9ppm TVOC: 10.07ppm	ACH 10.2 HCHO: 0.55ppm TVOC: 1.98ppm
	Thermal Comfort	Temp: 32.03℃	Indoor temperature: within 23-28℃
	Biotic Environment	Bacteria: 522~4262 FCU/m^3	Bacteria:0~96 FCU/m^3
E3	IAQ	HCHO: 0.106ppm	HCHO: 0.033ppm
	Acoustic	69.3dB(A)	54.34dB(A)
	Thermal Comfort	Temp: 34.2℃ velocity: 0.41m/s	Temp: 27.13℃ velocity: 0.275m/s
C1	Illumination	Average illuminance:187 (lux)	Average illuminance:806 (lux)
	Acoustic	67.16 dB(A)	54.9 dB(A)
	IAQ	CO2: 1110ppm	CO2: 698.1ppm
C2	Illumination	50 (lux)	675.22 (lux)
S1	IAQ	ACH:68.19 ch^{-1}	ACH:83.82 ch^{-1}
	Illumination	230.9(lux)	527.8(lux)
	Acoustic & Noise	59.1dB(A)	53.5dB(A)
S2	IAQ	ACH:1.13 ch^{-1}	ACH:2.01 ch^{-1}
	Thermal Comfort	Temp: 31.5℃	Temp: 26℃
S3	IAQ	ACH:1.19 ch^{-1}	ACH:2.04 ch^{-1}
	Thermal Comfort	Temp: 34℃	Temp: 24.5℃
	Illumination	368(lux)	537(lux)
	Acoustic & Noise	65.2dB(A)	50.7dB(A)
S4	IAQ	CO_2: 860ppm	CO_2: 750ppm
	Thermal Comfort	Indoor temperature:29.6℃	Indoor temperature: within 23-28℃
	Acoustic & Noise	69.4dB(A)	49dB(A)
S5	IAQ	ACH:0.67 ch^{-1} HCHO: 0.2ppm	ACH:2.53 ch^{-1} HCHO: 0.05ppm
	Illumination	Average illuminance:54.9(lux)	Average illuminance 328(lux)
	Acoustic & Noise	57.8 dB(A)	46.9 dB(A)
	Thermal Comfort	Temp:28.2℃ velocity:0.06m/s	Temp:25.03℃ velocity: 0.19m/s

DESIGN STRATEGIES FOR ADDRESSING CLIMATE CHANGE AND EXTREME WEATHER EVENTS

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Keywords: Design, Strategies, ESD, Climate Changes, Extreme Weather.

Summary

This work aims to address threats of climate change and EWE upon buildings, that are predicted to occur worldwide and in Australia in the 21st century and beyond.

The most relevant Extreme Weather Events (EWE) that are likely to happen more frequently in Australia are Extreme Temperatures and Heat Wave; Drought; Bushfire; Sea Level Rise and Coastal Erosion; Heavy Rainfall, Hailstorms and Flooding; Strong Winds and Cyclones.

Conventional design approaches are not sufficient to produce reliable future oriented outcomes. Even a perfect sustainable building will probably fail in coping with extremes such as sea level rise or bushfire. Environmentally Sustainable Design (ESD) is an essential approach to be used but together with other strategies that address climate change and EWE, reducing buildings' vulnerability.

The strategies identified in this paper for each extreme are particularly significant to designers and the civil construction industry, allowing them to deliver more reliable built environments now and for the future. All strategies require that designers take into consideration predicted weather data, not only historic climate records. It is extremely important to have knowledge of the kind of weather extremes a building in a specific location will face in the future, since its lifetime will be significantly affected by it.

1. Introduction

Buildings designed today will face a different reality during their lifecycle due to climate change and EWE. It is unlikely that buildings will be capable to deal with those issues. Probably, they will not succeed to deliver a desirable and comfortable place to live, work and entertain.

Unarguably, ESD can significantly reduce Greenhouse Gas Emissions (GHG) in any type of building, avoiding climate change and minimising ecological footprint. However, it is not immune to EWE. It will also face heat waves and extreme temperatures, intense and more frequent droughts and bushfires, possible heavy rainfall events and flooding, hailstorms and stronger winds.

Thus, it might be necessary to include extra design strategies to cope with EWE and new climate averages. Strategies that go beyond energy efficiency, water recycling and re-use, lifecycle, passive strategies and so on, an approach for managing vulnerability and assuring buildings' liveability.

The paper aims to highlight some important strategies for each main EWE that is likely to happen in Australia and other parts of the world, influencing design standards and the way architecture is conceived for the future. It provides designers with some practical strategies to be considered at the design stage in regards to climate change and EWE.

2. Architecture and Extreme Weather Events

Climate change predicts changes in magnitude and frequency of EWE as well as mean alterations of weather patterns leading to an exceeded design criteria and increased potential of damage to existing built environments. Thus, it is imperative to consider climate change impacts in the building stock which will be built in the next few decades to avoid extra cost associated with climate events, including catastrophes that may result in huge economic losses for the society.

The aim is to design and build weather proof buildings which cope with the climate now and changes in the future. Buildings should be robust enough to be protected against weather vulnerability, highly energy and water efficient, with longer lifetime, less environment impact and embodied energy along with more recycled materials.

Furthermore, these buildings should promote comfort and healthy indoor spaces. They must ensure liveability in extreme events and climate change conditions during their entire lifetime. Buildings should be supplied by renewable energy, specified with less water content and eco friendly materials. Finally, constructions should reduce waste during construction, operation, maintenance and demolition stages, causing minimum pollution and not harming biodiversity and ecosystems.

2.1 ESD Incompatibilities

Even though ESD principles are essential for dealing with climate change, some issues can be raised in regards to ESD coping with it, particularly EWE. Some passive design strategies may not be efficient or sufficient to keep a good internal environmental condition in extreme conditions. In addition, some technologies used in ESD might need more maintenance or replacement because of extreme events.

Some incompatibilities can be verified in passive cooling strategies such as natural ventilation. This strategy can exacerbate the indoor temperature in extreme temperatures and heat wave when extreme hot breezes cause thermal discomfort. In this case, mix strategies which integrate active systems may be a solution; however it consumes more energy and is less environmental friendly. In addition, extra shading or insulation might be necessary to comply with this kind of extremes, but it may jeopardise passive heating during winter.

Some ESD technologies such as photovoltaic panels may increase maintenance in extreme events like hailstorm. As a result, it would be costly to replace and consequently less environmental friendly as a result. A protection glass or mesh could avoid the damage, however it would decrease its efficiency.

Rainwater harvesting and recycling or re-use systems could be affected by the increasing risk of flash flooding and consequently vulnerability of water supply including drinkable water and soil contamination by sewage.

Landscaping can be used to control heat and humidity, used as a shading to avoid solar access and glare. It may be wind break against increased winds velocity and also employed as drainage system by permeable paving and green roofs minimising flooding effects. However, drought level restrictions would affect it directly. Lack of watering in drought conditions will increase dust and consequently poor air quality and more landscaping maintenance and plants replacement.

Robust constructions and structures are likely to be necessary to handle many EWE. Conversely, it means more concrete and materials, which result in more embodied energy, increased GHG, higher water demand in the construction process and consequently higher ecological footprint. It might have fewer openings and glass areas which could compromise passive strategies such as natural ventilation, daylighting levels and heating. Moreover, the excessive thermal mass could be more problematical to heat up, making passive heating unviable in winter.

3. Strategies for Addressing Extreme Weather Events

3.1 Extreme Temperature & Heat Wave

Mean temperature increase will influence specifications for energy efficiency in buildings. All elements such as insulation, shading devices, thermal mass and glazing should be dimensioned taking into account predicted temperature changes. Extreme temperatures and heat waves need to be addressed at the design stage.

Table 1 Australia's Future Temperature

IPCC's Emission Scenarios	Year 2030	Year 2070
Lower range (B1)		1-2.5ºC
Middle range (A1B)	0.6ºC-1ºC	
Higher range (A1F1)		2-5ºC

[**Source:** Australian Greenhouse Office]

Table 2 Average Number of Day per Year above 35ºC

Capital Cities in Australia	Present Average (1971-2000)	2030 Average (mid emissions) A1B	2070 Average (low emissions) B1	2070 Average (high emissions) A1F1
Sydney	3.5	4.4 (4.1-5.1)	5.3 (4.5-6.6)	8.2 (6-12)
Melbourne	9.1	11.4 (11-13)	14 (12-17)	20 (15-26)
Adelaide	17	23 (21-26)	26 (24-31)	36 (29-47)
Brisbane	1.0	2.0 (1.5-2.5)	3.0 (2.1-4.6)	7.6 (4-21)
Hobart	1.4	1.7 (1.6-1.8)	1.8 (1.7-2.0)	2.4 (2.0-3.4)
Perth	28	35 (33-39)	41 (36-46)	54 (44-67)
Darwin	11	44 (28-69)	89 (49-153)	230 (140-308)

[**Source:** Australian Greenhouse Office]

3.1.1 Strategies

Limiting natural ventilation during hot periods of the day is extremely important. Airtight building envelope also avoids ventilation during hot temperatures.

Extra shading devices and insulation will be necessary in extreme temperatures and heat waves. Thus, removable shadings devices or insulation would be a smart option.

Green roofs can insulate against heat gains and also absorb rainfall and storms acting as drainage system. Insulation should keep heat out in summer and heat in winter.

Thermal mass such as concrete, stone or tiled floors and brick soak up unwanted heat during the day. Increasing levels of insulation might be required for lightweight constructions. Also, surfaces that reflect heat in summer, like light coloured paints, are advised for both types of construction.

Larger floor to ceiling heights to allow additional cooling mechanisms that might be considered in the future. These systems should be very energy efficient, with low carbon emissions and preferably using renewable energy. Consider extra roof space facing north for adding photovoltaic panels for future energy demand.

Occupants should be educated to anticipate hot weather to manage the building accordingly. Providing a comprehensive manual is important for users to know how to operate buildings appropriately.

Appropriate deciduous trees for shading in summer and solar access in winter can be used but it may increase bushfire danger. In addition, water feature with minimal net water could be used to provide extra cooling in summer.

3.2 Drought

Rainfall and soil moisture decrease is predicted together with mean temperature increase. This combination leads to more frequent and severe droughts around Australia.

Table 3 Drought Prediction

Drought increase (%)	Year 2030	Year 2070
Australia	up to 20%	
Eastern Australia		up to 40%
South-western Australia		Up to 80%

[**Source:** Australia Bureau of Meteorology]

3.2.1 Strategies

It is essential to incorporate rainwater collection, re-use & recycling systems, and also to specify water efficient equipments on every new project. Design and specify materials and products which have less water content and use less water to install and to maintain.

Think carefully about water consumption of materials and building methods. Rainwater harvesting and recycling during the construction could minimise water demand on site. Particularly, in climate change conditions where higher temperatures will accelerate water evaporation and will increase water demand for many construction methods such as curing concrete.

Reservoirs and extra rainwater tanks could be incorporated to the building when needed. Rainwater collection should be estimated by the net water consumption over normal use for drought conditions plus climate change predictions. Leave space and spare connections for adding new rainwater tanks when the need arise in the future.

Be aware that even drought resistants plants today may be unviable in a future drought prospect. Thus, plants that last over 10 years should be carefully specified in relation to the future climate change prediction.

3.3 Bushfire

A combination of high temperatures, flammable vegetation, low humidity and very strong winds is highly linked to bushfire susceptibility (Ramsay et al, 2003). Bushfires are related mostly to dry seasons and climate change definitely will amplify its risks. Thus, it is extremely important to design buildings also surroundings to be less vulnerable.

Even though a given property is not in a ‘bushfire-prone area’, these strategies may be carefully analysed and applied when required in light of climate change conditions over the lifetime of a building.

Table 4 Extreme Fire Danger Rating Increase in Australia

	Year 2020	Year 2050
Australia	4-25%	15-70%

[**Source**: Australia Bureau of Meteorology]

Table 5 Numbers of Days of Very High or Extreme Fire Danger in Canberra

Canberra Today	Year 2020	Year 2050
23 Days	26-29 Days	28-38 Days

[**Source:** Climate Change in Australia]

3.3.1 Strategies for Landscaping

It is important to avoid construction in uphill topography because fire spreads faster. Earth mounds can be useful to deflect embers and wind-driven debris. Also, cut-and-fill and terrace the ground is used to avoid fire burning uphill, specially ground fire.

For instance, it is very important to choose a type of plant (trees and shrubs, ground cover and mulches) with low flammability characteristics. Plants without heavy litter dropping are recommended to avoid spreading ground fire.

Groups of plants acting as screen should be used to deflect wind driven attack. Plants that have dense foliage, low flammability and large size are ideal.

Create fuel-reduced area around buildings. It means clear space around buildings and non-combustible fences and walls. In addition, provide lawns and areas of cut grass, use mulches to maintain moisture content of vegetation.

3.3.2 Strategies for Building Design

The main objective is to reduce 'ignitions' by embers and burning driven by the wind, by heat radiation, by direct flame contact, and by wind damage.

Avoid litter and ember accumulation points, use non-combustible materials externally such as bricks, stone and metal or treated timber with fire retardant. Building design should be simpler, avoiding corners and re-entrants as much as possible. Furthermore, use non-combustible material for walls, columns and posts which support floors.

It is important that the roof structure can withstand gale-force winds. Also, roof space should be sealed and have sarking. Avoiding narrow roof gutters is very important as well as making it visible and accessible for maintenance. Roof light should be protected by screen or sprinkles or be made with special glass fire resistant (Ramsay et al, 2003).

Eliminating underfloor spaces using concrete on ground for example is a safer alternative than elevate wood floor. The building finished floor level should be higher than outside ground level and a non-combustible material should be used externally to prevent fire ignitions from debris in this vulnerable areas.

Attachments to a building such as verandas, decks, steps, landings, pergola and trellis may be vulnerable points of beginning a fire, so it may be prudent to avoid them, design longer eaves instead of pergolas or use non-combustible materials.

And last but not least, services should be designed as an additional instrument for successful bushfire management. Design for backup services such as dams, swimming pools, storage tanks, and rainwater tanks would maximise water supply for fire fighters in a bushfire event. In addition, gas cylinders should be located at a suitable distance from the building.

3.4 Sea Level Rise and Coastal Erosion

Coastlines may experience erosion, beach recession, sea inundation and flooding due to sea level rise, especially when combined with strong winds and storm surges (Minifie, 2007). Furthermore, prolonged and heavy rainfall events increase soil moisture making it more unstable, thus increasing chances of erosion.

Table 6 Sea Level Rise Prediction

	Mean Sea Level Rise by 2100
IPCC's Range	18 - 59cm
Ice Caps	10 - 20cm
Total	28 - 79cm
Australia East Coast	10cm
Total In Australia East Coast	38 - 89cm
* Actual Sea Level Rise Rate is 3.2mm year	

[**Source:** IPPC 2007 & CSIRO]

3.4.1 Strategies

A simple location choice avoiding vulnerable sites nearby coastal areas is a strategy itself. Undertaking an assessment risk about the location is important. Councils usually have risky areas demarcated.

Check viability of the development for insurance purposes at the chosen area. This makes insurance viable for the property.

Structures such as Palafittes, which are piles or stakes above rivers set into the sediment below the water allowing buildings to be built above flood levels, could be employed in flood prone zones. This concept could also be applied on dry land that may be subject to sea inundation or flooding due to future climate change.

Other strategies such as floatable homes could be used against flooding and sea inundation. It has been used in Holland where 26% of the country is located below sea level (Lijf et al, 2006). The homes are built in a concrete structure that floats with all services connected and operating normally during flood periods. Furthermore, constructions such as marines could be an inspiration for different infrastructures in cities vulnerable to sea level rise.

Other simple strategies may be applied to ensure safety, such as reducing slope angles. Appropriate vegetation on slopes has the ability to act as a barrier through its roots. Moreover, drainage systems are extremely important to avoid soil moisture saturation resulting in landslides.

3.5 Heavy Rainfall, Hailstorm and Flooding

Despite the decrease in mean rainfall, more heavy rainfall events are predicted, increasing the risk of flooding or flash flooding. Design for flood-proofing buildings means reducing potential damage on buildings by flooding in flood plain areas.

Table 7 Rainfall Estimates in Australia

Annual Precipitation	Year	Emission Scenario	Prediction
Central, Eastern & Northern Areas	2050	Low	-15 to +7.5%
	2050	High	-20 to +10%
	2070	Low	Around -15 to +7.5%
	2070	High	-30 to +30%

[**Source:** Australia Bureau of Meteorology & CSIRO]

3.5.1 Strategies

One of the most simple and effective flood proofing measures is to raise habitable floors in buildings and take advantage of the topography locating them higher than the flooding level, considering even higher levels due to climate change factor.

Any portion of a building or structure should be made by flood compatible materials which withstand immersion such as concrete, tiles, brick etc. It is important to clean and maintain all obstructions around the area to avoid extra rubbish on flood waters.

Drainage systems are really important to mitigate flood risk. For instance, Sustainable Drainage Systems composed by storm water tanks, rainwater harvesting and green roofs could be used as temporary storage minimising local flooding (Chell et al, 2005). In addition, permeable paving and landscaping areas would help draining extra rainwater.

The construction should be strong enough to resist lateral forces caused by impact of debris and uplift effect. Increased core walls and foundations could avoid flooded buildings to collapse under such forces.

Sewer system should be protected against flood damage because it can enter the building and contaminate ground and water supply. In addition, an adequate flood warning system and pre-planned evacuation measures are required to avoid greater risk of catastrophic damage. Ensure buildings have sites above maximum flood level and availability of flood free access for evacuation.

In regards to hailstorm, the areas which are generally most affected in building are roofs and windows. Thus, the strategy is to protect vulnerable points and specify stronger products such as resistant glass and roof tiles. Also, increasing the strength of roof fixings or roof replacement can significantly reduce to the potential damage. Insect inset screen can also add an extra protection for windows.

3.6 Strong Winds & Cyclones

Cyclones might increase power due to higher ocean's temperature and levels increase. Furthermore, cyclones can cause other extremes such as heavy rainfall, storm surges and flooding.

Table 8 Projections of Wind Speed in Australia

	Year 2030	Year 2070
Average Wind Speed	- 2.5% to 7.5% in Coastal Areas	
A1F1 Scenario		+15% some regions
B1 Scenario		Less than 10% everywhere

[**Source:** CSIRO]

3.6.1 Strategies

Design robust buildings which cope with extreme strong winds and is capable to withstand in case of loose parts of buildings such as roofs or trees blowing, hitting and damaging the building or even injuring people.

Roofs should be sufficiently anchored. Thus, specification and detailing are so important on the design stage. In addition, heavy materials such as brick, stone and concrete are more likely to manage this kind of extreme event.

Circular or polygonal building shapes are more suitable than rectangular or square plans. Also, symmetrical and compact floor plan is more stable. Orientation is also important; the smallest façade should face stronger winds.

Pitched roofs and roofs projections should be as small as possible to avoid suction. Openings should have strong closing/locking arrangements. Also, glass panels should be undersized and have extra outside protection such as metallic fabric mesh to avoid breakage.

4. Conclusion

This paper brings many factors together and issues to be addressed by designer using ESD while integrating in other strategies for coping with climate change and specially with EWE.

It is a general guide for designers to remember how important it is to make buildings liveable, comfortable and secure in light of climate change and extreme conditions during the 21st century and beyond. It gives practical strategies that can be considered straightaway in the design stage.

Designers or architects must understand that building designs must withstand the weather and it is a matter of considering climate change impacts over a lifetime of a building. It is extremely important to have knowledge of the kind of weather extremes a building in a specific location will face in the future.

Certainly, location assessment is deemed required for analysing all requirements and eventual vulnerability to possible climate change and extreme events predictions according to the lifetime of the building. The designer should be aware of it and choose appropriate strategies thinking in the future climate that the building may face.

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THE PRESENT CONDITIONS OF DESIGN AND CONSTRUCTION OF THE CERTIFIED GREEN APARTMENT COMPLEXES IN KOREA

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Summary

With an increasing demand for sustainable and environmentally-friendly buildings, Green Building Certification System (GBCS) has been in force since 2002 in Korea. The assessment categories of GBCS are largely divided into land use and transportation, energy · resources and environmental impact, ecological environment and indoor environment. A total of 6 types of buildings are dealt with in the GBCS. In particular, apartment complexes are the most common residential buildings in Korea, and it is anticipated that the number of applications for apartment complexes for the GBCS will continuously increase due to financial incentive programs that have been offered for certified apartment complexes since 2006. In this study, we aim to pick out the items requiring improvement for the green apartment complex. Twelve existing certified apartment complexes were selected. GBCS assessment results and actual conditions of design and construction were investigated and analyzed. The results showed that a total of 18 items that require improvement were identified in accordance with the average score-to-allotted point ratio. Relevant details that are expected to be helpful for the next design works were also presented.

1. Introduction

In the UNCED (United Nations Conference on Environment and Development) held in June 1992, UNFCC (United Nations Framework Convention on Climate Change) was adopted with the aim of reducing environmental problems caused by global warming. With the effectuation of the Kyoto-protocol, Annex 1 countries have been enforced to reduce the greenhouse gas emissions that act as a major source of global warming. It was reported that the building industry accounts for about 40% of the world's energy and resources consumption, 30~40% of its greenhouse gas emissions and 17% of the water used worldwide.[1] With the awareness that the building industry significantly contributes to environmental problems, attempts have been made in many countries to construct sustainable and environmentally-friendly buildings. In Korea, the Green Building Certification System (hereafter GBCS) has been in force since 2002. Especially, it is anticipated that the number of apartment complexes, which are the most common residential buildings in Korea, applying for GBCS has increased continuously because financial incentive programs for certified apartment complexes have been offered since 2006. Thus, it is important to establish a design guide to improve sustainability of apartment complex efficiently. In this study, we aim to pick out the items requiring improvement for the green apartment complex. Twelve existing certified apartment complexes were selected. GBCS assessment results and actual conditions of design and construction were investigated and analyzed. Then, items of which average score-to-allotted point ratios were low and relevant particulars helpful for the next design works were presented.

2. Outline of the GBCS

2.1 History and Operation Results of the GBCS

Since the GBCS for apartment complexes came into force in 2002, the GBCS for various buildings have been in force, such as residential and commercial building complexes and office buildings from 2003, schools from 2005 and retail and accommodation from 2006. Table 1 shows the history of GBCS. Certification types of the GBCS are divided into pre-certification and certification. Pre-certification is given for buildings in the design stage in accordance with the assessment results of their design documentations. Pre-certification is valid until the time of completion. Certification is given for the completed buildings and its

[1] Lee, P.J., 2002, Sustainable development and architecture, In Proceedings of the Joint Seminar on the Explanation of Green Building Certification System.

period of validity is 5 years. A total of 216 buildings were certified as a Green Buildings.[2] Table 2 shows the number of certified buildings from 2002 to 2006. It can be seen that the number of certified buildings in 2006 increases sharply. This is a consequence of the financial incentive programs being offered for pre-certified apartment complexes since 2006, allowing builders to add equivalent of 3% of the construction cost for the basic type to the price of a new apartment. Considering that the Price Cap System for New Apartments has been in force, this is considered to be a strong incentive.

Table 1 History of the GBCS

Date	Contents
1997~2000	- Drafts of green building rating criteria were announced by RCGBT (Research Council of Green Building Technology) supported by KOSEF (Korea Science and Engineering Foundation). - 3 certification systems were separately developed by KNHC (Korea National Housing Corp.), KIER (Korea Institute of Energy Research) and CrebizQM. - Trial certifications were conducted by MOCT (Ministry of Construction and Transportation) and MOE (Ministry of Environment) for the systems of KNHC and CrebizQM, respectively.
2000~2002	- Integration of 3 certification systems was determined by MOCT and MOE. - Integrated certification system was named as the Green Building Certification System. - KIER, HURI (Housing and Urban Research Institute) affiliated with KNHC and CrebizQM were designated as certification authorities. - The GBCS for apartment complexes was developed by KIER, HURI and CrebizQM.
Jan. 2002	GBCS for apartment complexes came into force.
Jan. 2003	GBCSs for residential and commercial building complexes and office buildings came into force.
Mar. 2005	GBCS for schools came into force.
Feb. 2006	Financial incentive programs for pre-certified apartment complexes came into force.
Apr. 2006	Revised GBCS for apartment complexes came into force.
Aug. 2006	KIEE (Korean institute of Educational Environment) was designated as the certification authority for schools.
Sep. 2006	GBCSs for retail and accommodations came into force.

Table 2 The Number of Certified Buildings from 2002 to 2006

Year	2002	2003	2004	2005	2006
	3	3	15	32	163
Building type	Apartment complexes	Office buildings	residential and commercial building complexes	Schools	
	172	30	7	7	

2.2 Assessment system of the GBCS for apartment complexes

The GBCS for apartment complexes was revised in Oct. 2005 in order to simplify the required documentations and add assessment items related to the remodeling of apartment complexes.[3] Revised GBCS has been in force since Apr. 2006. Table 3 shows the assessment systems used before and after the revision. Certification grades of the GBCS are divided into Excellent with 65 points or more and Best with 85 points or more.

Table 3 Assessment System of the GBCS for Apartment Complexes

Before revision		After revision		
Category	The number of assessment items (allotted points)	Category	The number of basic assessment items (allotted points)	The number of extra assessment items (allotted points)
Land use and transportation	11 (27)	Land use	5 (15)	3 (7)
		Transportation	3 (6)	1 (2)
Energy · resources and environmental impact	15 (41)	Energy	1 (12)	1 (3)
		Material and resources	6 (14)	2 (9)
		Water resources	3 (9)	1 (4)
		Environmental pollution	1 (3)	-
		Maintenance	2 (6)	1 (1)
Ecological environment	6 (18)	Ecological environment	5 (17)	1 (1)
Indoor environment	6 (14)	Indoor environment	5 (18)	3 (9)
Extra	6 (20)	-	-	-
Total	44 (120)	Total	31 (100)	13 (36)

[2] Song, S.Y. and Koo, B.K., 2007, The present condition and outline of the Green Building Certificated System, Magazine of the SAREK (The Society of Air-conditioning and Refrigerating Engineers of Korea), v.36 n.4, pp. 8-17.

[3] MOCT (Ministry of Construction and Transportation) and MOE (Ministry of Environment), 2005, Enforcement Regulations of Green Building Certificated System, revised on 11 Oct. 2005.

3. GBCS assessment results, actual conditions of design and construction and items requiring improvement

3.1 Outline of the Selected Certified Apartment Complexes

12 certificated apartment complexes constructed by 7 major construction companies of Korea were selected for this study. Among the 12 apartment complexes, 7 were pre-certified and 5 were certified. 3 of the pre-certified buildings were given the grade of Best, while 9 were within the grade of Excellent. Table 4 shows the outline of the selected complexes. There were few certified complexes by the revised GBCS at the time of investigation because it has been in force recently. Consequently, all of the selected 12 complexes were certified by the GBCS before the revision.

Table 4 Outline of the Selected Certified Apartment Complexes

	A1	A2	B1	B2	B3	C1	D1	E1	E2	F1	F2	G1	Average
Cert. type	Pre-cert.	Pre-cert.	Cert.	Pre-cert.	Pre-cert.	Pre-cert.	Pre-cert.	Cert.	Pre-cert.	Cert.	Cert.	Cert.	-
Grade	Best	Excell-ent	Best	Excell-ent	Excell-ent	Excell-ent	Excell-ent	Best	Excell-ent	Excell-ent	Excell-ent	Excell-ent	-
Certified date	10. 2005	12. 2004	7. 2004	3. 2006	3. 2006	12. 2005	11. 2005	3. 2006	12. 2005	8. 2004	8. 2004	6. 2005	-
Location	Gyeo-ngi	Seoul	Seoul	Gyeo-ngi	Gyeo-ngi	Busan	Gyeo-ngi	Jeju	Seoul	Ulsan	Ulsan	Inch-eon	-
Site area (m^2)	74,804	31,799	32,259	22,906	44,208	66,525	52,260	33,865	25,270	36,170	4,281	69,910	41,188
Building area (m^2)	14,837	7,851	2,961	4,650	9,089	12,970	122,894	6,129	5,719	6,767	7,984	9,157	17,584
Gross floor area (m^2)	225,357	80,653	146,483	56,188	108,150	189,779	122,894	67,171	83,779	65,275	86,182	201,758	119,472
Number of units	1,149	522	449	365	686	1,122	978	350	527	435	569	1,030	682
Building-to-site area ratio (%)	19.83	24.69	9.18	20.30	20.56	19.50	9.95	18.10	22.62	18.71	18.62	13.10	17.93
Gross floor-to-site area ratio (%)	214.44	177.90	296.32	179.90	179.87	219.80	169.99	159.98	224.08	151.09	169.82	219.97	196.93
Garden-to-site area ratio (%)	40.97	15.00	50.63	34.41	35.67	37.74	44.00	39.00	31.59	31.64	30.33	37.02	35.67
Number of car parks	1,716	598	1,253	490	964	1,690	1,029	638	627	550	748	1,787	1,008

3.2 GBCS assessment results and actual conditions of design and construction

Table 5 and Table 6 show the GBCS assessment results of the 12 selected certificated apartment complexes. The average total score and the average total score-to-allotted total point ratio of all the complexes are 74.82 points and 62.35%, respectively. Among all the categories, energy · resources and environmental impact category obtained the highest ratio of the average score-to-allotted points. On the contrary, ecological environment and extra categories obtained low ratios. In the case of the 3 complexes with the Best grade, the average total score and average total score-to-allotted total point ratio are 87.03 points and 72.53%, respectively. The average score-to-allotted point ratios of the categories of energy · resources and environmental impact and ecological environment are higher by about 20% than those of complexes with the Excellent grade. Table 7 shows the actual conditions of design and construction for each assessment item.

3.3 Items requiring improvement and relevant particulars for the next design works

3.3.1 Outline of the analysis

In this study, the average score-to-allotted point ratios of all the items were divided into five classes of A (Best), B (Better), C (Good), D (Worse) and E (Worst) for the purpose of evaluation. Classes A, B, C and D indicate that the average score-to-allotted point ratios are within the 80^{th}, 60^{th}, 40^{th} and 20^{th} percentile, respectively. E indicates that the average score-to-allotted point ratio is either equal to, or lower than 20% of those attained. The average score-to-allotted point ratios for A, B, C and D are higher than 93.83%, 81.33%, 55.56% and 48.35%, respectively (Refer to Table 6).

3.3.2 Land use and transportation

Among the allotted items with high points (3 points or higher), item 3 (gross floor-to-site area ratio) is categorized under the D class (48.37%/6 points). Among the allotted items with low points (2 points or lower), item 4 (interference in the right to sunshine of adjacent properties) and item 9 (connection of on-site pedestrian walkway to outside public walkway) were categorized under the E class (18.33%/2 points) and the D class (54.17%/1 point), respectively.

Considering the economical efficiency, it seems to be a little difficult to improve the item 3 and item 4. However, it is considered to be relatively easy to improve the item 9. As far as security problems don't arise, it is recommended to place as many gates as possible at the fence.

3.3.3 Energy · resources and environmental impact

Among the allotted items with high points, item 12 (Energy Performance Index[4]) and item 17 (reduction of CO_2 emission) are categorized under the D class (53.89%/12 points) and D class (54.83%/3 points), respectively. Among the allotted items with low points, item 15 (minimal use of furniture through the built-in wardrobe) and item 21 (use of rainwater) are categorized under the E class (38.33%/1 point) and the E class (25.00%/2 point), respectively.

Item 12 with the highest allotted point is a key to the sustainability. Among the items concerning EPI (Energy Performance Index), those items required improvement were selected based on the data of the 12 selected complexes. These items are the installation of windbreak space at the entrance of the unit and the building, external insulation, the installation of energy-efficient control systems of heating water pumps, the application of a heat recovery ventilation system, the installation of automatic power factor adjustment equipments for power condensers installed in a group and the installation of openings for daylighting and automatic lighting control systems for underground car parking. In the case of item 17, it is necessary to spread cogeneration and district heating systems nationwide. It seems to be relatively easy to improve item 15 and item 21.

3.3.4 Ecological environment

Among the allotted items with high points, item 28 (application of artificial landscaping methods considering ecological environment) and item 29 (garden-to-site area ratio) are categorized under the D class (49.76%/4 points) and D class (49.93%/5 points), respectively. Among the allotted items with low points, item 27 (on-site topsoil reuse ratio) and item 30 (connection to the outside green space) are categorized under the E class (13.33%/1 point) and the D class (52.08%/2 points), respectively.

It is considered that builders should take careful consideration of in items 28, 29 and 30 because they significantly contribute to the concept of a 'green' home for the residents.

Table 5 GBCS Assessment Results of the Selected Certified Apartment Complexes by Categories

Category	Allotted point	Allotted –to-total point ratio (%)	Total complexes			Best grade complexes			Excellent grade complexes		
			Average score	Average score-to-allotted point ratio (%)	Average score-to-average total score ratio (%)	Average score	Average score-to-allotted point ratio (%)	Average score-to-average total score ratio (%)	Average score	Average score-to-allotted point ratio (%)	Average score-to-average total score ratio (%)
Land use and transportation	27	22.50	18.74	69.42	25.05	19.59	72.54	22.50	18.46	68.38	26.09
Energy · resources and environmental impact	41	34.17	29.03	70.80	38.80	35.15	85.72	40.38	26.99	65.83	38.15
Ecological environment	18	15.00	10.35	57.52	13.84	13.02	72.35	14.96	9.46	52.58	13.38
Indoor environment	14	11.67	9.60	68.60	12.84	10.00	71.43	11.49	9.47	67.66	13.39
Extra	20	16.67	7.26	36.30	9.70	9.28	46.38	10.66	6.59	32.93	9.31
Total	120	100.00	74.82	62.35	100.00	87.03	72.53	100.00	70.75	58.96	100.00

4 KEMCO (Korea Energy Management Corporation), 2005, A manual for Building Design Criteria for Energy Savings.

Table 6 GBCS Assessment Results of the Selected Certified Apartment Complexes by Items

Category	Section	Item	Allotted point	Average score	Average score-to-allotted point ratio (%)	Class*
Land use and transpor-tation	Land development and changes of the land quality	(1) Ecological value of existing site	2	1.33	66.67	C
		(2) Establishment of urban planning	2	1.67	83.33	B
		(3) Gross floor-to-site area ratio	6	2.90	48.37	D
	Impact on adjacent properties	(4) Interference in the right to sunshine of adjacent properties	2	0.37	18.33	E
	Transportation	(5) Distance to the public transportation station	2	1.60	80.00	C
		(6) Distance from the center of apartment complex to the center of district and city	2	1.92	95.83	A
		(7) Installation of bicycle pathway and rack	2	1.83	91.67	B
	Provision of comfortable residential environment	(8) Provision of pedestrian walkway	3	2.50	83.33	B
		(9) Connection of on-site pedestrian walkway to outside public walkway	1	0.54	54.17	D
		(10) Accessibility to rivers, mountains or forests	2	1.58	79.17	C
		(11) Provision of community center or facilities for community use	3	2.50	83.33	B
	Subtotal	-	27	18.74	69.42	-
Energy · resources and environmen-tal impact	Energy consumption	(12) Energy Performance Index	12	6.47	53.89	D
	Conservation of resources	(13) Flexibility in changing the inside layout during lifetime	3	2.50	83.33	B
		(14) Use of environmentally-friendly products	2	1.85	92.50	B
		(15) Minimal use of furniture through the built-in wardrobe	1	0.38	38.33	E
		(16) Application of environmentally-friendly construction methods	3	1.73	57.78	C
	Environmental pollution	(17) Reduction of CO_2 emission	3	1.65	54.83	D
		(18) Installation of separating and storing system for recyclable solid wastes	1	0.85	85.00	B
		(19) Reduction of food waste	1	1.00	100.00	A
	Water resources	(20) Reduction of city water use	3	2.15	71.67	C
		(21) Use of rainwater	2	0.50	25.00	E
		(22) Provision of water permeable pavement	3	2.95	98.33	A
	Maintenance	(23) Environmental management plan for the construction	1	1.00	100.00	A
		(24) Provision of documents for building operation and maintenance	2	2.00	100.00	A
		(25) Provision of manuals for occupants	1	1.00	100.00	A
		(26) Installation of high-speed internet	3	3.00	100.00	A
	Subtotal	-	41	29.03	70.80	-
Ecological environment	Use of natural resources	(27) On-site topsoil reuse ratio	1	0.13	13.33	E
	Provision of green space in the complex	(28) Application of artificial landscaping methods considering ecological environment	4	1.99	49.76	D
		(29) Garden-to-site area ratio	5	2.50	49.93	D
		(30) Connection to the outside green space	2	1.04	52.08	D
	Provision of wildlife's habitat	(31) Provision of biotope for aquatic life	3	2.06	68.53	C
		(32) Provision of biotope for terrestrial life	3	2.64	87.89	B
	Subtotal	-	18	10.35	57.52	-
Indoor environment	Indoor air quality	(33) Use of low or no VOCs materials	3	2.33	77.78	C
		(34) Design for natural ventilation	3	1.65	55.00	D
	Thermal environment	(35) Installation of thermostat per each room or zone	2	1.98	99.17	A
	Acoustical environment	(36) Sound insulation performance of the wall between units	3	1.94	64.58	C
	Services	(37) Green space-to-balcony area ratio	2	0.70	35.00	E
		(38) Accessibility of the disabled and the elderly	1	1.00	100.00	A
	Subtotal	-	14	9.60	68.60	-
Extra	-	(39) Noise level in the complex	3	1.45	48.33	E
		(40) Use of alternative energy	3	0.13	4.17	E
		(41) Installation of grey water system	4	0.67	16.67	E
		(42) Preservation of existing natural resources	3	0.25	8.33	E
		(43) Sound insulation performance of the floor	3	1.50	50.03	D
		(44) Percentage of sunshine into unit	4	3.27	81.67	B
	Subtotal	-	20	7.26	36.30	-
Total		-	120	74.82	62.35	-

* A: Best, B: Better, C: Good, D: Worse, E: Worst (Refer to 3.3.1)

(dark grey) D or E classes items of which allotted points are high (3 points or higher)

(light grey) D or E classes items of which allotted points are low (2 points or lower)

Table 7 Actual Design and Construction Conditions of the Selected Certified Apartment Complexes by Items

Category	Item	Design and construction conditions
Land Use and transportation	(1)	Site with lower ecological value (pre-used or infra structure buried or reclaimed land)-to-total site area ratio: average 65.03%
	(3)	Gross floor-to-site area ratio: average 196.93%
	(4)	Maximum angle from ground level to building height: average 55.29˚
	(5)	- 2 or more public transportations within 200m: average 16.67% - The nearest public transportation within 150m: average 66.67% - The nearest public transportation within 150-200m: average 16.67%
	(6)	- Distance from the center of apartment complex to the center of district within 500m or city within 2km: average 91.67% - Distance from the center of apartment complex to the center of district within 1km or city within 5km: average 8.33%
	(7)	- Installation of 15 or more bicycles racks per 100 units: average 100.00% - Installation of bicycle pathway in the apartment complex: average 83.33%
	(8)	Provision of pedestrian walkway linked with community center in the apartment complex: average 83.33%
	(9)	- On-site pedestrian walkway connected to outside public walkway at several points : 41.67% - On-site pedestrian walkway connected to outside public walkway at very few points: 25.00%
	(10)	- Rivers, mountains or forests adjoined to apartment complex: average 58.33% - Rivers, mountains or forests within 500m: average 41.67%
	(11)	Community center or facilities for community use: 100.00%
Energy · resources and environmental impact	(12)	Energy Performance Index (Perfect EPI is 100. Required at least 60.): average 73.63
	(13)	Units with layout of variable or custom-made types-to-gross floor are ratio: average 66.20%
	(14)	Number of environmentally-friendly products applied: average 8.8 products (Mainly finish materials or water saving equipments)
	(15)	Built-in wardrobe-to-room area ratio: average 6.4%
	(16)	- Environmentally-friendly method's construction cost-to-total construction cost ratio: average 1.5% - Number of environmentally-friendly new technologies applied: average 1.3
	(17)	- Buildings with cogeneration heating system: 16.67% - Buildings with district heating system: 8.33% - Buildings with other heating systems: 75.00%
	(18)	- Recyclable solid wastes storage facilities and separate collection of 6 or more: 58.33% - Separate collection of 6 or more: 33.33% - Separate collection of 5 or more: 8.33%
	(19)	Installation of hydro-extracting equipments for food wastes: 100.00%
	(20)	Reduction rate of city water use: average 27.4%
	(21)	Installation of rainwater harvesting systems of which capacities are equivalent to 5% or more of needed service water: 25.00%
	(22)	Water permeable pavement ratio: average 53.4%
Ecological environment	(27)	On-site topsoil reuse ratio: average 5.46%
	(28)	- Alternative green retaining wall ratio: average 36.75% - Green roof ratio: average 1.21% - Green wall ratio: average 31.28% - Green fence ratio: average 55.56% - Green retaining wall ratio: average 34.87%
	(29)	Garden-to-site area ratio: average 36.62%
	(31)	- Biotope for aquatic life-to-site area ratio (on the natural ground surface): average 0.44% - Biotope for aquatic life-to-site area ratio (on the artificial ground surface): average 0.66%
	(32)	- Biotope for terrestrial life-to-site area ratio (on the natural ground surface): average 0.81% - Biotope for terrestrial life-to-site area ratio (on the artificial ground surface): average 1.27%
Indoor environment	(33)	- No use of UFFC (Urea Formaldehyde Foam Cavity) insulation: 41.67% - Number of low or no VOCs materials applied: average 4.25
	(34)	- Installation of heat recovered and controllable ventilation system per room: 25.00% - Installation of controllable ventilation system: 50.00% - Openable window-to-floor area ratio: average 17.53%
	(35)	Installation rate of thermostat per each room or zone: average 98.33%
	(36)	Thickness of the walls between units: average 199.17mm
	(37)	Green space-to-balcony area ratio: average 9.72%
Extra	(39)	Noise level difference between the values of complex and environmental standard: average -5.62dB (daytime), -4.96dB (nighttime)
	(40)	Installation of photovoltaic system for 20% or more of street lamps and solar collector with capacity equivalent to 20% or more of domestic hot water demand for common place (welfare center, community center and so on): only 1 apartment complex
	(41)	Grey water-to-total drained water ratio: average 2.74%
	(42)	Preservation of existing natural resources ratio: average 1.64%
	(43)	- Lightweight impact sound: 50.00% (1st grade), 41.67%(2nd grade) - Heavyweight impact sound: 41.67% (3rd grade)
	(44)	Continuous sun-shined unit ratio at least for 2 hours from 9am to 3pm on the winter solstice: average 81.18%

3.3.5 Indoor environment

Among the allotted items with high points, item 34 (design for natural ventilation) is grouped under the D class (55.00%/3 points). Among the allotted items with low points, item 37 (green space-to-balcony area ratio) comes under the E class (35.00%/2 points).

While ventilation is essential for indoor air quality, in the cold season uncontrolled natural ventilation through open windows may result in a significant amount of heat loss. Thus, it is recommended that the heat recovery ventilation system is applied for the item 34. Item 37 is excluded from the assessment items of the revised GBCS.

3.3.6 Extra

The extra category consists of items that either require significant cost or are difficult to be implemented practically. Every item in the extra category is grouped under the D or E classes, with the exception of item 44.

In the case of item 40 (use of alternative energy), there are problems that equipments' efficiencies are too low to be applied widely to the apartment complex. Item 41 (installation of grey water system) may increase the maintenance cost as well as the construction cost. Moreover, the city water rate is very low. However, it is recommended that these items be applied to common facilities such as a community center, etc., considering the demand for a reduction in the use of fossil fuels and the conservation of water resources. Because residents are significantly influenced by the item 43 (sound insulation performance of the floor), it is essential to apply a sound-insulated floor structure. Measures of the increase in the thickness of the floor structure, the insertion of the impact-absorbing material, etc. may be applied.

4. Summary and Conclusions

In Korea, the GBCS (Green Building Certification System) has been in force since 2002. A total of 6 types of buildings are dealt in the GBCS. In particular, it is anticipated that the number of applications for GBCS for apartment complexes in Korea has increased continuously due to financial incentive programs that have been offered since 2006 for certified apartment complexes. In this study, we aim to pick out the items requiring improvement for the green apartment complex. Existing 12 certified apartment complexes were selected. GBCS assessment results and actual conditions of design and construction were investigated and analyzed. Among the 23 items with high allotted points, 11 items were grouped under either the D (worse) or E (worst) classes, including gross floor-to-site area ratio, Energy Performance Index, reduction of CO_2 emission, application of artificial landscaping methods considering ecological environment, garden-to-site area ratio, design for natural ventilation and extra items, with the exception of the percentage of sunshine entering into the unit. Among the 21 items with low allotted points, 7 items were grouped under the D (worse) or E (worst) classes, including interference to the right to sunshine of adjacent properties, the connection of an on-site pedestrian walkway to the outside public walkway, minimal use of furniture through the built-in wardrobe, use of rainwater, on-site topsoil reuse ratio, connection to the outside green space and the green space-to-balcony area ratio. It is expected that the relevant specifics regarding these items will be helpful for future design works.

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THE NORWEGIAN RTD-PROJECT GLITNE: HOW CAN EXTENDED PRODUCER RESPONSIBILITY CONTRIBUTE TO MORE SUSTAINABLE BUILDINGS?

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Summary

The main goal of the research project, GLITNE, is to produce knowledge on how environmentally effective buildings can be made more competitive. Extended Producer Responsibility (EPR) is an environmental policy approach in which a producer's responsibility, physical and/or financial, for a product is extended to the post-consumer stage of a product's life cycle. The superior idea is that trough the introduction of EPR in the building industry, including environmental considerations the building project will become profitable. This may be realised though a clear documentation of the environmental properties of products and constructions, to advance environmental product development, and an EPR model, ensuring that environmentally effective buildings also are the economically most favourable.

Based on the experience with the different models for EPR in other industries and the special challenges connected with the building industry, a model were an independent third party is responsible for the product after use on behalf of the producer seems interesting (one of three models for EPR). This will be a target of further investigation.

The EPR model will be linked to a tool, designed as a model checker towards an intelligent Building Information Model (BIM). A building model may then automatically, at different stages in the building process, be checked with respect to its environmental properties.

The article presents the preliminary results for this innovating project, including the first steps towards finding a suitable valuation method.

1. Introduction

The research project, short name GLITNE[1], is financed by the Norwegian research Council, Norwegian Housing bank and National office of Building Technology. Snøhetta AS is the owner of the project, and SINTEF Building Infrastructure the research partner. Partners involved in different degrees in the project are Snøhetta, SINTEF Building infrastructure, Norwegian financial Services organisation, Entra eiendom, Teknobygg, National office of Building Technology and Administration Norway, Norwegian steel association, Wood Polymer Technology, The Norwegian Association for Ventilation and Energy Technology, NCC, Veolia miljø, OSO Hotwater, Protan and Bellona. Together they represent all phases in the building lifecycle, many stakeholders and liable actors in a buildings lifespan.

The main goal of the project is to provide knowledge about how environmentally effective buildings can become more competitive. This is underpinned by the following sub goals:

[1] GLITNE ("The glowing") is in the Norse mythology the house of "Forsethe" in "Aasgaard". The hall had a roof of silver and pillars of gold. "Forsete" is the god of justice, and was the son of "Balder" and "Nanna". He sat by the "hov" (place of worship) of the gods, and was a lawmaker and judge in difficult cases. Most often he managed to come to an agreement in all difficult cases.

- Based on existing knowledge produce a method and a tool to show the environmental consequences of a building, for the user, government and business.
- Produce knowledge on how the partners in the project may use the method in environmental product development and therein innovative solutions.
- Suggest a model for extended producer responsibility that will benefit the construction/ building industry.
- Provide facts as a input to national and international standards, laws and regulations on the area.

The results of GLITNE are mainly:

1. An established weighting principle/method to calculate the environmental load from a building
2. A structure to follow the initial environmental goals for a project, though design, construction, operation and demolition
3. A tool to make the method and structure above useful to all partners in the project, and hence the construction/building industry
4. An EPR model to make environmentally efficient buildings also the most cost effective one

In this paper it is discussed how EPR might be a solution for the building industry to anticipate environmental challenges, including a discussion of existing models for EPR. Does a suitable economic weighting method for the purpose of EPR exist? Different weighting methods are looked into an evaluated by defined criteria. And finally, some conclusive elements in adjusting an environmental tool such as GLITNE to the building process are presented. This is discussed due to important milestones in the building process and last, outlined due to a suitable tool for the participants in the building process.

2. Background

Nationally it has been a topic in Norway if EPR could be an effective policy instrument to move the building industry in a more environmentally friendly direction. For now it is concluded that "*today the knowledge base is too weak to possibly estimate what the intended and unintended consequences of system like this may be. An improved knowledge basis is a premise for an eventual recommendation of EPR as a suitable system for buildings*" (NOU, 2005).

The basic principle of EPR is that the producer is made responsible for the environmental effects concerning their products throughout the lifetime of the product, the intention of producer responsibility being tripartite:

- Increase recycling and recovery of wasted products, like e.g. building products.
- Awarding of products with high environmental standard, e.g. a construction.
- Stimulate consumers to select products, including buildings, with high environmental standard.

The building industry represents a large share of the environmental load form the society in the respect of resource use, generation of waste, emission of gasses with global warming potential, use of toxic substances etc. The consumption in the dwelling- and building industry are increasing and presumably not consistent with sustainable development. In Norway stricter requirements in terms of environmental programs, substitution of hazardous chemicals, polluted soil, control with hazardous substances in demolition, waste plans etc. are implemented. The largest contribution will most likely come from the new energy labelling program for buildings, probably in the course of 2009-10 (NVE, 2008).

The increasing focus on the significance of building with regard to the environmental loads from our society will most likely lead to stricter requirements. Norway has introduced EPR for several products that represent a significantly lower environmental impact than a building represents throughout its lifetime, e.g. milk cartons and electric products. Today environmentally friendly buildings are not favoured neither towards consumers or when considering business profitability. To build with less environmental load is considered more expensive, at least initially. This is a great hindrance for realising environmentally friendly concepts within the industry.

For the industry it is important to be an active partner, or perhaps also the driving force, in these changes. This active participation will be crucial for the success of any action for change both for the industry and for the resulting environmental improvements. This is a part of the motivation behind GLITNE. The partners want to show the government how EPR may work for the building industry and what conditions that must be fulfilled before such a system is a success. The success depends not only on the environmental effect but also on how it is received and implemented in the industry and in the market.

An important motivation for the partners is to clarify their own premises and make sure that their processes are optimal. They all mean that they have a potential to deliver products and services with lower environmental loads. The most important obstacles to realise this potential are price and demand. They also state that environmentally conscious choices depend on:

- Environmentally consciousness being rewarded
- The availability of tools to ensure these choices
- Improved information throughout the industry

The most important prerequisite to prevent poor environmental decisions that lead to bad solutions are official regulations that are follow-up by enterprise controls and public supervision. Public requirements are the triggering factor on internal follow up in the enterprises (Ovesen, 2008).

3. About EPR as an instrument for sustainable buildings

OECD has defined Extended Producer Responsibility (EPR) as "*an environmental policy approach which a producer's responsibility physical and/or financial, for a product is extended to the post consumer stage of a product's lifecycle*". This approach is based on that the producer has the biggest influence on improving a products environmental properties through production of components (for construction), fabrication (of the building) and waste treatment, reuse and recycling possibilities (of the components of the building) (USEPA, 1997).

3.1 Purpose of EPR

According to NOU (2005:12) the basis for EPR is giving the objective producer responsible liability. The producer has the responsibility for the product from production to waste treatment. This responsibility involves the producer being submitted to duties during the building process, the lifecycle and waste treatment. In this context EPR defines the producer as responsible for the building's environmental load throughout its lifetime. This would involve attaching responsibility for subjects also earlier in the cause-effect chain when a condition of responsibility occurs.

The purpose of an EPR model is to stimulate the market rewarding environmental awareness with increased profit throughout the value chain. Three important elements should be pointed out:

1. The placement of the responsibility of the product environmental load throughout the lifecycle of the product.
2. Rewarding products that are environmentally preferable.
3. Rewarding consumers that select environmentally preferable products.

A good model for EPR, that also takes into account all socioeconomic environmental costs, will also stimulate the reduction of material, resource- and energy use for all processes, elimination of the use of toxicants, reduction of waste production and increasing possibilities for reuse and recycling, and also adjustment and optimisation of the durability of composed products

There are three principally different models for EPR (Spicer et al. 2004):

1. The producer is directly responsible for the product after the user phase
2. A group/trade/industry assumes a collective responsibility for the product after the user phase
3. An independent third party assumes responsibility for the product after use on behalf of the producer. This can be accomplished through different financial mechanisms.

There are many factors in favour of alternative three. One of these, the need for adequate and predictable economic framework for reclaiming and recycling of products with a long service life, is very important to the building industry. How this may work in the Norwegian building industry will be studied further in GLITNE. Scenarios for the different partners in the project will be one of the methods in describing the consequences for the different alternatives.

3.2 How can EPR be a solution for the building industry?

Extended producer responsibility in the building industry as a voluntary arrangement is valuated as less realistic because of the structure of the industry, a major difference compared to the products that already have this type of mechanism implemented. Many small companies, the long lifespan of the product, changing owners, many partners (also from different companies), involved in the lifecycle, are some of the complicating aspects. A relatively fast implementation in the building industry must be done trough official rule.

Initially the producer responsibility is best taken care of though a defined producer buying the right to pollute. The capital will be used to compensate for the harm caused on the environment. In practise the money can be placed in a fund that pays for example for documented appropriate waste treatment in the future. As a public system this would resemble the pension scheme, and could contribute to good marked based arrangements based of free competition and minimal costs (Mysen, 2007).

There are mainly three principally different models identified as feasible dependent on who is responsible:

- The producer of a building product buys the right to pollute per product - a deposit to a fond when importing /producing
- The liable owner of the building initiative buys the right to pollute per object with the application duty according to the Planning and building act.
- Owners buying the right to pollute - paid as an annual insurance.

These three arrangements are possible by themselves or in combination. The main task in GLITNE towards the fall of 2009 is to test these possibilities in close cooperation with the partners, and to analyse the consequences for the industry. The results will be a recommendation regarding EPR as a possible solution for the building industry and if so how could the system be designed to suite the industry and the environment.

4. Survey of monetary based weighting methods

One of the goals of the GLITNE project is to find a monetary based principle for weighting of environmental effects. Monetary valuation is used to improve the basis for decision because:

- effects on environment and health expressed in monetary units can be used to negotiate environmental duties/taxes that internalise external costs
- decision makers, as for example public authorities, will put into action measures that should not cost more than it gains the general public

Environmental valuation is based on peoples willingness to pay a certain amount of money to avoid environmental damage or willingness to accept a compensation if environmental damage occur. The wish to include environmental effects is based on a "market failure", meaning that the market don't reflect the real social value of the environment (Damigos, 2005).

Through monetary valuation environmental effects traditionally regarded as externalities are included and form a basis for better decisions. It is important to remember that monetary valuation only is useful as a basis for decision; the intention is not to estimate a price that someone actually will pay or a real value of e.g. a specie. The social value of environmental good also exceeds the marked price for tree reasons (Brüer, 2003):

1. Lack of scientific knowledge means that there will always be undiscovered and non-valued values related to the functions of an ecosystem.
2. A functioning ecosystem is more worth than the sum of its components.
3. Any ecosystem has a primary value because of it use and non-use values. These primary values cannot be measured by the use of conventional economical terms (consumer preferences).

There are many opponents to monetary valuation of environmental effects, and their primary resistance is based on general resistance against weighting, based on ethical or moral reasons, resistance against the ranking of risks or uncertainty in the primary data.

In GLITNE the partners tends towards monetary based weighting, mainly because it provides a basis for them to make cost effective measures to improve their products, and an understandable and communicative measure of environmental effects related to their activities.

4.1 Important criteria for a suitable weighting method or tool

The goal of the survey was to find existing methods and tools for environmental evaluation of buildings preferably using monetary evaluation. It was also relevant to find tools that had other aspects relevant to the development of the GLITNE tool, e.g. IFC (Industrial Foundation Classes) based tools, tools that is used to any extent, that have a good user interface or structure. Both the internet and article databases were searched to find relevant information. The amount of material available on the two subjects is almost inexhaustible, the resulting report cannot cover all findings, but the most interesting findings are presented in Strand-Hanssen (2008).

The methods and tools found were subjected to a coarse evaluation, to find those relevant to form a basis for GLITNE. It is important that the method developed is based on the relevant standards, including those under development.

In LCI (Life Cycle Inventory) and EPD's it is mostly mid-point effects that are quantified. In monetary evaluation it is mostly the endpoint effects that are valued, this provides a challenge. In addition the aspects listed horizontally in Table 1 were considered important regarding the GLITNE method, based on discussions with the partners and literature:

4.2 Recommended weighting methods for the GLITNE project

The principles of economic weighting evaluated are listed in Table 1, together with a qualitative evaluation of the suitability of the methods in GLITNE.

Table 1: Summary of the evaluation it the different methods for monetary valuation (Strand-Hanssen, 2008)

Method	Theoretical validity	Market validity	Resource needs	Communication	Environmental effects	Flexibility	Total evaluation
Change in productivity	+	+	0	0	÷	?	Not suited
Loss of income	0	+	0	+	÷	?	Not suited
Preventive measures	+	+	÷	+	0	+	Not suited
Recovery measures	0	0	0	+	+	+	Further evaluation
Relocation	?	?	+	÷	÷	÷	Not suited
Travel cost	0	?	÷	?	÷	÷	Not suited
Hedonic pricing	÷	0	÷	+	÷	÷	Not suited
Wage differences	÷	+	÷	÷	÷	?	Not suited
Environmental taxes	?	?	+	+	?	0	Further evaluation
CV	+	0	÷	0	+	+	Further evaluation
Trade off game	+	0	÷	0	+	+	Further evaluation
Priority-evaluation	+	0	÷	?	+	+	Not suited
Artificial markets	+	?	÷	÷	÷	?	Not suited

+	Good
0	Neutral
÷	Poor
?	Not possible to evaluate

The methods found to be suitable for further evaluation in GLITNE were:

1. Costs for recovery measures
2. Environmental taxes
3. Contingent valuation (CV), (existing studies)
4. Trade off game (existing studies)

CV are subjected to substantial critique (presented e.g. in Howarth et al. (2006) og Sagoff (2004), mostly directed towards difficulties the respondents have understanding what they are actually assigning a value. important aspects related to GLITNE is that it is expensive to produce data and difficult to maintain them. In addition results strongly depend on how the survey is designed and carried out. There is a high risk of misleading answers because of misinterpretation of questions or the person answering giving misleading or strategic answers. There are no studies in Norway that can be used in GLITNE, and it is seen as less likely that the industry will accept studies in other countries as a basis for decisions in the Norwegian building industry.

Two interesting studies were found that uses environmental taxes as a basis to valuate willingness to pay, Green tax (Wu et al, 2005) and Ecotax (Eldh, 2003). They both use the principle that the taxes represent the shadow price of the willingness to accept that environmental damage using this principle. There are several taxes in Norway that are completely or partially environmentally motivated, as e.g. tax on the emission of CO_2, tax in the petroleum sector on the continental shelf, Environmental tax on pesticides, tax on HFK and PFK, natural resource tax on power etc.

Recovery measures are considered to represent a conservative value of willingness to pay. It is also considered difficult to assign value to natural resources. There are some existing studies that could provide values to be used also in GLITNE, e.g. cost of the measures necessary to reach the Kyoto targets. Dependent on which political targets selected and the inherent perspective, the price of CO_2 per tonne reduced is found to vary from 183 to 600 NOK (2007). There are also available costs for NOx, SO_2, nmVOC and NH_3 based on damage and recovery costs.

The selection of weighing principle is in the end a choice of value, depending on the view on nature, humans and on the society, including view on equity in time and between generations, belief in market economy and the market ability to solve environmental problems etc. The strategy to reach a conclusion GLITNE is to involve the partners in this discussion. The methodology-group within GLITNE will be presented with the alternatives and challenged to reach a conclusion. The method as such will also be presented to the industry beyond the partners, allowing them to express their views on the method.

5. Some success criteria for an environmental evaluation method for buildings

There are many aspects to consider for an environmental evaluation method to be a success. At this stage we have found that a close relation to the building process and the existing milestones are important, together with a format that will enable the complicated trade-offs necessary to construct an environmentally efficient building.

5.1 Suited to the building process

According to the partners (Ovesen, 2008), the most important phase in the building lifecycle for implementation of environmental measurements are the design phase. But almost everyone involved in the building process are responsible when it comes to setting environmental requirements at some level, including government, investors, developers, planners, architects and engineers, those involved in constructions, client, owners, consumers and insurance. Good environmental information is most important for the architects and the consulting engineers. The GLITNE method and tool must therefore be well suited for their needs in the design process. In programming the client/developer is the important user, in a user/demolition phase the owner would be very important (Ovesen, 2008).

The environmental design process begins with the developer (client or owner) of a building project deciding on an environmental strategy, often defined in an Environmental program. The goals in this program are further developed into requirements, measures in design phase, and realisation through construction and finalisation. Follow up in the user phase and demolition is also important.

Important milestones in the building process related to the Norwegian Planning and Building Act(PBL) are listed in *Table 2*. The GLITNE-EPR check will be linked to the PBL milestones, but the GLITNE method and tool will be in use from strategy phase to demolition.

Table 2: Phases of the building process, PBL milestones and GLITNE-EPR milestones.

Phase	PBL/milestone:	GLITNE- EPR
1. Strategy		
2. Programming		
3. Design		
a) Sketch	Application	→ GLITNE check
b) Pre-project		
c) Detailed project	Permission to start project	→ GLITNE check
4. Construction and completion	Certificate of completion	→ GLITNE check
5. FM		
6. Demolishing and disposal		

The tool will consist of several layers covering the relevant environmental aspects as they develop throughout the process and as build, this may be thought of as a three dimensional matrix (time or phases in the process, the environmental aspects and the measures taken in each phase for each aspect). The challenge is to link measures in the design phase to the resulting environmental effects as e.g. hazardous substances and CO_2 emissions. What happens to the total environmental load of the building if it is designed with a different type of exterior wall? This is among other things what the GLITNE method and tool wants to answer.

5.2 IFC based tool for environmental evaluation of buildings

The literature survey also included a survey of existing tools for environmental evaluation of buildings, about 100 tools were found, and about 30 of them are briefly evaluated in the survey. The goal was identifying relevant aspects to include in the GLITNE method and tool. Of special interest were the tools linked to CAD, especially if they were on IFC format. Interesting tools were LCAdesign, CSIRO, Australia, and BSLCA, Granlund, Finland. These tools have linked LCA and CAD models using BIM (Building Information Model) and IFC. In terms of methodology however they bring few new aspects as they use existing LCA methods. The GLITNE tool will be programmed in IFC, the details of this part of the project is described in Holthe et al. (2008).

The GLITNE tool will be designed as a model checker towards a BIM, communicating using IFC format. The checker will be linked to a BIM to calculate the environmental load at different stages in the building process, also listed in *Table 2*. To include also the energy aspects it must be linked to an energy simulation program. The data on the building materials, EPD's after ISO 21930, could be included in the checker or provided by an exterior database as illustrated in Figure 1. At this stage in the project the tool is split into modules, as e.g. Material, Energy and Transport. Monetary valuation is used to value some of the environmental load, and risk criteria is developed to include other aspects, and forms the basis for placing the building e.g. in different classes of "environmental risk".

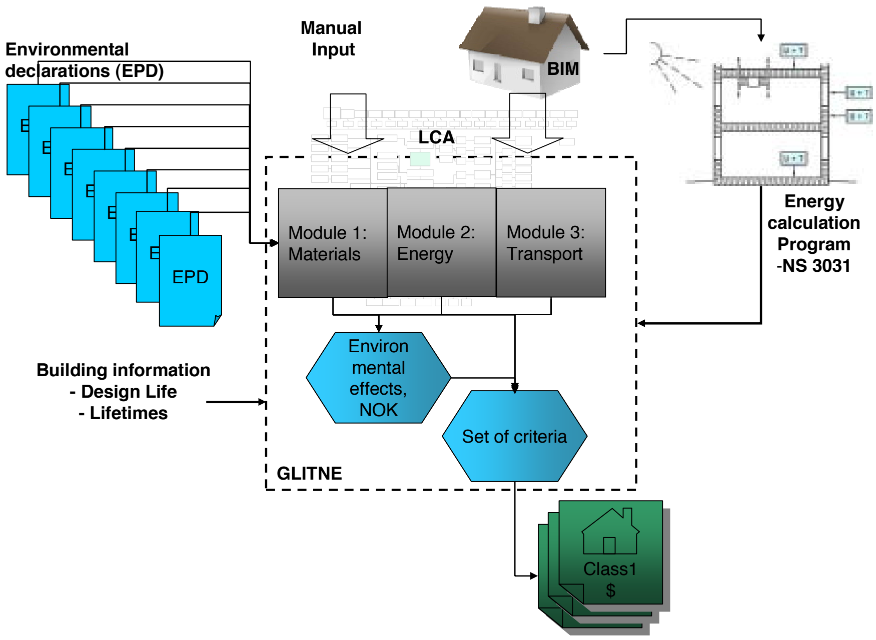

Figure 1: Schematic illustration of the GLITNE tool.

6. Conclusion and further work

An EPR model for the building industry is questionable, but it has solved the problems for other industries. The bottom-line question is whether or not the market alone can solve the problems the industry and the society are facing – that environmentally effective buildings are too costly to produce. Will the public respond to the increasing environmental awareness and invest more money in better buildings? It is seen that the market for ecological food has in some areas exploded. The same increased demand of environmentally efficient buildings is less likely simply because there are less obvious and direct effects, the environmental consequences may be to far away in time or in geography for the investor to acknowledge them. Assuming the market being unable to solve the problems, regulations must be implemented, one suggestion being EPR.

Three possible EPR models are identified, one of them managed by an independent third party assuming responsibility for the product, accomplished through different financial mechanisms e.g. as a fund, where any surplus may be used to find solutions for or reduce the environmental load from the industry. This may be thought of as a system of quotas, where e.g. the owner of the building initiative buys the right to pollute per object beyond a certain defined level.

A suitable weighting principle for the evaluation method could be based on environmental taxes or costs for remediate action. So far it seems like economic valuation alone cannot be used to define the EPR level. There is probably a need for supplementary criteria to be able to cover all relevant environmental aspects. Another possibility is to select and define quotas for some environmental aspects like CO_2, ozone depletion waste to deposit etc. Each building could then be allowed a certain pollution level within these aspects and the owner (or the responsible part according to the selected EPD model) pays for any emissions above these quotas. The money could be used to implement measures to reduce the environmental load in the industry both in direct measures, innovation and research.

A close relation to the existing processes and milestones in a building project is necessary for a tool/method to be a success. Application, permission to start project and certificate of completion are identified as relevant EPR evaluation milestones. The method and the tool must be valid in all phases of the building process and also include all relevant environmental aspects.

The survey of methods for weighting of environmental aspects and assessment methods for buildings, provides a basis for the further development of a GLITNE method and tool. According to the partners in the project it would be an advantage if the method was scientifically correct, but the findings in the survey amongst the partners reviled that this is not a prerequisite for the method to be a success. Factors like usability/user friendliness and advantage are valued as just as important. It is also argued that critique from some groups will arise irrespectively of the method (Ovesen, 2008). These aspects become very important when developing the interface of the tool. The details of the method, structure and tool will be further developed in close relation to the partners of the project. Some partners provide test cases, and some will assist to ensure that the result is well adapted to their needs. The project will be finalized at the end of 2009.

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APPLICATION OF BUILDING ENVIRONMENTAL ASSESSMENT, CASBEE, BY PUBLIC SECTOR AND ITS INFLUENCE ON THE BUILDING MARKET

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Keywords: Environmental policy, Local governments, Sustainable Building Reporting System, Information disclosure, Building permission

Summary

CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) has been revised and updated in order to be utilized more effectively in the building market. This progress includes introduction of new assessment item "Measures for Global Warming," the development of CASBEE for Home and the development of CASBEE for Urban Development. A number of local authorities now introduce CASBEE into their building administration as a part of sustainable building reporting system. Incentives based on the CASBEE rating are now provided. For instance, the maximum floor-area ratio of the building can be increased if the rating reaches the B+ class, the third of CASBEE's five grades. The city of Osaka subsidizes residential buildings that are A-ranked by CASBEE. Financial sector, such as banks, utilizes such information to offer better interest rates to the consumers who buy environmentally high performance residential units. The assessment of building environmental performance is prevalent among the building industry, in other words, among professionals. On the other hand, the results published by a municipal suggested that social recognition may have more influence on sustainability in the building market.

1. Introduction

CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) is a method for assessing and rating the environmental performance of buildings. In recent years, several local authorities introduced CASBEE into their building administration. Consequently environmental performance assessment of buildings is now carried out in many buildings in Japan. The system appears to have become a very strong driving force towards market transformation of the building industry. This paper firstly explains the change in CASBEE as a system in order to be utilized more effectively in the building market. Then it describes administrative use of such assessment system, and discusses the effects on the building market.

2. Progress of CASBEE Intending Utilization in the Building Market

2.1 The Outline of CASBEE

CASBEE is a comprehensive assessment ranked in five grades: Excellent (S), Very Good (A), Fairly Good (B+), Good (B-) and Poor (C). It has been developed under a committee established within the Institute for Building Environment and Energy Conservation, under the guidance of the Ministry of Land, Infrastructure and Transport. The first assessment tool, CASBEE for Office, was completed in 2002, followed by CASBEE for New Construction in July 2003, CASBEE for Existing Building in July 2004 and CASBEE for Renovation in July 2005. CASBEE assessment tools were developed on the basis of the following three principles: [1] Assessment can continue through the lifecycle of the building. [2] Assessment can consider both the "Environmental quality of the building (Q)" and the "Environmental load of the building (L)." [3] The idea of environmental efficiency can be employed to assess on the basis if Building Environmental Efficiency (BEE), a newly-developed indicator. CASBEE comprises the four basis tools, tailored to the building lifecycle, and expanded tools for specific purposes (Japan Sustainable Building Consortium, 2008a, 2008b). These are collectively called as the "CASBEE Family," as shown in Figure 1.

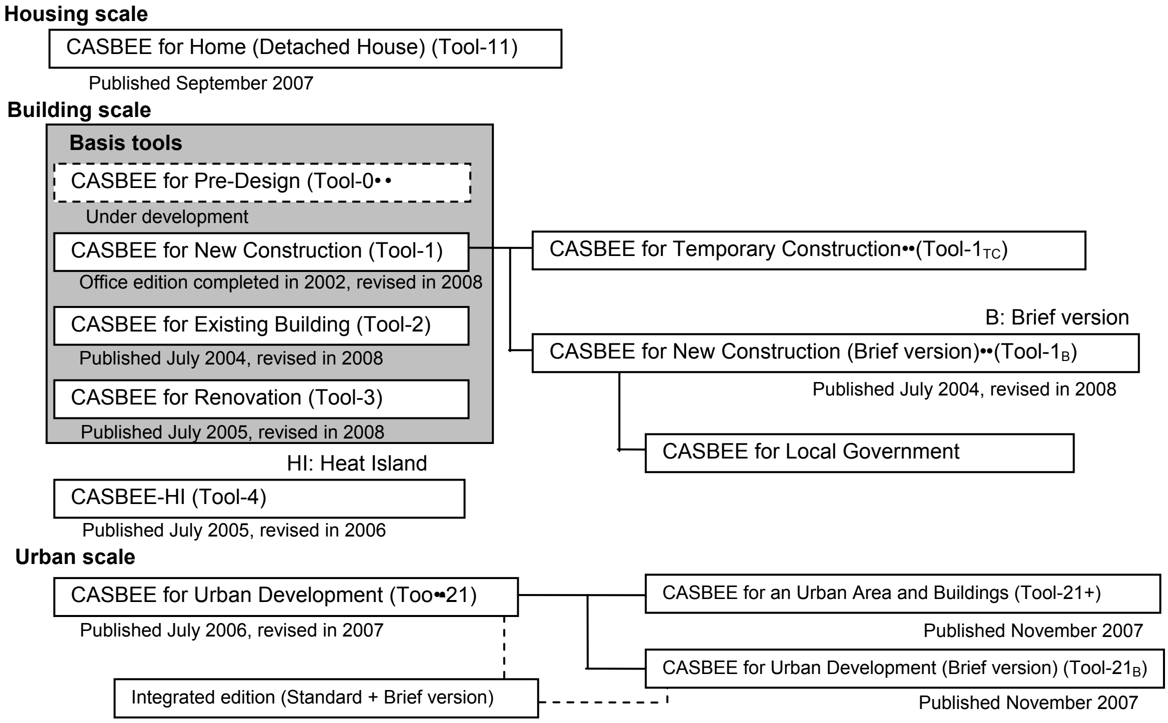

Figure 1 Structure of CASBEE Family

2.2 Incorporation of LCCO2 Assessment to CASBEE and New Assessment Item "Measures for Global Warming"

CASBEE (version 2006) is already capable of assessing efforts to reduce the energy needed to operate buildings, utilize existing building structural frames and recycled construction materials, and extend the service life of buildings. Such efforts can reduce CO2 emissions from the production of construction materials (embodied CO2), and reduce a building's Life Cycle CO2 (LCCO2) emissions, respectively. But Lifecycle CO2 was not directly counted in BEE (Building Environmental Efficiency) and CASBEE Rating.

New CASBEE (version 2008) incorporated a new item, "Measures for Global Warming," that can be rated by LCCO2 emissions. LCCO2 emissions are assessed in the simplified manner and reflected in the item "Measures for Global Warming" under "LR3: Off-site Environment." These results also affect the radar chart, Building Environmental Efficiency (BEE), and CASBEE ranking directly. CASBEE has changed to explicitly assess measures for global warming. This new assessment items has been introduced to all the CASBEE tools since the publication of CASBEE for Home in 2007. Further efforts to prevent global warming are expected to be promoted by the building sector (Sato, 2008).

2.3 Development of CASBEE for Home

In Japan, about 500 thousand detached houses have been constructed per year. To improve the quality of those houses, CASBEE for Home was developed in 2007. There are various stakeholders surrounding housing construction industry such as clients, designers, contractors, and builders. Therefore "CASBEE for Home" especially focuses on making users easy to understand. Among CASBEE tools, CASBEE for Home first introduced five-star indicator as a new expression of the five BEE ranks in addition to the BEE chart.

Structure of "CASBEE for Home" is similar to other tools in the CASBEE family. Both quality and environmental loads are evaluated. They include 54 sub-criteria that are modified from the other standards in Japan. These assessment items for comprehensive assessment consider not only house itself but also outdoor space of the house, home appliances, provided information to the occupants from house suppliers and the environmental strategies at the material produce stage and the construction stage•(Seike, 2008).

2.4 Development of CASBEE for Urban Development

2.4.1 The Purpose of Developing CASBEE for Urban Development•(CASBEE-UD)

Previous CASBEE tools assessed individual buildings, but, as a general rule, CASBEE for Urban Development•(CASBEE-UD) covers groups of buildings. The purpose is that "When a project is planned and implemented that comprises multiple buildings and other elements on a single, large-scale site under a unified design concept, assessment can go beyond the environmental design of each building, to identify new or expanded environmental measures, and their effects, that are made possible by the building group, and thereby contribute to the comprehensive improvement of environmental performance in urban renewal."

For convenience, previous CASBEE versions is referred as "CASBEE (building scale)," to distinguish them from CASBEE for Urban Development, which considers building groups (urban scale).• CASBEE-UD carries on the concepts of CASBEE (building scale), and it is one of the expanded CASBEE tools, developed with reference to the Q-3 (Outdoor Environment on Site) and LR-3 (Off-site Environment) assessment items of CASBEE for New Construction. However, CASBEE-UD is an environmental performance assessment tool for whole groups of buildings (urban scale), focusing on the phenomena that can accompany the conglomeration of buildings, and the outdoor spaces around the buildings. It is also a standalone system, independent of the previous building-scale CASBEE. CASBEE-UD excludes the interior of buildings from assessment (although there are exceptions in some assessment items), as shown in Figure 2.• Therefore, this configuration makes it possible to use [1] CASBEE-UD to assess an area of development as a whole, while [2] CASBEE (building scale) assesses the environmental performance of individual buildings within the designated area• (Japan Sustainable Building Consortium, 2008c).

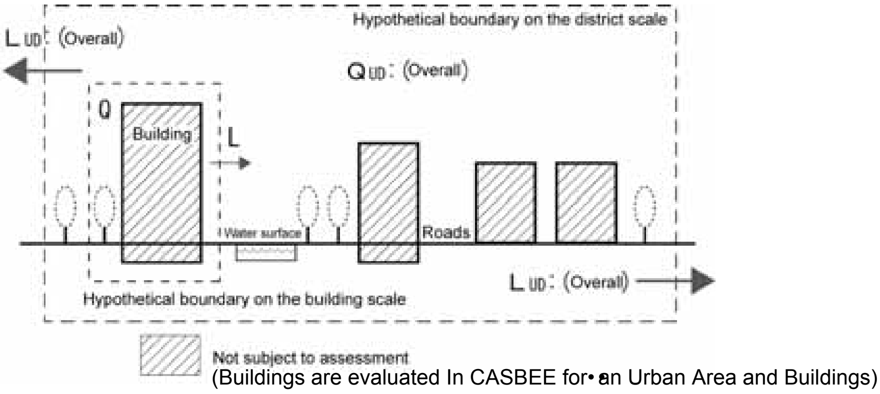

Figure2 Concept of Assessment subjects for CASBEE for Urban Development

The following are four examples of ways in which CASBEE-UD is used.

1)•• As a tool for environmental consideration in area development projects.
2)•• As an environmental labeling tool.
3)• As a planning and assessment tool for energy-saving remodeling plans on the urban scale.••••

4)• As a tool to support city planning with a view to sustainable urban development.

The first three applications, taken together, are expected to act as an incentive for environmental consideration in area development projects.• Following the pattern of CASBEE for New Construction, a brief version has been developed to enable easy application from the preliminary stages of a plan.

2.4.2 The CASBEE for an Urban Area and Buildings

Now the overall indication format for assessment results [1] and [2] in 2.4.1 is defined separately as CASBEE for an Urban Area and Buildings (abbreviated below to "Urban + Building"), to meet demand for assessment of the urban area as a whole, including buildings. Also, as the assessment items for CASBEE-UD includes important elements of the city and regional planning fields, which may not extend down to the building scale, we recommend that Urban + Building be applied to projects which are individual buildings but have high levels of public interest (major social impact). That approach enables assessment using CASBEE-UD together with building-scale assessment. Figure 3 shows an example of the BEE of an Urban Area and Buildings.

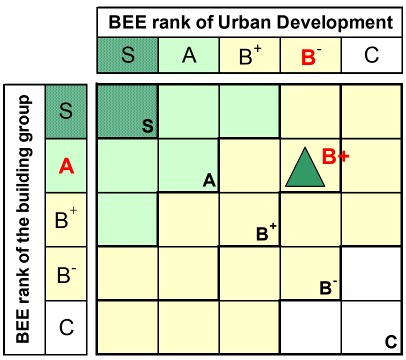

Figure 3 An example of BEE of an Urban Area and Buildings

3. Measures to Spread Environmental Performance Assessment for Buildings by Public Sector

3.1 Administrative Use of CASBEE by Local Governments

Public sector has been playing a major role in spreading environmental performance assessment of buildings in Japan. In recent years, many major cities and prefectures in Japan have been adopting “Sustainable building reporting systems• (SBRS)” as an environmental policy in their building administration. To operate this system, these local authorities utilize an environment performance evaluation method for buildings as policy instruments. Under required ordinances and guidelines, building owners are asked to carry out comprehensive assessment of their buildings’ environmental performance when a building above a certain size is newly constructed. These results must be reported to the authority and the authority must publish the submitted assessment results of environmental performance. Figure 4 shows the number of reports assessed by CASBEE published by the local authorities.• Over 2,000 CASBEE results have been submitted to the local authorities by Sept. 2007. Most authorities use the Internet to disclose the results and the summary of environmental measures taken by the building owner to improve environmental performance.• •

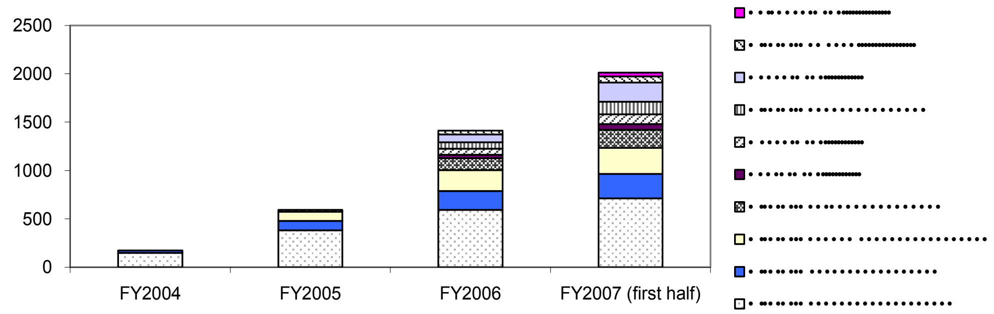

Figure 4 Number of CASBEE results submitted to the local authorities (as of Sept. 2007)

The reporting system is designed to promote voluntary actions by building owners for the environment through information disclosure to the local residents, by showing which building owners are active in environmental measures.

3.2 Localization of CASBEE

CASBEE is also intended to take regional conditions into consideration as background for the assessment. To promote environmental assessment for buildings, localization is one of the important processes to meet social demand of the region where the building market exists.

Local characteristics such as infrastructure, local economy, climate and history may be different. Local authorities that use this tool can tailor it to local conditions, such as climate and prioritized policies. Changes are generally made by modifying the weighting coefficients. Flexible response to regional character is a common feature of all elements of CASBEE.• CASBEE-Nagoya has its own scoring guidelines that instruct some criteria in relation to local contexts, such as materials from local industry, and that define some excluding criteria (Noda, 2004). Another example is CASBEE-Osaka that altered weighting coefficient from the original to reflect the high priority they give to heat island policy. They changed the weights of Q-3 Outdoor environment on site from 0.3 to 0.4• (City of Osaka).

3.3 Advanced Application of CASBEE to Promote Sustainable Buildings in the Building Market

3.3.1 Incentives by the Municipals

Further, it is possible to provide incentives to buildings which gain high ratings with CASBEE, as shown Table 1. In city of Osaka, the rating should at least reach the B+ class, the third of CASBEE’s five grades, if the approval for an administrative scheme, called “Planned design system (sougou sekkei seido),” is given to the building being assessed. The maximum floor-area ratio of the building can be increased in this scheme. In Nagoya, 250% maximum floor-area ratio will be given if the buildings are S-ranked by CASBEE, whereas 200% will be given to the A-ranked buildings.

Financial support can be provided for high score buildings assessed by CASBEE. The city of Osaka subsidizes residential buildings that are A-ranked by CASBEE. The city of Nagoya also subsidizes the residential buildings selected in order of BEE value by CASBEE.

3.3.2 Utilization of the Assessment by Financial Sector

Financial sector, such as banks, may utilize such information to offer better interest rates to the consumers who buy environmentally high performance residential units.• In Kawasaki, developers who are selling multi residential units must publish CASBEE results in their advertisements to inform consumers about the environmental performance of the buildings (City of Kawasaki). This scheme is called “Environmental Performance Indication System for Apartment Buildings.” Up to 1.5 % reduction in the interest rate is available for the consumers who bought units assessed as S-ranked by CASBEE-Kawasaki.

Table 1 Administrative use of CASBEE by local governments

Municipality	Started	Subject building scale (total floor area)	Adoption of Localized CASBEE	Incentives by government Extra floor	Subsidy	Awards
City of Nagoya	2004.04	> 2,000 m^2	CASBEE-Nagoya	yes	yes	
City of Osaka	2004.10	> 5,000 m^2	CASBEE-Osaka	yes	yes	yes
City of Yokohama	2005.07	> 5,000 m^2	CASBEE-Yokohama	yes		
City of Kyoto	2005.10	>= 2,000 m^2	CASBEE-NCb*			
Kyoto Pref.	2006.04	>= 2,000 m^2	CASBEE-NCb*			
Osaka Pref.	2006.04	> 5,000 m^2	Osaka’s own indicator + CASBEE-NCb *			yes
City of Kobe	2006.08	>= 2,000 m^2	CASBEE-Kobe			
Hyogo Pref.	2006.10	>= 2,000 m^2	CASBEE-NCb*			
City of Kawasaki	2006.10	> 5,000 m^2	CASBEE-Kawasaki			
Shizuoka Pref.	2007.07	>= 2,000 m^2	CASBEE-Shizuoka			
City of Fukuoka	2007.10	> 5,000 m^2	CASBEE-Fukuoka			
City of Sapporo	2007.11	> 5,000 m^2	CASBEE-Sapporo			
City of Kitakyushu	2007.11	>= 2,000 m^2	CASBEE-Kitakyushu**			

* CASBEE-NCb; Standard version of CASBEE-NCb
** Under development

4. Discussion

4.1 Increased Number of Professionals

The number of accredited professional CASBEE assessor is increasing year by year. Those who aiming to become assessor must attend an assessor training course, pass the assessor examination, and then complete registration. Applicants must be the first-class architects to be qualified. Even though the requirements of becoming CASBEE accredited assessor seem very demanding, the number of applicants increases rapidly because of the SBRSs introduced by many major municipalities. This suggests that assessment of building environmental performance is prevalent among the building industry, in other words, among professionals.

4.2 Environmental Performance of Buildings

It is crucial to investigate how the environmental performance of buildings improved because of the SBRSs using environmental performance assessment of buildings. The assessment results published by a municipal are shown in Figure 6. The SBRS of the municipal subjects buildings of total floor area above 5,000 m^2. This shows that apartment building accounts the largest part in new construction by building type. Many factories are low ranked in comparison to the other building types.

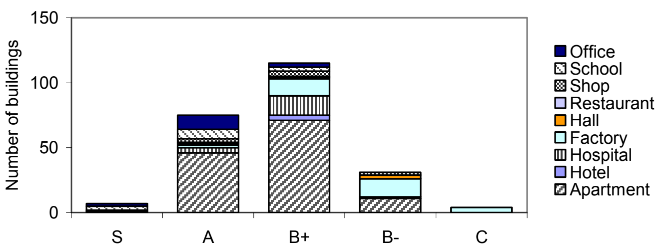

Figure 6 Assessment results of CASBEE in a municipal by building type.

Figure 7 describes variation of the environmental performance of reported buildings in the municipal from 2005 to 2007. Factories are excluded in this figure. This figure suggests that improvement in environmental performance of buildings can not be seen between 2005 and 2007 for both apartments and commercial buildings. It is also said that very few buildings are S-ranked since 2005. This also applies to other municipalities.

Tokyo metropolitan government (TMG) is the first municipal that adopted the SBRS and Environmental Performance Indication System for Apartment Buildings. TMG does not use CASBEE but operates its own assessment system. Since the indication system has started in 2005, TMG (2007) suggested that there was a slight improvement in environmental performance among apartment buildings. By comparing the assessment results between 2005 and 2006, the percentage of the top scored, so called “three stars,” building, increased from 12% to 25% in insulation, from 32% to 42% in energy saving, from 8% to 9% in durability and from 48% to 51% in outdoor planting. However TMG also reported that commercial buildings were not improved in terms of CO2 emission.

To make a conclusion, further accumulation of data is required. However, one reason for the improvement of environmental performance in apartments in TMG may be because of Environmental Performance Indication System for Apartment Buildings. The indication system directly sends information on the environmental performance to the end consumers in the building market. And the results can be far more easily compared by the end customers to utilize for their decision making. This situation encourages developers to improve environmental performance of buildings they provide. Social recognition seems to have a very important role in improving sustainability of the building market.

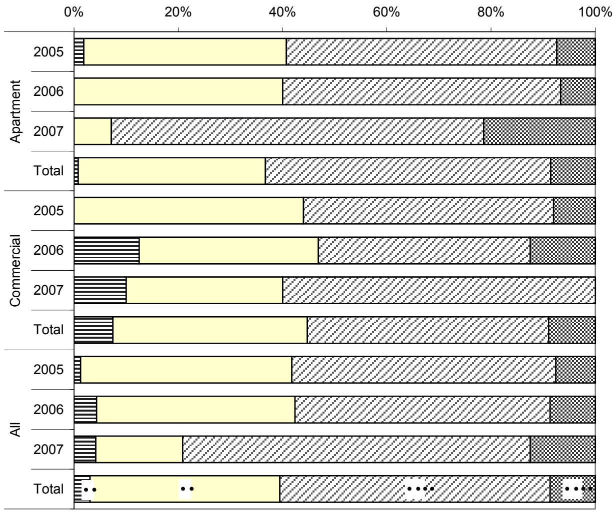

Figure 7 Percentage of BEE rank in a municipal from 2005 to 2007 (excluding factories)

5. Conclusion

1. CASBEE has been revised and updated intending wide use of assessment in the building market. This progress includes introduction of new assessment item "Measures for Global Warming," the development of CASBEE for Home and the development of CASBEE for Urban Development.

2. CASBEE has been seen as one of the most useful policy instruments by local governments. Together with incentives, administrative use of CASBEE is the most effective in spreading assessment of building environmental performance, so far.

3. The recognition of environmental performance of buildings has been widely spread among professionals in the building industry. However the social recognition, especially among the last consumers, of environmental performance of buildings may have more influence on sustainability in the building market.

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STRATIFIED CHILLED WATER THERMAL STORAGE SYSTEMS IN QUEENSLAND

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Keywords: stratified chilled water storage, thermal storage; energy efficiency; demand side management

Summary

Following the lead of Universities in the Northern Territory, Western Australian, and North Queensland, the Queensland Department of Public Works have installed a stratified chilled water thermal storage system at Runcorn to take advantage of lower electricity prices at night. This paper documents the thermal storage renovation of the Queensland State Archives at Runcorn (QSA2) and the oral presentation will also review thermal energy storage infrastructure at James University Cairns and Townsville campuses. In all these facilities there is a new focus on energy and water conservation improvements to existing heating, ventilation, and air-conditioning (HVAC) beyond minimal construction cost in compliance with building codes of Australia. These should be classed as environmentally sustainable design (ESD) integrations into the pre-existing traditional HVAC systems. The present draft focuses on the Runcorn QSA2 case study, but analogous examples will be provided from the James Cook University campuses as soon as operational trend logs are available. Three case studies are discussed, in Cairns, Townsville, and Brisbane. First was a 3 million litre tank at the Cairns campus of James Cook University, then a similar installation on the Queensland State Government Archives expansion at Runcorn, and most recently a 14 million litre tank at the Townsville Campus of James Cook University to replacing several ice storage systems with a district cooling system.

1. Off-peak chilled water storage

Chilled water plant within QSA Runcorn Stage 1 will be extended to meet the total load of both Stages 1 & 2. This involves provision of a new chiller and a new cooling tower within the space available within existing stage 1 plantrooms. This report also recommends the optional additional capital investment in an outdoor chilled water storage tank with larger centrifugal chiller capable of generating all of the cooling capacity 8 hours each night when electricity is cheap and energy and water are used more efficiently. The payback will be about 10 years based on the current cost of power, but may be sooner if demand for electric power increases faster than the provision of new power stations. Advantages of the proposed additional capital investment include lower energy costs, increased chiller life, reduced maintenance costs, and 16 hours cooling load storage capacity in-case of daytime power failure. The preferred option upgraded chiller installation will serve 70% more air handling loads, all the while reduce greenhouse gas emissions associated with the stage 1 + 2 chilled water plant by 28% below stage 1 only.

There were alternative-options for the dimensions and location of the outdoor chilled water tank: the arrangement of the design development at the rear of QSA2 at RL 80m; verses a wider and shorter arrangement amongst trees up hill at RL 86 m. In both cases the tank needs 3,000 kL effective chilled water storage capacity, and in any case the top of the tank is tied to the height of the building. Other alternative tank configurations with lower elevation overflows were excluded due to unacceptable increases in payback and operational risks. Dimensions of the thermal storage tank have now been determined to be either 14.696 m diameter × 19.60 m high if based at RL 80 m above sea level; or 18.564 m diameter × 13.84 m high if based at RL 86 m above sealevel. In either case the top working level of the tank shall be at least 98.6 m above sealevel, plus overflow and freeboard.

The advantages of placement at RL80 m are the minimum capital cost of connected chilled water piping and economical pumping that results in the payback analysis documented in the present report.

The pipework associated with siting the chilled water storage tank based at RL 86 m would have required substantially more underground trenching, and crossing under/over many other buried services such as watermains, sewers, power, and data/telecom. Furthermore the hillside tank location at RL 86 m would require the clearing of a number of mature trees and the excavation and leveling of reactive soils. From an engineering perspective it would be preferable to fix the location at RL 80 according to the design development, but it is understood that aesthetic impact of the large tank could be better in the hillside. With an ideal location on-top of the hill at RL 89 m, but that would depend on re-negotiation of a 287 m² Lands Lease held by Telstra in the SE corner of the 8 ha State Archives site. Perhaps our engineers and Telstra could collaboratively redesign our tank 11 m high x 20 m diameter to accommodate the Kuraby tower, but such was far beyond the scope of the project management constraints. Also be warned that Telstra have outsourced infrastructure design and maintenance to various parties, so it would have been unclear who to work with even if timelines were not a concern.

This report assesses the performance of existing air handlers, chillers and cooling towers and to provide design development guidance for stage 2, with particular attention to finding added cooling capacity with thermal storage. Water and greenhouse gas emissions impacts are also estimated in this report.

The original stage 1 facility included sufficient plantroom space to provide additional chiller and cooling tower capacity sufficient for stage 2 air conditioning loads. ESD initiatives considered in the present report are focused on air-conditioning systems to be installed in Stage 2, and necessary changes to the existing chilled water plant that serves both the Stage 1 and Stage 2 facilities. The chillers are water cooled with cooling towers that use a substantial amount of town water, and so water requirements and recycling opportunities are reviewed.

1.1 Thermal storage with centrifugal chiller

As another ESD initiative, the present report considers an off-peak thermal storage tank run at night, exploiting the tendency of cold water produced by chillers to sink while warmer spent water is drawn off the top. A rising boundary layer thermocline about 300 mm thick is established between the two zones as the tank is charged with chilled water by chillers running full load at the time of lowest electricity cost and highest efficiency.

Thermal storage tanks must have the strength to withstand the pressure of the chilled water, and corrosion-resistant. Aboveground outdoor tanks must be weather-resistant. Buried tanks must withstand the weight of their soil covering and parked cars. Tanks should be insulated to minimize external condensation and limit thermal losses to 1%.

Large steel tanks, with capacity of up to several million litres, are typically cylindrical in shape and field-erected of from plate steel. Epoxy coating is usually required to protect the tank interior, and may colour the exterior for aesthetic appeal. Southern Cross Encon has an economical unpressurized modular system of hot-dip galvanized steel panels manufactured in Toowoomba, and assembled on site before insertion of foam insulation and rubber bag liner. It is reported that there is a cheaper competitor on the Gold Coast who has had some failures in Sydney. The Encon system has a free surface that must be positioned a couple of meters above the highest cooling coil served.

Concrete tanks may be cast in place. Concrete tanks are sensitive to thermal shock. Large tanks are usually cylindrical in shape, while smaller tanks may be rectangular or cylindrical, and may be integrated into building foundations. Concrete tanks may be operated as pressure vessels, and so may be positioned below cooling coils. The cost of concrete tanks are 2 to 3 times the cost of the modular system offered by Encon.

This report was originally commissioned to assess the capacity and efficiency of the chillers and cooling towers to meet the increased load of the Stage 2 extensions, all the while maintaining spare capacity for breakdowns and routine service. The coefficient of performance (COP) of existing chilled water plant are not very high, owing to the intermittent cycling of plant to meet demand for the various cooling coils in the facility. Substantial improvements in operating efficiency and reliability is possible in the context of a thermal energy storage tank with newer larger higher-efficiency chiller.

Thermal energy storage, by way of stratified chilled water, provide the opportunity to allow chillers and cooling towers to run continuously at peak efficiency at night when electricity is cheaper and causes a lower greenhouse gas impact. Nightly full load chiller operation reduced wear and tear, and provides steadier temperature control of air-conditioning systems. Payback is considered by considering the likely cost of daytime electric power in the near future, as population growth is not being matched by increased power generation capacity.

"Design Guide for Cool Thermal Storage" by Dorgan & Elleson 1993 introduces key engineering concepts and economics of cool storage with both chilled water and phase-change media (ASHRAE Research Project 592). This was consulted during the detailed design of diffusers and controls. This reference advocates dual use of a single thermal storage tank for fire protection. This guide also discusses the advantages and disadvantages of "empty tank systems", comprised of two or more vessels where one is always empty at the start of charging so that warm water is processed by chillers and pumping into the empty tank. During discharging, stored chilled water is drawn for cooling and warm water pumping into another empty tank. In such systems the usable volume is reduced by the empty tank volume, and they require complex piping and controls to ensure pumps work correctly against varying dynamic head. Multiple tank systems increase first and maintenance costs, but one may be taken out of service while others continue to provide service.

2. Scope

The HVAC services covered in this report are the air-conditioning chilled and condensing water systems serving the existing Stage 1 and the proposed Stage 2 extensions to the Queensland State Archives. The study includes chillers and cooling towers, as well as associated pumps. Three existing chillers (#1, #2, & #3) and three existing cooling towers (#1, #2, & #3) will be supplemented by additional capacity to meet the Stage 2 extension (chiller #4 & cooling tower #4). A freestanding thermal energy storage tank is also considered together with the efficiency improvements now available in large centrifugal chillers.

The payback calculation for the proposed tank at Runcorn was based on a full-storage strategy, also called load shifting, that shifts the entire on-peak cooling load to off-peak hours (11PM-7AM). The system is designed to operate at full capacity during all off-peak hours to charge storage on a hot "design day". On rare occasion of extreme heat, the chillers must continue working after 7 AM to finish recharging the tank.

3. Investigation – existing service

The HVAC services covered in this report are the air-conditioning chilled and condensing water systems serving the existing Stage 1 and the proposed Stage 2 extensions to the Queensland State Archives. The study includes chillers and cooling towers, as well as associated pumps. Three existing chillers (#1, #2, & #3) and three existing cooling towers (#1, #2, & #3) will be supplemented by additional capacity to meet the Stage 2 extension (chiller #4 & cooling tower #4). A freestanding thermal energy storage tank is also considered together with the efficiency improvements now available in large centrifugal chillers. The original building was built in 1992 with two reciprocating chillers (#1 & #2) located in the basement plantroom and two cooling towers in the third floor plantroom. Space was made available in the plantrooms for an additional two chillers and two cooling towers. In 1996 a new screw chiller and cooling tower were added to provide more efficient operation and spare capacity for breakdowns and routine service. Each of the three chillers has a cooling capacity of 550 kW, but the newer screw chiller (COP up to 6) is twice as efficient as the older reciprocating machines (COP up to 3). The three cooling towers each have a condensing water flow capacity of 29.5 L/s at 35°C-29.5C°, capable of rejecting 2000 kW in total, 95% of installed chiller capacity. Chiller #1 & #2 each reject up to 733 kW, while the newer chiller #3 rejects no more than 641 kW. The cooling towers share common headers and a common sump level, working together to cool any combination of chillers that maybe required at one time.

The coefficient of performance (COP) of the existing three chillers logged over the 5 months September 2005 – February 2006. Estimated demand of condensing water pumps and cooling tower fans were added into the logged chiller motor loads before determining these COPs. The overall COP of the gang of machines was 3.3, owing to the large percentage of the time that machines were partloaded. This reinforces the advantage of providing a thermal storage tank, as all chillers perform more efficiently at full load.

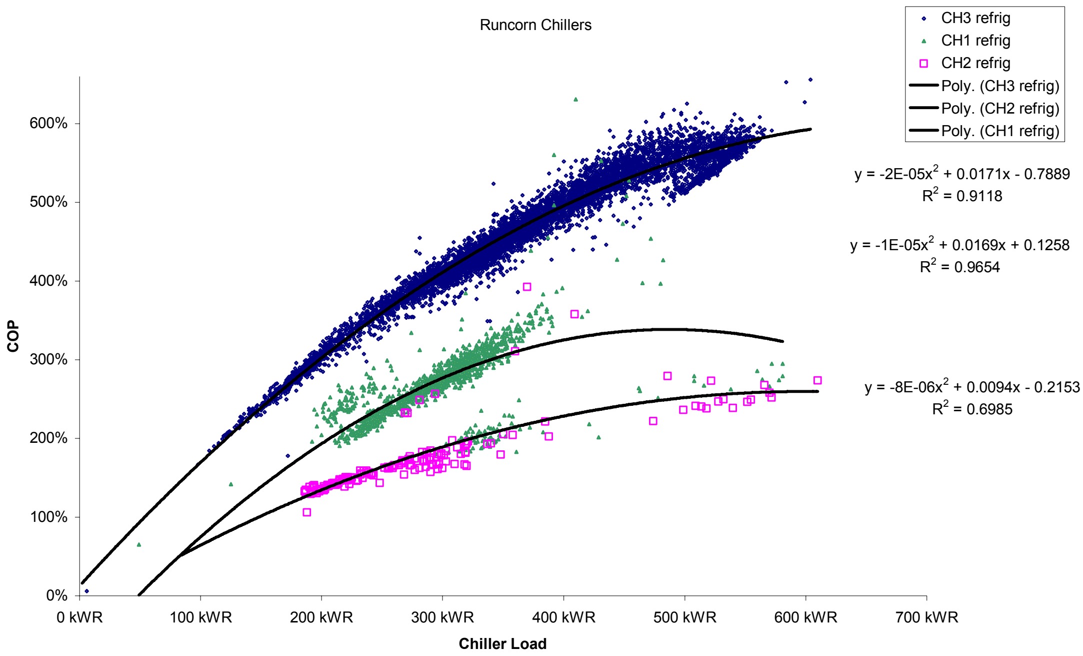


Figure 1 Part-load performance of existing Stage 1 chillers.

Figure 1 shows polynomial trendlines of best fit to summarize the partload COPs of each of the three existing chillers. The screw chiller (#3) has substantially better coefficient of performance (COP) than the older reciprocating chillers (#1 & #2), even though all three machines each have 550 kW refrigeration capacity. Chiller #1 was running more efficiently than chiller #2, even though the two are identical twins with sequential serial numbers. Leadership among the three chillers is manually switched seasonally by the decision of various human operators. From the above results it should be argued that chiller #3 be set as leader at all loading levels.

Chiller logs indicate that the Stage 1 building load did not exceed 950 kWr this past summer. Given that outdoor temperatures in that time exceeded nominal design conditions by 3°K, 1000 kWr capacity amply serve the stage 1 facilities.

The detailed study of chiller logs since late 2005 has been useful in the present report since this has been a warmer than average summer, as compared to the cooling degree days over the past 30 years, and so we are confident benchmarking the existing stage 1 load with the limited chiller log sequence that we have at hand. The chillerlogs are a record of entering and leaving water temperature and the cooling energy output and electric power input to each machine every 10 minutes for a period of over 5 months. These timeseries were converted into COP of each machine and total chilled water flow rate to represent the building load of Stage1. The time series of power into the three chiller motors was factored into an analysis of 30-minute power demand for Stage 1 as recorded by the power retailer Energex. Now it is possible to model and project chiller power requirements of state 1 back into history as far as Energex can provide load profiles, but in the present study the year 2005 and early 2006 were considered.

Slow and difficult liason with Energex lead to not exploring earlier load profiles, but the current season's weather pattern may be justified as a benchmark because it is warmer than usual and the local climate is trending towards a warmer regime.

3.1 Existing cost structure for electric power

In the past three years the cost of peak power has been increasing, but it may level after new power stations are brought onto line. Recent past tariff structure shows that off peak charges are very constant, but that "peak" consumption charges have been accelerating upwards. Future electricity pricing structures are not guaranteed, as the client regularly calls for tenders from contestable power retailers such as Energex. Figure 2 shows the recent trends in power purchase at Runcorn Archives.

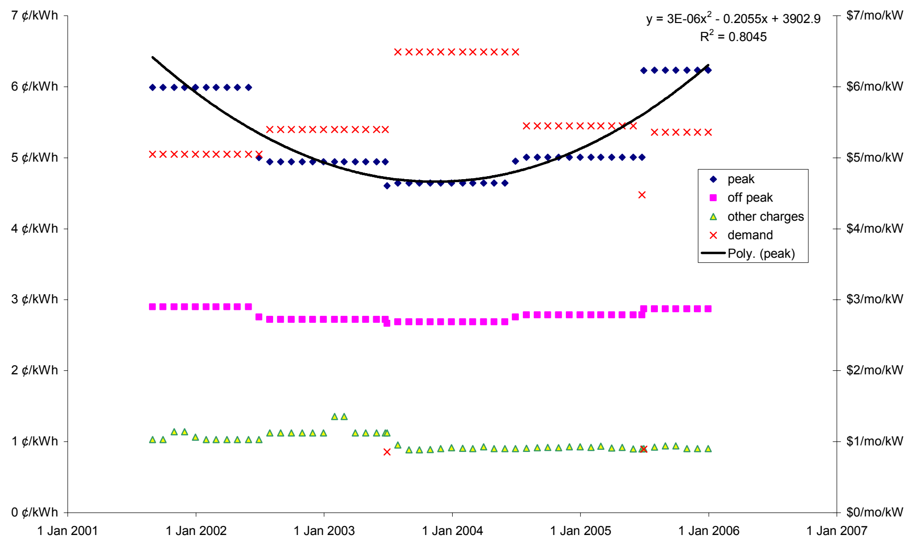


Figure 2 Recent Power Cost Structure.

In terms of market economics, it should not be surprising if the cost of peak daytime power consumption increases in the future as demand is growing faster than the construction of new power stations. Increasing demand for daytime power is certainly a direct effect of rapid population growth in southeast Queensland, as an increasing number of homes and businesses come on line. Indirect effects are the conversion of once cooler bushlands in suburban landscapes covered by dark coloured roofs and bituminous pavements, creating a local "heat island" that adds to "global warming" to increase a dependence on air conditioning throughout the general community. In terms of sustainability, the initiatives of QSA2 can lead the community by an example of "demand side management", reducing and shifting electric loads to the early hours of the morning when power stations and transmission networks have better efficiency.

4. Option selection

Design development proceeded to allow selection of two options (A) add a 550 kW screw chiller just to meet increasing load; or (B) to invest in a 1650 kW centrifugal chiller AND off-peak thermal storage tank. Option A without any storage tank, but a new 550 kW screw chiller lagged by one of the existing 550 kW screw chillers and the older 550 kW reciprocating chiller as last in demand was simulated as illustrated in the following graphic based on load profiles since September 2005, detailing 1st week January 2006 in figure 3.

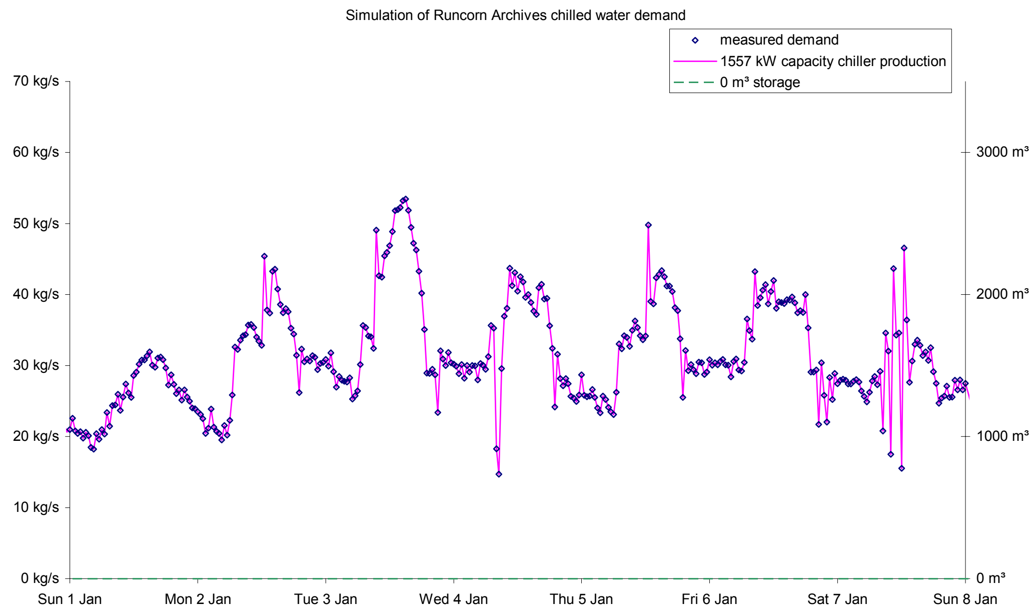
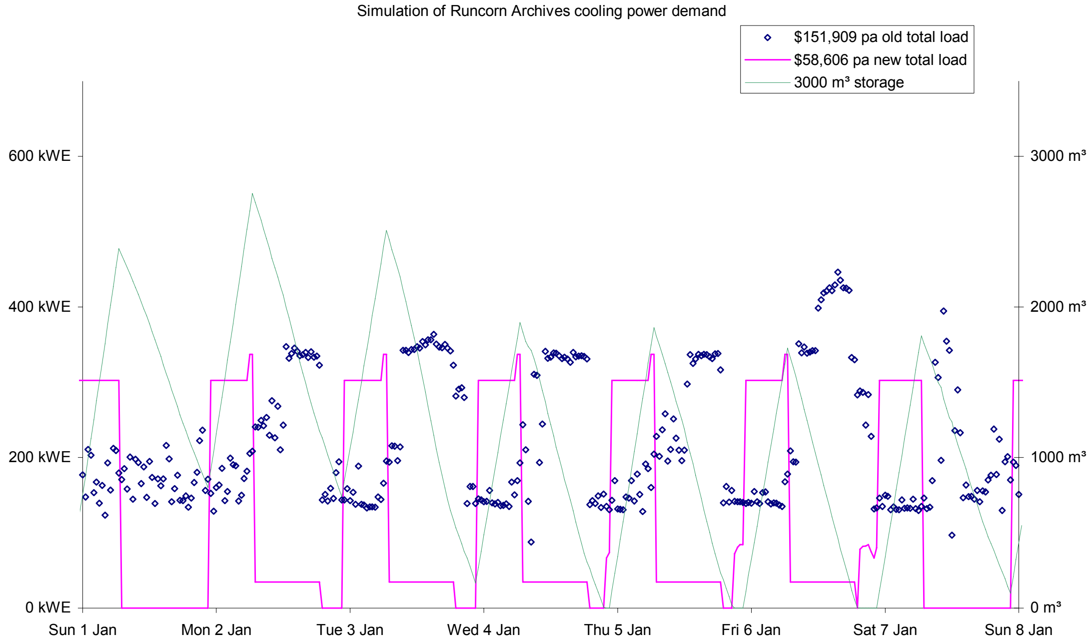


Figure 3 Simulation of Option A (not recommended)

Above is one week detail of over 5 months of measured cooling load in Stage 1, scaled up to represent the total of Stages 1 and 2. If the new chiller #4 were similar to the most recent existing screw chiller #3, then there would be some improvement of performance owing to their coefficient of performance. But none the less there would be times when either of the old reciprocating chillers #1 or #2 would need to be used, and so power use intensity would continue as has been the case in Stage 1. The existing mix of reciprocating and screw chillers provides part load control, but not very efficiently. Many reasons may contribute to the poor baseline performance of the Stage 1 chillers, as no significant correlation could be found in an analysis of 4 years of cooling degree days (weather data) and monthly power invoices.

Rather than Option A, it was decided a thermal storage tank be provided to exploit chiller efficiency. Option B was decided upon with 3000 m³ storage tank and new 1650 kW centrifugal chiller lagged by existing 550 kW screw chiller and the older 550 kW reciprocating chillers as backup was simulated as illustrated in the figure 4.



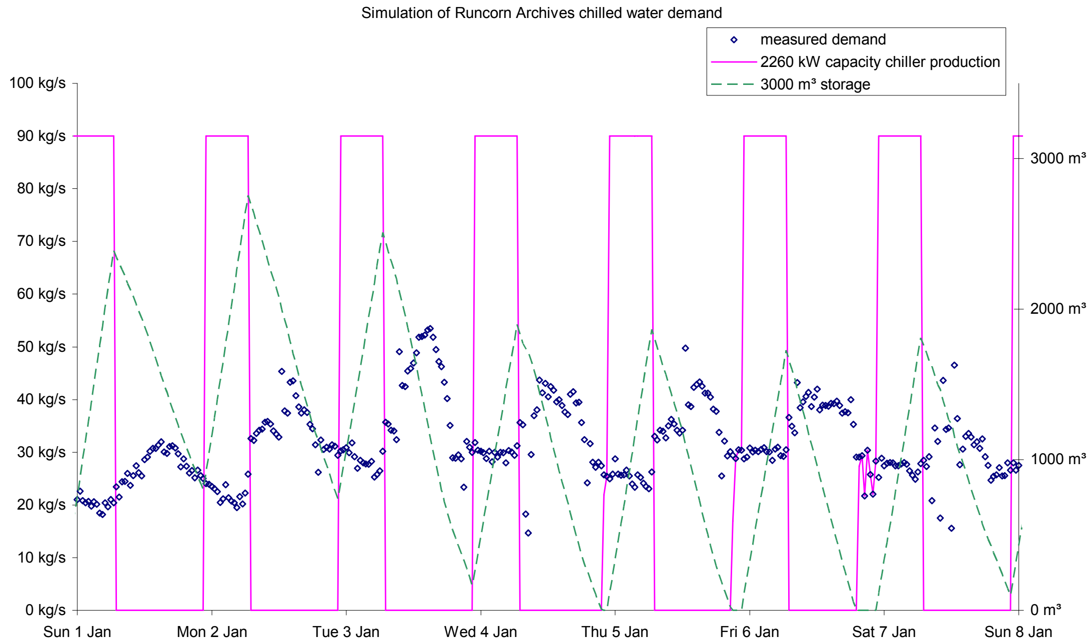


Figure 4 Simulation of proposed option B (accepted for construction)

The above are one week of detailed simulation results with 3000 m³ storage tank with new 1650 kW centrifugal chiller lagged by existing 550 kW screw chiller. The older 550 kW reciprocating chillers are provided only as backup, and so we have modelled the system to perform at high coefficient of performance at all times. In the above example illustration, the chillers run full load 8 hours per night, and the storage tank meets the load 16 hours per day, except for a couple hours late one Friday evening– being a special case of weather 35.5° the previous Monday exceeded the 34° outdoor design conditions, and caused the storage tank charge to only recover to 2ML. Storage capacity fully recovered over the following weekend, and a small penalty was paid for partload operation of the screw chiller until the 11 PM the Friday night.

Option B would produce half the greenhouse gas emissions of Option A (800 tonnes rather than 1750 tonnes p.a.).

If the design for Stage 2 extensions were driven entirely by the lowest capital cost without concern for maintenance and energy costs, then there would have been only one additional 550 kW screw chiller installed to meet the additional Stage 2 building load in the event that one of the older chillers were to fail. But there is a substantial power savings payback available, so the additional capital investment was made in a larger high efficiency centrifugal chiller and freestanding thermal energy storage tank in Figure 5.

Allowing $70,000 capital cost of increasing the new chiller specs and $720,000 for the chilled water storage tank, the building tenant is rewarded with annual cost savings of $79,000 p.a. based on current electricity price structure: Maximum demand penalty $5.359/kW/mo; plus "peak" consumption 7AM to 11PM Monday through Friday charged at 7.1332 ¢/kWh; plus off-peak consumption charged at 3.7704 ¢/kWh. Note that various charges may be added into both peak and off peak charges, so the key index is the net price difference between the two. The client would be advised to contact their power supplier to discuss forward contracting of electricity supply since they may be interested in rewarding off-peak thermal energy storage.

The thermal storage system with larger centrifugal chiller results in a simple payback period of ten years, but the payback is one year sooner for each one cent (1¢) per kW-hour increase in the difference between peak and off-peak charges.

Because this is a 7 day-per-week 24 hours-per-day facility, the economics of thermal storage are more favourable than in daytime-only facilities. The proposed concept would be to provide and operate a high efficiency/capacity centrifugal chiller almost entirely during off-peak times (11 PM until 7 AM the following morning) to serve the facility load and to regenerate the thermal storage tank. The chillers and cooling towers remain idle each day from 7 AM until 11 PM, while the thermal storage tank provides all of the State Archives cooling load for 16 hours each day. All that would be required operate during the day would be the chilled water pump and fans in air handling units, easily provided by the emergency generator in case of power failure. The chilled water storage tank and it's associated pump would be treated as the fifth machine for the Queensland State Archives "Chiller #5" with a capacity of 2200 kWr.

5. Completed installation

Figure 5 Queensland State Archives Stratified Chilled Water tank under construction

The installation was completed in early 2008 and commissioning was in progress in May/June 2008.

An inadvertent shutdown of chillers over one weekend in May was discovered the following Monday, all the while the chilled water storage tank fully maintained stringent temperature and humidity conditions in the facility for 72 hours. This was an inadvertent, but useful test of the installation. Operational trend-logs will be presented in the poster version of this paper to be presented at SB08, complete with discussion and preliminary conclusions. But the final report on this installation should wait until after the next summer.

EDUCATIONAL RIFT IN ARCHITECTURE – SUSTAINABLE VERSUS MODERN

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Keywords: sustainability in architecture, education, investment decisions

Summary

In the second half of the 80-ties, representatives of many disciplines participated in research involved with the implementation of the sustainable development philosophy. It was stated that "…*there exists a requirement for a better understanding of the resource values on which our lives depend. If we want the human mankind to change its way of thinking and accept the need to include the environmental issues, we have to start at the educational level…*". In 1999 this idea was undertaken by the Norwegian Government within a redevelopment of their education program. In 2002-2005, this issue became a task theme between Warsaw University of Technology and University of Norway. This international participation, brought forth a SureBuild Program, developing a strategy to include sustainable issues within the modernization process of school buildings in Poland.
In 2006, Warsaw University of Technology and NTNU Trondheim received a grant from the Norwegian Mechanism source. The current project is STEP, and its general aim is a scientific and research support allowing to achieve a better quality energy performance of the public buildings in Poland. The direct aim – is delivery of support tools for the decision making within the curricula of technical solutions used in new and existing public buildings, including initiation of changes in traditional building techniques, in favor of more optimized solutions.

1. Architecture and Environment

Sustainable development deals with each and every sphere of our everyday life. Our senses are constantly bombarded by external incentives. Some everyday phenomenon – such as intensively urbanized city areas, skyscrapers or electric energy – have become a part of our life to such an extent, that we do not pause over them, but accept them as something obvious. Above elements are part of the designer's workshop. Hence, if other solutions will be introduced, they will be accepted as a standard,. Therefore architectonic creations will act as one of the medias implementing the environmental policy.
The issue of sustainability in education was first raised in Chapter 36 of Agenda 21. Promotion of a wider scope of environmental knowledge means that each nation must accept uniform values. This aim may be achieved through reorientation of the formal education and definition of common goals. Additionally, it is required that every person will posses an adequate level of knowledge sufficient to understand the complex environmental issues.
The search for a harmony between men made and natural environment is not a new one. Until the beginning of the 20th Century the development of the economy and civilization depended on existing climatic and environmental conditions. Only industrial revolution and rapid growth of various technologies, wide access to a seemingly cheap energy and mass transport, conviction in the ineffability of new techniques, assumption as to the inexhaustible supply of resources, as well as promotion of the anthropocentric strategies - caused radical changes, both within the design process and construction industries.
This had high influence on the learning program introduced into various schools and was concerned directly or indirectly with building processes. This was especially evident in European schools of architecture, where two educational paths were taken – artistic, dealing with the philosophy aesthetic form and outlook of the designed volumes, and - engineering, dealing both with the aesthetic and construction issues. Leaving aside the first path, within the second - a certain status quo was established. It was the architect, who chose the location on the site and form of the building. His choice was then supported by a civil engineer and later various other technical engineers. Little care was taken as to the existing state of environment. Globally used building materials were – reinforced concrete, glass and stone cladding. Construction techniques and HVAC systems became similar all over the world. The appearance of buildings also became uniform. When seeing a picture of a single building or a complex of buildings, without any additional references to surroundings or traditional architecture – it was impossible to state the location or the country where the photograph was

taken. Modern aesthetic characterized by a high contempt of historic details and features – became part of the educational systems. Each and every decade of the 20th Century brought new Modern style, and each new style became further removed from the vernacular from which it had sprung.
Sustainable development appeared in the 60-ties[1] of the former decade – at first it was a pro-ecologic design only, promoted by a social group, who discarded the consumptive way life and accepted the need to limit the economic growth.
For most representatives of the environmental route, economic growth and profits became acceptable only after the introduction of sustainable development described in the Rome Club Report under the heading of "Factor Four" [2], where the concept described a possibility of both economic growth and environmental protection. It included doubling of the present standard of living with the use of half of the contemporary supply of stock materials. Authors proposed technological optimalisation, better performance of production without higher costs, lower volume of waste, lower use of oil products, as well as construction of low energy buildings.
Above changes can be perceived in the construction sector, where presently 50% of the total world energy is used for the construction and maintenance, including 40% of the output of the non-renewable stock. Additionally 50% of the world water requirements (including 26% during the construction process itself), is used for the same purposes. Transport of people and various supplies also use next 25% of the total energy production. Many scientists state, that large quantities of waste are produced during the construction and demolishing.
Application of the sustainable development is closely connected with three areas:

- human requirements
- renewing, or at least sustaining, of existing environmental parameters
- economic effectiveness and environmental management, also within the construction and derivative sectors.

Sustainable buildings have to be accessible to each member of society and should be created with the participation of designers and consultants of different disciplines, as well as final users. Hence, it should be assumed that harmony between architectonic solutions, technologies and costs, is possible only with the use of a clear management strategy. This is a holistic treatment of the relation between men and environment, or rather – built and natural environment.
This approach is only very rarely discussed within the education curricula of Architects. The knowledge that design should be conducted in accordance with the limited accessibility to natural resources and limited space, is very often not even mentioned. The issue of recycling - is often treated as an oddity, maybe a fashion to be soon forgotten. The same applies to the context of development of urban areas where planners should foresee a high need to transform areas already used, limiting the impact of the urbanised on natural environment.
From the time of the Rio Summit, application of environmental parameters within the planning and design processes has been accepted by nearly all European countries, but this does not mean that it has been implemented as part of the basic or even supplementary architectonic education in each of the existing Schools.
The new generation of designing Architects which appeared in the past fifteen years – is usually a group of self taught designers. Yet, this class of sustainable creators, already knows that during the design process they have to apply various procedures and program strategies allowing to calculate required maintenance energy and the impact of buildings on natural environment. Each and every parameter is inserted as an integral part already at the concept stage. Both – form and the function – are closely connected with particular location and requirements of the future user. Certainly, the issue of sustainable building has become a cultural phenomenon – widely used by the politicians, and economists – more and more knowledge also becomes part of the general education.
This state can be especially perceived in Germany – it dates back as far as 70-ties of the 20th Century – and it is closely connected with the importance of the Green Party. Presently, sustainability – has become one of

[1] Some researchers of Architecture argue that this movement appeared already in the 30-ties of 20th Century in USA, and was represented by George Fred Keck. In his design he used details analogous to those found in present environmental buildings – wide eaves and movable external shutters (1953 - Cahn House, Lake Forest, Illinois), large glazed façade used as sun collectors (1941 – Duncan House, Flossmoor, Illinois) , and heating with heat gains (1945 – a prototype Solar House, Rockford, Illinois). Duncan House was also monitored during the first year of use. Data was never used by later designers [3]

[2] Factor Four – described by Ernst Ulrich von Weisäckera and energy consultants Amory B. Lovins and L. Hunter Lovins, published in 1995 in Germany

the alternatives both for the German designers as well as contractors – especially after the enforcement of new laws and the Low Energy[3] and Passive Building Acts[4].
Cities such as Freiburg im Bresgau and Stuttgart were the first to introduce pro-ecologic requirements into the urban planning. Further research disclosed that approximately 30% of the consumer market is interested in sustainable issues. Over 58% of Germans assume that the government does not undertake sufficient measures to stop the climatic changes and over 94% accept higher initial construction costs in order to have environmentally friendly buildings. These statistics are characteristic to more developed European countries, unfortunately – those which have joined EU lately are in a less advanced phase of development and therefore consider the issue of sustainable development as an economic hindrance
In countries such as Poland – sustainability is a catch word only. Here, the designers are aware of the fact that the area of their influence is much wider than the design process itself. They are aware that there is a need for a multidisciplinary approach, definition of a network of influences allowing for a potentially sustainable development. Non existence of integration between each of construction areas produces high energy losses and building material waste. It has been stated in some academic and scientific papers and books that the *"…limits of contemporary sustainable investment process starts with the initiation of the building's idea and ends with the life of the building"* (change of function or demolishment). Still – the idea accepted by the scientists and many students of Architecture has not until now, been accepted into the education curricula of any of the Schools of Architecture in Poland.
Detailed research[5] conducted in early 90-ties at the Faculties of Architecture and Construction, only confirmed that Polish engineers are not well prepared within such educational fields as economy, management and environmental issues. Further investigations conducted in 2000 and 2003 – showed similar conclusions, including the need for further education at a post diploma level (80% of the students).
It is only due to high interest of some of the Polish researchers that any sustainable programs are conducted within the scope of construction industry at all; STEP program being one of them.
In 2006 Warsaw University of Technology in participation with the NTNU Trondheim received a grant from the Norwegian Mechanism source. The name of the project is STEP and its general aim is scientific and research support concerned with the achievement of a better quality energy performance of the public buildings in Poland.
The direct aim – is the delivery of support tools indispensable for the decision making in the curricula of technical solutions in new and existing public buildings, which will initiate the changes in traditional building techniques in favor of the more optimized solutions in accord with accepted criteria. Public buildings have a very special place in the Polish building substance. They are used by the local councils and national administration for the statutory purposes such as: education, health safety, cultural events etc. Energy performance of the existing buildings is low, and modernization processes are very limited. Those buildings are very often the local construction key elements and should be treated as demo cases - showing possible use of low energy technologies.

- Collecting and compiling of data in a table format – various functions – educational, office and cultural - constructed during 1990-2003 in European countries according to energy saving rules. The tables will disclose basic layouts, cross sections, elevations, known technical parameters as well as basic information as to the design conditions of the functions and layouts.
- Preparation of a diagram showing characteristic areas which can be distinguished in each phase of the construction investment process, pointing out the role and position of the Designer within the integrated design process. The Concept Design Phase plays one of the most important roles, especially in the case of the Client's and technical designers' s energy saving education. The Designers should therefore, prepare an integrated Brief - to be performed "for" and "in the Name" of the Client. The scope of tasks depends on the Client's expectations, Project's quality, assumed time schedule and accessible finance. The Design Data should include all information being the outcome of the Client's and design team requirements, site location, time and work schedules, energy saving and aesthetic effects, maintenance costs and existing budget.
- Additional data on the public buildings constructed or being under construction in accordance with energy saving requirements during 2004-2007 in European countries
- Co-operation with other task leaders in order to exchange technical data concerning chosen buildings

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[3] Published in 1982 laws define the upper coefficient of energy use allowed in new buildings as 150kWh/m^2. In 1995 this parameter was lowered for single housing as 100kWh/m^2 (analogous rules were accepted in Sweden in the 80-ties).
[4] A Passive Standard Building was for the first time introduced in Germany, Hessia Land, in 80-ties. The main aim was to limit the heating energy to 15kWh/m^2/annum. First four buildings were constructed in 1991 in Darmstadt – Kranichstein. In 2001, similar residential buildings were also constructed in Austria and Switzerland.
[5] First research was conducted in 1986 by ORGBUD, next one by the academic staff of the Faculty of Architecture, Warsaw University of Technology, Team of Economic design

- Definition of the scope of influence of energy saving issues on the massing and aesthetic features of the designed building
- Definition of the most important “demise” areas between the architectural knowledge and other engineering branches participating within the construction investment processes,

The best case catalogues will be a summary of research conducted within some of the work tasks, data will contain information for the designers or investors helping them to undertake investment decisions. Prepared education materials will be used in faculties and post diploma courses conducted at the Warsaw University of Technology and other didactic centers
Educational output data from each of the work groups will be used as schooling materials for post diploma courses destined for general use within the scope of this task.

2. Foreseen role of an Architect in the process of sustainable education

Some assume that the highly organized nature of Architecture is an aentropic form, where the constructed and maintained buildings act as a counterbalance for the growing level of entropy. This is a high simplification of the whole issue [1]. A living organism is an open system characterized by a constant level of entropy. It absorbs high energy matter, later transforming the energy in its cells and emitting less complex substances into the environment hence not allowing for any additional growth of the entropy. If we treat the environment as a holistic set of areas, then a total exchange of energy in the organic systems and the environment will always take place in accordance with the second law of thermodynamics.
Processes such as growth, decay and death – are constant elements within the slow exchange of energy taking place in the environment. The second law of thermodynamics still applies within a holistic acceptance of the organism treated as an open system existing within the environment, including a marginal constant growth of the entropy.
Therefore, this is a clear indication that when preparing a location analysis, the designers should widen the presently limited ecologic concept of the environment with this holistic analysis. Ecologists postulate that urban environment should be analyzed with the areas surrounding the actual site which is being developed. Each individual ecosystem should be analyzed in relation to all Earth ecosystems. Hence the term “environment” – should be understood in a global context.
A holistic sustainable building process does not mean therefore that the environment is protected from the human intervention, but that it formulates relations between the effects of the human intervention in the ecosystem and the environment, finding of ways to limit those interventions and acceptance of the volume limits of each of the ecosystems.
Sustainable design solutions are usually multidisciplinary. Definition of negative influences of constructed buildings and their possible limitation already within the concept stage, depends on the skills and education of the design team.
From the very beginnings of civilization, human kind had a tendency to be surrounded with objects of beauty. The idea of beauty fluctuated in time and place – but the idea was always similar regardless of other influences. Hence, if a building will be designed and constructed in accordance with the low energy and environmental strategies only, but the aesthetic parameters are not existent, only very few will choose it as a place of inhabitation. Unfortunately, since environmental issues are still regarded as a novelty, the load bearing elements are usually very heavy, facades are devoid of details and color, whereas interiors are dark and gloomy. Too often environmental solutions – such as solar or wind chimneys, solutions supporting passive heating and cooling of the building – are perceived as something additional, attached to the building after the original thought of the designer has been already formulated.
There are some contemporary buildings which have been designed and constructed according with the sustainable principles maintaining harmony between the environment and user requirements. Hence, one of the tasks to be provided by the Architect - a teacher in the issues if sustainability – is such introduction of detail, that it will be perceived as an integral and widely accepted feature of the newly constructed buildings.
Still the connections with the environment reach further than the Architecture itself. Designers, developers, financial and public organizations have their own priorities, not necessarily in accordance with the sustainable aims. Each of those participants should participate in the actions to protect our environment. In order to achieve this, following actions should be widely undertaken:

- a better level of general education accessible to all age groups;
- preparation of a frame educational network – to be taught at every level of education;

All designers, not just architects should participate in both of the above described areas.
There is no better way to educate the society, than through constant existence of certain solutions and characteristic features. Hence - a wide possibility to use them in the architects’ professional life – the use of

aesthetics' and creations as an integral part of the educational programs. Their subconscious influence on the human actions and functioning of surrounding environment. It may be therefore accepted that outside the residential areas, it is the educational buildings that can be used as support education tools – and simultaneously co-operation of designing teams should become the main aim of the Architects – acting as Tutors.
The issue of a higher awareness, has been stated already within the text of this paper – it has been pointed out that the differences between "environmental" and "architectonic" quality should be removed. It is the Architect, who has the best possibility to integrate local societies into the design process already at the concept level, and then include their requirements and needs. This co-operation should result in following outcomes:

- a higher level of ownership, and at the same time a higher acceptation and level of belonging to the place of residence;
- a higher level of environmental protection;
- preservation and revalorization of local eco-systems;
- limitation of transport distances – as part of the inhabitants choice, not legal requirements;
- limitation of the noise level emitted within the urban areas.

Above processes have been in most cases included in the legal acts and are being enforced in many European countries.
The area where the Architects have most influence to create the awareness of sustainable development – is educational buildings. Designing teams can actively participate in the realization of two teaching methods:

- "see" and "touch" method
- "stating questions" method – "why", "where", "who" and "what".

These solutions can be easily provided with the use of a limited access to the internal building systems e.g. partially glazed HVAC system elements - teaching the children that their building is not just a classroom and playground area, but have additional elements allowing to preserve correct environmental and living standards.
The demands for designing low energy sustainable buildings call for a new way of designing, as it is no longer sufficient to improve the technical parameters only. One of the main issues is the requirements to accept the issue of Integrated Design Process - by all parties involved in the design. This participation should appear already in the initial stages of design. Hence a certain awareness will be created allowing for a better understanding of the impact of the architectural and technical decisions – already at the sketching level. The first step in the process is therefore the introduction of a core design team – to discuss the basic targets and directions regarding the site and function. Participating actors are: the building owner, user, architect, urban planner, as well as environmental specialist, energy specialist and biology consultant. Initial discussion should cover such data as the form and program of the building and site, energy issues, internal and external environment parameters, potential building materials as well as the level of financing.
It is rather unfortunate that most of the contemporary designers does not have sufficient scope of knowledge dealing with ecology, biology and climatology as well as building physics – indispensable for the design and construction of sustainable buildings. This further means, that such knowledge should be incorporated into the scope of education taught in the faculties of architecture as well as other technical disciplines directly or indirectly connected to the construction industry,
Architecture is not only one of the Art disciplines, but also a social practice connected with various areas. Creation of urban environment within the natural environment is a basic example of human influence on the transformation of the natural ecologic systems. Education of architects within the scope of issues concerned with environment and provided by the outcome of the STEP Project should prove to be very valuable.

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"Identifying Sustainability Priorities and Engaging Stakeholders" - The Hong Kong Housing Authority's Experience
(ID Code SB430)

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Summary

The Hong Kong Housing Authority (HA) provides affordable and sustainable public housing for those in need. To achieve our vision of sustainable housing, we try to balance and integrate the environmental, social , economic and aesthetic concerns of the community. We have been contributing to the broader sustainability of Hong Kong by providing affordable quality housing and a healthy living environment for about 30% of the population in subsidised rental flats and improve their quality of life. As a public sector client, we have been driving sustainability initiatives through the value chain in the public housing sector, in collaboration with all stakeholders from planning, design, construction to occupation stages. Sustainability means getting the best use out of our housing stock by prolonging the life of our buildings, engaging our community in our development proposals and their subsequent operation, and building effectively through an environmentally aware approach. This paper gives an overview of our approach, whereas the details are contained in a family of papers submitted to SB08 by my colleagues.

Keywords: public housing, sustainability, stakeholder engagement, environment,

1. Introduction

The primary role of the Hong Kong Housing Authority (HA) is to provide subsidized public rental housing to low income families who cannot afford private rental accommodation. The public housing programme has evolved to meet public expectations, from an emergency housing programme in the 1950's, into the more sophisticated public housing services that we provide today, covering planning, design, construction, management and maintenance. Over the years, we have been working to ensure the implementation, maintenance and sustainability of an effective housing programme that will not only meet Hong Kong's requirements but also contribute towards a stable and happy community. The improvements we make are a direct response to public demand as society has prospered and as public expectations and the demographics of Hong Kong have changed. At the end of March 2007, about a third of Hong Kong's population was living in 680 000 public rental housing flats.

One of our key missions is to provide affordable quality housing with a healthy living environment, thereby improving the quality of life in Hong Kong. This, we believe, allows our tenants to contribute more effectively to the community and the local economy, and allows the HA to contribute to the overall sustainability of Hong Kong. As a public sector client, we have been driving sustainability initiatives through the value chain, in collaboration with all stakeholders from planning, design, construction, maintenance and estate management fields in the public sector. We continually work to improve our operations with the full integration of environmentally friendly, user friendly, functional and cost effective considerations. We have put this vision into action through our *Strategy for Sustainable Housing*, and I shall give an overview of our approach as follows –

a) We identify our sustainability priorities in three aspects: environmental, social, economic;

b) We engage our stakeholders with overarching policies and systems;

c) We work hand in hand with stakeholders throughout the three major stages of the estate life cycle: planning and design stage, construction stage and occupation stage, integrating the environmental, social and economical initiatives in a holistic manner.

2. Identifying Sustainability Priorities

Sustainable development goals are now major considerations in the development of Hong Kong. We are progressively exploring ways to improve our performance, balancing the priorities in three aspects: environmental, social and economical. The best results can be achieved through the full integration of the needs for economic and social development with those of conserving the environment. We have to find ways to maintain prosperity and improve the quality of life, while reducing the environmental impact of our activities and help to preserve common resources and so create a sound basis for future generations. We cannot achieve this alone and we need to collaborate with our stakeholders in the value chain, to ensure that we will achieve sustainable development goals.

2.1 Environmental Priorities

Given the high-density, high-rise environment in Hong Kong with its enormous political, technical, time and cost constraints, we need to build efficiently and act in an environmentally friendly manner through effective design, construction and management to the benefit of our tenants and the community at large. We are committed to properly managing and reducing our consumption of resources in our day to day activities, in particular the reduction of waste and energy consumption. We are always looking for better construction methods to decrease our environmental footprint and reduce the overall impact of our development, occupation, management and maintenance processes.

2.2 Social Priorities

Social sustainability enhances the well-being of people. Low rents in public housing represent a subsidy to low income families and consequently the housing programme promotes social stability, economic prosperity and harmony in the community. The HA wants to see public housing estates as safe, healthy and secure places to live, so that our tenants enjoy a satisfying and good quality living environment.

We must therefore prioritize the demands on us according to our policy pledges, by providing public housing to those who need it most. Our goal of providing a safe and healthy living environment applies not only to our tenants, but also in the working environment, safety and protection for those who are engaged in our construction, maintenance and property management services. Our policies are geared to enhancing social cohesion and contributing to the well-being of the community as a whole.

2.3 Economic Priorities

The economic performance of an organisation is the key to its success and hence its ability to continue in business. Cost effectiveness is critical to the HA because decisions on the housing programme, whether design, construction, or operations and maintenance will have an impact on the public purse. We achieve cost-effectiveness through a number of measures, including the public listing of some of our assets and the constant review of management measures to get the best returns out of HA resources and sustain the useful life of our buildings. Enforcing tenancy controls is critical to reduce abuse of public housing. Refurbishment programme and allocation policies reduce vacancies in flats. We prolong the service life of our stock by providing efficient maintenance and upgrading our housing blocks through the Total Maintenance Scheme.

3. Engaging Stakeholders: Overarching Policies and Systems

Sustainability in housing cannot be achieved without engaging each and every one of its stakeholders. Our stakeholders include planners and designers, building, maintenance and property services experts, tenants, users and workers, as well as the community at large. To achieve this balance, we have formulated and applied our policies on sustainability across all our activities and communicated them to our staff, tenants, and business partners. Sustainability is embedded in our operating procedures, planning and design guidelines, tendering, contracting, and our tenancy agreements, and guides our stakeholders on all fronts. We monitor the application of our policies and systems regularly, and measure against established targets, and backed-up by training and promotion so that our expertise meets our needs and tenant's awareness is raised.

3.1 Partnering with the Industry

Improvements in the way that we work, both in construction and property management operations have only been possible with the collaboration of our business partners. As we develop new initiatives we involve our partners, so that we can be sure that they are practicable, and that they too, own the decision. The HA has been instrumental in driving improvements in the industry, in safety, health & environment, working conditions, and the protection of wages. Dialogue with the industry and efforts to promote partnering are critical to the success of new initiatives in the delivery of housing services. We tap the expertise of our partners through regular meetings or ad hoc groups, to develop the operational details more effectively.

Since 2001, we have run project partnering workshops in all building, piling and some maintenance contracts, to promote effective communication amongst our contractors, subcontractors, our staff and consultants. With six years' experience, many project teams have reported communication benefits with problems being solved more promptly on site, less paper work, smoother progress and improved quality of work. Partnering means that we are more open and we build rapport in working towards our common project objectives of quality, safety, environmental performance and customer service with synergistic and reliable results.

In mid 2006 we took partnering a step further and embarked on a Modified Guaranteed Maximum Price Contracting model in a pilot project at the Eastern Harbour Crossing site Phase 4. This contract arrangement requires the contractor to commit to a maximum price based on his design proposals at the contract award stage. It allows for design development and the sharing of cost savings between the employer and the contractor from alternative design proposals that are made after contract award, hence providing financial incentives, integrating the contractor's expertise and enhancing design and build-ability.

3.2 Communication with Residents

Clear communications is essential in HA activities, so that everybody is fully informed of our plans, that they understand and respond to initiatives and so help ensure their success. In 1995 we launched the "Estate Management Advisory Committees" (EMAC), which allow our tenants to contribute to management of our estates, by acting as bridges between the HA and the residents (Photo 1). Each Committee consists of the Housing Manager, a District Councillor of the constituency, and representatives from Mutual Aid Committees and residents associations. They act as an advisory body and make suggestions on day-to-day management issues, assess the performance of contractors and allocate funds for minor improvement works. In 2005/06, we issued more than 260 editions of a half-yearly EMAC newsletter, helping to keep the two million public housing tenants in touch with important housing issues and local estate news. The EMAC Scheme has made a significant contribution to building partnership between the managers of estates and the tenants.

The "Housing Channel", launched in 2004, has been extended to cover over 850 residential blocks in almost 130 estates. Video programmes are broadcast on LCD monitors installed in the ground floor lift lobbies of our blocks. The channel enhances communication with the tenants and keeps them informed of new services and developments within their estates. Over 50 videos were produced, including topics on developments in the Review of Domestic Rent Policy, the Total Maintenance Schemes, the Rent Assistance Scheme, the promotion of green practices in estates, and even news and weather information.

Photo 1: Event Organized by the EMAC Play a Vital Role in Stakeholder Engagement in HA Estates.

4. Engaging Stakeholders: Planning and Design Stage

We motivate our planners, project managers and designers who play a crucial role in the "embryonic stage" of our estates during the planning and design work, which will ultimately affect the construction and occupation phases throughout the life of the buildings. It therefore follows that we must positively engage this group of creative people and align their thoughts with our corporate vision and values, through design reviews, experience sharing sessions, and promulgation of design guidelines.

4.1 Adopting Micro-climate Studies for Environmentally Responsive Design

Since 2004, we have employed micro-climate studies for all new estates designs, to verify environmental performance. We do this by applying computational fluid dynamics techniques, so that our designers may refine their scheme designs to maximize the advantages of the form, orientation and disposition of buildings and thereby optimize the benefits of local wind patterns, natural ventilation, dispersion of pollutants, day-lighting, thermal comfort, and ultimately help to improve energy efficiency during the occupation stage.

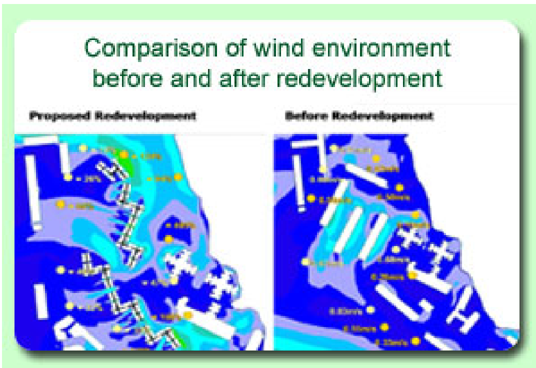

Photo 2: Micro-climate Studies are used in development of all designs, and this is for Upper Ngau Tau Kok

The studies help us to provide a healthier, more natural and more user-friendly living environment. We have already applied these modelling techniques on 26 projects. The first project employing these techniques, Upper Ngau Tau Kok Phases 2 and 3, which is due for completion in 2008, has been assessed under the Hong Kong Building Environmental Assessment Method (HK-BEAM) and has achieved the provisional top-level Platinum Rating.

We have also researched into the detailed design of the facades of our buildings by addressing orientation and sun-penetration for better thermal comfort, reduced glare or more natural lighting, depending on the location of each flat. A pilot project at the Eastern Harbour Crossing Site Phases 3 and 4, in Eastern Kowloon, will be completed soon.

4.2 Developing a Common W-trap System for Drainage Works

The SARS outbreak also led to the re-appraisal of soil and waste drainage systems to address the risk of transmission of disease through dried-up traps to floor drains. We worked with the City University of Hong Kong to develop a common W-trap system so that floor traps always provide an adequate seal. A number of plumbing suppliers have expressed interest in manufacturing the traps for use in HA projects and they will be used on all new developments where practicable, at first in Eastern Harbour Crossing Phases 3 and 4.

4.3 Community Participation in the Design and Planning Processes.

Engaging The Community has become a vital process in our delivery of public housing. Comprehensive design approval processes, and a mature feedback system, ensure estate planning and design match with tenants and community needs. We consult Government Departments as a start and then District Councils to gauge the community needs. Public and media briefings on new proposals and a range of communal activities such as meetings with residents groups, art promotions, exhibitions and planting activities all play an important part in securing public support to development proposals.

We have explored several models of user-oriented neighbourhood design. At Yau Tong Estate, Ma Hang Headland, Upper Ngau Tak Kok Estate and Lam Tin Estate, we have worked with a variety of interest groups; academics, residents, schools and NGOs in a series of facilitated workshops, where they were briefed on the constraints and opportunities of the project, and help them to articulate the concerns and aspirations in the neighbourhood. We ran drawing and mural painting competitions to strengthen public awareness and appreciation of local heritage. We succeeded in drawing up a design brief to meet common objectives and will continue this work to integrate community aspirations in future designs. The experience gained will be invaluable in future projects.

Photo 3: A Workshop held with the participation of local schools in the development of Yau Tong Estate

4.4 Life Cycle Costing and Life Cycle Assessment

In view of our large stock of buildings and large customer base, we have a culture of using simple designs and materials that are long-lasting, easy to care for and environmentally friendly. In 2002 to 2005, we commissioned consultants to study the life-cycle costing and assessment on typical domestic buildings. The study confirmed that the materials that we use achieve an optimum environmental performance and life-cycle cost effectiveness (Photo 4). Designers are now using this tool to help their decisions on the choice of new materials in future designs and thereby reduce our maintenance burden in future.

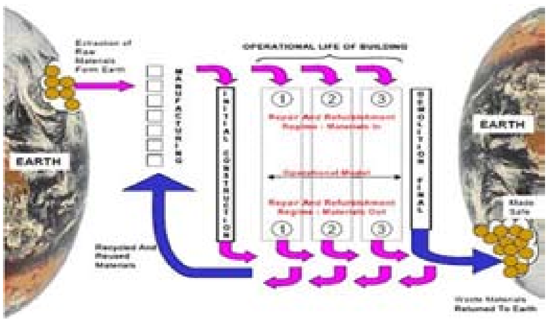

Photo 4: Life Cycle Process Of Building Materials From Extraction, Through Manufacture To Final Disposal.

4.5 Regenerating the Public Housing Stock

While the majority of our housing stock consists of modern blocks built after a Comprehensive Redevelopment Programme in 1988, we continuously maintain and evaluate our older estates, which we define as over 40 years old. Comprehensive structural survey of nine estates has just been completed according to technical criteria developed in consultation with local and international specialists. Options of protection, restoration and structural strengthening are studied. As a result of these investigations, we announced in March 2006 that So Uk Estate would be demolished. While the 16 blocks of this estate built in the 1960's are all structurally sound, the extensive repairs required would not be cost-effective, and there would be considerable nuisance and disturbance to tenants. For all other estates where they are not beyond economic repair, we would prolong their further use by 15 years.

5. Engaging Stakeholders: Construction Stage

The construction stage can have a huge impact on the community and if not properly managed can lead to complaints and delay to projects. To motivate our contractors, subcontractors, suppliers and workers, we have introduced contractual provisions to require our contractors to develop best practice including safe and green building practices. They in turn, cascade the message down through the supply chain to workers on site. We conduct rigorous site inspections and have implemented thorough Performance Assessment Scoring Systems (PASS) to monitor performance so that they meet their obligations by strict compliance with specified standards.

5.1 Applying Pre-casting and Mechanized Construction Methods

With labour shortage in Hong Kong in the late 1970's, we started construction of housing blocks with various mechanized forms. Mechanized construction can make the process simpler, safer, quicker and cleaner. By 1990's these techniques were widely used and became mandatory contractual requirements. Our teams worked with contractors to perfect the use of large panel formwork systems, pre-fabrication techniques for a wide range of building components (Photo 5). Our latest pilot project sees an increase in the extent of prefabrication from our usual 20% of the concrete work, to approximately 60%. There are social, economic and environmental benefits, most notably in quality, in site safety, waste reduction and so a reduced impact on the environment.

Photo 5: Increased Use of Pre-cast Concrete and Prefabricated Elements in Building Construction Works

5.2 Applying Hard Paved Construction for Building and Piling Works

A further enhancement to reduce the impact of our works and improve conditions at site level has been the requirement for temporary paving in all of our construction sites. We have specified "hard paved construction" for use in all building and piling contracts since June 2005. The practice has provided healthier and cleaner sites with much better dust control, material storage and handling, and surface water runoff.

Photo 6: Hard Paved Construction Sites now used, this one at Eastern Harbour Crossing Phase 4

Some builders have gone further with the use of re-usable pre-cast concrete slabs instead of in-situ concrete. "Hard paved construction" has been shown to be effective, not only in minimizing the environmental impact but also in improving site safety, and gradually changing the behaviour and culture of the workforce where more clean and green working practices are becoming the norm.

5.3 Applying Hydraulic Crushers for Demolition and Jack Piles for Piling Works

Demolition and piling works are usually noisy and dusty activities which have the greatest impact on the community. We have been working with the industry to reduce noise emissions, and introduce efficient, safe and environmentally friendly demolition and piling techniques. Since 2001, we have carried out trials of hydraulic concrete crushers in demolition works rather than using traditional pneumatic breakers. In 2004 we published guidelines and specifications to facilitate their use by project teams for works close to noise sensitive receivers, such as domestic buildings, schools and hospitals. We have conducted a comprehensive study in 2003, and after consultation with the Buildings Department, we have applied the use of "jack piles", which is a new type of more environmentally friendly piling technique.

5.4 Safety Management Means Business

We have been progressively introducing measures to improve site safety, increase safety awareness and promote best practices beyond basic regulatory requirements. These included the Silver Card advanced safety training scheme, Housing Authority Safety Auditing System, Pay for safety, environment and hygiene scheme. These systems have been instrumental in improving safety management and the overall awareness of the managerial staff engaged in projects, by setting objective safety standards on sites. The HA has a good record for site safety with 9.9 accidents per 1000 workers in 2007 (provisional), compared to about 60 accidents per 1000 workers in the industry as a whole, (Figure 1).

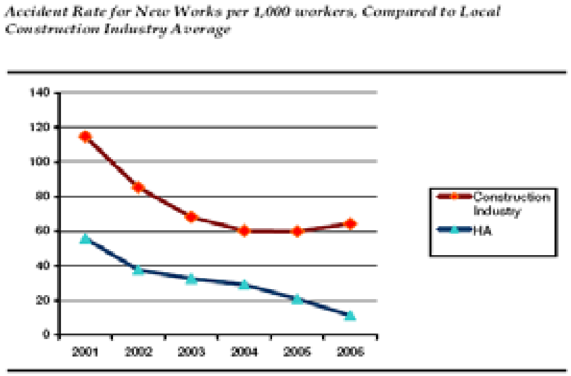

Figure 1: The decline in the accident rate in HA projects by comparison with the Industry as a whole.

5.5 Securing and Monitoring Wages Payment to Workers

With the multi-layered subcontracting in Hong Kong, construction workers have often suffered from wage arrears. Commercial disputes between contractors and sub-contractors may lead to late payments or non-payment at the lower levels of subcontracting and if wage arrears occur, then as a public sector client, the HA may be criticised, even though the contractors may have been paid for the work done. Labour disputes between contractors and sub-contractors and their workers also affect quality of service and cause delays.

In response to some serious incidents on building contracts in late 2005 to early 2006, we consulted the industry, including sub-contractors and workers, and developed improvement measures to secure and monitor the payment of wages to workers. These have been adopted in our building contracts and nominated sub-contracts from May 2006. The measures include employing Labour Relations Officers to conduct on-site checks and verify records of workers in employment, records of attendance; payment of wages and acknowledgement of receipt; monitor the situation and identify any anomalies. The Labour Relations Officers will also receive, acknowledge and record complaints and inquiries from workers.

6. Engaging Stakeholders: Occupation Stage

Throughout this occupation stage we engage our tenants, property managers and the community to foster a green and healthy living habitat in harmony, making effective use of housing resources and prolonging the useful life of buildings.

6.1 Green Delight in Estates

Through education campaigns and outreach programmes with "green groups", we have collaborated with tenants, staff and service providers to reduce domestic waste, promote schemes to save energy and water, and clear hygiene black spots. Working with our tenants is the most effective way of spreading the environmental awareness message to a large proportion of the Hong Kong public.

In 2005, we have launched a long-term community environmental programme, called "Green Delight in Estates", to promote environmental awareness among our tenants through educational and community activities (Photo 7). Various activities are being organized with local "green groups" where they have implemented green initiatives for 30 estates in 2005/06. The programme was extended to a further 30 estates in 2006/07 and will be progressively rolled out to all public rental housing estates. A tenants survey conducted at the end of the first year concluded that the programme has raised environmental awareness and the green groups are working with us to promote waste reduction and recycling campaigns. We have also started energy saving campaigns with the green groups and the Electrical and Mechanical Services Department to promote energy conservation amongst our tenants.

Photo 7: Partnering with Green Groups to as part of the "Green Delight in Estates" Programme.

6.2 Reducing Domestic Waste

In 2006 to 2007, residents of HA estates generated 0.74 kg per person per day compared to 0.82 kg per person per day in 2003. Waste recovery has also been a concern, both from the perspective of recycling and for disposal of potentially toxic waste such as used rechargeable batteries. Our residents also make significant contributions to environmental protection by using the recycle bins provided in each block. Recovery rates for recyclables in the past year have increased and in total, 12.36% of paper, 28.31% of aluminium cans and 6.19% of plastic bottles were recovered for recycling from our estates.

6.3 Estate Landscaping and Greening

Landscaping and planting schemes in public housing estates have long been an HA priority (Photo 8). In 2005/06, the HA professional and Horticulture Teams have continued their work to improve the standards of landscaping, both in new developments and improvements to existing estates. About 4,100 trees, 527,400 shrubs and 92,000 annuals were planted during the year. We set ourselves five targets on greening works for 2005/06, which have all been achieved, which have upgraded of the landscaping in selected estates and promoted the benefits of a green environment through the EMAC. Theme gardens have been set up to enhance awareness of greening, with Rhododendron Gardens at Lei Muk Shue and Nam Shan Estates and every year we organize tree planting days to help to raise awareness of our efforts and achievements.

Photo 8: HA Estates have extensive Landscape Facilities, with this example in Tseung Kwan O New Town.

6.5 Customer Satisfaction

We have been conducting customer satisfaction surveys with our residents for many years, to gather feedback on new estates and compile statistical data. We use this to review our designs, our space standards and specific requirements for estate facilities and communal areas. Latest survey results in 2007/08 indicated that less than 1% was dissatisfied with the estate and our services, whereas 74% of households were either very or quite satisfied. These surveys are invaluable in our drive for improvements and we apply the findings to refine our standards, management services and project administration.

6.6 Community Participation After Occupation to Meet Users Needs

In May 2006, we conducted a community workshop at Lei Muk Shue Estate to explore how best to respond to feedback and refine the design to meet user and estate management needs that arose after intake. The workshop proved to be an effective platform in gauging community opinion. The open forum allows people to voice their concerns and propose improvements. We have since then conducted post occupation review workshops at various estates. These were well received by residents and we believe through these workshops trust was established between tenants and management. By showing that we are sensitive to the well-being of residents and respond to their concerns, we encourage a sense of ownership as the community develops.

6.7 Healthy Life Styles and Obligations to Neighbours

Healthy living became a major concern in Hong Kong after the SARS crisis in 2003. High-density, high-rise living imposes obligations on all of us. Our behaviour directly affects our neighbours and our recognition of our obligations builds a more harmonious relationship between residents and the estate management teams. Clean Neighbourhood Campaigns are organized in our estates every year. In parallel, we introduced a Marking Scheme to address the problems caused by the unsociable behaviour of a minority of our residents that could affect hygiene and public health. Infringement of accepted public hygiene standards such as littering, spitting, urinating in public areas, mosquito breeding, smoking in lifts, throwing rubbish and objects from height, will all attract severe penalties. For serious threats to estate hygiene, we adopt a zero tolerance policy and allot demerit points to offenders, who will receive verbal and written warnings, and eventual termination of their tenancies if 16 or more demerit points are accumulated within two years. In October 2005, this scheme was reviewed in response to feedback from the public and cases which result in injury to a person, will lead to the immediate termination of tenancy.

6.8 The Total Maintenance Scheme

In February 2006, we implemented a new Total Maintenance Scheme. This was a major innovation in the maintenance of our estates, by proactively identifying maintenance needs and responding promptly to emergencies and requests for repairs, and at the same time strengthening publicity on maintenance issues. The scheme makes use of “In-flat Inspection Ambassadors” who visit all households, inspect flats thoroughly to identify maintenance needs and immediately rectify any problems. It aims to complete the inspection of 30 estates in a year and of all rental flats in a five-year cycle. The scheme will set up of a maintenance database on individual flats, strengthen research and development in maintenance and diagnostic methodology, and establish a maintenance hotline, as well as map out a comprehensive promotion and education plan.

7. The Future

Public housing in Hong Kong has made an enormous contribution towards the well-being of the community. While the sustainability of our housing estates requires tremendous dedication from our stakeholders, our sustained driving force as a public sector client also requires tremendous steer and support from top management. We define our sustainability priorities very clearly, develop and maintain a sound strategy for the future which will not only achieve our goals but also respond to the changes that may arise from time to time.

The sustainability of our programme is inextricably linked to economic, social and environmental performance. We need adequate budgets to enforce cost effective and meaningful applications. To enlist support and be accountable to the public, we prove our work through objective indicators, and monitor results for continuous improvement. We set achievable initiatives on sustainability with a firm vision. We demonstrate through our day to day actions that our vision and mission are credible; and our provision of services is cost-effective. Last but not least, we spend relentless efforts in engaging people, engaging our community in all stages of work. We must continue to engage all stakeholders to gain their support as we articulate our strategies and set out our plans for driving further sustainability initiatives. With this momentum, we build a healthy, harmonious, eco-friendly neighbourhood to be enjoyed by our tenants of all ages and abilities, at all times in the years to come.

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LOCAL ENVIRONMENTAL IMPACT ASSESSMENT OF CONSTRUCTION PRODUCTS

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Summary

In order to satisfy the Essential Requirement n° 3 of the Construction Products Directive (Hygiene, Health and Environment), in 2005 the European Commission mandated CEN to prepare tests with which construction products can be tested with respect to the potential release of dangerous substances to indoor air, soil, groundwater or surface water (local environmental impact). A horizontal approach is considered the best route for such test development. Horizontal approach means it is product independent, so applicable to one or several relevant families of construction products. In this context, the aim of this work is to study the release of substances from construction products into water – a phenomenon called "leaching behaviour". The present research has been carried out on three different (especially from leaching behaviour point of view) construction products: the concrete paving slabs (an inorganic porous product), the wood duckboards (an organic porous product) and the zinc gutters (a metallic non – porous product). The research was conducted at two experimental scales: laboratory scale (exposure to controlled conditions) and pilot scale (exposure to non-controlled / outdoor conditions). A comparison of data from the two scales testing showed that a simple transfer of laboratory data to outdoor conditions (or service conditions) is not possible. An alternative approach to the direct transfer of data is provided: the use of the tests results to feed models that describe and simulate the product leaching behaviour.

1. Introduction

The Essential Requirement (ER) n° 3, "Hygiene, Health and Environment", of the Construction Products Directive (CPD, 89/106/EC) states that the construction works must be designed and built in such way that they will not be a threat to the hygiene or health of the occupants or neighbours, nor to the environment [EC, 1989]. So far, the compliance of this ER is not integrated into the construction products CE marking process, due to lack of harmonised methods allowing the assessment of environmental and health characteristics of products. Thus, in 2005, the European Commission mandated CEN to set up methods with which construction products can be tested with respect to the potential release of dangerous substances to indoor air, soil, groundwater or surface water (local environmental impact).This kind of assessment method represents a complementary approach to the Life Cycle Assessment (LCA) which refers to the global scale environmental impacts for generic scenarios, but does not take into account the local scale impacts and specificities. An overall (global and local) environmental assessment approach will be a more relevant decision - making tool for the impact assessment of the construction products. The LCA approach is well developed and adapted for the construction products assessment and serves to the Environmental Product Declarations (EPDs) establishment. Several EPDs are already available in different databases as for example the French National database named INIES [INIES, online].

In this context, the goal of this work is to contribute to the development of a local environmental impact assessment approach. The aim of the research is to study the release of substances from construction products into water – a phenomenon called "leaching behaviour".

The European Commission considers that a horizontal approach is the best route for products assessment [EC, 2005]. Horizontal approach means it is product independent, so applicable to one or several relevant families of construction products. In order to comply with this requirement the research has been carried out on three different (especially from leaching behaviour point of view) construction products: the concrete paving slabs (an inorganic porous product), the wood duckboards (an organic porous product) and the zinc gutters (a metallic non – porous product). The study was conducted at two experimental scales: laboratory (exposure to controlled conditions) and pilot (exposure to non-controlled / outdoor conditions) scales, in order to establish correlations between the two kinds of exposure conditions.

2. Materials and Methods

2.1 Materials

The concrete paving slabs were manufactured by using a CEM I – based concrete, supplied by a concrete mixing plant (ready-mix concrete). The concrete was cast in rectangular moulds of 16x13x4cm^3 and cured in bulk form at room temperature in a humid environment for 28 days. The wood duckboards are a pine wood type (Pinus Sylvestris) industrially preserved with some active substances based on boron-copper-propiconazole, for outdoor use in risk class IV (i.e. wood placed horizontally outside, wood in contact with fresh water etc.). The zinc gutters is made of a zinc alloy with 0.13% Cu and 0.05%Ti. The target elements that will be monitored during different tests are: Al, B, Ca, Cu, K, Na, Si, Zn, Cl^-, SO_4^{--}, DOC for the concrete slabs; B, Ca, Cu, K, Zn, Cl^-, SO_4^{--}, DOC for the wood duckboards and Zn for the zinc gutter.

2.2 Laboratory Scale Experiments

2.2.1. Physico – chemical characterization and static leaching tests

The physico-chemical characterization of the products consisted in the determination of the: 1) moisture content, porosity and pore-water composition of the two porous materials (concrete and wood), 2) total content in target elements, 3) pH influence on target elements release and 4) the buffering capacity of the material called "Acid / Base Neutralisation Capacity (ANC / BNC)". These determinations were carried out and reported in previous works [Schiopu *et al.*, 2007; Schiopu, 2007]. Here, it is briefly presented the static leaching test (i.e. equilibrium conditions are reached during the test) based on the European standard TS 14429 [CEN, 2004]. This test allows the determination of the pH influence on release and the ANC / BNC of the product. The test consists of a series of extractions on separate samples with pre-selected amounts of acid or base, in order to obtain eight final pH values, covering the range pH 4–pH 12. The obtained solutions (called "eluates") were analysed for pH and targets elements (ICP–AES for the metals, by using a Dionex Ionic Chromatograph 25 for the anions, and a COT-meter 5000A Shimadzu for the DOC).

2.2.2. Dynamic leaching tests

In order to study the leachant hydrodynamics influence on the release, two types of dynamic leaching tests were carried out: the Continuous Monolithic Leaching Test (CMLT) and the MultiBatch Test (MBT).

The CMLT is a dynamic test with continuous flow of the leachant, based on a protocol developed by Polden / Insavalor [Polden, 2005]. The monolithic sample(s) was (were) placed in a reactor and completely submerged in demineralised water (the leachant) all along the test period (64 days), at a L/A ratio of 5 cm^3/cm^2 (the L/A ratio means the ratio between the volume of leachant and the geometric surface of the sample) and a renewal rate of 0.52 cm^3/cm^2/hour. In the reactor, the local homogenization of the leachant was assured by an efficient stirring. This stirring was performed by a loop recirculation of the leachant with a peristaltic pump at a flow rate of 18L/hour. The eluate was collected in separate fractions after a fixed period of time: 2, 4, 8 hours, 1, 2, 4, 9, 16, 36 and 64 days. Two types of eluate sampling were carried out: 1) a punctual sampling (a minimum quantity of eluate (~25mL, needed for analysis) collected at the end of the fixed periods of time) and 2) an average sampling (all eluate collected during the fixed period). The eluate parameters (pH, conductivity, redox potential) and the concentration in the targets elements were monitored.

The MBT is a dynamic test with sequential total renewal of leachant. The protocol is based on the Dutch standard NEN 7345 [NNI, 1995]. As for the CMLT, the monolithic sample(s) was (were) placed in a reactor and completely submerged in demineralised water at L/A ratio of 5 cm^3/cm^2 but without any stirring. A total renewal of leachant was carried out at the same fixed period of time as for the CMLT sampling (2, 4, 8 hours, 1, 2 etc. days). All the eluate was collected and analysed at the end of each fixed period. The parameters of two dynamic tests (leachant nature, L/A ratio, sampling period, etc.) were chosen as similar as possible, in order to make pertinent comparison of their results. The main protocol differences between CMLT and MBT consist in the reactor type (open - i.e. matter exchange with the exterior - or closed) and in the eluate hydrodynamics (continuous or sequential renewal).

2.3 Pilot Scale Experiments

The products were exposed outdoor for one year, on a test field at Scientific and Technical Centre for Building Industry (CSTB), in Grenoble, France. The products were placed horizontally in order to reproduce two scenarios (Figure 1): "run -off" and "stagnation" scenario. In "run-off" scenario, the rainwater ran - off over the products and went into the leachate collector (run-off leachate). In "stagnation" scenario, the concrete paving slabs and the wood duckboards were immersed into the leachant, which accumulated up to a maximum volume imposed by the set-up design (stagnant leachate) and may overflowed into a leachate collector through an overflow pipe fixed at 20 mm above the upper surface of the product (overflow leachate). In the case of the zinc gutter, the leachant accumulated directly into the gutter up to maximum depth of 40 mm. After each "efficient" rainy event (i.e. a minimum of 2 mm/day), the different types of leachates and a rainwater sample (from a blank setup) were collected in polyethylene barrels whose contents were measured and analysed. For "stagnation" scenario the volume of the stagnant leachate was calculated and the sampling was done directly into the product tank or into the gutter, respectively. The local meteorological parameters (rain, temperature, relative humidity of the air) were monitored every ten minutes by a meteorological station located on the test site.

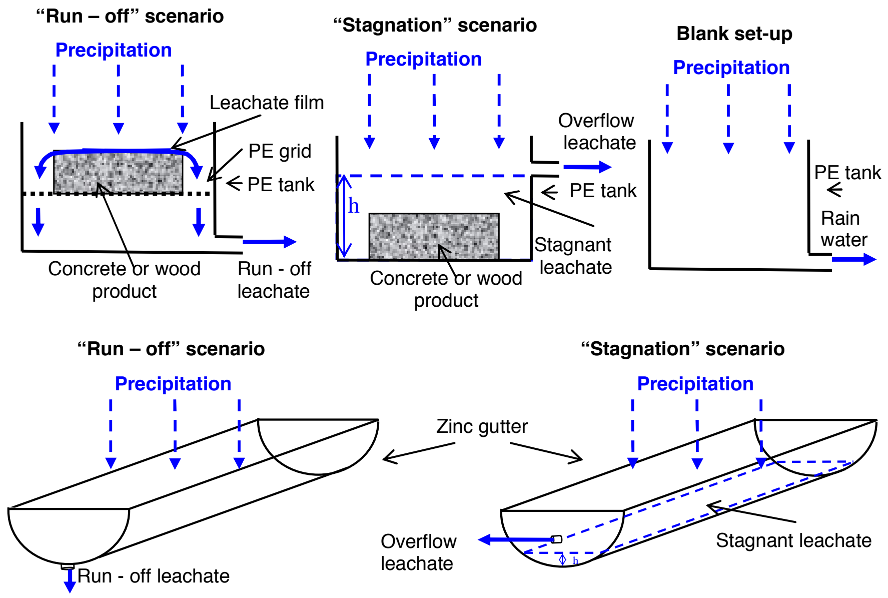


Figure 1 Pilot scale experiments scheme

3. Experimental Results

3.1 pH influence on release and the Acid / Base Neutralisation Capacity (ANC / BNC)

The pH at which the leaching takes place is one of the most influent parameter and depends on: 1) the pH of the leachant, 2) the pH induced by the matrix of the product (its "own natural pH") and 3) the ANC/BNC of the material ("resistance" to external influence on pH).The ANC/BNC is given by the amount of acid / base per kg of material (moles acid/base per dry kg of material, moles OH^- are expressed as "- moles H^+") needed to obtain a certain pH of the eluate.

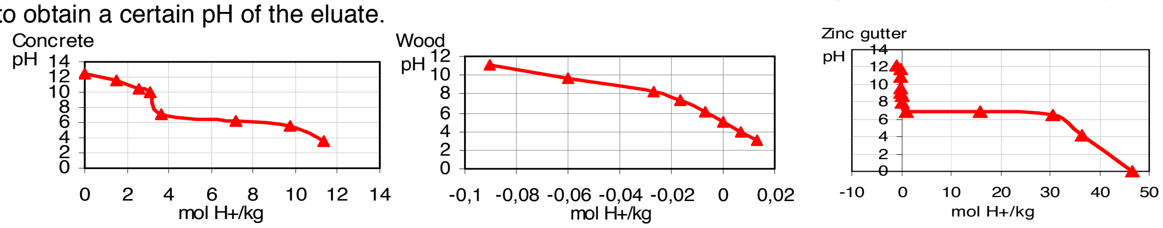


Figure 2 Acid / Base Neutralisation Capacity (ANC / BNC) curves

The ANC/BNC of the three studied materials are very different (Fig. 2). In the case of concrete, a high ANC is observed: a steady pH is maintained even if 6 moles of acid/kg of material have been added. This high ANC is mostly due to the carbonates which are major constituents of concrete. The wood presents a very weak BNC due to its own acidic pH and no ANC. In the case of the zinc gutter, the plateau observed at pH 7 can not be assigned to an ANC because the steady pH is due to the dissolution reaction of the zinc (the "matrix" is the target element in itself). Hence, the material does not "resist" to external influence on pH. Thus, among the three studied matrices, the concrete based product presents the highest resistance to external influence on pH.

The results of the pH influence on the release behaviour are expressed in mg/L of constituent as a function of the final pH of the eluate. The Fig. 3 shows the pH influence on Zn release from the three materials.

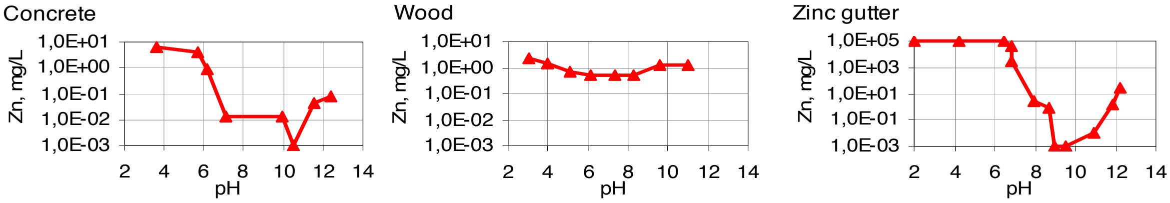


Figure 3 pH influence on the release behaviour

As expected, for the zinc gutter (metallic matrix), the pH is an extremely influent parameter for the Zn release. Its solubility changes by orders of magnitude as a function of pH (3 log units per pH unit). In the two other studied matrices (a non-metallic inorganic and an organic matrix), the zinc is present in a cationic form and its behaviour is different from the one of the zinc gutter case. Moreover, between an inorganic and an organic matrix, some differences occur, due especially to the dissolved organic matter (DOC), which is a crucial factor in the release of metals. Thus, in the organic matrix (i.e. wood), an increase of release is observed in alkaline medium compared to the behaviour in inorganic matrix. This could be explained by the high DOC concentration and availability in this medium. For the same element, release curves are similar; only the absolute level differs between different materials. This implies that the release controlling factors are the same but the relative importance of the influence differs from one matrix to another (buffering effect). For the other target elements (not shown here) the same conclusion could be drawn [Schiopu, 2007]. The results also showed that although same tests could be used for different products in a horizontal approach, some of them, such as TS 14429, do not bring essential information if they are applied to "simple" products such as zinc gutter (99,8% metallic zinc). Indeed, the results are as expected in line with the Pourbaix diagram for zinc [Pourbaix, 1966]. Thus, the physicochemical characterisation of a product could be more or less complex and must take into account the knowledge already available.

3.2 Laboratory / Pilot Comparison

The release behaviour observed at laboratory scale through the two dynamic tests (CMLT and MBT) is compared to the release observed at pilot scale. At laboratory scale, for each of the three products, over 64 days of continuous exposure to leachant, the cumulated L/A ratio (leachant volume to product surface ratio) was 800cm^3/cm^2 in the case of the CMLT and 50cm^3/cm^2 in the case of the MBT. At pilot scale, over one year of outdoor exposure, the total rainfall was 800mm and different L/A ratios were registered. In "run-off" scenario the L/A ratios were 50cm^3/cm^2 for the concrete slab, 44cm^3/cm^2 for the wood duckboards and 45cm^3/cm^2 for the zinc gutter. In "stagnation" scenario, the L/A ratios were 27cm^3/cm^2 for the concrete slab, 23cm^3/cm^2 for the wood duckboards and 30cm^3/cm^2 for the zinc gutter. Hence, the L/A ratio depends on the exposure conditions and product type (geometry, water absorption capacity etc.). 34 "efficient" rainy events (> 2 mm/day) were registered over the duration of test. The pH of the rainwater ranged between 5.7 and 7.9 (mean value 6.7). The air temperature varied between -9℃ and +38℃ (mean value +15℃) and 33 days registered below zero temperatures.

The Fig. 4 shows the pH evolution and for some of the target elements, the evolution of surface-related cumulative release (quantity of element released cumulatively per surface unit of the product sample, mg/m^2) as a function of product/leachant contact time. The contact time (and not the exposure time) was chosen for the representations because unlike laboratory tests, in field conditions, the products were not continuously in contact with the leachant (see 4.1).

In the case of the concrete slabs, figure 4 shows an increase of pH during MBT up to 10 days of leaching, followed by a slightly decrease afterwards. During the CMLT and "stagnation" scenario the pH evolution seems equivalent. Nevertheless, the causes are different: during the CMLT a depletion of alkaline and high soluble elements (i.e. Na, K) in pore water is registered, whereas during the "stagnation" scenario the carbonation effects could be the principal cause of the pH decrease; this is in agreement with Ca behaviour where the release is less important in out-door exposure conditions. For the "run-off" scenario, the pH evolution is dependent especially of the rain and inter-rain periods duration. At both experimental scales, the Zn (amphoteric element) behaviour is correlated especially with the pH evolution: the release decreases with the pore water pH decrease. For the wood duckboards, at both experimental scales the release rate of boron (coming from the preservative treatment of wood, based on B-Cu-propiconazole) is higher initially when exposure is started and gradually reduces as time (and L/A ratio) goes. This element is available to leaching up to total content release. In "stagnation" scenario, after 2 months of contact time the release increases probably due to a physical degradation of wood matrix. It must be noted that in the case of this product some artefacts could be assigned to the high heterogeneity of treated wood. For the zinc gutters, the Zn release increases during CMLT and the release is still under significant progress at the end of the test, whereas in the case of the MBT, the release rate decreases along time. This could be explained by the gradient effect which lessens during the MBT (the leachant is not continuous renewed). In outdoor conditions (pilot test), the release is under significant progress after one year of exposure and the release rate is controlled by a complex set of parameters: rain intensity and duration, air humidity, air pollution (SO_2, NO_X), product's surface state (e.g. patina formation/degradation).

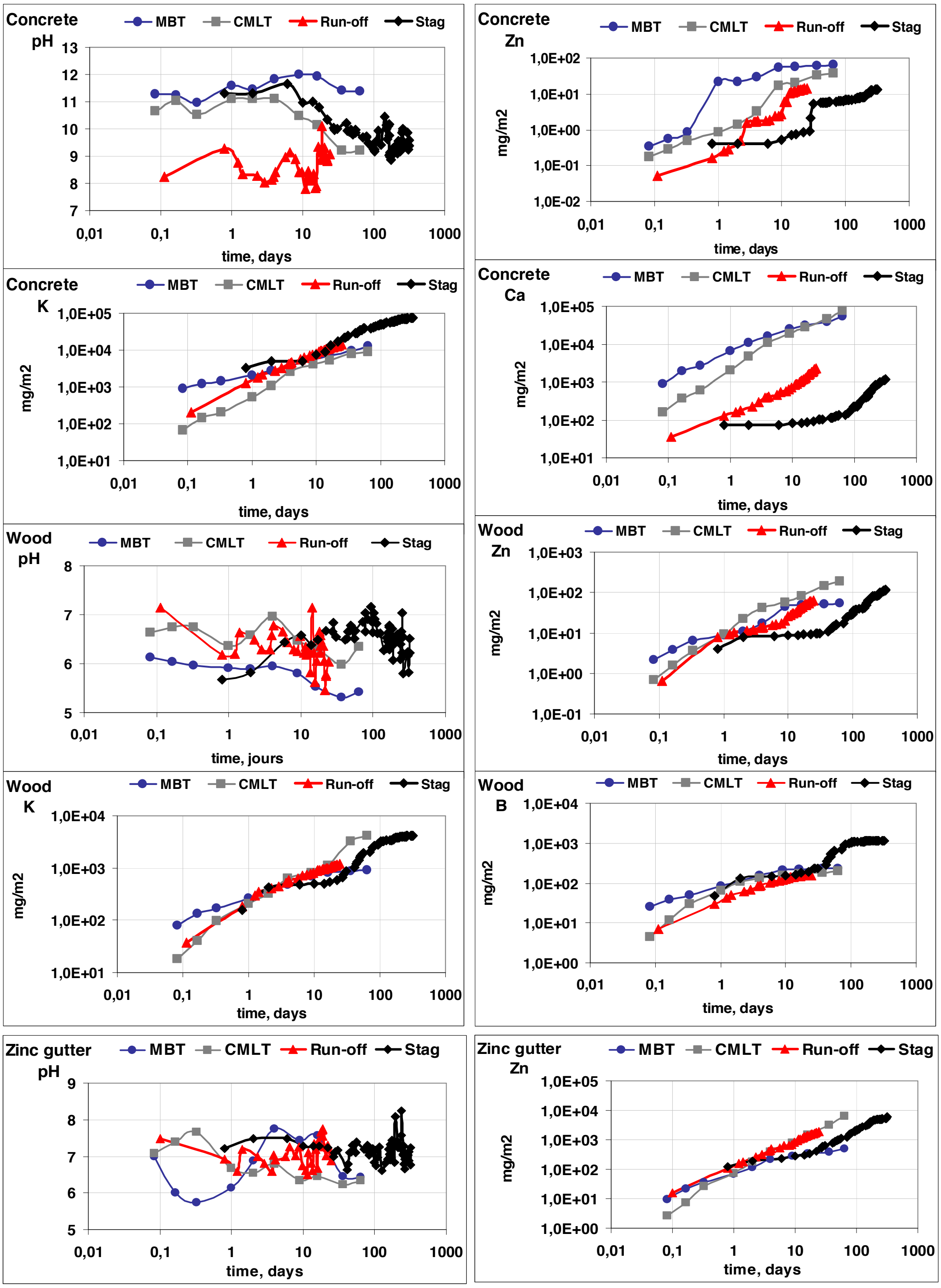


Figure 4   Evolution of pH and cumulative release as a function of product/leachant contact time

Comparisons of data obtained from the laboratory tests with data from pilot tests show that a simple transfer of laboratory data to service conditions is not possible. Indeed, even if release behaviour of some elements could appear as equivalent, the causes may be different. An alternative approach to the direct transfer of data is given hereafter: the use of the tests results to feed models that describe and simulate the product leaching behaviour. Such a model (chemical / transport) was developed for the case of the concrete slabs.

4. Coupled Chemical / Transport Model

4.1 Model Development

Several steps could be distinguished in the model development process: 1) the chemical model development, 2) the transport model development, 3) the coupled chemical-transport model development and 4) the model validation.

The chemical model consists of a combination of the mineralogical phases and chemical reactions occurring during the product / leachant contact. From the experimental data (especially the static leaching test TS14429) and by using PHREEQC software coupled with the LLNL data base, it is possible to identify the mineralogical phases which may control the target elements release. Three principal steps can be identified in the development of the chemical model:

1) the first step consists of the identification of all mineralogical phases in which the target elements could be found, based on DRX results [Schiopu, 2007], on literature and by using PHREEQC/LLNL. All the mineralogical phases identified in this first step are not necessary the most reactive during leaching. Thus, identification of phases controlling the leaching phenomena was carried in a second step.

2) the approach for identification and quantification of phases controlling the leaching phenomena was to find by simulation the leachates composition obtained experimentally at various pH values (TS 14429 test). The influence of phases that are not integrated in the LLNL data base was taken into account based on literature data. This was the case for the calcium-silicate-hydrate gel (CSH) and the iron oxides which may control the Ca and the Cr release, respectively [Schiopu, 2007]. Some indications about the nature of phases controlling the leaching are given by the saturation index (SI) calculated according to the formula: SI = log ($\Pi a_i v_i$ / Ks), where a_i is the activity of the target element, v_i is the stoichiometric coefficient and Ks is the solubility product equilibrium constant. The phases being in a near equilibrium state with the leachate (i.e. SI close to zero) are considered as controlling phases.The quantification of phases was made based on experimental data obtained at pH values for which the release was maximum (very acid pH, in general) and / or total content.

3) the improvement of chemical model all along the model development process, including during the coupled chemical-transport model step and model validation step by simulating the pilot test.

In a porous monolith as the concrete slabs, the main mechanism of transport is the diffusion. The one-dimensional diffusion equation is used, by considering an equivalent sheet geometry with the same monolith volume ($V_{concrete}$) and the same contact surface area ($A_{concrete}$). The monolith is considered exposed to leachate by only one face and this equivalent sheet is of thickness h = $V_{concrete}$ / $A_{concrete}$. In the leachate comportment, in the case of the open reactors (i.e. CMLT and leaching under outdoor exposure conditions), the transport is realized both by diffusion (coming from the porous monolith) and convection (due to the leachate hydrodynamics).

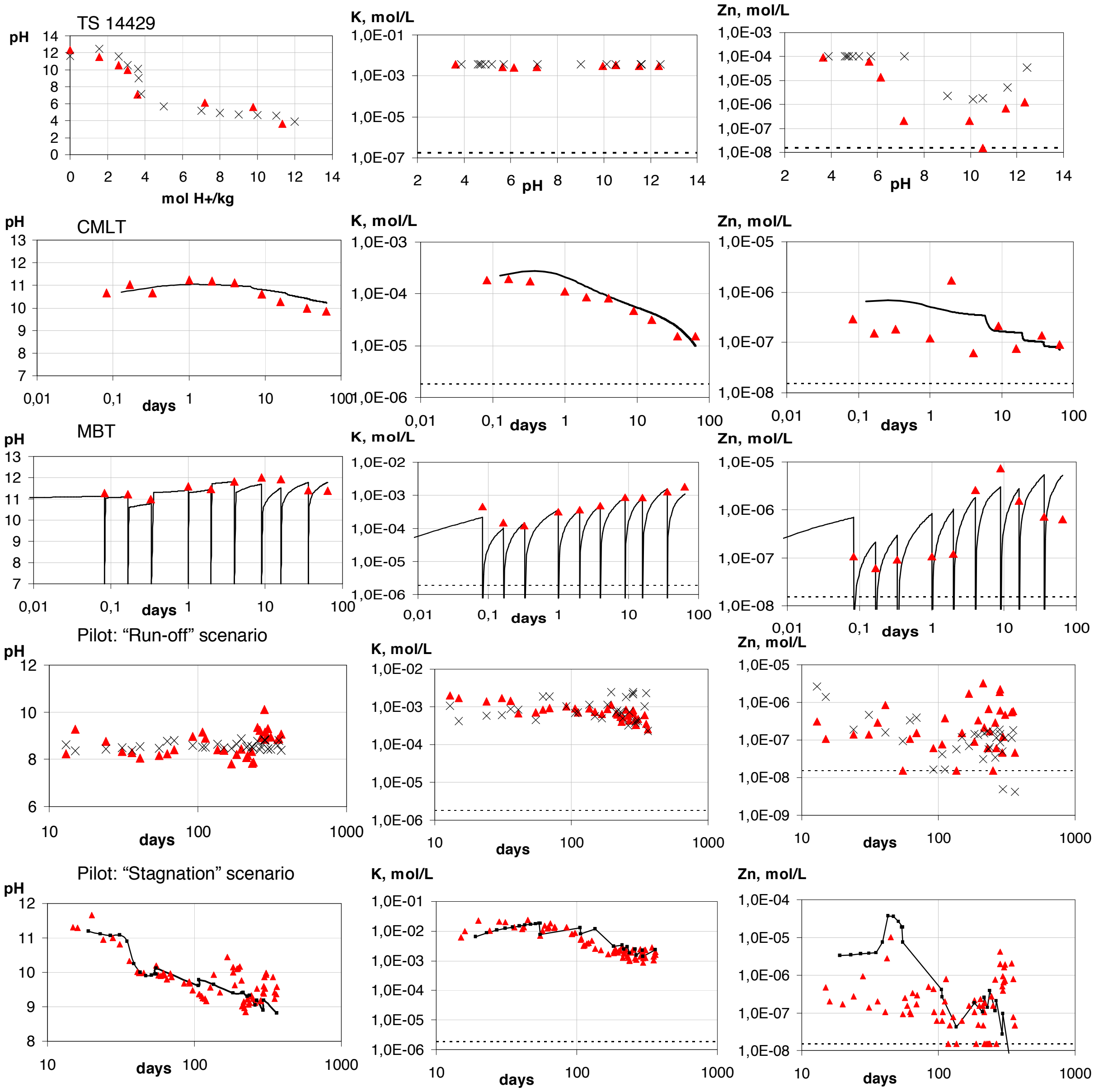
The coupled model chemistry-transport takes into account the physicochemical phenomena as well as the transport phenomena. The development approach consists in an iterative process of comparing the experimental and simulated results obtained for TS14429 and the two dynamic tests (MBT and CMLT), up to an acceptable fit. The chemical model is improved by integrating a kinetic model of dissolution for the CSH and portlandite phases which are major constituents of the matrix. For these two phases, the general kinetic model implemented in PHREEQC is used [Parkhurst and Appelo, 2003]

The model validation was done by simulation of concrete leaching under outdoor exposure conditions. The chemical model developed at laboratory scale was used and improved by integrating the rain water composition and the carbonation effect. The transport model developed at laboratory scale was used (the same diffusion coefficient and the same transport mechanisms) with the specific hydrologic balance of the field test. As function of the scenario type (i.e. "run-off" or "stagnation") the contact conditions were different. The approach adopted for the modelling was to discretize the exposure time according to these conditions. For both scenarios, two main types of conditions were identified: 1) exposure conditions which do not allow substance transfer and 2) conditions which allow and generate substance transfer. The first category (13 % of the exposure time) corresponds to the initial 14 days of exposure without any precipitation (dry conditions) and to the freeze periods (33 days in all, spread over 100 days in winter). The second category (i.e. substance transfer) is dependent on the scenario type. Thus, in "stagnation" scenario, the periods named "1s conditions" (85% of the exposure time) correspond to the stagnation and evaporation of the stagnant leachate. The periods named "2s conditions" (2% of the exposure time) correspond to the strong rain duration, when the stagnant leachate overflows into the collector. In "run-off" scenario, the periods named "1r conditions" (7% of the exposure time) correspond to the rain duration, when the rainwater runs off over the product and goes into the leachate collector. The periods named "2r conditions" (80% of the exposure time) correspond to inter - rain duration, when the diffusion continues into the saturated concrete matrix (intern diffusion). For the « stagnation » scenario simulation, the exposure time was discretized in 15 periods: 8 periods correspond to "1s conditions" and 7 periods to "2s conditions". The freeze periods were taken into account only in the exposure time duration. No structural modification of the concrete was considered. For the « run-off » scenario simulation, the exposure time was discretized in 67 periods: 34 periods correspond to "1r conditions" and 33 periods to "2r conditions".

The conceptual coupled chemical/transport model implemented in PHREEQC is explained elsewhere [Parkhurst and Appelo, 2003]. PHREEQC has not a dedicated module to simulate the open stirred reactor (complex boundary conditions for the diffusion equation). An extension of its application field for modelling the dynamic leaching tests and scenarios was realized and explained in previous works [Schiopu, 2007; Tiruta – Barna, 2008]. The mass balance equation has been written for all elements existing in the leachate. The results are the concentrations of elements in each phase and leachate, including the pH. To couple chemical and transport models, PHREEQC uses the split operator approach. To solve the model, the methods are the Newton-Raphson algorithm for the equilibrium equations, the Runge – Kutta algorithm for the equations describing the kinetics reactions and the finite differences method (explicit scheme) for the transport equations.

4.2 Results

For each target element and pH, the tests simulation results are compared with the experimental results on the same graph (Fig.5). For all tests, the simulated results are of the same order of magnitude as the experimental data. For the Zn, the simulated patterns are in agreement with the experimental data but some deviations are registered; they were assigned especially to very weak concentrations closed to the detection limit (high experimental uncertainty). In the model, the concrete slab was represented by an assembly of 3 very soluble elements considered completely dissolved in the pores water, i.e. Na, K, Cl-, and 8 reactive mineralogical phases, i.e. calcite, Cr-ettringite, CSH, ettringite, portlandite, tenorite, zincite and iron oxides. The effective diffusion coefficient was identified to be $6 \cdot 10^{-12}$ $m^2 \cdot s^{-1}$.



Legend: ▲ experimental x or ▬ simulation - - - detection limit

Figure 5 TS 14429 experimental and simulation results

Figure 5 highlights the variable conditions imposed by the sequential renewal of the leachant during MBT (pH curve). These disturbances generate physicochemical phenomena (e.g. dissolution/ precipitation of the various phases, variation of concentration gradient), artificially induced by the sequential renewal of leachant, which strongly influence the release (strong fluctuations of the leachant / leachates composition). This is not the case for the CMLT when the leaching conditions are constant; the continuously renewal assures the same characteristics of leachant during the test. Hence, the CMLT experimental curves are better representations of the physicochemical phenomena taking place during the test. The MBT experimental curves represent only the leachate composition at the end of each leaching sequence and therefore they are dependent on the sequences duration. At pilot scale, for such complex system as a concrete product exposed to natural/not-controlled conditions the simulated results are in good agreement with measured concentrations.

5. Conclusion

The main results show that in order to assess the substances emission from construction products into water, in a « horizontal » approach framework, the following steps are required and must take into account the product and the exposure conditions specificities:

- physicochemical characterisation of the product, which could be more or less complex, depending on the product and on the knowledge already available ;

- characterisation of leaching behaviour, under static (equilibrium) and dynamic conditions, which must take into account the use of the product during its service life. The Continuous Monolithic Leaching Test (CMLT) seems more suitable for release dynamic assessment;

- modelling of the products behaviour in a specific exposure scenario. The laboratory data cannot be directly transferred to service conditions but they are essential for the modelling of environmental behaviour. The static leaching test TS 14429 is essential for the chemical model development, i.e. the identification and quantification of mineralogical phases controlling the elements release. The dynamic leaching tests, CMLT and MBT allow the transport model development and the coupled model calibration. The model was validated by application at field scale over 1 year of exposure. The simulated results are in good agreement with experimental results.

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SOLAR REDUCTION OF A VERTICAL DECIDUOUS CLIMBING PLANT CANOPY

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Keywords: deciduous climbing plant, shading device, shading coefficient, bioclimatic

Summary

Strategic integration of vegetation to reduce heat gain and to improve environmental quality is increasingly being adopted by building designers. One option to reduce solar gain is to grow climbing plants on a supporting framework external to a building. This is a relatively recent design feature that has little data available to predict its shading performance. This issue is being investigated through a collaborative research project between University of Brighton (UK) and Kasetsart University (Thailand). A thermal model which integrates the shading effects of different leaf layers and their coverage has been developed and experimental investigation started at the University of Brighton. Experiments were set up to collect the environmental and physical growth data of a deciduous climbing plant canopy. The results enabled the development of dynamic shading coefficients which represent the shading efficiency of the plant canopy at different time of its growing cycle. Similar experimental studies were performed at Kasetsart University but with non-deciduous plants. This paper reports on the work carried out at Brighton. It summarises the development of the thermal model, the experimental measurements and analyses to establish a time series function representing the dynamic shading coefficient. The dynamic coefficients were applied to a computer simulation programme to predict the effect of different percentage areas of the climbing plant canopy to indoor thermal conditions.

1. Introduction

In response to the global awareness of environmental impact of buildings, more designers are adopting 'bioclimatic' principles to regulate the indoor thermal environment. One such design is the use of live plant canopies as external shading devices, which can not only regulate the solar gains, air temperature and humidity, but also improve air quality and the aesthetic of the building. As climbing plants grown on an external framework is a recent design feature, knowledge on their performance is scarce. This research project, in collaboration with Kasetsart University, explores and validates, through experimental investigation, an appropriate methodology for evaluating the thermal and environmental performance of climbing plant canopies. This paper reports on the outcomes of the experimental studies on the shading performance under the UK climate. The thermal studies by Kasetsart University including the air quality evaluation are reported in separate publications.

2. Bioshading device

The shading device consists of one or more vertical climbing plants that trail on a metal framework which is located in front of the building façade as shown in figure 1. The climbing plant for the experiment was selected based on a number of established criteria that include: plant height, growing cycle, façade orientation, leaf coverage, soil type and local climate. To take advantage of winter solar gain in the UK, only deciduous plants were considered. Virginia Creeper was selected for the study after a detailed evaluation process (Lam, 2007).

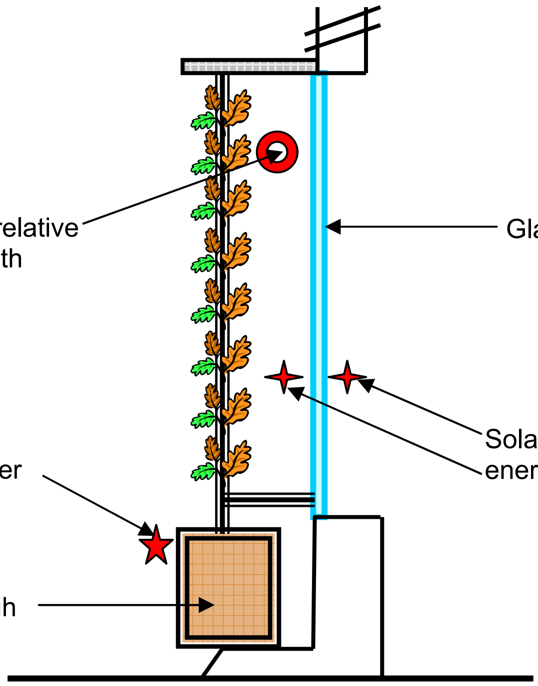


Figure 1: Vertical climbing plant shading device

3. Bioshading coefficient

Unlike a static shading device, the shading coefficient of a climbing plant canopy is not constant but changes with growth behaviour of the plant. A new term 'bioshading coefficient' is proposed to represent this dynamic shading performance (Ip et al., 2004) as:

$$BSC(s) = \frac{Q_{bioshader(s)}}{I_{0(s)}\left(\sum_{k=0}^{n} L_k\right)_{(s)}} = \frac{Q_{bioshader(s)}}{I_{0(s)}\left(A\right)_{(s)}} \tag{1}$$

The solar gains behind the bioshader canopy $(Q_{bioshader})$ can be broken down into three main components; they are: the amount of transmitted radiative heat transfer through the bioshader (I_{trans}), the long wave radiation between the leaves and the building facade (I_{l-w}), and the amount of direct radiation passing through the open gaps of the bioshader.

These three components of radiation received behind the bioshader can be expressed as:

$$\begin{aligned} Q_{bioshader(s)} &= \left(L_0 I_0\right)_{(s)} + \left[L_1 I_0 T_1 + L_2 I_0 T_2 + \ldots\ldots L_n I_0 T_n\right]_{(s)} \\ &\quad + \left[L_1 I_{(l-w)(1)} + L_2 I_{(l-w)(2)} + \ldots. L_n I_{(l-w)(n)}\right]_{(s)} \\ &= \left(L_0 I_0\right)_{(s)} + \left(I_0 \sum_{k=1}^{n} L_k T_k\right)_{(s)} + \left(\sum_{k=1}^{n} L_k I_{(l-w)(k)}\right)_{(s)} \end{aligned} \tag{2}$$

Applying this result to equation 1, the bioshading coefficient at time s becomes:

$$BSC(s)=\frac{(L_0I_0)_{(s)}+\left(I_0\sum_{k=1}^{n}L_kT_k\right)_{(s)}+\left(\sum_{k=1}^{n}L_kI_{(l-w)(k)}\right)_{(s)}}{\left(I_0\sum_{k=0}^{n}L_k\right)_{(s)}}=\frac{(L_0I_0)_{(s)}+\left(I_0\sum_{k=1}^{n}L_kT_k\right)_{(s)}+\left(\sum_{k=1}^{n}L_kI_{(l-w)(k)}\right)_{(s)}}{(I_0A)_{(s)}} \quad (3)$$

Where:

s = Time (in days) starting from the beginning of the year

$BSC(s)$ = Bioshading coefficient at time s

$Q_{bioshader(s)}$ = Solar gain measured behind the bioshader canopy at time s $[W]$

$I_{0(s)}$ = Ambient solar radiation perpendicular to the bioshader at time s $[Wm^{-2}]$

$A=\sum_{k=0}^{n}L_k$ (Area of the façade shaded by bioshader) $[m^2]$

L_k = Area of multi-leaf layer k $[m^2]$

k = Number of leaf layer

s = Time (in days) starting from the beginning of the year

T = Leaf solar transmission coefficient

n = Maximum number of leaf layers

$I_{(l-w)}$ = Radiation exchange per unit area between leaf and facade $[Wm^{-2}]$

The above equations are mathematical representations showing the key variables and their relationship in the bioshading coefficient. They enable the identification of parameters to be measured and monitored in the experimental investigation.

4. Experimental investigation

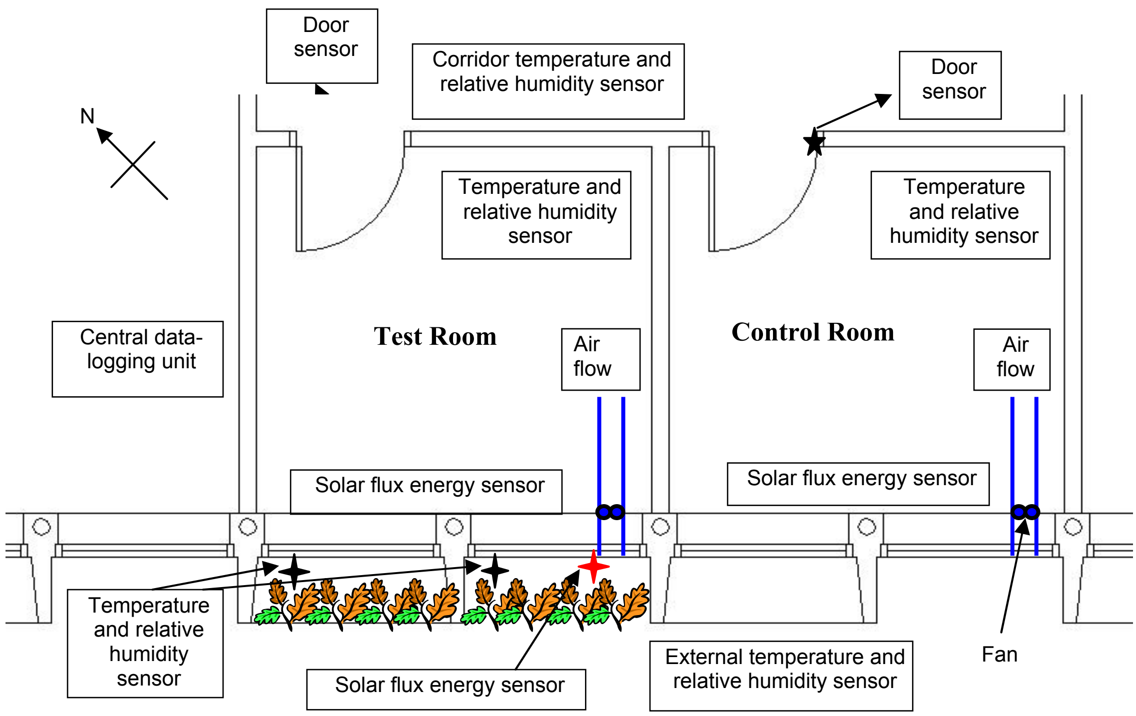


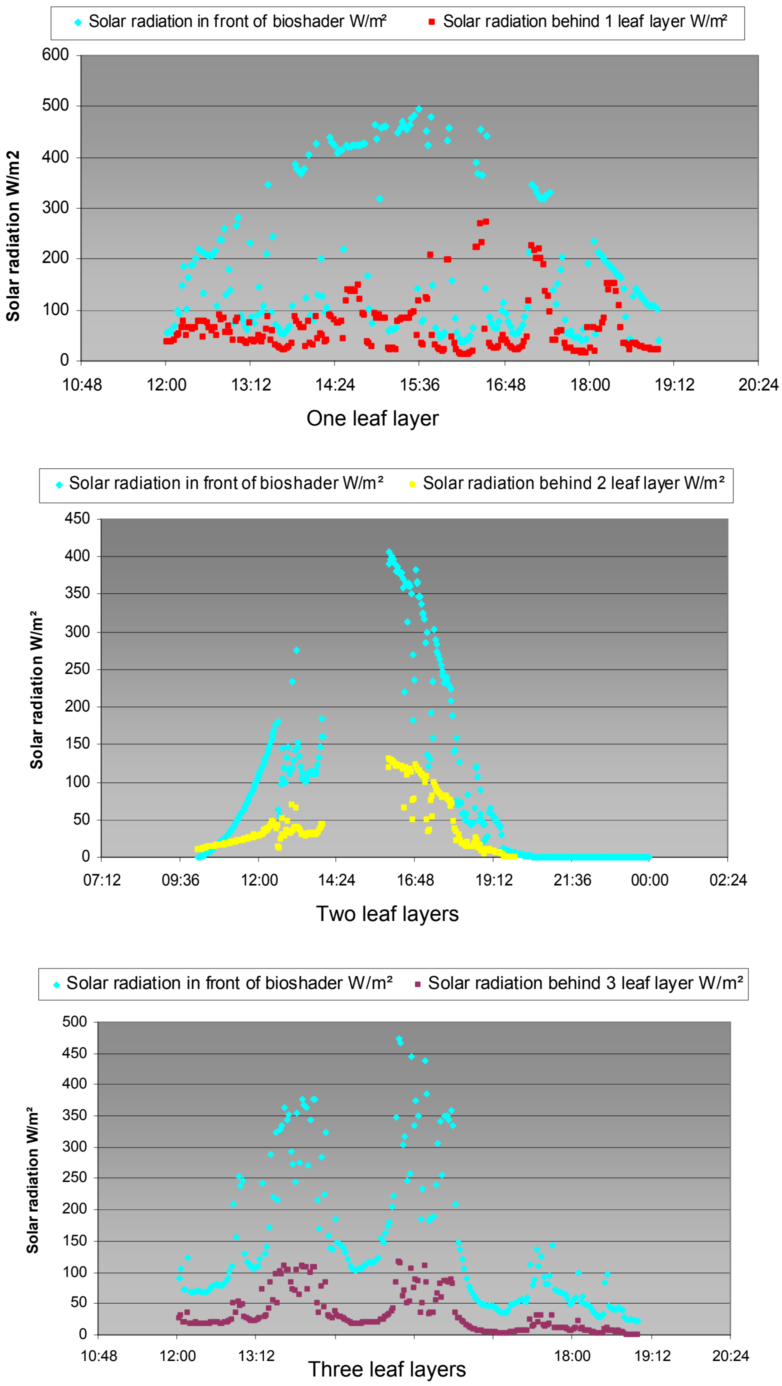
Figure 2: Plan showing locations of sensors and monitoring equipment

Two offices, one for the test and the other for control, on the first floor of a university building were used for the experiment. Two proprietary metal trellis were installed external to the test room. Monitoring equipment and sensors were employed to measure the parameters identified in the thermal model these include: temperature and relative humidity sensors, solar flux sensors, a dome solarimeter, air velocity sensors, door sensors, a data-logger and a personal computer. Figure 2 shows the locations of these sensors and equipment in the offices.

5. Results and analyses

5.1. Solar reduction of leaf layers

Examples of solar radiation data measured over one day behind one to four layers of Virginia Creeper leaves are summarised in figure 3. The corresponding horizontal solar radiation is plotted for reference. These data were collected on different days with different weather conditions. Scattered data distribution indicates more varied solar radiation levels as happened on cloudy days.



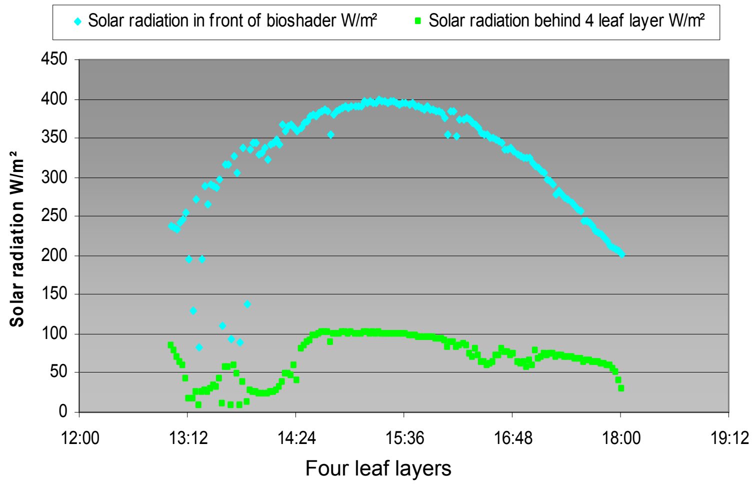


Figure 3: Solar radiation measured in front the canopy and behind 1 to 4 leaf layers

5.2. Leaf coverage

The change in leaf layers and their corresponding area on the plant canopy were extracted from digital images taken at regular intervals. The results for Window A in the test room are summarised in figure 4. Similar results were recorded for Window B. Pruning was necessary as the plant had reached its maximum coverage and overgrown due to the restriction of the window.

5.3. Bioshading coefficient

Taking the results of the leaf solar reductions and their corresponding coverage, a series of bioshading coefficients were established based on the concept of bioshading coefficient developed in section 2. A best fit curve was plotted to provide a continuous mathematical representation of the bioshading coefficients.

The R-square value of this curve is over 0.87 which shows very good fit between the day of the year and the bioshading coefficients. The time-series equation to represent the shading performance of the bioshader is expressed as:

$$BSC_{(s)} = 6 \times 10^{-5} s^2 - 0.027s + 3.5324 \qquad (4)$$

Where:

$BSC_{(s)}$ = Bioshading coefficient on day s

= 1 if $s \leq 133$

= 1 if $s \geq 316$

s = Day of the year ($1 \leq s \leq 365$)

The bioshading coefficient time-series in figure 5 shows the cycle shading performance which corresponds to the three growing phases over the year between April and October.

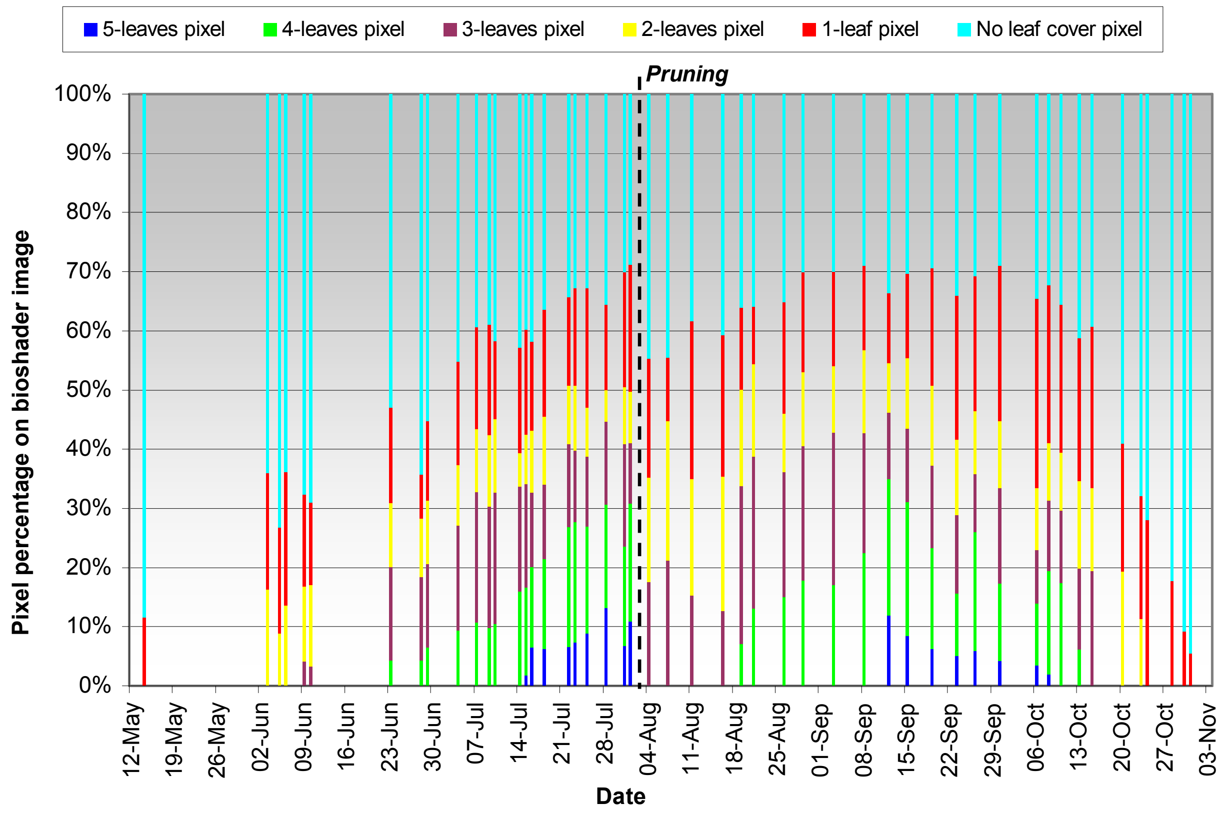


Figure 4: Coloured pixel distribution showing coverage by different layers of leaf on Window A of test room

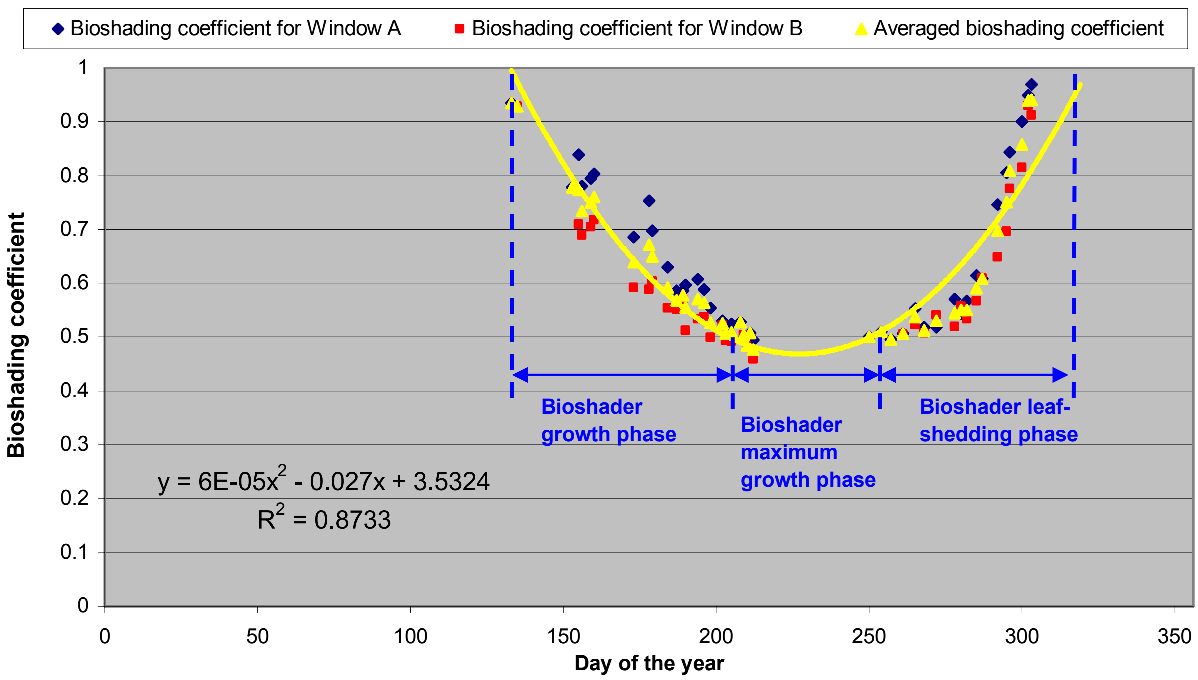


Figure 5: Bioshading coefficients and the best-fit curve

6. Computer simulation

Bioshading coefficients were applied to a dynamic thermal simulation IES VE (IES, 2007) software to predict the shading effect to the indoor thermal condition. The building model, image shown in figure 6 together with the simulation weather profile, is constructed to meet the minimum standard of the current building regulations in the UK. The south facing façade of this naturally ventilated building is shaded by the vertical climbing plant canopies. Four percentages (20%, 50%, 70% and 90%) of glazed window areas shaded by the external climbing plant were studied. Results for the south facing middle office on the first floor are illustrated in figure 7 to demonstrate the shading effect. Each graphs in figure 7 shows the resultant temperatures with and without the shading devise. The results show the shading effect is more pronounce in the summer as the leaf cover increases. The indoor temperatures during the peak summer in August were significantly reduced even the glazed area is as high as 90%. Taking the first of August as an example the average resultant temperature for all cases with the shading device is below 24°C while the temperature can be as high as 35°C without shading. The drop in temperatures ranges from 6°C for 20% and 50% glazing, to 10° and 11°C for 70% and 90% glazing.

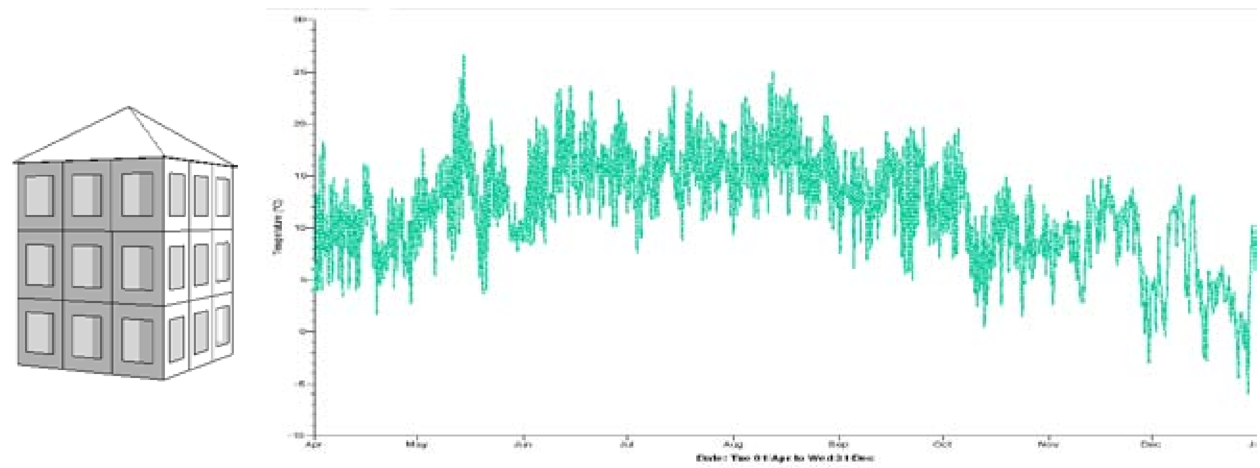


Figure 6: Simulation model and weather profile (IES, 2007)

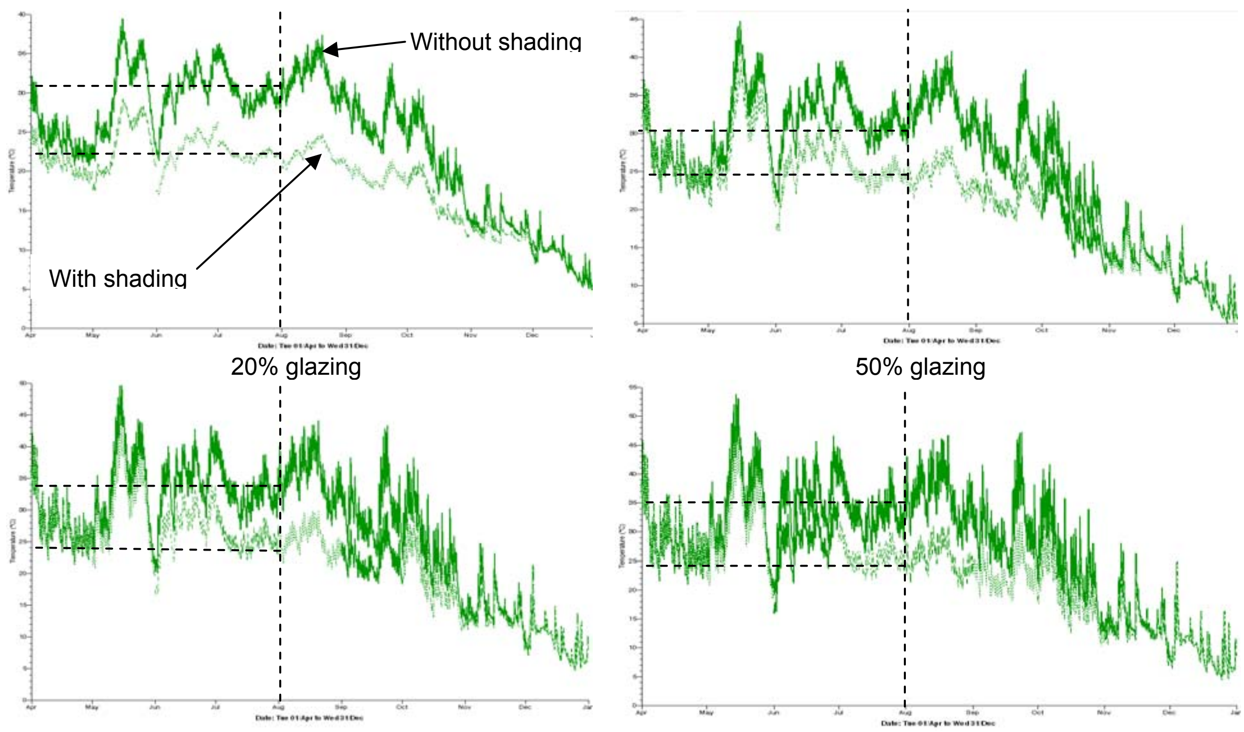


Figure 7: Effect of climbing plant shading to the indoor resultant temperatures with different percentage glazed areas

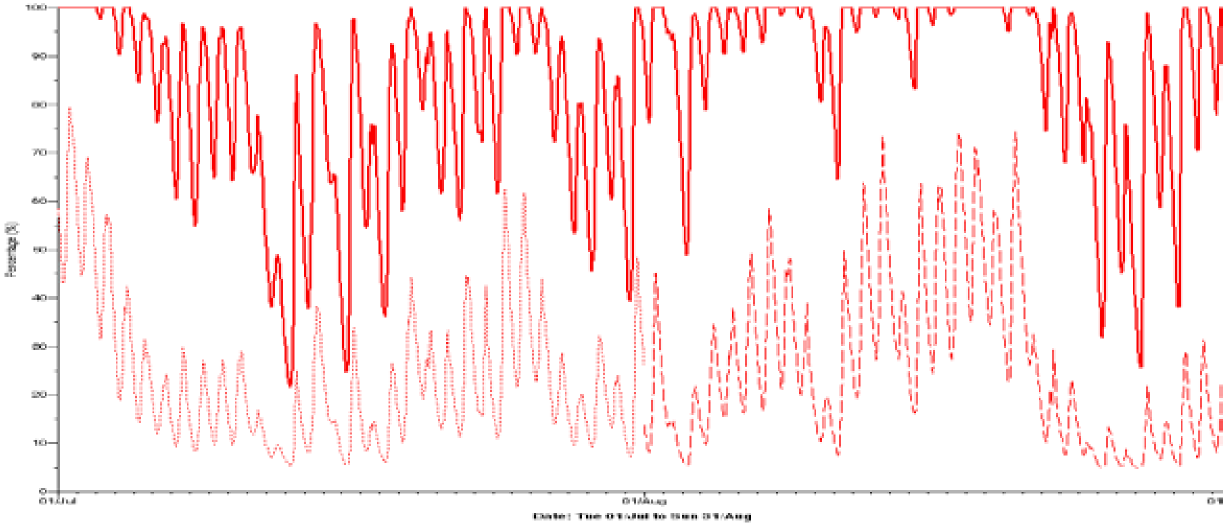


Figure 8: Percentage dissatisfied with 90% glazed area shaded by the climbing plant canopy

Figure 8 shows the predicted percentage of occupants dissatisfied with the thermal comfort for July and August for the case of 90% glazing. The dissatisfaction has significantly reduced from an average of around 80% to an average of about 30%.

7. Conclusion and future work

This research has successfully developed a methodology to quantify the shading performance of an external deciduous climbing plant shading device. The mathematical model has identified the key parameters related to the shading performance. Through an experimental setup at the University of Brighton, these parameters were measured and applied to establish the daily bioshading coefficients and subsequently a continuous function of a best fit time-series equation. This equation provides the shading performance data for the simulation program and enables the climbing plant shading device to become an integral component of the thermal model in the dynamic thermal simulation of the building. The current work can only be considered as embryonic yet revealing to the broad range of further and future work in this field. The collaboration with Kasetsart University in Thailand will continue to explore measurement of wider range of regional plants; to develop the scientific techniques to measure and quantify the dynamic heat and mass transfer of plants; and to include other parameters, such as air quality, that improves the environmental quality due to the integration of plant in the built environment.

Acknowledgement

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INTEGRATING ENVIRONMENTAL ASSESSMENT AND DESIGN

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Keywords: environmental, assessment, performance, target, ITACA, design

Summary

The environmental load due to the building industry has become a main issue for Italy. In the last few years, Italian regions and iiSBE Italia worked together to develop a tool to assess the environmental performance of new residential buildings, called Protocollo ITACA, to become a common reference to verify the environmental performances of buildings. Eventually this tool went public, being mentioned in a great number of design competitions and becoming increasingly well known by building designers as well as constructors.

Protocollo ITACA assesses a list of criteria concerning various different aspects related to the building and its impact on the environment (such as materials, water and energy consumption, indoor air quality, etc). The scores achieved in each of the criterion will contribute to determine the environmental performance level of a building. Such environmental assessing system can become an useful support to design, to be used during the creative phase, proposing a precious aid to the systematic control of the achievement of the performance thresholds required. Once set a target minimum environmental performance, the designer should be able to assess and monitor the effectiveness of the different design options in order to satisfy the performance required.

In order to define a way to gradually lead the designer through the integration of environmental assessment and design process, two different experiences have been carried out, each one of them reflecting a particular approach: the first test, on the Piano Casa of Liguria Region, involved the designers directly through a self-assessment process; the second test, on the Sustanaibility Meta Distretto of Treviso, involved the designers only in the collection of significant data, while the assessment phase was carried out by a technical department. Strengths and weaknesses of the two procedures will be compared.

1. Protocollo ITACA

1.1 Introduction

In an economical and social context where the environmental topics have become increasingly more relevant, due to an increased awareness on the effect of our actions on the near future, it has become necessary for the building sector to question its responsibilities and to set new targets. The building sector is one of the main actors in the increase of resources consumption and the related environmental loadings.

Some designers which in the last years have tried to apply a sustainability-oriented design, considering the building as a complex system interrelated to its environmental context, have found themselves confused by the absence of clear reference points, while being on the other hand confused by different and mixed information – due to the recent proliferation of manuals, guidelines, and training courses. The excess of available data can lead to misinformation, falling short of the expectations and good will of those who try, with their work, to contribute to improve the built environment, aiming at higher performance standards.

Protocollo ITACA represents an effective solution to define sustainability targets, while providing a method to clearly assess the design efforts made to satisfy such targets.

1.2 What is Protocollo ITACA

Protocollo ITACA is an assessment system developed by the ITACA workgroup (Istituto per la Trasparenza degli Appalti e la Compatibilità Ambientale – Institute for Transparency and Environmental Compatibility in Contracts) which allows to assess the energetic and environmental quality level of a building, measuring its performance against a number of assessment areas and criteria, following the structure suggested by the iiSBE Method.

1.3 Protocollo ITACA – Synthetic

Protocollo ITACA, in its first edition, was composed by 70 criteria grouped in 7 main areas, to approach the theme of sustainability in an ample and diverse way. To aid the actual application of the system a more compact version became necessary. This need led to the draft of a Synthetic version of the Protocol which reduced the number of criteria and areas, while keeping the same underlying structure. Up to this day, the main applications of the Protocollo ITACA by the public administrations have been based on the Synthetic version.

1.4 Application of Protocollo ITACA

Protocollo ITACA was designed as an assessment system of the energetic-environmental performance level of a building. It is thus used wherever it proves necessary to define the environmental sustainability level of a building, through a codified process.

Protocollo ITACA is becoming a strong reference for private and public bodies, which need to define classifications or threshold levels of the environmental quality.

The version of the Protocollo discussed in this paper is aimed at the assessment of the performance of residential buildings.

1.5 Technical specifications of Protocollo ITACA

Protocollo ITACA is based on a requirements matrix, organized in single criteria depending on various assessment areas. To each requirement corresponds a performance indicator and a reference scale. Through the processing of the design data, it is possible to obtain the value of the performance indicator for each requirement, to be confronted with its reference scale. The output is a number of scores which represent the performance levels obtained. These scores, suitably aggregated, will concur to the definition of the global performance level of the building. The term “performance” indicates the response to a precise need, which in this case is the improvement of the sustainability level of the building.

For each criteria, the Protocollo ITACA gives the following information :

the *intent*, defining which environmental quality target was set; the *performance indicator*, or the parameter used to assess the performance level of the building under the criterion; this parameter can be a number or a scenario; the *measurement unit* – for numerical indicators only; the *verification method*, defining the procedure to establish the performance level of the building under the criterion; the *performance scale*, defining the score obtained by the building based on the performance indicator level obtained through the verification method; the *legislative references*, i.e. the laws or regulations in the area; the *reference standards*, i.e. the technical regulations used to set the performance scales and the verification methods; the *required documentation*, i.e. the information to be provided to justify the attributed score; the *notes*, to clarify doubts on the criterion verification.

Following the instructions specified in the *verification method*, it is possible to calculate for each criteria the *performance indicator* value. Through a comparison with the *performance scale*, this value is related to a score expressing the improvement achieved by the building over the minimum acceptable performance.

During the assessment the building can obtain, for each criterion and sub-criterion, a score ranging from -1 to +5, based on the performance level achieved.

-1 represents a sub-par performance, lower than common building practice;

0 represents the minimum acceptable practice, based on laws, standards or common building practice (when no regulation is available);

3 represents a significant improvement of the performance, compared to regulation or common building practice. It corresponds to the best building practice;

5 represents a significant improvement of the best bulding practice. It corresponds to experimental practices.

The scores achieved in each criterion or sub-criterion are weighted and aggregated to determine the scores of each area. The weighted output of the area scores is the global score.

2. Case Studies

2.1 "Piano Casa" of Liguria Region

The first testing started in July 2007, in the Social Housing Incentive Program promoted by Liguria Region, aimed at increasing the social housing apartments to be rented. The target of this initiative was to give a concrete answer to the detected need of the various types of social housing solutions. It has been decided to attribute financing benefits to the projects that proved to reach a set environmental performance level.

2.1.1 Test targets and restrictions

To estimate, in a transparent and objective way, the effectiveness of the sustainable design solutions of each project applying to the program, a point-based assessment system was need. Thus the system prepared by the ITACA workgroup was selected as reference, with some changes to the basic scheme.

The project's environmental performance level was asked to be calculated directly by the designer, following the indications of the assessment system.

2.1.2 Structure of the test

Each designer received a series of documents to support the self-assessment phase. Such documentation was aimed at explaining the contents of the assessment system, to calculate in an autonomous and semi automatic way the performance level obtained by the building, and to prepare the documentation needed in the validation phase.

The designers received:

the *Assessment System*, i.e. the document explaining each criteria through which the building was to be assessed, and their verification methods;

the *Calculation Tool* to self-assess the project, i.e. an electronic-format document through which the designer could calculate the final score achieved by the building;

the *Data Gathering File*, i.e. a synthesis document which had to be filled with the main data used in the performance indicator calculation for each criteria.

After calculating the performance indicator for each criteria, the designers filled out the *Calculation Tool* for the self-assessment of the project. Through this tool, the designers inserted the calculated values of the performance indicators, and obtained automatically the final assessment value.

2.1.3 Results

Regarding the Assessment System, the verification procedure was not always applied correctly, partly due to errors in the interpretation of the requirements of the Protocollo partly to the absence of reference standards and regulations. Moreover, the design documentation provided was in some cases not adequate and sufficiently detailed to verify the adequateness of the given data and the correctness of the calculation of the performance indicator. This implied, for almost every design team, the request of further documentation integration. On the other hand, the functioning of the *Calculation Tool* for the self-assessment of the design proved to have been understood in most cases.

2.2 "Meta Distretto Bioedilizia" of Treviso City

A further chance to test the integration of an energetic-environmental assessment tool in the design process was offered by a consulting and collaboration project with the City of Treviso and its "Meta Distretto Bioedilizia" (Sustainable Building Meta District).

2.2.1 Test targets and restrictions

The requirement of the Meta Distretto was to develop a system which could be able to aid quality in buildings, while avoiding the need for prescription in the local regulations. The aim was to introduce the option to attach to the technical and graphic design documentation a new document, certifying the level of the environmental performance of the building. The Meta Distretto wanted to define a tool which could be able to perform the assessment automatically.

2.2.2 Structure of the test

An electronic tool was prepared in order to support both the designer to collect the relevant building information and the technical department – performing the assessment of the projects – to assign automatically the final score. The electronic tool to self-assess the projects was divided in two distinct and complementary modules.

The first module (Module A) collected all the project data to be used in the assessment, processing them to obtain the value of each performance indicator. Module A was filled by the designers by inserting the required data or selecting the appropriate scenarios. The second module (Module B) was formed by the weighting system, the performance scales and the algorithm which processed the results of Module A, to output automatically the final score. Module B was managed by the technical department.

2.2.3 Structure of the Modules: Module A

To perform self assessment of the project, the designer used the data input module to collect the significant project data. This module, called Module A, was to be filled out in each section, dived as follows:

Context and site input: a file collecting data on the context and the site (Note: some context data can cancel the applicability of the performance criteria in which they are involved, and thus causing an automatic redistribution of the final weights of the criteria); *Building input*: a file collecting data on the building in general; *Indoor environment input*: a file collecting data on the indoor zones of the building; *Materials and building elements input*: a file collecting information on materials and building elements; *Technical systems input*: a file collecting information on the components of the technical systems; *Scenarios:* a file collecting the scenarios of the qualitative criteria, among which the designers had to select the best scenario describing the specifics of the project; *Calculation sheet*: a file collecting the simplified tools prepared to calculate the indicators of the criteria; *Summary output table*: a file containing the indicator values to be confronted with the reference values of the performance scales in Module B.

Module A had to be filled out in all its sections, inserting the design values or selecting the scenarios. The data obtained was processed and transformed automatically into the performance indicators required by the assessment system. The designer had no direct access to the spreadsheets, but could only read the results of the process in the Results sheet. The output data in this sheet constituted the values required to complete the assessment through Module B.

2.2.4 Structure of the Modules: Module B

Module B, to which the designers had no access, was a Tool reserved to the technical department. It was linked to the results obtained by Module A, from which it extracted – for each criterion – the performance indicators and compares them to the performance scales.

Through a weighting process of the values and their aggregation, a summary output table was obtained, showing the area scores and the final assessment score.

2.2.5 Results

This tool can be considered as an innovation which allows designers to assess the energetic and environmental performance of a building in a guided, simple way. Also the technical department personnel found in it a strong support to the final score processing, without the need of specific training.

On one hand, the automation of the calculation procedures allowed to quicken the assessment process and to reduce errors in the interpretation of the verification methods. On the other hand the designers were unable to see the direct effect of the design choices, useful to improve the overall performance of their projects. This is a direct consequence of the thematic areas composing Module A, which had no clear correspondence between the inserted data and the assessment system criteria, giving to the designers no perception on when and how such data were processed to define the final score.

2.3 Conclusions

The merits of the environmental assessment systems such as Protocollo ITACA have been the schematic organization of the requirements, the definition of reference performance levels, and the development of specific methods to assess the performance of buildings. It is thus possible to define in a transparent, measurable and shared way the sustainability targets which have been selected. Such assessment systems can become an useful support to design, to be used during the creative phase through which control the performance thresholds achieved.

The Italian experiences described in this paper aimed at testing different approaches in integrating the use of the environmental assessment system within the design process. The advantages given by the assessment tool prepared for the Sustainable Building Meta Distretto of Treviso turned out to be helpful to avoid calculation errors and diversity of data, as found during the test carried for the Liguria Region, but on the other hand it created a gap between the designer and the assessment tools of the project. In our opinion understanding the connections between the design choices and their effect on the environmental themes is fundamental to give consciousness to the designer on its actions, and to further stimulate his creativity. Thus the next challenge is to define a tool which can combine the two different approaches described.

BUILDING ENVELOPES WITH CONTROLLED THERMAL RESISTANCE

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Keywords: controlled thermal resistance, energy performance, low energy buildings

Summary

The paper is devoted to the analysis of possibility for construction of low energy buildings with envelopes controlled for minimization of energy consumption by air conditioning systems. It describes the possibilities to reduce energy consumption of large public buildings mainly in summer time when there are the highest electricity demands for cooling. Energy consumption depends on parameters of outdoor and indoor air, energy performance of the envelope and inside heat and moisture emissions. The paper gives a complex mathematical model for controlled envelope's thermal resistance depending on outdoor parameters. It proposes constructive suggestion to create buildings whose walls, roofs and glassed surfaces have changeable thermal characteristics and methodology of control for separate elements (double skin facades, multiple films on windows, ventilated curtain walls, automated venetian blinds). The paper analyses the impact of building envelope thermodynamic characteristics on the parameters of supply air in air conditioning systems. It describes the change modes of thermal resistance, resistance to water vapour transfer and resistance to solar radiation considering the different states of inside and outside air conditions. As the result the paper gives theoretical algorithm of regulation of building envelope thermodynamic characteristics in ideal conditions based on minimization of energy use by air conditioning systems

1 Introduction

Traditionally low energy buildings are supposed to have maximally big thermal resistance of building envelope. In reality big thermal resistance is justified only in coldest winter days in countries with cold climate or in hot summer days with intensive solar radiation. In other periods buildings with full air conditioning would have to have different properties of building envelope that could allow heat flow in one or another direction. There are also periods when minimal resistance to vapour transfer is required. Sometimes the building envelope is needed only to prevent from rain, insects or to give the intimacy and it is not needed from the point of energy efficiency, as it does not have to form the shield against the heat or vapour flow(Todorovic 2004).

The fact is known to the scientists who use simulation of building energy performance during the whole year. Building energy performance simulation models allow choosing optimal characteristics of building envelope on the basis of annual heat consumption. The model described in this paper would help to optimise building energy performance even more on the condition that we can change the properties of building envelope.

The properties of real building envelope allow:

1) to minimize heat flow from the inside space to outside environment and vice versa;
2) to minimize or completely prevent vapour transfer across the building structures;
3) to minimize or prevent the influence of solar radiation on the inside space conditions.

The abilities of building envelope to prevent heat flow arousing due to the temperature differences of inside and outside air is characterized by thermal resistance of building stricture R_T, m^2K/W.

The ability of building structure to prevent water vapour transfer is characterized by the resistance to water vapour transfer R_V, m^2 h·Pa/mg.

Speaking about the solar radiation there is no common parameter for characterization of the building envelope ability to resist the influence of solar radiation. But this property of building envelope may be shown as resistance to solar radiation R_R. The resistance to solar radiation:

$$R_R = \frac{\Phi_R - \Phi_I}{\Phi_I}, \qquad (1)$$

where: Φ_R is heat flow from solar radiation coming to the outer side of building envelope, W; Φ_I is the solar radiation heat flow that got inside, W.

2 Modelling of air conditioning system working regimes

In order to ensure optimal comfort conditions of indoor air quality in dwelling buildings the air conditioning system has to consist of the following main parts: heating devices, humidifier, air cooler, control equipment for the automatic regulation of heating devices and air humidity. For the comfortable air conditions the supply air temperature has to be in the *comfort zone* confined in area of temperatures θ_{Smin} ... θ_{Smax} and air humidity φ_{Smin} ... φ_{Smax}. This zone is shown at the *H-x* diagram (Figure 1) and represents the calculated climatic conditions that can be ensured by the previously mentioned regulation facilities of ventilation system(Kreslins 1976).

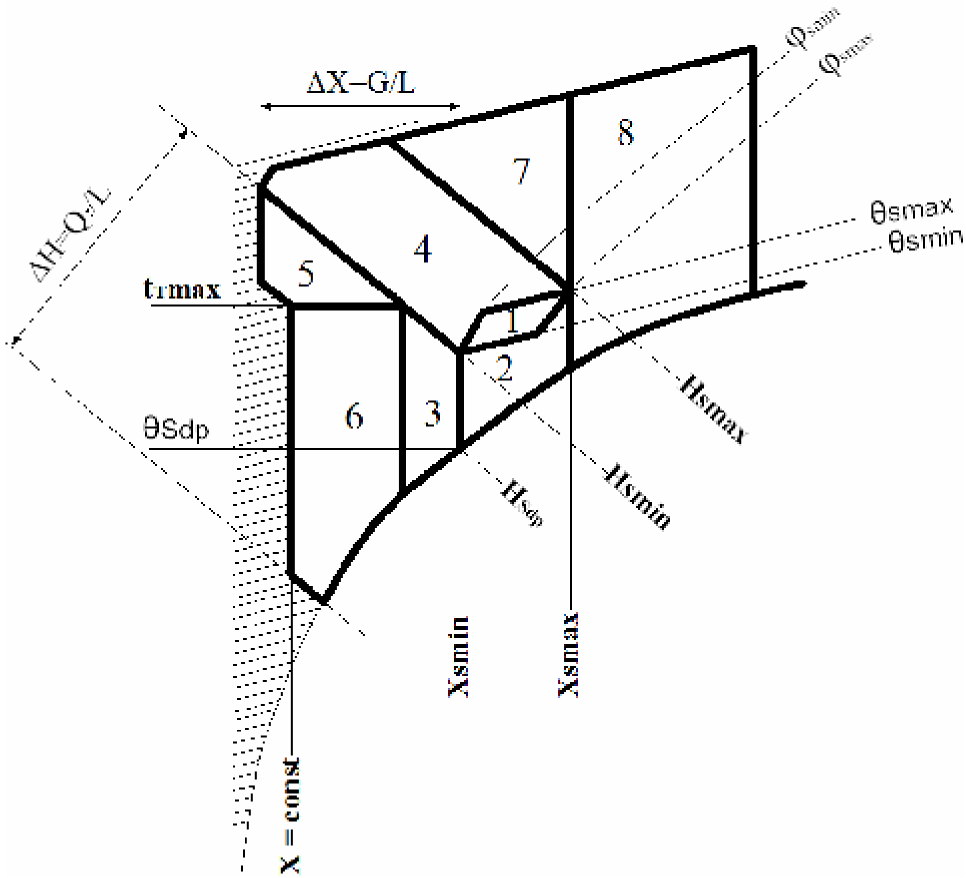

Figure 1 The indoor air comfort zone and regulation regimes on H-x diagram(H – enthalpy, kJ/kg; x – moisture content, g/kg; θ – temperature, °C; φ – relative humidity; Q_T – heat source capacity, kW; G – humidifier capacity, g/s; L - air quantity, kg/s)

There are eighth system regulation regimes depending on the conditions of the outdoor air and required indoor air parameters:

- in the 1st zone the outdoor air parameters match required indoor air parameters so the heating devices and air humidifier are switched off;
- in the 2nd zone the air is heated by the convector till the minimal required temperature θ_{Smin} if φ_{Smin} ... φ_{Smax} or till maximal relative humidity φ_{Smax} if θ_{Smin} ... θ_{Smax};
- in the 3rd zone the air is heated by the convector till enthalpy is H_{Smin} and then it is moisturized till φ_{Smax};

- in the 4th zone the air is only moisturized till the comfort zone upper level - till φ_{Smin} if θ_{Smin} … θ_{Smax} or till θ_{Smax} if φ_{Smin} … φ_{Smax} ;
- in the 5th zone the air is moisturized till moisture content is x_{Smin} and then additionally heated by other heating devices till θ_{Smin};
- in the 6th zone the air is heated till the maximal possible temperature $\theta_{Tmax}= t_{Tmax}$; moisturized till moisture content is x_{Smin} and then additionally heated by other heating devices till θ_{Smin}
- in the 7th zone the air is cooled till comfort zone minimal temperature, θ_{Smin} or less in case, when internal heat gains are too high;
- in the 8th zone air is cooled till X_{Smax} or till X_{Smax} and then additionally heated by heating device till θ_{Smin}.

There are four main temperatures that are usually distinguished in air conditioning. Two of them are widely used in all other calculations: the temperature of outside air θ_e, and the temperature of inside air θ_i,. Two others are connected to the thermodynamic processes in the air of inside space and may be higher or lower than inside and outside air temperatures (Kreslins 1984). These temperatures are: the temperature of supply air and temperature of exhaust air (Figure 2).

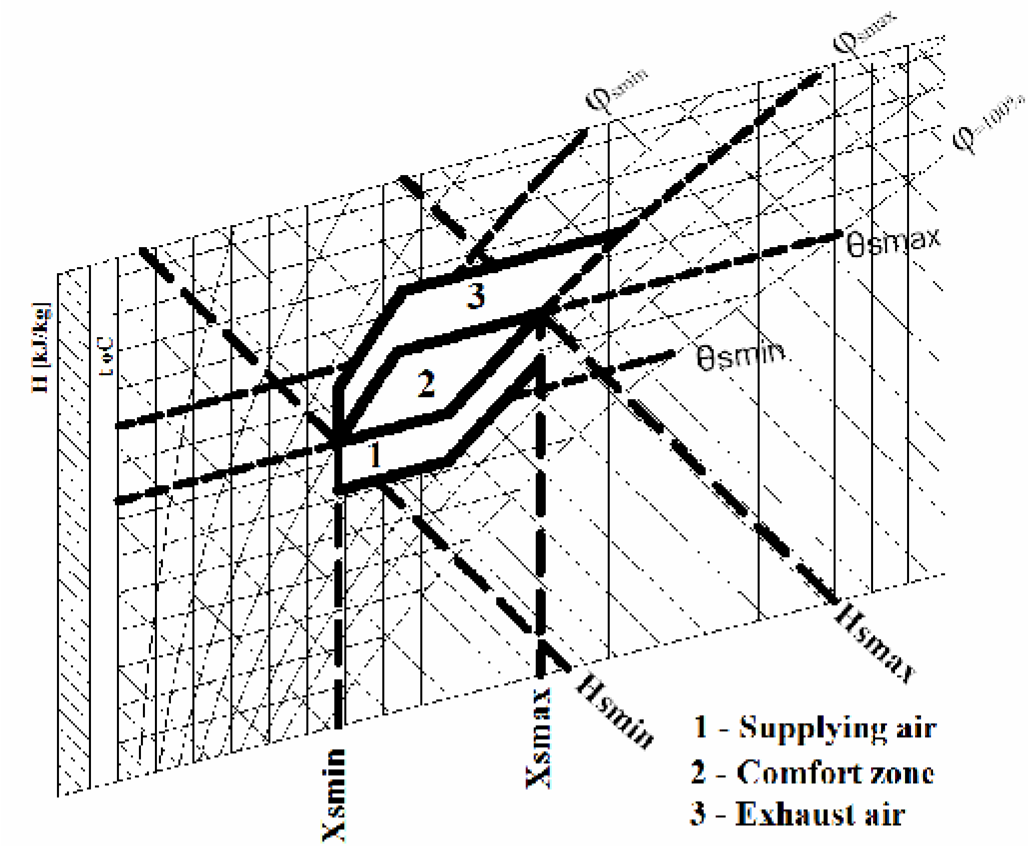

Figure 2 The air parameters in air conditioning system

3 Possibilities to improve performance of air conditioning system using building envelopes with controlled thermal resistance

Building envelopes with controlled thermal resistance can be efficiently used in hot summer periods, when the outside air temperature is much higher than inside air temperature. In such case the classic air conditioning system should work in 8th regime (Figure 3).

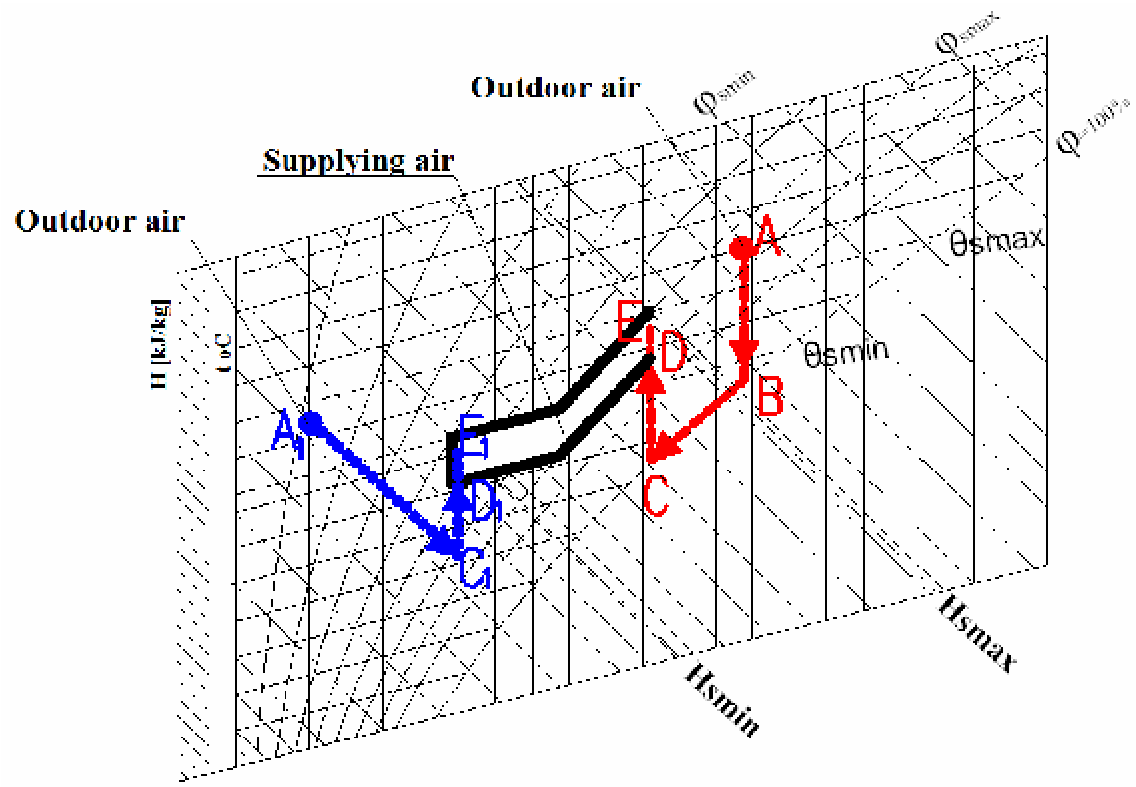

Figure 3 Typical air conditioning working regimes ("dew point regime")

In that working regime after the outdoor air cooling (process A-B-C) the heating device heats up supply air till minimal required temperature (C-D) and internal heat gains further heat air till comfort zone (D-E). Although it is possible to reduce heating loads using solar radiation and heat transfer from outside air to inside thought the building envelope in order to heat up outdoor air till minimal required supplying air temperature. For that purpose it is necessary to reduce thermal performance of building envelope and resistance of glazing surface to heat radiation.

In general the capacity of air conditioning system could be calculated using the following equation:

$$Q_{total} = \Delta H_{cooling} + \Delta H_{heating}, kWh \qquad (2)$$

where: ΔH_c – energy consumption for outdoor air cooling, kWh; ΔH_h – energy consumption for supplied air heating, kWh.

In case when external heat gains could be used for supply air heating the energy consumption of air conditioning system for air heating will be equal to external heat gains:

$$\Delta H = Qe.g \qquad (3)$$

The simplified external heat gains could be calculated as follows (ASHRAE 2001):

$$Q_{e.g} = \frac{1}{R} A(\theta_i - \theta_e), kWh \qquad (4)$$

where: R - thermal resistance, m^{2}K/W; A – area of building envelope, m^2; θ_i – indoor air temperature, ^{0}C; θ_e – outdoor air temperature, ^{0}C;

On the basis of the before mentioned equation the thermal resistance of building envelope could be calculated:

$$R = \frac{A(\theta_i - \theta_e)}{Q_{e.g}} \text{ m}^2\text{K/W} \qquad (5)$$

4 The algorithm of thermal resistance and radiation resistance regulation in ideal building envelope

If there are heat sources in the inside space and outside air temperature θ_e is lower than inside air temperature θ_θ, to ensure constant inside air temperature the building envelope heat losses has to be equal to the internal heat gains. In that case the thermal resistance of building envelope structures has to be:

$$R_T = \frac{(\theta_i - \theta_e)A}{\Phi}, \text{ m}^2\text{K/W} \quad (6)$$

where A is area of building envelope structures in m^2; Φ is heat gains or heat losses in W.

If in the same situation with internal heat gains (Φ>0) outside air temperature is higher than internal air temperature, thermal resistance of structures has to be as big as possible (∞), but in case when $\theta_i=\theta_e$, the value of thermal resistance does not matter and it may have any value.

The similar analysis of other possible situations gives an algorithm of change and optimal values of thermal resistance and resistance to solar radiation. The algorithm of changes in values of thermal resistance and resistance to solar radiation is shown in Table 1.

Table 1 The algorithm of changes in values of thermal resistance

Outdoor air position	Difference in air parameters	Thermal resistance of building envelope
1	$\theta smin \leq \theta_e \leq \theta smax$	any
2	$\theta smin \leq \theta_e$ and $Xs_{min} \leq X_e \leq Xs_{max}$	∞
	$\theta smin \leq \theta_e \leq \theta smax$ and $Xs_{min} \leq X_e \leq Xs_{max}$	any
3	$\theta smin \leq \theta_e \leq \theta smax$	∞
4	$\theta_e \geq \theta smin$ and $\varphi_e \leq \varphi s_{max}$	∞
	$\theta smin \leq \theta_e \leq \theta smax$ and $\varphi_e \leq \varphi s_{max}$	any
5	$\theta_e \geq \theta smin$ and $X_e \leq Xs_{min}$	0
6	$\theta_e \geq \theta smin$ and $X_e \leq Xs_{min}$	0
	$\theta_e \leq \theta smin$ and $X_e \leq Xs_{min}$	∞
7	$\theta_e \leq \theta smin$ and $\varphi_e \leq \varphi s_{max}$	∞
8	$\theta_e \geq \theta smax$ and $X_e \geq Xs_{max}$	0
	$\theta_e \leq \theta smin$ and $X_e \geq Xs_{max}$	∞
	$\theta smin \leq \theta_e \leq \theta smax$ and $X_e \geq Xs_{max}$	any

5 The algorithm of vapour resistance regulation in ideal building

Similarly to the analysis of thermal and radiation resistance regulation we can analyse the regulation of the resistance to water vapour transfer.

If there are moisture sources in the air of inside space characterized by moisture production rate G, kg/h and water vapour pressure of outside air is lower than water vapour pressure of inside air (p_e<p_i), the resistance to water vapour transfer has to be:

$$R_v = \frac{(p_i - p_e)A}{G}, \text{ m}^2\text{s·Pa/kg} \quad (7)$$

In case when both pressures are equal the resistance to water vapour transfer can have any value, but when p_e>p_i, the resistance has to be as big as possible (∞).

The algorithm of water vapour resistance regulation is shown in Table 2. It takes into account also moisture content x in grams in the kg of dry air.

Table 2 The algorithm of vapour resistance regulation

G	x_e	R_V	x_{ex}	x_s	x_I
>0	$>x_i$	∞	$> x_s$	$< x_I$	$> x_s$
	$= x_i$	any	$> x_s$	$< x_I$	$> x_s$
	$< x_i$	$\frac{(p_i - p_e)A}{G}$	$= x_s$	$= x_I$	$< x_s$
=0	$>x_i$	∞	$= x_s$	$= x_I$	$= x_s$
	$= x_i$	any	$= x_s$	$= x_I$	$= x_s$
	$< x_i$	∞	$= x_s$	$= x_I$	$= x_s$
<0	$>x_i$	$\frac{(p_i - p_e)A}{G}$	$= x_s$	$= x_s$	$> x_s$
	$= x_i$	any	$< x_s$	$> x_s$	$< x_s$
	$< x_i$	∞	$< x_s$	$> x_s$	$< x_s$

R_V- resistance to water vapour transfer, m^2 h·Pa/mg;G -moisture production rate, kg/h; x_e – outside air moisture content, g/kg; x_{ex}- exhaust air moisture content, g/kg; x_I - internal air moisture content, g/kg; x_S- supply air moisture content, g/kg

6. Conclusions

In practice the choice of the regulation mode depends on the level of technical development and economical considerations.
Some of the regulation decisions, such as shutters or solar reflectors, are known for generations. They are in compliance with the model described in the paper but they were known long before and without it. On the other hand the given algorithm shows all possible directions of technical development in order to minimize annual heat consumption of buildings.
At the present stage of scientific and technical development it is naturally to expect fast progress of technology toward the building structures with changeable characteristics. For example, even now it is possible to imagine inflatable buildings with changeable thickness' insulation air layers, or regulation of structures' vapour permeability by perforation with changeable dimensions.
The paper gives the algorithm of regulation for hypothetical ideal constructions, which can be used as the guide for the future development of building structure technique.

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DIGITAL SCHEMAS FOR MODELLING AND EXCHANGING ENVIRONMENTAL INFORMATION ON BUILDINGS

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Summary

The open international standards for exchange of information (Information Foundation Classes, IFC) and the definitions of what to be exchanged (International Framework for Dictionaries, IFD) are emerging as the new standards in building information modelling. Together with an emerging third standard (Information Delivery Manual, IDM), these standards set the premises for electronic exchange of building specific information in the business process. IFC, IFD and IDM facilitate the use of a wide range of model-based applications in the building industry, included future tools and applications for environmental assessments of buildings. Today, only a few such environmental assessment model-based applications exist. The information flow propounded by the use of IFC, IFD and IDM depends on clearly defined data in the information package to be exchanged. With the new ISO 21930, Environmental declaration of building products (EPD), a standardized way of defining life cycle based environmental information on building products is established. An EPD is intended to provide information for environmental planning, design and assessment of buildings, by giving information that verifiable and accurately, and ensuring that any environmental impacts are completely accounted for. A template based on ISO 21930 is an optimal information package (schema) for environmental information to be exchanged in building information modelling. The template should also be incorporated in the IFD Library.

1. Introduction

The ongoing research project GLITNE (2006-2009) is a joint project of major actors of the Norwegian building sector. The main target is to produce knowledge on how environmentally effective buildings can be made more attractive and financially competitive. A method is being developed based on Life Cycle Assessment (LCA) and economic weighting of environmental effects. This is further described in Strand-Hanssen et al. (2008). The method will be integrated in a computerized tool to be used in the building process by relevant actors. It is of major importance that this method and tool are suited for use in the design process of a building. This requires that the tool present necessary information on a suitable level for the actors in the building process (client, architect, technical consultants), integrated with the working processes. This can be accomplished by making the tool communicate with a Building Information Model (BIM).

All environmental assessment tools, such as the forthcoming GLITNE tool, are depended on the quality of input data. To assure this, the input data should be based on LCA standards, be verifiable and accurate. International Standard Organization (ISO) 21930:2007 'Environmental declaration of building products' (EPD) defines EPD as *environmental declaration providing quantified environmental data using predetermined parameters and, where relevant, additional environmental information.* ISO 21930 is based on the LCA standards. Thus, when e.g. performing an environmental assessment of different building products, such as a wall or a window, the assessment should be based on data from EPDs.

The increasing use of building information modelling in the building industry opens the use of a wide range of model-based applications. Industry Foundation Classes (IFC) is emerging as an open international standard that makes it possible to exchange building information between a BIM (Building Information Model) and different tools, databases, CAD software etc. International Framework for Dictionaries (IFD) will, together with IFC, describe which building information that actually is being exchanged. IFD is an open digital library, where concepts and terms are semantically described and is given a unique identification number. The forthcoming standard Information Delivery Manual (IDM) set the premises for electronic exchange of building specific information in the business processes.

The building information flow made possible by IFC, IFD and IDM, depends on clearly defined data in the information package to be exchanged between a BIM and a model based application. This can be defined as an exchange schema (IFC schema).

In this paper, the following is discussed; what environmentally relevant information for a building product should be exchanged between an IFC based BIM and an IFC based environmental model-based application? This is discussed due to the content of EPDs and ISO 21930. How could such environmental building specific information be exchanged between a BIM and a model-based application? Two existing LCA/IFC based tools are presented and the use of IFD Library is discussed.

2. Environmental decision making in the building process

The foundation of environmental qualities is defined in the strategic phase of the building process. It is important that environmental goals are set in the strategy phase for the building project to secure that initial environmental goals are pursued also later on in the process. The building process includes a broad spectre of participants; such as project manager, architects, contractors, constructers, users etc, and these participants are involved in a variety of roles, actions and communications. To achieve environmental goals set in the early stages, it is important to present the necessary environmental information to the relevant participant in order to obtain informed and suitable decisions.

2.1 Present situation

Numerous methods and tools exists for environmental assessment of buildings, from green product guides and checklist, building assessment and rating schemes to LCA based tools of various kinds (Environment Australia 2001, Strand-Hanssen 2008). In environmental management, the principles and framework of life cycle assessment (LCA) has grown to be widely used, based on international standards. As defined in ISO 14040 Environmental management – Life Cycle Assessment – Principles and framework, LCA is *compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle*. The method assess the impact on the environment of a product (including buildings) from "cradle to grave", i.e. from acquiring raw materials for product manufacture to its disposal at the end of its useful life.

Despite the huge amount of developed environmental assessment tools, they are only seldom used. There could be several reasons for this. Two major explanations are that the developed tools are not suited for a specific need in the building process nor addressed to the right decision maker. The end users will only use a specific software tool repeatedly if it is helpful (Bazjanac 2004). There are several practical problems related to the use of LCA as well. As stated by Melby Strand (2003), this is primarily related to the time needed to perform an assessment, but also the lack of agreed methods for the final assessment steps. And finally, there is a lack of satisfactory input data on building products composed in available databases. The lack of data is one of the largest obstacles of bringing assessment systems into use. Because of this, there is little knowledge of the environmental consequence of different design alternatives in buildings, especially regarding the building construction. As a consequence, the environmental evaluation is delayed until late in the design phases when it is too late to consider any changes in the basic design decisions, if considered at all. Evidently, it is an initial choice of level of complexity, between a complex tool that provide detailed information of environmental impacts associated with different design decisions, ore a simple tool (merely checklists) that provides guidance only.

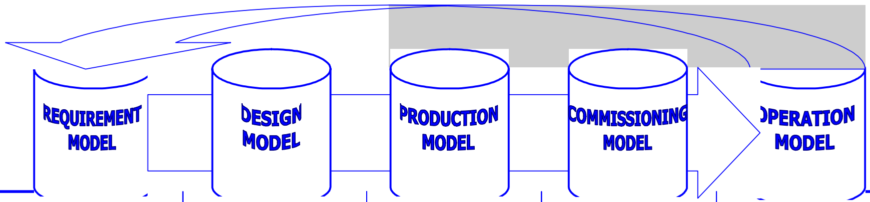
2.2 Future situation – if BIM based?

The increasing use of digital building information modelling in the building industry opens for the use of a wide range of model-based applications, so also for methods and tools for environmental assessment of building performance.

Building Information Modelling (BIM) is the term used for the creation and use of coordinated, consistent, computable information about a building project in design, in construction, in building management and operation (Wix et al. 2007). A BIM is the collection of objects that describe a building. It covers geometry, spatial relationships, geographic information, quantities and properties of building components. Quantities and properties of materials and elements can be extracted for use in model based applications, and the BIM can also be used to store results of e.g. environmental calculations.

As stated in Haagenrud et al. (2008) it may also include building processes undertaken during design, construction and operation/maintenance, related to the people and organizations involved. For the different participants in the building process, the use of BIM makes it possible to insert, extract, update or modify information on different stages in the building process to support and reflect the needs of any given participant.

The exchange and sharing of data between a BIM and an application require interoperability. This is the key idea of buildingSMART that supports open interoperability between BIM based software applications by using open interoperability standards such as IFC, IFD and IDM. The processes of the brand buildingSMART are driven by the organization International Alliance of Interoperability (www.iai-international.org). These standards will give a series of opportunities; e.g. for easier updating of data and tracking changes, that can be time-consuming and a source of errors. Further, a great benefit is the possibilities of more information based decisions for the participants involved when using suitable environmental applications on different stages in the building process. The environmental impacts and some of its content are shown in figure 1, divided in different building information models reflecting the process (requirement, design, production, commissioning and operation). Other aspects of sustainability are also included. Because of the possibility of interoperability (standards within buildingSMART) some of these models may be as one model.



	REQUIRED	DESIGNED	CONSTRUCTED	DELIVERED	ACHIEVED
PERFORMANCE IN USE	• user requirements • desired performance in use	• designed technical solutions • estimated performance	• constructed building	• validated conformity	• user satisfaction • performance in use
ENVIRONMENTAL IMPACTS	• targeted environmental impacts over the life cycle	• estimated environmental impacts over the life cycle	• environmental impacts during construction	• estimated environmental impacts in use	• environmental impacts of building and its use
ECONOMIC IMPACTS	• targeted whole life costs • targeted business benefits and value of the facility	• estimated life cycle costs	• construction costs	• estimated running costs	• running, maintenance and refurbishment costs, recycling, reuse, demolition and waste disposal costs • value of facility
OTHER	• targeted social, cultural and institutional impacts		• construction safety • construction ethics		• social impacts in the neighbourhood • impacts to the cultural heritage

Figure 1 Aspects within sustainability, included environmental impacts and some of its contents in different phases of the building process (Haagenrud et al. 2008, Huovila et al. 2007). The different models reflect the phases of the process.

One major challenge yet to be overcome is the lack of relevant environmental data to be used in software applications. Another aspect to consider is the need for clearly defined environmental data in the information package to be exchanged between a BIM and a model based application.

3. Environmentally relevant building-specific information

Simulating the environmental performance or impact of a building requires detailed information of the design and operating conditions. The amount and accuracy of the data required vary depending on the purpose of the simulation and in which stage of the building process the simulation is performed. This section it is focused on the exact data needed for defining the environmental qualities in materials and products in the building process.

3.1 Environmental Product Declaration (EPD)

One of the key aspects in a LCA is the quality of the input data; weather the data is generic or specific, their relevance and accuracy etc. With poor or insufficient data quality, the result of a LCA will be significant reduced. Participants involved in building design, users, owners and manufactures of building products have shown increased interest for environmental product declaration, and several national initiatives lead to the standardization work done in ISO/TC 59, Building construction, Subcommittee SC 17 Sustainability in Building Construction. The work in this standardization group has now resulted in a new standard for environmental declaration of building products; ISO 21930:2007. The standard is expected to form the basis for Type III environmental declaration programmes leading to Type III environmental declarations of building products (EPD). The principles and procedures for Type III declarations are described in ISO 14025.

In ISO 21930, EPD is defined as *environmental declaration providing quantified environmental data using predetermined parameters and, where relevant, additional environmental information.* An EPD is intended to provide information for planning, design and assessment of buildings, by giving information that is verifiable and accurate, and ensuring that any environmental impacts are completely accounted. The EPD are based on the LCA standards, but an EPD may also include only a certain life cycle stage. In these cases, the EPD becomes an information module.

When a building product is declared e.g. only for the product stage, the EPD is expressed per declared unit. When declared for the entire life cycle (cradle to grave) the EPD is based on a full LCA and the unit is expressed as a functional unit. The distinction between declared and functional unit is crucial, as the declared unit gives the quantity of a building product (e.g. mass, volume, square meter) and the functional unit gives the performance of a product system for a building product (e.g. m^2 glass wool insulation with heat resistant R = 1 m^2K/W and 60 years). When comparing and assessing building qualities, the environmental information should be based on EPDs with functional units.

3.2 EPD schema as a basis for environmental data to be exchanged

Because EPDs are based on LCA and consider all important environmental aspects, they are ideal to form the basis of an exchange schema between a BIM and e.g. a tool for selection of environmentally preferable materials and products. EPDs should also form the basis of e.g. whole buildings LCA. The mandatory and additional environmental aspects in ISO 21930 are given in table 1.

Table 1: Mandatory and additional indicators in ISO 21930.

MANDATORY:
• Environmental impacts:
  ○ Climate change (greenhouse gases)
  ○ Depletion of the stratospheric ozone layer
  ○ Acidification of land and water sources
  ○ Eutrophication
  ○ Formation of tropospheric ozone (photochemical oxidants)
• Use of resources and renewable primary energy:
  ○ Depletion of non-renewable energy sources
  ○ Depletion of non-renewable material sources
  ○ Use of renewable material resources
  ○ Use of renewable primary energy
  ○ Consumption of freshwater
• Waste to disposal
  ○ hazardous waste, or
  ○ none hazardous waste

DECLARED IN ACCORDANCE WITH NATIONAL STANDARDS AND PRACTICE: • Emission to water • Emission to soil • Emission to indoor air
ADDITIONAL ENVIRONMENTAL INFORMATION, e.g.: • Biodiversity • Human toxicity • Environmental toxicity • Geographical aspects • Product performance • Hazard and risk assessment on human health and environment • Preferred waste management option for used building products
USE OF RESOURCES IN ALL PHASES OF THE BUIDLING PROCESS SHOULD BE DIFFERENTIATED IN: • Water/ wind power • Fossil energy • Bio-energy • Nuclear power • Other energy • Secondary fuels • Non-renewable resources

There exist a number of EPD programmes worldwide, covering several product categories (www.gednet.org). In Norway, a system called EcoDec has been developed by SINTEF Byggforsk over a period of 10 years. EcoDec is aimed specifically at building products. The content of the EcoDec system is fully based on ISO 21930.

Despite the interest for environmental declarations in the international building industry, so far, only a few has been produced and are available. The accelerating use of BIM and model based applications on international open standards provides the manufactures of building materials and products with an opportunity to disseminate their product relevant information in a format that software tools will be able to import directly. This will enable the end user to select products for their advantage, based on environmental considerations. Depending on where in the building process design alternatives are compared, there is a need for generic and product specific data, both which may by produced by using the new international standard ISO 21930.

3. Exchange of building specific information with open standards

3.1 IFC, IFD and IDM

In order to enable the sharing of information and data and interoperable flow between a BIM and a software application, three pillars in the buildingSMART context form the basis. This is (Haagenrud et al. 2008, Bell and Bjørkhaug 2006):

- An exchange format that define how to share the information, IFC
- A reference library to define what information that are being shared, IFD
- Information requirements that define which information to share when, IDM

IFC is an international open standard (ISO/PAS 16739) and a data format for exchange of data between a building information model and a software tool. Tucker et.al. 2003 state that *the IFCs are a set of electronic specifications representing objects that occur in constructed facilities (including real things such as doors, walls, fans, etc. and abstract concepts such as space, organisation, process etc.). These specifications represent a data structure supporting an electronic project model useful in sharing data across applications.* Each specification is called a class, and is used to define things that have common characteristics. The latest IFC version, IFC 2x3, was published in 2006 (http://www.iai-international.org/Model/R2x3_final/index.htm). The purpose of an IFC schema is to facilitate the exchange and sharing of information. It is not a software application, but may be used by a programming language and in this way be included in a software tool.

IFD (ISO 12006-3) is an open library, where concepts and terms are semantically described and given a unique identification number. Cooperating with IFC, the IFD standard will define the building information that is actually being exchanged. Thus, IFD is not an alternative, but a supplement to IFC. IFD is implemented in Norway, the Netherlands, Canada and USA. What is interesting about IFD is that it offers a 'Globally Unique Identifier', the so called GUID. The GUID can be compared with e.g. a personal identification number. When the user adds the properties in an IFD Library, it is done once (and for all) and may be used repeatedly and by other users as well (http://dev.IFD-library.org).

In the standardization group ISO TC59/SC 13 work has been started to set the premises for the electronic exchange of building specific information in the business processes, IDM, and will specify (http://idm.buildingsmart.com):

- A defined activity in the building process (why it is relevant);
- Who are the actors involved in the activity (and the information flow between them);
- What is the information created and consumed in the activity;
- How this information should be supported by software solutions.

IDM consists of three parts: i) exchange requirements, defining the set of information within IFC that needs to be exchanged in a defined business requirement in the relevant stage of the building process, ii) functional parts, being the technical content required by software developers to support the exchange requirements, and finally iii) process maps, that capture the connection between exchange requirements and business processes. To illustrate a simple process map, the case of environmental selection of a window is used (fig. 2).

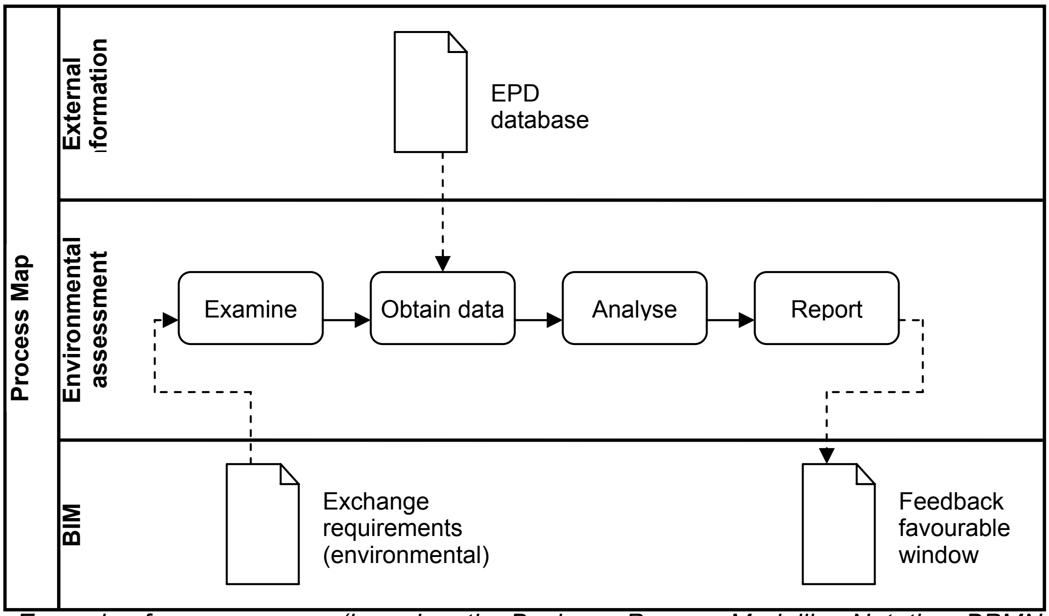


Figure 2 Example of a process map (based on the Business Process Modelling Notation, BPMN, www.bpmn.org).

The environmental assessment is undertaken in four steps; examine, obtain data, analyze and report. This is made possible by defined exchange requirements from the BIM, as defined in section 3.2 as an IFC based EPD schema. By obtaining external information from an EPD database, an analysis is accomplished and a report sent back to the BIM.

3.2 IFC and environmental specific information

What exchange does the existing IFC model enable; environmental data, environmental assessment and/or environmental indicators? In the IFC standard the 'Environmental Impact Value' was first defined in the IFC 2x2 version of the standard. From IAI the Environmental Impact Value is defined as *an amount or measure of an environmental impact or a value that affects an amount or measure of an environmental impact.* Further, the IfcEnvironmentalImpactValue could represent the volume of carbon dioxide emission, amount of operational energy or mass of aluminum used in a product. There are also given examples of impact types that may be applied, such as CO_2-emmisions, embodied energy, mass of aluminum, operational energy, resource and water pollution. This environmental impact value may be attached to any object as defined by the IFC standard. Thus, there is no environmental information in the IFC standard today, only suggestions to what this value might be.

The ongoing STAND INN project (scheduled to end late 2008) addresses new manufacturing processes based on IFC standards, and performance based standards for sustainable construction, in order to create new and more efficient business processes in the construction sector (Haagenrud et al. 2008). One of the objectives in STAND INN is to integrate environmental indicators with BIM/IFC following the scheme of elements presented in international standards dealing with environmental aspects of buildings. In STAND INN it is stated that environmental impacts should be expressed in terms of life cycle inventory (LCI) or LCA following the formats agreed in ISO. The final results from environmental assessment should be enclosed as environmental impact indicators to BIM (Wix et al. 2007). This means that the IFC standard to some extent provide support for capturing data to calculate environmental indicators. It also means that the IFC model only exchange rudimentary environmental data, such as environmental indicators that may be the result of a numerous environmental assessments done by other applications.

This is where the IFD standard complements IFC. By combining the IFC and IFD standard, the opportunities of unique identification are possible by the earlier mentioned GUID. By identifying in the IFD Library, all indicators, definitions, units etc. as stated in ISO 21930 with a unique GUID, these properties may be connected to an object. When using an (future) assessment tool for environmental assessment of building products or whole buildings LCA, the application to is able to 'talk with a BIM' and request just the right properties. The result of such an assessment may be stored in the BIM connected to the object (material or building product) in question. This is further discussed in section 5.

4. Interpretation of existing LCA & IFC based tools

In Wix (2007) several sustainable projects are studied. The study reveals that two thirds of the responses used CAD rather than BIM, and this is considered to reflect the fact that BIM use is not yet widespread in the building construction industry. The most widely supported application was energy performance declaration. The third major application supported was environmental analysis, and the findings showed that there were some useful applications supporting environmental impact analysis, but as yet not linked with BIM. One exception was the Redhill project, that showed that with a well structured material database and data collection within the BIM, an environmental impact analysis could be done both easy and highly effective. Strand-Hanssen (2008) found two tools that perform an LCA of whole buildings by using IFC compatible building information models where found, being BSLCA (Finland) and LCADesign (Australia). These applications where further studied by Sivertsen and Surnflødt 2007. In this section it has been focused how the exchange of building exchange seems to be done, and what environmental data that form the basis for the LCAs.

4.1 BSLCA

BSLCA is developed within the company Olof Granlund Oy (Finland). The background for developing the tool being that the existing LCA tools are missing the links to other designs tools (Laine et. al. 2001). BS LCA is a database solution with a Windows interface, and handles environmental impacts of the building envelope and building service system (e.g. HVAC). The tool consists of four modules, Structures (building envelope), Systems Design (building services such as HVAC, electrical, building automation, kitchen and hospital equipment), Networks and Energy. Only the first module (Structures) is IFC compliant.

The environmental assessment starts with importing building structures related geometry data from architectural CAD systems. BSLCA consist of a product library (such as HVAC) and a construction library (typical building constructions). Both libraries are connected to the material database. The environmental data in the libraries have been published by the Helsinki University of Technology (more environmental data may be added to the database when available). It is uncertain whether the data are based on environmental declarations. The various objects from the IFC architectural model are automatically labelled with environmental data. BSLCA is depended on information input from other applications, such as RIUSKA, used to calculate the energy consumption.

For the LCA, different characterisation and/or valuation methods are used (DAIA, EcoIndicator 95, EPS-96). It is open for adding several methods. In Laine et. al. 2001 it is pointed out that the contents of the IFC standard limit the possibilities to build all data transfer requirements based on IFCs. Sivertsen and Surnflødt 2007 show that only the building construction is imported.

4.2 LCADesign

LCADesign is an Australian tool, and is developed due to satisfy the needs of 'environmentally conscious design' (Tucker et. al 2003) and facilitate the assessment of environmental impact of a building construction by automatically exchange from 'intelligent' 3D CAD drawings. The tool enables the comparisons between different design alternatives.

LCADesign performs the LCA in the following steps; first the application extract information (including dimensions, location, building products, etc) from a 3D CAD to provide component quantities (automated take-off) by using IFC. Then the user of the application must tag the objects from the CAD model with the environmental information on products selected from the database within LCADesign. A generic database and set of reasoning rules for component composition are used to calculate quantities of resources and emissions for each product. The final step is to select measures (impact category and single values) so that different profiles may be compared. The LCA methods used for environmental impact calculation are CML, EPS and Eco-indicator 99.

The life cycle inventory (LCI) database in LCADesign is based on the so called Boustead model, and consists of environmental product declarations and data for various products through modelling their process of manufacture, from raw material extraction, manufacturing, use and final disposal (and consequently to the associated environmental impacts).

The interpretation of BSLCA and LCADesign is summarized in table 2. It shows that both applications automatically import the architectural model from a 3D CAD system by using IFC. In BSLCA the objects are automatically given their environmental characteristics, in LCADesign, the objects must be tagged manually. Both applications are using internationally known LCA methods. Both applications use input based on national environmental data, LCADesign using EPDs.

Table 2 Interpretation of BSLCA and LCADesign.

Characteristics / application	BSLCA	LCADesign
LCA based	Yes. Ecoindicator 99, DAIA	Yes. Ecoindicator 99
Use of IFC	Yes. Import of architectural model	Yes. Import of architectural model
Identifying environmental characteristics in objetcs	Automatically	Manually tagged
Input data (environmental)	National	National, use of EPDs

5. Discussion and conclusions

The possibilities of the buildingSMART standards in environmental assessment of buildings are huge, and it is a unique opportunity for software developers to create future applications for decisions support in building information modelling. The challenge in integrating BIM and environmental simulation of any kind has several components; i) environmental calculation methods, ii) data exchange and iii) user interaction, defining when the simulation should be done and the graphical user interface.

As stated in Melby Strand (2003) and shown in section 4, different LCA methods are developed. International consensus on which weighting method to be used is non-existent. On the other hand, this is not necessary due to the consensus on the input data basis; LCA and thus ISO 21930. LCA has grown to be a widely accepted method for assessment of environmental building qualities and there are several tools worldwide. The content of ISO 21930 is well suited as a foundation for an exchange schema for automatically exchange between a BIM and a model based environmental application:

- LCA based information, thus all relevant environmental aspects is included (without double accounting)
- Detailed and accurate
- Enables the possibilities of both generic and specific data
- Basis for environmental planning, design and assessment

If the basis for the data exchange between a BIM and an application is based on ISO 21930, any LCA based IFC application may be used. By using the terms in IDM, this is called exchange requirements. An IFC schema should contain all the environmental aspects, units for input and out put etc. What also makes IDM a suitable tool is that it e.g. defines when a simulation should be carried out. In environmental assessment, it is utterly important that a given stakeholder gets the needed information in time for the right decision to be made. Thus the use of BIM and IFC-based applications are especially suitable for all the actors involved in the building process. By making process maps, the information flow between the actors is identified in connection with a certain decision, and this reassure the right information to be incorporated in the exchange requirements.

In order to calculate an EPD based on the rules in ISO 21930, an application is required. Several EPD programmes and applications exist worldwide, but the lack of databases containing EPDs or similar LCA based information is striking. This is a huge challenge but also a great opportunity for manufactures of building products to describe their products in such a way that existing and future software tools will be able to import it directly. This again enables the end user to select the best suited products for their purpose. If such databases existed, with both generic and specific (Type III) declarations, the basic input for environmental assessments would have been in place.

A template from the EPD standard for building products should be incorporated in the open ISO standard IFD, giving a GUID to every environmental impact, definitions of different emissions (such as CO, CO_2), units etc. When this is defined in an IFD Library, these GUIDs make it possible for a model based application to know what information to exchange with a BIM in a standardized way. Already developed LCA and IFC based tools for automatically exchange of environmental relevant building specific information use automatically import of the architectural model from a 3D CAD system by using IFC. The environmental characteristics of the objects are shown to be tagged both automatically and manually. With a GUID from IFD Library there would be no doubt in which environmental characteristic a given object would have.

The relevance and potential of IFC/BIM for the different users/actors in the building process are areas of great interest in further research and development.

6. Acknowledgements

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DEVELOPMENT AND USE OF A SIMPLIFIED SYSTEM BASED ON "SBTOOL" FOR THE ENERGY-ENVIRONMENTAL SUSTAINABILITY ASSESSMENT OF RESIDENTIAL BUILDINGS LOCATED IN THE PROVINCE OF TREVISO, ITALY

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Summary

The environmental sustainability of buildings is at present involving ITC-CNR and iiSBE Italia at both national and international level with a formal convention aimed at performing and calculating the environmental sustainability level of buildings by the permanent use of SBTool, the GBC tool managed by iiSBE International. It is a second generation scoring system that allows the evaluation of the building environmental sustainability with regard to a high number of criteria and that can be updated depending on the building local context.
The system, realized for buildings located in the province of Treviso, was conceived for new residential buildings or relevant refurbishments and it is available in two versions depending on the number of housing units in the building. It was created in MS Excel, in order to make its diffusion and application simple and immediate, and it calculates the building performance with regard to a certain number of criteria.
The system final output is the sustainability level score of the building resulting from the weight and aggregation of the criteria scores. The scores are assigned through methods and tools described and explained in specified guidelines which have been defined for each evaluation criterion.
The innovative aspect of the system is its self-sufficiency: it integrates (even if hidden to the user) the tools for the calculation of each criteria indicator through a user-friendly interface, for which the biggest effort was the definition of the input screens layout.
Some case studies were carried out in order to demonstrate the effectiveness of the assessment tool thus supporting the designers towards the definition of a green building and the assessors in the control of the actual performances of the applied technical solutions.

Preface

ITC-CNR and iiSBE Italia have collaborated for a long time on the subject of energy-environmental sustainability of buildings in order to use in a permanent way, either directly or indirectly, the SBTool, the reference tool of the GBC methodology.
This methodology is essentially based on a score system which allows the assessment and certification of the environmental sustainability level of the building based on a high number of criteria and which is adaptable to the territorial context.
Starting form SBTool and according to the assessment criteria included in the Simplified Protocollo ITACA (" with 28 technical sheets"), ITC-CNR and iiSBE developed a verification tool for the environmental sustainability of residential buildings, realized for the "Metadistretto Veneto per la Bioedilizia" and promoted by CNA of the Province of Treviso. [1]
The assessment system involves the design of new residential buildings or important refurbishment interventions; it was developed in Excel language in order to make its diffusion and application simple and immediate, and it is aimed at the assessment of the environmental sustainability of a building by measuring its performance with regard to thirty-three criteria grouped in five assessment areas: energy and resources consumption, environmental loadings, indoor environmental quality, service quality, context quality.
Each criterion is associated to an either quantitative or qualitative indicator: in the former case a specified calculation procedure is implemented within the tool while in the latter case the user is proposed a certain number of possible scenarios. Actually, the tool directly integrates the calculation tools which process the data included in the project documentation in order to set the performance indicators values for the assessment.

Assessment tool features

The main features of the assessment tool are:

- Simplicity of the interface: to simplify the approach to the environmental sustainability assessment for technicians and professionals; to this end, the topics that characterize the environmental sustainability verification were re-interpreted and put into a language common to the actors of the design process.
- Thoroughness of the contents: to respect the holistic nature of the sustainability verification of buildings, considering the context where the buildings are located; among the numerous performance criteria proposed by the SBTool, the most suitable to the territory were chosen by using the usual methodological approaches of the design process, if present.
- Objectivity: quantitative and qualitative performance indicators were defined; the former were defined together with the relevant referenced calculation procedures (regulations, technical-scientific literature), the latter together with detailed scenarios in order to minimize the interpretations.
- Self-sufficiency regarding the analysis tools: this is a very complex aspect which involved a thorough analysis of the performance indicators for the criteria, in consequence of which proper simplified calculation methodologies were developed. The choice of the indicators themselves was strongly influenced by the different calculation methodologies. The effort was trying to use, when possible, indicators that didn't require any further elaboration, i.e. already provided in the technical design documentation as provided for by the law.
- Transparency: the methodological approaches (benchmarks and verification procedures), normative and legislative references and input/output relations were made explicit.
- Flexibility: it is possible to modify criteria weight and benchmark values.

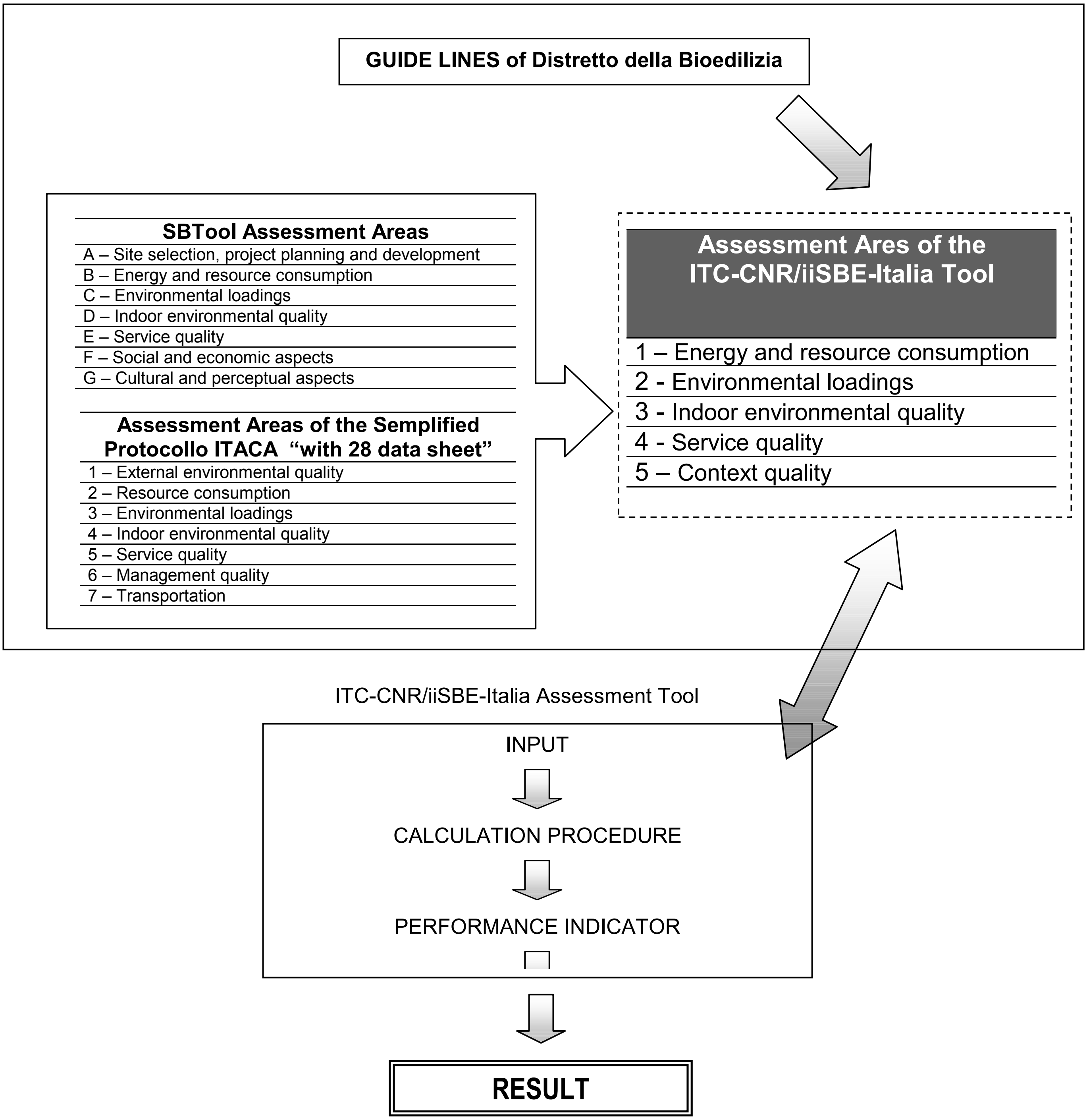


Figure 1 Scheme of the assessment tool

1.1 Assessment areas and criteria

The assessment areas were chosen starting form the Guide Lines for the Diffusion of the Environmental Sustainability and for the Promotion of the Living Quality of the Distretto della Bioedilizia of the Province of Treviso, by keeping the SBTool setting and adapting it to the needs of the building type and to the specific territorial features. Also, the effort was trying to be as consistent as possible with the Simplified Protocollo ITACA, by taking into account all the difficulties that it implied, in fact:

- the Protocollo itself is currently being updated;
- the assessment of each criterion is connected to the difficulty of implementing and integrating the specific calculation procedures.

In the assessment tool developed by ITC-CNR and iiSBE Italia the assessment areas E, F from SBTool and the assessment areas 5, 6 from the Simplified Protocollo ITACA were grouped into the area named “Service Quality”; instead the area G from SBTool and the area 7 of the Semplified Protocollo ITACA are part of the area named “Context quality”.

A certain number of criteria and sub-criteria, whose main features are listed below, was chosen for each assessment area:

- they have a relevant economic, social and environmental value; -
- they can be either quantified or defined as qualitative, in the latter case they correspond to predefined performance scenarios;
- they have a holistic approach;
- they have a proven scientific value;
- their special properties are of public interest.

For each criterion, the following aspects were defined:

- requirement, i.e. the environmental quality objective to be reached;
- performance indicator: it measures the building performance level with regard to the assessment criterion;
- unit of measurement, defined only in case of quantitative criteria;
- verification procedure: it defines the procedure for the calculation of the performance indicator of the assessment criterion;
- input data, i.e. the data needed for the calculation of the performance indicator;
- performance scale, i.e. the reference benchmark to which the performance indicator has to be compared in order to calculate the assessment criterion score;
- legislative reference, i.e. the mandatory legislative provisions;
- normative references, i.e. the reference technical regulations used to define the performance scales and the verification procedures.

For each criterion, and sub-criterion, if any, the building is assigned a score that can vary from –1 to 5 by comparing the calculated indicator with the performance scale benchmark.
Zero represents the standard reference related to the current building practice, in accordance with the regulations in force.
In particular, the meaning of the performance scale scores is described in the Table 1.

Table 1 Interpretation of the assessment area scores of the performance scale

-1	It represents a **performance below the standard** and the current practice.
0	It represents the **minimum acceptable performance** defined by laws or regulations in force; in case they do not apply it represents the **current practice.**
1	It represents a light performance improvement with respect to the regulations in force and to the current practice.
2	It represents a moderate performance improvement with respect to the regulations in force and to the current practice.
3	It represents a significant performance improvement with respect to the regulations in force and to the current practice. It is considered as the **best current practice**.
4	It represents a moderate performance improvement of the best current practice.
5	It represents a **substantially advanced performance** with respect to the best current practice, of an experimental nature.

A weight is assigned to each assessment area, category, criteria and any sub-criteria according to the importance they have within the assessment process. Weights are editable and updatable depending on the features of the building to be assessed. (Table 2)

Table 2 List of criteria and relevant weights

Assessment Areas and Categories	**Weights (%)**
1. Energy and resources consumption	**30**
1.1. Total non renewable energy used during the life-cycle	40
1.1.1. Expected energy embodied in the construction materials (yearly basis)	20
1.1.2. Expected primary energy required for heating during operation	50
1.1.3. Expected solar gains during summer	30
1.2. Renewable energy	25
1.2.1. Expected energy use from renewable resources	100
1.2.1.1. Expected solar thermal energy production	40
1.2.1.2. Expected solar photovoltaic energy production	60
1.3. Materials	20
1.3.1. Intended use of recycled materials	33
1.3.2. Intended use of natural materials (from renewable resources)	33
1.3.3. Intended use of recyclable materials and materials that can be disassembled	33
1.4. Potable water	15
1.4.1. Intended use of potable water for irrigation	50
1.4.2. Intended use of potable water for internal use	50
2. Environmental Loadings	**30**
2.1. Greenhouse gases emissions	45
2.1.1. Expected annual greenhouse gas emissions produced by different forms of energy used for the annual operation of the building	100
2.2. Water	30
2.2.1. Effluents	50
2.2.2. Expected rainwater recovery	50
2.3. Impact on the site	25
2.3.1. Heat island effect– external areas	25
2.3.2. Heat island effect– coverings	25
2.3.3. Soil permeability	25
2.3.4. Impact of the building on the solar radiation accessibility of adjacent buildings.	25

3. Indoor environmental quality	**25**	
3.1. Indoor air quality		20
3.1.1. Pollutants control		100
3.1.1.1. Pollutants control: VOC		50
3.1.1.2. Pollutants control: VOC: radon		50
3.2. Ventilation		20
3.2.1. Design strategies to maximize the ventilation efficiency in naturally ventilated environments		100
3.3. Air temperature and relative humidity		15
3.3.1. Design strategies to keep air temperature and relative humidity acceptable in naturally ventilated environments		25
3.3.2. Design strategies to avoid the air overheating during summer in the absence of air conditioning systems		50
3.3.3. Design strategies to minimize the air temperature by keeping high comfort conditions		25
3.4. Natural and artificial lighting		15
3.4.1. Design strategies to ensure a sufficient natural lighting in the main environments		80
3.4.2. Direct beam solar radiation penetration		20
3.5. Noise and acoustics		25
3.5.1. Strategies for noise reduction through envelope components		100
3.6. Electromagnetic contamination		5
3.6.1. Magnetic fields with industrial frequency (50 Hertz)		100
4. Service quality	**10**	
4.1. Controllability		60
4.1.1 Operation efficiency of the technological systems		100
4.2. Performance maintenance during operation		40
4.2.1. Availability of building technical documentation		50
4.2.2. Development and implementation of a maintenance plan		50
5. Context quality	**5**	
5.1. Proximity to public transport		20
5.2. Control of private vehicles use		20
5.3. Support to the use of bicycles		20
5.4. Proximity to occupational centres (offices)		20
5.5. Proximity to commercial and cultural centres		20

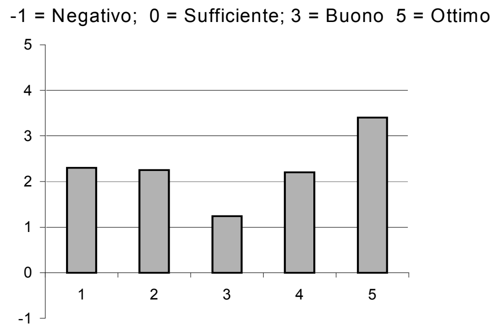
The system was defined for the assessment of dwellings of different size and it is available in two versions depending on the number of housing units. In the first working-sheet, where the general building data are collected, it is possible to choose the reduced version (1) or the full version (2) whether the building has got two or more housing units respectively.
Each version is composed of two parts:

- one to collect the input data, to be filled in by the designer (Form A);
- one to carry out the assessment; in this part all the criteria performance indicators previously calculated or gathered from the project documentation are compared with the scale performance benchmarks. Benchmarks are defined according to the regulations in force, the technical literature and the current building practice. (Form B).

Once Form A has been filled in with the building data, in Form B all the criteria indicators are automatically calculated through the integrated calculation tools and they are assigned a score.
The obtained scores are weighted and aggregated in order to define those of the categories, which are in turn combined to assign those of the assessment areas. The weighted aggregation of the assessment areas scores will return the final building score.
In addition to the global building score, the systems provides, as further outputs, some indicators related to absolute significant performances of the building; they allow a comparison also beyond the specific context of the performance scales (Table 3).

1.2 Assessment tool validation

The validity of the assessment tool launched by the collaboration between ITC-CNR and iiSBE Italia was internally proven through the assessment of a case-study building with residential/commercial destination of use located in the province of Mantua while an external feedback form the CNA of Treviso is still expected: actually, the tool was given out to the municipalities of the Province of Treviso, which will contribute to the process validation by providing the results of their assessment carried out on a certain number of buildings. Testing in still in progress.



	AREA DI VALUTAZIONE	Punteggio	Peso	Punteggio Pesato
1	**Energia e consumo di risorse**	**2.3**	30%	**0.69**
2	**Carichi ambientali**	**2.3**	30%	**0.68**
3	**Qualità ambientale interna**	**1.2**	25%	**0.31**
4	**Qualità del servizio**	**2.2**	10%	**0.22**
5	**Qualità del contesto**	**3.4**	5%	**0.17**
	Punteggio Totale dell'edificio		2.07	

	Prestazioni assolute	Per area	Unità di misura
1	Previsione dell'energia primaria contenuta nei materiali da costruzione annualizzata	**6.97**	GJ/m^2
2	Previsione di fabbisogno di energia primaria utilizzata per il riscaldamento in fase operativa	**55.00**	kWh/m^2 anno
3	Previsione degli apporti solari durante il periodo estivo	**9.05**	kWh/m^2 anno
4	Uso di acqua potabile per irrigazione	**0.00**	m^3/m^2
5	Uso di acqua potabile per usi interni	**118.50**	m^3/m^2
6	Previsione delle emissioni annue di gas effetto serra dovute alla climatizzazione invernale dell'edificio	**11.25**	kg/m^2

Figure 2 Example of the provided outputs

1.3 Remarks on the assessment tool

The specifications which steered the realization of the tool and its development environment (Microsoft® Excel), which was chosen due to its wide diffusion, called for some compromise in order to balance the need of a user-friendly interface with the need of guaranteeing the thoroughness of the contents and the integration of calculation procedures for the different performance indicators.
Data to be provided for the assessment can be found in the project documentation and they do not imply any further processing. This makes the use of the system remarkably easier, but it does not leave out of consideration the fact that the user must be able to understand and manage the methodological approach by evaluating the order of magnitude of each indicator and by deciding about the soundness of results.
As a matter of fact, the simple development environment of the system does not allow to introduce accurate and detailed controls regarding the consistency of the entered input data and it therefore requires an adequately aware use of the assessment tool. This is one of the reasons for deciding to highlight in red the negative scores: in this way the attention of the user is drawn to any mistakes in the design choices or in filling the input datasheet which may cause one or more performance criteria to remain unfulfilled.
The choice of including the negative score in the performance scale was justified by the fact that not all the criteria refer to standards and laws; in this case the benchmark scale does not refer to specific legislative limits, but is defined by the analysis of case-studies through calculation methods derived from technical-scientific literature.
Whoever has developed a project without considering those theoretical bases and without a proper performance target, might have indeed chosen building and technological solutions which do not satisfy the minimum sustainability requirements.

Another important aspect is the compatibility with the Simplified Protocollo ITACA which results from the meaningful correspondence between the results yielded by the two tools. In expectation of an updating of both the assessment tools, in the next future the system realized for the Metadistretto della Bioedilizia will converge into the Protocollo ITACA according to the most recent changes of the regulations in force.
Nevertheless the possibility of adapting the assessment tool to the specific territorial features and to the local regulations (when more restrictive than national ones) remains its most peculiar aspect.
At last, thanks to the amount and type of criteria introduced into the assessment tool and to the performance-based methodological approach, the tool would be easily adaptable also for the evaluation of existing buildings.

1.4 Conclusions

At present, the developed assessment tool is the only one to integrate the calculation procedures therefore allowing to automatically transform the information normally included in the project documentation (that can be easily entered in the input datasheet) into the final result, that is the building environmental sustainability level.
Also, thanks to the User Manual, which specifies the relations between input parameters and performance criteria indicators, the designer can increase his awareness about the consequences that may derive from the defined building and technological choices.
The complexity of each calculation engine is hidden to the user in order to maximize the interface simplicity and manageability, though the methodological approaches and the normative and technical references are clearly specified in the tool manuals.
The achieved goal of facilitating the diffusion of the environmental sustainability topics for the realization of green-buildings with a low impact on the environmental and territorial context could be further proven by the results of the ongoing assessment of a certain number of case-study buildings.

Notes

[1] In addition to the authors of the article, the assessment tool has been developed with the contribution of:

- B. Barozzi, L. Danza, M. Orlandi: ITC-CNR;
- Valentina Colaleo: iiSBE Italia.

SUSTAINABILITY ASSESSMENT OF URBAN SOCIAL HOUSING: A FIRST MODEL FOR NORTHEAST REGION OF BRAZIL

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Keywords: sustainability, assessment, indicators, social housing

Summary

Sustainability assessment of buildings is an important tool to verify and to demonstrate which route to follow in order to achieve sustainable development. Some methods, for sustainable building evaluation, can be found in the literature and are currently being used as, for instance, BREEAM, HK-BEAM and LEED. These methods, however, almost exclusively takes into account only environmental issue. On the other hand, a wider concept of sustainability includes, at least, two others dimensions: economic and social. Regarding social housing in developing countries, this kind of evaluation has also to be based on local priorities and to consider local technical and cultural values. This article deals with indicators for sustainable housing in order to develop a tool for social housing assessment. The set of indicators proposed in SBTool is taken as initial reference, once it includes some social and economical indicators, suggesting the beginning of building evaluation from the sustainability point of view. Moreover, it is designed to handle regional-specific issues and consists of an initiative that aggregates international experiences that contributes for developing new systems. The objective of this paper is to apply this tool to two social housing settlements situated in the cities of Recife and Olinda, Brazilian northeast region, taken as study case. These settlements have different building typologies: (i) multi-familiar dwelling, three-story building; and (ii) isolated houses and two-story building for two distinct families. The results show that, beyond collecting and evaluating data, this approach allows drawing guidelines to overcome the developing countries challenges. For example, decrease housing deficit and improve building performance without compromising the environment. In other words, sustainable housing designs have to consider improvement of inhabitant's quality of life, economic and technical feasibility; and environmental compatibility.

1. Introduction

In general, methods for assessing sustainability of built environments are based on quantitative and qualitative indicators, defined and measured on the basis of the comprehension of sustainable development concept and the role of the built environment in this context. Hence, the diversity of methods proposed reflects these different interpretations, yet marked by regional specificities that induce values and relevance of what should be measured (DING, 2008). The complexity of assessing sustainability is inherent in its very concept still evolving (AZEVEDO et al, 2007).

Developing countries, like Brazil, demand social housing, destined to meet the shortfall of stock of habitations, intended to a populace with low (or no) income and low level of education. These needy populations commonly originate irregular human settlements[1] in urban areas close to major Brazilian cities, as a result, mainly, of the search for better alternatives to generate income and reduce costs with transport. The precarious life conditions in these spontaneous settlements are even sharper due to the lack of minimum urban infrastructure, which also contributes to the degradation of the area irregularly occupied, requiring its recovery. Initiatives to meet this specific demand, usually provided solely by public resources, involve large numbers of housing units, and require the adequacy of the whole infrastructure for water supply, sanitation, energy and transport, and also need to provide options for generation of income. These ventures, in fact, consist of construction of human settlements, where the types of housing are heavily influenced by financial constraints and availability of spaces, and whose quantity is still pushed by demand. However, to be sustainable, they must be environmentally compatible, socially acceptable and economically viable.

Sustainability of social housing is admittedly an issue of significant importance for developing countries. The global Agenda 21 (UN, 1992) and Habitat II Agenda (UN, 1996) as well as Agenda 21 of the state of Pernambuco[2] (PERNAMBUCO, 2002) denote the relevance of social housing / human settlements, treating them as one of the factors to be prioritized in the search for a more sustainable world. In the search of understanding on sustainability in the construction industry were established the Agenda 21 for Sustainable Construction (CIB, 1999) and the Agenda 21 for Sustainable Construction in Developing Countries (CIB,

[1] *Cadernos MCidades Habitação, Volume 4 – Política Nacional de Habitação, Ministério das Cidades, 2006.*
[2] *Brazilian state located in the northeast region of Brazil - zwww.ibge.gov.br/ibgeteen/povoamento/constrterrit/mapapolitico.htm*

2002). The second agenda was due to the particularities of these countries not fully addressed in the first one, more targeted the reality of developed countries.

In Brazil, sustainability assessment of built environment is beginning to receive attention. This work is a result of the construction process of a tool for assessing sustainability of social housing, oriented to the specific characteristics of the Metropolitan Region of City of Recife - MRR, capital of the state of Pernambuco. This paper summarizes the procedure employed in the construction of the tool, highlighting some of its indicators. It will also be shown the results obtained with the tool in two case studies.

2. Objective

Aspects related to sustainability of social housing in the Brazilian context have been object of study (SATTLER, 2007). However, in Brazil, it is not yet available a set of indicators of sustainability oriented to social housing and systematically organized to allow some kind of assessment.

This work aims to contribute to the conception and systematization of indicators enabling the start of a tool for assessing sustainability of built environments, initially targeted to social housing in MRR. With the application of this tool to two case studies, this paper contributes not only to validating the tool but also to a comparative analysis between these two projects, whose results may steer potential opportunities for improvements.

In a broader approach, it is understood that the method in development for assessing sustainability of built environments can help guide decision-making, providing guidelines for the design of new more sustainable social housing in the MRR.

3. Method

Initially a set of indicators for built environment sustainability is chosen as a base reference: SBTool (version 2007). This choice is based on the differentiated approach adopted by SBTool, that distinguishes it among other available tools: is an initiative that adds the international experience in which Brazil also participates; presents character of scientific research, allowing the inclusion of regional specificities, contributing to the development of new systems, provides an assessment in a broader view of the concept of sustainability, with the inclusion of social and economic indicators, and the availability of information[3].

A critical analysis of all indicators proposed by SBTool for residential buildings was carried out, prioritizing those for design and occupation phases. This analysis sought to verify: understanding, applicability, relevance and technical feasibility of the indicators, focusing on social housing and the specific conditions of MRR. Other indicators, not included in SBTool, have also been proposed. The same form of scores (scale of -1 to +5) was maintained, seeking also reduce the level of subjectivity inherent to SBTool. The legislation was taken as reference to acceptable practice (scores 0). It was also included a weighting criterion, according to the degree of importance/feasibility assigned to each indicator.

Aspects related to developing country, as discussed by GIBBERD, 2002 and REFFAT, 2004, have also been taken into account, helping to understanding the emphasis given to each indicator.

Once constituted the base of indicators, technicians from city halls of Recife and Olinda (MRR), who are responsible for management and development of social housing projects in these municipalities, were asked to make another analysis of the indicators in order to verify their applicability and feasibility, providing also values for weights and benchmarks. Note that, at this stage of the research, it is more important to evaluate the relevance and applicability of the proposed indicators than the final result obtained with the tool.

3.1 General structure of indicators

The same general structure, presented below, was defined to the conception of each indicator:

- Indicator: definition of the indicator itself (what is to be measured).
- Understanding: explanations about the indicator and its context for better understanding and other considerations for its quantification.
- Intention: designates the purpose of the evaluation.
- References: indication of legislation, technical standards or instructions, booklets and other documents that should be taken as reference in the quantification of the indicator.
- Quantification/score: Definition of parameters for measuring and the resulting assessment of each indicator. The division and scores follow the SBTool model, as indicated below:
  - Negative practice: when minimal specifications are not followed (score: -1).
  - Acceptable practice: specifications defined in the legislation or considered as minimal (score: 0).
  - Good practice: specifications above the minimal requirements and therefore give the indicator a higher grade from the sustainability perspective (score: +3).
  - Best practice: Most demanding specifications, considered as the highest degree from the point of view of sustainability (score: +5).

[3] *www.iisbe.org – Nils Larsson*

- Degree of importance in the context of social housing /weighing: Establishment of weights, which can be adjusted in order to consider the local context, depending on the technical and economical feasibility, and relevance of each indicator, as explained below:
  - Not applicable: weight 0 (when the proposed indicator is not adequate to the kind of project).
  - Still far from the local reality / Non-existence of financial or technological resources: weight 1.
  - Little importance / It is not priority: weight 2.
  - Important / Ought to be considered and resources should be provided: weight 3.
  - Very important / It is already possible to be considered: weight 4.
  - Indispensable / Must be considered: weight 5.

3.2 Indicators

The set of indicators was divided following the basic dimensions of sustainability, depending on the emphasis given to each, so the final result expresses the performance of the project, according to these dimensions.

Table 1 Sustainable Indicators

Environmental Indicators	Area destined to the project	Vulnerability to flooding
		Vulnerability to sliding of hillsides
		Proximity to water courses
		Proximity of the sewerage system to water courses
		Proximity of the sewerage system to water reservoir
		Employment of environmentally compromised area
		Recovery level of the environmentally compromised area
	Project Planning	Environmental impact report
		Availability of treated water
		Controlled exploitation of water
		Recycled and reused materials
		Biodegradable materials
		Material with less negative environmental impact
		System for monitoring electricity, gas and water individual consumption
		System to capture and use of rainwater
		System to capture and use of gray water
		System for the use of solar energy
		Infrastructure for selective collection and storage of solid waste
		Infrastructure for composting of organic solid waste
		Planned demolition of buildings
	Reuse and recycling[4]	Use of pluvial water
		Reuse of gray water
		Selective collection of solid waste
		Reuse of organic solid waste
	Rationalization of natural resources[4]	Treated water consumption
		Electricity consumption
		Electricity consumption from renewable sources in the project itself
		Solid waste production
		Liquid effluents production
	Landscape	Provision of green common area
		Use of native plantings
		Provision of trees with shading potential (and for CO_2 sequestration)
	Indoor environment quality	Heat Island – floors
		Heat Island – roofs
		Thermal transmittance - external walls
		Thermal transmittance - roofs
		Natural ventilation
		Building orientation
		External noise

[4] *Estimates obtained from the specifications of the project, at design phase, to help the development of guidelines.*

		Internal noise
		Internal noise – bedroom
		Internal noise – lounge
		Natural lighting
		Artificial lighting
Economic Indicators	Economic insertion and local development	Proximity to public transport
		Proximity to centres of employment - job opportunities
		Mixed use – activities for income generation
		Garage for bicycles
		Use of materials produced by local companies
		Use of goods and services provided by local businesses
		Costs with use and maintenance
	Planning and development in long terms	Compatible projects
		Adaptability of structural system and envelop to spatial adequacy
		Adaptability to changes in water, energy, sewage systems
		Adaptability to the use of other energy and water sources
		Performance of buildings envelop
		Documentation handed to the dwellers
	Technical and financial feasibility	Resource for technical and financial studies
		Results of technical and financial studies
		Percentage increase in the cost of a more sustainable construction
Social Indicators	Project localization	Proximity to basic commerce centre
		Proximity to public medical centre
		Proximity to public educational centre
		Proximity to options for cultural entertainment
		Proximity to public green space
	Accessibility	Adequacy of sidewalk to disabled (reduced mobility)
		Adequacy of sidewalk to visually handicapped
		Adequacy of horizontal circulation to disabled (reduced mobility) – External and internal common areas
		Adequacy of horizontal circulation to visually handicapped – External and internal common areas
		Adequacy of vertical circulation to disabled (reduced mobility) – Common areas
		Adequacy of vertical circulation to visually handicapped – Common areas
		Adequacy of bathrooms to disabled (reduced mobility) – Common areas
		Adequacy of privative area (residential unit) to physical handicapped
	Environmental education and social integration	Area for social events
		Area for physical activities
		Area for children entertainment
		Social and environmental education programs for dwellers
	Safety	Sentry box
		Security system against the entrance of strangers
		Fire safety
	Privacy	Private parking
		Residential unit privacy
		Private external area
	Conservation of the local culture	Compatibility with the local urban context and its cultural values
		Conservation of the cultural and historical heritage
	Participation	Dweller's participation
		Evaluation of dweller's satisfaction

4. Case Study

The case studies are social housing ventures (state housing), to be constructed in the cities of Recife and Olinda (MRR). These cities were chosen because they are fairly representative of the urban context of Brazilian northeast region. And, yet, present challenges related to the sustainability of residential buildings typical of developing countries, for example, reduce the high housing deficit, recovery of degraded area due to irregular occupation, increase durability of buildings, development of activities to generate income for the people, increase the use of recycled materials and with less negative environmental impact, among others. These initiatives are intended to needy populations that gave origin to irregular spontaneous settlements.

4.1 Characterization of State Housing V8 e V9 in Olinda

The project, called ***State Housing V8 and V9***, consists of the re-urbanization of a spontaneous irregular settlement, which also occupied part of an area originally reserved for environmental protection, and includes the construction of housing units of two types: detached single-family ground floor houses and double-storey houses (for two families). The first type sum a total of 43 units, the second reaches a total of 524 units. Each resident has an area of approximately 27m^2 to 31m^2 with living room, a bedroom, bathroom, kitchen and service area, and an area planned for future expansion, whose foundation will be built by Olinda City Hall. In addition to the residential units, it will be deployed 46 business units, once that many of the current residents have small businesses (commerce or service) on the spot, which guarantee them income.

There will be improvements in urban infrastructure, such as re-structuring the access routes for moving and transport, paving, micro-drainage, deployment and recovery of water, sewage and public lighting systems, improvements in solid waste collection, deployment and rehabilitation of parks/squares for community activities and leisure (track of cooper, gymnastics, and ramp to skate, bicycle paths and sports court). It is also planned deployment of social facilities (school, kindergarten and acoustic shell). Environmental and social education is also planned.

Recovery of the environmentally degraded area is also expected, including means to avoid possible disorderly re-occupation in the future, as the urbanization of the river bank, with parks, squares and gardens.

4.2 Characterization of State Housing *Abençoada por Deus* in Recife

The project, called ***State Housing Abençoada por Deus***, consist of the construction of a residential condominium destined to shelter some communities that originated spontaneous irregular settlements. Four-storey buildings (ground floor plus 3 upper floors) are employed to accommodate 428 apartments. Each housing unit has an area of 39m^2 with living room, two bedrooms, bathroom, kitchen and service area.

The system for the treatment and final disposal of sanitary sewage, through anaerobic reactors and filters, will be installed in the condominium. Day care centre and playground for children are expected to be built, and also community centre and square favouring dwellers social living. Also planned is the rehabilitation of environmentally degraded area, after the removal of families for the new residential area, including ways to prevent another disorganized occupation, with the urbanization of the river bank through with parks, squares, and gardens. Replanting of forest and swamp is also expected.

An important difference between these two cases is that in Recife the project provides the recovery of the local originally occupied irregularly with transfer of families to a new residence in another area, while in Olinda the project provides the continuation of the families in the occupied area, after its recovery.

5. Results

Due to limited space, only a few indicators will be discussed. The chart presented below summarizes the results, which consist of weighted averages from the values assigned to the indicators and weights established by designers and managers of public municipalities of Recife and Olinda. Information was obtained from documentation of the projects.

5.1 Economical sustainability

Under the economic dimension, it is given emphasis to streamlining the economic resources, to promoting income generation and to the development of local economy.

- Proximity to public transport

The easy access to legal public mass transport (bus, subways, trains, etc.) is a basic requirement for the social housing dwellers as a result of a strong dependence upon it. Both projects are set in urban area, facilitating the access to the main available public transport in MRR, which is the bus. Weight: 4.

Olinda - Score: +3	Recife - Score: 0
Mean distance among bus stop and building is between 100m e 260m.	Distance among bus stop and condominium entrance is approximately 500m.

- Proximity to centre of employment - Job opportunities

For social housing it becomes indispensable the existence of job opportunities in its vicinity, facilitating the access to formal labour market, also contributing to the reduction of costs with transport. Weight: 5.

Olinda - Score: +5	Recife - Score: +5
Both projects are set in urban area, favouring the access to labour market and public transport.	

- Mixed use – activities for income generation

The existence of infrastructure in the project to enable its users develop income generating activities, is an important guideline for social housing. This also contributes to reducing costs with transport and to the achievement of these activities in an orderly way, minimizing the possibility of irregular improvisations that can compromise safety and quality of public space. Weight: 3.

Olinda - Score: 0	Recife - Score: -1
The project provides for buildings for commercial use, close to the	No area aimed to activities for income

housing units, aimed at activities for generating income for the dwellers, whose built area is around 5.36% of the total built area.	generation for the dwellers are available in the project.

- Documentation handed to the dwellers.

Refers to availability to the dwellers, before the occupation of habitation, of information documents on the proper use and maintenance of the property, including drawings of the projects (as built). Weight: 3.

Olinda – Score: -1	Recife – Score: -1
It is not provided for availability of information on the use and maintenance of the property to the dwellers.	

- Technical and financial feasibility.

Use of renewable energy, reuse of water, use of materials with less environmental impact, efficiency in the use of energy, among other examples, are solutions of unconventional buildings design, tending not to be accepted initially. This indicator stimulates the achievement of technical and economic studies that justify these solutions (including computer simulations of natural and artificial lighting, and thermal comfort that provide better efficiency in the use of energy). Weight: 2.

Olinda – Score: -1	Recife – Score: -1
There are no technical and financial studies for providing solutions to more sustainable project.	

5.2 Environmental sustainability

The environmental indicators are those preferably related to a rational use of natural resources in order to promote equilibrium between development and environmental preservation.

- Use of material with less negative environmental impact.

It is not yet available, on a consolidated basis for the MRR, data regarding to embedded energy and gas emissions associated with building materials, so this indicator takes as a reference the project specifications, with respect to the restriction of materials that do not contain contaminants agents, such as CFCs, asbestos, etc, or those acquired irregularly (unauthorized) such as wood, or aggregates and ornamental stones extracted from irregular deposits. Weight: 2.

Olinda – Score: +3	Recife – Score: -1
Ornamental stones will not be used. Aggregates will be extracted from the local itself or from legal deposits. Only certified wood will be used.	Reference is made only to legalization of deposits of material used in re-embankment.

- Vulnerability to sliding of hillsides.

The area considered as adequate is that presents less risk of damage to property and dwellers with the occurrence of the sliding hillsides. Weight: 5.

Olinda – Score: +5	Recife – Score: +5
Both projects are not situated in areas near to hillsides.	

- Controlled exploitation of water.

It is common in the MRR supplementary water supply through the use of wells when the public water supply system does not meet demand. However, the indiscriminate use of wells does not favour the rational use of water and can cause problems such as salt water intrusion (salinization of aquifers - in coastal region), subsidence, etc. The use of wells, deep or not, shall be monitored by the Water Resources Company of Pernambuco (CPRH), the authorized governmental agency responsible for water management. Weight: 3.

Olinda – Score: +5	Recife – Score: +5
Both cases provide for the exclusive use of public system of water supply.	

- Infrastructure for selective collection and storage of solid waste.

This indicator is based on the existence of infrastructure enabling the selective collection and storage of solid waste, in order to facilitate recycling. Weight: 4.

Olinda – Score: -1	Recife – Score: -1
In both cases there is not any infrastructure appropriated to selective collection and storage of solid waste.	

- Thermal transmittance - external walls.

The thermal transmittance is calculated based on the Brazilian Standard (ABNT, 2003), according to the materials that compose the external walls. Weight: 3.

Olinda – Score: +3	Recife – Score: +3
The calculated thermal transmittance of the external walls corresponds to 2.34 W/(m².K).	The calculated thermal transmittance of the external walls corresponds to 2.65 W/(m².K).

- External noise.

The external noise reduction is measured according to the Sound Transmission Class (STC) of the windows, pursuant to the classification given in Table 4 of the Brazilian Standard NBR 10821 (ABNT, 2000). Weight: 2.

Olinda – Score: +3	Recife – Score: +3

The Sound Transmission Class reaches 28, considering glass of 6mm, according to the program BD Acustica 1.2[5].

5.3 Social sustainability

As for social sustainability, the indicators are preferably related to the socialization, welfare and the quality of life, promoting the appreciation of cultural and communitarian aspects.

- Proximity to educational centre

When it comes about social housing, educational centres in the vicinity contribute to access to education favouring also transport costs reduction. Weight: 4.

Olinda – Score +3	Recife – Score: 0
The project envisages construction of municipal school, from infant education until 8th year of elementary school, within the radius of at least 1000m.	The project envisages the construction of a school only for early childhood education (day care), within the radius of at least 1000m.

- Adequacy of privative area (residential unit) to physical handicapped

Prediction of residential units adapted to physical handicapped, based on the specifications of Brazilian Standard NBR 9050 (ABNT, 2004). Weight: 3.

Olinda – Score: -1	Recife – Score: -1
In both projects there is no prediction of housing units adapted to the physical handicapped.	

- Areas for physical activities

Corresponds to provision of infrastructure for physical activities, promoting also welfare and social conviviality. Weight 4.

Olinda – Score: +3	Recife – Score: -1
It is planned the deployment of soccer fields, sports courts, bicycle paths, apparatus for gymnastics, and a skate ramp.	There is no prediction of facilities for physical activities.

- Socio-environmental education programs for dwellers

It is common for dwellers of these state housing present low education and little experience in condominium conviviality. In addition, alternatives such as rational use of energy and water, waste recycling, among others, require awareness of the users so that, in fact, they may be employed effectively. Thus, it becomes necessary social and environmental training for dwellers. Weight: 4.

Olinda – Score: 0	Recife – Score: 0
It is expected, in both projects, social assistance, provided by the municipal managers, during a short period of time, but environmental issues are not prioritized.	

- Residential unit privacy

Takes up, as reference for privacy of housing units, the minimum distance between buildings, provided for in the legislation, in addition to positioning of openings, use of appropriate windows and glass and the existence of external elements (vegetation, for example), which promote privacy. Weight: 4

Olinda – Score: 0	Recife – Score: 0
It was not identified, in both projects, other alternatives to promote the internal privacy than the minimum setbacks between buildings established in the legislation.	

The following graphic resumes all the results obtained for the several indicators.

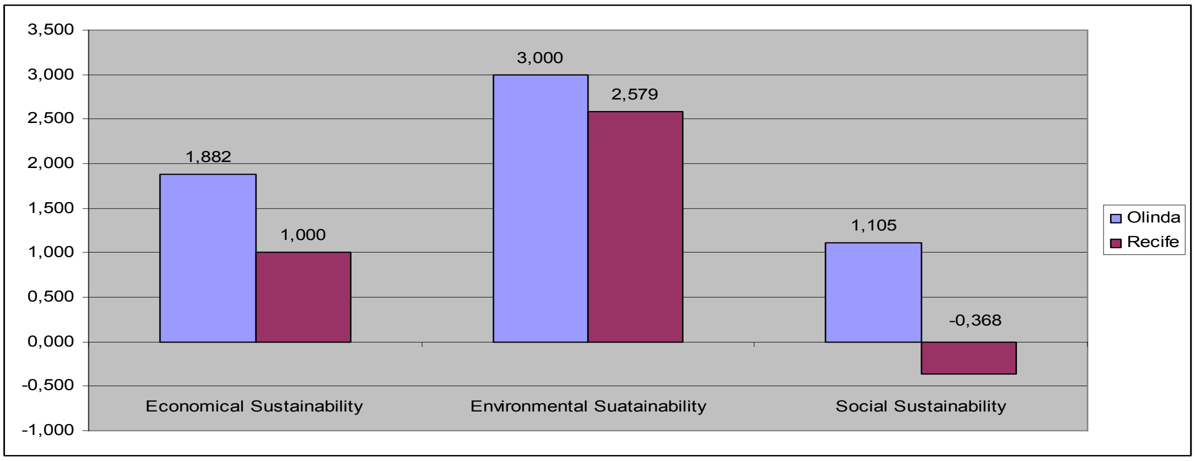

Figure 1 Sustainability levels of Recife and Olinda projects.

[5] *www.fau.usp.br/pesquisa_sn/laboratorios/labaut/conforto/index.html*

6. Conclusions

This paper proposed some indicators that are systematized in order to provide a tool for assessing sustainability of social housing in the Metropolitan Region of Recife, oriented to design phase.

Two case studies are evaluated using this tool. It is necessary to remark that the information contained in the documentation of the projects (specifications and budget spreadsheets, for example) do not always allow accurate results, requiring some estimates. On the other hand, it is emphasized that more important than the final result is the contribution of the work to a methodology for evaluating sustainability of built environment able to steer the market to more sustainable solutions in architecture and construction.

It is also important to point out that what is predicted in a state housing project is not always accomplished, due mainly to lack of financial resources, influenced by social housing policy. The precocious deterioration of state housing in the Metropolitan Region of Recife questions these housing policies. So, results obtained on the basis of design phase may not reflect the real level of sustainability of a state housing project at its concluison.

The continuity of the work will allow the improvement of the tool and the methods employed in the measurement of indicators. An experimental prototype (*Sustainable Built Environment Assessment Tool*) of the proposed method is being elaborated to be accessed via internet, allowing the participation of stakeholders with suggestions for new indicators and adaptations.

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PUTTING A PRICE ON SUSTAINABLE SCHOOLS – SUSTAINABILITY AT WHAT COST?

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Keywords: BREEAM, sustainability, low/zero carbon, school design, capital costs

Summary

The drive for more sustainable development is one of the defining issues of the early 21st Century. This is at odds with the often perceived view that the short-term costs of sustainable practices are too high to justify their application within buildings. Research was undertaken by BRE and Faithful+Gould to identify real cost data for a broad range of sustainability technologies and design solutions for a primary and secondary school. The capital cost for each design or specification adjustment was assessed and compared with a Building Regulation compliant base case study school building. This outlined the additional cost associated with achieving the BREEAM Schools 2006 ratings and a zero carbon school. The results show that major performance improvements can be achieved at little extra cost and even at no cost at all. Reaching the highest standards and striving for zero carbon performance does incur some cost premium, but the research shows that careful consideration of the design and specification at an early stage can minimise these cost premiums.

1. Introduction to BREEAM

BREEAM has become a benchmark of environmental responsibility for buildings in the UK, and has gained international recognition for objectively and holistically assessing the environmental performance of all building types. BREEAM was devised by BRE in 1990 and has become a highly sought after label that demonstrates the environmental credentials of all building types and developments. Credits are awarded for implementing environmental aspects within the building design. Each credit is weighted according to its importance and the resulting points are summed to give a total BREEAM score and rating.

BREEAM Schools forms part of the BREEAM buildings portfolio and was funded by the Government Department for Education and Skills. The scheme forms the basis of an independent and credible certification scheme against which the UK Government have set targets for new build and major refurbishment projects.

2. The Approach

The capital cost for each design or specification adjustment was assessed and compared with a base case study school built to comply with Building Regulations. The cost of each design solution was determined using real and recent project data collected by sustainability and cost consultants Faithful+Gould. By using BREEAM Schools credits as a measure of environmental improvement, it was possible to identify the additional capital cost associated with each incremental improvement in environmental performance. This made it possible to identify 'quick wins' and design initiatives that need to be built into the specification at the earliest opportunity for no extra cost or relatively little cost. Whole life costs were not assessed in this study because specific information about the site, maintenance methods and the future energy costs were not available.

2.1 Location related issues

In BREEAM Schools several credits are dependent on the location of the school and other details relating to the site. These include proximity to public transport, existing ecological value and whether the site is greenfield or brownfield. In this study, two location scenarios were assessed:

- ***Greenfield site*** with poor transport links and no location credits are achieved.
- ***Brownfield site*** with good transport links and a selection of location-based credits are achieved.

This places each building within a site-specific context that relates to the BREEAM Schools 'Land Use & Ecology' and 'Transport' associated credits.

Some credits could not be assessed in this study as the costs were very site-dependent. These included improving the acoustic performance of the school, sourcing recycled aggregate and improving the ecology of the site. As these credits could not be assessed, more innovative and potentially costly technologies, such as renewable technology, were incorporated. This may not always represent the most cost-effective means of achieving a BREEAM Schools 'Excellent' rating and for a real building the site-dependent credits could be achieved at a lower capital cost.

3. Case studies – achieving BREEAM Schools ratings

3.1 Primary school

The Building Regulation compliant 'base case' primary school building has the following attributes:

- Construction capital cost is £1570/m^2 including preliminaries and contingencies but excluding furniture, fittings and equipment, external works and fees.
- New build, single-storey building with a gross floor area of 1367 m^2 and accommodating 210 students and staff.
- Utilises natural ventilation and thermal mass as its sole form of cooling. Each classroom has a full-height glazed window and a ventilation stack. The ventilation stack on top of each classroom allows air to flow throughout the room. Brick and blockwork cavity walls, concrete ground-floor slab.
- No mechanical ventilation is used except where required by regulation/functional requirements (eg toilet and kitchen facilities).
- Radiators served by condensing gas boiler, low-temperature hot water heating.
- Nylon carpet and vinyl flooring in circulation area. Standard fluorescent electric lighting.
- Double-glazed aluminium windows with softwood rooflights.

The following measures were included and costed for a good location:

- Pass: Insulation with a global warming potential (GWP) of less than 5; external lighting in compliance with the Institute of Lighting Engineers' guidance; water-saving appliances.
- Good: Energy-efficient external lighting; registration for Considerate Constructors' Scheme; mains leak detection system; energy-efficient internal lighting.
- Very Good: Water meter with pulsed output; recycling facilities; mains-fed water coolers; *Green Guide* 'A'-rated floor finishes; cyclist facilities; building user guide; proximity detection shut-off system.
- Excellent: Sub-meters; site investigation; *Green Guide* 'A'- rated external hard landscaping; renewable and low emissions energy feasibility study; low carbon renewable energy system (eg biomass boiler).

3.1.1 Primary school BREEAM Schools ratings

Table 1 % increase in capital cost for a primary school to achieve Pass, Good, Very Good and Excellent BREEAM Schools rating in a good and poor location

Location	BREEAM score and rating for a base case school	Pass	Good	Very Good	Excellent
Good	19.3 Unclassified	0.0	0.7	1.8	5.9
Poor	11.0 Unclassified	0.3	1.1	3.0	9.85

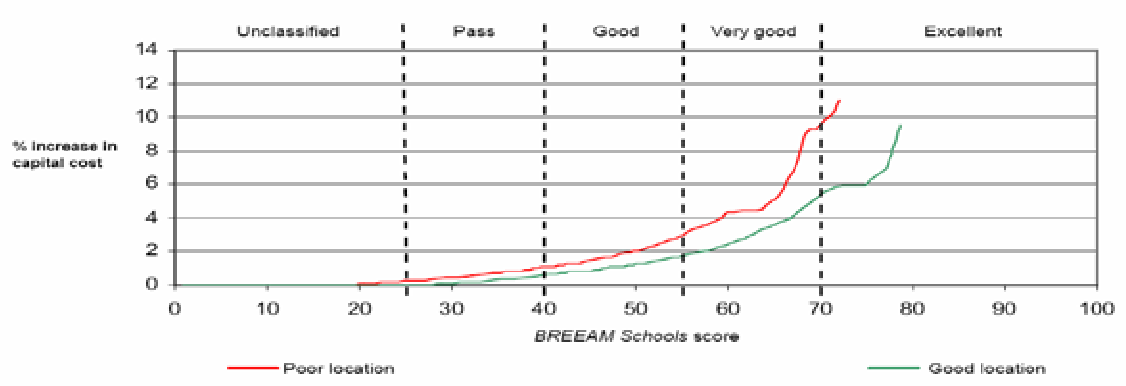

Figure 1 Cost versus environmental performance for a primary school in a good and poor location

3.2 Secondary school

The Building Regulation compliant 'base case' secondary school building has the following attributes:

- Construction capital cost is £1711/m^2 including preliminaries and contingencies but excluding furniture, fittings and equipment, external works and fees.
- New build, 3-storey building with a gross floor area of 3116 m^2 and accommodating 500 students and staff.
- Utilises natural ventilation and thermal mass as its sole form of cooling. Brick and blockwork cavity walls, concrete ground-floor slab.
- A central corridor divides the floor in two lengthways, and classrooms are located either side of the central corridor.
- No mechanical ventilation is used except where required by regulation/functional requirements (eg toilet and kitchen facilities).
- Radiators served by a condensing gas boiler, low-temperature hot water heating.
- Nylon carpet and vinyl flooring in circulation area. Standard fluorescent electric lighting.
- Double-glazed aluminium windows.

The following measures were included and costed for a good location:

- Pass: Insulation with a GWP of less than 5; external lighting in compliance with the Institute of Lighting Engineers' guidance; water-saving appliances.
- Good: Low NOx boiler; energy-efficient external lighting; registration for Considerate Constructors' Scheme; mains leak detection system; water meter with pulsed output.
- Very Good: Recycling facilities; mains-fed water coolers; *Green Guide* 'A'-rated floor finishes; building user guide; proximity detection shut-off system; whole life cost model; site investigation.
- Excellent: Cyclist facilities; sub-meters; *Green Guide* 'A'-rated external hard landscaping; renewable and low emissions energy feasibility study; lowcarbon renewable energy system (eg wind turbine).

3.2.1 Secondary school BREEAM Schools ratings

Table 2 % increase in capital cost for a secondary school to achieve Pass, Good, Very Good and Excellent BREEAM Schools rating in a good and poor location

Location	BREEAM score and rating for a base case school	Pass	Good	Very Good	Excellent
Good	21.1Unclassified	0.0	0.2	0.8	3.9
Poor	12.8 Unclassified	0.1	0.5	2.7	4.4

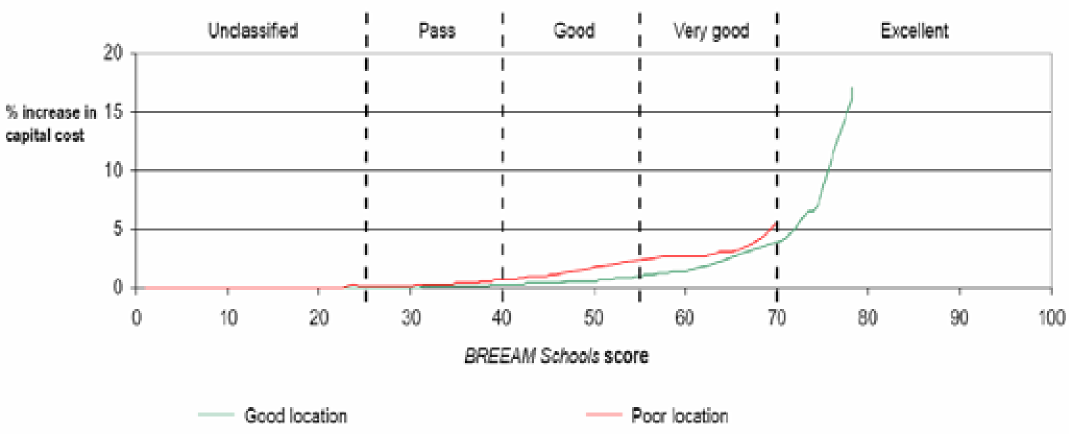

Figure 2 Cost versus environmental performance for a secondary school in a good and poor location

4. Case studies – achieving a low/zero carbon school

Having considered the cost implications for achieving the BREEAM Schools ratings, the study sought to understand the improvements that would be required to achieve a zero- or low-carbon school over and above a base case Building Regulations compliant school. A zero-carbon school is defined as one where the net CO_2 emissions are zero (ie energy used to power, heat, cool, ventilate and illuminate the building using standard hours of use). This includes small power services such as computers and appliances. Carbon emissions were reduced using low-cost measures such as increasing insulation levels, reducing infiltration rates and maximising the use of daylight before applying renewable energy technology. Renewable energy systems were then applied as a means to reduce further the carbon emissions.

4.2 Primary school results

Table 3 Zero/low-carbon primary school – total costs and cost/m² saved

	kg/CO_2/m²/year	Biomass Photovoltaic's	Biomass Wind power	Ground source heat pump Solar hot water collectors Photovoltaic's	Ground source heat pump Solar hot water collectors Wind power
Building regulation requirement	18.4				
Actual building emission rate	18.35				
Lighting controls	5.12	£5.80	£5.80	£5.80	£5.80
Heat	7.24	£18.30	£18.30	£49.20	£49.20
Hot water	2.7			£19.30	£19.30
Electricity	3.34	£46.30	£9.30	£103.90	£9.30
Total £/m²		**£70.40**	**£33.30**	**£153.70**	**£70.50**
Total		**£96 273**	**£45 583**	**£210 097**	**£96 38**

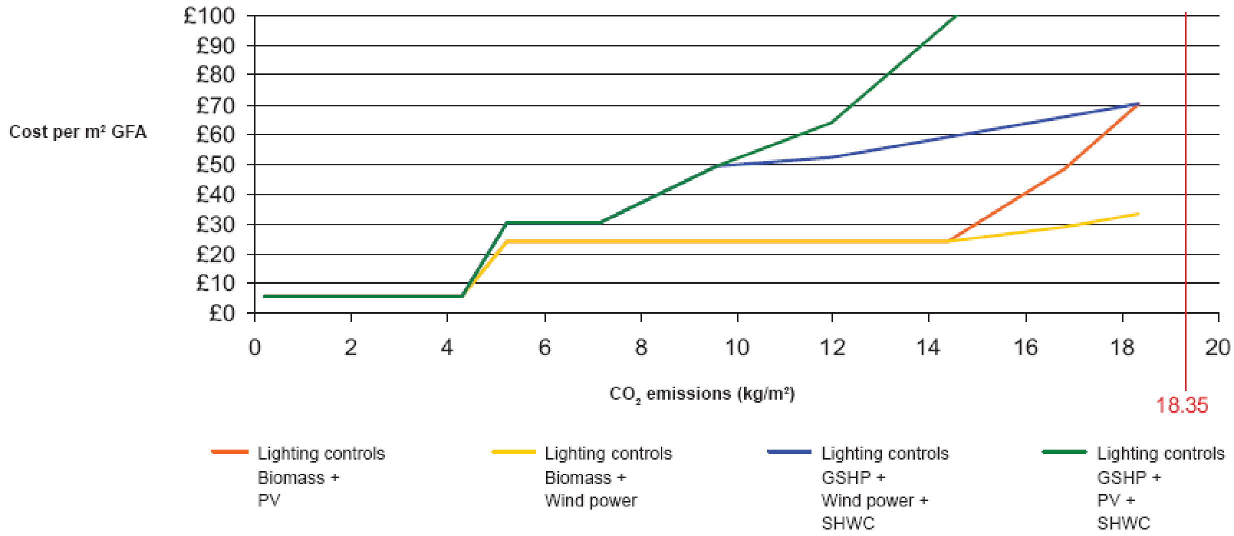

Figure 3 Cost (£/m²) to reduce carbon emissions for a primary school addressing a combination of renewable and low-carbon emission technologies

4.2 Secondary school results

Table 4 Zero/low-carbon secondary school – total costs and cost/m² saved

	$kg/CO_2/m^2/year$	Biomass Photovoltaic's	Biomass Wind power	Ground source heat pump Solar hot water collectors Photovoltaic's	Ground source heat pump Solar hot water collectors Wind power
Building regulation requirement	21.71				
Actual building emission rate	21.36				
Heat	10.55	24.40	24.40	35.60	35.60
Hot water	2.7			19.30	13.20
Electricity	7.7	109.40	21.90	206.90	41.20
Total £/m²		**£133.80**	**£46.20**	**£262.40**	**£89.90**
Total		**£416 925**	**£45 583**	**£817 506**	**£280 150**

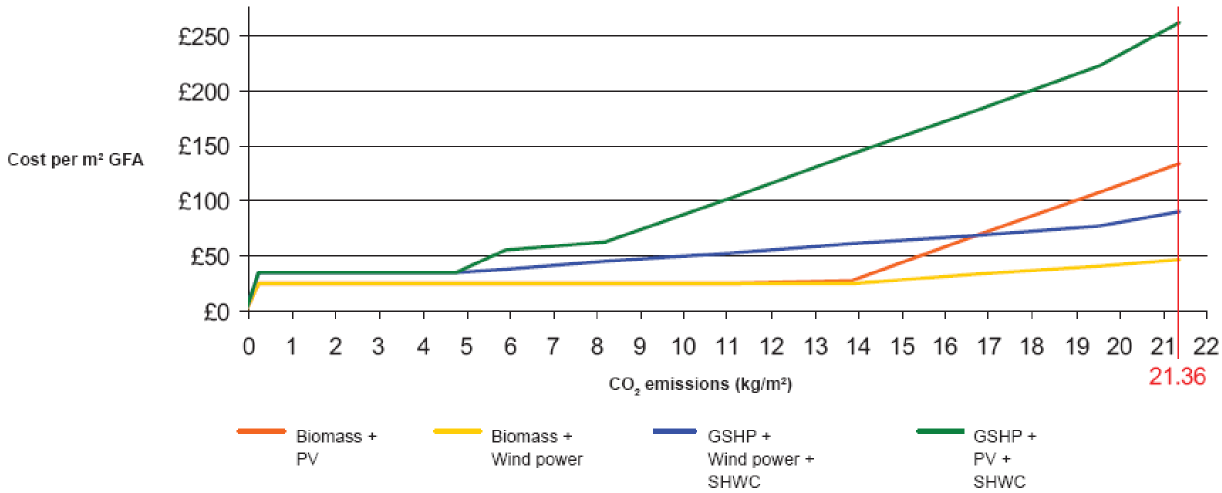

Figure 4 Cost (£/m²) to reduce carbon emissions for a secondary school addressing a combination of renewable and low-carbon emission technologies

4.1 Discussion of results - achieving a low/zero carbon school

The primary and secondary schools demonstrated that lighting controls yield the greatest reduction in carbon emissions. Improving the U-value is the next best option but provides significantly less savings than the lighting controls. The reduction of air infiltration from 10 to 5 $m^3/m^2/hr$ provides the least reduction in carbon emissions.

4.1.1 Carbon footprint of electricity use

The base case primary school had carbon emissions due to electricity consumption of 3.29 $kg/CO_2/m^2/year$ while the secondary school had carbon emissions of 7.77 $kg/CO_2/m^2/year$.

The energy modelling process suggests the most significant means of reducing carbon emissions is through the installation of automatic daylight-controlled dimming. This is particularly apparent within the two case-study schools which had high daylight factors and consequently enabled electric lighting to be switched off for much of the time. As schools are mainly operated within daylight hours, electric lighting should only be required at the beginning and end of the day in winter. In practice, lights are left on even if daylight is sufficient unless the designer also takes care to improve the uniformity of the daylight distribution and can provide glare-free daylight suitable for viewing electric whiteboards without having blinds down and lights on. The carbon emissions for electricity are fairly low due to the savings on electric lighting with high daylight factors. If it was not possible to make such large savings on lighting the achievement of zero carbon would be much more difficult as the 'on-site' generation of electricity through renewable technology is more demanding than for heat.

4.1.2 Carbon footprint of space heating and hot water

The base case primary school had carbon emissions due to space heating of 7.24 kg/CO_2/m^2/year while the secondary school had carbon emissions of 10.55 kg/CO_2/m^2/year. Both schools had carbon emissions from hot water of 2.7 kg/CO_2/m^2/year.

While improved U-values and lower infiltration rates reduced the carbon emissions associated with the heating load of school buildings, the introduction of daylight dimming lighting controls increased heating-related carbon emissions by reducing the indirect contribution of heat from the lighting load.

4.1.3 Application of renewable and low emission technology

The heat and electricity demand were targeted separately to reduce the net carbon emissions to zero with on-site renewables and low emissions technologies such as:

- ground source heat pumps (GSHP) for heating,
- biomass for heating and hot water,
- wind and photovoltaics (PV) for electricity,
- solar hot water collectors (SHWC) for domestic hot water demand.

It would not be possible to supply all the heat demand using solar hot water alone and therefore this has only been considered to supply hot water. These paths to zero carbon may simply not be available to some schools as these costs assume:

- good ground conditions suitable for good efficiencies of GSHP,
- a sufficient wind resource for wind power,
- sufficient suitable roof area for PV/solar hot water collectors, and
- fuel availability for biomass.

It should be noted that in some circumstances low/zero carbon will be difficult to implement and will have a major impact on the costs presented in this section. The following scenarios outline the low-emission and renewable technologies that were applied in the order listed until net carbon emissions in the base case schools became zero.

5. Conclusion

This study illustrates that many sustainability measures can be implemented at little cost and a limited number of items are available at no additional cost. It should be noted that costs may significantly increase if sustainability advice is received too late. Ensuring that sustainability is considered broadly at the outset (and in detail at appropriate stages in the development of the design) will minimise cost and maximise environmental performance. Other broadly applicable findings are as follows:

- Development location and site conditions have an impact on the costs associated with achieving higher (ie Very good or Excellent) *BREEAM Schools 2006* ratings. Any estimates of the cost of achieving a BREEAM rating should include a thorough review of site conditions.
- Effective management of the development process is critical to ensuring that all low-cost options are identified and achieved. Costs can rapidly increase once all the low-cost options have been implemented or exhausted. To enable environmental performance to be maximised at lowest cost, sustainability must be considered at the earliest possible stage of the design process and every effort should be made to incorporate all the possible low cost items.
- The case studies in this report assume that solutions are implemented at the design stage, rather than retrofitted. Identified low- or no-cost options include:
    - specifying water-efficient appliances,
    - ensuring all timber is procured from appropriate certified sources,
    - committing to good construction practice (such as through the Considerate Constructors' Scheme),
    - providing low-energy lighting,
    - enhancing thermal performance through increased insulation levels,
    - avoiding air-conditioning where possible. Not only does this help to reduce energy use and associated CO_2 emissions, but the use of a passive or mechanical system also avoids the need for expensive refrigerants (particularly those with a high global warming potential) and refrigerant monitoring systems.
- Providing technologies such as photovoltaic panels or rainwater harvesting is still relatively expensive compared with most other sustainability options and has significant maintenance implications.
- While outside the scope of this study, good controls and commissioning can lead to significantly lower energy consumption making it more likely that design aspirations will be achieved.

Although initial capital costs may be higher, purchasing or procuring an energy-efficient school can result in significant cost savings on energy bills. If the mains water consumption is metered, implementing low water-use facilities will also have a positive effect on reducing operational expenditure.

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Appendix A. BREEAM

BRE's Environmental Assessment Method (BREEAM) is used to measure a building's environmental performance. The main objectives of the scheme are:

- to differentiate buildings that meet higher levels of environmental performance from the rest of the market,
- to encourage, reward and promote best environmental practice,
- to raise awareness of the benefits of building to best environmental practice standards.

BREEAM considers broad environmental concerns such as climate change, resource use and impacts on wildlife, and balances these against the needs for a high quality, safe and healthy internal environment. They identify those projects that improve environmental performance through good management, design and specification, and credits are awarded where specific performance levels are achieved in each category. The credits are then weighted according to the relative importance of the environmental issue that they address to give a point score. The weightings were established through a large and varied stakeholder consultation and are revised periodically as priorities change.

Table 5: The following BREEAM 2006 ratings are awarded on a scale of achievement: Pass, Good, Very Good and Excellent based on the scores given below.

BREEAM rating	BREEAM score
Unclassified	< 25
Pass	≥ 25 – < 40
Good	≥ 40 – < 55
Very Good	≥ 55 – < 70
Excellent	≥ 70

For more information on BREEAM visit www.breeam.org

EVALUATION OF SUSTAINABILITY FOR HOUSING AGGLOMERATE PROJECTS IN THE STATE OF SÃO PAULO – BRAZIL

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Keywords: housing projects, sustainable assessment methods

Summary

To improve the quality of the building construction environment, developed countries have designed methodologies to assess sustainability both of building constructions and urban areas. In developing countries the situation is somewhat more complex, considering that the fast and disordered urban growth has generated several environmental and mainly social problems. Among other problems, São Paulo, with almost 11 million inhabitants, has a significant housing deficit, both owing to the insufficiency of housing units to meet the existing demand and the low quality of existing units. In the context presented by the authors, the purpose of this article is to analyze some sustainable assessment methods existing internationally, applying them to a housing agglomerate project that was designed in light of sustainable urban planning principles such as differentiated design, use of solar energy for water heating, and participation of the community in the project development, among others. With such analysis, the authors intend to review the situation of housing agglomerates in regard to sustainability and, at the same time, analyze the applicability of international methods to the Brazilian reality, identifying the main difficulties and contributing to build an overview of the situation of housing agglomerates with a view to implementing a national method to assess building construction and urban area sustainability.

1. Urbanization in developing countries

Urbanization is an important issue to be addressed, considering the constant demographic growth of large cities. Current cities are not self-sustainable organisms but rather large consumers of agricultural and industrial inputs and natural resources, without however recycling or reusing them (ANDRADE, 1998; WALSH, 2006).

If on the one hand the urbanization process has contributed to the evolution and development of modern societies, on the other, it has significantly modified the natural space therefore generating extremely negative environmental and social impacts, mainly in developing countries. In developing countries, the urbanization process was fast and intense, and was characterized by the absence of organization or planning on the part of the local government and a spontaneous development whose rules were dictated by real-estate speculation. This mainly benefited the development of services infrastructure for the nobler areas of the cities intended to the high- and middle-income classes, whereas other less appreciated areas that were occupied by classes with a lower purchasing power remained almost or even completely without urban infrastructure (ANDRADE, 1998).

In Brazil, in spite of decreasing urban growth rates, large cities such as São Paulo still suffer as a result of that spontaneous urbanization (ANDRADE, 1998; WERNA, 2001). The growth that was uncontrolled for years now represents a difficulty to be overcome by urban management, both in environmental and economic terms, and mainly in social terms (BONDUKI, 1994).

In social terms one might say that the low-income population is excluded from the right to decent housing because it is not able to get access to the formal housing unit market. The solution found by that extremely poor population goes from the production of squatter settlements to the establishment of an informal sector of small real-estate promotion (for example, renting rooms in tenement buildings). They are always settled in disagreement with official regulations with precarious dwellings in risk areas – for example, hills – or areas of water supply source protection deprived from comfort or services infrastructure (ROCHEFORT, 1998).

Gibberds (2001) states that housing conditions in developing countries do not achieve even the minimum standard to meet the basic needs of quality of life such as access to water/sewage and energy, which makes the possibility to achieve higher environmental quality levels even more remote.

2. The context of Brazilian housing agglomerates

Generally speaking, Brazilian housing agglomerate projects do not present features relating to environmental concerns or any other principle relating to sustainable development (FREITAS, 2001). Moretti (1997) states that the Brazilian laws are extremely restrictive, limiting the use of differentiated designs and inducing to the development of some project typologies with high infrastructure implementation cost, such as:

- Single-family units isolated in the tract of land – making the land use coefficient extremely low and raising the cost of infrastructure;
- Mesh-type roadway system, without a hierarchy of roadways generating high paving costs and large impermeable areas;
- Execution of large land movements to adapt the land to the housing agglomerate that is often designed for practically leveled soils, increasing erosion and sedimentation and compromising soil stabilization.
- Negative impacts such as: sunlight obstruction and neighborhood disturbance during construction.

To improve that situation, in recent years, the CDHU – Companhia de Desenvolvimento Habitacional e Urbano do Estado de São Paulo (Housing and Urban Development Company of the State of São Paulo), responsible for the development of housing programs intended to low-income classes – adopted some actions regarding the improvement of socially-oriented housing conditions. From 1998 to 2002, the CDHU designed a project called Ecodesign that consisted of an initiative among the company's technical professionals for environment management training. The product of that project was called Project Manual for EHIIS – Empreendimentos Habitacionais Integrados de Interesse Social (Integrated Socially-Oriented Housing Projects). Its purpose is to apply social and environmental management concepts, guidelines and procedures called Integrated Socially-Oriented Housing Projects.

The greatest challenge to be overcome by the Manual is to incorporate social and environmental sustainability principles into urban and socially-oriented housing projects through an integrated view of products and processes, and the adoption of environmental principles and criteria.

In 2001 the actual application of the Ecodesign concept in a CDHU project was started (FIGUEIREDO, 2002). The purpose was to address variables such as ecology and use of land, a healthy community life, materials selection and specification, water and energy conservation, maintenance and operation management.

The application of those principles occurred in the implementation of a housing agglomerate in partnership with the Municipal Government of Atibaia – the Atibaia D housing agglomerate that will be detailed in the case study below.

3. The Atibaia D housing agglomerate

The housing agglomerate under study is located in the City of Atibaia, 67km far from the City of São Paulo, outside the Metropolitan Area. In the Master Plan prepared by the municipal government the estimated population was 126,851 inhabitants for 2005 according to IBGE (Brazilian Institute of Geography and Statistics) data. The population income of the housing agglomerate's area corresponds to US$ 400.00/month.

Before the construction of the housing agglomerate the soil had low vegetation and had no trees or buildings. The declivity is approximately 12% towards the existing creek.

Figure 1 Two views from GoogleEarth: first in 2002 and second 2008

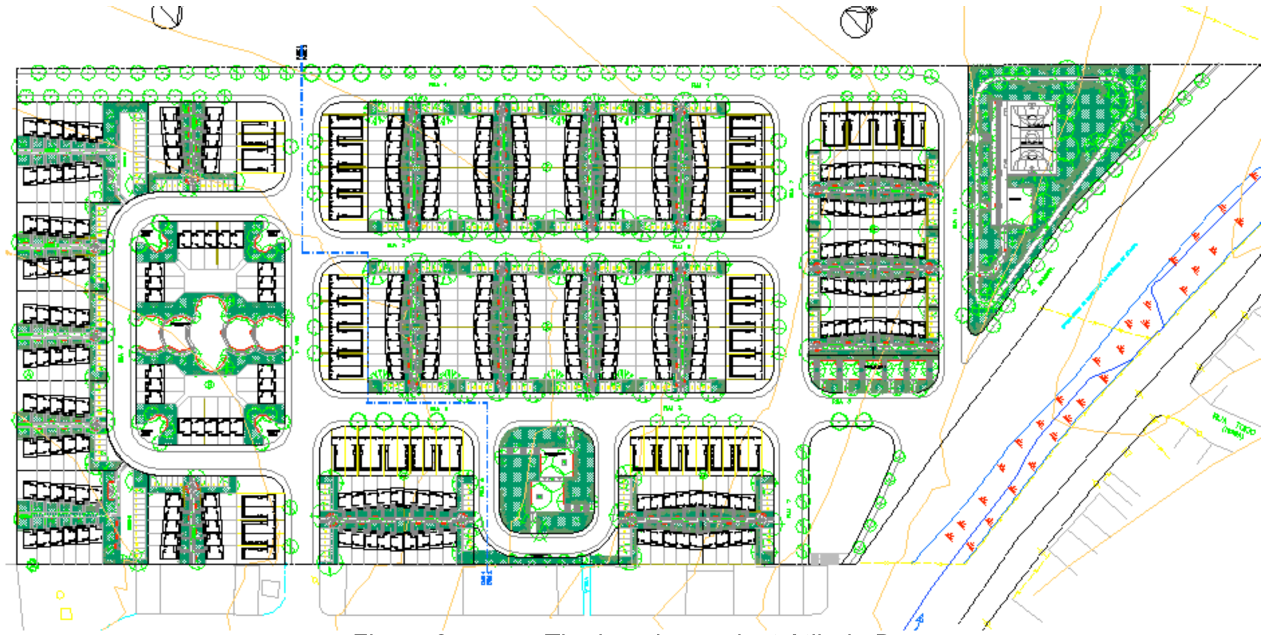

Figure 2 The housing project Atibaia D

The Atibaia D housing agglomerate project is differentiated not only for its design but also for its Ecodesign principles used in its development. In relation to design, unlike traditional housing agglomerates, the Atibaia D has groups of townhouse-type housing units for better use of the urban infrastructure.

Hierarchical use of roadways not only takes advantage of the infrastructure and reduces paving costs but also configures a more pleasant and not monotonous outdoor environment.

The project was designed in the form of small villas, where the access to the housing units occurs on foot through a narrower and entirely tree-planted street. The parking space is perpendicular to the housing unit access way. Some principles to be followed were defined and are mentioned below:

- Population participation in the project, engineering works planning and production of the public space
- Creation of the housing agglomerate's natural resource management system (water, vegetation, energy and solid waste)
- Priority in the use and preservation of local resources
- Technology suited to the local labor/users
- Reduction, minimization or elimination of waste generation.

Programs provided to reduce the housing agglomerate's environmental impact include:

- Basic sanitation
- Landscaping (denser green areas/recomposing the original vegetation)
- Selective Garbage Collection
- Use of solar energy to heat water in some units
- Minimizing waste in the engineering works.

The urbanization and building construction studies prepared by CDHU estimated 369 housing units to be built, part of them on a global contractor's work basis and another part of them through self-help housing production (housing bees). The housing agglomerate has two typologies: 208 two-story houses and 61 one-story houses. Of the one-story houses, 12 are intended to physically disabled individuals.

All future residents are being trained for construction, maintenance and landscaping activities of the housing agglomerate that will remain under the responsibility of users, including implementation and maintenance. The civil engineering works started in 2004 and are expected to end in the first half of 2008.

4. Assessing of housing agglomerate through different methods

For its differentiated project, the Atibaia D housing agglomerate was selected for the purpose of verifying the applicability of international methods to housing agglomerates with a differentiated project and also to analyze its sustainable performance according to international parameters.

Through the case study, the Atibaia D housing agglomerate was evaluated using five methods chosen according to the criteria below:

- Methods already studied internationally and with already-published bibliographical analysis;
- Methods prioritizing urban areas;

- In the case of being specific for assessment of buildings that included categories of assessment of the surroundings and of the building with its neighborhood;
- Methods that made access available to its files and structure, such as spreadsheets, checklists, etc.
- Possibility for the method to be used for self-assessment.

The methods were obtained via the Internet, through file download. The methods chosen according to our criteria were:

- Building Research Establishment – Ecohomes (United Kingdom),
- Sustainable Building Assessment Tool – SBAT (developed in South Africa)
- Sustainable Building Tool – SBTool (an international initiative involving several countries)
- Leadership in Energy and Environmental Design – LEED-ND (United States)
- Category 01 of the AQUA method adapted to Brazil from the French method: NF Batiment Terciare – Haute Qualité Environnementale – HQE.

The LEED-ND method is the only one of the selected methods whose purpose is to assess urban areas using specific indicators. Other methods were studied to be compared with the LEED-ND. Although they are intended to building constructions and are not specific for neighborhoods, districts or urban areas, all of them have indicators to assess, for example, the impact of the project on its surroundings, in relation to sunlight and winds, in addition to verifying the services available, such as hospitals, schools, parks, access ways, transportation systems, and infrastructure existing in the surrounding area.

Those indicators would serve to supplement the project assessment, making its evaluation possible through methods that are not specific for urban areas. The housing agglomerate's assessment using those methods was performed based on the construction projects and guidelines provided by the CDHU. That work did not follow through the construction phase of the housing agglomerate

5. Analysis of assessment results using sustainable methods

Table 1 EcoHomes results

EcoHomes - Categories	**Score/Total %**	**%**	**Classification**	
Energy	2.75/22	12.5	Pass	36%
Transport	5/8	62.5	Good	48%
Pollution	4.55/10	45.5	Very Good	58%
Materials	0/14	0	Excellent	70%
Water	5/10	50		
Land use and Ecology	4/12	33		
Heath and Wellbeing	0/14	0		
Management	3/10	30		
Not pass	**24.29**			

ECOHOMES (BRE, 2006) - The housing agglomerate did not achieve the minimum scoring to be approved by the system because the method is restricted to United Kingdom or European Union standards that do not exist or do not have a Brazilian standard equivalence, in addition to being intended to building construction assessment, leaving few indicators for the assessment of the project and location and its surroundings. Only 15% of indicators account for project location and its surroundings.

Table 2 SBAT results

SBAT	**Score/Total**	**%**	**Classification**	
Economic	3.9/5	78	Very poor	0-1
Environmental	1.5/5	30	Poor	1-2
Social	1.9/5	38	Average	2-3
			Good	3-4
Average	**2-3**	**46**	Excellent	4-5

SBAT - Its indicators are very general allowing for the assessment of a large project as a whole, considering that it is not restrictive to specific building construction items. The Atibaia D project gives great emphasis to economic factors, which makes sense considering that the resources are scarce and the construction has to be economically viable. The social aspect assessment had a low score, showing that the housing agglomerate did not meet the indicators proposed by the social category. The environmental aspect assessment had the lowest score of the three categories, once the Atibaia D housing agglomerate project does not provide for any of the environmental requirements of the system, such as: implementation of a vegetable garden and orchards, water treatment and reuse, and use of recyclable materials. The only requirements met by the housing agglomerate are: use of renewable energy for water heating, selective garbage collection provided by the municipality and the policy of non-wasting during engineering works.

Table 3 - SBTool results

SBTool - Categories	Score/Total	%	Classification	
Site Selection, Project planning and development	3/5	50	Acceptance practice	0
Energy and resource consumption	1.2/5	10	Good practice	3
Environmental loadings	1.7/5	15	Best practice	5
Indoor environmental quality	0/5	0		
Service quality	0/5	0		
Social and economic aspects	4/5	15		
Cultural and perceptual aspects	3/5	5		
Acceptance practice	**2.6/5**			

SBTool (Larsson, 2008) - In general, the system is extremely complex, but also malleable. The weight of indicators may be changed or disconnected according to the reality in question. As mentioned before, the system is a generic tool but may be adjusted to different realities. It was not possible to perform the assessment of the following categories: indoor environmental quality and service quality, whether for lack of data or even for not being applicable to the urban configuration of the housing agglomerate. Several other indicators of other categories were not applied for the same reason.

Table 4 Aqua results

Aqua – category 1	Performance
Sub-category 1.1	Average
Sub-category 1.2	Good
Sub-category 1.3	Good
Final performance	**Average**

The AQUA method has a quite different configuration from the other methods for establishing a profile rather than a scoring classification. In this case, we did not use the entire system, but the first of the 14 categories, which generated an assessment using the indicators applicable to that category only. Unfortunately the housing agglomerate did not have a better performance because a requirement for superior performance is the rational use of water and energy concomitantly, and this is not the case of Atibaia D.

Table 5 LEED-ND Pilot version results

LEED-ND - Categories	Score/Total	%	Classification	
Smart Location % Linkage	19/30	63	Certified	40-49
Neighborhood Pattern & Design	27/39	70	Silver	50-59
Green Construction & Technology	5/31	16	Gold	60-79
Others	3/6	50	Platinum	80-106
Silver	**54**	**51**		

The pilot version (USGBC, 2007) was the one which best adapted to the Atibaia D housing agglomerate, first for being a specific method for urban areas and second for having indicators more easily adaptable to the Brazilian reality. A differentiating characteristic of the system is that it combined sustainability indicators with geo-processing information, something that has already been used in urban planning issues in developed countries (NOBREGA, 2006).

As a whole, the Atibaia D housing agglomerate performance was considered medium using the methods that assess building constructions and their surroundings only. In spite of the good performance using indicators related to the urban context such as infrastructure and services, the housing agglomerate does not present any initiative regarding the efficient use of potable water, there is no project for collecting rainwater or reuse of served water applied in the project and it does not present any initiative regarding the use of recyclable or recycled materials.

5. Final remarks

In terms of environmental practices, the Brazilian civil construction industry has recently started to address sustainable construction procedures, and most construction processes do not have a significant environmental impact.

Brazil does not have laws on water reuse or provisions for locally produced excess energy that may be thrown in the network; this makes the implementation of small alternative energy stations difficult, because they become economically unfeasible.

Indicators relating to daylight or natural lighting and sunlight achieved maximum level, for the fact of Brazil being a tropical country unlike the countries where the methods were developed, with a lower rate of sunlight.

Indicators relating to greater local density and location of the land close to services and transportation were met at their highest level: the housing agglomerates are located in dense areas and assisted by some services; the problem is more complex services such as hospitals and mainly employment centers that are usually located in downtown areas quite distant from the housing agglomerate.

Construction materials are a significant obstacle to be overcome, because there are almost no data about raw materials and manufacturing processes.

The social issue has to be addressed more deeply both in relation to labor and the local community.

In some methods that assessed the effective consumption of water and energy, the housing agglomerate performance was excellent, mainly because there is no purchasing power for greater consumption. The average consumption of a low-income family of a housing agglomerate is less than 18% of the consumption of an American family (EIA – Energy Information Administration, ANEEL – Agência Nacional de Energia Elétrica (Brazilian Agency of Electric Energy).

An important aspect to be pointed out is the difficulty faced by designers when creating a sustainable land development project. That type of project requires a systemic view and the constant work of a team, unlike the traditional method whereby projects are implemented in line. The project has to be designed to be highly efficient during use and operation, which sometimes means higher spending in the project and construction than the land developer wants to invest.

The comparison among the methods and their indicators reveals that all of them use practically the same indicators to asses the performance of their building constructions or urban areas. The comparison also shows that, in general, there are indicators that may be applied to different realities, because they are essential to demonstrate a good environmental or sustainable performance. What differentiates a system from another is its organization and structure, that is, how it organizes, assesses and weighs the criteria to provide the final classification to the project.

In general, the methods are applicable to the Brazilian reality. However, several indicators must be adjusted to the Brazilian reality for the certification of a sustainable project to be real on all levels, whether on the more general level that is the international level where all provide for the effective use of water and energy, responsible consumption of resources, etc., or on more specific sustainability levels that are the national, regional and local levels, which require compliance with specific needs.

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THE IMPORTANCE PROCESS: ENABLING CREATIVITY IN PERFORMANCE-BASED DESIGN THROUGH SYSTEMATIC, MODEL-BASED, SEARCH OF MULTIDISCIPLINARY IMPACTS

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Summary

In this paper we examine a process to provide designers information about the “Importance,” or ranked correlation of design decisions to explicit multi-criteria performance metrics. Historically, the Architectural, Engineering, and Construction (AEC) industries have relied on prescriptive requirements and experience-based precedent to promote building performance. The increasing complexity of building performance today, however, requires confronting multi-dimensional trade-offs across a wide range of performance metrics. With rapidly expanding goals and options competing with limited time and resources, designers struggle to frame, manage and extract value from data-rich simulations and analyses. The Importance process uses systematic exploration of problem and solution spaces to identify performance drivers. It builds upon building information modeling, model-based analysis and optimization, and decision analysis methods including sensitivity analyses, to systematically generate information about the impact of various design decisions on overall building performance according to a defined value function. In this paper we use a simple test case to demonstrate the Importance process and to highlight the design guidance created. Future work will test the usefulness of the Importance process by evaluating its ability to enable creativity in performance-based design.

1. Introduction

Buildings are a major source of demand for energy and materials and are currently responsible for approximately: 39% of carbon emissions, 65% of electricity consumption and 30% of raw material use in the United States (USGBC 2008). Managing and reducing these impacts has become a high priority for businesses and government. The American Institute of Architects (AIA) in the 2030 Challenge, and the Federal Government in the Energy Independence and Security Act, for example, call for 0% estimated annual fossil fuel energy consumption for new building designs by the year 2030. Throughout the industry, sustainable design is being defined using a variety of existing and emerging metrics, such as carbon footprint, energy cost savings, indoor environmental quality and embodied energy, to name a few. The complex nature of sustainability, however, forces trades-off between multiple and competing objectives. Whole-building energy simulation and optimization are important tools for facing the challenges of performance-based design. While building energy modeling capabilities currently lag behind multi-disciplinary analysis and optimization activities in other engineering disciplines such as aerospace (Mavris et al, 1998) or structural engineering (Ghobarah, 2001), researchers are currently working to automate collections of building performance simulations to model interactions among combinations of options, and to optimize for single or multivariate criteria (Ellis et al, 2006.)

Typical results of multi-criteria building optimization support Pareto-optimal design solutions, where a set of equally-ranked optimal solutions are identified (Grierson and Khajehpour, 2002). Such analyses serve as powerful and efficient filters of a given solution space, and rigorously identify a sub-set of “best” solutions that meet a prescribed set of constraints according to an implicit or explicit value function. Key to such an exercise and to multiple attribute decision making (MADM) in general, is the selection of a solution or set of solutions from a finite number of alternatives (Mavris et al, 1998.) As a result, the design guidance provided by either single or multi-criteria optimization is restricted in domain to the solution space modeled, and, as such, the process may be limited in its ability to enable creativity.

Creativity in design is a sought-after yet often ill-defined goal. More than 80 definitions exist in literature (Dasgupta, 1994). Frequently, the solution space for creative design is considered unbounded. Some have ascribed the unrestrained nature of creativity to the “co-evolution” of problem space and solution space, stating that the creative design process, unlike optimization, is not restricted to the search for a satisfactory solution within a fixed problem space. Rather, creative design is about parallel problem formulation and solution generation through constant iteration, synthesis and evaluation between spaces (Dorst et al, 2001). Central to many definitions of creativity are the concepts of usefulness and uniqueness. In the context of performance-based building design, we here define usefulness as generating value according to a prescribed value function, and uniqueness as lacking equivalent alternative(s) within the prescribed solution space.

Our proposed Importance process builds on the work of others who are automating building performance simulation tools as well as those who evaluate performance's sensitivity to decisions using either decision analysis or design of experiment techniques (Howard, 2007, Giunta et al, 2003). Our work generates a ranking of the numerical correlation of simulation inputs (problem space elements) to simulation outputs (solution space elements) for buildings. We prioritize design decisions according to specified building performance metrics using a defined value function. Our test case is a simple building that characterizes the trade-offs implicit to maximizing building performance. As practiced today, energy simulation analyses tend to fall short of providing satisfactory design guidance, and can be non-systematic and error-prone. Current research in building simulation is providing reliable ways to improve building analysis through (semi-) automation, parametric modeling and optimization; new developments in interoperability are providing greater flexibility in data exchange between software allowing a greater number of performance trade-offs to be assessed (Maile, 2007). Our Importance Process is a synthesis of various techniques with an additional post-processing step that presents designer information about the nature of the relationship of their design decisions to expected value. Future work will test the effectiveness of such a process on the usefulness and uniqueness of the solutions generated.

1.1 Points of Departure

Several key points of departure form the building blocks of our Importance process, including building information modeling, building simulation, process modeling, and decision analysis methods. Table 1 summarizes the level of assistance provided by these points of departure toward the six steps essential to our process. These steps are 1. identify problem space / define metrics; establish solution space / define value function 2. systematically generate options, 3. analyze options according to assigned metrics, 4. use value function to evaluate options, 5. prioritize decisions with regard to the value function / establish Importance 6. iterate problem and solution spaces. An “X” indicates the step is achieved; a “P” indicates the step is partially achieved using an existing method.

Table 1: Points of Departure, and their ability to assist with the 6 proposed steps in our process

Elements of design guidance	Establish problem and solution space	Systematically generate options	Analyze options according to assigned metrics	Use value function to evaluate options	Prioritize decisions with regard to the value function	Iterate and synthesize problem and solution spaces
Points of Departure						
Building Information Modeling (BIM)		P	P			
Building Performance Simulation			X			
Parametric Modeling	P	X	P			
Optimization	P	X	X	P		
Decision Analysis	X	P	P	X	X	P
Design of Experiment	X	X	P	X		P
Multi-attribute decision-making	X		X	P	X	

Table 1 shows that no one method currently supports all six of the steps necessary to create a strong decision basis in AEC industries to advance sustainable decision-making in buildings. Existing barriers may include erroneous inputs or limited accuracy of simulation engines (Judkoff et al., 2008); the complexity or computation challenges of probabilistic modeling (Grierson, Khajehpour, 2002); or the diversity of preferences of the stakeholders involved (Haymaker, Chachere 2005). While much pertinent and significant work exists in each area, further work is needed to fully integrate the various tools and theories into a new process that will allow AEC designers to better leverage building performance analyses to enable creativity and generate more useful and unique solutions according to an assigned value function.

1.2 Test Case

To create a test-bed for this investigation we adopted the Relocatable Classroom as a model. While simple, it serves to emulate the basic challenges in performance-based design: unknown building science relationships, uncertain assumptions, and competing performance trade-offs. The Relocatable Classroom model represents any portable or modular classroom in use across the United States. The structure is a simple rectangular box with typical dimensions of 24 feet wide, 40 feet long, and 12 feet high, limits which ensure it can be transported on the back of a flatbed truck. Detailed professional energy analyses have already been performed for this building type (Apte et al., 2005; DEG 2000) and California High Performance Schools has published a best practices manual for the Relocatable Classroom (CHPS, 2006). Figure 1 shows the basic geometric form: a single room outfitted with two windows with overhangs, one door, lighting, heating and cooling, a plenum. Since floor level is raised, insulation can be placed on all six sides of the structure.

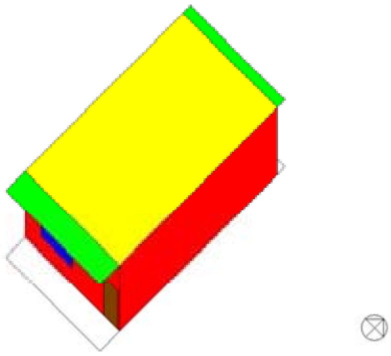

Figure 1 A Relocatable Classroom DOE-2 model represented in DrawBDL

Using the Relocatable Classroom we present the following challenge: to identify the set of design decisions that result in the most cost effective, energy efficient, and thermally comfortable Relocatable Classroom possible. To meet this challenge and investigate our Importance process, we developed a software tool to automate simulation runs and assess the Importance of available decisions. Our prototype tool is a vertical decision support model created as a wrapper to the building simulation tool DOE-2 (Winkelmann et al., 1993.) using Analytica modeling software (Henrion et al., 1996).

For our test case, we modeled seven design decisions: 1) Roof Color (white or metal) 2) Roof Construction (high, medium, or low insulation) 3) Wall Construction (heavy-weight construction, mid-weight construction, or light-weight construction) 4) Floor Construction (high, medium, or low insulation 5) Window Glass (clear, low-e or grey tint) 6) Lighting Power Density (1.66 w/sf or 1.22 w/sf) 7) Packaged Heating and Cooling (heat pump, indirect evaporative cooling, or none). Keeping everything else in the model fixed, we evaluated building's performance using three metrics: first cost, annual energy consumption and hours outside the range of thermal comfort. Finally, we calculated the sensitivity of a linearly weighted value function to these seven decisions. The following section outlines how our prototype software performs the Importance process on the Relocatable Classroom test case.

2. The Importance Process Applied

The Importance process assesses the correlation of individual design decisions to expected building performance. To identify key performance drivers on our simple test case, we exhaustively modeled all possible combinations of the seven decisions. For more complex building designs, we will rely on statistically significant sampling techniques to evaluate performance across an exponentially increasing solution space (Giunta et al, 2003). However, for the Relocatable Classroom model, in collaboration with software engineers at Lumina Decision Systems Inc., we developed a custom prototype, which automatically executes exhaustive simulation of building performance in DOE-2 and performs deterministic sensitivity analysis on the results within Analytica modeling software. Figure 2 diagrams the information flow in the evaluation of Importance in our test case. Note that in preliminary testing, we fixed all design decisions and uncertainties outside the seven decisions analyzed. We named our prototype tool Decisions Assistance Using Importance System (DAIS).

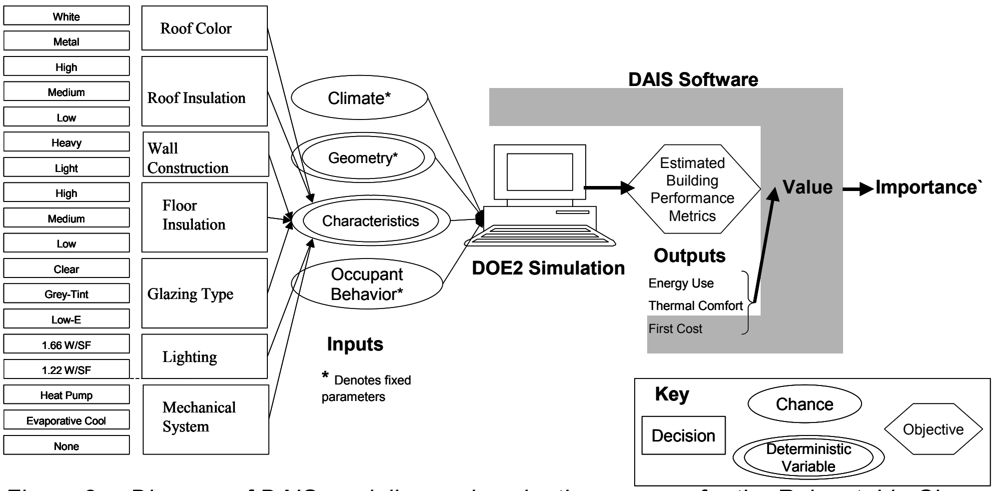

Figure 2 Diagram of DAIS modeling and evaluation process for the Relocatable Classroom

Figure 2 illustrates how DAIS wraps an existing building simulation tool to systematically evaluate the modeled solution space and assess the relative importance of the decisions considered. While several process integration tools exist (Noesis, 2004), little work has been done to date to use such wrappers in conjunction with building performance simulation. The following section outlines the structure of our DAIS prototype software.

2.1 DAIS Structure

In general, DAIS v. 1.0 automates the transfer of information from a user-selected design decision to an existing simulation engine, runs a statistically significant set of simulations, and returns the results to a vertical decision support model environment. Specifically, DAIS runs DOE-2 to estimate energy use and thermal comfort; it tabulates first cost directly in a look-up table; it calculates value using pre-defined value function; it performs a deterministic Importance analysis ranking the impact decisions inputs to assessed value; finally it presents this information to the designer in an Importance chart enabling the designer to better iterate problem and solution space. The following discussion outlines how DAIS v. 1.0 performs these 6 steps:

2.1.1 Step 1: Establish goals, identify metrics and define a value function

Systematic problem space exploration requires definition of project specific goals, metrics and value. We currently, define our problem space by selecting the performance metrics energy use, thermal comfort and first cost. We hard-coded the first cost associated with each option into DAIS. We defined and coded a linear weighted value function in DAIS using the select metrics.

The metrics selected for our test case represent the fundamental nature of performance trade-offs: improving one performance metric by adjusting one parameter may diminish the performance of a second metric. For example, a low cost, low energy building may result in unacceptable thermal comfort; a low energy building that maintains a high level of thermal comfort may result in a high first cost, etc. While a variety of metrics may be critical, (e.g.; indoor environmental quality, maintainability, acoustical environment, carbon emissions . . . etc.), for our test case we constrained our value function to depend on just three. As previously noted, this significantly bounds the problem and makes full analysis of the solution space achievable for our test case.

We normalized the metrics into units of dollars and used a single utility value function to assess value. Thermal comfort, for example, is calculated by the potential loss in productivity ($) for a given number of hours outside of a predetermined thermal range. Other research explores the plurality of AEC design decisions (Haymaker, Chachere 2005) or the qualitative nature of design judgments (Papamichael, 1993.) While, we will continue to develop and hone our value function as our research progresses, we currently use the following equation:

$$\text{Value} = \text{Thermal Comfort}(\$)*\text{Weight}_1 - \text{Total Energy Use}(\$)*\text{Weight}_2 - \text{First Cost}(\$)*\text{Weight}_3$$

The goal of normalizing the metrics to units of dollars is to establish designer indifference to a given set of options. In other words, using a single utility function, decision makers will be indifferent to any design solutions of equal value. This is distinct from some multi-attribute decision making, where it can be difficult to objectively balance alternatives using incomparable metrics.

2.1.2 Step 2: Systematically generate options

DAIS automates the exchange of information to and from the building simulation program DOE-2 to a vertical decision support model environment. It does this by systematically 1) generating a DOE-2 "include" (.inc) file in Analytica; 2) executing a DOE-2 simulation run using this include file; and 3) returning the resulting data.

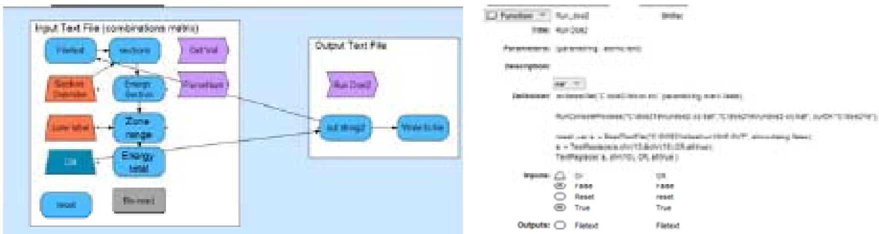

Figure 3 DAIS generates combinations (left), runs a console process in Analytic (right) and executes a DOE2 simulation. The results are fed back to DAIS (left)

Note that existing energy simulations tools do not necessarily successfully or accurately all model building design alternatives (Judkoff et al., 2008). While errors do not occur for our simple test case, future research will have to be prepared for and address a host of challenges related to simulating complex building designs.

2.1.3 Step 3: Analyze options according to assigned metrics

The simple test case of the Relocatable Classroom constrains the solution space to 972 possible design alternatives. In preliminary analysis, we fixed the uncertainties related to 1) climate and 2) occupancy schedule. In addition, we fixed the orientation of the building. Analysis was limited to varying the building performance characteristics for the following design decisions: 1) Roof Color 2) Roof Construction 3) Wall Construction 4) Floor Construction 5) Window Glass 6) Lighting Power Density 7) Packaged Heating and Cooling. Using the results simulated by DOE-2 for annual energy consumption and thermal performance, along with the first cost data tabulated within DAIS, DAIS evaluates value for each design alternative modeled using the defined value function.

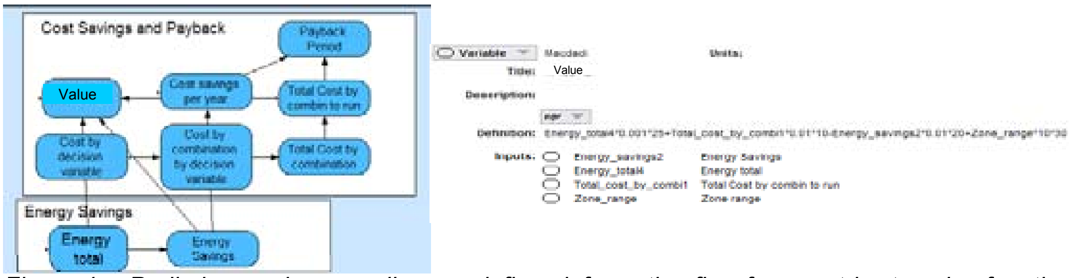

Figure 4 Preliminary relevance diagram defines information flow from metrics to value function, (left); Sample value function defines value in DAIS (right)

2.1.4 Step 4: Use value function to assess Importance

For the simple Relocatable Classroom model, DAIS calculates Importance using high-low sensitivity analysis over all 972 design alternatives.

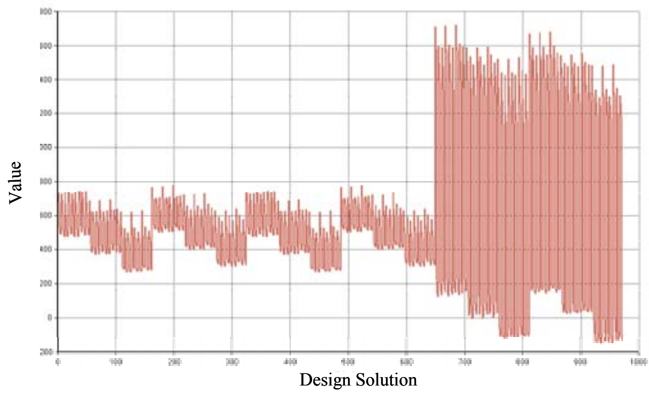

Figure 5: Value function assessment for all defined Relocatable Classroom design alternatives

Figure 5 illustrates the value function evaluated in DAIS over the entire solution space as defined by the seven design decisions modeled. This graph visibly demonstrates that certain decisions have significantly more impact on defined value than others.

2.1.5 Step 5: Prioritize decisions with regard to the value function

DAIS presents user information about the ranked correlation of design decisions to the expected value of building performance in the form of an Importance chart. Figure 6 shows such a chart for energy performance for the Relocatable Classroom in a cold climate. Starting at a given baseline, each decision can be "upgraded" to a higher performance option (e.g., R-11 to R-13 insulation) to the highest (R-19 insulation) option. Figure 6 shows the potential impact of the first upgrade according to the defined value function (in blue) and the potential impact of the second upgrade (in green.) In the case of windows, where the cost "upgrades" show a negative impact on performance for the given design scenario tested: a school building (winter schedule) in a cold climate, blocking increased amounts of solar heat gain results in an overall value function reduction.

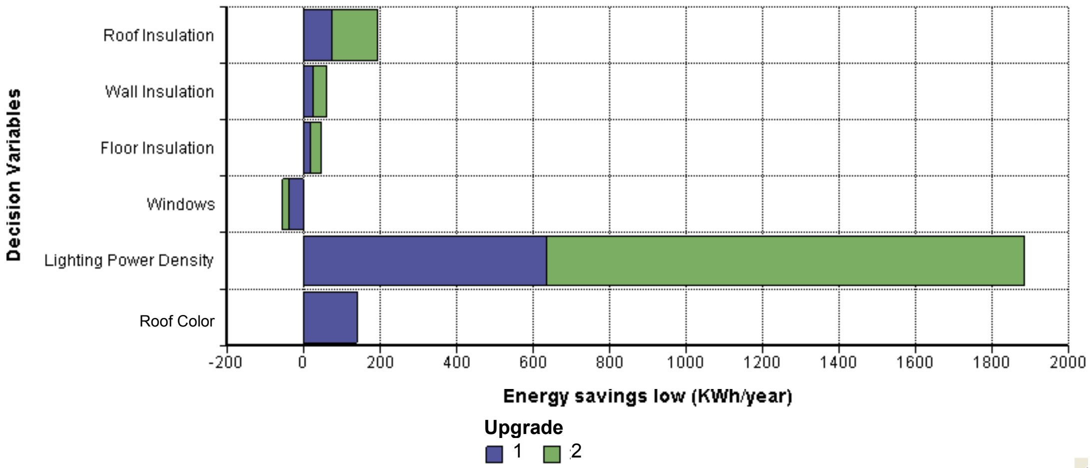

Figure 6: Chart showing "Importance" analysis results for the Relocatable Classroom in DAIS v 1.0

The Importance chart shown in Figure 7 represents post-processing of traditional optimization or design of experiment (DoE) performance results. It is made possible in DAIS by linking a vertical decision support tool, Analytica (equipped with sensitivity analysis functionalities) to a building performance simulation tools, e.g., DOE-2. Since systematic exploration of a problem space is required to evaluate sensitivity, optimum or pareto-optimum solutions are identified during the process. However, we propose that rather than ending with the identification of these generated optimum(s) within a fixed problem space, the addition of post-processed sensitivity analysis will be critical to promoting creativity in performance-based design for buildings.

2.1.6 Step 6: Iterate and synthesize problem and solution space

The design assistance provided by building simulation and analysis tools in performance-based design, ultimately, is a function of how well these tools help designers navigate performance trade-offs to promote creative, useful and unique, building designs of value. Existing challenges to optimization or design of experiment approaches include proper framing of the multi-dimensional problem spaces and accurate evaluation of the elusive solution spaces associated with complex building design. To the extent that the problem and solution space are properly characterized, the systematic search of optimization may leave little room for innovation. However, if characterization is imperfect, a computer generated "optimum" design may, in fact, be inferior to an unrealized alternative. To promote creativity, design exploration should maintain design freedom while supporting knowledge transfer (Mavris et al, 1998.) Our intuition is that the Importance process, building on systematic and automated computer-based search, may offer design guidance beyond the bounds of the modeled solution space and provide further opportunity to iterate and synthesize problem and solution spaces. Our on-going research will focus on cataloging the extent to which the Importance process enables creativity and generates unique and useful solutions as compared to traditional performance-based design methods.

3. Conclusions and Future Work

Today's AEC professionals are struggling to reconcile competing design trade-offs in performance-based design. Currently, trial and error techniques dominate while optimization applications are being developed. Building on modeling insights from other fields and as demonstrated by DAIS, the AEC community may be able to leverage existing building simulation tools using vertical decision support models. By applying the Importance process and presenting designers information about the correlations of their design decisions to building performance objectives, designer may be better equipped to understand the behavior of problem and solution spaces, and better able to transfer this knowledge beyond the bounds of what has been modeled to generate new, creative design solutions. Significant opportunities exist for improved design guidance in performance-based, sustainable design. Impacts on practice may include incentive for vendors to create new functionalities in energy-modeling software and motivation for designer to seek out Importance information when deciding how to allocate design resources. Future work will test the impact of the Importance process on enabling creativity by comparing the usefulness and uniqueness of design solutions generated with and without the assistance of the Importance process.

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A REVIEW OF APPROPRIATENESS OF INTERNATIONAL ENVIRONMENTAL ASSESSMENT TOOLS FOR A DEVELOPING COUNTRY

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Keywords: Sustainable Building Assessment Tools, SBAT, assessment methods, rating tools

Summary

The World Green Building Council (WGBC) has 10 existing members including the United Kingdom, Taiwan, Australia and America. These members have adopted building rating systems, such as Building Research Establishment Environmental Assessment Method (BREEAM), Comprehensive Assessment System for Building Environmental Efficiency (CASBEE), Green Star and The Leadership in Energy and Environmental Design, respective in order to stimulate market demand for high-performance buildings.

The Green Building Council for South Africa (GBCSA) was established by the South African Property Owners Association earlier this year (May 2007) and aims to promote environmentally sustainable practices within the South African commercial and industrial property market.

As with the existing members, an appropriate rating system will be required by the GBCSA. The paper studies the implication of the use of any of the three aforementioned rating systems for South Africa's developing context and compares these systems against the South Africa's indigenous rating tool, Sustainable Building Assessment Tool (SBAT).

The paper suggests that the SBAT is a more appropriate tool for use within a developing country and presents findings for the study.

1. Introduction

The concept of sustainable development has been defined by the World Commission on Environment and Development (WCED) in their Brundtland Report as meeting the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). This was recognized as a balance between the environmental protection, economic growth and social development dimensions in 1992 at the Rio Declaration by the United Nations NGO Committee on Sustainable Development (UN, No date a).

According to Cole (2003) environmental assessments and labeling programs are currently undertaken on a voluntary basis, but are considered as having the potential to create market demand for green buildings.

Building environmental rating systems provide a way of showing that a building has been successful in meeting an expected level of performance in various declared criteria (Cole, 2003). Cole (2003) adds that it is in the adoption and promotion of such systems that contribute significantly to the shifting of the public's awareness and perceptions of what building quality is. This can be confirmed by the increasing number of people demanding information on environmental aspects of buildings, such as whether or not a building was good for their health or if it fit into a sustainable society (Carlson & Lundgren, nd) since the development of the very first building assessment tool, the Building Research Establishment Environmental Rating Assessment Method (BREEAM).

1.1 Relevance

Currently almost each European country, the United States of America, Canada, Australia, Japan, Hong Kong and South Africa have their own assessment tool (Silva, 2007). Da Silva adds that each of these tools shares a *"common goal to stimulate market demands for higher environmental performance levels"* and with "the remarkable exception of South Africa's SBAT," all of the existing tools *"deal exclusively with the environmental dimension of sustainability"* (Silva, 2007).

1.2 Scope of Research

The research focuses on the review of current literature and the review of the five rating tools used by the existing member countries of the World Green Building Council (WGBC).

1.3 Research Aim and Questions

The research aimed to review changes that have occurred globally within the sustainable development field. In light of the changes found, the research questions derived are as follows:

- How do the global changes within the field of sustainability affect the SBAT?
- How does the SBAT compare with the international tools used by national GBCs used?

1.4 Structure of the Paper

The paper is structured under the following heading; background, methodology, literature review, assessment framework, discussion and conclusions.

2. Background

2.1 South African Context

The Republic of South Africa is considered to be the most developed and modern country on the African continent. Since 1994, when the first democratic government was elected, South Africa has had positive economic growth (Knight, 2006). However, on the other side of this positive aspect is a country which still has major social and economic problems including poverty, inequality, unemployment, HIV/Aids and property and personal insecurity (Beall et al, 2005).

2.2 SBAT framework

The SBAT was developed to support the development of a more sustainable built environment within South Africa's developing country context. The tool draws on international best practices and has been refined through use in South Africa that reflects the local context and policy. The tool provides a robust framework/methodology that assesses the sustainability performance of proposed designs and existing buildings. The framework/methodology includes five criteria in all three sustainability aspects, namely:

- Economic – local economy, efficiency, adaptability and flexibility, ongoing costs, capital costs;
- Environmental – water, energy, waste, site, materials and components; and
- Social – occupant comfort, inclusive environments, access to facilities, participation and control, education, health and safety (Gibberd, 2001).

Each of the 15 criteria has a set of five sub-criteria linked to indicators that are used to measure the sustainability performance of a proposed design or existing building (see Table 1). The SBAT has been used to assess commercial, residential buildings.

Table 1 The Structure of the SBAT

Sustainability aspect	Criteria	Sub-Criteria	Indicator
EC ECONOMIC	EC1 Local Economy	EC1.1 Local Labour	Use of local (from within 50km of the site) labourers
		EC1.2 Local Materials	Building material sourced from within the country
		EC1.3 Local Materials and Components	Material and components sourced from within the country
		EC1.4 Local Furniture and Fittings	Furniture and fittings sourced from within the country
		EC1.5 Maintenance	Maintenance and repairs can be undertaken by local SMMEs (turnover of <R5m)
3 Sustainability aspects in total	15 criteria in total	75 sub-criteria in total	75 indicators in total

Source: Sebake and Gibberd, 2008

3 Methodology

Literature of global commitments to sustainable development was reviewed. This led to the development of an assessment framework which will be used to assess the GBC rating tools.

4 Literature Review

4.1 Global Commitments to Sustainable Development

4.1.1 Global Monitoring Report [2007]

The development of the Millennium Development Goals (MDGs) derived from the Millennium Declaration in 2000, at the United Nations Millennium Summit. The MDGs consist of eight goals, and 18 concrete targets for development; which outline the shared responsibilities of *“developing countries to pursue poverty reduction and good governance and of developed countries to support the efforts of developing countries; by increasing aid, opening trade to exports from developing countries, and providing debt relief”*. The MDGs fall within the three spheres of sustainable development, namely economic (poverty alleviation, development of global partnerships), environmental (ensure environmental protection) and social (achieve universal primary education, promote gender equity, reduce child mortality, improve maternal health and combat HIV/Aids and other diseases).

The World Bank’s Global Monitoring Report (GMR) 2007 is the fourth annual GMR. The report takes into account the progress taken toward the achievement of the MDGs. It further assesses the contributions of developing countries and other international institutions in their undertaking toward meeting the commitments.

The 2006 GMR (WB, 2006) showed that governance was needed as a core continuous part of the wider task of monitoring the progress of reaching the MDGs.

The current GMR highlights 2 areas that need more global attention, namely gender equity and fragile state (WB, 2007).

4.1.2 Global Reporting Initiatives third generation (G3) [2006]

A third generation of GRI Guidelines, G3, was released in October 2006 following several years of research, development, and consensus-seeking by multi-stakeholder technical working groups, each assigned to focus on different parts of the guidelines ending with a period of public participation and comment. The G3 replaces previous versions of the GRI Guidelines released in 2000 and 2002. The G3 Guidelines provide universal guidance for reporting on sustainability performance (including economic, environmental and social aspects). This means they are applicable to small companies, large multinationals, public sector, NGOs and other types of organizations from all around the world. It is the way that the guidelines are created (through the multi-stakeholder, consensus seeking approach) that enables them to be so broadly applicable. (http://www.globalreporting.org)

The guidelines provide a set of core indicators, which have been developed through GRI’s multi-stakeholder participatory processes. Additional indicators represent emerging practice that may only be relevant to some organisations. (GRI, 2006)

4.1.3 The Living Planet Report [2006]

The World Wildlife Fund (WWF) published the first Living Planet Report in 1998. The report still shows the state of the natural world and the impact of human activity upon it. It has been published biennially since the late nineties. The current report developed in collaboration with the Zoological Society of London and the Global Footprint Network corroborates that humanity is using the planet’s resources faster than they can be renewed – the latest data obtainable (for 2003) shows that humanity’s Ecological Footprint has more than tripled since 1961. Humanity’s footprint now surpasses the world’s ability to regenerate by about 25 per cent (WWF *et al*, 2006).

In addressing sustainable development the report requires that the world, on average, meets at a minimum of two criteria, which are well known accounting tools for measuring progress toward sustainability in the areas of the socio-economic and ecological imperatives. The tools are the Human Development Index (socio-economic) and Ecological Footprints (ecological) (WWF *et al*, 2006).

4.1.4 Strategic Framework for Sustainable Development in South Africa

The strategy was developed DEAT to articulate South Africa’s national vision for sustainable development and direct its planned participation to re-adjust South Africa’s development path towards sustainability. It provides the basis for a long-term process of integrating sustainability as a key component of the development dialogue and shows South Africa’s commitment to the principles developed at international summits, described above, and conferences in the economic, social and environmental fields

4.1.5 Johannesburg Securities Exchange [2004]

The Johannesburg Securities Exchange (JSE) has developed criteria to measure the ‘triple bottom line’ performance of companies in the FTSE/JSE All Share Index. In May 2004, it launched the first Socially Responsible Investment (SRI) Index, which is built on four pillars of sustainability, namely: corporate governance, the economy, the environment, and society (Figure 1. Source: Barron and Gauntlett (2002) and

Department of Environmental Affairs and Tourism (2006)). At present, only forty nine companies are listed on the SRI Index. For the reason that listing is voluntary, the sample population on which data are based is heavily weighted towards the leading performers in the field of corporate sustainability, and the results from a random sample of listed companies would produce lower, less positive results. It is known, however, that holding, property, and investment companies have extremely limited awareness of environmental impacts and issues and have no significant institutional structures in place to deal with them (DEAT, 2006).

Figure 1 Integrated Model representing sustainable development

Most companies dealing in the material economy (that is, those that handle, process, and transform materials/ substances) are addressing environmental concerns at some level and nearly three-quarters of the companies assessed on the SRI Index (71%) had protected environmental principles in a policy or formal mission statement. Only 55% of the companies listed, however, have formal policies in place to ensure that their suppliers are paying attention to sustainability, and there is little evidence that these policies are influencing supplier behaviour.

The majority of the businesses claim to have all the elements of environmental governance and management in place, but it was complex to assess their efficacy in practice. Of these businesses, 84% give responsibility for the environment to a senior executive and/or a board committee.

4.2 International Environmental Assessment Tools

In May 2007 the South African Property Owners Association (SAPOA) established a Green Building Council of South Africa (GBCSA). This was in order to promote environmentally sustainable practices in South Africa's commercial and industrial property industry (Creamer Media, 2007). Australia's Green Star was selected as a basis of a national rating system. The Australian rating system will be customised for South Africa (GBCSA, 2007).

South Africa is one of 17 countries in the process of forming a national Green Building Council. These national councils will be member countries of the existing World Green Building Council (WGBC) which was founded in 1999 following the prior existence of the United States Green Building Council. The goal of this world-wide council is to intensify the shift from convention to more sustainable practices within the global property industry.

The existing member countries include the United States, Australia, Emirates, Japan, Russia, Spain and United Kingdom. Table 3 presents the existing member countries and the rating systems used in each country. It is interesting to note that LEED and Green Star have been adapted for use in other countries and that the BREEAM, CASBEE and EEWH are only used nationally.

Table 2 WGBC Member Countries and the Rating Systems used

Country	Rating System Used
Australia	Green Star
Canada	LEED Canada N-C 1.0 (Adapted from GBC USA's rating system)
Emirates	LEED Green Building Rating System (Adapted from GBC USA's rating system)
India	LEED India (Adapted from GBC USA's rating system)
Japan	CASBEE
Mexico	LEED Green Building Rating System (Adapted from GBC USA's rating system)
New Zealand	Green Star NZ Adapted from GBC Australia's rating system)
Taiwan	Ecology, Energy saving, Waste reduction and Health (EEWH)
United Kingdom	BREEAM
United States of America	LEED

The rating systems used by the existing GBCs will be reviewed, together with the SBAT:

- The Building Research Establishment (BRE) developed BREEAM in 1990, which has been adapted for Canada, Emirates, India and Mexico (see Table 2). The method is available for offices, housing, courts, industrial units, prisons, retail and schools.

  BREEAM uses nine categories to assess building performance, including management, energy use, health and well-being, pollution, transport, land use, ecology, materials, water. (http://www.breeam.org/)
- The United States GBC (USGBC) developed the LEED (1993) tool, which has been adapted for Canada, Emirates, India and Mexico (see Table 2). LEED assessment tools are voluntary, consensus-based national rating system for developing high-performance, sustainable buildings.

  LEED uses six categories, including sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation. (http://www.usgbc.org/LEED/)
- Comprehensive Assessment System for Building Environmental Efficiency (CASBEE, 2002), a labeling tool based on environmental performance of buildings developed in Japan by the Japan Sustainable Building Consortium (JSBC). The tool evaluates new, existing or renovated offices, schools and apartments.

  CASBEE uses four primary categories: energy efficiency, resource efficiency, local environment, indoor environment. (http://www.ibec.or.jp/CASBEE/english/index.htm)
- Australia developed Green Star (2003), which has been adapted for use by New Zealand. This environmental rating scheme evaluates the environmental design and achievements of buildings. Green Star drew from existing rating systems including BREEAM and LEED, but it is tailored to the Australian marketplace and environmental context. The rating scheme is used to assess new and existing offices.

  Green Star uses ten categories including energy, management, water, indoor environmental quality, transport, ecology and use, emissions, materials, innovation. (http://www.gbcaus.org/)
- Ecology, Energy saving, Waste reduction and Health (EEWH) System, is a green building certification system in Taiwan. It was launched in 1999. No information was available regarding the building types and building lifecycle stages assessed.

  EEWH comprises nine indicators that fall into four categories - ecology, energy saving, waste reduction and health (Wikipedia contributors, 2008).

5 Assessment Framework

Table 3 Summary of Global Commitments to Sustainable Development

	Summary of UN Millennium Development Goals, ISO Framework for Environmental Assessment, Global Reporting Initiative Guidelines, The Living Planet Report	BREEAM	CASBEE	EEWH	Green Star	LEED	SBAT
ECONOMIC	Poverty eradication						■
	Develop Global Partnership						
	Employment						■
	Labour / Management relations						
	HR Investment and procurement policies						■
	Economic performance						■
	Market presence						
	Indirect economic impacts						
ENVIRONMENTAL	Ensure environmental sustainability	■	■		■	■	■
	Environmental impacts of buildings (materials)	■	■	■	■	■	■
	Environmental impacts of buildings (energy)	■	■		■	■	■
	Environmental impacts of buildings (water)		■		■	■	■
	Environmental impacts of buildings (waste)			■			■
	Environmental impacts of buildings (emissions)	■			■	■	■
	Environmental impacts of buildings (renewable resources)						■
	Environmental protection	■		■	■	■	
	Environmental legislation						
	Products and Services						
	Transportation	■			■		■
	Accessibility		■				■
	Adaptability	■	■				■

	Flexibility	■					■
SOCIAL	Training and education						■
	Quality of life						
	Diversity and equal opportunities						
	Health			■			■
	Public / stakeholder participation						■
	Public / stakeholder awareness						■
	Safety						■
OTHER	Durability	■					
	Maintainability	■					
	Indoor air quality	■			■	■	
	Indoor environments	■					
	Management				■		
	Design and innovation				■	■	

6 Discussion

Table 4 presents a summary of the literature reviewed. This finds that since the broadening of the scope of sustainability in the early 1990s, a number of organizations have followed suite (i.e. the GRI and the Living Planet).

The framework for assessing the performance of buildings developed by ISO has, however, continued to concentrate on the environmental performance. This focus on environmental aspects can also be seen in the assessment tools reviewed (see Table 2).

It is interesting to note that although the JSE requires listed companies to report on all aspects of sustainability, including non-financial ones (social and environmental), the newly formed GBCSA's focus is solely on environmental issues (as derived from the council's use of the environmental assessment rating tool, Green Star).

Table 4 Summary of the international and local activities related to Sustainable Development

Year	Economic	Social	Environmental
2004	Johannesburg Stock Exchange (JSE) Securities Exchange – the Socially Responsive Investment Index		
2005	Strategic Framework for Sustainable Development in South Africa		
2005			ISO: Framework for Assessment of Environmental Performance of Buildings
2006	Global Reporting Initiative third generation (G3)		
2007			Green Building Council of South Africa
2007	The Living Planet Report		

Cole (2003) stated that assessment methods would need to broaden *"the scope of discussion beyond environmental responsibility"* by embracing *"the wider agenda of sustainability"* which equates social and economic aspects with environmental ones.

7 Conclusions

There have been some activities within the sustainable development field since the SBAT was completed in 2003; however none of these activities negatively affect the SBAT framework.

In contract, they serve to confirm that the SBAT reflects the progress of the wider field of sustainability performance measurement, which seeks to broaden *"the scope of discussion beyond environmental responsibility" by embracing "the wider agenda of sustainability"* (Cole, 2003).

The SBAT is currently the only assessment tool which assesses all three aspects of sustainability; however, it has not maintained its potency through the release of updated versions as suggested by Cole (2003).

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SUSTAINABLE ASSET MANAGEMENT: REDUCING THE ENVIRONMENTAL EFFECTS RELATED TO MAINTENANCE AND PARTIAL REPLACEMENT OF FAÇADE COMPONENTS

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Keywords: façade, maintenance, replacement, life cycle assessment (LCA), energy, transport, service life

Summary

In this research, the factors that determine the environmental effects related to maintenance and replacement of façade components are analysed using an activity scenario analysis based on life cycle assessment.

A scenario consists of maintenance activities, such as painting, and replacements of façade components, such as glazing. Additionally, energy used for space heating which is influenced by the thermal insulation of the façade, and transportation of maintenance workers are taken into account. The scenarios are created for a reference apartment building.

The data used to calculate the environmental effects of the scenarios are from the IVAM LCA database. The contributions to nine environmental effects as described in the CML method are calculated. A calculation tool is developed to be able to calculate the environmental effects that are caused in each year of the scenario. With the tool, multiple building components can be defined and specific scenarios can be assigned to them. This way, components that are exposed to different local climate conditions can be treated differently, according to the need for maintenance. The results of the calculation show the accumulated environmental effects over the years. Scenarios of up to 150 years can be calculated in order to assess long term effects of strategic decisions.

The results of the research show that the use of energy for space heating is the factor that contributes most to the environmental effects. Therefore, improving the thermal insulation of glazing significantly reduces the environmental burden. Transport related to façade maintenance activities and replacement of components is another important factor. Other factors that influence the environmental effects of the activity scenarios are the materials of the façade components and the time intervals between activities.

1. Introduction

Buildings make a significant contribution to the human-induced environmental burden. This is not only due to construction and demolition; activities undertaken during the operational phase, such as building maintenance and energy use, also have environmental effects. In Europe, on average, about 100 times more houses are in use than are built annually, meaning that the existing housing stock is both slowly growing and ageing (Federcasa 2006; Itard *et al.* 2008). Moreover, the thermal quality of the existing housing stock is, on average, lower than that of new housing (Beerepoot 2007; Itard *et al.* 2008). Thus, in order to lessen the annual impact of housing on the environment, it would be more efficient to improve the existing housing stock than simply to focus on building new houses.

In this research, the focus is on the maintenance of existing buildings. 4 variables related to maintenance are assessed: the use of different materials for building components or during maintenance activities; the times at which maintenance activities and replacements take place; the transportation of maintenance workers during activities; and energy used for space heating.

The aim of the research is to:

- Assess which (combinations) of the variables mentioned above have the greatest potential to lessen the environmental impact related to building maintenance.
- Assess how maintenance scenarios can be made more sustainable, and how the knowledge acquired in the course of the research can be implemented in practice.

In the following section, a brief explanation of the methodology used is provided. Next, the results of the research will be shown. Finally, the conclusions of the research and the implementation of the findings into practice will be discussed.

2. Methodology

Life cycle assessment (LCA) can be used to quantify the contribution of products or activities to environmental problems, or environmental effects (ISO 1997). The following environmental effects are taken into account:

- abiotic depletion: a measure of the speed and rate at which non-renewable materials are depleted;
- global warming: a measure of the amount of greenhouse gases emitted to the atmosphere, which leads to heat radiation being kept in the atmosphere;
- ozone layer depletion: a measure of the amount of substances emitted which will break down ozone in the stratosphere, which reduces protection against harmful solar radiation;
- photochemical oxidation: a measure of the amount of substances emitted which will form ozone in the lower atmosphere, leading to health problems;
- human toxicity: a measure of the emission of substances which are toxic for human beings;
- fresh water aquatic ecotoxicity: a measure of the emission of substances to water, which are toxic for fresh water ecosystems;
- terrestrial ecotoxicity: a measure of the emission of substances to the soil, which are toxic for ecosystems on land;
- acidification: a measure of the emission of substances which will lead to damage to water and forest ecosystems;
- eutrophication: a measure of the emission of substances that will lead to a lower biodiversity.

The environmental effects are determined by first making an inventory of the flow of all substances to and from the environment over a building's complete life cycle. Each substance's potential contribution to pre-defined environmental effects is calculated. In order to do this, for each environmental effect, the impact of a particular of substance flow is compared with that of a reference substance. This process is called the impact assessment. The complete set of environmental effects is known as the environmental profile of a product or activity. This research used the CML 2000 LCA method to calculate the environmental profiles of maintenance activities and replacements (Guinée 2002). Once the environmental effects of a complete maintenance scenario have been calculated, the results can be interpreted.

A building's maintenance scenario describes the maintenance and replacement activities that take place during its operational phase. This research is limited to doors, windows and door and window frames. The activities taken into account in this research are: painting, replacing sealant, replacing hinges and locks, and replacing building components, such as frames, doors, windows and glazing. Each scenario starts with the replacement of all building components.

A maintenance scenario provides the following information:

- the types of activities taking place;
- the first occurrence and frequency of maintenance activities;
- the first occurrence of and time interval between replacements;
- the interdependence of the activities.

Figure 1 Floor plan (left) and side view (right) of the gallery flat reference dwelling (SenterNovem 2007).

For this research, an assessment is made of the maintenance activities specific to a Dutch reference building, a gallery flat built between 1966 and 1988(Novem 2001; SenterNovem 2007). Figure 1 shows the building's floor plan and a side view. The reference building consists of ten floors of seven dwellings each along and open gallery. Because maintenance activities are often performed simultaneously on multiple dwellings, the entire building of 70 dwellings is assessed.

3. Results

In this section, two sets of results will be dealt with. The first set contains scenarios in which the aspects of energy used for space heating and transportation of maintenance workers is taken into account. These factors are indirectly related to maintenance and replacement of building components. The second set of results contains scenarios in which different materials for building components and paint have been used, as well as scenarios in which the factor of time has been investigated.

The first set of results is shown in Figure 2 and Figure 3. On the x-axis, the environmental effects explained above are shown. Each of these environmental effects has its own unit, which is why the results are indexed. Additionally, the differences between the scenarios can be shown best by indices. Figures 2 and 3 contain comparisons between several maintenance scenarios. The first scenario is a reference scenario which is indexed at 100. It contains maintenance and replacement activities which take place at reference intervals. The glazing in the reference building is plain double glazing. Energy used for space heating and transportation of maintenance workers are not taken into account. The reference scenario is compared with a scenario in which transportation of maintenance workers over a 50km one-way travel distance is taken into account. The environmental impact of the total scenario increases by 5-110% when transportation is taken into account. Thus, taking transportation into account is important and reducing the environmental impact related to transportation is an effective measure in reducing the overall environmental impact. A reduction of environmental impact related to transportation can be realized by reducing the distance travelled, switching to fuels that are more environmentally friendly or switching to cars that use fuels more sparingly.

The third scenario in Figure 2 is a scenario in which energy used for space heating is taken into account. It shows that the environmental impact increases by 30-970%. This means that energy use has a much bigger influence on the environment than all maintenance activities combined. When the thermal quality of the façade improves, the energy used for space heating decreases. In the fourth scenario, the plain double

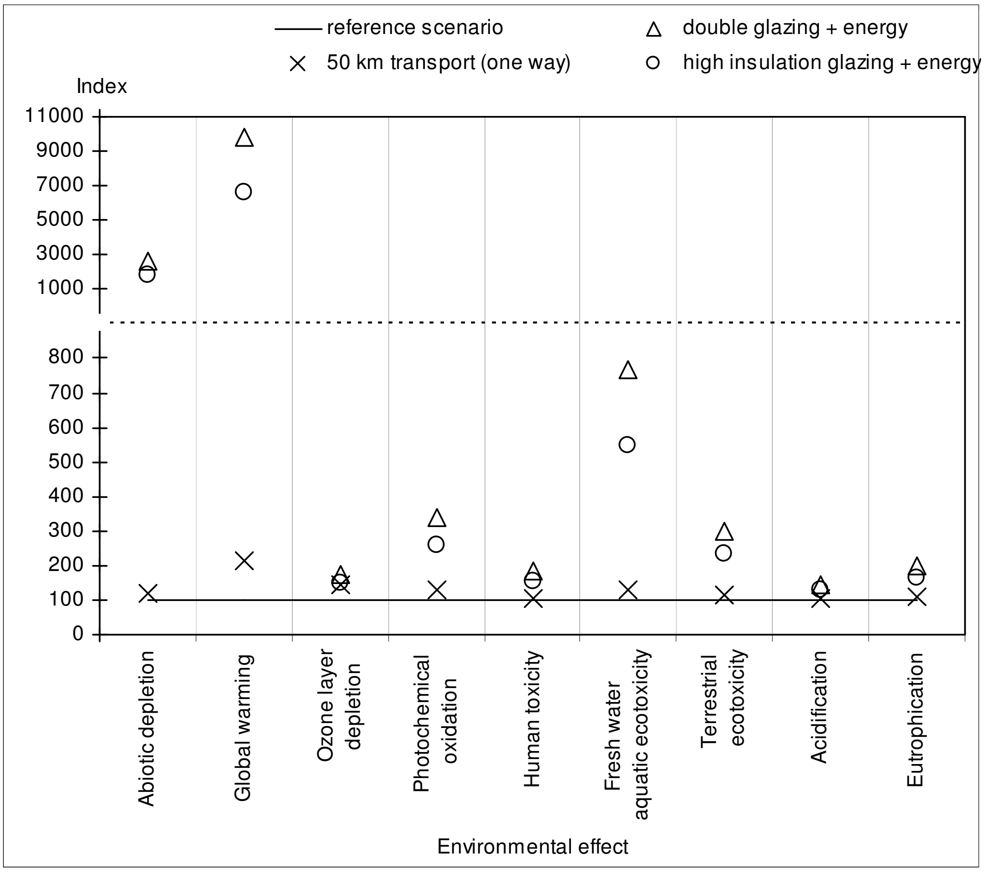

Figure 2 Comparison between the reference scenario and scenarios in which transportation of maintenance workers or energy used for space heating are taken into account.

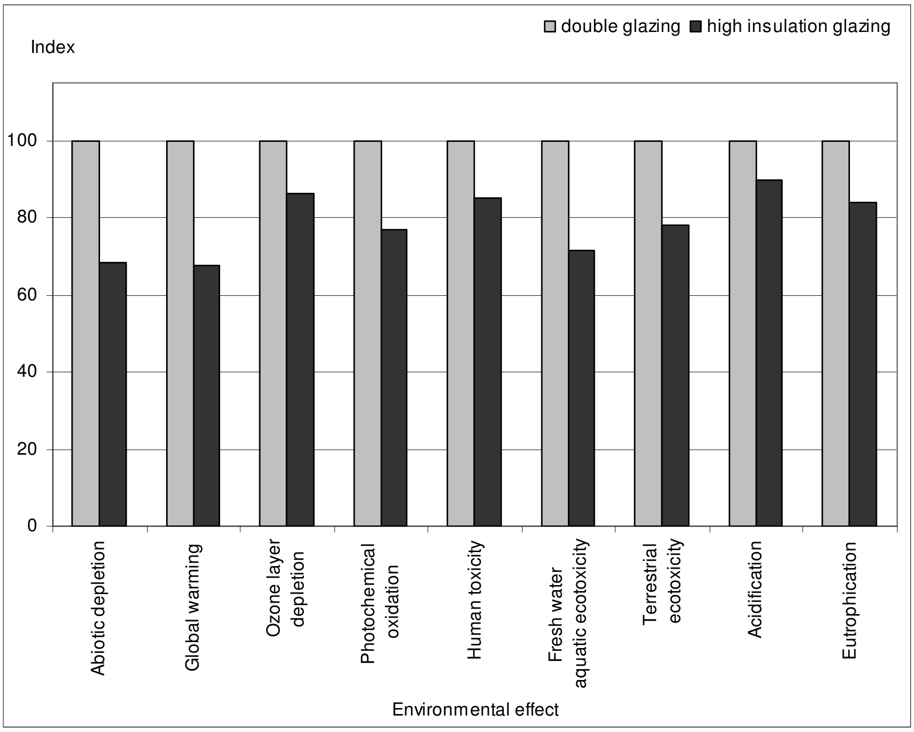

Figure 3 *Comparison between the reference scenario which contains double glazing and a scenario in which the glazing is replaced with high insulation glazing. Energy used for space heating is taken into account.*

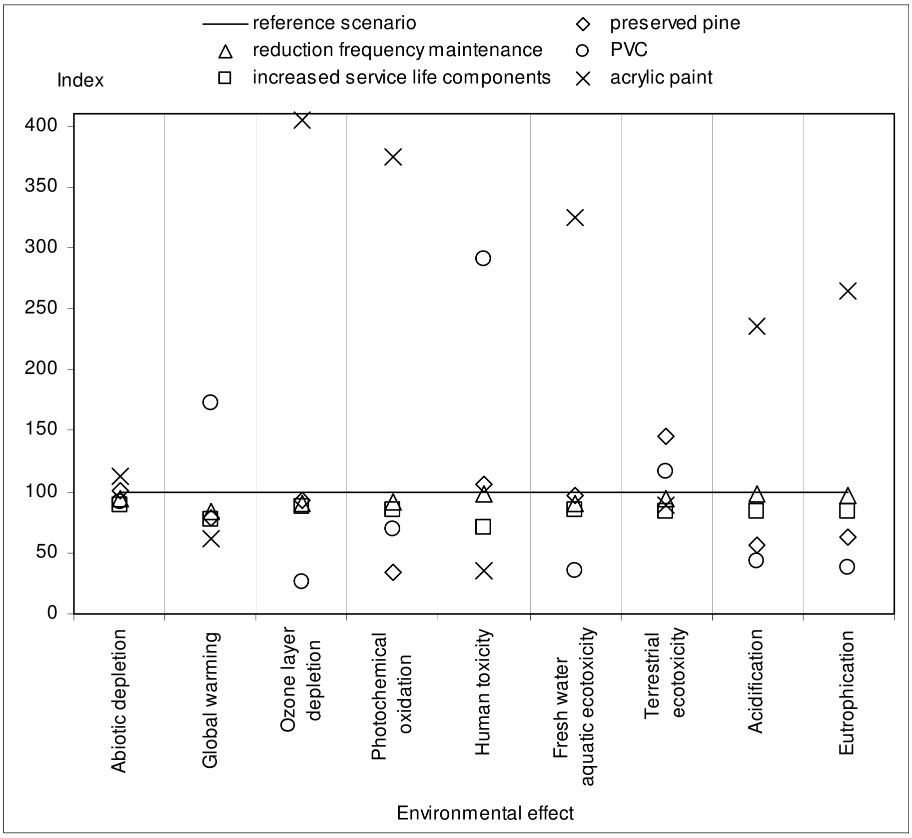

Figure 4 *Comparison between the reference scenario and scenarios in which different materials are used or different time intervals between activities.*

glazing is replaced by high insulation thermal glazing. As a consequence, the energy use for space heating decreases by 32.5%. Both Figure 2 and Figure 3 show the results of the third and fourth maintenance scenarios. In Figure three, the reference scenario including energy use is indexed at 100. The results show that replacing double glazing with high insulation glazing leads to an overall improvement of 10-30%. Moreover, the environmental effects that show the biggest improvement – abiotic depletion and global warming – are also the effects with which governmental policies are concerned. These policies aim at reducing CO_2 emissions and the use of non-renewable resources. Thus, replacements of building components which reduce the energy used for space heating are very effective in reducing environmental burden of existing dwellings.

The second set of results is shown in Figure 4. The reference scenario in that figure is the reference scenario of Figure 2, including transportation of maintenance workers. The reference building contains building components made of meranti FSC timber, painted with high solid paint. In all scenarios in Figure 4 transportation of maintenance workers is taken into account.

A comparison was made between the reference scenario and scenarios in which preserved pine or PVC building components are used. Figure 4 shows that the use of different materials leads to an increase of the contribution to some environmental effects and a decrease of the contribution to other effects. The same is true for the use of a different kind of paint, which is shown by a scenario in which acrylic paint is used.

In Figure 4, a comparison is also made between the reference scenario and two scenarios in which the service life of building components and the frequency of maintenance activities are lengthened and decreased respectively. Both measures show an improvement of all environmental effects, though the changes are not as big as when different materials are used. Figure 4 shows the results after 50 years of maintenance. The benefits of lengthening the service life of building components and decreasing the frequency of maintenance activities increase in time, because more replacements and activities will be avoided in a longer time period. Lengthening the service life of building components is more effective than decreasing the frequency of maintenance, but these aspects are related: the service life of a building component might be lengthened by increasing the frequency of maintenance. In that case, there will be a balance between the reduction of environmental impact realized by the lengthening of the service life and the increase of environmental impact by increased maintenance activity and related transportation.

4. Discussion

For all scenarios, a transportation distance of 50km one-way for maintenance workers has been taken into account. According to maintenance companies, this is a realistic estimate for the Netherlands. If the transport distance were to be altered, the conclusions of the research would remain the same. However, the differences between the scenarios might be less significant if the transport distance would be shorter.

This research does not take transportation of building components from the harbour in Rotterdam to the building site into account. If that would have been taken into account, then the environmental impact associated with replacing building components would increase equally for all scenarios. The positive impact of lengthening the service life of building components would thus increase. The overall conclusions of the research would not change considerably.

The true values for the service life of building components and maintenance intervals strongly depend on building design, quality of the technical details and the local climate. The reference values used in this research are a mean value for the Netherlands, based on information of producers of building components. In practice, the service life of building components can be much higher if it is designed well, but it can also be much lower if the building is designed poorly.

5. Conclusions and implementation

Of the four variables considered, reducing energy used for space heating by replacing building components proves to be most effective in reducing the environmental impact related to the maintenance of dwellings. This measure will lead to an improvement of all environmental effects, because the environmental effects caused by energy use are much stronger then the environmental effects that are directly caused by maintenance. Second, the use of alternative materials for building components is effective in reducing some of the environmental effects, but it may also cause an increase in some other environmental effects. There is no definitive answer to the question which material is best for building components: it depends on factors such as time (service life of building / length of the maintenance scenario), the local climate and the origin of the materials used. The decision to use solvent-based paint or water-based paint can be made by looking at other aspects than environmental impact. The differences in environmental impact for different kinds of paint are relatively small and the health effects of the paint during the application are more important in labour conditions law. Third, lengthening the service life of building components will lead to a reduction of environmental effects due to the fact that less building components are needed during the service life of the building. However, this measure cannot be reached without adjusting the frequency of maintenance. If more frequent maintenance is needed, the reduction of environmental impact may be counterbalanced by the negative effects of transportation of maintenance workers, which is the fourth measure to reduce the environmental effects related to maintenance of dwellings.

The implementation of the research findings in practice involves two actors: the building's owner and the maintenance company. Buildings' owners make the decision whether or not to replace existing building components with components with improved thermal insulation properties or made of a different material. Reducing the distance travelled by maintenance workers is a responsibility that is shared between the building's owner and the maintenance company. The former can specifically state a desire to limit travel in the maintenance agreement, while the latter can service employees efficiently and switch to more sustainable means of transport. Both actors, together, decide on the strategic maintenance plan for a building, in which is decided at what time activities take place and what is the policy regarding the lengthening of the service life of building components. Finally, the maintenance company decides on the materials used for maintenance activities, such as paint and sealant. Since the influence of these materials on the environment is not significant compared with a complete maintenance scenario – except when they need more transportation to be applied - the decision can be made based on other factors, such as costs and the health of maintenance workers.

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INTERACTION BETWEEN EXTERNAL ENVIRONMENT AND BUILDING STIMULATED BY DYNAMIC ENVELOPE WITH INTER-SPACE

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Keywords: heat transfer; buffer zone; building envelope; external environment

Summary

The presented study treats the problem of heat exchange between building space and external environment through transition space more generally. The main goal of this study is the estimation of the effects of external partition with inter-space on thermal behaviour of the adjacent building zone. The analysed wall consists of a transparent external part, ventilated air space and inner part. Heat exchange between solid volumes (walls) and air volume (inter-space) as well as heat storage potential play a significant role in energy balance. The following changeable thermophysical properties were considered in the presented work: convective heat exchange, radiation heat exchange, air heat storage potential, material heat storage potential. All analyses have been conducted using computational numerical techniques based on compound heat transfer model and advanced simulation software. For the purpose of this study hypothetical characteristics of external environment were defined in daily profile forms. The variable parameters were external air temperature and diffuse/direct solar radiation.

1. Introduction

An optimal solution of inter-space between outer and inner parts of a building envelope are currently well described for some particular, practical applications. The rules how to provide required, proper conditions and optimise the systems from thermal point of view were investigated e.g. for solar walls, double-skin facades, solar spaces etc. The first two of them are limited to a small scale building application. The third is rather used in modern, huge and tall buildings and has a wide range of options to control the effects between external and internal environment. Therefore, the use of active semi-translucent buffer zone (BZ) like double-skin façades (DSF) is very popular with architects at almost all latitudes. In majority of climatic conditions the main exploitation problem is summer overheating, not only in the gap of the façade but also in the adjoining room. On the other hand, the limitation of sun access (e.g. by vertical shading) results in deterioration in illuminance. The worst side effect is decreasing thermal or visual comfort. Sustaining such comfort is connected with increasing cooling or lighting energy requirements.

The results of a whole building simulation give not only energy efficiency of buffer space but also precise temperature distribution inside each part of the external partition. Recent works showed many different strategies in BZ design and solution to optimise the control strategy of shading systems, air flows or both. It means that the previous strategies were devoted rather to eliminate or protect against environmental effects, based on additional element like blinds or ventilation system. The presented work shows possible storage potential of each façade component and the potential of controlled heat exchange between air in inter-space and external and internal skin.

One of the main thermal problems during exploitation of double façades is considerable temperature fluctuation between day and night and temporary overheating or overcooling effects. In order to reduce these effects and sustain stable thermal conditions on the inner part of the façade shading devices with proper control strategies are generally applied (BBRI 2002, Leal et al. 2003, Gratia & DeHerde 2004, Stec et al. 2005). However, the main question is what should be the best solution for buffer space in the context of geometry, construction and control of internal parameters under different environmental conditions. For moderate climate of Central Europe the weather exceeds some extreme conditions in the middle of summer or winter. However, the temperature during the year usually varies from –25°C (winter) to +25°C (summer) with different daily fluctuations depending on individual locations, altitude or local conditions.

2. Boundary conditions

For the purpose of the presented study external weather conditions were assumed to be changeable according to the following assumptions:

- extreme temperature changes from –25°C in winter to +25°C in summer with possible daily fluctuations from 5 K to 25 K,
- diffuse and direct solar radiation is considered separately and is assumed to be minimum 100 W/m^2 or maximum 500 W/m^2 at noon.

These assumptions allowed to consider the behaviour of BZ under conditions representing different climates, locations, latitudes or local microclimate influences. The results of the presented analysis allowed to formulate more general conclusions. The set of climate data parameters (temperature differences ΔT, direct I_{dir} and diffuse I_{dif} solar radiations) for 20 hypothetical cases is presented in Table 1.

Table 1 Hypothetical climate conditions

Case	ΔT [K]	Idir [W/m^2]	idif [W/m^2]
1	5	–	100
2	5	–	500
3	5	100	–
4	5	500	–
5	10	–	100
6	10	–	500
7	10	100	–
8	10	500	–
9	15	–	100
10	15	–	500
11	15	100	–
12	15	500	–
13	20	–	100
14	20	–	500
15	20	100	–
16	20	500	–
17	25	–	100
18	25	–	500
19	25	100	–
20	25	500	–

Temperature function varies periodically from minimum and maximum values with assumed ΔT from 5 to 25 K. Solar radiation achieved maximum values at noon and the length of the periods depends on the season of the year. Figure 1 shows exemplary data for “the shortest” winter day in the year. Temperatures vary with ΔT=10K and solar radiation reaches maximum values 500W/m^2. Other climate files were done in the same way. For the purpose of numerical analysis the whole single type period was three weeks, including two weeks of start-up days and one week of analysis.

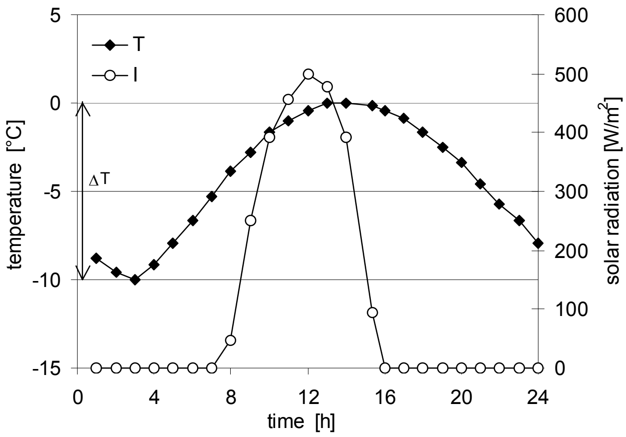

Figure 1 Demonstration of daily function for winter day

3. Analyzed construction

For the case studied herein the whole single glazed external partition is considered as an airtight envelope. The U value of this partition is 5.40 W/m^2K and optical properties are assumed as for "clear float" glass . The space gap is 0.5 m wide and represents a separate space on each floor. No additional shading system was applied in an inter-space. In the case under discussion different proportions between glazing and opaque part of second skin are considered: 20, 40 60, 80 and 100% of glazing. The heat transfer coefficient for opaque and transparent part is set to U = 2.70 W/m^2K (twice as small as the outer one U = 5.40 W/m^2K). The total area of the DSF is 9 m^2 (3 m × 3 m) with the volume of 4.5 m^3. The adjacent zone is 3 m wide and 5 m deep with the total volume 45 m^3. Three traditional opaque partitions (only specific heat capacity) were considered. All considered opaque walls have the same thickness (d=0,2 m), specific heat (c_p=1000 J/kg K) and conductivity (λ=0,75 W/mK). They differ in density as follows:

- lightweight (**L**) wall ρ=125 kg/m^3,
- average-weight (**A**) wall ρ=1250 kg/m^3,
- heavyweight (**H**) wall ρ=2500 kg/m^3.

Radiation heat transfer between air in buffer zone and the façade was considered by different thermophysical properties of the inner part. All of them were covered from the outside by thin coating with different values of absorptivity and emissivity (Table 2).

Table 2 Absorptivity and emissivity of the inner part.

CASE $a\varepsilon$	ABSORPTIVITY a	EMISSIVITY ε
99	0.9	0.9
91	0.9	0.1
59	0.5	0.9
55	0.5	0.5
19	0.1	0.9
11	0.1	0.1

Casual gains from equipment, lights and occupants were also set to zero in order to remove their impact on the simulations and so make the results of the interpretation easier.

Convection heat transfer depends on different air flow. In the case studied herein the most popular outdoor air curtain was chosen. For thermal analysis the air-flow rates of A – 1 ac/h, B – 5 ac/h and C – 10 ac/h were constant during the whole year. One-story high façade, completely tight from the surroundings and the adjacent room was chosen. It means that no air flow between following stores and between zone and the façade were assumed. The DSF space was defined as one, uniform thermal zone representing single control volume (Hensen et al. 2002).

The control volume approach was adapted to describe physical elements of the zones and networks. Spaces, described by geometry, construction and operational data are interconnected using network models that describe air and moisture flow paths. Construction components, surfaces and zones are represented by nodes for which energy and mass balance is performed. Conduction, convection and radiation exchanges are described in relation to other nodes systems (Clarke 2001).

4. Results

4.1 Boundary conditions

The effects of heat transfer between building and the environment are stimulated by the characteristics of the buffer space. The analysis has been conducted for several temperature fluctuations according to daily characteristics presented in figure 1. Five cases were considered where temperature fluctuations between day and night $\Delta T=T_d-T_n$ were respectively: 5K, 10K, 15K, 20K and 25K. The maximum external temperature T_{emax} was assumed to be +25°C and the minimum –25°C (for $T_{emax}–\Delta T_{5K}$ =20K–5K). During the day (8:00-16:00) diffuse solar radiation was assumed according to the layout presented in figure 1 with maximum values at noon 100 W/m^2. The results presented in figure 2 show the relationship between internal resultant temperature (T_{imax}) and external temperature (T_{emax}) for five amplitudes of external temperature. Internal air temperature was controlled at the level of 20°C.

The highest differences between different daily temperature fluctuations were noticed for maximum external temperatures above assumed internal temperatures. When external temperatures changes sinuously from 25°C to 20°C (T_d-T_n=5K) the internal resultant temperature exceeds 24°C. However, if external temperatures dropped to 0°C during the night (T_d-T_n=25K) the internal resultant temperature is below 21°C (~3.5K less). It means that for maximum external temperature 25°C, maximum external temperature fluctuations ΔT_e=25 are balanced during the day by solar heat gains. When daily fluctuation is only ΔT_e=5K (or less) solar radiation causes a significant overheating problem. For maximum diffuse solar radiation 500 W/m^2 internal temperature is almost 28°C. Below external temperature equalling 15°C the effect of daily fluctuations cause only slight differences of about 0.3K, while for sub-zero temperatures it becomes imperceptible.

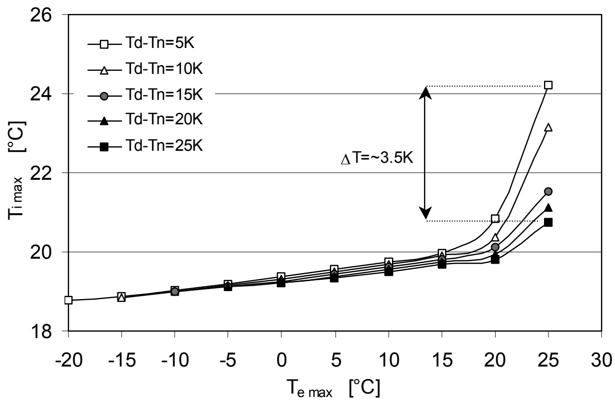

Figure 2 The effect of external temperature on the resultant temperature inside the building

4.2 Time lag

For the purpose of proper interpretations of further results, initial analyses have been conducted to show the effect of time lag. These analysis have been conducted for fully glazed façade with air changes in inter space 5ac/h. Exemplary results for ΔT=10K and solar radiation 500W/m^2 show the thermal dynamic of buffer space. Diffuse radiation gives higher differences in time when maximum temperature is noticed. The moment of maximum temperature in the buffer space is shifted by about 1.5 hours with reference to maximum ambient temperature and by 3.5 hours after maximum solar radiation. It means that reported extreme values of the analysed parameters appear at different hours.

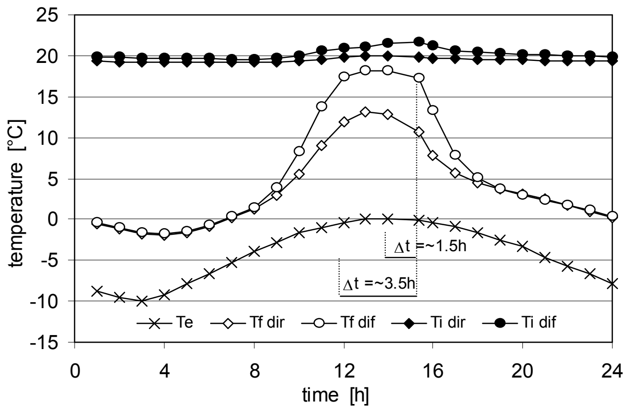

Figure 3 The time lag of thermal effects in the buffer space

4.3 Thermal mass

Thermal mass effect of the construction as well as mass flow effect (air flow) between the buffer space and external environment were also analysed. Air changes rates were assumed constant during the whole period and equal respectively: 1 ac/h and 10 ac/h. Thermal mass storage effect was considered on the basis of geometry (A_w/A) and material (cases L, M, H) of the inner skin. The A_w/A=1.0 means a fully glazed wall and 0.2 means 20% of glass. In winter internal air temperature was assumed to be more than 20°C (heating control point – hcp), in summer less than 24°C (cooling control point – ccp).

The results presented in figures 4 and 5 show the effect of thermal mass and air flow in winter. Analysing minimum resultant temperature (in winter – fig. 4) inside the heating zone the effect of thermal mass is really slight similarly to maximum resultant temperature (in summer – fig. 5). However, for a relatively low window/wall ratio 0.2 (20% of glass) temperature differences reach 0.5 K. The intensity of air flow in the façade space gives a similar small effect on resultant temperature inside the heated or cooled zones. Increasing air changes per hour from 1 to 10 indicate temperature changes of more or less 0.1 K.

4.4 Surface heat flux

The effect of solar energy absorption on inner part of the DSF was analysed for selected values of absorption and emission coefficients. All analyses were done for the zone with controlled air temperature (minimum 20°C in winter and maximum 24°C in summer).The differences (for medium weight wall) presented in figures 6 (for winter) and 7 (for summer) show a reliable effect of surface properties on internal temperature in summer. The recorded values in maximum resultant temperature differ by more than 1 K for little glazed wall. As expected, the highest differences were obtained between high and low absorptivity. In winter the highest temperature was for high absorptivity and low emissivity surface and the lowest for high emissivity and low absorptivity coefficients. However, the differences between extreme values were 3 times smaller than for the summer (3.5K).

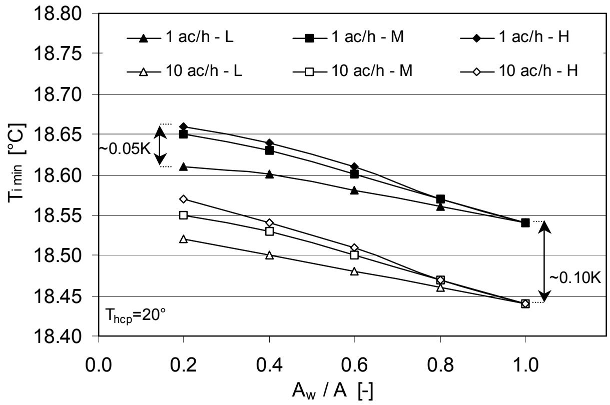

Figure 4 The effect of air flow and thermal mass on the minimum, internal resultant temperature

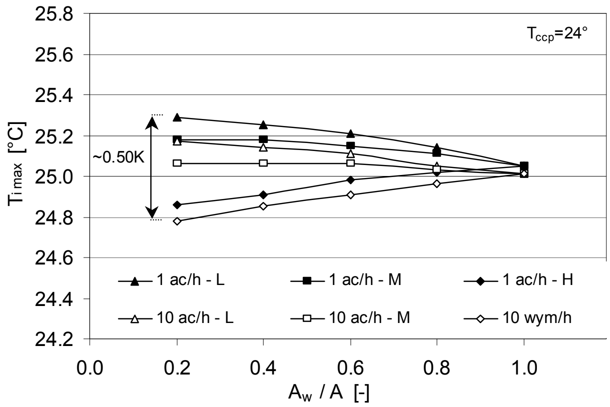

Figure 5 The effect of air flow and thermal mass on the maximum, internal resultant temperature

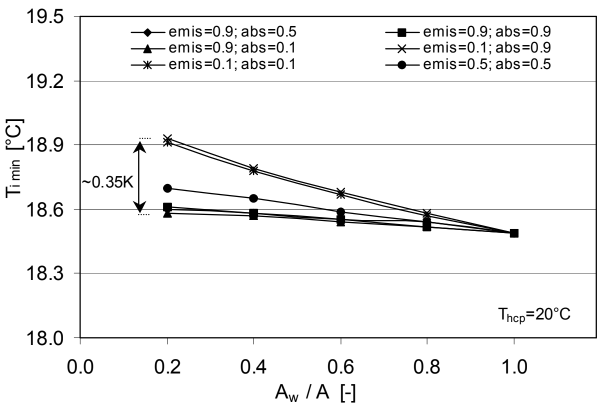

Figure 6 The effect of absorber properties on the minimum, internal resultant temperature

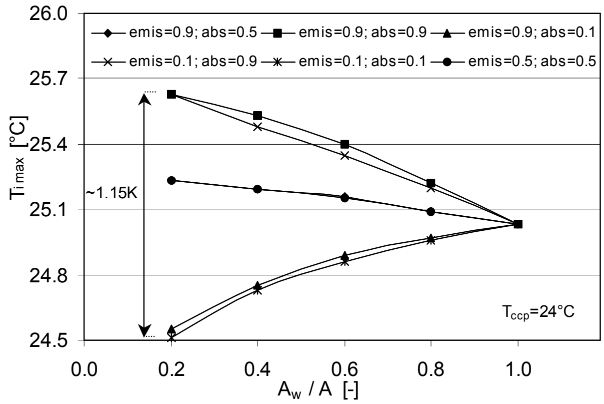

Figure 7 The effect of absorber properties on the maximum, internal resultant temperature

4.5 Energy efficiency

Energy performance of the DSF system was presented by Saelens & Hens in 2003 and Saelens et al. in 2005. This analysis is limited only to some discussion concerning the properties of opaque part within the first, inner part of the DSF.

Energy demands were analysed for different properties of inner part, because this parameter gives the largest temperature differences. The results obtained for medium mass wall "M" were shown in figures 8 and 9, for winter (heating) and summer (cooling) respectively. Possible savings in heating or cooling energy demands are not bigger than 10 kWhs per year. The savings of heating energy are about 7% between high absorptivity (A=0.9, ε=0.1) and high emissivity (A=0.1, ε=0.9) buffer side surface. In summer the anti-sun surface layer should have possibly low emissivity and absorptivity (A=0.1, ε=0.1) which can lead to reducing cooling energy by even about 70%.

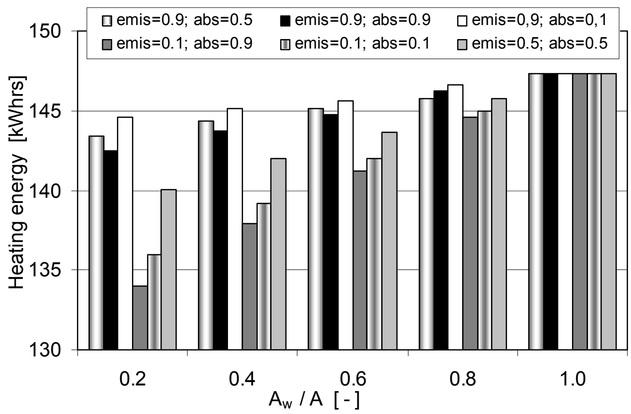

Figure 8 Heating energy demands

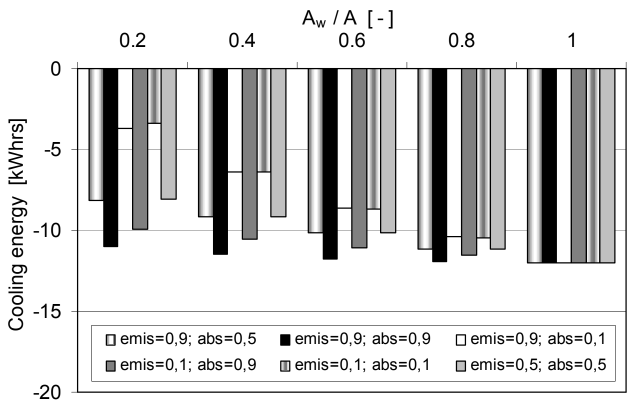

Figure 9 Cooling energy demands

All conclusions mentioned above concern the inner part of the wall with a small window (20% of glass). For a larger glass area the effect of surface properties becomes less noticeable.

Summary and conclusions

The first part of this study was devoted to show the effect of changeable climate parameters on the behaviour of a zone buffered from the outside by additional space. The effect of daily temperature fluctuations is noticed where maximum external temperatures are above assumed internal temperatures. The highest difference (~3.5K) was obtained in summer (T_{emax}=25°C) for daily temperature fluctuation ΔT_e=5K.

In the second part the effects of conduction and convection heat transfer between inter-zone and construction are discussed. Different properties of internal space were analysed to show the effect of ventilation rate, glazing opaque ratio and surface properties on thermal behaviour of the building. The greatest thermal effect on internal temperature was received for different surface properties (radiation heat exchange), especially surface absorptivity. The highest difference reported for summer is about 1.1K.

Energy analysis for surface properties parameters show saving potential in requirements by about 7% for heating and even 70% for cooling. However, cooling energy provides only 10% of the whole energy demands. It is also confirmed in other publications for Central Europe climatic conditions (Heim 2006).

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INSERTION OF ENVIRONMENTAL GOALS IN THE BRAZILIAN STATE COMPANY PUBLIC PROCUREMENT

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Keywords: green procurement auction, state company, environmental goals guideline

Summary

This paper relates the study for environmental goals insertion in public procurement procedures for Brazilian large state company that is subordinated to Ordinance nº 2.745/98 that is a simple way of the Law 8.666/93, without standing back the isonomy and economy doctrine of the company. Motivated by the chapter 4 of the agenda 21: change of the consumption patterns; aided by the articles 37, 170 and 225 of the Brazilian Federal Constitution, this work aims to be an instrument to guide future procurement, by introducing criteria of environmental order such as: water consumption; energy consumption; pollutant emission; residues generation; toxins in the goods and durability, all aligned with the procedures of acquisition of goods and engineering services, as well as compatible with governmental politics, environmental legislation and certification ISO 14.001. The conclusion brings up to an end that these measures have legal base application and also appliance for future accounts rendered and they won't be impacting in the value of the final product, specially considering the life cycle analysis of the project in the operation and maintenance phase of the enterprise, besides being base to make possible the improvement of the environmental performance of the buildings.

1 Introduction

1.1 Contextualization

During the 1970's began the first demonstrations about the sustainable development and at the same time the environment exploitation in a large scale by the men (NSSD, 2003). During the 1980's the sustainable development aims have been defined during global convention as Montréal (1982), Rio de Janeiro (1992) and Kyoto (1997). This aims, up to that time implicit in many national politics, gained United Nations Convention on Climate Change (UNCED) compromising and recognition the carried out in the Rio de Janeiro in 1992 that turned in a global plan action for the XXI century. It was published the Agend 21, which was establishing a long term vision to balance the natural planet resources (UNITED NATIONS, 1992).

The Agend 21 was adopted by 178 governments and all the society sectors initiated a reinterpretation process of them into the specific contexts of several local Agends and Sectorial ones. Public policies started to impose environmental requisites to countless economical activities for environmental products demand less aggressive grew in parallel (CIB, 2000).

Changes in the public procurement processes were necessary for administrative routines in order the public administration were adapted to the environmental questions, particularly the Chapter 4 of the Agend 21. This chapter defines the change consumption standards of containing the next areas of programs: Examination of the unsustainable production and consumption standards and the development of politics and national strategies to stimulus to changes in these standards (UNITED NATIONS, 1992).

The establishment of objectives and environmental goals must take place mainly in the annual cycle of the administration strategic projection and they will be part of the objectives and strategies of the institution itself, turning in goals and/or criteria adopted in the public procurement processes.

The Public Administration is great natural resources consumer and user and have strategic paper in the promotion and indication of new standards production and consumption, and, therefore must be an example in the reduction of the socio-environmental negative impacts produced by its activity.

1.2 Objective

The paper purpose is to test the feasibility of inserting environmental goals by checking the legal bases for Public Procurement in Brazil, combating so, all the forms of natural resources waste and public goods; to contribute to an appropriate the public administration management, including socio-environmental criteria in the purchases and services employment of the government departments, moving the civil servants regarding the environmental aspects and the improvement of their environment quality work.

1.3 Methodology

The inquiry has descriptive characteristics, by bibliographical survey and from the point of view of the form of approach of the problem, it presents the results in accordance with a qualitative way.

2. Sustainable Public Procurement Process Evolution

The green procurement also known as eco-acquisition, or positive procurement or sustainable procurement is a solution to integrate environmental and social considerations in all the stages of the public agents and employment purchase process with the objective to reduce impacts on the human health, to the environment and on the human rights. It satisfies the final consumers specific necessities of through the product purchase that offers the biggest benefits number for the environment and the society. The discussion on the legality of the most sustainable option in the green procurement is the constant one in the whole world, and standards for incorporation changes proposed in this area with legislation limits in many countries realities. In the table 1 it can be visualized several countries data list about the sustainable public markets (FGV, 2006).

Table 1 Worldwide Experience on Green Procurement

South Corea	Environmental certification Government system and green label to identify products and sustainable services. Second country to approve green procurement federal law.
Japan	Governments and industries created jointly a private organization, which organizes sustainable initiatives consumption, which they include from trainings, publications, up to the development purchases catalogues on-line. The green procurement Japanese system is the world most complete and dynamic in use (GPN - Green Purchasing Network)
Switzerland	Implemented system and law ingoing. It developed products and services standards and it promotes government agents and educators trainings.
Sweden	Sustainable procurement program initiated into 2001 creating an enterprise composed by public entities and public and private enterprises that defines priorities of action for green procurement carrying out scientific life cycle studies and economical analyses.
México	Integrates a public green purchases group created in the context of the agreement of free commerce of NAPHTHA (North American Free Trade Agreement) and has environmental public program implemented management, which includes public servants qualification, recycling, economy of energy, among others. The Mexican law included green procurement principles, demanding energetic efficiency and economy in water use in the government contracts and acquisitions.
England and Wales	The governments has been practicing out sustainable procurement for more than a decade. There is an intense public workers training program. The trainings board explain what is sustainability, the necessity of creating a organization strategy, mapping the market impacts and risks focusing on the risks analysis in the products life cycle. These governments advanced in such a form, allowing wage compensation for good performance of the workers regarding the aims established in the green procurement procedures.

Adapted by the author based on FGV, 2007

In Brazil, up to the moment, the government initiatives in the Federal spheres are shy and punctual. The MMA-Ministério do Meio Ambiente (Environmental Protection Agency) sent alteration proposal of the procurement Auctions Law to the Congress, for environmental sustainability criteria inclusion in the public administration (BRAZIL, 2007). The federal government prohibited the consumption of products with use of CFC (destructive gas of the ozone layer) for the public departments. As Valéria Damico (2005), the Sao Paulo state Government published Decree to oblige the wooden from Amazon region legal origin use, in the works and public state contracts, which must promote the sustainable products market.

2.1 Sustainable procurement in Brazil

Recent estimations demonstrate that purchases and government employment represent around 10 % of the internal Brazilian product indicating that the public sector, through its purchase power must be an important inductor of sustainable practices in the society (FGV, 2007).

In Brazil, the Law 8.666/93 that treats general standards on procurement auctions and administrative contracts, which superficial reading establishes less price as predominant criterion can work like obstacle to the sustainability incorporation in the purchases and public employment, preventing in the country the public power being a great inductor of the sustainability practice.

Table 2 Some Brazilian sustainable practices

Decree 2.783 of September of 1998	Prohibits the acquisition of products or equipments that contain or use the substances that destroy the ozone layer for the Public Federal Administration.
Sao Paulo - Decree 48.138/2003	Sets up water consumption reduction and rationalization measures.
Sao Paulo - Decree 45.643/2001	Obliges the acquisition for the Public sector and Foundational: - Use of lamps of high performance, with the less mercury tenor of among the available ones in the market (base in technical decisions). - Use high efficiency cables and lines and low polychloride of vinila (PVC) and lead tenor.
Acre	Government favorizes wood certified in the Government Palace State renovation fase and furniture procurement.

Adapted by the author on basis on BRAZIL, 2004

2.1.1 Proposal the Federal Government Law 8.666/93 alteration

Proposal of the Government contained in Bill set out for the National Congress in January 2007 in constitutional urgency regime vote the Law 8.666 change, which regularizes art. 37, I incise XXI, of the Constitution (BRAZIL, 2007).

The proposed alterations aim to adapt the auctions and government employment to the present information new technologies in the Brazilian current scenery, as well as pay attention to the beginnings of government employment transparency, economy, competitiveness and celerity with sights to make the auction process concomitant with the best worldwide practices. The figure 3 demonstrates other public Brazilian administration proposals suggested.

Table 3 Propositions of the commission managing the A_3P (Public Administration environmental Agend)

Draft of proposal of Recommendation of the CONAMA	Insertion of the environmental dimension in the administrative activities of the government organs, including actions to reduce costs with the elimination of wastes, stimulate the training of workers on the environmental questions, support to the development of clean technologies, between others.
Draft of Entrance hall setting two-story impression up in the services of reprografy	from determined quantity, in the documents made by the Environmental protection Agency.
	Inclusion of specification for acquisition of new printers that prime on both page sides without necessity to re-put the paper.
Insertion of environmental criteria in the electronic auction.	The application of electronic procurement systems of, which up to certain limit dispenses auction.
Institution of a model of green and / or sustainable building for the new constructions in Federal Unities of Conservation	Partnership with the IBAMA, when there is taking into account the funcionality integrated to the environmental sustainability (using constructive materials with low rate of built-in energy. Photovoltaic panels, biodigestores, green ceiling, permaculture, recycling, rain roof catchments system, gray water re use, natural ventilation, day lighting, and so on.

BRASIL, 2004

3. Legal Bases for Brazilian Green Procurement

The Federal Constitution establishes that the economical order should be based on the increase in value of the human work and on the free initiative with objective to secure to all the citizens a worthy existence, according the social justice dictates. Regarding the employment of works, services, purchases and alienation, by public procurement means. Brazilian federal constitution defines that this process should secure conditions between all the bidders equality. The relative prices system force at present in the Brazilian economy do not notice the social and environmental subsidies which enterprises enjoy launching to the society and to the environment externalities of products or services processes. The criterion of less prices treats unequal way the equals, and, so, fall to a public administrator to establish sustainability criteria in the purchases and public employment that better qualify and differentiate products and services, so these distortions are corrected and equality of conditions must be offered (Nascimento, 2005).

The infraconstitutional legislation also reminds us that the search of the most advantageous proposal must be in accordance with the public administration principles among them the defense of the environment and the regional and social inequalities reduction. The Law 8.666 prohibits restrictions to the competitive character that are impertinent or irrelevant for the specific contract object and nothing indicates that the defense the environment and inequalities reduction are impertinent or irrelevant conditions (BIDERMAN et al., 2006). According to Dr. Silvia Nascimento (2005) the Public procurement Law interpretation must be coherent with the remainder of the national legal standards, in individual, with the precepts of the National Politics Environment Law (Law 6.938/81) that orients the State in the of the public interest environment subject management. The above-mentioned law establishes among his objectives, which it is necessary to make the social-economic development compatible with the environment quality preservation, to set environmental quality standards criteria and relative standards to the environmental resources use and handling, to develop inquiries and technologies for environmental resources rational use, to spread handling environment technologies and to bring up a public environmental quality preservation and ecological balance the necessity conscience, promoting environmental resources preservation and restoration. So, the public procurement should establish practices to respect these precepts.

3.1 Federal Constitution

Public Administration General Principles: Art. 37 of the Federal Constitution: Legality, impersonality, morality, publicity and efficiency (BRAZIL, 1988).

3.1.1 Administrative contracts

Art.37, XXI, Federal Constitution: order of works, services, procurement and alienation, by means of public auction, which secures equality of conditions between all the bidders and it takes the technical and economical qualification as an essential condition of the obligations fulfillment guarantee (BRAZIL, 1988).

3.1.2 The Environment

Art. 225 of the Federal Constitution: it imposes to the Public administration the environment defense and preservation duty for the present and future generations: To preserve and to restore the ecological essential processes and to promote the ecological ecosystems handling: To control the production, marketing and techniques that constitute a life risk, the life quality and the environment (BRAZIL, 1988).

3.1.3 Economical Activity General principles: Art.170 Federal Constitution

Economical order been based on the increase in the human work value and on the free initiative and it has how aim secure to all worthy existence, according the social justice dictates.

Principles: IV – free competition; VI – environment defense; VII - regional and social inequalities reduction (BRAZIL, 1988).

3.2 Legislation Infraconstitucional

3.2.1 Federal law nº 8.666, of 21.06.1993: General standards on public procurement and administrative contracts

Art.2º - Obligation of procurement auction: works, services, alienation purchases, concessions, permissions and rentals.

Art.3º - The equality observance principle and most advantageous proposal search, in accordance with the Public Administration principle.

3.2.1 The Environment National policies: Federal law nº 6.938, of 31.08.1981 – SISNAMA

Objectives – Art. 4

I – Make compatible social-economic development with the environment quality preservation and the ecological balance;

III – Establish environmental quality criteria and standards of relative to the environmental resources use and handling;

V - Environmental technologies of handling Diffusion and formation of a public conscience on the necessity of quality environmental preservation and the ecological balance;

VI – Environmental resources Preservation and restoration sighting rational use.

3.3 Auction - Proceeding

The process is divided in two phases: Competence (federal Law nº 8.666/93 Art.27) that is the bidder qualification examination (federal Law nº 8.666/93 Art.30); and proposal to examine the adaptation of the procurement requisites object.

3.3.1 Propositions Object-Prohibitions

For works and services the Art.7º, §5º prohibits that the procurement object includes goods and services without similarity of marks, characteristics and exclusive specifications, except when technically justifiably, under penalty of nullity and responsibility (§6º).

For purchases the Art.15, §7º demands the good complete specification, when the indication of mark or label was prohibited.

Works and Services:

Art. 12 – Regarding basic projects and executive of works or services will be considered the next requisites: Security with the adoption of technical standards of health and of security of the work adapted; functionality and adaptation to the public interest; the execution economy, conservation and operation; job for workers possibility, materials, technology and existent raw materials in the place; the execution easiness, conservation and operation, without damage for the durability of the work or the service; and environmental impact.

Object – Purchases

Art.15 – Align whenever possible to the standardization principle, which imposes technical specifications and performance compatibility, observed, when it will be the case, the maintenance conditions, technical back-up and guarantees offered [...].

4. Implementation and Recommendations

In the public authorities hands, the green procurement is a environmental protection powerful instrument. If this power be used to promote the goods production and the most sustainable services, it will be able to wait for improvements and considerable changes in the market structures in short and middle time. The administration shall:

a) create commissions and study groups involving different areas workers to carry out diagnosis of the situation, identify critical / real points and prepare an integrated projection, technical measures possible and operational efficiency proceedings, defining projects and activities, the actions cost and when goods/resource will be paid by the economy itself (pay back time);

b) To promote the continuous improvement for the systematic evaluation, proceedings projection, officials formation, new technologies introduction. Always evaluate and control the environmental performance, to identify improvement faults and benefits through the inclusion of specific clauses in the contracts elaborated with enterprises suppliers of services and goods supply, with sight to the education and environmental management capacity, for all the workers involved (ICLEI, 2003);

c) The results presented by the studies groups will have to produce activities to be proposed and implemented through training and diffusion of the knowledge by acting strategically in the decision political levels; making the workers aware of the problems; adopting new administrative proceedings, establishing partnerships; using rationally the available resources; establishing aims; appropriately materials disposal, recycling; and spreading the actions, advancements, indicators and sectors exchange experiences (BRAZIL, 2007);

d) Organize a “green procurement” guide containing an evaluation on products and services that provide environmental profits and resource economy, for product or products class, identifying the environmental aspects responsible for significant impact, in order to orient the taking decision process;

e) Determine aims and terms in order to respect them.

4.1 Environmental general criteria to guide the employment and acquisitions

There are several criteria that can be adopted in defining time the purchase or acquisition of goods or services classified as "green":

a) Natural resources Consumption: materials origin, energy in the production and in the transport;

b) Produce air and water pollution: phase of production; transport; use, operation and demolition;

c) Waste generation: Production; use (waste); and demolition (recyclable);

d) Building Performance: energy; durability; and indoor air quality.

The environmental impact resulting from natural resources use are treated in the level of definitions of the projects, when the definitions of engineering on institution politics basis, looking for technology of proved efficiency/profit in these resources use. The correct basic importance environmental aspects and impacts identification, as well as the evaluation and resulting actions for reduction or elimination (ECOCAMARA, 2007).

Inside these criteria, one classifies several visions, not forgetting that must be done in the global thinking life cycle analysis process (SILVA, 2007): First asking: Which source of energy is used in the process? And to last more? And will it cause any health harm?

4.1.1 General services

The bigger relevance third part services on cost like those of cleaning, vigilance, food and transport, will have to be standardized in manuals of compulsory use.

Actions that must be taken for services employment: the environmental legislation Compatibility and technical specifications alteration with water economy use practices, spills identification; energy efficiency; hard products consumption reduction for cleaning; use of less pollutant fuel in the vehicles used in the services execution (methanol or biogas); employees involved habilitation.

4.1.2 Works and engineering services procurement

Environmental supervision of the works and services by independent and co-responsible engineering; environmental conformity certification, containing the environmental attended demands, attended and not attended; certificate environmental agreement verification to the payment; and constructive methods revision, origin of inputs just like the certified wood by the BAD (performance evaluation report).

4.1.3 Materials acquisition

The enterprises must create materials catalogues previously selected when the specification and purchase are careless considering the environmental aspects and volume of purchases and must be selected and classified as strategic when the list is simplifying. In the Sao Paulo state today there are only 7.500 items in the materials catalogue versus 63.000 items in the conventional process (DAMICO, 2005).

4.1.4 Objective and goals

What is the environmental improvement waited through the green procurement implementation? The project of the entitled ICLEI "Relief" (Environmental Relief Potential of Urban Action on Avoidance and Waste Streams Detoxification Through Green Public Procurement) calculated the environmental potential of the contribution of the sustainable purchases. It demonstrated that a change for 100 % of consumption of organic production of wheat, meat and milk done by public authorities would produce a reduction in the eutrofization effects equivalent to the produced ones for 2,1 millions people by the pesticides use reduction, figure 4 (ICLEI, 2007).

What the price implications of a more sustainable alternative acquisition? In the cases where the most recent option applies for investments to the sight and offers economy during the operational phase, it is recommendable longer terms where future savings can finance the next investments.

What the appropriate terms are? To establish realistic terms the government can consider the principal purchases planned in the future and estimate the necessary time to integrate the criteria of in the budgets search and product specifications.

Table 4 Potential environmental impact reduction resulted from purchase option

Product	Category of Impact	Reduction of the environmental pressure for the option of green purchases	Equivalent-person middle emission
Bus	photochemical Formation of the ozone (t C2H4-equiv.)	-3.350	-3.350-113.110 (middle - emission European)
Bathroom suites	Consumption of water (liters)	-190.407.539	-3.086.387(middle - European consumption)
Computers	Emissions of gases of greenhouse effect (t CO2 - equiv.)	-835.320	-101.503 (middle - global emission)
Food	Euthrofization (t PO_4 – equiv.)	-24.044	-2.125.000 (middle - emission European)
Electricity	Emissions of gases of greenhouse effect (t CO2 - equiv.)-	-61.350.363	-7.481.752(middle - global emission

ICLEI, 2007

Where:

Bus – the new purchases subject standards of emissions of the EURO IV norm; hydraulic Equipments - substitution of basins of 9 liters for basins, with 6/3 liters with double flow of unloading and the installation of economical water tap; Computers - all new purchases attending the requisites of Energy-Star with monitors of TFT; Food-100 % of meat, wheat and milk produced organically; Electricity-100 % of use of renewable origin.

Equivalents – person - when European, the fact describes the middle emission of a citizen in the European Union. And when global, it describes the emission of a middle person living at any place in the world.

Taking as a reference the environmental profit quoted in the figure 4, the aims can be determined on basis of the resultant impacts of determined activities they are reduced through the determination of which up to determined date a definite percentage is reached like example: Up to 2009, secure that all the public acquired buses are fitted in the lowest gases emission standards.

4. Conclusions

This study indicates that there are legal sufficient bases to inspire of sustainable procurement initiatives in the country, lacking disseminate this information between the people in charge for the purchases and public employment, as well as the daring in testing this new practice.

Viability, in Brazilian legislation view, sustainable politics consumption introduction for the Public Administration (NASCIMENTO, 2005):

a) The object specification with requisites to meet the environmental conservation and preservation in the public procurement necessity;

b) Using environmental criteria in the public procurement according to the best type technique and technique and price possibility; and

c) Application, to a pollutant one, the administrative environmental impediment sanction to contract with the Public Administration for up to 3 years (Federal Law nº 9.605/1998 Art.72, § 8º).

As recommended strategy the progressive described criteria adoption, as soon as the change of the standard can bring resistances and/or technical difficulties.

The public procurement law interpretation must be coherent with the standards remainder, particularly with the Environment National Politics precepts Law (Law 6.938/81) that guide the State in the public interest management on the environment subject. The mentioned law establishes among his objectives, which the social-economic development has to be environment quality preservation compatible, to set up criteria and environmental quality standards and relative standards to the use and environmental resources handling, to develop inquiries and technologies for rational use of the environmental resources, to spread technologies of environment handling and to form a public conscience on the environmental quality preservation necessity and the ecological balance to environmental resources preservation and restoration. So, the public procurement should establish practices to respect these precepts (NASCIMENTO, 2005).

From a general vision, the practices look for consumption reduction, indicate also both of materials and of services cost reduction. The market is known when regulated by the relation between offer and demands what makes the state also responsible at the products final price and services that have collected value of echo-efficiency, since it will be able to stimulate this market, increasing the demand and consequently reducing prices.

4.1 Problems to be administered

a) Sustainability as prevalent criterion or decision criterion?

b) Relative "price": What is a less price? public procurement best type price Establishment, meaning more favorable conditions under the environmental optics in cheaper price detriment.

c) To value the positive biggest price ingoing or the cheaper price negative externalities?

d) The practiced option results and policies divergence;

e) Cost-benefit relation: the society and environment damages;

f) Quantification of the intangible ones;

g) lack of data book for the life cycle thinking culture and eco-design;

h) Product/service sustainability profile versus enterprise sustainability profile: approach in the product/service or coherence in the corporation integrated and systemic evaluation?

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EROSION AND SEDIMENT CONTROL ON 100 THOUSAND SQUARE METER ON A LARGE BRAZILIAN STATE'S COMPANY CONSTRUCTION SITE MEETING SS PRE-REQUISITE LEED GREEN BUILDING CERTIFICATION

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Summary

This paper relates the experience of implanting some BMPs for erosion and sedimentation control aligned to SS Pre-requisite 1- Construction Activity Pollution Prevention for LEED-NC 2.2 certification on 100.000m^2 of a large Brazilian State Company headquarters construction site. Presents a short project description, site, the method for environmental assessment proposed and main demands for the requirement fulfillment for the execution avoiding scope alteration as foreseen in the contract, Report of Urban Impact, Statement of environmental impact, projects and procedure manuals. It also relates how the brainstorm and workshops have happened with the disciplines involved teams. It shows the results after the plan established, concluding that the environmental goals should be defined in the development design phase of a project. In general there is no concern with basic actions that will be able to generate pollution in the water bodies receivers in Brazil. The solid particles or particulate matters risen by wind drags nearly always is neglected and finally it states that the necessary measures for being in conformity with the SS Pre-requisite 1 do not impact in the final cost of execution, but need be backed contractually for guarantee of its application.

1. Introduction

Any site where soils are exposed to water or wind can have soil erosion and sedimentation problems. Erosion is a natural process in which soil and rock material is loosened and removed. Sedimentation occurs when soil particles are suspended in surface runoff or wind and are deposited in streams and other water bodies.

Human activities can accelerate erosion by removing vegetation, compacting or disturbing the soil, changing natural drainage patterns, and by covering the ground with impermeable surfaces. When the land surface is developed or hardened in this manner, storm water can not seep into or infiltrate the ground. This results in larger amounts of water moving more quickly across a site which cam carry more sediment and other pollutants to streams and rivers (Berman, et al. 1991).

In addition, as stormwater runoff moves across surfaces, it picks up trash, debris, and pollutants such as sediment, oil, grease, and other toxics. Changes in ambient water temperature, sediment, and pollutants from stormwater runoff can be detrimental to aquatic life, wildlife, habitat, and human health. Soil exposed by construction activities is especially vulnerable to erosion. Runoff from an unstabilized construction site can result in the loss of approximately 35–45 tons of sediment per acre each year . Even during a short period of time, construction sites can contribute more sediment to streams than would be deposited naturally over several decades. Excess sediment can cloud the water reducing the amount of sunlight reaching aquatic plants, clog fish gills, smother aquatic habitat and spawning areas, and impede navigation in our waterways (USEPA, 2007).

The primary stormwater pollutant at a construction site is sediment. To control erosion at a construction site, it is important to understand the different types of erosion that can occur. Runoff carrying the soil particles becomes sheet erosion which eventually forms smaller rills and larger gullies. The best way to stop erosion is to keep the soil in place through vegetation, erosion control blankets, or other methods that prevent the soil from becoming dislodged during rain events. The erosion process is typically influenced by climate, topography, soils, and vegetative cover (Berman, et al. 1991).

1.1 The project and site characteristics

Designed to be the administrative Brazilian Oil Company headquarters in the Espírito Santo State (figure 1). One of the main directives of this project should be the reference for others projects in the Vitoria city by their energy and environmental performance, earning notoriety and the marketing recognition by the economic performance, environmental responsibility and the permanent compromise with the most modern concepts of environmental efficiency inserted in their architectural collection.

The Vitória city, Espírito Santo State capital, is the largest island of a group of 33 islands archipelago, and it is located on the southeastern region of Brazil, latitude 20º19'09" south and longitude 40º20'50" east of Greenwich located in Brazil Southeast which is the more developed Country Region (ARAUJO, 2007).

The site is situated on north of Vitória Island, the local climate is tropical humid, and maxim monthly average temperature is 30º C and minimum of 24º occurring most of rainstorm from October to January and the average is 1345 mm/year. November 1996 was the hardest rain 200,64 mm in the last 15 years (ARAUJO, 2007).

The chosen site was the last urban empty area in the city that could fit the project. Located in the most important avenue of the city, on a mix of residential and commercial neighborhood which becomes much more vulnerable and sensible.

The site is located over a solid rocky one with a small layer of superficial land, including some blocks emerged. Justified by the architectonics characteristics, to be implanted it was necessary a lot of activities such as clearing, grading, excavating, drilling and blasting operations what became larges unstabilized areas.

Figure 1 The original site aerial view, electronic perspective and the project implanted (electronic way).

1.2 Objective

Know the BMPs-Best management practices to erosion and sedimentation control, how and when they could be applied an know if LEED methodology is viable to apply on Vitória City constructions site analyzing by economic and environmental point of view.

1.3 Methodology

Based on its objectives this research is characterized as descriptive. All the practices was based on recommendations to NPDES–National Pollutant Discharge Elimination System and chosen to meet SS Pre-requisite 1- Construction Activity Pollution Prevention for LEED-NC 2.2 tool, The main author works on this site to implant the plan. Some workshops were organized to choose the best management practices where participated technical and engineers construction's builder stuff and the owner's technical body. From the technical procedures or research strategies point-of-view it assumes characteristics of survey and case study.

1.3.1 Evaluation tool and requirements

In the present paper LEED methodology will be used because the authors' choice for LEED was based on the fact that it is one of the most popular evaluation tools worldwide, and it has a simplified structure, assessing the sustainability of the whole building performance. Based on well-founded scientific standards, LEED method emphasizes strategies for the local sustainable development, water saving, energy efficiency, material selection and indoor air quality (USGBC, 2005).

Comprising a checklist that attributes credits to the fulfillment of pre-established criteria, each criterion is divided into credits that are basically project, construction or management actions that contribute to the reduction of the environmental impacts of the buildings. LEED results from a balance between prescriptive credits and performance specification, having as preference the environmental principles by norms and recommendations by accredited institutions (USGBC, 2005).

Is not a decision made that it will be a certificated Building, but the project manager decided that the construction time must be done aligned to the LEED-NC rating system that profess as prerequisite reduction pollution from construction activities by controlling soil erosion, waterway sedimentation and airborne dust generation. Since it the project was not registered on USGBC –United States Green Building Council, and it was not backed contractually, could not impact in the final cost of execution.

The requirements are create and implement an Erosion and Sedimentation Control Plan for all construction activities associated with the project. The ESC Plan shall conform to the erosion and sedimentation requirements of the 2003 EPA – Environmental Protection Agency Construction General Permit or local erosion and sedimentation control standards and codes, whichever is more stringent. The Plan shall describe the measures implemented to accomplish the following objectives: Prevent loss of soil during construction by stormwater runoff and/or wind erosion, including protecting topsoil by stockpiling for reuse; Prevent sedimentation of storm sewer or receiving streams. Prevent polluting the air with dust and particulate matter. The plan outlines the provisions necessary to comply with Phase I and Phase II of the National Pollutant Discharge Elimination System (NPDES) program. While the CGP only applies to construction sites greater than 1 acre, the requirements are applied to all projects for the purposes of the prerequisite (USEPA, 2007).

1.3.2 The Brazilian Legislation

To comply to The Brazilian legislation it was necessary a environmental research called DIA- Declaração de impacto ambiental (statement of environmental impact) and RIU–Relatório de Impacto Urbano (report of urban impact), besides de whole environmental ordinances. Based on DIA the local government establishes some mandatory rules and conditions that are going to be fulfilled for project Implementation permit be liberated. In this special case there is another permit for existing rocks blastering operations on site to locate the foundations. Some of them are about Wind erosion control, tracking of sediment off-site by vehicles leaving the construction area, Hazardous Waste Management, Contaminated Soil Management, Sanitary/Septic, Waste Management, Vehicle & Equipment Maintenance, Stockpile Management, Spill Prevention and Control, Solid Waste Management and so on.

Usually there is no environmental concern on the civil construction Industry in Brazil and because that, a high level of environmental performance was not written on legal contract signed between the building owner and consortium hired of builders. So, the operational site environmental manager had to look hard for find legal base and National Standards to meet the LEED SS prerequisite 1 requirement for guarantee of its application.

1.3.3 Brain storms, discussion and decisions

The decisions involved multidisciplinary knowledge, and some workshops were organized to choose the best management practices where participated technical and engineers construction's builder stuff and the owner's technical body.

The Operation site were planning for 3 different fases on DIA in order to detail each temporary installation like Hazardous Waste storage and the locating selective collection waste place and so on. None of the fases planed were followed. The contractor did not realize the necessity of planning the site and the decisions were made at local whenever needed or not. In case of being part of the permit, some of the requirements were done, but not monitored and no analyzed if were working or not.

The discussion focal point was always the drainage, runoff and others erosion control measures, because the site is on rock hill one, becoming difficult and not necessary to establish those measures on construction site on their mind.

Since erosion and sedimentation control was LEED requirement as prerequisite, it was necessary prepare the documentation to comply and evidence the historical site situation by maps, plans and photos and others drawings and reports. So the program started. But even the complete program to prevent erosion and sedimentation had been made it was not followed and applied (USGBC, 2005).

Figure 2 The mud flooded site outside situation shown on newspaper and mud situation inside the site.

In January 8th, a very hard storm occurred and serious consequences happened. Discharge of storm water from the construction site were likely to carry pollutants and sediments to neighborhood, impacting the buildings close to the site becoming headline on local newspaper's first page (figure 2).

Unfortunally, this event was the diverter from the non environmental responsible time and the necessity of program to prevent the stormwater pollution be implemented

First of all, it was made a soil analyses to know how much permeable it is and the runoff coefficient to compare how much local rainfall occurs to decide which measures should be taken. The summer time is worst for storm water and until January almost nothing had been done. At that time, it should be hurry, more rainstorms should be coming, and the measures must be applied.

The decision were restart from the beginning by the program using both permit as guidance to assist in developing the Stormwater Pollution Prevention Planed in order to follow the steps: Site assessment and planning, Selecting erosion and sediment control BMPs, Selecting good housekeeping BMPs, Inspection maintenance and recordkeeping in order to identify the potential sources of stormwater pollution at the construction site by attending the ten principles to erosion and sediment control by structural and non-structural practices used during the construction process to keep sediment in place (erosion control) and to capture any sediment that is moved by stormwater before it leaves the site (sediment control).

2. The erosion and sediment control program

2.1 Finding up the program requirements

Applicability—describing the geographic area covered and who is eligible to apply; Authorization—describing the types of stormwater (and non-stormwater) discharges that are covered; Permit requirements—outlines the elements that should to be addressed to prevent the contamination of stormwater runoff leaving the construction site; Implementation—BMP installation, inspection, and maintenance requirements; Other requirements—may include additional requirements such as spill prevention; Standard conditions—list of conditions that are applicable to most NPDES permits; Termination—lists conditions for terminating permit coverage after construction is complete (USEPA, 2007).

2.2 Site evaluation and data collection to selecting appropriate BMPs

First, it was necessary localize the site pollutants and the areas where it could come from or generate, aspects and impacts (figures 3, 4):

• Description of controls to reduce pollutants; Maintenance/inspection procedures; Records of inspections and follow-up maintenance of BMPs.

CONSTRUCTION SITE POLLUTANTS									
	Primary Pollutant	Others Pollutants							
Areas of Consideration	Sediment	Nutrients	Heavy metals	pH (acids & bases)	Pesticides & herbicides	Oil & grease	Bacteria & viruses	Trash, debris, solids	Other toxic chemicals
Clearing, grading, excavating, and unstabilized areas									
Paving operations									
Concrete washout and waste									
Structure construction/painting/cleaning									
Demolition and debris disposal									
Dewatering operations									
Drilling and blasting operations									
Material delivery and storage									
Material use during building process									
Solid waste (trash and debris)									
Hazardous waste									
Contaminated spills									
Sanitary/septic waste									
Vehicle/equipment fueling and maintenance									
Vehicle/equipment use and storage									
Landscaping operations									

Figure 3 Construction Site Pollutants Matrix (USEPA 2007).

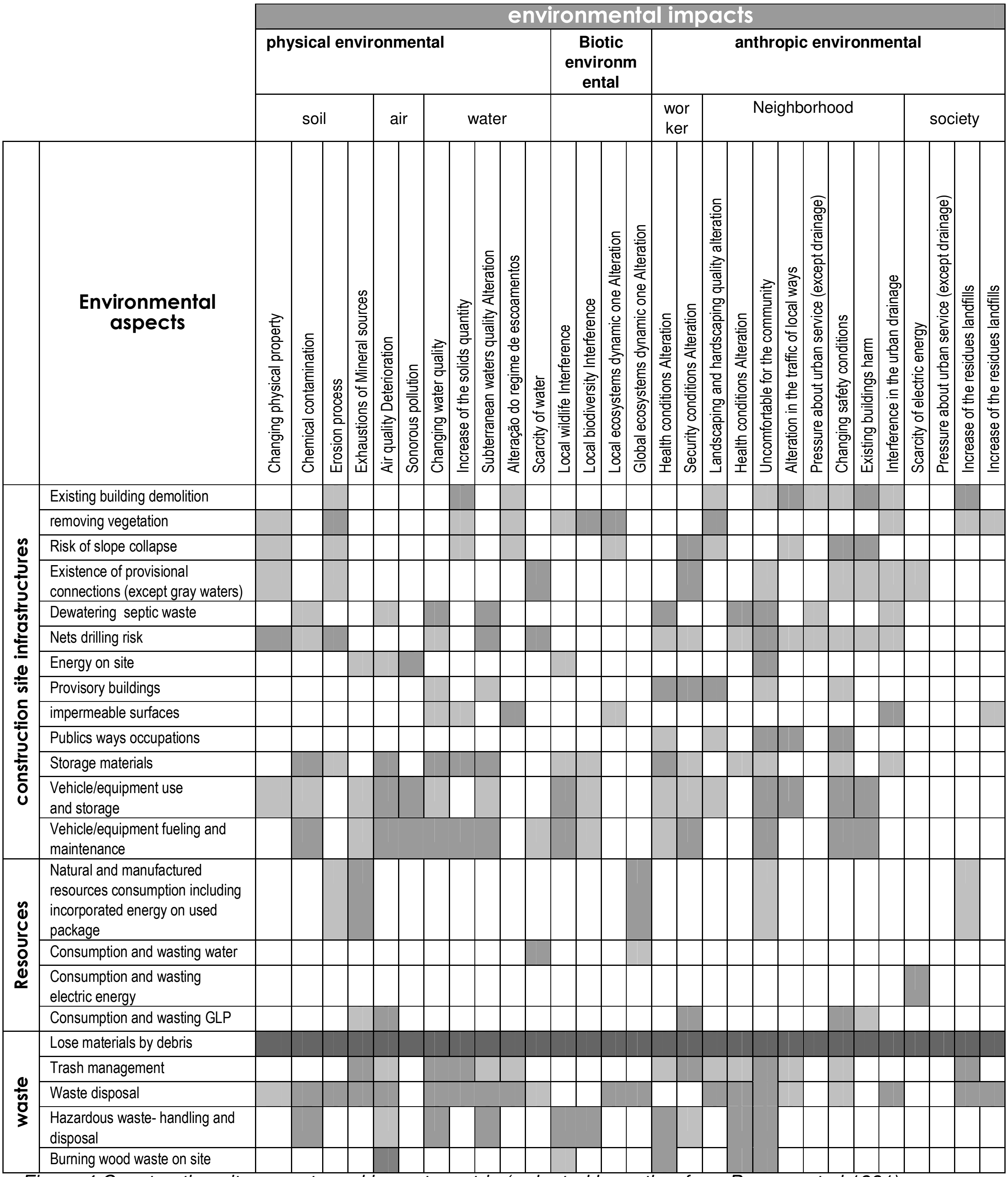

Figure 4 Construction site aspects and impacts matrix (adapted by author from Berman,et al 1991).

2.2.1 Minimize disturbed area protecting natural features and Control stormwater flowing onto and through the project

In spite of the Drilling and blasting Operations be the principal activity by that time and the whole site was revolved it was carefully considered the natural features of the site by carefully delineating and controlling the area that was been disturbed by grading or others construction activities, it was greatly reduced the potential for soil erosion and stormwater pollution problems. Limit disturbed areas to only those necessary for the construction of the project (figures 5). Natural vegetation was the best and cheapest erosion control BMP to protect and preserving topsoil. Another technique applied for minimizing the duration of exposed soil is phasing. By scheduling or sequencing your construction work and concentrating it in certain areas, it was minimized the amount of soil that was exposed to the elements at any given time. It was limited the area of disturbance to places where construction activities are underway and stabilizing them as quickly was possible.

Figure 5 Mapping the critical areas and preservation of existing vegetation (future public park).

Got site to final grade temporarily stabilized almost all bare soil areas as soon was possible and provided additional stabilization on erosion prone areas such as slopes and drainage ways. Areas needed for future roads, construction, or other purposes had been temporarily stabilized. Establishing a vegetated cover on as much of the site was possible did help to minimize erosion and sediment problems (figure 6).

Figure 6 the native vegetation growing evolution after have been removed.

2.2.2 Protected slopes and channels

Convey concentrated stormwater runoff around the top of slopes and stabilize slopes as soon as possible. This could be accomplished by using pipe slope drains or earthen berms that did convey runoff around the exposed slope, avoiding disturbing natural channels and the vegetation along natural channels (figure 14 16).

2.2.3 Establish perimeter controls to retain sediment onsite and control dewatering practices stabilized construction exits

Maintained natural areas and supplemented them it was installed controls on the downslope perimeter of the project to help prevent soil erosion and stop sediment from leaving the site. Sediment barriers was used can trap sediment from small areas, it was required, if consider using a temporary sediment trap or sediment basin. These practices detain sediment-laden runoff for a period of time, allowing sediment to settle before the runoff is discharged. It was Identified the best locations where vehicles will enter and exit the site. Wash racks and a hose-down system remove even more mud and debris from vehicle tires avoid Vehicles entering and leaving the site track significant amounts of sediment onto streets (figures 7, 8 and 9).

Figure 7 The outlet tire wash.

Figure 8 The outlet tire wash.

Figure 9 the sediment box view.

2.2.4 Inspect and maintain controls

Inspection and maintenance has been important as proper planning and installation of controls. So a checklist is applied every month, besides local daily visits to verify the site conditions. It was realized that without adequate maintenance, erosion and sediment controls will fail. Perform maintenance or corrective action as soon as problems were noted (California Stormwater Quality Association. 2004).

2.3 Housekeeping

Key Pollution Prevention Principles for Good Housekeeping were applied focused on construction projects generate large amounts of building-related waste, which can end up polluting stormwater runoff if not properly managed. Some of the best management practices applied are pollution prevention or good housekeeping practices that were designed to prevent contamination of stormwater from a wide range of materials and wastes at the site as: waste management system; proper building material staging areas; paint and concrete washout areas; The site doesn't have proper equipment/vehicle fueling and maintenance local and is necessary plan it soon and Develop a spill prevention and response plan as figure 10, 11 and 12.

Figure 10 equipment/vehicle fueling.

Figure 11 Grease spill.

Figure 12 fueling by biodiesel.

2.4 Dust and particulate matter control

Wind erodes soils and transports the sediments offsite, where they may be washed into the receiving water by the next rainstorm. Therefore, various methods were dust control needed to be employed to prevent dust from being carried away from the construction site. Localize how and where the dust is generate was necessary to decide how it should be treated by Identified the points critical and attack-them with more quickness; New opened accesses and do suppression of vegetation while the work was requiring; Dominant winds Mapping; Defined contingency plan for all grading process, including drilling and blastering operations and particulate control plan from it by watering (figure 20); In The phase of grading and excavations, verified manual of procedures and standards for safety slopes inclination and Material stock pile stabilization.

3. Results and Conclusions

Table 1 Results- before and after the Erosion and Sedimentation Control Plan

Before the plan situation	After plan results
 *Figure 13 The erosion process.*	 *Figure 14 Seeding the slopes and water velocity dissipation.*
 *Figure 15 The erosion process.*	 *Figure 16 Slope drains and Drainage swales.*

Before the plan situation	After plan results
 Figure 17 Flooded.	 Figure 18 Sediment basin and dewatering operation control.
 Figure 19 Dust by traffic.	 Figure 20 watering prevent dust by Soils storage piles and traffic.
 Figure 21 Dust by drilling.	 Figure 22 Watering prevent dust by drilling and blastering activities.

The results shown that the measures are very simple, cheap and efficient, but need be planed concluding that the environmental goals should be defined in the project development design phase, as well as the definition for guide the legal procurement processes. The level of detailing of the drawings for documenting the fulfillments of the SS Pre-requisite 1 is above the habitual Brazilian's design offices routine. Brazil has national laws to regulates the pollution prevention activities on the construction site but usually not followed.

The solid particles or particulate matters risen by wind drags nearly always is neglected finally it states that the necessary measures for being in conformity with the SS Pre-requisite 1 do not impact in the final cost of execution, but need be backed contractually for guarantee of its application. In general there is no concern with basic actions that will be able to generate pollution in the water bodies receivers and impacting the whole neighborhood.

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SIMULATION METHODOLOGY FOR HIGH-RISE OFFICE BUILDINGS WITH DOUBLE-SKIN FAÇADE IN THE HOT AND HUMID CLIMATE

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Keywords: simulation methodology, high-rise office building, double-skin façade, computational fluid dynamic

Summary

A number of recent investigations and findings are reported in the literature pertaining to the used of double-skin façade for passive ventilation in buildings and the researches have revealed close link between natural ventilation design and the design of double-skin façade. It was found that significant energy saving is possible if natural ventilation strategy could be exploited with the use of double-skin façade. In this research, CFD was used to analyse the correlation between thermal comfort parameters and different double-skin façade orientations to be used in high-rise office buildings in hot and humid climate. A comprehensive methodology is proposed and results were presented.

1. Introduction

Extensive research has been carried in defining what is thermal comfort and the parameters that affecting it. All those findings had confirmed the importance of human factors and human influence towards the creation of a thermally comfortable indoor environment (Fanger 1970 and Ruck 1989). In more recent experimental studies concerning the effects of some human factors on the comfort conditions in particular geographical location, Dear, Leow and Foo (1991) found that people working in naturally ventilated buildings in hot and humid country could accept a temperature value of up to 3°C warmer than Fanger's values. This with other similar findings especially the newly published ASHRAE standard 55-2004 (2004) have given the opportunity in introducing natural ventilation for commercial buildings in the hot and humid region.

A number of interesting investigations and findings are reported in the literature pertaining to passive ventilation in buildings and the thermal performance of double-skin facades. Even though most of the researches are done mainly in temperate countries conditions but they have revealed close link between natural ventilation design and the function of double-skin façade. Grabe et al. (2001) developed a simulation algorithm to investigate the temperature behaviour and the flow characteristics of double facades with natural convection through solar radiation. Similar works on natural convection ventilation also reported by Ziskind et al. (2002, 2003), Bansal et al. (1994), Hamdy and Fikry (1998), and Priyadarsini et al. (2003). Most of them are using the idea of stack effect or the solar chimney concept and found that passive ventilation in summer is possible even for multi-storey buildings. In particular Priyadarsini et al. (2003) have concluded the energy efficiency of stack system used in residential of a hot and humid climate region.

Li Y and Delsante (2001) went a step further to investigate the effects of natural ventilation caused by wind and thermal forces in a single zone building with two openings. Ventilation graphs are plotted using the air change parameters (thermal air change, wind air change and the heat loss air change) for design purposes. Gratia and Herde (2004) attempted to look at the impact of double-skin façade facing southern direction in a temperate climatic condition. Thermal analysis using simulation software of different seasons of a year was done for a low-rise office building with and without double-skin façade. It was found that significant energy saving is possible if natural ventilation could be exploited through the use of double-skin façade.

This paper attempts to bridge the gap of looking into the possibilities of natural ventilation in high-rise office buildings specifically in the hot and humid climate region with the use of double-skin façade. The unique façade construction is thought to be able to act as a stack in providing required ventilation for the thermal comfort of the internal space. Airflow effects induced by wind and thermal forces on a high-rise office building are observed with all the thermal comfort parameters included are analysed.

2. Research Methodology

A virtual prototyping computational fluid dynamic (CFD) simulation software called Airpak (2003) is used in this research to model the complex energy transfer through the component layers of the multiplayer façade through the optimisation of the appropriate opening sizes on the glazing, the width of the intermediate space and the ventilation rate through the internal office space. The validation of the software has been carried out by comparing the experimental and simulation results from another commercial simulation software called FloVent which carried out by Manz H (2003). Both of the results are compared and analysed and it was found that the variation is within 5% of the acceptable error tolerance.

In view of the complexity of the problem at hand, the modelling of the computer model has been broken down into different 'levels'. The initial single office module in 3D is constructed with the geometrical dimensions of 3.5m x 5.0m x 3.5m in height. Numerous simulation runs have been carried out for the benchmarking purposes in which a typical curtain walling office module was observed and a simplified 'nomogram' has been established to define the initial parameters for thermal comfort in the tropical region. These results are compared with the simulation runs from the office module with double-skin façade construction. Following-up with the simulations analysis of a single office module discussed above, the computer model is 'extended vertically' to incorporate a 'concealed ground floor space' which usually used as shop front space for most high-rise office buildings. The office space is only starting at 1st level. Two different groups of modelling are constructed at this stage. First group is the benchmarking model with standard curtain walling system generally used in most modern high-rise office buildings (Figure 1). The other group is replaced with a standard vertically vented double-skin façade construction (Figure 2).

The strategy is to 'break-down' a very complex problem of simulating a multi-storey high-rise building into a '6-storey building block'. Simulations will be run for the 1st building block of 6-storey for the modelling of the office building from ground floor to 6-storey. Subsequently another 6-storey building block of the model will be constructed for modelling of the office building from 7-storey to 12-storey. The last building block will be the modelling of the office building from 13-storey to 18-storey. The building height of 18-storey or about 60m high will constitute the majority of the office buildings height in a medium to medium-dense modern city. This will give a good representation for investigating the problem at hand.

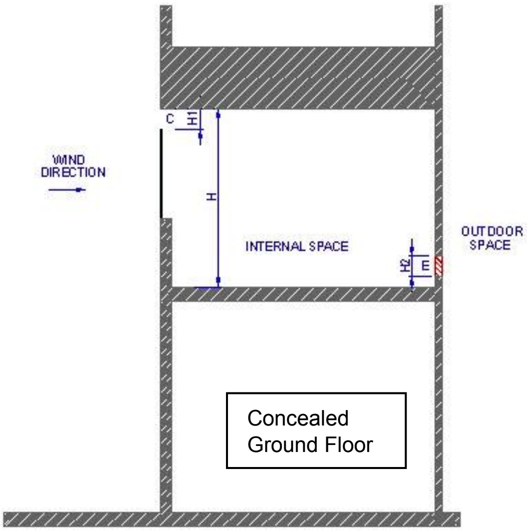

Figure 1 Standard curtain walling model.

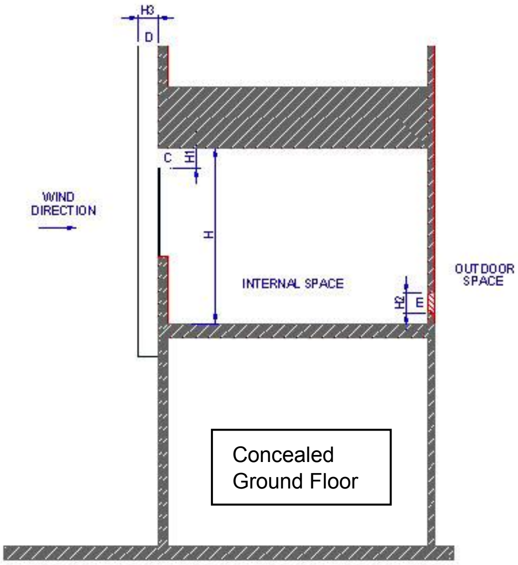

Figure 2 Double-skin façade model.

3. CFD Modelling

The first block (Stage 1) of the six-storey building (Figure 3) consists of a ground floor (which is not served by the double-skin façade, as this will be the typical design for any high-rise building) and 5 stories of office spaces above. The double-skin façade is a ventilated-shaft design which is 2.8m from ground level. In earlier findings it is a practical and economical option to introduce a shaft to improve the stack effect of the natural ventilation and in turn will improve the airflow rates required to reach thermal comfort level within the interior office space.

The heat sources for the CFD model will only be introduced at alternate floor, starting from 1st-storey. This was done to reduce the complexity of the model and computing time, but at the same time will be able to give a comprehensive view of the indoor thermal comfort of the office spaces. Each alternate floor will have two occupants, two computers and four ceiling lights, which are the same as the initial single office model. Each human model is assigned with 75 W/m^2 of heat generation with clothing value (clo) of 1.0 and metabolic rate (met) of 1.2 for sedentary office activities. Heat generated for the computers are 108 W/m^2 and 173 W/m^2 respectively and the heat flux of the lighting fixture is assumed to be 38 W/m^2 each.

Boundary conditions for wind velocity, external temperature and relative humidity were set to the ranges similar to the climatic conditions for Singapore. The ambient temperature in Singapore is hot with high humidity and relatively low wind velocity throughout most of the year. Only the optimum opening sizes on the inner pane and the air gap sizes of the double-skin façade (DSF) are being considered (as shown in Figure 4) for this stage of simulations, based on the findings from the preliminary modelling. The optimum vent size at the rear wall was found to be 300mm by 600mm from previous findings. The scope of the problem in investigation has been 'narrowed down' and carefully 'controlled' to find the 'optimum DSF configuration' for use in Singapore climatic conditions.

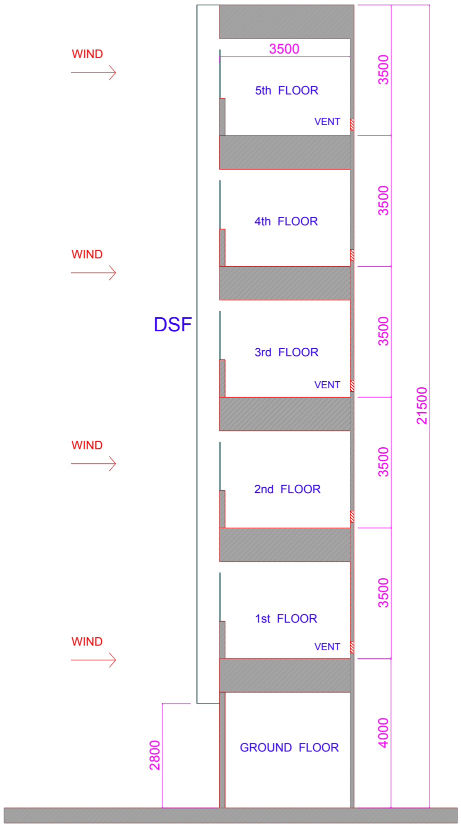

Figure 3 Model geometry of Stage 1 of the 6-storey office building.

4. Results

4.1 Comparison of results for single-skin and double-skin facades

The results obtained from the benchmarking simulations, which is a typical curtain walling system façade, are compared to the results from the proposed prototype double-skin façade.

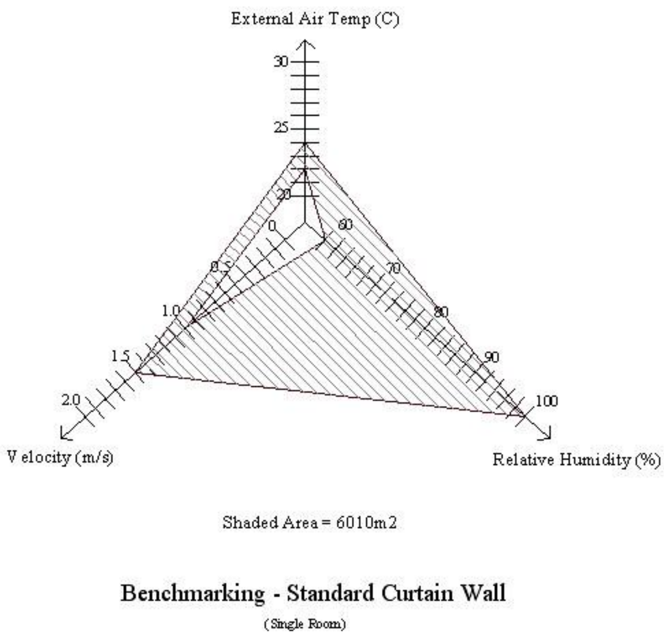

Figure 5 Nomogram showing the acceptable thermal comfort conditions (shaded area) for standard curtain wall system.

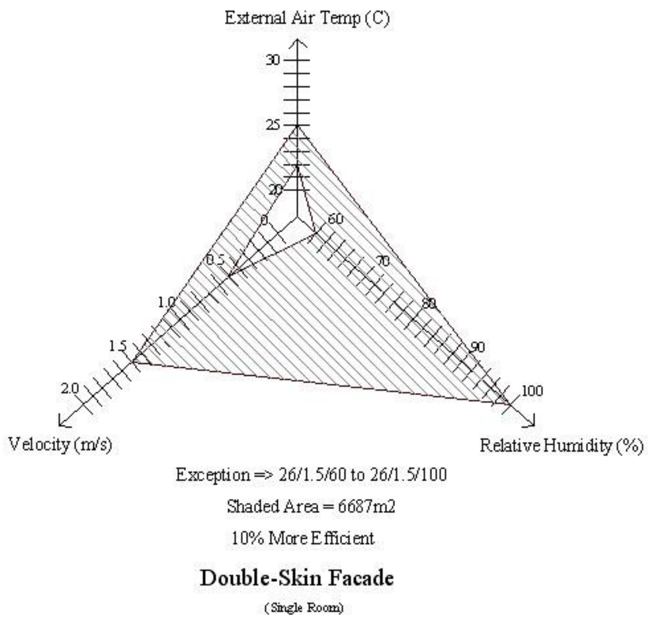

Figure 6 Nomogram showing the acceptable thermal comfort conditions (shaded area) for double-skin facade system.

The nomograms are formed by three axes, which represent the three important parameters in thermal comfort analysis, temperature, air velocity and relative humidity. Boundaries of thermal comfort are plotted onto the nomograms from the analysis of the simulation results and they are compared to see whether there are any advantages for using double-skin construction for an office building in the tropical climate.

Figures 5 & 6 above have shown that there are positive points in using the double-skin construction, as the 'shaded area' for the double-skin façade is larger than the normal curtain walling construction, even though this finding is only representing the low level results for the high-rise office building in study. The findings are encouraging as the double-skin façade construction does improve the internal thermal comfort for a naturally ventilated office space by as much as 10%, as compared to conventional curtain wall system.

4.2 Simulation results for South facing DSF system (Stage 1)

The first group of simulations is generated with the DSF system constructed at the south facing façade of the building only. The simulation periods are at 10 a.m. or 2 p.m. on either 15 January or 1 July of the month with wind direction perpendicular to the DSF wall and with wind velocities of 0.5 m/s, 1.5 m/s and 3 m/s. The external ambient temperatures were set from 26°C to 30°C with relative humidity ranging from 70% to 100%. The opening size for the inner pane of the DSF system used is 300mm. The air gap sizes used for the DSF are 300mm, 600mm, 900mm and 1200mm. The air vent size at the rear office wall is fixed at 300mm x 600mm.

There are a total of 18 location points being identified to record the simulation results on thermal comfort parameters. Six of those location points which are 0.8m above the office floor level and 0.2m away from the two human figures. These six points are chosen to monitor the thermal comfort conditions experienced by the occupants. Table 1 shows some of the comparative results for the simulation with different parameters used for the boundary conditions and DSF configurations taken at strategic locations. The indoor Operative Temperature (OT) calculated in the above table was using the formula stated in Figure 7 and the value was used to identify acceptable thermal comfort for naturally ventilated spaces in hot and humid climate using the graph given in the same figure.

Table 1 Simulation results for different boundary conditions

(Note: Shaded results are acceptable thermal comfort conditions)

Simulation	Orientation	Date	Time	Air Temp. °C	Wind Vel. m/s	Air RH %	Air Gap Size mm
S1-1	South	15 Jan	2pm	28	1.5	80	300
S1-2	South	15 Jan	2pm	28	1.5	80	600

S1-3	South	15 Jan	2pm	28	1.5	80	900
S1-4	South	15 Jan	2pm	26	1.5	80	300
S1-5	South	15 Jan	10am	26	1.5	80	300
S1-6	South	15 Jan	10am	28	1.5	80	300

Simulation	**Floor Level**	**Temp. ^{0}C**	**Air Vel. m/s**	**Radiant Temp. ^{0}C**	**RH %**	**PMV**	**OT ^{0}C**
S1-1	1	28	0.04	30	70	1.99	29
	3	29	0.01	30	77	1.8	29
	5	29	0.01	30	76	1.85	30
S1-2	1	30	0.02	33	71	2.41	31
	3	31	0.04	32	77	1.97	31
	5	31	0.03	31	75	2.13	31
S1-3	1	30	0.03	32	71	2.38	31
	3	30	0.06	32	77	2.04	31
	5	30	0.04	32	76	1.9	31
S1-4	1	27	0.04	29	71	1.8	28
	3	28	0.05	29	76	1.66	29
	5	27	0.03	29	75	1.6	28
S1-5	1	27	0.02	29	70	1.97	28
	3	28	0.04	30	76	1.62	29
	5	28	0.03	29	75	1.59	28
S1-6	1	28	0.03	30	70	1.92	29
	3	29	0.01	29	77	1.78	29
	5	29	0.01	30	75	1.84	29

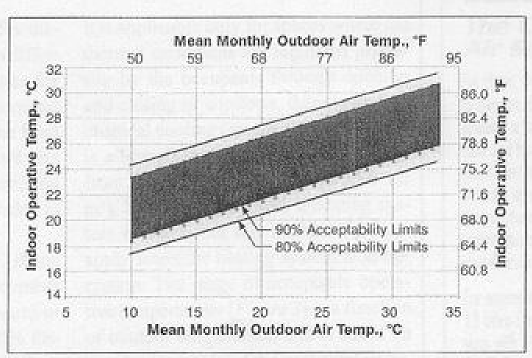

Figure 3: Acceptable operative temperature ranges for naturally conditioned spaces.

Air speed < 0.2m/s			
Difference between radiant & air temp < 4C			
Top = Ata + (1-A)Tr			
V	<0.2m/s	0.2-0.6m/s	0.6-1m/s
A	0.5	0.6	0.7

Figure 7 Thermal environment conditions for human occupancy from ANSI/ASHRAE Standard 552004.

4.3 Analysis of results and findings for Stage 1

Selected results for South facing DSF with external wind velocity of 1.5m/s and air humidity of 80% respectively are tabulated in Table 1. The variable parameters in consideration for this instance are external air temperature, the DSF air gap size and the time of the day. Results for S1-1, S1-2 and S1-3 (South facing DSF) as shown in Table 1 and Figure 8 indicated that the DSF air gap size of 300mm gives the best result for the particular conditions in a natural ventilated space. The findings are the same for the Northern orientation façade as presented in Figure 9. In most cases the lower floor of the office space would generate the lowest operative temperature due to the 'stack effect' provided by the DSF configuration. This has enhanced the natural ventilation strategy to provide better internal thermal comfort condition for the office spaces.

There is not much of a difference in terms of the internal thermal comfort conditions for either period of time in a given day (morning or afternoon) as seen in the results for S1-4 and S1-5 for South facing DSF. There is an internal temperature difference of 0.5°C for the mid-floor of North facing DSF and this could be due to the slower internal air velocity generated (Figure 9).

The South facing DSF configuration has produced an 80% Acceptability Limit for the 300mm air gap size for external temperatures between 26°C and 28°C, according to the Thermal Environment Conditions for Human Occupancy from ANSI/ASHRAE Standard 55-2004 as indicated in Figure 7. This is tabulated in accordance with the context that the office building is located in the Northern Hemisphere of tropical climate like the country of Singapore. The North facing DSF configuration did not produce any acceptable internal thermal comfort condition for the office space (Figure 9) as the operative temperatures for all the floors are above 30°C. This has again confirmed that the southern orientation is the best facing for buildings in the Northern Hemisphere.

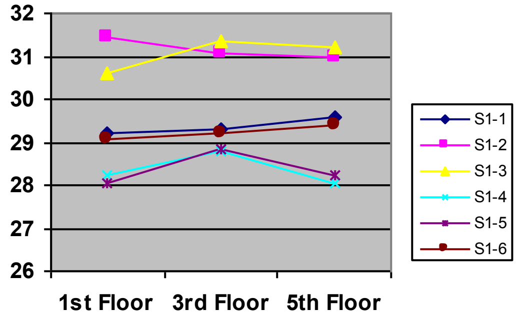

Figure 8 Comparison of Operative Temperatures (°C) for South facing DSF.

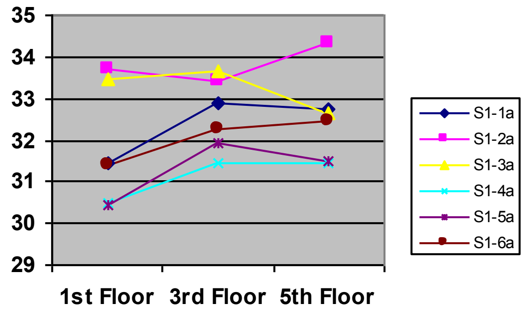

Figure 9 Comparison of Operative Temperatures (°C) for North facing DSF.

4.4 Analysis of results and findings for Stage 2

The selected results for both South and North facing DSF configurations are having similar parameters as Stage 1 for direct comparison. The external wind velocity is 1.5m/s and air humidity is 80% respectively and the variable parameters in consideration for this Stage are external air temperature, the DSF air gap size and the time of the day. South facing DSF with a DSF air gap size of 300mm gives the best result. The findings are the same for the Northern orientation façade. In most cases the lower floor of the office space would generate the lowest operative temperature due to the 'stack effect' provided by the DSF configuration.

There is not much of a difference in terms of the internal thermal comfort conditions for either period of time in a given day (morning or afternoon) as seen in the results for South facing DSF but for North facing DSF morning period has a higher operative temperatures compare to afternoon period. This could be due to the higher internal radiant temperatures generated during this particular period of time.

The South facing DSF configuration has produced an 80% Acceptability Limit for the 300mm air gap size for external temperature of 26°C up to 9th Floor. The North facing DSF configuration did not produce any acceptable internal thermal comfort condition for the office space as the operative temperatures for all the floors are above 31°C.

4.5 Analysis of results and findings for Stage 3

The selected results for both South and North facing DSF configurations are having similar parameters as Stages 1 and 2 for direct comparison. The external wind velocity is 1.5m/s and air humidity is 80% respectively and the variable parameters in consideration for this Stage are also external air temperature, the DSF air gap size and the time of the day. Results for South facing DSF indicated that the DSF air gap size of 300mm gives the best result for the particular conditions in a natural ventilated space, as in Stages 1 and 2. The findings are the same for the Northern orientation façade. In most cases the lower floor of the office space would generate the lowest operative temperature due to the 'stack effect' provided by the DSF configuration, as in Stages 1 and 2 also.

There is not much of a difference in terms of the internal thermal comfort conditions for either period of time in a given day (morning or afternoon) as seen in the results for South facing DSF.

The South facing DSF configuration has produced an 80% Acceptability Limit for the 300mm air gap size for external temperatures between 26°C and 28°C. The North facing DSF configuration did not produce any acceptable internal thermal comfort condition for the office space except for the lower floor for 300mm air gap configuration with external air temperature of 26°C during morning period.

4.6 Comparison results for different orientations

The simulation results for the three stages of the modelling have shown that the South-facing orientation provide a better outcome compared to the North-facing direction. The optimum air gap size for the double-skin façade construction is found to be 300mm and the best results were obtained during the morning period.

Figure 10 below recorded the comparison of selective results between the four major orientations for a double-skin façade installation for a typical high-rise office building. The results show that the South-facing façade has the best outcome followed by the East-facing façade during the morning period in the month of January. The North-facing and the West-facing façades do not provide an acceptable indoor thermal comfort for the purposes of office function in a high-rise building.

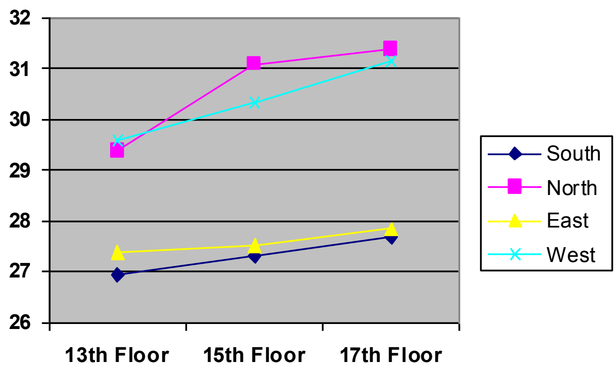

Figure 10 Comparison of Operative Temperatures (°C) for four major orientations.

5. Conclusion

Figure 11 below shows the complete 18-storey office building with typical multi-storey double-skin façade configuration. The proposed DSF starts from 1st storey at 2.8 meters from ground level up to the 17th storey with 1-meter parapet above the roof level. The office spaces are assumed to be divided into a number of small office usages and are tenanted out to various occupants. All office spaces are assumed to face the DSF at the front and facing open corridor at the rear.

With the completion of the three stages of simulations, numerous simulation runs had been carried out with various ambient temperatures, different external air velocities, different orientations of the double-skin façade, different periods of time during the day, etc in order to find out the appropriate window periods for acceptable indoor conditions for office workers in the Singapore context. These findings will be of outmost important as an indication whether double-skin façade is really possible to be used as a mean to introduce natural ventilation to the high-rise buildings in the tropics. The results and findings will also bear an important decision in how to carry out the optimization of the façade system for the whole high-rise office building.

The simulation methodology proposed is comprehensive in simulating a rather complex high-rise office building with accurate results. Further works could be carried out in developing a methodology to simulate office building with different combination of office sizes and usages in an efficient and accurate way.

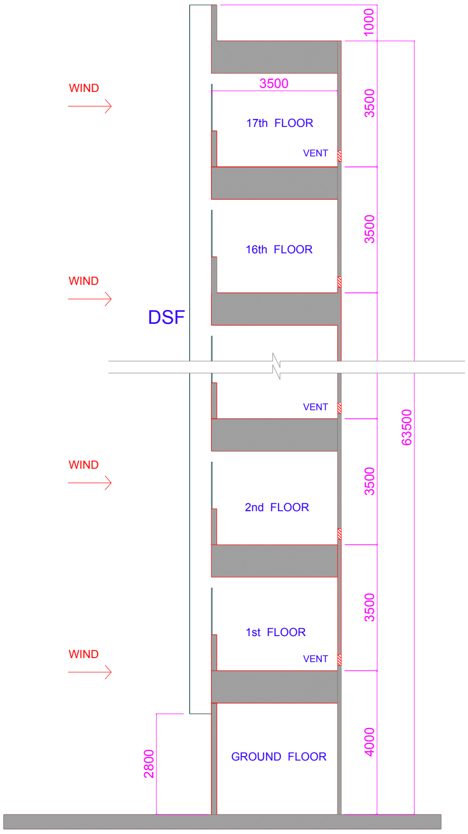

Figure 11 The model of the complete 18-storey office building.

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SUSTAINABLE BUILDING LABELLING SYSTEM FOR THE MALAYSIAN BUILDING AND CONSTRUCTION INDUSTRY

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Keywords: Sustainable Building, Malaysia, Labelling System, Office Buildings, Performance Criteria

Summary

The Green Building Mission launched recently by the Malaysian Government is an indication of a promising effort to ensure sustainable production and delivery of the construction industry products to fulfil these demands. The paper highlights the environmental issues faced by Malaysia and initiatives taken towards a cleaner environment. The development of a sustainable building label for the construction industry under these initiatives are described. Several existing building assessment methods were reviewed to examine their suitability for adaptation. The proposed labelling system takes into consideration of the local issues to provide a useful guide for the planning and construction of sustainable buildings in Malaysia and transformation of the construction industry into sustainable practices.

1. Introduction

The United Nations Framework on Climate Change Conference held in Bali Indonesia in December 2007 highlighted the potential of the building and construction sector in reducing global greenhouse gas emissions and carbon footprints through existing technologies and solutions. In this context, the adoption of sustainable buildings present key opportunities in regenerating the natural environment and community culture by enhancing the value of products and services to business, customers and society in general.

There is increasing public awareness and interest in Malaysia on how buildings affect the environment, worker productivity and public health. Both the public and private sector are beginning to demand buildings that optimize energy use; promote resource efficiency; and improve indoor environmental quality. Developers, owners, operators, insurers, and the public at large have started to value and market the benefits of sustainable buildings. These factors create new design, construction, and operation demands on building/urban facilities and the infrastructure which supports them.

Unfortunately, in Malaysia and in most developing countries, regulatory procedures to guide sustainable building and construction are still very limited. Additionally, in many cases, existing technologies for producing sustainable buildings are still poorly known across the building and construction spectrum and more often, these technologies are not being supported by existing policies and market signals (Shafii et al 2005, Shafii et al 2007, UNFCCC 2007, SBCI 2007, Marrakech Task Force 2007). In order to encourage the implementation of sustainable buildings, and setting a long term pathway to a low-carbon future for Malaysia, therefore a supporting building assessment framework is urgently required.

The paper describes the environmental issues surrounding Malaysian construction industry, and how these are addressed in the development of the buildings labelling system. A review of selected existing building assessment systems were undertaken for consideration of adaptation to Malaysia's requirement. The performance criteria of the adapted system is presented.

2. Environmental Issues in Malaysia

2.1 Energy Efficiency

The industrial sector has always been the biggest user of electricity, consuming about 54% of the overall electricity generated in 2001. The residential and commercial sector consumed 46% (18% Residential and 28% Commercial), while public lighting, mining and other sectors consumed about 1%. Peak demand in Peninsular Malaysia alone has grown from 3447 Megawatts in 1990 to 9712 Megawatts in 2000 and 10,060 Megawatts in 2001. A projection of these analysis indicated an increase by more than 117 percent, i.e.

21668 Megawatts by year 2010. In 2001, 76% of the electricity was generated using gas, 9% using coal, and 8% from Hydro power.

In Malaysia not much published data is available yet on the Energy Performance or actual annual energy consumption of buildings. However, the energy index (total energy used in a building for one year divided by the gross floor area of building) of typical office buildings is between 250-300 kWh/m2/year depending on the type and function of buildings. The breakdown of average energy consumption in an office building is 52% for air conditioning, 20% for lighting and 28% for general equipment *(Kristensen,2003).*

Although the shift of economy towards energy–intensive industries is a major reason behind the increased in energy demand, inefficient energy consumption by the public also account for the higher energy demands. Some office buildings and hotels maintain indoor temperatures as low as 18- 20 degrees centigrade against the thermal comfort range of 23-25 degrees C. Occupants have to wear sweaters at the work desk while energy is unnecessarily wasted for excessive cooling. The cost implication and continuous upward trend in energy consumption is a serious concern to the Malaysian government as this will eventually make energy supply over-costly and unsustainable. For environmental and economic reasons, initiatives have been taken by the Malaysian government for future buildings to be energy efficient in order to avoid depletion of fossil fuels whilst at the same time reducing the impacts upon combat climate.

2.2 Water

The growth in population and GDP over the last three decades has resulted in heavy demand for water. The problem of population growth is particularly felt in the urban areas, due to rural-urban migration and growing urbanization. The domestic and industrial water demand in Malaysia is expected to triple over the next 50 years. Estimation based on doubling the per capita water consumption by 2020, predicts that water shortages will occur within the next 5 years.

In general, the efficiency of water consumption in Malaysia is low. The amount of water consumed by the agriculture, industrial and domestic sector are approximately 62%, 21 % and 17% of the total water resources, respectively (Table 1). Table 1 shows the water consumption of OECD countries, including Malaysia. As irrigation water is charged on a per-area basis rather than on volume used and is relatively cheap, there is little incentive for farmers to use the water efficiently. Not surprisingly, Malaysia consumed a big share of their water resources in agricultural sector (Table 1).

In Malaysia, there is also a high proportion of unaccounted water in urban water supply systems, as one quarter to one third of the domestic and industrial water is lost before it reaches the consumers. These losses are the result of leaks in the distribution systems and illegal connections.

With increased demand from population growth and industrialization as well as competing for diminishing water availability, the optimization of water utilization must be dealt by the government urgently, in order to move towards efficiency, effectiveness of use conservation and sustainability.

Waste water is also an environmental issue in Malaysia. The 9th Malaysia Plan intensifies research and development on reuse of sludge for industrial, agricultural and landscape purposes as well as wastewater.

2.3 Solid Waste Management

Due to growing population and increasing consumption, Malaysia generates waste at 19,100 tons per day. In Kuala Lumpur waste generation is about 3,000 tons a day and forecasts shows that this will increase each year. In 2007, about 7.34 million tonnes of solid wastes were generated in Malaysia, enough to fill up 42 buildings of the same size as the world-renowned Petronas Twin Towers (Bernama, 2006). Whilst recycling has almost drawn universal acceptance as a means of waste disposal, Malaysia's domestic recycling rate still hovers at a mere five per cent.

The disposal of solid waste has been solely through open landfills. At this rate, more sanitary landfills and incinerator plants are needed in the future to prevent water contamination and environmental pollution. Although land in Malaysia is seemingly abundant, taking more and more land to be used as landfills is simply not a sustainable solution to this growing problem.

Table 1 Water consumption in OECD countries and Malaysia

Country	Water Use Share in Agriculture (%) [2000]	Country	Water Use Share in Industry (%) [2000]	Country	Water Use Share in Domestic (%) [2000]
Ireland	0.0	Greece	3.2	Netherlands	6.1
Iceland	0.1	New Zealand	9.5	Portugal	9.6
Austria	1.0	Australia	10.0	Germany	12.4
Switzerland	1.9	Portugal	12.1	United States	12.7
Finland	2.7	Japan	17.9	Spain	13.5
United Kingdom	2.9	Spain	18.5	Finland	13.6
Sweden	8.9	Malaysia	21.1	Australia	14.7
France	9.8	Denmark	25.6	France	15.7
Norway	10.5	Italy	36.7	Greece	16.3
Canada	11.8	United States	46.0	Malaysia	16.8
Germany	19.8	Sweden	54.4	Italy	18.2
Netherlands	33.9	Netherlands	60.0	Canada	19.6
United States	41.3	Austria	63.9	Japan	19.7
New Zealand	42.0	Iceland	65.8	United Kingdom	21.7
Denmark	42.3	Norway	66.9	Ireland	22.6
Italy	45.1	Germany	67.9	Norway	22.7
Malaysia	62.1	Canada	68.7	Switzerland	24.2
Japan	62.5	Switzerland	73.8	Denmark	32.1
Spain	68.0	France	74.5	Iceland	34.0
Australia	75.3	United Kingdom	75.4	Austria	35.1
Portugal	78.3	Ireland	77.4	Sweden	36.7
Greece	80.5	Finland	83.7	New Zealand	48.5

3. Initiatives Towards a Cleaner Environment

The implementation of sustainable buildings in Malaysia will have to address major issues faced by the Malaysian construction industry, i.e. water conservation waste water reduction, energy efficiency and waste management. The Green Building Mission launched recently by the Malaysian Government is an indication of a promising effort to ensure sustainable production and delivery of the construction industry products to fulfill these demands.

The 9th Malaysia Plan (2006-2010) placed further emphasis on preventive measures to mitigate and minimise negative environmental effects, intensify conservation efforts and ensure sustainable development of depleted and renewable resources for a cleaner Malaysia.

The Malaysian Government is promoting and campaigning for the use of energy efficiency buildings like low energy case and zero energy case in demonstration buildings built for their own facilities. Their commitment to energy efficiency programme is further reflected in the development of Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings (MS 1525). Additionally, the government has also encourage the development and utilization of renewable energy whereby the Clean Development Mechanism (CDM) has been used to support the implementation of small renewable energy programmes (SREP).

The Ministry of Energy, Water and Communications of Malaysia runs the Water Conservation Awareness Campaign which is targeted to conserve 10% of water consumption by valuing it in reduction of domestic water usage by 10%. The government has started a campaign to construct green buildings. One of the suggestions being made is discouraging the use of treated water for washing cars, floors and gardening. As Malaysia received abundance of rain the collection of water through rain harvesting is encouraged. This untreated water is deemed to provide a better option for such activities (Bernama, 2006)

In addressing waste issues, the Government has focussed on the 3 R's principles - reuse, reduction and recycling of materials and promoting companies that undertake these activities. Meanwhile, the housing and local government is also drafting a master plan on solid waste management, which includes recycling campaigns, landfills and installation of incinerators. Eventually, waste reduction and recycling is no longer an option in Malaysia, but a necessity to protect both the environment and quality of life.

Guidance is needed in implementing these environmental measures and issues in buildings. The development of a building labelling system to take into consideration of these issues are described in the foregoing paragraphs.

4. Existing Sustainable Building Assessment / Labelling Systems

Sustainable Building Labelling Systems provide a common set of criteria & targets to achieve sustainable buildings. It also offers structured advice, including goals, strategies, and actions that are suitable for improving building performance. These systems also enable actors in the building industry to be more measured and accurate towards developing sustainable forms of designing, constructing and operating buildings. However, assessment systems vary with the requirements and priorities of the countries in which they were developed. After all, sustainability should be looked upon in the local context therefore for a fair evaluation and assessment of buildings, the system must address local issues. As assessment systems are unique for different countries, there has been considerable interest in developing robust and validated systems that can provide comprehensive performance assessments of buildings which encompass a broad range of physical conditions, cultural dimensions and environmental priorities occurring in different countries.

The development for a building assessment system/labelling system is crucial to address the issues mentioned in 2. and to guide sustainable development in Malaysia. As a first attempt, the Pro-tem Committee of The Malaysian Sustainable Building Council has focused on the development of an assessment system for new office buildings. Part of these development is described in section 4.

4.1 Comparison of Assessment Systems

Existing assessment systems namely, LEED (Leadership In Energy and Environmental Design, USA), BREEAM (Building Research Establishment Environmental Assessment Method, UK), SB Tool (Canada) and Green Mark (Singapore) were reviewed to study the respective scope of assessment, weights, scoring and reporting system. Of the four systems, Green Mark is the only one being developed within the tropical context. The information derived from these studies provide the basis for the development of an effective building assessment system in accordance to Malaysian requirements.

4.1.1 Scope of Assessment

Although many comparisons have been made by earlier researchers, this section is intended for summarising the important factors of the assessment methods and its relevance to the Malaysian context.

LEED (USA), BREEAM (UK), SB Tool (Canada) and Green Mark (Singapore) covered the essential critical criteria related to sites, resource use, ecological loading and indoor environmental quality (Table 2). Out of these systems, SB Tool is the most comprehensive, encompassing the broader context of sustainability which include social issues like amenities for the disabled and enhanced security measures as well as economic issues through life cycle costing (Ng, 2005). Security is an important issue addressed in current building development. The design and construction of safe and secure buildings continues to be the primary goal for owners, architects, engineers, and project managers.

LEED and Green Mark do not take into account of embodied energy. The absence of national database, made it difficult to precisely assess building life cycle environmental aspects, especially embodied energy (Scheuer and Keoleian, 2002). Buildings with short life spans will have relatively higher embodied energy compared to energy use during its operational service. Consequently, environmental impacts from construction work for buildings with shorter life cycle will be significant (Davies, 2001, SBCI 2007).The average lifecycle for Malaysian buildings varies from 30-40 years. Based on interpolation, from data by Jones 1998, the embodied energy of buildings with such lifecycle represents more than 20% of the energy used in its lifecycle.

Most assessment methods give credits for use of recycled materials in reducing environmental burdens. Although recycling saves landfill space, more energy may be used in the recycling process, producing negative impacts upon the air quality when compared to production from natural resources

SB Tool made substantial advances towards integrating LCA results and accepts input data for a very broad range of materials as part of its basic structure.

Amongst the assessment methods, BREEAM facilitates thorough studies on the life cycle environmental impact of buildings.

Table 2 Comparison of the scope of assessment between building Environmental assessment methods (Ng,2005)

SBTool	BREEAM	LEED	Green Mark
Scope of Assessment			
Site Selection, Project Planning and Development	√	√	√
Site Selection	√	√	
Project Planning			
Urban Design and Site Development	√	√	√
Energy and Resource Consumption	√	√	√
Embodied energy	√		
Operational energy	√	√	√
Renewable Energy		√	
Commissioning of building systems	√	√	
Materials use	√	√	√
Water use	√	√	√
Environmental Loadings	√	√	√
Greenhouse Gas Emissions	√		
Other Atmospheric Emissions	√	√	√
Solid Wastes	√	√	
Rainwater, Stormwater and Wastewater	√	√	√
Impacts on Site	√	√	√
Other Local and Regional Impacts		√	√
Indoor Environmental Quality	√	√	√
Indoor Air Quality	√	√	√
Ventilation	√	√	
Thermal comfort	√	√	√
Daylight and illumination	√	√	√
Noise and Acoustics	√		√
Functionality and Controllability of Building Systems	√	√	√
Efficiency of space utilization			
Design for maintenance of core functions during power outages			
Controllability	√	√	√
Long-Term Performance		√	
Maintenance of building envelope performance			
Flexibility and Adaptability			
Maintenance of Operating Performance		√	
Social and Economic Aspects		√	
Cost and Economics			
Social Aspects		√	
Others	Management	Innovation	Management
	Transport		Innovation

4.1.2 Weights

Weights assigned to building assessments imply priorities of the performance criteria, respective basic attributes and features within the system. A comparison of the weights between systems are not as straight forward for the scope of assessments between system might be different, although most are based on common fundamental principles. The fundamental principles of the Whole Building Design Guide (wbdg.org) for sustainable buildings were used to facilitate comparisons of weights. The 'Whole Building' Design uses the integrated design approach based on the following principles:

(i) Optimize Site Potential
(ii) Optimize Energy Use
(i) Protect and Conserve Water
(ii) Use Environmentally Preferable Products
(iii) Enhance Indoor Environmental Quality (IEQ)
(vii) Optimize Operational and Maintenance Practices

A comparison of the weights of the various systems based on these scopes of assessments are shown in Table 3. The weights for BREEAM, CASBEE, SB Tool and Green Globe shown in Table 3 were extracted from Howard (2005).

Table 3 Comparison of Weights

	TECHNICAL CONTENT						
	Optimise Site Potential	**Optimise Energy Use**	**Protect and Conserve Water**	**Use Environmentally Preferable Products**	**Enhance IEQ**	**Optimise Operational & Maintenance Practices**	**Others**
BREEAM	15%	25%	5%	10%	15%	15%	15%
CASBEE	15%	20%	2%	13%	20%	15%	15%
SB TOOL	15% 12.5%	25% 20.8%			15% 16.7%	15% 16.6%	30% 33.4%
GREEN GLOBES US	11.5%	36%	10%	10%	20%		12.5%
LEED	20%	25%	7%	19%	22%		7%
GREEN MARK	12%	35%	15%	5%	15%	3%	15%

It is evident that optimizing energy use is the most sought after in many assessment methods. The Green Globes (36%) and Green Mark (35%) top the list in making energy efficiency their priorities. Recent development reported that Green Mark has revised the energy efficiency requirements to 50%.

The requirements for Sites and Indoor Environment Quality (IEQ) share equal importance at second place, ranging from 12%-22% (Table 3).

The priorities given to optimize site potential is not unexpected as the construction of sustainable buildings starts with proper site selection. The location orientation, and landscaping of a building affect the local ecosystems, transportation methods, and energy use. Siting for physical security has also become a critical issue in optimizing site design. The location of access roads, parking and lighting are essential elements that must be integrated into the design for a sustainable development.

The IEQ remain an important element in all assessment methods for its significant impact on occupant health, comfort, and productivity.

In many parts of the world, fresh water is an increasingly scarce resource. Green Mark gives high scoring to water conservation measures.

The use of Environmentally Preferable Products contribute to improved worker safety and health and achievement of environmental goals. This would minimize life-cycle environmental impacts such as global warming, resource depletion, and human toxicity. LEED gives high priority in the use of environmentally preferable product.

Operations and maintenance considerations will contribute to improved working environments, higher productivity, reduced energy and resource costs. Materials and systems which reduce maintenance requirements, consumed less water and energy are cost-effective and will reduce life-cycle costs. SB tool, CASBEE and BREEAM give high consideration to these factors.

4.1.3 Reporting Systems

One of the criteria of an ideal environmental assessment method is the ability of the assessment method to communicate the results effectively across to the different groups of users.

LEED, BREEAM, Green Mark presents the building evaluation results in an overall score /label indicating the level of performance achieved. The scores of each performance category can also be determined by the number of credits achieved in each category

GBTool presented the performance scores of the various performance categories in graphical form in which the performance level above the minimum acceptable standards is clearly visible, therefore in a better position to communicate the results more effectively across to users.

5. Proposed Malaysian Sustainable Building Labelling System

5.1 Considerations

The participants developing the Malaysian Sustainable Building Labelling System comprise of academic, mechanical engineers, civil engineers, architects, design consultants, building developer and members of professional associations (Association of Architects, Institution of Engineers, ASHRAE) who are experienced in the building construction practices and construction of green buildings in Malaysia. The team agreed on the first attempt to develop a labeling system for new office buildings. The green buildings in Malaysia so far, only address energy efficiency measures, which is only one part of the entire sustainable building assessment criteria. This industry driven initiative was the result of the much publicised promotions on sustainable buildings at the regional conference in Kuala Lumpur (SB07 South-East Asia) and support from construction stakeholders.

Various aspects appropriate to the needs and its pertinence were considered when developing the labeling system. Some of the key points being considered in the development of the system and leading to decision making are listed below.

a. The actors who will use and apply the system
b. Organizations which are involved in the system's development / delivery
c. Organizations support and or endorsement of the system
d. Organizations which are involved in the system's development / delivery
e. Organizations support and or endorsement of the system
f. Scoring system
g. Range of building performance aspects that are covered
h. Scope of environmental issues does the tool cover?
i. Extent of system to cover strategies for achieving desired performance levels
j. Is the system easy to adopt and implement?
k. Is it easy (real and perceived) to conduct an assessment?
l. Is it easy to access and understand the results?
m. Time required to gather data and conduct an assessment
n. The perceived value to different actors
o. The kind of market recognition offered for certification
p. Transparency of the process and results
q. Do the inputs and outputs serve as an educational tool about environmental issues?
r. Does the tool communicate emerging concerns and issues?

5.2 Adapted System

LEED and Green Mark are most commonly used to assess buildings in Malaysia. LEED is globally known and provides a complete framework for assessing building performance and meeting sustainability goals. Likewise, Green Mark is favoured for its tropical context and simplicity and effectiveness in transforming the building industry towards sustainable development. The new proposed system is a hybrid with the performance criteria addressing local issues and requirements. The proposed scope of assessment and performance criteria are listed in Table 3.

Table 3 Proposed Performance Criteria for Malaysian Requirements

SCOPE OF ASSESSMENT	Performance Criteria
Sustainable Sites	site selection, transport, landscape and exterior design, sloping sites, intensive brown field treatment
Water Efficiency	Water reduction, wastewater technologies, rainwater harvesting
Energy and Atmosphere	energy efficiency, renewable energy, ozone depletion, calculation , design for tropical climate
Materials and Resources	construction waste management, building and material reuse, resource recycling,

	diverting construction waste away from landfill, certified materials based on local certification.
Indoor Environmental Quality	thermal comfort, indoor air quality, pollution control, daylight and views, minimum IEQ Performance and relevant to MS1525
Innovation and Design Process	Innovation in design, tri-generation and thermal storage

All standardisation and certification issues will be in reference to local / Malaysian requirement.

The proposed scoring structure comprised pre-requisites items for minimum performance levels. The performance criteria shall be weighted accordingly with priorities to local issues on energy, water, waste and indoor environmental quality.

The system is still under development and expected for completion and trial use soon.

6. Conclusions

Sustainability is always seen in the local context. The consumption of energy and water and waste reduction are amongst the major environmental challenges for the implementation of sustainable buildings in Malaysia. The establishment of a sustainable building labelling system will provide a complete framework for guiding building and construction towards environmental performance and meeting sustainability goals. In order to be effective, the labelling system must be developed in the local context. The proposed scope of assessments and performance criteria reflect the prioritised issues in Malaysia.

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SUSTAINABLE BUILDINGS IN THE TROPICS

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Summary

An integrated approach is required in designing sustainable office buildings so as to come up with an optimal solution that balances all the important issues that have to be addressed. Various strategies have been identified for office buildings in the tropics. Daylighting has been identified as a potential source of energy efficiency measure because daylight is abundant in the tropics for most of the hours. Air-tightness of buildings to reduce energy required for dehumidification and use of energy efficient office equipment to reduce plug loads are also addressed. Rainwater harvesting has also been identified as the most practical and economical method for providing alternative water supply to substitute potable water use in the tropics. In addition, the management of construction waste and use of sustainable building materials have also been outlined. Source control to ensure good indoor air quality through selection of healthy materials as well as regulating the ventilation rate to balance indoor air quality with energy efficiency are also important considerations. Heat Island Effect is a greater concern in the hot tropics because the outdoor temperature is higher than desired. The impacts of transportation energy associated with office buildings are also highlighted so that measures can be taken to reduce the ecological footprint of the buildings.

1. Introduction

Sustainability in a building is more than just energy efficiency alone. There are many other important issues that have to be addressed in order to make the building sustainable. Designing sustainable buildings is an integrated process where the relevant issues have to be considered hand in hand in order to come up with an optimal solution. For example, more greenery is encouraged as an approach to reduce the heat island effect but more greenery may require higher irrigation demand so plants must be carefully selected. Designing for energy efficiency calls for more airtight building but the indoor air quality should not be compromised and so on and so forth.

The focus of this paper is primarily on office buildings in the tropical climate with examples mainly drawn from Singapore and Malaysia

2. Energy Efficiency

Energy saving is without doubt the quickest, most effective and most cost effective manner for reducing greenhouse gas emission and for helping countries to meet their Kyoto Protocol target. Energy efficiency in buildings is one area where important savings can be made.

In the tropics, designing office buildings for energy efficiency is less complicated than that for buildings in the temperate climate. In the tropical climate, only cooling and dehumidification are required but not heating. Air-conditioning takes up about 60% of the total building energy consumption. In order to improve the energy efficiency of the building, the first and foremost task is to reduce the cooling load and this is done by keeping the heat and moist air out and reducing the internal heat gain.

2.1 Daylighting

In the tropics there is a lot of potential in utilizing daylight for improving the energy efficiency of buildings. The tropics enjoy an abundance of daylight throughout most of the hours. In Malaysia, for example, the average horizontal diffuse radiation is 15,000 lux or higher between 8 – 17 o'clock and only 350 lux is required for indoor office lighting. A proper daylighting design can therefore greatly reduce the electrical light usage in the perimeter zone of tropical office buildings.

Daylight is free of charge and therefore does not contribute to the energy consumption of the building as artificial lighting does. Moreover, daylighting has a higher lumen efficacy (i.e. carries less heat per light unit) than artificial fluorescent lighting – and can have more than double the lumen efficacy when spectrally selective glazing is used. Spectrally selective glazing lets visible light pass through and in turn reflects infrared and UV light out. Hence, the use of daylighting translates into a lesser heat load from lighting and consequently a smaller energy consumption for the chiller. Numerous studies have also shown that people working in daylit environments work more efficiently and experience an improved well-being. In other words, there are several benefits of using daylighting in buildings.

2.2 Air Tightness

In the tropics there are no requirements for ensuring air-tightness of the building envelope, presumably because the temperature difference between indoors and outdoors is not very great. However, considerable energy can be saved by ensuring an air-tight building envelope, so that the hot and humid outdoor air does not infiltrate into the air-conditioned zone. Substantial energy is used by the air-conditioning system to dehumidify the hot and humid outdoor air if it gets into the air-conditioned building. In addition, air-tightness is a pre-requisite for using desiccant heat recovery on the air system (refer to section 2.3)

2.3 Desiccant Heat Recovery of Air

In tropical Malaysia and Singapore, about 50% of the outdoor air humidity content is removed to achieve a comfortable indoor climate. The latent cooling of outdoor air intake is considerably higher than the sensible cooling. Desiccant heat wheels allow the recovery of about 60% of the total cooling energy (latent and sensible) for the fresh air supply. For an efficient desiccant heat recovery to take place it is necessary to have an air-tight building so that the return air (dry and cool) can be directed through the desiccant heat recovery wheel and does not dissipate through a leaky building envelope.

2.4 Energy Efficient Equipment

Another potential area for energy consumption reduction is in the area of equipment energy use. Equipment energy use (plug loads) constitute a very big proportion of energy use in a typical office building. The energy consumption can be easily reduced by choosing energy efficient equipment in the first place. For example, a laptop only consumes 15-35W of power as compared to a PC with LCD monitor which consumes 70-90w of power. In addition, energy efficient printers, photocopiers, fax machines etc should also be chosen. Proper control of the usage of the equipment is also another way of reducing energy use. The equipments should only be used when necessary and should be switched off when not in use or put into sleep mode when they are on standby.

It is obvious that the selection of energy efficient equipment and proper control of usage require the cooperation of the client. The importance of the selection of energy efficient equipment to be put in the building has to be communicated to the client right from the start because this will affect the total building energy consumption.

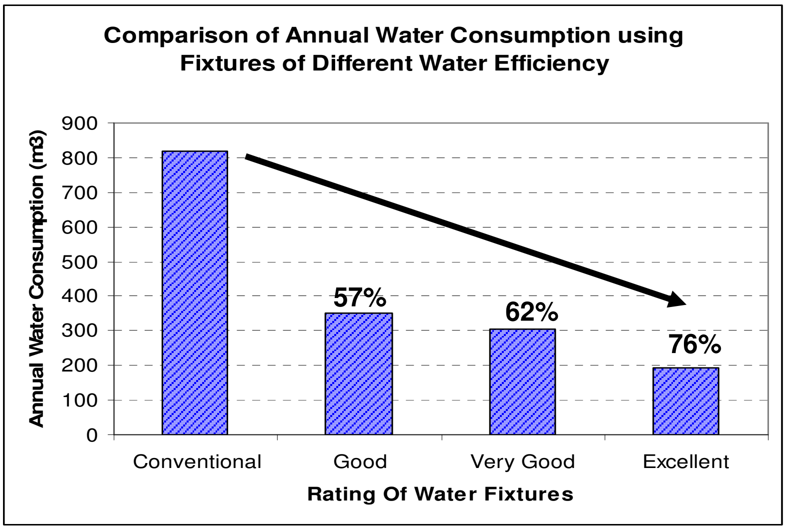
3. Water Efficiency

Other than energy resources, water is increasingly becoming a scarcity issue in many parts of the world, including Malaysia. Plentiful water resources in the past are no longer so in the context of modern water demand and increasing populations, industries and agricultural production. The cost of supplying safe and clean water is increasing and if this problem is not properly addressed, it could lead to a water crisis.

Sustainable water management principles need to be incorporated into the building. Sustainable water management means reducing the demand for water usage through the use of very water efficient fixtures and appliances where possible and identifying alternative sources of water supply to substitute the potable water use.

3.1 Water Efficient Fixtures

Increasing the efficiency of fixtures can lead to significant reductions in potable water demand from end users. In Singapore, the Public Utilities Board has launched the water efficiency labeling scheme for water fixtures. These fixtures include cisterns, taps, showers and urinals. The efficiency of the various fixtures are evaluated according to their flow rate. Figure 1 shows that 57-76% of potable water savings can be achieved when water efficient fixtures are used in the office building.



Note: Calculations based on flow rate specified in the different water efficiency rating from PUB, Singapore

Figure 1 Potable Water Savings from Use of Water Efficient Fixtures

3.2 Alternative Sources of Water Supply

3.2.1 Rainwater Harvesting

Rainfall is generally abundant in the tropical region and fairly consistent across the various months with occasional periods of drought. The average annual rainfall in Malaysia is around 2000 mm. Rainwater can be harvested from the roof or from other paved areas in the building.

3.2.2 Stormwater Harvesting and Management

Stormwater harvesting is the collection of water from the paved areas of the building. Stormwater harvesting helps to reduce surface runoff and relieve the load on the drainage system during heavy rain to lessen the possibility of flooding. Minimizing non porous areas will minimize surface runoff hence by having landscaped area helps to reduce surface run off and promote infiltration into the ground.

3.2.3 Greywater Recycling

Grey water is the wastewater collected from showers, sinks, floor drains which although no longer clean, is not as contaminated as toilet water (black water). By intercepting grey water before it goes to the septic tank or the municipal wastewater system, and providing some treatment (in certain cases, no treatment may be required) the water may be reused to irrigate plants. More complex treatment is required if the grey water is to be used for toilet flushing. Grey water from the kitchen sink is not recommended to be collected. This is because the grey water that comes from the kitchen sinks tend to contain more grease, oil and other food particles which will require a higher level of treatment to recycle the water.

3.2.4 Blackwater Recycling

Blackwater is the discharge from the toilet and the microbial contamination associated with blackwater means that the water needs to be treated to a very high level. This requires expensive technology like reverse osmosis.

3.3 Recommendations for the Tropics

Reducing the potable water demand should be the first step with the use of water efficient fixtures and promotion of user awareness. As rainfall is abundant in the tropics, rainwater harvesting is probably the most appropriate and perhaps less expensive alternative source to substitute the use of potable water for toilet flushing and irrigation.

4. Waste Management

Construction and demolition debris frequently makes up 10-30% of the waste received at many landfill sites around the world (Fishbein,1998). In the tropics, particularly the south east asian countries, recycling of construction and demolition waste is still not very widely practiced by the local contractors. In Malaysia, industrial and construction waste makes up almost 30% of the total solid waste generated. The recycling and reuse of construction and demolition waste can help to alleviate the pressure on landfills and natural resources. Waste minimization and avoidance must also cover the planning of the building such that wastes that are produced in the building during use can be separated and recycled.

4.1 Waste Reduction

The first step in a construction waste reduction strategy is good planning. Design should be based on standard sizes and materials should be ordered accurately. In addition, the use of high quality materials such as engineered products reduces rejects. The conventional construction method of extensive cast in-situ activities usually results in unnecessary waste hence new construction methods or technologies should be looked into. The adoption of prefabrication in construction is one way to reduce waste.

4.2 Re-use of Materials

Identify potential re-usable or salvageable materials from onsite or offsite sources. Re-usable or salvageable materials may include bricks, tiles, doors, windows, furniture, plumbing fixtures, steel etc. By re-using materials salvaged from demolition sites eliminates the need for new resources.

4.3 Recycling of Waste

For recycling of construction waste, the most important step is on-site separation. Initially, this will take some extra effort and training of construction personnel. Once separation habits are established, on-site separation can be done at little or no additional cost.

It is important to identify before recycling the waste, the people who will accept it. This helps to designate the type of waste to separate, and in making arrangements for drop-off or delivery of materials. Containers for material recycling must be set up on site and clearly labelled. Construction personnel must be trained in material sorting policy, and bins must be monitored periodically to prevent waste mixing as a result of crews or passersby throwing trash into the bins.

4.4 Waste Management Plan

A waste management plan has to be developed and should incorporate the following:

1. Types of waste materials produced as a result of work performed on the site
2. Estimated quantities of waste produced
3. Identification of materials with the potential to be recycled
4. Cost savings accrued by recycling rather than disposing of waste in landfills
5. On-site storage and separation requirements
6. Transportation methods
7. Destinations

5. Use of Sustainable Building Materials

Selection of sustainable building materials is one direct way of incorporating sustainable design principles into buildings. Selecting materials manufactured by environmentally responsible companies encourages their efforts at pollution prevention. In addition, by choosing products with recycled content (manufactured with post industrial or post consumer waste) helps to increase the resource efficiency of the building materials. The embodied energy content of recycled materials is much less than that of the virgin materials.

Sustainable materials should generally be non toxic, recycled and recyclable, obtained from local sources (to minimize transportation energy), durable and long lasting. Figure 2 shows an example of output from the BEES (Building for Environmental and Economic Sustainability) program developed by the National Institute of Standards and Technology in the United States. BEES is a program developed to help people select environmentally preferred materials. The output shows that it is better to choose the recycled PET(polyethylene terephthalate) carpet tiles over the nylon carpet tiles because the environmental performance of PET tiles is better even though the nylon carpet tiles were transported over a longer distance in the simulation. The BEES program is developed for use in the United States and may not be accurate for the other regions. There is currently no program developed for use in the tropics. However, as many materials might be imported from United States, BEES can still give us an indication of the performance between two alternative materials.

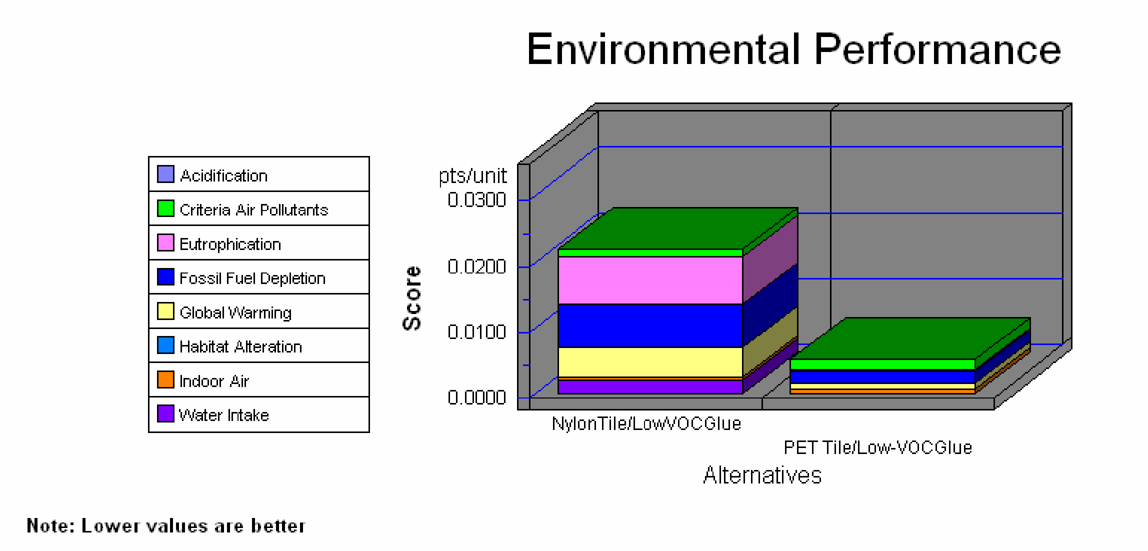


Figure 2 Selection of carpet tiles using BEES program (Example)

6. Indoor Air Quality

Indoor air quality (IAQ) has been increasingly gaining attention in office buildings due to its adverse effect on human health with the emergence of the Sick Buildings' Syndrome. The amount of pollutants in the office environment has a strong impact on IAQ performance as it can have an adverse effect on the health of the occupants. Source control for good indoor quality can be achieved by choosing healthy materials in the first place. Figure 3 shows that paints have great variation generally with high initial emissions that decay rapidly. Wool carpets have lower initial emissions but they persist over longer time. Particle boards have the lowest initial emissions but the decay is so slow that emissions can last for months or years.

To balance indoor air quality with energy efficiency, Carbon dioxide (CO_2) monitoring can improve indoor air quality and save energy when it is part of a demand control ventilation system. With CO_2 sensors connected to the ventilation system, the amount of fresh air supplied to interior spaces can be regulated to ensure that the CO_2 level does not exceed 1000 ppm (the threshold limit). More fresh air is supplied when there is increased occupancy demand, and when there are less people, ventilation will be reduced to reduce energy consumption.

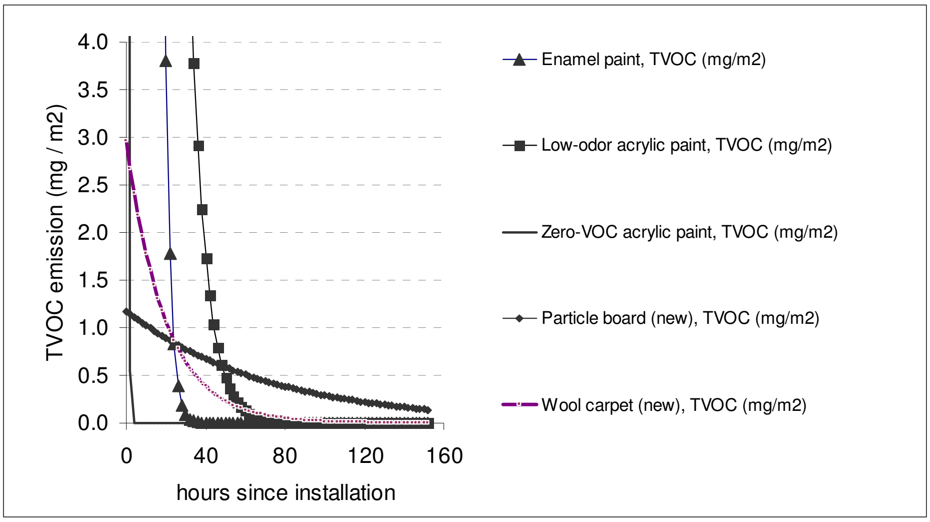


Figure 3 TVOC emissions from various indoor materials

7. Urban Heat Island Effect

Urban heat island is the built up of heat in the urbanized cities characterized with a higher temperature than the rural area. The high concentration of hard surfaces around the building could result in heat island effect due to the absorption of solar radiation by these surfaces in the daytime. This is a larger problem in the tropics because the outdoor temperature is already higher that what is preferred and any temperature increase in the cities is detrimental to outdoor comfort and also increases the cooling load.

Planting trees and vegetation is a simple and effective way to reduce heat islands. Trees and vegetation cool the air by providing shade and through evapotranspiration (the evaporation of water from leaves). A mature tree with 9m crown transpires approximately 150 litres per day and that corresponds to about 8000W of evaporative cooling or about 100W/m^2 of tree footprint. Shade reduces the amount of solar radiation transmitted to underlying surfaces, keeping them cool. Shaded walls may be 5° to 20°C cooler than the peak surface temperatures of unshaded surfaces. These cooler walls decrease the quantity of heat transmitted to buildings, thus lowering air conditioning cooling costs. Cooler surfaces also lessen the heat island effect by reducing heat transfer to the surrounding air.

Green plot ratio can be used as a measure of greenery provision in building developments since provision of greenery has been shown to be an effective way to reduce heat island effect. This ratio takes into the consideration the 3-dimensional coverage of the foliage by plants (Ong, 2003). Green Plot ratio is the average leaf area index (LAI) of the greenery on site and the LAI can be considered as the ratio of leaves to ground covered. The higher the green plot ratio, the larger the total area of leaves exposed to the sun as compared to the area of the ground itself. This reduces the ambient temperature because the plants are providing a lot of shade to the ground and they will also cool down the surrounding through evapotranspiration. The Green Plot Ratio is used as a rating criterion in Green Mark - a green assessment system developed by the Building Construction Authority of Singapore.

Another way to minimize heat island effect is to use high albedo surface materials. Materials that have a higher solar reflectance index help to reduce heat absorption. Solar reflectance index (SRI) is a measure of a material's ability to reject solar heat as shown by small temperature rise. Figure 4 shows the solar reflectance index of various roofing and paving materials (USGBC, 2005). It can be seen that darker materials generally exhibit low reflectance and consequently lower SRI. Lighter coloured materials have a higher reflectance and thus higher SRI which help to reduce heat absorption. However care must be taken to avoid glare from light coloured surfaces. High albedo materials are still not widely used in Malaysia and Singapore.

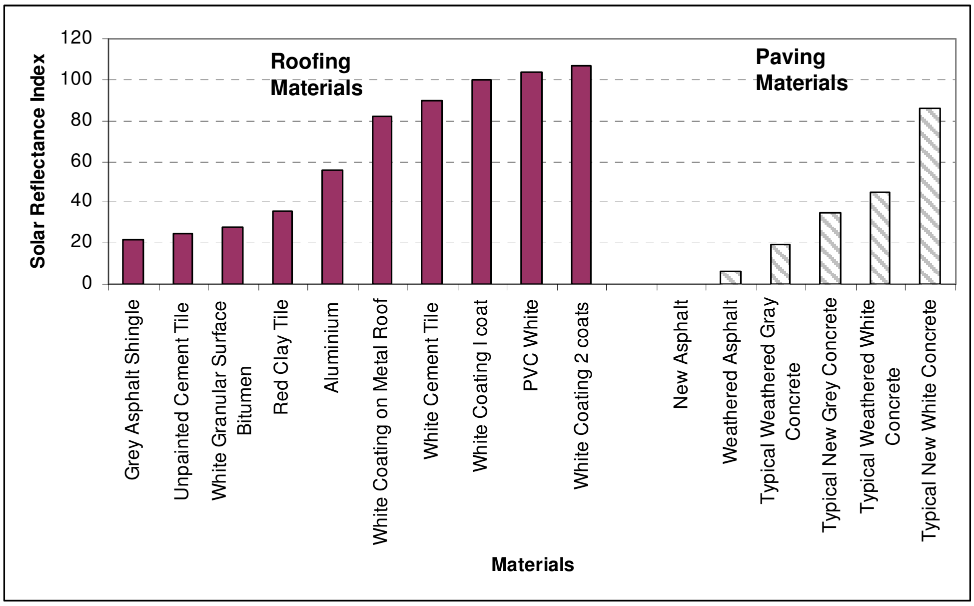
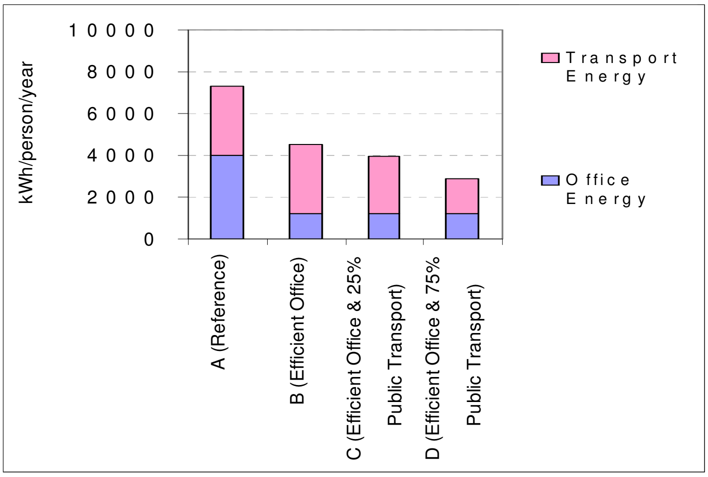


Figure 4 Solar Reflectance Index of Various Materials

8. Transportation energy

As buildings are designed to become more energy efficient, the energy required to transport the occupants of the building to their workplace becomes significantly larger in comparison to the building energy consumption. For a building to be considered sustainable, the transportation energy associated with the building has to be considered and reduced as well. Figure 5 shows the breakdown of energy consumption using a calculation example for buildings in Kuala Lumpur. The calculations were based on results of study conducted by CETDEM (2006). Figure 5 shows that for a reference building in Kuala Lumpur with an energy efficiency index (EEI) of 250kWh/m^2/yr, the transportation energy amounts to 80% of the total building energy consumption. As the building becomes more energy efficient (EEI of 80kWh/m^2/yr), the transportation energy is about 2.7 times as much as the total building energy consumption. If 25% of the occupants take the public transport, the transport energy reduces to 2.2 times that of the building energy. And if 75% of the occupants take the public transport, the transport energy is almost the same as that of the building energy. It can be seen that the total energy consumed in the building and commuting to the building (transport energy) decreases significantly if commuting energy use is reduced.

The accessibility of the building to public transport is very important in reducing the need to drive. Sometimes the location is not within the control of the developer, the building owner can come up with various strategies such as providing company shuttle bus, offering incentives for carpooling etc.



Note: Assume transportation is by private car and public transport is by bus

Figure 5 Breakdown of energy consumption (example from buildings in Kuala Lumpur)

9. Building Environmental Assessment Systems

Building environmental assessment system facilitate as an objective yardstick for buildings to be rated according to various environmental criteria. Although no single system is perfect, each developed environmental assessment system seeks to quantify the performance so that buildings can be compared to one another in terms of their environmental performance.

There are currently no building environmental assessment systems developed for the tropics except Green Mark from Singapore. LEED (from USA) and Green Mark (from Singapore) are being adopted in Malaysia currently since Malaysia has not developed their own systems (but doing so at present).

Points chasing has become a phenomenon associated with building environmental assessment systems. It is common for people to want to pursue easy and cheap points which might not bring the best benefits for the building. However, the fault does not lie with the systems but rather the practitioners. It is thus very important for the consultants who are advising the clients to indicate the various aspects that are best for the building in terms of performance and associated cost effectiveness. Some criteria might have a higher initial investment cost (e.g. energy efficiency measures) but if they have a good payback due to good operational savings for the client, it is important that the consultants recommend and justify the measures to be implemented. It is also important for the consultants to advise the client so as to ensure the delivery of a building that is well-balanced in all the sustainable aspects.

Nevertheless, building environmental assessment system is still an effective tool to ensure that sustainable measures are implemented in the building design. However, using systems developed in other countries is not optimal because the priorities vary in different countries. Hence it is still important to develop or adapt systems to the local context.

10. Business Case for Sustainable Buildings

Going sustainable does not have to be very expensive, be it in the tropics or other parts of the world. A preliminary study conducted by Building Construction Authority (BCA) of Singapore showed that the green cost premium of incorporating green features in the building according to Green Mark is less than 10% with a payback of less than 10 years. The study indicate that there is no great disparity in the payback periods between Green Mark certified and Green Mark Platinum as the greater cost of higher level of rating can generally be recovered back through energy and water savings. The study also indicates that the trend of the local green cost premium in Singapore is generally quite consistent with the findings of green buildings in United States. It can be expected that the green cost premium will go down in future when there is greater demand and wider adoption of green technology.

BCA Green Mark Award Type	Green Cost Premium (%)	Payback Period (years)
Platinum	2% to 8%	2yrs to 8yrs
Gold Plus	1% to 3%	2yrs to 6yrs
Gold	1% to 2%	2yrs to 6yrs
Certified	0.3% to 1%	2yrs to 5yrs

(Source: BCA, 2008)

Figure 6 Range of green cost premiums & payback period vs levels of certification

11. Conclusions

Designing for sustainable office buildings in the tropics is less complicated as compared to designing for one in the temperate climate. The hot and humid climate in the tropics meant that only cooling is required, hence the hot and moist air had to be kept out of the building to reduce energy required to cool and dehumidify. Daylighting is found to be underutilized in the tropics because people generally associate heat gain and glare with daylight entry into the building. However, a good daylight design using diffused light helps to reduce the artificial lighting load and consequently translate into a lower cooling load for the building. Occupants working in daylit environment are also found to be more productive. Attention also needs to be given to air-tightness of the building and the use of energy efficient equipment in the offices. As the tropics has abundant rainfall, rainwater harvesting should be implemented in buildings which not only help to reduce potable water demand for toilet flushing and irrigation, but also reduces storm water runoff to mitigate flood risks. It is a greater challenge to bring in fresh air into the building in the tropics because of the humid air. Hence to maintain a balance between ventilation and energy consumption, source control through proper selection of healthy and non-toxic indoor materials is important to introduce as little contaminants into the building as possible. Regulating the fresh air intake with CO_2 sensor is also advisable. In addition, proper waste management, use of sustainable materials, reduction of heat island effect and focus on reducing commuting energy are all important aspects of designing for a sustainable office building.

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SUSTAINABLE URBAN REGENERATION - A METHODOLOGY FOR URBAN SUSTAINABILITY

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ABSTRACT

The concept of sustainable development essentially calls for an integration of economic, social and environmental considerations in decision making. Yet, urban re-development activities over the last decade shows that most local re-developments were centered on economic initiatives and/or physical changes without given sufficient attention to social, environmental and community well-being. This is deemed a crucial reason for social dissatisfaction in the recent past over the people's objection to public sagas such as the on-going Queen Piers confrontation[4]. Further developments are at risk unless this conflict is addressed. Otherwise, this could lead to a huge loss of public resources, creating a human unfriendly urban environment; and badly affecting needs of future generations. Quantitative analytical tools such as CASET (Computer-Aided Sustainability Evaluation Tool) have been used by the planning authorities to evaluate the merits of proposed urban development projects. Apparently, these tools have overlooked the contribution and significance of public opinions that could overturn the success of a new proposal. The present study attempts to introduce a methodology, *i.e.* an integrated assessment approach, in which quantitative tools are supported by scenarios analysis (qualitative) with a built-in public participatory mechanism. This study will help to understand better the interrelated dynamics of ecology, economics and social values for an urban development and to identify policy interventions which could enhance human well-being, avoids conflicts of interest and thus saves resources immensely.

KEY WORDS

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[4] Queen's Pier, named after Queen Victoria, is a public ceremonial pier in front of City Hall in Edinburgh Place, Central, Hong Kong. Following the controversy and the demolition of the Star Ferry Pier in Central in early 2007, public/activists declared their dissatisfaction over the conservation policy of the Government of Hong Kong. The criticism received over its handling of the Star Ferry Pier caused the Government to propose the idea of a piece-by-piece relocation of the Pier to a new location on the reclaimed waterfront. Thus, the government was compelled to postpone the demolition of Queen's Pier until a consensus could be reached on the course of action.

Sustainability, urban development, CASET, quantitative, qualitative, public participation, integrated assessment.

BACKGROUND OF STUDY

With the strong tendency that world development continues to move in an unsustainable direction, the integrity of life support systems has come under an increasing threat (Swart et al., 2004). Since the seminal report of the Brundtland Commission (WCED, 1987), creation of physically and socially sustainable cities is considered as the global policy objective of the sustainable development. While there are different definitions of sustainable development (Robinson, 2003), the term sustainable development goes beyond the boundaries of science and business development and trade to include human development, values, and differences in cultures. Thus, it is very important to maintain resilience in environmental and social systems by meeting a complex array of interacting environmental, social and economic conditions (Swart *et al*., 2004). This suggests that there are three imperatives for sustainable development: the ecological, the social and the economic, which are increasingly interdependent.

Sustainable urban development design is essentially based on a multidisciplinary approach. Experts from different areas such as economic, environmental and social aspects need to work interactively and closely in order to achieve sustainability principles of a project. Put in differently, a wide range of different experts and institutions should be involved in the formulation and implementation of national sustainable strategies. Sustainability science therefore studies how the interactions, behaviors and emergent properties of combined natural and social systems works effectively, and provides decision makers with better advice about the effects of various forms of behavior or intervention (Swart *et al*., 2004).

However, in Hong Kong urban development and or renewal has been narrowly understood as the physical redevelopment of land (Ng, 1998). In 1980s, while the government's efforts for comprehensive redevelopment have not been successful, some individual piece-meal redevelopments have been carried out by the private sector (Ng, 1998). These developments were a result of a series of property booms (Yeh, 1990). Such developments by the private sector have often led to an inefficient use of land, with few improvements to community facilities (Todd, 1985). Moreover, these developments offer little chance to provide much needed public open space or community facilities and renders comprehensive redevelopment of the surrounding block problematic in future (Adams and Hastings, 2000). Clearly, effort by the government on redevelopment was very insignificant with minimal financial commitment (Ng, 1998).

In the global arena in the 1980s, public–private partnerships emerged as a significant part of urban policy; especially in both Britain and the United States (Barnekov *et al*., 1989; O'Toole and Usher, 1992). This international experience was thought relevant to tackling the growing urban problems in Hong Kong. Thus government authorities early in the 1980s decided to promote partnership between the private and public sectors through the establishment of Land Development Corporations (LDC) (Adams and Hastings, 2001). LDC was established with the aim of increasing efficiency of coordination and implementation of development schemes. LDC was supposed to have both the merits of private sector and public sector (Ng, 1998).

Public-private partnership approach in Hong Kong also has not brought the intended sustainability goals of urban development due to various reasons. First, LDC did not have control over developments and no legal power of land resumptions. Second, many of the LDC's development proposals put much emphasis on commercial viability with less emphasis on potential of social well being (Ng, 1998). Finally, the most important reason was the ignorance of public inputs into the developments. Goals and objectives of different actors (government, private sector developers and community residents) of the society need to be compromised in order to achieve sustainable development goals (Ng, 1998). But, the history of redevelopments in Hong Kong shows that public participation, which is the most important actor in the scene, has been ignored due to some reasons. Instead, urban re-development activities over the last decade were centered on economic initiatives and/or physical changes without given sufficient attention to social, environmental and community well-being. This has been the case even in most recent developments in Hong Kong. This is deemed a crucial reason for social dissatisfaction in the recent past over the people's objection to public sagas such as the on-going Queen Piers confrontation.

From the beginning, the fate of the pier has been intimately linked with the central reclamation project. Following the controversy and the demolition of the Star Ferry Pier in early 2007, public/ activists started to show displeasure over the conservation policy of the government. The main reason behind this controversy is the adopted unbalance approach towards urban development in Hong Kong. On the one hand, government authorities argue that being overzealous in saving the past may hurt Hong Kong's competitiveness, and urge activists to take a more balanced view between economic benefits and conservation. On the other hand, activists accuse authorities for not being able to adopt an approach giving sufficient attention to conservation and environment. However, one thing is sure. That is, further developments are at risk unless this conflict is acknowledged and addressed. Otherwise, this could lead to huge confrontations between the general public and authorities, which will hamper future development activities.

There has been a widespread recognition that it is a range of issues that lead to the decline of major urban centers as desirable or acceptable places to live. Whilst there has been some evaluation of initiatives and schemes, there has been no real attempt to benchmark urban regeneration activity (Nicholas, 2004). Thus, urban redevelopment process in Hong Kong is in need of a proper guiding framework which meets sustainable principles of urban development. Moreover, Hong Kong needs a workable redevelopment model that achieves the necessary balance between commercial and social priorities.

Reasons for not reflecting public views / desires in the process of urban development need to be addressed soonest. One possible reason might be that wrong methodologies or frameworks adopted in the decision making stage of the development (sustainable assessment stage), which might not properly reflect the public ideas and interest into developments. Especially, too much dependent and belief on the usage of quantitative techniques may have over looked public inputs into the development. The purpose of this study is to shed light on a new integrated assessment (IA) approach with a significant public participatory mechanism (qualitative approach) for sustainable urban development, with the goal of exploring prevailing sustainability issues behind urban development projects in Hong Kong. In other words, it introduces an integrated assessment (IA) approach, in which quantitative tools and models are supported by scenarios analysis (qualitative) with a built-in extensive public-participatory mechanism. The proposed approach unfolds the pros and cons of a sustainable planning methodology that relates closely with a public-participatory process.

COMPUTER-AIDED SUSTAINABILITY EVALUATION TOOL (CASET)

A number of countries have attempted to develop integrated sustainability assessment tools. In 2001, the Hong Kong government has developed a sustainability assessment (SA) system, called CASET, developed under the Study on Sustainable Development in Hong Kong for the 21st Century (SUSDEV21). CASET is supposed to assist Government in evaluating new strategic initiatives or major programmes from a sustainable development perspective. This tool is built upon 42 sustainability indicators and eight guiding principles (economy, health and hygiene, society and societal infrastructure, biodiversity, leisure and cultural vibrancy, environmental quality, mobility and natural resources). Its purpose is to promote the integration of sustainability principles into the government's decision-making process, through assessing the impacts of proposals on the economic, environmental and economic conditions of Hong Kong in an integrated manner.

The assessment is based on eight guiding principles covering economy, health and hygiene, natural resources, society and social infrastructure, biodiversity, leisure and cultural vibrancy, environmental quality and mobility, and 42 associated quantifiable indicators. These guiding principles look very specific and broader enough to cover up sustainability aspect of a project. It is required to assess the impacts of proposals against the relevant indicators (only the relevant indicators would be selected for assessment). Apart from these 42 quantifiable indicators, the assessment also requires to evaluate other non-quantifiable yet important considerations in the process to ensure that the assessment is comprehensive.

In summary, the steps of assessment system can be summarized as follows (see Figure 1 for the Flow chart for a detailed description of the process):

1. Figure out the objectives and assumptions of the proposal;

2. A checklist of simple "yes" and "no" questions covering economic, social and environmental implications of the proposal;

3. An assessment of the possible impact of the proposal (development) against each and every affected indicators;
4. Cross-check the validity of the outcomes and consider possible alternative options, if necessary;

5. Summarizes the key findings of the assessment process, which includes an SA diagram to illustrate the positive and negative implications of the proposal.

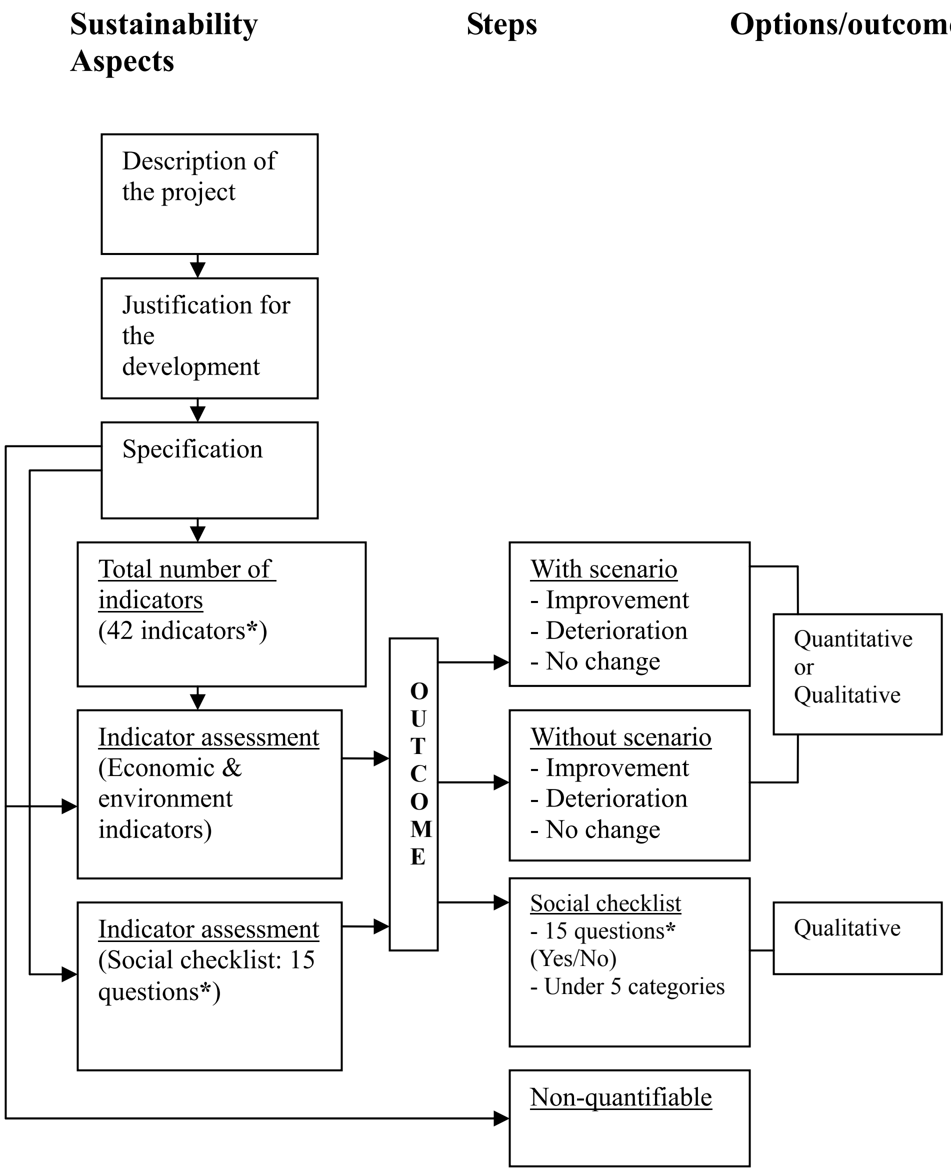


Figure 1: Flow Chart of the CASET

Note: *Pre-set indicators

Table 1: Summary of Sustainability Assessment Results (Hypothetical)

Indicator	Without Scenario	Variation 1
Carbon dioxide emitted per year	☒	☒☒
Construction Waste	❍	☒
Cost-Benefit	❍	☑☑☑☑
Criteria air pollutants	❍	☒
Energy consumption	□	(
Excessive noise	((	□□
Fixed capital	□	□□□
Freight costs	☒	☑☑
Freshwater supplied and consumed	❍	☒☒
Income differential	☒	☑☑
Landfill capacity	❍	☒
Local freshwater	❍	❍
Marine water quality	❍	☒☒
Municipal Waste	❍	☒☒
Open space shortfall	☒☒	☑☑☑
Significant Landscape Features (Area)	❍	☑☑☑
Significant Landscape Features (Point)	❍	☑☑
Toxic air pollutants	❍	☒
Travel distance	❍	☑☑
Travel speed	❍	☑☑
Unemployment Rate	❍	☑☑☑
Social Checklist		
Equal opportunity	❍	☑☑
Social cohesion	❍	☑☑☑
Physical/mental health	☒	☑☑
Leisure and cultural facilities	☒☒	☑☑☑☑☑
Leisure and cultural activities	❍	☑☑☑☑☑
Archaeological/historical sites	❍	☑☑☑

First SD Strategy Checklist		
Renewable Energy	❍	☑

Legends

❍ Annotates no change to the current baseline situation

	Very Small	Small	Moderate	Moderate to Large	Large	Very Large
Improvement	☑	☑☑	☑☑☑	☑☑☑☑	☑☑☑☑☑	☑☑☑☑☑☑
Deterioration	☒	☒☒	☒☒☒	☒☒☒☒	☒☒☒☒☒	☒☒☒☒☒☒

Note: not all the indicators (42) have been included in this hypothetical example

Limitations of CASET

According to CASET, sustainability assessment (sustainability performance) is presented with scenario and without scenario. Both of them have been assessed against the baseline situation as recorded in the CASET. It should be noted that these baselines are derived based on the whole territorial figures, and not project specific. So here we compare project specific values against the overall territorial values, which itself is a controversial issue in the CASET. The summary of the sustainability assessment of the project is presented in the form of a table such as in Table 1. Accordingly, as shown in the table, very large improvement to current baseline situation is indicated through larger number (6 in this case) of '☑', while very large deterioration to current baseline situation is indicated through larger (6 in this case) of '☒' s.

However, there is a reasonable doubt that the CASET is able to absorb the social-human aspects in the assessment. CASET needs all qualitative variables to quantify in some form in its assessment, which is not an easy task and also not a sensible thing. The other important thing is that the outcome of the assessment is highly subjective: outcome may be manipulated or an arbitrary one. Unless parallel effective public participatory approach is adopted, the outcome may be biased in favor of the assessors.

However, there are some advantages of CASET as well. CASET can be used as a guiding mechanism and it is a good starter for a sustainable analysis. It will also help to analyze and discuss advantages and disadvantages of some quantitative aspects of a project.

INTEGRATED ASSESSMENT (IA) APPROACH - SCIENCE DRIVEN APPROACH TO SUSTAINABLE DEVELOPMENT

In a recent study, Swart *et al.*, (2004) emphasized the integration of science and scenario analysis in addressing the challenge of sustainability science, especially the core question of how to scan the future in a structured, integrated and policy-driven manner. In the literature, there have been many attempts to define IA. In one of them, integrated assessment (IA) is defined as

> "an interdisciplinary process of combining, interpreting and communicating knowledge from diverse scientific disciplines in such a way that whole cause-effect chain of a problem can be evaluated from a synoptic perspective with two characteristics: (i) it should have added value compared to single disciplinary assessment; and (ii) it should provide useful information to decision makers" (Rothmans and Dowlatabadi, 1997).

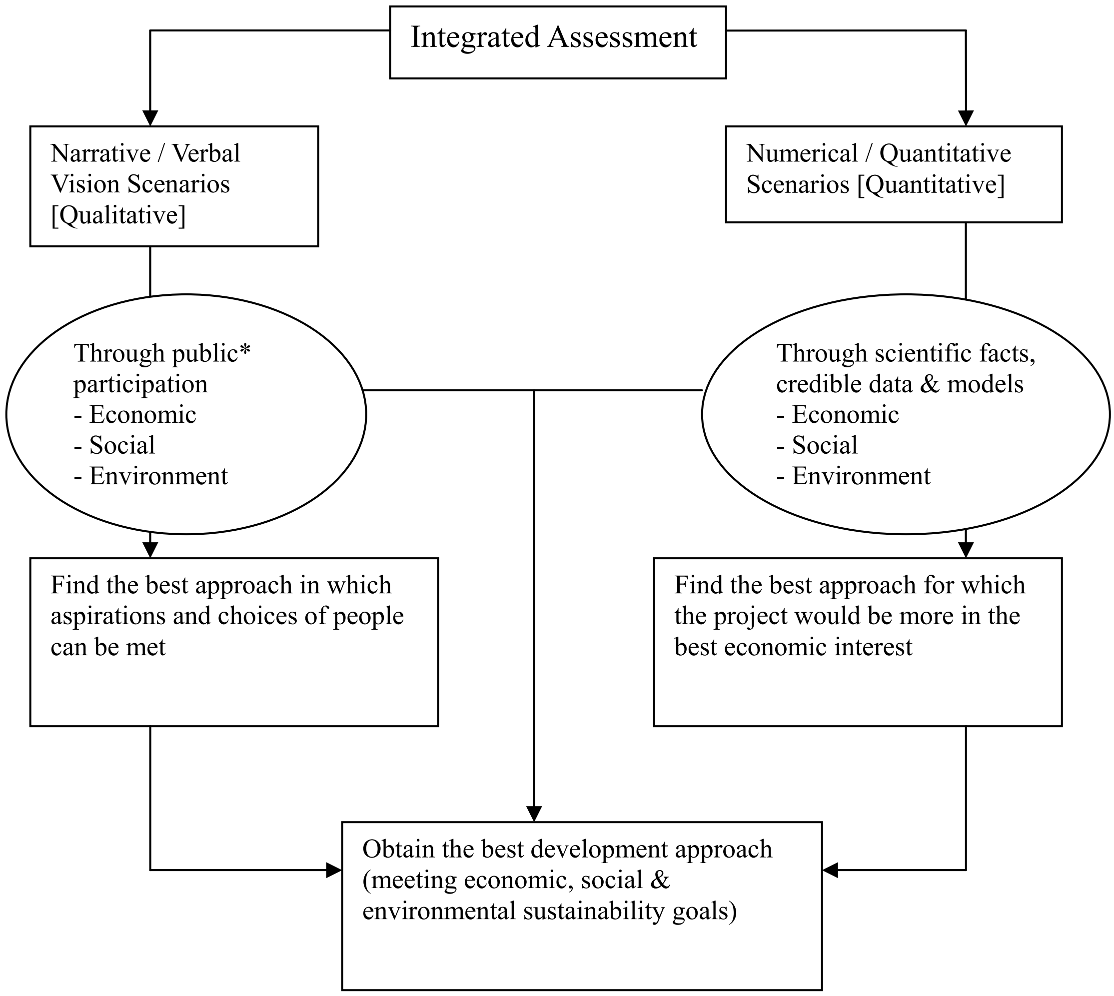
Therefore, IA is an effective mechanism that combines knowledge (science) and action (policy) in an effective way. While the link between science-driven research activities and sustainability policy development remains weak (Cohen *et al*., 1998), the call to strengthen the contribution of science to a sustainability transition has grown louder (Raven, 2002). Recently, Kates *et al*., (2001) proposed a framework for an emerging sustainability science for generating useful knowledge to support a transition to sustainable development. Integrated assessment is such an evolving field of research area, which is located in a territory between science and public policy (Tansey *et al*., 2002).

On the other hand, IA approach is typically of a more experimental character than traditional predictive approaches (Tansey *et al*., 2002), which is not based on present assumptions about choice and behavior of people. IA approach is seen to be capable of accommodating dynamics and fundamental character of interactions between nature and society.

Integrated assessment (IA) could accommodate a multitude of factors - conceptual (verbal), relational (models) and numerical (data) - that can be inter-linked in a logical manner. Broadly, it integrates two complementary components: verbal vision scenarios (narrative scenarios/qualitative analysis) and the use of numerical assessment models (quantitative analysis) (Figure 2). Lack of one or the other renders an IA analysis incomplete.

IA approach needs both ends to take effectively into consideration. On the one hand, it needs to explore possible alternative ways of the project based on scientific knowledge. Unless the alternative futures presented are documented as feasible and solidly taken into account based on scientific knowledge they will lack the required credibility. On the other hand, it also needs inputs from the public. Incorporation relevant values, perceptions and choices of societal actors about the future into research process are necessary to accommodate forms of knowledge normally not considered by analysts (Swart *et al*., 2004). Otherwise, it would miss aspiration of people into the development. If they are based solely on aspects of reality which can be illustrated through computer models and in numerical forms, they will not address important factors of society, political and individual aspirations and choices.

A METHODOLOGY FOR SUSTAINABLE URBAN DEVELOPMENT



*Public: representatives of NGOs, experts, government institutions, and the wider public

Figure 2: Relationship between qualitative and quantitative scenarios (Integrated Assessment Approach)

Therefore, what we need is an approach which can combine quantitative and qualitative analyses to elevate non-quantifiable cultural, institutional and value aspects of the society to avoid limiting the analysis to quantifiable aspects which are not necessarily the most crucial. Such an approach will make sustainability science more relevant to policy development and action through stakeholder participation (Swart *et al.*, 2004).

In an IA approach, scenario analysis (SA) plays an important role. SA helps to explore or identify a range of possible alternatives/futures in order to assess their desirability or feasibility. On the other hand, SA will help to understand better the inter-related dynamics of the economic, ecological and social systems, which is the most important issue in dealing with sustainability problems. This understanding is needed in order to identify policy interventions which could enhance human well being, while softening the adverse environmental effects of human activities. It ensures that the project achieves some measures of political and social relevance. Thus, the process to the development of the IA approach is very important. Scenario development is a result of the interaction between the choices of users and opportunities and constraints framed within the 'possibility space' created by the design approach to the modeling (Tansey *et al*., 2002). Scenario development process requires user input to make choices about possible alternative development paths of a project.

It shows that 'space' which the development model (methodology) is based on extends beyond domain of one discipline. It extends to a wider social context within which decisions are made. This indicates that design process of the methodology of sustainable development is a non-trivial exercise, and is a must in order to improve the quality of outcomes. Consequently, a significant effort should be made to research and develop an appropriate methodology encroaching aforesaid areas and disciplines in order to meet goals of sustainable development.

Advantages of IA

a) IA is based on a multidisciplinary sphere. It reaches beyond the bounds of a single discipline and address more than one aspect of the problem under consideration (Tansey *et al*., 2002).

b) It has a central purpose 'to inform policy and decision-making, rather than to advance knowledge.

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c) In Hong Kong, present ways of consumption and living have led to problems like the overuse of ecosystem destruction, urban heat islands, pollution, growing inequality in cities and the degradation of human living conditions. Thus, Hong Kong has a special need to adopt an approach such as IA.

d) There is a greater role for public stakeholders in IA for both substantive and procedural reasons (Tansey *et al*., 2002).
   - Stakeholders may have a substantive role to play in providing context specific 'local' knowledge to researchers
   - Since stakeholders are likely to be affected by the policy under consideration in an IA exercise, they have an important procedural role to play
   - Thus, more relevant and effective policies can be designed through stakeholder participation and that they will be more successful in the implementation phase as a result.

e) IA – including new participatory and problem-oriented approaches – provides a powerful tool for integrating knowledge, scanning the future in an organized human choice into sustainability science (Tansey *et al*., 2002). Integrated assessment analysis is a process of analyzing possible future events by considering alternative possible outcomes (scenarios). The analysis is designed to allow improved decision-making by allowing more complete consideration of outcomes and their implications

CONCLUSION - EXPECTED OUTCOMES OF THE STUDY

- This methodology will lead to generate a planning mechanism/framework (a set of sustainable guidelines) that enhances sustainable development / redevelopment. It will help decision makers with better advice about the effects of various forms of behavior or intervention in the society.

- This framework will help to guide urban redevelopment process and facilitate comprehensive approach for urban renewal in Hong Kong SAR. Broad guidelines which may be considered as an alternative or supplementary framework to prevailing quantitative techniques may be derived from this methodology.

- This methodology would benefit the society with saving public money as it may suggest the best development approach for which the project would be in the best interest of Hong Kong (best way of investing resources in developments).

- The problems of uncertain futures and conflicting values can be managed through an essentially societal process, in which the computer models and quantitative techniques are tools for guiding discussions (Tansey *et al*., 2002). Present study/methodology will lead to produce a research methodology to operationalise precisely this kind of vision for the future of IA through combination of quantitative techniques and models and qualitative participatory approach.

- The policy implications that may be derived from this methodology will enable researchers to explore a number of critical research themes:

  - the role of quantitative techniques including computer models as a mediator between scientific and civic cultures
  - the role of hybrid process that combine expert analytical methods with participatory approaches in the context of policy development (Tansey *et al*., 2002).

Future research work
An extensive discussion and review / analysis will be carried out using this methodology based on a mini-case study focusing a past development project in Hong Kong.

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INTELLIGENT APPROACH TO ARCHITECTURAL DESIGN FOR FIRE SAFETY

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Summary

The Computational Fluid Dynamics (CFD) techniques are currently widely adopted to simulate the behaviour of fire. The major shortcoming of the CFD is the requirements of extensive computer storage and lengthy computational time. In actual applications, although comprehensive field information of velocities, temperature, pressure, fraction of different constitutes etc. can be obtained from the CFD simulation, the user may be only interested in few important parameters which index the performance of the compartment design in the event of fire. Height of thermal interface (HTI) is one of the key indices. It is the average height above the floor level inside the fire compartment at which the temperature gradient is the highest. In practice, the fire compartment is considered untenable when the HTI descends lower than the respiratory level of the occupants. In the course of fire system design optimization, a series of CFD simulations is required for the parametric study. This approach is theoretically feasible but requires lengthy computational time. This paper proposes to apply Artificial Neural Network (ANN) approach as a fast alternative to the CFD models to simulate the behaviour of the compartment fire. A novel ANN model denoted as GRNNFA has been developed particular for fire studies. The GRNNFA model owns the features of removal of the noise embedded in the experimental fire data. It has been employed to establish a system response surface based on the knowledge of the available training samples. Since the available training samples may not be sufficient to describe the system behaviour especially for fire data, it is proposed to acquire extra knowledge of the system from human expert knowledge. The human expert intervened network training was developed to remedy the established system response surface. After the transformation of the remedied system response surface to the problem domain, Genetic Algorithm (GA) is applied to evaluate the close optimum set of the design parameters.

1. Introduction

Currently, the CFD is the most widely adopted approach to simulate the behaviours of fire systems. It is a sophisticated and useful technique to evaluate the behaviours of the systems. The CFD model divides the domain of a system into finite numbers of small volumes. The nonlinear system behaviour of the fire system is determined by solving a large set of differential equations describing the interactions between the small volumes. Extensive iteration steps and large size of matrices are usually involved in the CFD computation. The major drawback of the CFD is the requirement of extensive computer storage and lengthy computational time. Also, the results predicted by the CFD are flow field information of all small volumes (e.g. velocities, temperature, pressure, mass fractions of different species, etc.). These numerical results are still required to be further manipulated (i.e. post-processing) for telling the user the performance interpreted from the CFD simulation results especially when the user is not an expertise in fire. One of the examples is the height of the thermal interface in a single compartment fire. Even though the temperature field has been obtained from the CFD simulation, the field data is still required to be post-processed to determine the height at which the average temperature gradient is the highest.

Currently, ANN techniques were only applied to fire detection system. Many studies have confirmed the applicability of the ANN techniques to fire detection system. The superior performance comparing to other traditional models have also been addressed. However, application of the ANN techniques to determine the consequences of fire is still very limited. Lee et al. (2000) applied Feedforward MLP model for determination of sprinkler actuation. The prediction results are comparable to zone models. The FAM was employed by Lee et al. (2001) to determine the occurrence of flashover. The highest rate of correct prediction was determined to be 97.6%. Lee et al. (2002) have also developed a probabilistic inference engine (PEMap) based on the theories of maximum information entropy for treating the uncertainties embedded in fire data. It was also applied to determine the occurrence of flashover. The results show that the performance of the PEMap is competitive to the FAM but with a comparatively simple network structure and working mechanism.

These pioneer works have confirmed the applicability of the ANN techniques in determination of fire consequences.

A novel ANN model denoted as GRNNFA (Lee et al., 2004a) has been developed particularly for prediction of compartment fire. It has been proven to be a rapid alternative to the CFD simulation for predicting the height of the thermal interface in a single compartment (Lee et al., 2004b). The high speed computation of the GRNNFA facilitates the formulation of a soft computing based optimization model.

The next section of this paper introduces the development of a novel hybrid ANN model, denoted as GRNNFA, which was designed particularly for fire studies. The novel approach of network training by employing human expert intervention is also introduced to remedy the system response surface created by the GRNNFA model. Then, the optimization model by GA is also illustrated.

2. GRNNFA Model with Human Expert Intervened Network Training

2.1 Development of the GRNNFA Model

The structure of the original GRNN model developed by Specht (1991) is self-determined. Every sample presented to the GRNN is recruited as a kernel and stored inside the network. However, large set of kernels is resulted if the batch of the training samples is large. Specht (1991) proposed to introduce a clustering process to compress the total number of training samples to fewer number of kernels. Different clustering approaches for reducing the number of kernels of the GRNN model were proposed. The major shortcomings of the clustering schemes are the requirement of predefinition of number of kernels prior to the clustering process. The investigations Carpenter et al. (1991) and Moore (1989) also reveal the instability of these clustering models by using Euclidean distances for the similarity measurement. On the other hand, the FA (Carpenter et al., 1991) with guaranteed convergence in network training has been proven to be stable. As a result, the FA is used for clustering the training samples incrementally and stably into fewer numbers of kernels in the GRNNFA. The basic architecture of the GRNNFA model is shown in Figure 1.

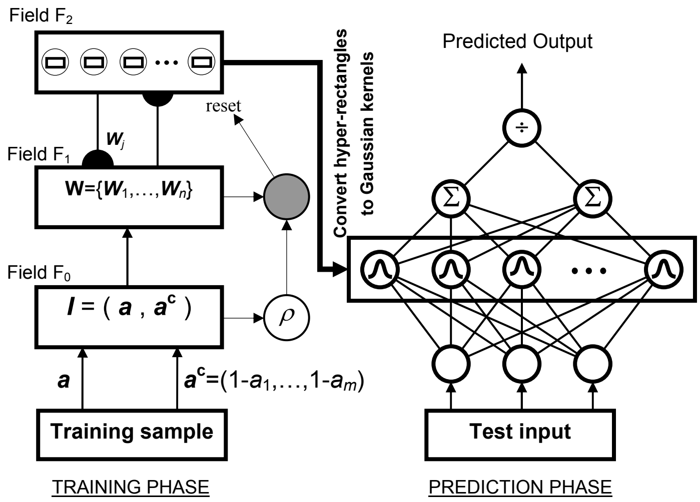

Figure 1 Architecture of the GRNNFA model

2.2 Human Expert Intervened Network Training

Most of the intelligent systems are designed to minimize the human intervention in network training phase for the purpose of automation. The knowledge of the system is solely recruited from the available training samples. However, when the number of training samples is limited, especially for the fire data, the knowledge recruited from the available samples may not be sufficient to describe the system behaviour. Human expert experience can provide the information missing from the limited training samples. It is proposed to simplify the prediction model by putting part of the nonlinearity of the decision action back to the human brains. Similar idea was successfully applied by Iba and Mimura (2002) to gene regulatory network by interactive evolutionary computing. The idea of applying the human intervention to ANN model is proposed. If the training samples are limited in size, human expert intervention is considered as the only way to further improve the performance of the prediction model. The human expert intervention facilitates the modelling of the expert knowledge into the system which can also be considered as a supervised tuning of the system to the 'preferences' of the expert. The trained model not only captures the system behaviour from the limited samples but also recruits the expert knowledge into the network. The human expert intervened network training algorithm consists of the following generic procedures:

a. Historical data of the system is recruited as training samples for network training.
b. The GRNNFA model is trained by the available training samples. A system response surface is created to represent the knowledge of the training samples.
c. Human experts are invited to examine the established system response surface and identify any 'defective' location at the surface.

d. If a defective location is found, CFD simulation will be carried out to create an extra sample at that location. It provides an extra knowledge of the system for further network training.
e. The GRNNFA model is trained again with the presence of the extra samples. The system response surface is hence remedied.
f. Repeat step c. to e. until the human experts satisfy the remedied system response surface.

3. System Design Optimization by Genetic Algorithm

The last section illustrates the approach of establishing the system response surface. This system response surface, according to the objective of the design optimization (i.e. the objective function), is transformed to the problem domain. GA can be applied on the transformed surface to arrive a close optimum solution. The genetic algorithm (GA) is a evolutionary optimization approach developed on the basis of the natural selection theory as described in the book of ‘On the Origin of Species by Means of Natural Selection or the Preservations of Favoured Races in the Struggle for Life’ written by Darwin (1859). Holland (1975; 1992) developed an algorithm to apply the natural selection theory on genetic chromosomes which is a string of Deoxyribonucleic Acid (DNA) of which four basic blocks are included (i.e. ‘A’, ‘T’, ‘G’ and ‘C’). In the traditional binary coding of the GA, the basic blocks are ‘1’ and ‘0’. Crossover and Mutation are the two basic operators developed from biological theories. They are used for breeding new chromosomes from one generation to the next generation. In each generation, the ‘best fit’ chromosomes are selected as parent chromosomes for breeding the next generation. The overall design optimization approach is described as follows. The GRNNFA creates a system response surface from the collected samples. During the network training, human expert knowledge is adopted to remedy the response surface. GA optimization is then applied to achieve the close optimum design parameters.

4. Applicatoin of the GRNNFA-GA Optimization Model

This section demonstrates the application of the GRNNFA-GA optimization model for determination of door width of a fire compartment. The fire experimental data for the GRNNFA model training was extracted from Steckler et al. (1982) experiments. It is a set of full scale steady state experiments of flow induced in a single compartment fire. A total of 55 experiments were performed that included different fire locations, fire intensities and window and door sizes. The height of the thermal interface was estimated from the room temperature profile data as the position of rapid temperature change between the lower cold layer and upper hot layer of the compartment. Owing to diffusion and mixing effects of the fluid flow, the thermal interface height could not be determined precisely. It was ascertained that the interface height could only be achieved within a range of ±8% to ±50% accuracy (Steckler et al., 1982). The values of the interface height recorded in the format of mean ± error were used to compare the GRNNFA predictions.

4.1 System Response Surface Establishment

Different controlled parameters were varied to result different measurements. Table 1 summarizes the parameters and measurements. The HTI was chosen to be the target output of the GRNNFA model. Since there are only total 55 numbers of samples available, the bootstrapping technique was adopted to evaluate a statistically justified prediction results. The value of K of the kNN and the vigilance parameter of the GRNNFA model were set to be 2 and 0.92 respectively

Table 1 Controlled parameters and measured results of the Steckler et al. (1982) Experiment

Controlled parameters	▪ Width of opening ▪ Height of the sill of the opening ▪ Fire Strength ▪ Distance of fire bed from the front wall ▪ Distance of fire bed from the centerline ▪ Ambient temperature
Measurements	▪ Air mass flow rate ▪ Neutral plane location ▪ Height of the thermal interface ▪ Average temperature of the upper gas ▪ Average temperature of the lower air ▪ Maximum mixing rate ▪ Air velocity profile at opening ▪ Temperature profile at opening

4.2 Human Expert Intervened Network Training

The above procedures established the system response surface the GRNNFA and the training samples adopted from Steckler et al. (1982). The system behaviour of the height of the thermal interface has been validated. In this step, the human expert intervention is involved in the network training. Five different cases which are unseen from the training samples were examined by the human expert. The five cases and the original sample distribution are shown in Figure 2 and Figure 3 respectively.

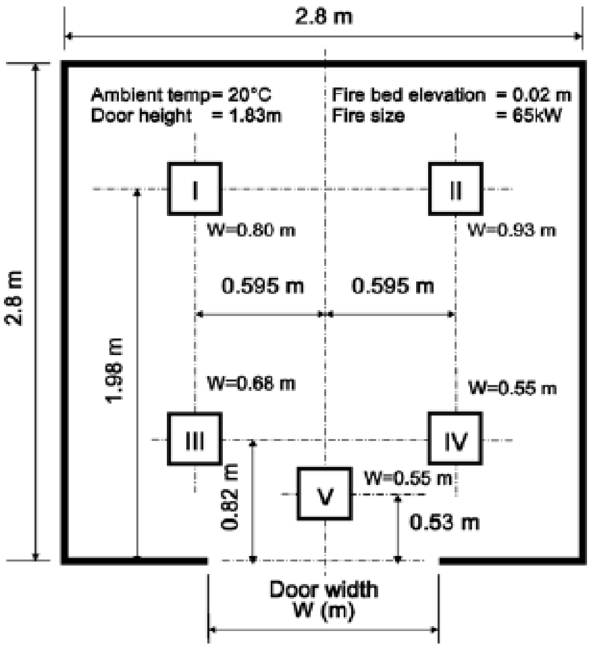

Figure 2 Distribution of the five cases to be examined by the human expert

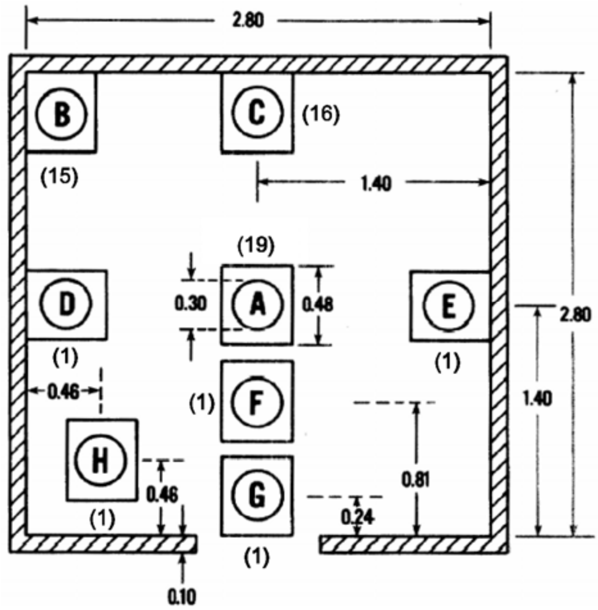

Figure 3 Distribution of the original samples in Steckler et al. (1982). Numbers of samples at the different locations are bracketed

The trained GRNNFA model was applied to the five cases to predict the corresponding HTIs. The predicted results are shown in Table 2. According to the validated conjectures which are considered as the human expert knowledge, the HTIs of the five cases should be ranked as: HTIII > HTII > HTIIII > HTIIV > HTIV. However, Table 2 gives a different ranking: HTIII > HTII > HTIIII > HTIV > HTIIV

The original data distribution is shown in Figure 3. The bracketed values shown in the figure indicate the number of samples in each fire location. It is seen that majority of the samples are located at ‘A’, ‘B’ and ‘C’. Comparing to the five test cases, test case I and II benefit from these samples.

For test case V, although most of the samples are remotely away from this location, there are still two samples (i.e. locations ‘F’ and ‘G’) contributing their knowledge to this fire location. For case III and IV, they receive less benefit from the remote samples. However, there is a sample at location ‘H’ contributes to case III. Although this sample also contributes to case IV (mirror at the center of opening), the door width of this sample (i.e. 0.74m) is closer to case III (i.e. 068m) than case IV (i.e. 0.55m). It was proven by Lee et al., (2002) that the accuracy of prediction is significantly affected by the data distribution density. This particularly applies in the knowledge distribution in the experimental results of Stecker (1982). Since the data distribution density at test case IV is less than that at test case V, it can be concluded that the available samples are not sufficient to describe the system behaviour at the test case IV.

Table 2 The HTIs of the five cases predicted by the GRNNFA

Case	Distance from door center (m)	Door Width (m)	HTI (m)
I	2.067	0.80	1.207
II	2.067	0.93	1.225
III	1.013	0.82	0.954
IV	1.013	0.55	0.897
V	0.530	0.53	0.913

An extra sample was created by applying CFD simulation on test case IV. Fire Dynamic Simulator (FDS) (McGranttan et al., 2000) was employed. The predicted HTI was 0.992m. The GRNNFA was re-trained by the original 55 numbers of samples together with the extra sample created by the FDS. The re-trained model is denoted as GRNNFA*. Figure 4 shows the ranking of the HTIs of the five test cases before (i.e. GRNNFA) and after (i.e. GRNNFA*) the network re-training. The error envelop indicated on Figure 4 was estimated by the FDS simulations on the five test cases with the minimum error range of the HTI as indicated on Steckler et al. (1982) incorporated. It shows that the network re-training with the extra sample drags the case IV back to fall within the error envelop. In fact, other cases has also benefited from the re-training since they have also been moved closer to the center of the error range. The above example demonstrates the remedy of the system response surface by the human expert intervened network training. The human expert knowledge was not required to be quantified but employed for identifying the defective location of the system response surface.

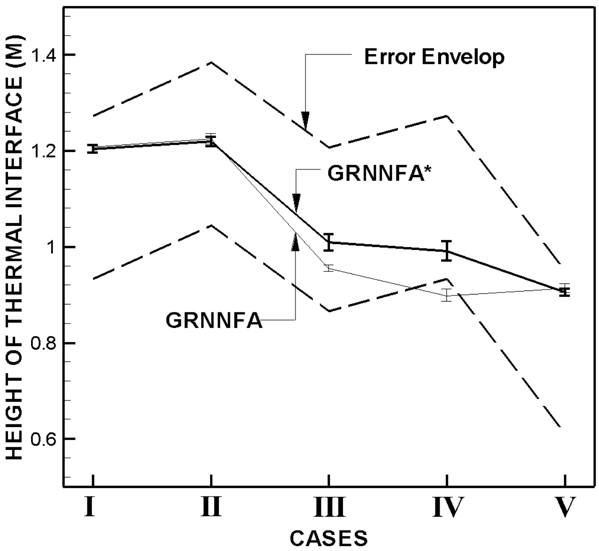

Figure 4 Improvement of the GRNNFA prediction by introduction of the extra sample

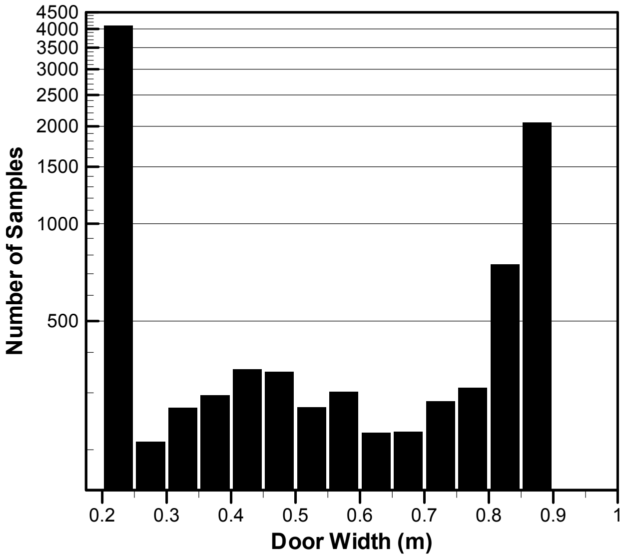

Figure 5 Distribution of the 10,000 door widths with which the HTIs were not lower than 1.0m above floor level

4.3 Optimization of Design Parameter by Genetic Algorithm

The remedied system response surface was ready to be used after the network training. The objective of this design parameter optimization is to determine the minimum door width with which the HTI would not lower than 1.0m above floor level disregarding the location of the fire. The objective function is defined in formula: arg{W, Min[$H(W,D_x,D_y)-1.0]^2$; $\forall(D_x,D_y)\in\Omega$} where H is the HTI resulting from the door width W, distances of the fire bed from room center D_x and from the front wall D_y. The physical domain of the fire bed location is defined as Ω.

The objective is to minimize the value of J. It was found that different set of $\{W,D_x,D_y\}$ may result the same value of HTI. In order to determine minimum door width irrespective to the location of the fire bed, Monte-Carlo simulation was carried out. Total 10 000 numbers of fire bed locations were randomly created within the physical domain Ω to arrive 10000 corresponding door widths with which the HTIs were not lower than 1.0m. The typical progress of the GA optimization is shown in Figure 23. It can be observed that the close optimum solution was reached by only 10 generations. Also, the objective function did not has further reduction over 200 generations. The distribution of the 10 000 door widths is presented by the histogram as shown in Figure 5.

By counting 99.9% of the 10000 samples (i.e. 9990 samples) from the leftmost, the door width of the 9990th sample falls into the range of 0.85–0.9m. The following conclusion can be drawn: There is at least 99.9% confidence level that the average height of the thermal interface induced by the fire (62.9kW) will not lower than 1.0m above floor level when the door width is 0.9m disregarding the location of fire inside the compartment identical to the experimental setup of Steckler et al. (1982) experiment.

5. Conclusions

This paper presented the development of a set of generic optimization procedures with applications of the GRNNFA model, the human expert intervened network training and GA. The GRNNFA model established the preliminary system response surface according to the information of the available training samples. Since the available samples may not be sufficient to describe the general behaviour of the system, human expert intervened network training was developed to remedy the system response surface by the implementation of the human expert's knowledge. Subsequently, the GA was applied on the remedied system response surface to arrive a close optimum solution.

This optimization approach was demonstrated by the application to determine the door width of a single compartment with which the HTI would not lower than 1.0m above floor level irrespective to the location of the fire bed. The Steckler et al. (1982) experimental results were adopted as the training samples. The trained GRNNFA model revealed the two conjectures of the HTI's behaviour (i.e. the HTI will be raised by placing the fire bed away from the door opening or increasing the width of the door opening). The conjectures were also validated theoretically and numerically. The established system response surface was examined by the human expert. The defective location of the surface was then determined by his knowledge. CFD simulation was carried out at that location to create the extra sample for the network re-training. The re-trained GRNNFA produced the remedied system response surface. It was shown that the human knowledge together with the CFD simulation significantly improve the system response. After the completion of the GA optimization applying on the response surface, the close optimum door width was found to be 0.9m.

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EDUCATION OF DESIGNING FOR SUSTAINABLE ARCHITECTURE

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Abstract

Improving statues of society's economic affects to change and destroy environment. During a building's existence, also affects the local and global environments via a series of interconnected human activities and natural processes. Studies in developed and developing countries show, to enhance environmental sustainability, a building must holistically balance and integrate all three principles: Sustainable Design, Economy of Resources, and Life Cycle Design in design, construction, operation and maintenance, and recycling and reuse of architectural resources. These principles comprise a conceptual framework for sustainable architectural design. The other fact that design management has been neglected in building design, which is a very difficult process to manage. Because, a large number of professionals involved, including architects, project managers, structural engineers and service engineers to build environment. Studies show, to achieve sustainability (controlling all affects) in building industry, the design process needs to be planned and controlled more effectively, in order to minimize the effects this industry in our environment. To achieve this goal (sustainable architecture), it requires holistic integration of all architectural activities into the design process throughout the life cycle of buildings.

To respond to this requirement some world universities developed a conceptual framework to educate architecture students to meet this goal of coexistence. This allows them to further and analyze specific methods architects can apply to reduce the environmental impact of the buildings they design.

In Iran, also like other countries building industry making a lot of environmental problem. Studies in this area show, to achieve sustainability in building industry, Iranian Universities need to establish special academic programme for this country. To achieve sustainable architecture education Shiraz University started to educate postgraduate architecture student about how can possible design and construct building regards to goal of sustainability for Iranian building industry.

This paper cited to define the method of education design for sustainability in master degree for architecture students in the Faculty of Art's and Architecture, Shiraz University and other fields which are related to building industry to achieve sustainability in Iranian building industry.

Introduction

In modern society, more than 70% of a person's lifespan is spent indoors. An essential role of architecture is to provide built environments that sustain occupants' safety, health, physiological comfort, psychological well-being, and productivity[1]. According to studies a large percentage of defects and environment in building arise through decisions or actions taken in the design stages. It is also widely known that poor design has a very strong impact on the level of efficiency during the production stage. The increasing complexity of modern buildings in a very competitive market – place in recent years, has significantly increased the pressure for improving the performance of the design process in terms of time and quality.

The fact that design management has been neglected understandable to some extent because, building design is a very difficult process to manage. It involves thousands of decisions, sometimes over a period of years, with numerous interdependencies, under a highly uncertain environment. The design process therefore needs to be planned and controlled more effectively, in order to minimize the effects of complexity and uncertainty. The lack of adequate design planning, results in insufficient information being made available to complete design tasks and inconsistencies within construction documents. Poor communication, lack of adequate documentation, unbalanced resource allocation, lack of coordination between disciplines, and erratic decision making have been pointed out as the main problems in design process management[2].

Studies show that in pursuit to achieve adequate planning and design, responsive to the above problems, sustainability concept of understanding needs to exist in almost all related specialties. In the architecture field, the subject has caught attention of many related specialists, in the recent years. To achieve the objectives and the concept of sustainability, it is required to teach the concept knowledge to architectural and related field college and university students. Educational curriculum and courses in this field are mainly to control and assess the factors effective in design and construction. According to studies, to enhance environmental sustainability, a building must holistically balance and integrate all three principles — Sustainable Design, Economy of Resources, and Life Cycle Design — in design, construction, operation and maintenance, recycling and reuse of architectural resources[3].

1. Development as the case for changing environment

Studies show that in the existing conditions, "development" in all sciences can ruin and destroy natural state of the earth and the species living on it. According to statistics the rate of destruction and degeneration is estimated at 27000 extinctions per year, which means 74 cases per day or three cases per hour. Specialists believe that global warming, Ozone layer reduction due to usage of various pollutants, increased environmental pollution and extinction of living species are all in all because of improper development in human societies. They believe that concern for environmental problems is essential for the future of human beings' life. Numerous reviews also reflected that construction and civil developments are one the most effective factors to degenerate and destroy natural environment and if the current pace of construction is not controlled or changed, irrecoverable or uncompensated damages may evolve.

2. Destroying the earth due to building construction

Architectural professionals like other specialists have to accept the fact that as a society's economic status improves, its demand for architectural resources-land, buildings or building products, energy, and other resources-will increase. This in turn increases the combined impact of architecture on the global ecosystem, which is made up of inorganic elements, living organisms, and humans. For instance, the energy and water used by its inhabitants produce toxic gases and sewage; the process of extracting, refining, and transporting all the resources used in have numerous effects on the environment. Other side during a building existence it affects the local and global environments via a series of interconnected human activities and natural processes. At the early stage, sit development and construction influence indigenous ecological characteristics. The procurement and manufacturing of materials impact the global environment[4].

3. How can we save the environment from continued devastation

As it was mentioned earlier development is known as one of the greatest needs of the human being as it alters and manipulates the environment. Construction is known as a high potential industry for man–power employment (hundreds of thousands of construction workers and related techniques), and also the main factor for ruining agricultural lands, eroding the soil, polluting the environment and providing hazard to health and well being of the people such that it has also brought with it energy crisis. This emergency in mid 1960's, along with increase in air pollution and environment pollution was a serious global warning that invoked environmentalist groups who supported the idea of protecting land against industrial pollutants world-wide and who followed the issue in its extended concept under title "sustainability". Therefore saving the environment from continued devastation by our built environment is the single most important issue for our tomorrow.

3-1. Sustainability (environmentalist view)

The new term sustainability that concerned environmental issues was first introduced in 1986 by the world committee on globalization of environment under the topic: (fulfillment of the current time needs without hazards to the future generations' resources in coping with their needs); the dimensions and scope of this issue increased daily so that proper strategies may be put forward world-wide. Architects, in line with other specialists, are pursuing, in their own profession, new approaches to provide for appropriate living conditions for people. Obviously, it must be reminded that living, working, entertainment and resting … all and all are the actions and activities taken in spaces designed by architects. Since weak and strong points of a building has direct effects on eco-system and environment, architects bear fairly sensitive duties in this concern. Application of sustainability and sustainable development concepts in architectural design has introduced a new terminology called "sustainable architecture" the most important topics of which were titled "eco-tech architecture, architecture and energy-green architecture".

3-1-1. Sustainable construction

Sustainable construction means: management of a clean and healthy area on the basis of effective exploitation of natural resources and ecological principles; its main objectives concerning mitigation of damage on environment, energy resources and the nature has three branches.

1- Reduced consumption of un-renewable energy resources
2- Development of natural environment
3- Deletion or reduction of toxic materials consumption that damage the nature through construction industry

Sustainable construction may therefore be defined as a building that has the least incompatibility and inconsistency with its own surrounding locality, and in a broader sense, with the region and the world. Studies show that construction techniques in a wide spectrum are in line to secure integrated quality, economically, socially and environmentally. Therefore, logical use of natural resources along with proper construction management may help protect limited natural resources and reduce energy which in turn helps improve natural precincts quality [5]

4. Role of architect to protect the environment

Design and building construction is usually carried out by architects and under his or her supervision in cooperation with the expertise of other specialists in the construction industry. Architectural college students however, get familiar with a number of related subjects such as principles of buildings, building techniques and materials, building structures, and environmental control, which are taught and exercised in an integrated manner with other courses of the curriculum program (such as Principles of Buildings Building Techniques and Materials, Building Structures and Environmental Controls) which are taught and exercised in an integrated manner with other courses of the degree programme. Hence, in a field originated on sustainability, the potential role of architecture is defined, in broad and comprehensive perspective, in terms of human natural habitat; all different samples of which, including urban areas, urban textures, livable hubs and finally, single abodes and open spaces are related to one another by the architecture. Such a comprehensive panorama draws "sustainable design" path so that it interferes and meets different lines of expertise and makes intra-expertise group activities (for different fields of structural and facilities design engineering and planning) essential and inevitable. In regard of this heavy responsibility of architects in design and control of all different specialties involved in the building industry, architects have a grossly sensitive role in optimum implementation of the above activities towards environmental protection.

5. Current methods of education fro architecture and sustainability in Iranian Universities

Studies and reviews on architectural education methods in the Iranian universities, with respect to the status of sustainability ideas show that:

- Educations are mostly carried out without considering to the interactive relationship and dependencies between human and its local habitat.
- Efforts and endeavors are scarce mostly in the context of conventional educational courses.
- Most of the solutions lead to short-term planning
- In the current educational methods, dissociation of fields provided with lack of interaction between study fields.

According to this status, current methods of higher education in most courses is emphasized on individual and competitive learning and not so much on participation and cooperation of different specialty branches; it therefore delivers to the society, managers and authorities who are not trained for group cooperation and participation. Some studies argued how and why our current design approach and perception of architecture must radically change if we are to ensure a sustainable future. Those studies also argued forcefully that this can only be achieved by adopting the environmentalist view.

6. Study on education of sustainable architecture in some universities around the world

Studies carried out on sustainable architecture in the foreign universities show that there is no specific sample institute that centers on or follows one particular and concentrated educational model. The training courses related to sustainable environment design, offered in universities and other educational centers are mostly part of a set of approaches and curricula predicted out of proposal or a combination of several educational approaches from a few educational models. Most of the trainings are concentrated on theoretical sustainability notion such that its non-practical specialized basics are more highlighted than its practical and empirical actions. The reason for such approach in specialized education is the fundamental notion that architectural students (environmental design majors in general) must get adequately mastered in the course of special training, on design skills and architectural doctrines. In fact, students of this major field are gradually educated to gain and realize their role and position in attaining sustainable society.
In sustainable architecture education, training is experienced in its limited form in a design workshop. This type of atelier design enjoys a better stance than the single-field one. In this composed atelier, only students with architectural background are absorbed, but on the side of design professors, they enjoy and take advantage of the presence of professors from other specialties related to the subject, especially those in fields related to environmental design (structure, facilities, planning, urban development and landscape design) and also those in environmental science. Therefore, students can experience all different aspects and dimensions of problem solving and can concentrate on the subjects as much as possible. In such atelier, smaller workgroups are generally formed. Each group is tasked to concentrate on a part of the problem. Finally findings of each group will put to discussion to achieve to agreed decision.

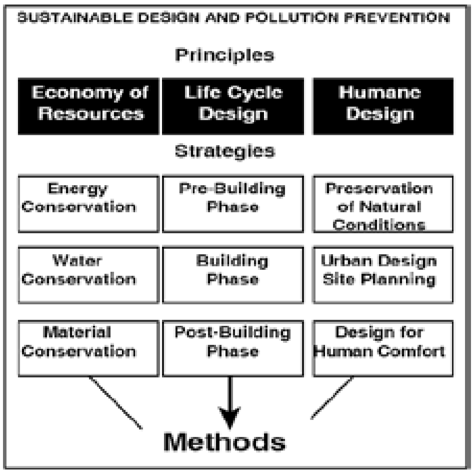
6-1. Curriculum sustainable architecture in the some world universities

The curriculum in the university of UTSOA for sustainable architecture offers two design-based and one scholarly program study on scholarly is about the relationship between the built and natural environments. In design-based curriculum offers for graduate students without a previous degree in architecture. In post professional program, they designed programme for students who already have an undergraduate professional degree. In Master of Science in Sustainable Design program, also they designed for students who wish to prepare for the Ph.D. or for employment in research, activism, or public policy. All program target increasing student and faculty interest in three areas of inquiry — natural systems, building systems, and cultural systems. The study of natural systems relies upon the disciplines of physics and ecology as they relate to architecture. The study of building systems includes investigation of those component technologies that are required to construct environmentally responsive architecture. The study of cultural systems requires that natural and building systems be investigated within the complex social and political context of architectural practice. In sum, the Sustainable Design Program is practical, technical, and philosophical in scope.

Another example of sustainability curriculum is the sustainable architecture graduate program in Architecture and Fine Arts College of the south London University, described as following: Attention and emphasis of the majority of curricula is paid today to environmental design. On the other hand, in order to gain special and specific skills like application of sustainability principles by students, many methods and technologies in the area of environmental design are available. Students who take part in such compact programs do not have much time to dig into the roots.

The graduate program on sustainable architecture emphasizes mainly on this aspect of the problem that instead of training architects who use up the existing prevailed set of proposed methodologies, graduate students must redirect themselves towards more research and innovative ideas and new think formation. To achieve this, authorities have made efforts to develop solid sustainability thinking foundation in students' minds, with the help of a set of theoretic courses and argument-and-discussion sessions or seminars. The main objective of this program is therefore, instead of design and computer modeling, set and emphasized on research and scientific argument and discussion.

The other university is Michigan University, which is established sustainable design programme to educate architects to meet this goal of coexistence. They have developed a conceptual framework in three levels of the framework (Principles, Strategies, and Methods) correspond to the three objectives of architectural environmental education: creating environmental awareness, explaining the building ecosystem, and teaching how to design sustainable buildings. The overall conceptual diagram for sustainable design is shown in figure 1.



They proposed three principles of sustainability in architecture.

- **Economy of Resources** is concerned with the reduction, reuse, and recycling of the natural resources that are input to a building.
- **Life Cycle Design** provides a methodology for analyzing the building process and its impact on the environment.
- **Humane Design** focuses on the interactions between humans and the natural world. These principles can provide a broad awareness of the environmental impact, both local and global, of architectural consumption.

Figure 1 *Principles, Strategies, and Methods sustainable architecture to educate in Michigan University*

6-1-1. List of sustainable architecture courses in Hong Kong University

The list of sustainable architecture courses in Hong Kong University, called "sustainable design" is offered in graduate program. The framework of the curriculum and the courses introduced as below:

- Understanding sustainability thought

- Maintaining balance among social, economical and environmental factors
- Internal energy and work energy
- Climatic and morphological details of the building
- Design of active envelop of the building
- Social aspect of sustainable technology
- - Renewable energy resources
- Recycling- based design

From the preceding discussions it is clear that in seeking sustainable architecture there is no unequivocal course of action that will suit all ethical stances all objectives and all situations. There is no class or style of design which will guarantee success if followed. Rather, there are difficult interrelated decisions to be made that are contingent on particular circumstances. This study show goal of sustainable design is to find architectural solutions that guarantee the well-being and coexistence of constituent groups [6].

6-2. Instructions to sustainable architecture

According to study sustainable design is the thoughtful integration of architecture with electrical, mechanical, and structural engineering. It addition to concern for the traditional aesthetics of massing, proportion, scale, texture, shadow, and light, the facility design team needs to be concerned with long term costs: environmental, economic, and human with the considering following points[7]:

- Principles of Sustainable Design
- Connecting with nature
- Understanding Environmental Impact
- Understanding People
- Understanding Place
- Understanding natural processes
- Embracing Co- Creative Design Processes

Therefore, sustainable architecture thus embraces a multi-value structure: aesthetics, environment, society and politics. In other word "design and construction" that is compatible with local environment. An architect shall cleverly consider a few factors: resistance, durability and life span of the building, proper materials and the concept. All sustainable architecture principles must materialize in a complete process that leads to development of safe and healthy environment.

6-3. How sustainable architecture principle influence design and planning

We have highlighted the cultural construction of sustainability, drawn attention to a variety of ethical positions, explored the nature of decision making and design advice, and discussed the complex system involved, but how do all these come together when we as architect are faced with making day-to-day designs? To illustrate the complexity of the problem we as architects face in terms of the social, scientific and professional positions[6]. Therefore, minimizing energy consumption and promoting human health should be the organizing principles of sustainable design.

6-4. Strategies for approaching ecological design and planning

As it was pointed earlier, in the current university education structure, most specializations related to design and construction on the surrounding environment are offered and taught separately under a given distinct specialization title and grouped in departments based on the science branch they belong to. Architectural students get acquainted in their classes with these study subjects and other related topics. They can experience the application of newly known concepts in their design assignments; but majoring in different fields such as architecture, construction and facilities, urban development, planning, landscape design and internal decoration, students rarely work together to learn from each other as a group. This is while in the principles considered to achieve sustainability, communication and group working is given special attention as one of the main themes to sustainable design.

In educational approach, in order to transfer the sustainability perspective to the students, instead of defining the problem in the context of limited perspective "design", need decided to let students experience the architectural design in a wider range. In this view, the role of architect in creating built environment shall not be limited to design, but in performing the role, architect shall directly get involved in providing sustainable peripheral so that all dimensions of the proposed problem may be seen, designed and resolved in the context of a project with sustainability in the architect's mind. Application or employment of an intermediate place (between university area and professional medium) is another new empirical approach based on which, professional identify for architect is developed and followed and also fundamental and structural changes in architectural trainings is sought. In this substituting method, in pursuit to provide empirical education to architectural students and establish bi-directional relationship between architecture sector and education department, an intermediate place is prepared in which, students in cooperation with one another and with a group of professional architects and architectural professors discuss and learn the real experience of sustainability. The intermediate space is handled as a laboratory office, much like educational hospitals. In fact, a professional educational office is established that holds coexistence business and dynamic interaction simultaneously with university sector and free market.

6-5. Methods for achieving sustainable design

The ultimate goal and challenge of sustainable design is to find win-win solutions that provide quantitative, qualitative, physical, and psychological benefits to building users. There are many possibilities for achieving this seemingly difficult goal. The three principles of sustainable design — economy of resources, life cycle design, and humane design — provide a broad awareness of the environment issues associated with architecture. The strategies within each principle focus on more specific topics[1]. Integrate and apply the relevant knowledge in areas related to building surveying practice such as design, material selection and detailing of building construction development, application of building regulations survey and maintenance of buildings, assimilation of building services knowledge in the design of buildings, contract administration, management of property and building projects etc. Understand the fundamental technical, economic and legal aspects of a project in the construction industry; and develop skills in building communication in the form of drawings, technical reports, specification, charts, diagrams and illustration. This method as a design process can help to achieve sustainable design.

6-6. Shortage of teaching material for environmental education

The survey indicated a significant shortage of teaching materials for environmental education in architecture. In preparing resources and valid documents, it is required that serious efforts are taken so as to be able to respond to necessary needs of the near subject. One of the new solutions to prepare local resources may be the establishment of sustainability programs proposed in this paper [4].

7. Current statues of education on sustainable architecture in Shiraz University

According to the curriculum of architecture education, which is defined to Iranian Universities non-continuous architectural Master degree program curriculum, in regard of extensive dimensions and also ever increasing needs of the architectural field including environmental design and development, counts on science and specialization power as a necessary means to provide proper ground for the growth of specialized tendencies and consequent enhancement of efficiency. This curriculum for establishment program on architectural engineering was termed as securing public efficiently. Therefore, it was later proved the proper place for introduction of sustainability. In this extent in order to achieve objectives and ideals of sustainable development, the architectural department of the faculty of Art’s and Architecture of Shiraz University has been offered a two-hour arbitrary course on sustainable design to get students (of this field) familiarized with sustainability notion in construction design.

The course on principles and foundations of sustainable architecture-based design is offered in two parts. The first part of the class is to familiarize students with principles and fundamentals of sustainable architecture-based design including man-built environment, health issues, safety, welfare and economics. This part is composed of seven sessions. In this sessions all student presented in the class internal and foreign resources (books and internet) about sustainable architecture. In the second part of the program, which lasts another seven sessions, students tried to review the methods, which is used to apply sustainable factors in finished projects. In this program teachers tried enhance students' sensitivity to environmental issues and to scientific fundamentals to achieve sustainable design and knowledge.

7-1. Suggested method for continuing sustainable architecture education

As it was mentioned earlier, the objective in sustainable architecture programs is to embolden students' sensitivity to environmental issues, scientific fundamentals and their capabilities in the framework of ongoing educational courses and towards responsive design of environment. However, attention and emphasis of the majority of curricula in graduate programs is put on environmental design, gaining special and specific skills in the domain of the problem under consideration. Application of guidelines, methods and special technologies in the design domain keeps students so busy that they do not have much time to dig into the roots, reasons and necessities of the problem, with such compact study programs. Graduate programs on sustainable structure emphasize mainly on this aspect of the problem that graduate students of architecture must try to direct themselves towards more research work and innovative idea development. To achieve this, curriculum authorities have made efforts to develop solid sustainability thinking foundation in students’ minds. In this program, instead of training architects who merely use the existing prevailed set of proposed methodologies, graduates must be more self-relying on carrying out research and come up with new sustainability ideas.

On this basis, the second proposal with respect to training a new generation of architectural specialists is to use professional work and educational experiences, which requires establishment of bi-directional relationship between professionals and education sectors in order to provide and intermediate office- like space (which runs much like educational hospitals), common to all architectural students willing to take part in sustainable architecture issues. In the space, students, professionals and professors work together to make a bridge between construction industry and educational center to maintain sustainable development and environment.

7-1-1. The first proposed method for sustainable architecture training: Familiarization of students with principles and fundamentals of sustainable architecture – base design
This sustainable development training method is started from 2007 in this faculty. In this method, while presenting sustainability issues to the students, professors try to persuade them to do research works and present the results in the class (two-man group classmates). All students in the class are practically introduced to various sustainability parameters (even reviewing real projects already finished). This training method provides large volume of information to the students during the term so that they would be able to apply experiences to carry out sustainable architecture oriented design. Accordingly, after acquaintance, of students with principles and fundamentals of sustainable architecture, the sustainability group of this faculty intends to offer sustainable architecture plan project (a separate project design) in the next term. Considering the rate of acquaintance of students with principles and fundamentals of sustainable architecture, it seems that students may be able to do their plan applying the above principles.

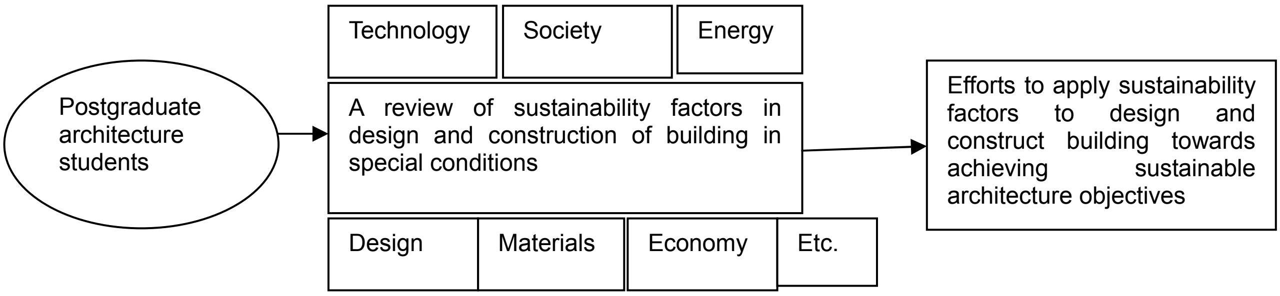


Figure 2 Diagram of processes of the first method for sustainable architecture education

Figure 3 Photos form sustainable architecture class in faculty of Art's and Architecture,Shiraz University

7-1-2. The second method in sustainable architecture education system:
Sustainability education with cooperation and collaboration of experts related to construction industry, where architectural specialists are the main pillar who has responsibility and authority to guide education toward sustainability. In the second method also, efforts are toward defining and posing the sustainability topic in classes and persuading students to do research works (in two sessions) in their own fields of specialization (even reviewing real sustainability projects) toward achieving sustainability. This part will almost last up to mid-term. In the second part of the exercise, while defining a design project in a real construction site, design process is carried out commonly, trying to reach sustainability. In this type of project, putting emphasis on resolving a problem instead of merely designing a project may be an effective help in sustainable education. At this level, group members concentrate on various aspects of the problem according to their line of interest, but they all work for an optimum output in the conceptual framework of the group. Considering the formation

trend of the program, it may be said that intra- field training approach is mostly the backbone and common problem and that would be resolving a problem instead of simply designing. In order to persuade communication among major–fields, it may be required that parts of the work is carried out on actual human settlements in need of various specializations. Using this method it would be possible (in the long run) to review the subjects more deeply (by the above experts) and define various educational programs with various tendencies. Even by using these methods it is possible to define PhD programs for architecture students.

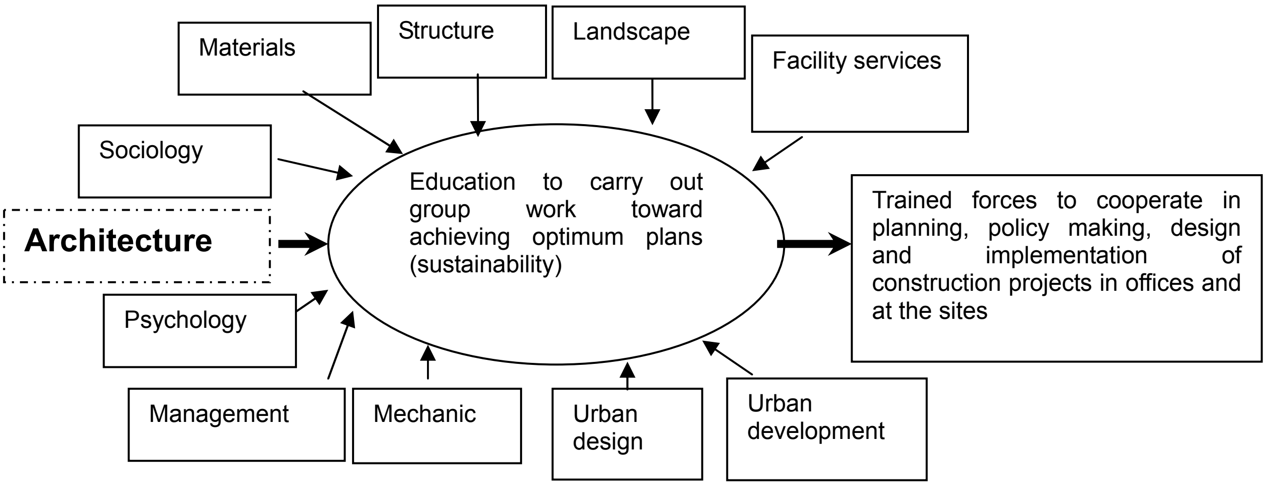


Figure 4 Diagram proposed for second method for sustainability in building industry

8. Conclusion

Studies revealed that caring for environmental issues are one of the necessities of today is societies. In view of formation and momentum of the environmental issues being posed nowadays, it seems to be necessary to institutionalize and publicize this line of through universities and colleges. Educational schemes on their way to achieve sustainability objectives will need to apply special educational methods. This requires full use of existing capacities to make the methods operational. Construction sector is one of the influential factors to alter the environment this subject has recently caught attention of experts. To achieve environmental sustainability in the building sector, it is crucial to educate architecture students in environmental issues, which is called Sustainable Architecture. For successful application it must be understood by all whose work touches on building owners, architects, engineers, contractors, material suppliers and operators. Most cannot be expected to have either depth or breadth in the knowledge available. It is clear, therefore, that participants in the building industry require assistance in matching available technology with the specific problems encountered in their day-to-day activities. It is expected that professional and academic bodies will be attracted to develop collaborative education system. Because studies show the result of this collaboration benefit not only current students but also practicing building professionals who need continuing professional education. In the long run, the field of building technology can be advanced and the object of sustainable development can be promoted. Accordingly, two methods for teaching sustainable architecture in the faculty of art's and Architecture in the Shiraz University are being followed up to train students toward conducting construction projects with sustainability in mind. If educational objectives are met, more control over construction industry activates natural resources and especially environmental potation, which in the disastrous of all factors may be in reach.

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SUSTAINABILITY AND LEGISLATION.

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Summary

Laws are made by people and for the people. If the majority of the people do believe something must be done or something should not be done legislation is there to arrange activities in society. This also goes for the building sector. In this research various government policies and advice are analysed in order to obtain sustainable buildings. Many laws are clear and useful. In this research some specific cases with very clear sustainable impact and some cases with questionable impact are analysed. The majority of people as individuals consider sustainable issues as very important, but as soon as serious investment or a reduction of personal comfort is involved, often the sustainability possibilities will be neglected. Sustainability aspects at little cost, bringing a clear and guaranteed profit to the owner in the long run can be successful. This research shows that sustainability aspects are to be communicated as simply as possible, and will be most successful when future savings in operating cost can be proven for the future home owner. Surprisingly sustainability items can be very successful under a logical and profitable financing scheme in one country and a total failure with a different financing scheme in the country next door.

Introduction

The aim of housing laws and related legislation is to ensure safe, useable, healthy and energy efficient buildings. Due to general public environmental awareness, political pressure and personal involvement, many local authorities show strong intentions emphasizing sustainability aspects to be included for new homes in order to improve the sustainability level of the local building stock.
In order to achieve this goal a wide array of mandatory items, preferred solutions, advice and recommendations are given to the public both in building and operating a home. The subjects vary from the obligation to use a specific building material, the minimum thickness or performance of thermal insulation material, types of windows and energy related issues like heating and cooling equipment and generating hot water. Also lots of advice on how to operate a home is given.
In this research the effectiveness of some of this advice has been analysed. This study also focuses on possible new options that could be added in order to achieve more sustainable housing, profitable for the occupant, the community and the environment.

1. What is sustainable building?

Sustainable building can be seen as building in such a way that environmental load is reduced to a minimum both during the construction and operation of the building. The building itself must be safe, useable and comfortable to people with a minimum use of fossil energy or preferably no fossil energy use at all. Quite contradictory requirements, as the building is there to create an attractive and desired climate for people that is different to the outside climate. In order to realize this difference a separating structure is needed and energy is needed to maintain the difference. As a consequence sustainable building can be approached focussing on two items: the building design process choice of materials and systems and the operation of the building.

2. Building a house, the basic materials.

For building a house, materials and labour are needed. Materials are produced from natural resources this process involves energy and labour. Once the material is produced it needs to be transported to the building site, involving energy and labour next the material needs to be mounted and connected to other material and waste needs to be disposed of, again involving energy and labour.
The embodied energy of all these accumulated actions can be assessed, the energy needed to realize that specific material in that specific quantity on that specific spot. It is obvious, that such a calculation of embodied energy can only bring a rough estimate as the exact amount of energy of every aspect cannot be precisely established. Common sense will help.

As an example in a specific recommendation sea sand is advised. Sea sand is plentiful so depletion of sea sand is no issue, but desalination and transporting the sand over a long distance will involve great amounts of energy. It is obvious that locally excavated sand in terms of embodied energy is preferred.

For building walls many materials are available such as wood, brick, concrete even straw bale. Every material has some advantages and some disadvantages.

Wood can be locally produced from well operated and maintained forest. The Swedish Forest Council claims that in Sweden in spite of the very large production and export of timber, the actual surface of forest is increasing due to a very active policy on planting new trees. Planting trees is an easy process, and can be done highly efficiently. Trees will grow almost without any cost or effort, harvesting is easy and processing can be done highly mechanized again at low cost. Working with wood has been done for ages and craftsmanship and tools and equipment are available almost everywhere. In terms of embodied energy wood seems to be the ideal material as the carbon is stored for life of the wood. Yet wood also has its disadvantages. It can burn needs maintenance and can be deteriorated by biological means. So wood in some cases is not the ideal material at all. Medieval European cities often were entirely built out of wood, as in the middle ages no electric light was available, often an open fire was used for heat, cooking and lighting. As sometimes things go wrong, one house might catch fire, and with it the entire city. Today we are surprised that many cities suffered this situation more than once, and only after many years when building in stone or brick became mandatory by law, the image of the city completely changed.

This could suggest brick to be the ideal material. Brick is a very durable material - brick walls aging over 500 years can be seen all over Europe. It needs almost no maintenance, but building a brick wall is very labour-intensive and manufacturing brick uses a lot of energy.

Another excellent example of a material with advantages and disadvantages is straw bale. A material that in some places is an agricultural left over, almost free. Very limited embodied energy, available forever, with excellent thermal insulation and when covered with some 20 mm plaster offers a very high fire resistance. But special craftsmanship is needed and the long-term behaviour is questionable.

In modern building in The Netherlands pre-cast concrete is used. Due to the small distances in The Netherlands transportation is never a limiting factor. It is known that concrete consists of cement, sand, gravel and water. Sand and gravel are to be excavated from the environment, so it is logical to consider for sustainability reasons replacing a certain amount of gravel with waste concrete granulate from a demolition. In a government guide line it is stated that for sustainability reasons without any further consideration 20% of the gravel can be replaced by granulate from waste concrete. Questioning the manufacturer of the pre-cast concrete elements about the possibility of this 20% replacement the answer was that this was never done for two reasons. Adding granulated material from a demolition means adding material from an unknown source, so the quality of the end product could not be guaranteed. Also the process of making pre-cast concrete is mechanized in such a manner that granulate would disturb the process and so generate higher cost.

Surprisingly the same answer was heard in the float glass factory producing window panes 24 hours a day, 365 days a year for seven years. This process was considered to be so precise and sensitive that no one would even think of risking a disruption by adding unknown material.

2.1. Building a house, the life time consequences of choices

Once materials and products are chosen a specific design should be made related to the chosen materials and products. The importance of this statement can best be illustrated by using an example of a façade consisting of sandwich panels, with doors and a window. (figure 1) It looks like this façade is made without knowing anything about the materials and products involved. In figure 2a the black surfaces give the dimensions of the wasted parts of the original sandwich panels, as sandwich panels are produced in a linear process. Panels have been cut to make doors and window fit and brand new material is turned into useless waste. In figure 2b the alternative design is given: no on site cutting of panels, no waste generated. Less material is needed, less waste is created and most important, less money is spent with only a little extra design effort. It is obvious that legislation cannot prevent waste to be generated, however a tax penalty on building site generated waste could well be considered, or high cost for waste disposal.

Figure 1 Sandwich panels, Doors and windows in the existing situation.

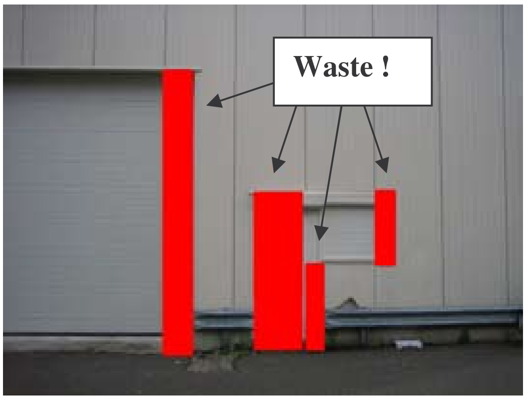

Figure 2a Wasted surface of sandwich panels

Figure 2b With a little extra design no waste

When designing a house it makes sense to think about a covered outside area suitable for laundry drying. Modern tumble dryers consume some 400-500 kWh of electricity a year, and this energy consumption can be avoided with a proper place for drying laundry. At an average overall electricity use of some 3500-4500 kWh per year, a simple design decision can save more than 10% of the yearly electricity bill. In the purposely-designed Swedish low energy example a balcony has been designed for this purpose.

The balcony also acts as an overhang preventing summer sun entering the house and heating it up. In this case the overhang will also prevent rain water reaching the wall and window frame, resulting in a reduced maintenance need. (Figure 3)

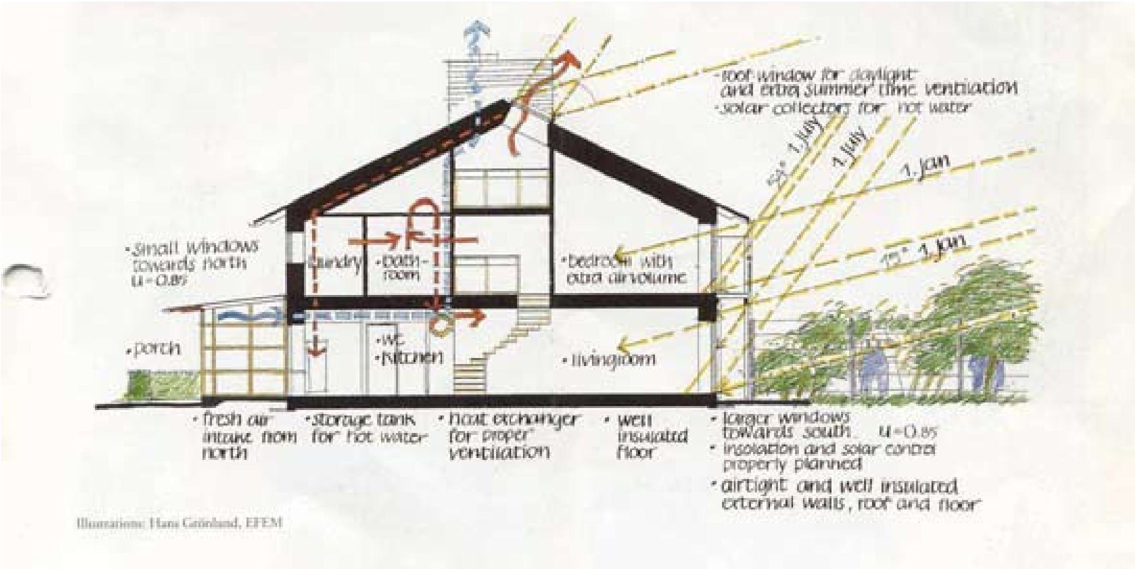

Figure 3 The Swedish Low energy housing concept with balcony and overhanging roof.

3. Operating a house, Energy consumption

Another important life-time issue is the energy performance of the house. On average some 8000 kWh of energy is needed for heating alone in modern Dutch housing. This energy usually is realized by burning natural gas. Energy consumption for other than heating purposes (light, household equipment, pumps etc) usually amounts to some 3500-4500 kWh per year. In Germany the passive house standard developed in 1992. A house is considered “passive” when yearly heating demand is less than 15 kWh/m2. For an average 100 m2 house this means a total yearly heating demand of 1500 kWh. A passive house can be characterized by 400 mm thermal insulation, high performance windows, an air tight structure and a heat recovery ventilation system, obviously all expensive items to realize. Yet no financial support at all is given to people in the process of realizing such a project, not even support or priority in obtaining building permits.

3.1. Operating a house, electricity

Another important aspect for the generation of sustainable energy is the use of Photo Voltaic panels. If a house is situated with a South facing roof, even in Northern Europe (52 degrees North) it is quite feasible to install Photo-Voltaic panels, or PV panels. PV panels and the related installation are expensive, some 400 Euros per m2. The yearly sustainable electricity yield in useable electricity amounts to some 100 kWh /m2. At present 1 kWh of electricity will cost some 20 eurocents, so the yield in money consists of 20 Euros per year. Period for return on investment is over 20 years making PV a very bad investment. In spite of many subsidies for buying PV systems in the Netherlands PV never reached any significant contribution in the sustainable energy supply.

Surprisingly in the country next door to The Netherlands, in Germany, PV are very popular and many companies exist in the field of supplying and installing home PV systems. Under German law the payback for the sustainable PV kWh is 50 eurocents, and this contract has a fixed price for 20 years. A rough calculation shows the pay back time is reduced to 8 years. Also in specific cases individuals can have an income tax reduction when investing in sustainable energy. Of course the 50 eurocents for

the sustainable PV kWh output must be paid. This is realized with a slight increase of electricity prices or electricity tax, so the person investing in sustainable energy makes a profit, to be paid by the person not investing in sustainable energy.
It is most surprising that this system has worked well in Germany since 1997, but has only recently been discovered by other governments.

In this respect it is also surprising that calculators running on batteries are still being sold. Calculators powered by solar cells or PV have existed for years offering the same quality at the same cost but without batteries that run out sooner or later and are reduced to chemical waste. With a double or triple VAT for such polluting products with available sustainable alternatives the problem of generating toxic waste caused by the disposed batteries could be solved easily?

3.2. Operating a house, domestic hot water use

For modern housing in the Netherlands roughly 25% the energy is for heating, 25% for hot water and 50% other. So quite a significant amount of energy is needed for generating hot water. The worst advice found in reducing energy use was to set the water heater to 120 ºF (48 ºC) Unfortunately this temperature is ideal for the Legionella bacteria to develop, especially in non chlorinated drinking water. A Legionella bacteria outbreak once happened in The Netherlands on a fair back in 1999 with 133 confirmed cases and 28 deaths. It is clear that saving energy must be done with safety first. This is illustrated by the American Society of Professional Engineers (ASPE) recommending temperatures for water heaters to be at least 140 ºF (60 ºC).

A far easier method for saving energy on domestic hot water is using heat recovery of shower wastewater. A simple device is placed around the drained shower water. Wasted shower water has a temperature of some 28 ºC, this will heat up the cold water supply from 10 ºC to 27 ºC so less warm water is needed. The device once installed will run for ever, no electricity, no controls needed, it will only work when showering and stop when you stop showering. No possibility for Legionella to develop. The principle is given in figure 4

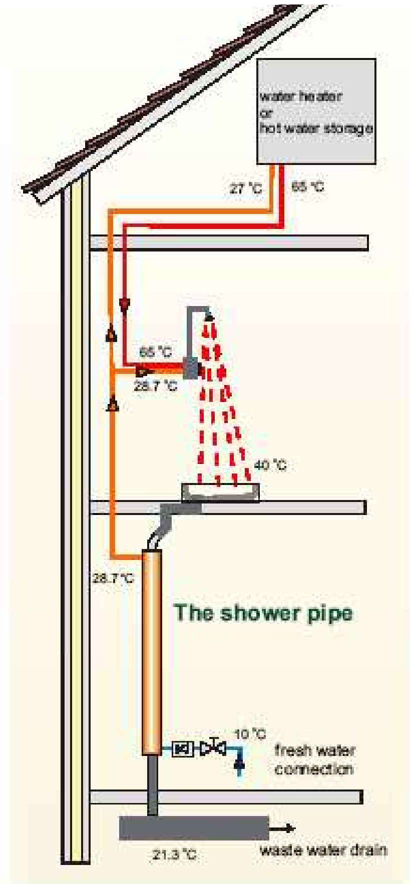

Figure 3 The heat recovery Shower waste water equipment

The recent water shortage in Brisbane, Australia shows that active promotion and giving information really helps. In order to save water the price of water saving devices was halved and installing was free. Also people were provided with a 3 minute sandglass, for timing showers so they could contribute personally to solving the problem of limited water supply.

4. Conclusion

Sustainable building and operating a house is an important issue. Many, very many technological and technical options exist to contribute to sustainable building, however when applying these options one must be fully aware of the consequences. Any reduction of safety is unacceptable. An investment in sustainable issues must be paid back in a reasonable period, else the initiative will be a failure. Successful, profitable items are to be communicated as clear as possible.

THE OPTIMIZATION OF THE OVERALL PERFORMANCE OF BUILDINGS

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Summary

Building plan and shape are the result of a complex process. Functional, technical and aesthetic considerations all contribute to the building design. Wind, solar availability, shelter, exposure, air quality and noise conditions will affect the relationship between the building and its external environment and influence the shape and the design of the envelope. Materials selection, heating, cooling, daylighting, indoor air quality (IAQ), acoustic behaviour and energy strategies should be meshed at an early stage with the other requirements to ensure the buildings sustainability and overall comfort conditions.

To accomplish this goal it is necessary to predict the thermal, acoustic, lighting and IAQ behaviour of the buildings, on the design phase, in order to be able to do the right choices, regarding, for instance the geometry, fenestration strategies, construction solutions and materials, to improve the occupants overall comfort and, simultaneously, to reduce the energy costs and increasing the sustainability of the buildings.

So it is necessary to have an integrated approach to ensure the best overall behaviour taking into account all of the, sometimes incompatible, comfort and sustainability requirements.

The aim of this study is to select a range of optimized solutions (envelope construction solutions, materials, fenestration and ventilation strategies, etc.), in order to improve the overall performance of buildings (comfort and sustainability).

1. Introduction

As the building sector in the EU is responsible for 40% of the final energy demand (30% in Portugal) and of 1/3 of the greenhouse gases emissions, it is mandatory to control the energy consumption in the building sector, while maintaining or even improving the indoor comfort conditions and reducing the environmental impact.

Having this challenge in mind and considering that a healthy and comfortable indoor environment is a basic premise in all buildings, it is during the design phase that the sustainable building concepts should be applied, through the implementation of a combined strategic action that allows improving the comfort and the energy performance, while reducing the environmental impact, by a judicious selection of materials, technologies and construction methods to be used.

To achieve this goal it is necessary the use of environmental friendly products (to minimize the Volatile Organic Compounds - VOC - and other emissions), methods and techniques for buildings, re-use of components or use of recycled materials, minimize the use of materials or components that rely on scarce materials resources, select materials that balance durability and low embodied energy and design and plan the building for demolition and re-use and also to minimize the operation cost, namely the energy need for heating, cooling and domestic hot water.

To guarantee an adequate thermal, acoustic and daylight behaviour and the internal air quality (IAQ) of the buildings it is necessary to consider thermal storage (thermal inertia) using the building structure, selecting exterior walls systems and insulation according to the climatic zone, implement passive heating and cooling solar systems (using solar and photovoltaic panels).

It is also necessary to select the correct fenestration for each orientation, according to the latitude, lighting and natural ventilation, considering also the solar gains, the outdoor obstructions and choosing the shading devices to optimize the energy and comfort needs to ensure the acoustic and thermal exigencies, the indoor visual comfort related to the visual task to be performed.

It is necessary to optimize the building envelope, by improving insulation, glazing, optimizing natural ventilation and daylighting techniques through appropriate design in order to reduce the thermal losses of the building.

The solutions adopted in buildings, usually, only optimize no more than one of the necessary comfort requirements. In many cases, the best solutions to accomplish different comfort requirements are not compatible, especially in what concerns natural ventilation and lighting strategies and the acoustic and thermal performance. For instance, the type of window used can have a strong and opposite influence on the thermal and acoustic performance of the building, just not to mention its interference on the indoor air quality (IAQ).

The solutions adopted on the conventional buildings are only compatible with one or two of the necessary requirements, and don't fulfil the others (for example the windows' frame air tightness is good for the thermal and acoustic performance, but not to natural ventilation and doesn't interfere with the natural lightning). Therefore, it is necessary an integrated analysis to ensure the best overall behaviour (for instance, the definition of the area, shape, shading device, way of opening, type of glazing of a window, considering its orientation, the external environment, etc.).

Therefore, and as the buildings are complex systems, where all aspects are interconnected and influence each other, it is necessary to have an integrated approach to the building, that should enhance indoor health and comfort besides the energy savings and environmental sustainability, to ensure the best overall behaviour taking into account all of the, sometimes incompatible, comfort requirements.

The aim of this study is, then, to select a range of optimized solutions (envelope construction solutions, materials used, fenestration and ventilation strategies, etc.), in order to improve the overall performance of buildings accomplishing all the comfort requirements, because a well designed building has the potential to reduce energy costs and also to improve the occupants' comfort.

This study will consist on the optimization of the overall comfort conditions throughout the analysis and control of four major parameters related to the thermal insulation level, the acoustic insulation level, the illuminance levels (taking into account the indoor daylight requirements) and the number of air changes per hour (related to the indoor air quality), considering the factors that have influence on the buildings behaviour.

To achieve this goal a three bedroom dwelling, representative of the conventional Portuguese buildings, will be studied, estimating the heating and cooling needs necessary to maintain the indoor temperatures between 20 and 25ºC (comfort zone) according to the Portuguese thermal regulation (RCCTE, 2006), the acoustic behaviour of the envelope elements, estimating the weighted normalized airborne sound insulation index and the weighted normalized impact sound pressure level index, the indoor daylighting conditions, and the Indoor Air Quality (IAQ), for several construction solutions for its envelope and partition elements.

2. Methodology

To improve the overall performance of buildings it is necessary to select the right solutions (envelope construction solutions, materials, fenestration and ventilation strategies, etc.), considering the building characteristics, such as shape and orientation.

To evaluate the range of solutions, a three-bedroom dwelling, representing typical Portuguese buildings was selected in order to ascertain the potentialities of each one of the construction solutions and materials, in order to identify the ones that can improve the occupants overall comfort.

As, in general, in Portugal residential buildings are only acclimatized during occupied periods, the HVAC system was defined to maintain the indoor temperatures above 20ºC in winter and under 25ºC, in summer, according to the Portuguese legislation (RCCTE, 2006), only during this period.

The occupied period considered was between 7pm till 8 am and the non-occupied period between 8 am and 7 pm.

2.1 Simulation Tools

The Prediction of the building thermal behaviour will be done using computer modelling, with EnergyPlus, estimating the heating and cooling needs to maintain the indoor temperatures between 20 and 25ºC during the occupied period, for different construction solutions for the envelope and for the partition elements. The IAQ will be assessed by the number of air changes per hour (ach) ensured by the air inlets on the windows frame and by the mechanical ventilation of the WCs. In summer, during night periods the building is ventilated to use the cooler outside air to reduce the temperature inside the building. The number of hours where the occupants were uncomfortable in the zone was determined by EnergyPlus based on ASHRAE 55 - 2004 graph (Section 5.2.1.1) (ASHRAE 55, 2004).

The acoustic behaviour will be considered estimating the weighted normalized airborne sound insulation indexes and the weighted normalized impact sound pressure level index ($D_{n,w}$, $D_{2m,\,n,\,W}$ and $L'_{n,w}$), using the Acoubat Sound Program.

The lighting behaviour will be verified using the Desktop Radiance Tool, for the 21st of December and for the 21st of July, calculating the illuminance levels and the daylight factor which is the International Commission on Illumination (CIE from its French title) recommended method to determine the performance of a daylighting system, and is independent on the window design and location, outdoor obstructions, optical characteristics of inner surfaces and windows. It is useful for estimating the amount of glazing needed to illuminate a space.

2.2 Building Charateristics

The building under analysis, with 129.3 m^2, has three south oriented bedrooms. The kitchen and the dining and living room are north oriented (Figure 1).

The WCs are mechanically ventilated and the windows have adjustable air inlets in the frame to guarantee the ventilation of the dwelling.

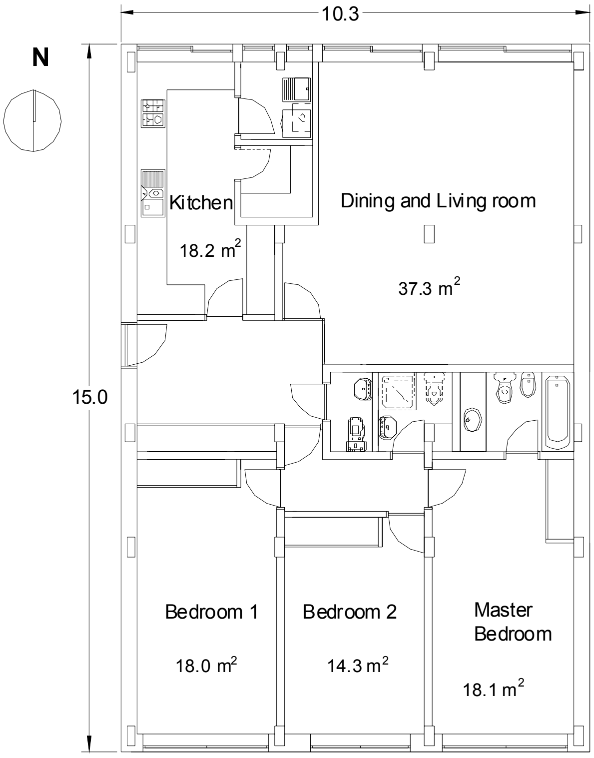

Figure 1 Schematic plan of the studied building

On an initial stage, the windows, with 1 m high, had a glazing area corresponding to 15% of the floor area (30% of the wall area), to maximize the use of the solar gains in winter and the daylight use (3.36 m^2 on the kitchen, 5.15 m^2 on the dining and living room, 2.75 m^2, 2.20 m^2 and 2.75 m^2 for the bedrooms). On a second stage, the glazing area was doubled to 30% of the floor area (window doors with 2 m high) to evaluate the influence of the window area on the energy needs, acoustic and daylight behaviour.

2.3 Construction Characteristics

The factors studied are the ones that need to be considered when designing the building envelope including amongst others: the area of windows, their orientation and type shading device used; the insulation levels used in the building; the air tightness of the building construction; the colour of the building and its surface properties; the potential for natural ventilation; and the amount of exposed internal thermal mass.

The construction solutions analyzed are shown in Figure 2 and listed on Table 1, for the different types of elements of the building envelope. The constructive solutions selected, single and double pane walls (hollow concrete blocks, brick, hollow brick and plasterboard), concrete, hollow core concrete and beam and pot slabs and materials (concrete, brick, plaster), cover a wide range of situations.

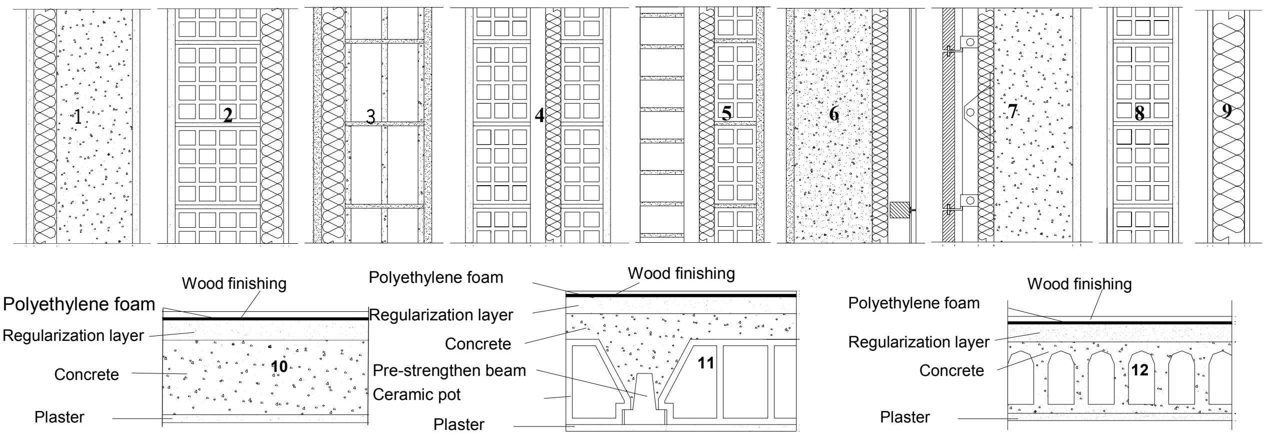

Figure 2 Vertical cross-section of some of the construction solutions of the buildings walls and floors (external and partition elements)

The study was done for two insulation materials (expanded extruded polystyrene, XPS, and mineral wool, MW), with several thickness (0, 2, 4, 6, 8 or 10cm). The insulation could be placed: in the exterior or in the interior of the single pane walls; or in air cavity or in the interior of the double pane walls (Figure 2).

The windows have an adjustable shading system (venetian blinds) on the outside to maximize the solar gains during winter and minimize the unwanted solar gains during summer and at the same time allowing the control of the daylight, thus, avoiding the use of artificial lighting.

Table 1 Construction solutions characteristics

Element	Construction Solutions (see Figure 2)	
Façade (with several insulation material thickness, finished with plaster on both sides)	Single pane concrete wall with 15cm (1)	
	Single pane hollow brick wall with 22cm (2)	
	Single pane hollow concrete wall with 20cm (3)	
	Double pane wall, hollow brick with 15cm and hollow brick with 11cm (4)	
	Double pane wall, brick with 11cm and hollow brick with 11cm (5)	
	Double pane wall, concrete wall with 20cm and plasterboard wall with 1.3cm (6)	
	Double pane wall, stone with 5cm and concrete wall with 15cm (7)	
Walls separating dwellings and common circulation zones	Double pane hollow brick wall (11cm + 11cm), with 4 cm of mineral wool in plates placed in the air cavity and finished with plaster on both sides	
Partition walls	Single pane hollow brick wall with 11cm, finished with plaster on both sides (8)	
	Double pane plasterboard wall with 1.3cm and with 10cm mineral wool (9)	
Floors and ceilings	Concrete with 20cm, 4cm regularization layer, 0.5cm of polyethylene foam and 0.8cm of wood as top surface finishing and plaster as inferior surface finishing (10)	
	Pre-stressed concrete “T” beams and 26cm hollow pots, 4cm regularization layer, 0.5cm of polyethylene foam and 0.8cm of wood as top surface finishing and plaster as inferior surface finishing (11)	
	Hollow core concrete slab with 20 cm, 4cm regularization layer, 0.5cm of polyethylene foam, 0.8cm of wood as top surface finishing and plaster as inferior surface finishing (12)	
Windows	Metallic window frames with adjustable air inlets, venetian blinds on the outside and overhangs on south windows	Double pane clear glazing (8+10+6) mm
		Double pane Low-E glazing (6+10+4) mm

3 Results

3.1 Thermal behaviour

The typical Portuguese dwelling usually doesn’t have HVAC systems and has double pane hollow brick walls (15cm + 11cm) with 4cm of expanded extruded polystyrene placed in the air cavity (solution 4 in Figure 2) and windows with metallic frame and double glazing. In this situation the inside temperatures are under 20ºC and above 25ºC, for long periods, as Figure 3 shows for the coolest and hottest day.

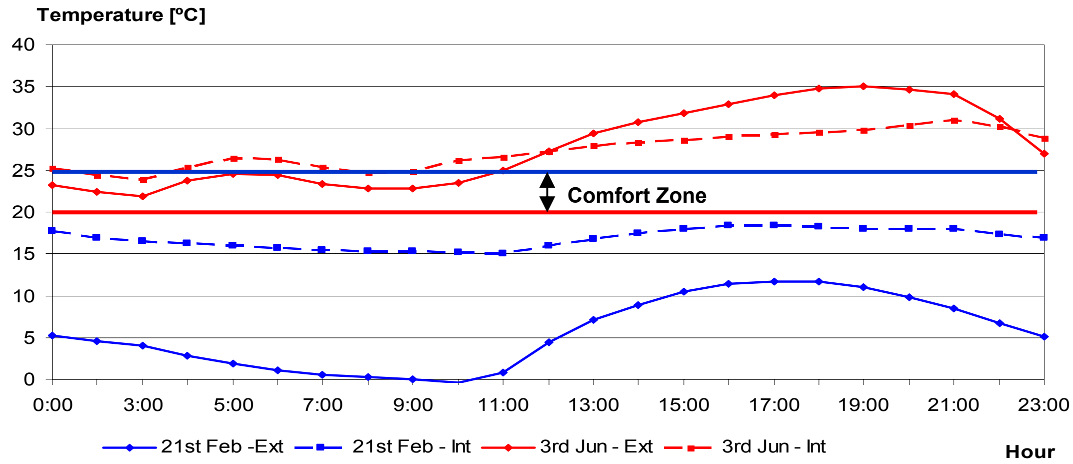

Figure 3 External and internal temperatures for the coolest and the hottest day – without HVAC.

So, it is necessary a mechanical system to maintain the indoor temperature above 20ºC in winter and under 25ºC in summer, during occupied period, which will mean a 3016.6kW/year consume (75% of which in winter).

On Table 2 are listed the heating and cooling needs and the comfortable period during occupied hours, for two different constructive solutions for single walls (a 15cm thick concrete wall, with plaster on the inside, and a 22cm thick hollow brick wall, finished with plaster on both sides), with several thickness of expanded extruded polystyrene on the outside and windows with 15% of the floor area (corresponding to 30% of the area of the wall).

Table 2 Thermal behaviour of the dwelling with single external walls and windows with 1m high

Constructive solution	Heating needs [kW/year]	Cooling needs [kW/year]	Heating + Cooling needs [kW/year]	Comfortable period [%]
Concrete wall with 15cm thickness, with several thickness of expanded extruded polystyrene placed on the outside				
Without insulation	3258.0	849.1	4107.2	36
2cm XPS	2546.4	748.4	3294.8	43
4cm XPS	2287.6	732.0	3019.6	48
6cm XPS	2161.1	726.8	2887.9	50
8cm XPS	2086.5	724.1	2810.6	52
10cm XPS	2037.2	722.5	2759.7	54
Brick wall with 22cm thickness, with several thickness of expanded extruded polystyrene placed on the outside				
Without insulation	3101.0	848.5	3949.5	38
2cm XPS	2481.7	745.2	3226.9	44
4cm XPS	2260.0	732.3	2992.3	48
6cm XPS	2146.6	728.2	2874.8	51
8cm XPS	2078.0	726.1	2804.1	52
10cm XPS	2032.0	724.5	2756.5	53

As Table 2 shows, a concrete wall has a worse thermal behaviour in winter than a single pane hollow brick wall with 22cm due to its higher conductivity, but during summer it has a better performance due to its higher thermal mass.

As can also be seen on Table 2, if the external walls don't have insulation, according to ASHRAE 55, only in 36% (concrete wall) or 38% (brick wall) of the occupied period the occupants were comfortable because not only of the low temperatures verified inside but also due to the radiation asymmetry between indoor walls surfaces and low surface temperatures. Increasing the insulation level, the number of comfortable hours is increased in 10%.

The same occurs when the windows are replaced for equivalent window doors (windows with 2m high which correspond to 30% of the pavement area and to 60% of the area of the wall)), duplicating the winter solar gains. In this case, both walls have a similar thermal behaviour, better during heating season than the one with windows with 1m high (15% of the pavement area, corresponding to 30% of the area of the wall), but worse during summer due to higher solar gains. For example for a single pane brick wall with 4cm of extruded expanded polystyrene, the heating needs are reduced in almost 30%, but the cooling needs are increased by 43%, resulting only in 3% reduction on the global needs.

The same kind of study was done considering the placement of the insulation material (on the outside or in the inside of single walls) and it was verified that the heating and cooling needs are similar and are more significant for higher mass and insulation levels and in the cooling period (5%), due to the effect on the thermal inertia.

The same type of analysis, but with windows doors with 2m high and Low-E glazing, was carried out. In this situation the solar gains were increased and the heat losses were reduced. In this case a concrete wall with 15cm and 6cm of expanded extruded polystyrene on the external face has a better thermal behaviour than a single pane hollow brick wall with 22cm and 10cm of expanded extruded polystyrene, and uses less space.

The reduction on the heating needs is of 24% and an increase of 37% on the cooling needs meaning a reduction of 4% in the global needs each year. The increase on the cooling needs due to the higher glazing area could be minimized with a better shading device or with the use of reflective glazing which will reduce also the solar gains during winter.

This study shows that it is necessary to pay attention to the glazing area and to the shading devices, because even with a good glazing and shading systems it is required to control the solar gains during summer.

The same kind of analysis was done for double pane walls. In this case it was verified that there are no significant differences (2%) in the thermal behaviour due to the type of insulation material (extruded expanded polystyrene or mineral wool). The differences on the energy needs, due to the different types of constructive solution (double pane walls with hollow concrete bocks, brick or hollow brick) are of about 3%, being smaller for the higher insulation thickness.

The increase on the insulation thickness can reduce the energy needs in more than 33%, for example when comparing a concrete wall without insulation and with 10cm of polystyrene expanded extruded, and a minimum of 4.6% when replacing 4cm by 6cm of the same insulation material.

Reducing the number of air changes per hour (from 1.0 to 0.6 ach, minimum value according to the Portuguese Thermal Regulation) will decrease the energy needs to almost 1/4, considering an optimized solution with 10cm of insulation and Low-E glazing. In this case there is no need to heat the space during winter (Figure 4).

In this situation the occupants will be comfortable in more than 80% of the time. In the other 20% of the time, the mean radiant temperature is under the desirable values.

Another possible approach is to reduce the north façade windows' area (kitchen and dining and living room), that have few heat gains, avoiding unnecessary heat losses.

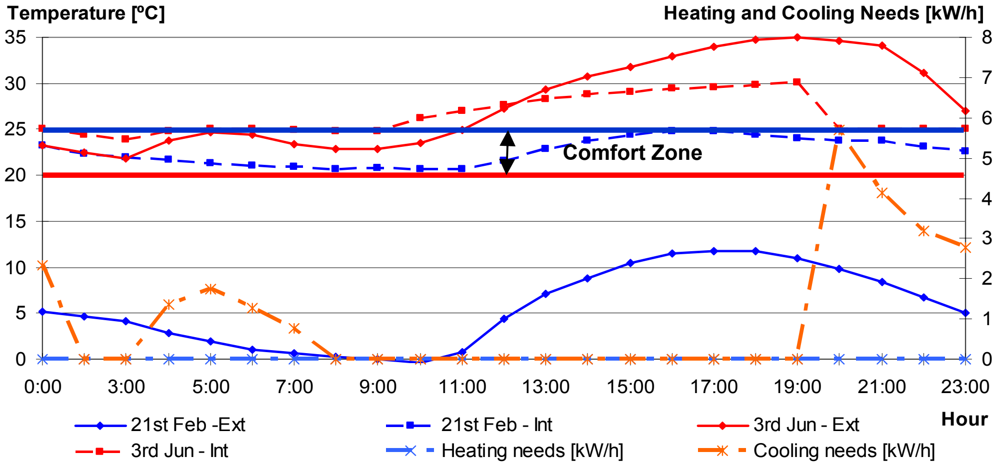

Figure 4 External and internal temperatures for the coolest and the hottest day – without HVAC

3.2 Acoustic behaviour

The acoustic requirements according to the Portuguese Building Acoustics Legislation (Decree-Law nº 129/2002) for residential buildings are the ones presented on Table 3.

Table 3 Acoustic requirements according to the Portuguese Building Acoustics Legislation (Decree-Law nº 129/2002)

Partitions	Weighted normalized airborne sound insulation index ($D_{n,w}$)	Impact sound insulation index ($L'_{n,w}$)
Between dwellings	≥ 50 dB	≤ 60 dB
Between dwellings and garages	≥ 50 dB	-
Separating dwellings from commercial areas	≥ 58 dB	≤ 50 dB
Between bed or living rooms and common circulation zones of the building	≥ 48 dB	≤ 60 dB
Between bedrooms or living rooms and vertical circulation paths (stairs), when the building has elevators	≥ 40 dB	-
Weighted normalized airborne sound insulation index of façades, measured at 2 m from them ($D_{2m,n,w}$)		
Sensitive zones (as defined on the Decree-Law nº 9/2007)	Exposed to $L_{den} \leq 55$ dB(A) and $L_{night} \leq 45$ dB(A)	≥ 28 dB
Mixed zones (as defined on the Decree-Law nº 9/2007)	Exposed to $L_{den} \leq 65$ dB(A) and $L_{night} \leq 55$ dB(A)	≥ 33 dB

On Table 4 are shown the estimated values for the weighted normalized airborne sound insulation index ($D_{n,w}$) and the weighted normalized impact sound pressure level index ($L'_{n,w}$) of the three studied floors.

The beam and pot slab studied don't fulfil the minimum requirements of the Portuguese Building Acoustics Legislation (Decree-Law nº 129/2002).

The concrete slab and the hollow core concrete slab fulfil the airborne, but not the impact insulation requirements.

Table 4 Acoustic behaviour ($D_{2m,n,W}$) of the dwelling floor

Element	$D_{n,W}$	$L'_{n,w}$
Concrete with 20cm, 4cm regularization layer, 0.5cm of polyethylene foam and 0.8cm of wood as top surface finishing and plaster as inferior surface finishing	52dB	67dB
Pre-stressed concrete "T" beams and 26cm hollow pots, 4cm regularization layer, 0.5cm of polyethylene foam and 0.8cm of wood as top surface finishing and plaster as inferior surface finishing	49dB	72dB
Hollow core concrete slab with 20 cm, 4cm regularization layer, 0.5cm of polyethylene foam, 0.8cm of wood as top surface finishing and plaster as inferior surface finishing	51dB	70dB

The acoustic behaviour of the floors, especially in what concerns the impact sound insulation, must be improved, using better resilient elements and floating pavements. A possible solution is the use of a resilient layer of expanded extruded polystyrene, which will improve the acoustic and also the thermal behaviour of the floor. This solution will fulfill the airborne and the impact insulation requirements ($D_{n,w}$ = 51dB and $L'_{n,w}$ = 57 dB). The wall separating dwellings and common circulation zones (double pane wall, hollow brick with 11cm and hollow brick with 11cm, with 4 cm of mineral wool in plates placed in the air cavity and finished with plaster on both sides) has a weighted normalized airborne sound insulation index, $D_{n,w}$, of 50 dB, fulfilling the exigencies of the Portuguese acoustic regulation. In the partition wall (single pane hollow brick wall with 11cm) the $D_{n,w}$ is of 38 dB.

On Table 5 are shown the estimated values for the weighted normalized airborne sound insulation index of the façade ($D_{2m,\,n,\,W}$). For the situation under analysis, almost all the cases fulfil the Portuguese acoustic regulation. The exceptions are the kitchen and the dining and living room with 2m high windows. As Table 5 shows, for external walls with 4cm of expanded extruded polystyrene and for the two types of windows (1 m and 2 m high, corresponding to 15% or 30% of the area of the wall, respectively)), there are no significant differences considering the different constructive solutions, as they are all heavy. However, comparing the performance of the situation with 1m and with 2m high windows, there are differences of 2 dB. So, to improve the quality of the façade walls it is essential to balance the window area and the acoustic quality of the glazing.

The reduction on the north windows area, as previously suggested, will also have a favourable effect on the acoustic behaviour.

Table 5 Acoustic behaviour ($D_{2m,n,W}$) of the dwelling external walls

Constructive solution	Single pane walls with 4cm of polystyrene expanded extruded on the outside		Double pane walls with 4cm of polystyrene expanded extruded on the air cavity	
	Concrete 15cm	Hollow brick 22cm	Hollow brick and hollow brick (15+11)cm	Massive and hollow brick (11+11)cm
Double glazed windows (6+10+8) mm with 1m high (15% of the pavement area and 30% of the area of the wall)				
Kitchen	34	34	34	34
Dining and living room	33	33	33	33
Bedroom 1	34	34	34	34
Bedroom 2	35	35	35	35
Double glazed windows (6+10+8) mm with 2m high (30% of the pavement area and 60% of the area of the wall)				
Kitchen	32	32	32	32
Dining and living room	31	31	31	31
Bedroom 1	33	33	33	33
Bedroom 2	33	33	33	33

Traditionally Portuguese buildings are heavy ones, and the study performed shows that in general the façade fulfil the requirements, for the case where the glazing has 1m high (area is of about 15% of the pavement area, corresponding to 30% of the area of the wall), if the windows area is doubled the requirements are not verified. So, in this case it is necessary to increase the quality of the windows.

3.3 Daylighting behaviour

The illuminance levels and the daylight factor for an overcast sky, recommended by CIE, are shown on Table 6 (CIE, 1975). Figure 5 shows the illuminance levels and the daylight factor for the 21st of December and for the 21st of July, for the bedroom 2, for windows with 1 m high (15% of the pavement area, corresponding to 30% of the area of the wall).

Table 6 Illuminance and Daylight factor for an overcast sky (CIE, 1975)

Illuminance Levels (Lux)		Daylight Factor (%)	
Dining room	100	Bedroom	0.5% at 3/4 of room depth
Living room, kitchen	200	kitchen	2% at 3/4 of room depth
Study	300 - 500	Living room	1% at 3/4 of room depth

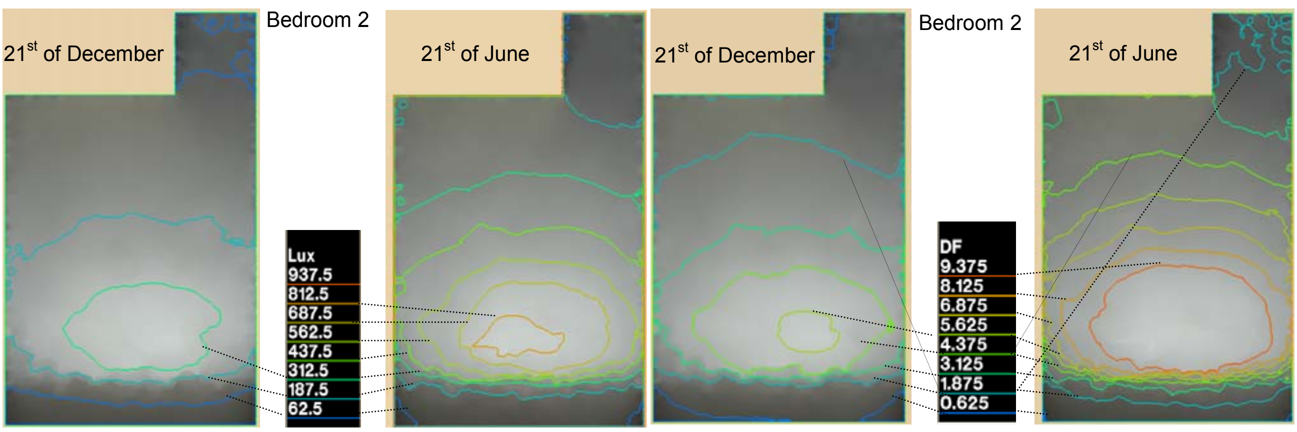

Figure 5 Illuminance Level and Daylight Factor for the bedroom 2, for an overcast sky

The recommended illuminance levels for the studied zones in winter are respected only on the area near the window, and in almost space during summer, but, for the Portuguese luminous climate, the recommended external minimum illuminance considered for an overcast sky is exceeded in more than 90% of the time during the year (Silva, 2002). According to the CIE recommendations, a daylight factor of 2% - 5% is usually the optimum rage of daylighting for overall energy use, and considering the recommended daylight factors for bedrooms these values are fulfilled during winter, but are largely overcome in summer or even in winter when the windows have 2 m high (30% of the pavement area, corresponding to 60% of the area of the wall) (CIE, 1975). The reduction on the north windows area will also have a favourable effect on the daylight behaviour, minimizing the glare, as, even in winter, in the zones nearest to the windows, the daylight factor and the illuminance levels will be high.

3.4 Global behaviour

Analyzing the results of the study it was possible to verify that, even with conventional solutions used in Portugal, it is possible to achieve a good global behaviour, considering the buildings' thermal, acoustic and daylight behaviour, but it is necessary to increase the insulation level of the external walls, and the acoustic quality of the glazing. It is also necessary to improve the acoustic behaviour of the pavements, increasing the quality of the resilient layer and using floating pavements.

5 Conclusions

From the analysis performed it was possible to conclude that there are a great number of constructive solutions, that when adequately used will fulfil the comfort exigencies.

In Portugal it is necessary to improve the thermal insulation levels of the façades and the acoustic quality of the glazing parts of the façade. It is also necessary to use windows with improved frames, with low permeability, to guarantee that the number of air changes per hour is of 0.6.

The selection of the shading devices must also be done carefully to reduce the heat losses during the heating season and the heat gains during the cooling season, and at the same time allowing the penetration of natural light and not reducing the acoustic behaviour of the façade.

The improvement of the night cooling of the buildings with high thermal inertia, during summer, and with the control of the radiation that penetrates into the building will also improve the thermal behaviour of the building.

The shading devices must be movable allowing the control of the radiation but, at the same time admit the entrance of the daylight, control the glare and adjust for variations on daylight availability.

The acoustic behaviour of the conventional floors and of the windows must be improved.

It is necessary to select the correct fenestration for each orientation, according to the latitude, lighting and natural ventilation, considering the solar gains, the outdoor obstructions and choosing the shading devices to optimize the energy and comfort needs to ensure the acoustic and thermal exigencies, the internal air quality and the indoor visual comfort.

But through the integrated approach to the building performance it was possible to conclude that the overall comfort exigencies are not restrictive, because there are a large number of constructive solutions that will assure all the requirements being only necessary to integrate the exigencies of the different requirements.

The windows area and the quality of the frame, the glazing and the shading device are the most important factors to take into account to fulfil the overall comfort requirements. The solution adopted for the fenestration must be selected carefully and may be different for each orientation.

The optimization of the building envelope, by improving insulation, glazing, and optimizing natural ventilation and daylighting techniques through appropriate design in order to improve the overall comfort does not limit the creative process of the designer.

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INFLUENCE OF SOLAR HEAT HIGH REFLECTANCE PAINT ON THE TEMPERATURE ABATEMENT OF BUILDINGS

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Keywords: solar heat high reflectance paint, temperature abatement, urban heat island, radiation, roof

Summary

Solar heat high reflectance paint is highly reflective in the sunlight radiation range while highly radiative in the black body radiation range is expected to counteract temperature increase in the painted object.

The effect of solar heat high reflectance paint roofs on the yielded temperature abatement as follow:

a) During the summer, in the roof surface, average reduction of temperature of about 16.9°C as maximum and of about 4.1°C as minimum temperature; and in the underside surface, average reduction of temperature of about 10.5°C as maximum and of about 4.5°C as minimum temperature.

b) During the winter, the temperature abatement due to the solar heat high reflectance paint corresponded to average reduction of temperature of about 11.4°C as maximum and of about 4.1°C as minimum temperature in the roof surface as well as of about 6.6°C as maximum and of about 3.5°C as minimum temperature in the underside surface.

1. Designing of solar heat high reflectance paint

Figure 1 shows the radiation energy distribution of sunlight and a black body. As can be seen from this figure, the sunlight is recorded an energy peak of about 0.5µm, while a black body at 50°C is recorded a peak at of about 9µm. Paint that is highly reflective in the sunlight radiation range while highly radiative in the black body radiation range is expected to counteract an increase in temperature in the painted object and to reduce the thermal load of the object.

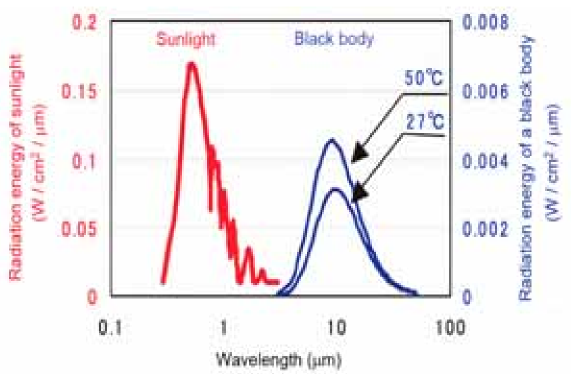

Figure 1 Radiation energy

2. Temperature abatement verification test at a roof of building in Tokyo

2.1 Outlines of experiment

Temperatures of the roof surface and underside surface were measured for two buildings of the same construction in Tokyo. The roof surface of one of them was painted by solar heat high reflectance paint and the other was not. Simultaneous with the temperature measurement at each spot, atmospheric temperature and amount of global solar radiation were measured and recorded.

2.2 Experimental results

Table 1 shows the average temperature and maximum amount of global solar radiation based on all data collected throughout the test period. The results indicate that the temperatures abatement of the roof surface and underside surface of the painted roof are lower than the non-painted roof. Comparison between the effect of painted roof and non-painted roof on the yielded temperature abatement as follow:

a) During the summer, in the roof surface, average reduction of temperature of about 16.9°C as maximum and of about 4.1°C as minimum; and in the underside surface, the average reduction of temperature of about 10.5°C as maximum and of about 4.5°C as minimum temperature.

b) During the winter, the abatement of temperature due to the high reflection paint corresponded to the average reduction of temperature of about 11.4°C as maximum in the roof surface and of about 4.1°C as minimum temperature as well as of about 6.6°C as maximum and of about 3.5°C as minimum temperature in the underside surface.

Table 1 Average temperatures and global solar radiation

Roof	Average temperature	Summer		Winter	
		Roof surface	Roof underside surface	Roof surface	Roof underside surface
Painted roof	Max. temp.	32.4°C	29.8°C	10.1°C	8.3°C
	Min. temp.	23.3°C	25.4°C	1.5°C	5.0°C
Non-painted roof	Max. temp.	49.3°C	40.3°C	21.5°C	14.9°C
	Min. temp.	27.4°C	29.9°C	5.6°C	8.5°C
Atmospheric temperature	Max. temp.	33.0°C		16.8°C	
	Min. temp.	25.2°C		1.9°C	
Max. amount of global solar radiation		858 W/m^2		479 W/m^2	

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A REVIEW OF ENERGY PERFORMANCE AND COMFORT IN DWELLINGS: THE HUMAN FACTOR

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Keywords: occupant behaviour, energy performance, indoor comfort, health, dwellings

Summary

Building activity, through the life span of a dwelling leads to environmental burden through material and energy consumption. Related research aims at accelerating energy performance focusing on building envelope and mechanical systems. However, strong indicators reveal that the precautions do not lead to the expected energy saving levels. Reasons for this could be problems about the building itself and occupant behaviour. This paper summarises the previous research about the relationship between occupant behaviour and energy performance, considering indoor comfort/health. First, actual behaviour of the occupant is briefly explained, then how actual behaviour relates to energy performance and indoor comfort/health is studied. Reviewed literature is categorised according to the factors related with occupant behaviour as; occupant characteristics [social, educational, economical] in household and individual levels and dwelling characteristics [site- climate, architectural layout, building envelope, mechanical systems and lighting & appliances]. Main findings of this study are: [1] most of the research about occupant characteristics and especially on education and economy aspects do not validate the proposed indicators with achieved saving levels, [2] and also in some of these studies periods of collecting data and validation about occupant characteristics are not well defined, [3] systematic studies are missing covering both occupant and dwelling related aspects, [4] previous research generally focus on energy consumption or indoor comfort/health. It should be emphasized that long term measurement covering both winter and summer behaviour in relation to energy performance and comfort, and its validation is needed.

1. Introduction

Human being shapes the physical environment around itself and in response; the physical environment that he deformed begins to change him. Currently, this mutual interaction has been leading to environmental depletion and energy resource decay in broad term and without hesitation the measures proposed for reducing energy consumption have to meet the demands for optimum liveable environment for the inhabitant. Nevertheless, in most cases, these two goals can not be achieved at the same time, this is either because of the defects in the building systems and components or resulting from the unexpected behaviour of the occupant. Aim of the paper is to develop an understanding of the relation between occupant behaviour, indoor comfort and energy performance in dwellings. Previous research conducted about the subject matter is analyzed in order to derive out the actual behaviour of an occupant, how it occurs, the consequences in terms of comfort, health and energy performance and to produce a framework for evaluation of the relationship.

Considered literature focuses on the relationship between occupant behaviour and energy performance or occupant behaviour and comfort/ health. Few studies make assessments of actual occupant behaviour from both energy performance and comfort/ health respects. This kind of research is mainly within the context of a specific dwelling type [single family dwellings-multifamily dwellings/apartments], condition of the dwelling [renovation/new built or old/new], the energy conservation approach ['energy efficient'/conventional] or from a project framework. Besides, when the occupant behaviour is considered, it is either a typical activity domain [heating, cooling, ventilation…] or an activity scenario [studying, eating, cooking….]. Reviewed literature is classified according to the parameters related to the occupant behaviour [Figure 1]. This selected literature is mostly preferred because of being conclusive parts of research projects, which could be important in terms of validation of data and they take homogenous measurement samples in terms of occupant size. Besides, more attention is drawn to the studies that analyse especially occupant behaviour both from energy performance and indoor comfort/health aspects.

In the literature reviewed, common method used is post occupancy evaluation. Data about actual behaviour of occupants are collected mainly through interviews, questionnaires and diaries; and in some of the cases through measurements like photography, micro switches and observation. Data about indoor air quality, thermal comfort and energy performance is collected also through field measurements and evaluated with simulation and/or statistical analysis.

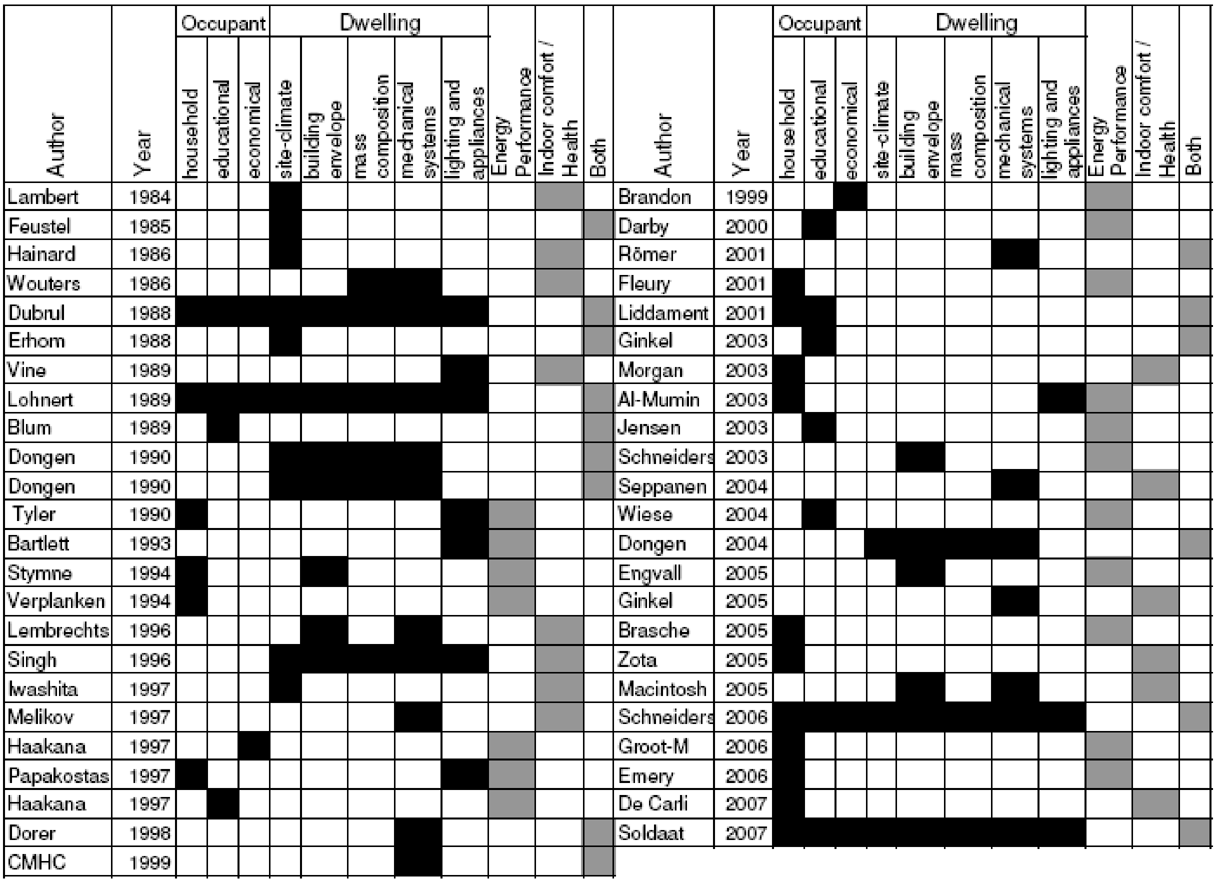

Figure 1 Overview of the studies according to the author, year and context.

2. Actual Behaviour of the Occupant

Planned behaviour is a consequence of behavioural intentions. These intentions result from attitudes, norms, and control perception. Underneath behaviour lie beliefs of behaviour, norm and control. Perception also influences behaviour but in separate twofold pathway [Armitage et al. 2003]. In Giddens's structuration theory, the analysis of environmental behaviour focuses principally on the behavioural or social practices in which human agents participate. Discursive and practical consciousness affects behaviour through lifestyle, rules and resources affect behaviour through provision systems [Spaarragaren et al. 2000].

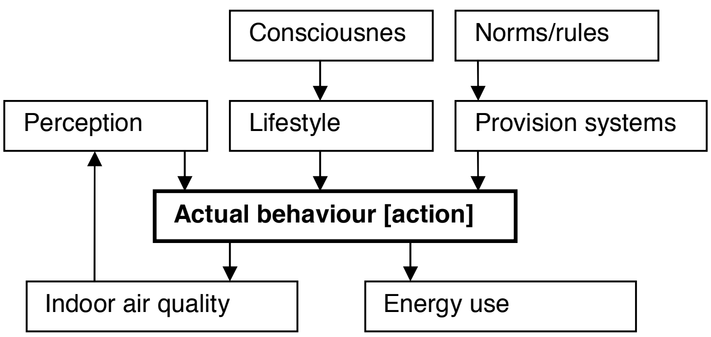

Figure 2 Frame of the actual occupant behaviour.

As actual behaviour influences indoor air quality and energy consumption in dwellings, existing or resulting indoor air quality influence behaviour through perception [Figure 2]. For example ventilation behaviour [Engvall et al. 2004] is strongly correlated with indoor air quality through perception. The occupant reacts depending on how he perceives fresh/ stuffy air, dry/humid air, cooking odours and other strong odours. At this point it should be emphasized that adaptation is involved in perception. Occupants adapt to the changing indoor air quality levels in every 15 minutes. Besides, adaptation raises the acceptability to indoor pollutants when the pollutant source is human behaviour like smoking, whereas building originated pollutants are less acceptable. Also cross adaptation is observed when among many sources of pollution, acceptability changes according to the concentration change of the main pollutant that the occupant is exposed [Gunnarsen et al. 1992].

3. Relation between Occupant Behaviour – Energy Performance and Comfort

Analyzing energy performance of a dwelling has building related and occupant behaviour related aspects. Occupant influences energy performance through its daily activities like studying, watching TV, washing up etc, through internal heat gain generated from metabolic rate [Tanimoto et al. 2008] and through reactions to the changes in the indoor environment. Since indoor air quality and indoor comfort level have health consequences, health could also be an indicator to evaluate indoor air quality and energy performance, consequently. The total energy consumption cannot be predicted closer than ±15-20% if the inhabitant's influence is unknown [Pettersen, 1994]. In literature, occupant behaviour in dwellings is analysed by specific daily activities, most of which are interrelated in terms of the output patterns such as heating and electricity use, cooling and ventilation etc. Relation between occupant behaviour, energy performance and comfort is bilateral: Either the occupant behaviour affects them and/or they affect occupant behaviour. This relation makes it obvious that the actual behaviour of the occupant must be analyzed, through how it occurs.

3.1 Occupant Characteristics

3.1.1 Household Characteristics [Social]

Size and composition of a household has an influence on occupant behaviour [Fleury et al. 2001; Liddament, 2001], and especially in terms of electricity consumption by household appliances and lighting [Papakostas et al. 1997; Al-Mumin et al. 2003; Tyler et al. 1990]. Occupation density together with poor ventilation, volume of the house and heating system has a significant impact on NO_2 concentration. Increase in NO_2 concentration may lead to health problems like asthma and allergen illnesses [Zota et al. 2005]. Considering occupant lifestyle, there are conflicting results in literature, some studies claim that it has strong effects in energy consumption and should be changed through education for energy conservation [Groot-Marcus et al. 2006], whereas some others show that differences in lifestyle do not have much effect on space heating energy behaviour [such as Emery et al. 2006]. Occupant age affects the time spent at home; the elder and the children are less outside [Brasche et al. 2005]. Habits are also major elements of behaviour, the stronger the habits are the weaker the influence of knowledge and attitude on behaviour [Verplanken et al. 1994]. For example, clothing habit is a means for the occupants of the dwelling to maintain their own energy balance with indoor climatic conditions, and the extent to which they rely on physiologic responses to maintain that energy balance determines the magnitude of their thermal discomfort and attendant dissatisfaction. Indoor thermal conditions influence body heat balance which leads to thermal discomfort feeling through physiological strain and this process results in behavioural thermoregulation [clothing] [Morgan et al. 2003]. In naturally ventilated buildings, clothing behaviour of the occupants is more related with outdoor temperature than in mechanically ventilated buildings [De Carli et al. 2007].

3.1.2 Educational Characteristics

Educational profile of the occupants has two perspectives, one is the education level of the occupant which may result in awareness about energy consumption and environment, second is motivation leading to awareness. Motivation could be through information and economic measures. In a study in Finland, first economic reasons provided the motivation for households to save energy: the occupants were eager to save energy by changing their lighting appliances, sealing windows, lowering room temperature and reducing hot water consumption. Households wished to get advice on use of electricity, space heating, ventilation and use of water. Half of the users began to turn down lights in the rooms not occupied, 29% reduced water use, 27% change clothing habits [Haakana et al. 1997]. In Denmark, eco accounts are used to provide information [Jensen, 2003] for tenants, after one year, heating energy reduced by 9% and electricity consumption by 22%. Product information about energy conservation also affects behaviour but relies on the actual willingness of the user to initiate or change specific behaviour patterns [Wiese et al. 2004]. Provided feedback and general information to the occupants about energy consumption, have strong influence on occupant behaviour. For example, when occupants do not know that ventilation demands are only met at the highest speed level of the exhaust fan, either the indoor air quality level or energy consumption level is not achieved due to the misuse of the system [Ginkel et al. 2003, Liddament, 2001]. Feedback should not be handled alone; factors such as the conditions of housing, personal contact with a trustworthy advisor when needed, and support from utilities and government which can provide the technical, training and social infrastructure are important to make learning and change possible [Darby, 2000]. Satisfaction of the occupant and their education about using the energy efficient features, good performance of a passive house, and about cleaning and maintenance requirements are important behavioural aspects. Lastly, occupant involvement in design stage is mostly crucial for achieving aimed energy performance levels [Blum et al. 1989].

3.1.3 Economical Characteristics

Economics treat attitudes, beliefs, values and the like as mere preferences and tastes are exogenous to economic models. Economic psychology provides psychological and financial influences in combined and contrasting means [Brandon et al. 1999]. Psychological influence would be observed in owner occupied houses where energy consumption level is less [Schneiders et al. 2006]. Financial influence is to supply energy consumption feedback to users [Haakana et al. 1997]. Design Context Booklet, the report of Task VIII conducted in IEA-SHC program, states the economical determinants of user behaviour as individual; ownership, income level, savings, employment situation or general; subsidy and advancement, tax reduction, energy, building and appliances costs [Lohnert et al. 1989].

3.2 Building Characteristics

In this study, the components of a dwelling that have impact on occupant behaviour directly or indirectly, are categorized as site & climate, architectural layout, building envelope, mechanical system and lighting and appliances.

3.2.1 Site and Climate

Outdoor air temperature, horizontal global irradiance, wind velocity and wind direction have an impact on user behaviour in terms window opening [Erhorn, 1988; Feustel et al. 1985]. The weather plays a main role in opening or closing the window. Users tend to open windows less depending at day/night and temperature below 12 ℃ and when the wind velocity is greater t han 3 m/s whereas horizontal global irradiance has a minor impact on user behaviour in correlation with outdoor temperature. The use of windows is linearly correlated with the outside temperature for temperatures between -10 ℃ and 25 ℃ and inversely correl ated with wind velocities. When it is raining or snowing, windows are less often used [Hainard et al. 1986]. In mild climates, residents' behaviour during the summer season and whether the residents opened windows/doors or operated air conditioners is very different [Iwashita et al. 1997]. Next to the weather characteristics, the quality of the outdoor environment; air pollution [odour] and noise [Van Dongen et al. 1990] are important factors. People shut the windows when the outside noise level is between 60 and 65 dB[A] and take more serious precautions like sound insulation, changing spatial organization, when it is more noisy than 65 dB[A] [Lambert et al. 1984].

3.2.2 Architectural Layout

Occupants use natural ventilation less when volumes of rooms are smaller; windows are less oriented to sun and more oriented to the prevailing wind direction [Van Dongen, 1990]. Windows that are fixed on the bottom of the frame and that open inwards are more often open than other types of windows [Wouters et al. 1986]. Upper wings of windows are open twice more often than the lower ones that are opening outwards. If the window in open stand can not be fixed at several positions through a grip, it is possible that the window will never be used [Van Dongen, 2004]. On the corridor side of the apartments the windows or vent-lights were opened maximal half an hour on average and on the balcony side maximal 1.4 hour when nobody was at home. Fear for burglary and for escaping of pets also plays a role here [Van Dongen, 1990].

3.2.3 Building Envelope

Basic natural ventilation is through the cracks in building envelope [Van Dongen, 1990]. Air tightness of the wall and material choice for fill, insulation and cladding are also influencing. Thus, construction quality and maintenance are crucial. Reducing the air tightness of the envelope may cause an impaired air quality perception and may lead to health related consequences [Stymne et al. 1994; Singh, 1996; Engvall et al. 2005]. This is a proof of the necessity for further studies to figure out occupant reaction to the change in indoor air quality conditions. However, a profound review about airborne particles in the indoor environment reveals that existing scientific evidence does not necessarily prove that indoor air quality has direct health consequences [Schneiders et al. 2003].

3.2.4 Mechanical Systems

The type of heating system plays a role. In dwellings with central heating windows are less often open than in other dwellings [Wouters et al. 1986]. Closely related with heating system, ventilation system is important both in terms of occupant use and indoor air quality effects. Ventilation rate should be as low as possible for energy conservation, on the other hand to sustain indoor air quality, it should be at a certain level which may conflict with energy conservation aim and this relation is strongly open to the occupant behaviour impact [Dubrul, 1988; Soldaat et al., 2007]. Behaviour is related with ventilation system type: Natural and/or Mechanical ventilation use differ together with household size, house's age, and its being single or multifamily [Stymne et al. 1994]. When household includes elderly and children, mechanical ventilation is less used. Grills are preferred more than windows for natural ventilation [Van Dongen, 1990]. However, mentioning that air temperature fluctuations may cause feeling of draught in rooms, largest temperature fluctuations appear in mechanical exhaust ventilation system and the minor changes are measured with balanced ventilation systems [Melikov et al., 1997].

Thermal comfort and health aspects are means for ventilation behaviour: Higher ventilation reduces the prevalence of air borne infectious diseases. Ventilation rates below 10 Ls^{-1} per person are associated with a significantly higher prevalence of one or more health or perceived air quality outcomes. Increases in ventilation rates above 10 Ls^{-1} per person, up to approximately 20 Ls^{-1} per person, are associated with a significant decrease in the prevalence of Sick Building Syndrome [SBS] symptoms or with improvements in perceived air quality [Wouters et al. 1986]. Poor ventilation in longer periods would lead to fungi growth in bathrooms, but there is no clear relationship stated between ventilation and dust mite allergies [Ginkel et al. 2003]. They further state that number showers, together with age of the ventilation system have a direct relationship with the mould growth in bathrooms [Ginkel et al. 2005]. Besides, Seppanen puts forward respiratory allergies and asthma as health consequences of poor ventilation system use. On average, the prevalence of SBS symptoms is higher in mechanically ventilated buildings than in naturally ventilated buildings. Better hygiene, commissioning, operation and maintenance of air handling systems may be particularly important for reducing the negative effects of Heating Ventilation and Air conditioning [HVAC] systems [Seppanen et al. 2004]. Römer indicates that together with the introduction of balanced ventilation to houses, as energy consumption decreased around 15-20%, health risk is elevated mainly due to the change in tap water temperature, relative humidity, dust and air exchange rate [Römer, 2001]. Lembrechts et al. [1996] point out that seldom use of the mechanical ventilation system in full capacity, result in radon increase in Dutch dwellings, together with the decrease in air tightness levels and building material use change. Dirty filters/heat recovery cores/ Heat Recovery Ventilation [HRV] cabinets, substandard ventilation and unbalanced supply and exhaust air flows create health problems in dwellings [CMHC, 1999].

Satisfaction and comfort level with respect to heating and ventilation system performance: If the air inlets do not fit with the esthetical preferences of occupants they may remove them. Noise from ventilation system plays a main role here [Van Dongen, 2004]. In a field study about HRV use, it is found out that; cooking, noise from outside, smoking, shower and cooling are mentioned behaviours not to use HRV so additional exhaust ventilation is required. Occupants have complaints about perceived air quality and dust around filters, nevertheless feel control over the HRV system [Macintosh et al. 2005] and satisfied. Most failures leading to discomfort and dissatisfaction are observed owing to bad manufacturing of components, improper selection and installations of components, bad system flow balancing, and inadequate commissioning, too high sound emission at supply and extract terminals and sound transmission, excessive window airing by occupants and general poor acceptability [Dorer et al. 1998].

3.2.5 Lighting and Appliances

Lighting behaviour in a dwelling depends on the type and characteristics of the dwelling, the type and duration of activities performed there, and the lighting habits of the members. Variations and behavioural factors about lighting and appliances among households can also be explained, in part, by the demographic composition of an area or country and its institutional setting [Bartlett, 1993]. Several studies are conducted to measure how different household appliances are used [Papakostas et al. 1997; Al-Mumin et al. 2003; Tyler et al. 1990] and it could be stated that use of household appliances is also directly and mostly related with culture and habits. Appliance control behaviour is clearly different according to occupant characteristics and thermal comfort level [Vine et al. 1989].

4. Discussion

Occupant behaviour is influenced by [1] occupant's educational and economical background and household properties, [2] dwelling's outdoor environment and climate characteristics, its architectural layout and envelope, mechanical systems installed, and lighting and appliances used in the house. Behaviour is either a reflection of the occupant's inherited and developed personal characteristics or a reaction to the perception of the indoor comfort conditions created. Dwelling's architectural characteristics, service systems and outdoor environment affect occupant behaviour in terms of their contribution to the indoor comfort conditions. Therefore in order to understand the occupant behaviour with respect to indoor comfort and energy performance of the house, these relations must be analysed in correlation [Figure 3]. However, in the literature revised, research that covers these aspects in correlation is lacking but they rather approach from one aspect. Besides, since perception is part of the behaviour and adaptation to indoor air quality has a considerable impact on perception; it should be studied to what extend adaptation affects perception.

Secondly, most of the research covering occupant characteristics aspects, and especially focusing on education and economy do not validate the proposed indicators with achieved saving levels and periods of collecting data and validation about occupant characteristics are not well defined. This reduces the reliability of these research results.

In literature, systematic studies are missing covering both occupant and dwelling related aspects, research generally focus on energy consumption or indoor comfort/health. It should be emphasized that long term measurement covering both winter and summer behaviour in relation to energy performance and comfort, and its validation is needed. Occupant and building characteristics that are covered in literature are categorised in Table 1. Further research should cover the interrelation of actual behaviour - energy performance and indoor comfort through the framework [Figure 3] and characteristics list [Table 1] proposed in this study. Moreover, it is important to realize if behaviour should be modified or the technology should be adapted to achieve reduced energy consumption levels and how.

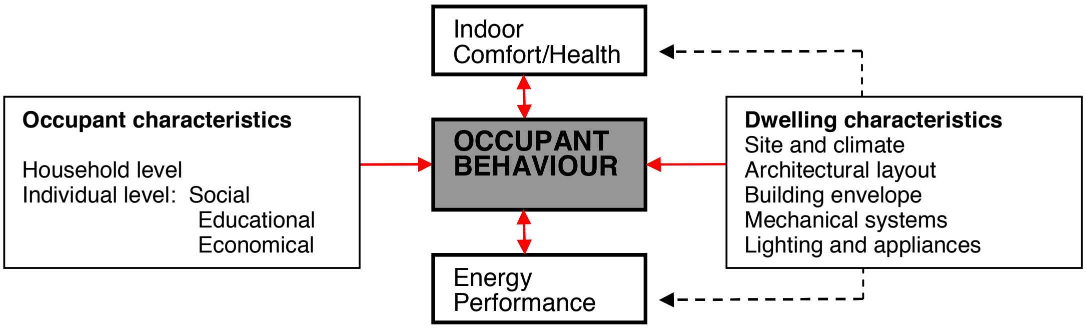

Figure 3 Occupant Behaviour Evaluation Framework.

Table 3 Characteristics affecting occupant behaviour [related with indoor comfort/health - energy performance]

Occupant Characteristics				Building Characteristics				
House-hold level	Individual Level			Site-Climate	Architectural Layout	Building Envelope	Mechanical systems	Lighting & appliances
	Social	Educational	Economical					
o Size o Compositon o Age o Presence	o Culture o Lifestyle o Hobbies o Habits	o Awareness o Knowledge o Realization o Attitude o Motivation o Sensitivity	o Ownership o Energy use pattern o Income level	o Weather: global irradiance wind direction, wind speed o Site: noise, odour	o Floor heights [volume] o Special design elements	o Air tightness o Material use o Insulation level o Window design	o Space heating system o Water heating system o Ventilation system o Appliances	o Lighting o Household appliances

Lastly practical information should be produced for actors in building process about design of systems and equipments to better adapt the systems to user behaviour. In addition to this practical guidance, more information for legislation especially about air tightness and ventilation rate standards is needed.

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ENERGY EFFICIENCY AND SAVING ON LIGHTING SYSTEMS IN EXISTING BUILDINGS: INTERVENTION STRATEGIES

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Summary

In this paper, we present the final results of a comparison of lighting energy performance in two groups of spaces, namely lecture rooms in an academic building (Faculty of Engineering, University of Trento). The study was carried out at the "CUnEdI: Centro Universitario Edifici Intelligenti" of the University of Trento. The first group of three lecture rooms is operated in a conventional manner: luminaries are switched on and off manually by the users. In the second group (spatially similar lecture rooms in the same floor/building and with the same orientation) different automated control regimes were implemented and monitored over a whole academic year. In all 6 lecture rooms (with both conventional and automated operation regimes) occupancy sensors and power consumption meters were installed to monitor these parameters separately for each lecture room.

In the referred research a new design methodology has been developed and verified, that relates energy saving and visual comfort. The analysis of the energy saving potential of automated lighting scenarios, carried out using specific standardization techniques, have been monitored in real use conditions and not in controlled laboratory environment, in order to prove the automation systems efficiency in operating time.

1. Introduction

Climate changes are one of the main challenges that our society will face in the incoming years. In this context the built environment plays an important role: the residential and commercial sectors account for more than 40% of end energy consumption in the European Community and are thus responsible for an important part of carbon dioxide emissions systems [UNEP, 2007]. Lighting has a substantial impact on the environment [ECCP, 2001]: the commercial sector account more than 25% of energy consumption in EU for the lighting sector.

Considerable savings could be achieved even by application of intelligent control technologies in existing buildings, with acceptable economical parameters [Zalesak M., 2006]. New European Regulations refer specifically to the use of occupancy and light sensors to control the artificial light and to improve the systems efficiency [prEN 15193, 2006].

Design software tools are intended to help designers with the qualitative and quantitative elements of daylighting design through features that commonly include: visualization of the luminous environment of a given daylighting design, prediction of daylight factors in a space lit by diffuse daylight, control of the penetration of the sun's rays and visualization of the dynamic behavior of sunlight [IEA, 2000].

In the last years, multiple studies have been carried out internationally to collect data on building users' interactions with building control systems and devices, in order to develop a stochastic model for predicting lighting energy consumption [Reinhart, 2004]. ADELINE has been used for the physically based computer simulation/visualization techniques developed for the specific case study analyzed in this research.

The analysis of the state of the art synthetically reported in this paragraph, about sustainability and voluntary protocols, innovation in field of energy saving, lighting automation systems and visual comfort, underlines the importance of lighting system effectiveness.

Based on the literature overview, it is becoming increasingly important to establish a realistic baseline of the actual lighting energy consumption in buildings for the different scenarios nowadays used (both manually and automatically operated), which incorporates occupant behavior. The features of lighting simulation tools currently available emphasize the importance of defining suitable reference cases for benchmarking the performance of automated lighting control.

At the same time, there is indeed need for a comprehensive understanding of the occupants' needs and preferences in daylit spaces that relates level and characteristics of the light and users' performance, even because recent developments in automated control systems and novel materials and technologies require new investigative directions [Brennan, 2007].

2. Method

In the research referred in this paper innovative design tools for lighting systems have been elaborated, specifically:

- the methodological approach for the energy efficiency evaluation (design methodology, software tool outputs evaluation methodology, data analysis method);
- the application for technological system choice of multiple criteria decision analysis;
- the development of specific model sheets to monitor and analyze visual comfort conditions.

These design tools have been implemented in a specific case study during the academic year 2006/2007: the Faculty of Engineering of Trento. The cross layout of this building is characterized by two parallel wings, both with the same south exposure. The referred lecture halls (manually and automatically operated) are symmetrical and have the same shape (Fig.1). This configuration allows their simultaneous comparison.

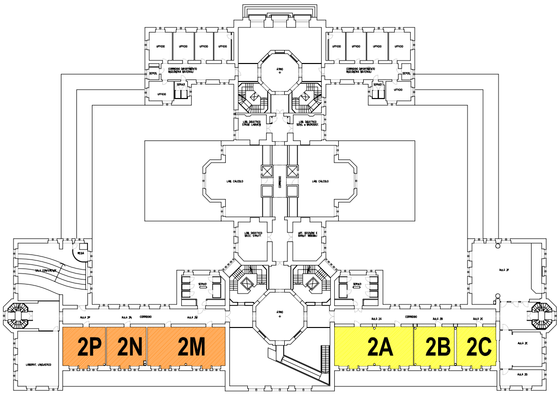


Figure 1 Building layout (east wing: traditional classrooms; west wing: automated classrooms)

The goals of the complete data analysis, concerning a whole year of data monitoring, are:

- to calculate the different percentage of the energy saving potential for various applications (Scenarios) of building automation systems for lighting control;

- to understand the users behavior in lecture halls with the traditional lighting system and to quantify the amount of energy loss for an improper use of the artificial light;

- to deeply analyze how the automated systems work, in order to improve the scenarios efficiency.

The comparison objects in this research are the performances, in terms of energy efficiency and visual comfort maintained, of lighting system operating manually and lighting system operating by automation system described by Scenarios.

The manual light system is assumed in this research as operated by switching on/off; the Scenarios are defined as follow:

Scenario 1 (2P): occupancy detection and minimum illuminance level control, as primary condition to switch on the lighting system (if $E_m > E_{threshold}$ then switch off);

Scenario 2 (2N): occupancy detection and minimum illuminance level control as primary condition to switch on the lighting system (if $E_m > E_{threshold}$ then switch off); dimming regulation of the artificial light as function of the natural light level detected in discrete points, as second automation level;

Scenario 3 (2M): occupancy detection by zones (the space has to be divided into discrete parts, each one detected by a presence sensor) and minimum illuminance level control as primary condition to switch on the lighting system (if $E_m > E_{threshold}$ then switch off); dimming regulation of the artificial light in more rows of dimming channels in order to approximate an ideal continuous dimming in the space, as second automation level; use of different and more efficient lighting sources.

Scenario 1in summer calculation (2P): scenario 1 and dimming regulation of the artificial light in 3 rows of dimming channels. That means that the light system is regulated and dimmed through 3 light detectors and 3 dimming channel in order to have a minimum illuminance.

2.1 Methodological approach development and application

The method of the case study evaluation has been divided in four phases [Frattari A., Albatici R., Chiogna M., 2007]:

- Analytical phase: monitoring and analysis of existing situation
- Programmatic phase: definition of project objectives and system requirements
- Propositional phase: system solution
- Evaluation phase: evaluation and verification

The developed methodology focuses on the following issues:

1. simulation, calculation and discussion of the ADELINE software tool outputs and comparison with the monitored data, developed in collaboration with the Fraunhofer Insitute of Stuttgard;

2. elaboration and statistical analysis of the users behaviour, calculated with the Technical University of Wien, in order to introduce improvements in the modelling process;

3. evaluation of the visual comfort maintained and perceived by the users, in relation with the illumination levels, in order to verify if the proposed model allows the visual comfort users requirements, in collaboration with the Ophthalmology ward of S. Chiara hospital in Trento.

2.2 Multiple criteria decision analysis: application for technological system choice

Many different criteria should be considered, in order to design a lighting automation system in compliance with environmental sustainability principles (efficient use of electrical light and control of the user's visual comfort) and at the same time with feasibility principles (use simplicity, economic convenience in installation and maintenance phase, esthetical characteristics, ect.).

For this purpose a specific design tool has been developed, based on multiple criteria decision analysis. The decision maker (DM) for the developed case study is the lighting designer/system integrator.

The specific approach developed in this research can be described as MADM, because it includes a unique object: the definition of the best automation devices for the implementation of an energy saving oriented lighting system and for the development of the system functionality measurement, monitoring and analysis. The system components have been defined in relation to a finite number of alternative solutions.

The definition of formal value structure has been developed, formally in form of criteria-tree.

The meta-criteria of the analyzed decision problem are reported in Fig.2 and, in order to specify and qualify each meta-criterion, the correspondent criteria have been definite and ordered in an importance growing scale.

Using the ordinal ranking weighting system, an evaluation scores has been defined. Moreover a graphical sheet has been developed, that can be filled simply by the system integrator and that calculates directly the score in tenth of the device tested. The calculation output includes an evaluation table as well, that is not only useful to get an overview of the problem but is also used to recover how the data are measured.

1	TECHNICAL ANALYSIS	1.1	functioning principle
		1.2	visualization and operating outputs
		1.3	wiring/transmission system
		1.4	power supply
		1.5	installation
2	DESIGN ANALYSIS	2.1	design
		2.2	commissioning
		2.3	supervision
		2.4	diagnosis
		2.5	technical support
3	MAINTENANCE ANALYSIS	3.1	glitch/electrical failure signal
		3.2	minimum operation level guarantee
		3.3	technical maintenance
4	EFFECTIVENES ANALYSIS	4.1	flexibility
		4.2	interface possibility
		4.3	installation modality
5	FORMAL ANALYSIS	5.1	color
		5.2	shape/dimension
6	ECONOMICAL ANALYSIS	6.1	price

Figure 2 Value tree for the case study decision problem

2.3 A model sheet to monitor and analyze visual comfort

The goals of the visual comfort subjective test experimented are:
- to check, if present, the uncorrected refractive errors of the students, for different contrast conditions;
- to define the critical detail for the student in a typical lesson condition, for defined boundary conditions;
- to compare the veiling luminance level perceived and the literature discomfort value;
- to evaluate the visual discomfort indexes of the students;
- to analyze the visibility, as calculated and perceived value, for defined boundary conditions.

The sheet is divided into the following 5 sections.

2.3.1 Boundary condition definition
The boundary conditions of the evaluated situation have been checked and monitored, as primary factors affecting the visual test results. For this aim, it was necessary to use a luxmeter to measure the inside illumination level, a weather station to evaluate the outside illuminance conditions, and a questionnaire to describe the individual visual deficit.

2.3.2 Critical detail definition
It was necessary to define the critical detail in the classrooms monitored, considering the two room sites: the 2M is 12 m long; the 2N and 2P are 6 m long. For this reason, two different optometric boards have been prepared: one with the standard dimension to detect the visual acuity from a distance of 5m, one with a double dimension to detect the visual acuity from a distance of 10m.
These two measures represent the critical distance, from the last work desk of the classrooms to the black board. Two different contrast conditions have been examined: positive and negative contrast.

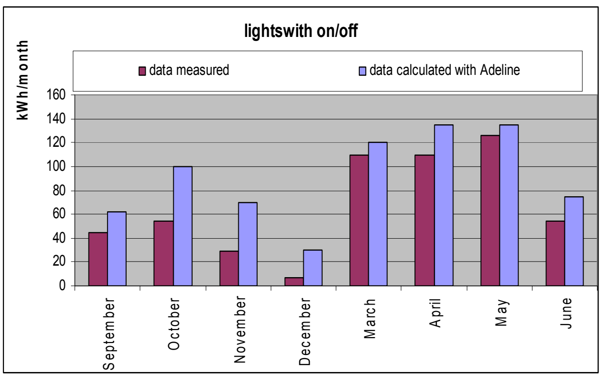
2.3.3 Visual discomfort evaluation
For different illuminance conditions the veiling luminance has been calculated [IEA, 2000]. The illuminance level has been measured in different significant points of the classrooms, describing the mean student's condition and as well the more critical position.
A model of the room has been adapted thanks to this data to the measured conditions and the contribution of each single glare source for different position has been calculated.
In the experimental test the glare perception has been evaluated. In particular the environmental conditions and the consequent glare feeling changing the shatter and blend position has been considered.

2.3.4 Visibility evaluation
Visual acuity and threshold contrast are two different aspects to define the visibility of a target. Visual acuity sets the minimum size for a target to be seen and threshold contrast sets the minimum luminance contrast that is required for a target of a given size to be seen. The contrast sensitivity function combines these two measures by showing the minimum contrast required for a target of different size to be seen. The visibility levels for different illuminance conditions have been calculated by the Adrian Model [Adrian, 1989 and 1993].

3. Results and discussion

3.1 Software tools outputs comparison

The Fig.3 shows the energy consumption comparison between data recorded for Scenario 1 (lightswitch on/off) and Scenario 2 (dimming) versus simulation outputs results. The Scenario 1 has been run only in winter semester. By the data analysis the energy saving for this scenario has been calculated the 40% of the respective energy consumption in traditional classrooms. On the basis of this result the summer semester energy consumption has been calculated.



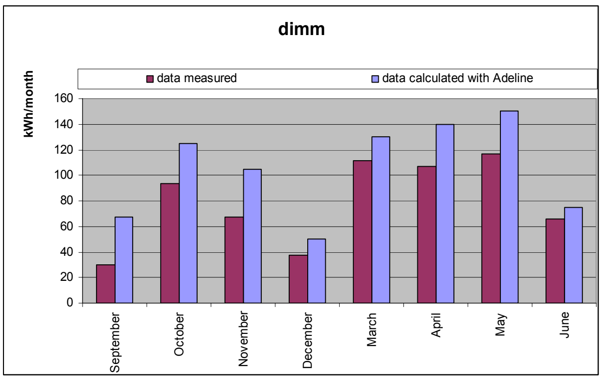


Figure 3 Energy saving calculated by Adeline and recorded for Scenario1 and 2.

These results can be improved setting the shading system variables. Indeed the ADELINE parameter file can be set as follow: none shading system fixed shading system, daylight-optimized shading system.

If it is supposed a shading coefficient equal to 0.7 for fixed shadow, the percentage difference between simulation results and real data follow sensibly as reported in Fig.4 The mean difference percentage changes:
- from 20% to 13% for the *Lightswitch On/Off Scenario*;
- from 22% to 15% for the from , *Continuous Dimming for Reference Point Scenario.*

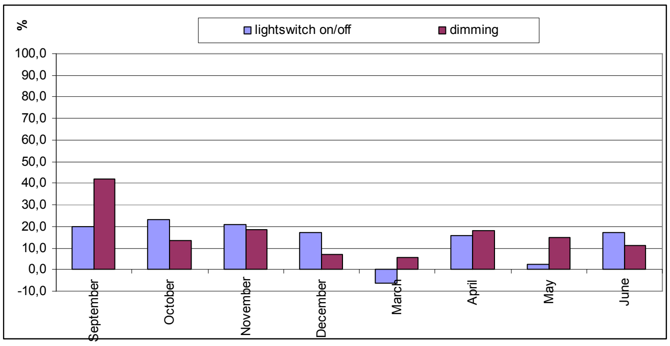
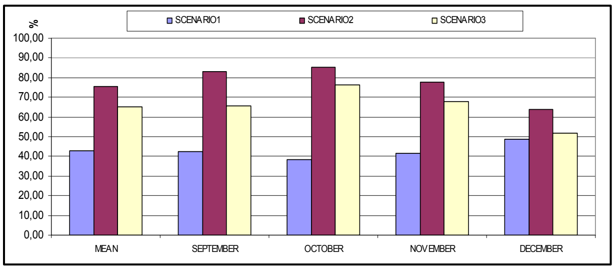


Figure 4 Energy saving percentage difference for Continuous Dimming for Reference Point and Lightswitch Adeline calculation: results for 0.7shading factor setting

Manual On/Off Probability, in ADELINE implemented equations, is defined by Hunt and predicts the probability for use of artificial lighting in a manually operated on/off-switching control system. The method is based upon patterns of switching behaviour observed in field studies in England. Hunt found out that the probability of someone switching on the artificial lights in a space is correlated with the minimum daylight illuminance on the working plane. From the data set of the field study, an empirical algorithm was defined [Hunt, 1979].
Running Adeline for the saved electrical energy calculation, the results obtained do not describe correctly the real situation for the traditional classrooms. Indeed a difference between the 80% and the 160% in winter semester and between 30% and 50% in summer semester has been evaluated.
The inside illuminance simulated by Adeline is underestimated, because of the user's behaviour positioning the curtains. The difference could be explained by the different use of the room considered: the first one is an office, where a person works alone; the second one is a classroom where more persons should attend a lesson. It has been verified that during the lessons the windows can be partially covered (because they could have been forgotten close by the previous lesson, because the lesson could include partially projections, sometimes for any specific reason) so that it would be necessary to select a shading factor = 0,7 to simulate better the real situation [Frattari A., Chiogna M., De Boer J., 2007].

3.2 Data recording evaluation

Using standardisation techniques that consider differences in occupancy duration, as well as indoor and outdoor illuminance levels, it was possible isolate the quantitative difference between energy performance of conventional and automated control scenarios [Frattari A., Chiogna M., Mandavi A., 2007]. The monthly energy saving results, obtained using the named normalization factor, are reported in the Fig. 5.



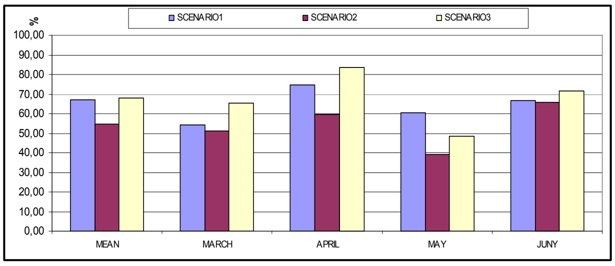


Figure 5 Energy saving of the three scenarios in the summer semester

Considering the whole observation period the energy consumption percentage is:
• 40%, if all three rows of luminaries are switched on when occupancy is detected and the room illuminance level (measured in the middle of the room) is below a predefined minimum level (Scenario 1- winter semester)
• 65%, if three rows of luminaries are switched on when occupancy is detected and dimmed (in two separately controlled circuits) so as to provide predefined minimum illuminance levels, measured at two points in the room, each corresponding to a circuit (Scenario 2). This lighting system has a better performance in winter than in the summer

• 65%, if the three rows of luminaries are switched on when occupancy is detected and dimmed (in three separately controlled circuits) so as to provide predefined minimum illuminance levels (measured in three points in the room, each corresponding to a circuit).
There are any significant different results if the lecture room is controlled in terms of two separate spatial zones (front and back) with dedicated occupancy sensors.
From October to December the energy saving percentage decreases, indeed it increases from March to April, in accordance with the outside illumination level. The disability and discomfort glare influence this trend, because an improper use of the shadow system often causes the unnecessary use of artificial light.
The minimum illuminance level value maintained in the traditional classrooms is low, especially in winter semester in the early morning and late in the afternoon.

Comparing winter and summer trends, the mean energy saving for Scenario 3 is above the 70% for the whole year. Checking the difference between Scenario 2 and 3 in summer semester, there is not any significant improvement of the system efficiency. This means that any effectiveness is detected in the lecture room controlled in terms of two separate spatial zones (front and back) with dedicated occupancy sensors.
The mean difference between winter and summer semester performance is mainly significant for the Scenario 2: indeed the energy saving percentage for this scenario deceases from the 75% in winter semester to the 55% in summer semester.

3.3 Visual comfort evaluation test

The detail definition in different illuminance levels has been defined for the fixed conditions expressed above, concerning the population age, the critical detail dimension and the background/target reflection factors. In particular 3 different illuminance settings have been evaluated:

a) inside illuminace between 200 lx and 300 lx, in order to describe the inside illuminance conditions in the traditional class room, when the artificial light is turned off in low outside illuminance conditions;

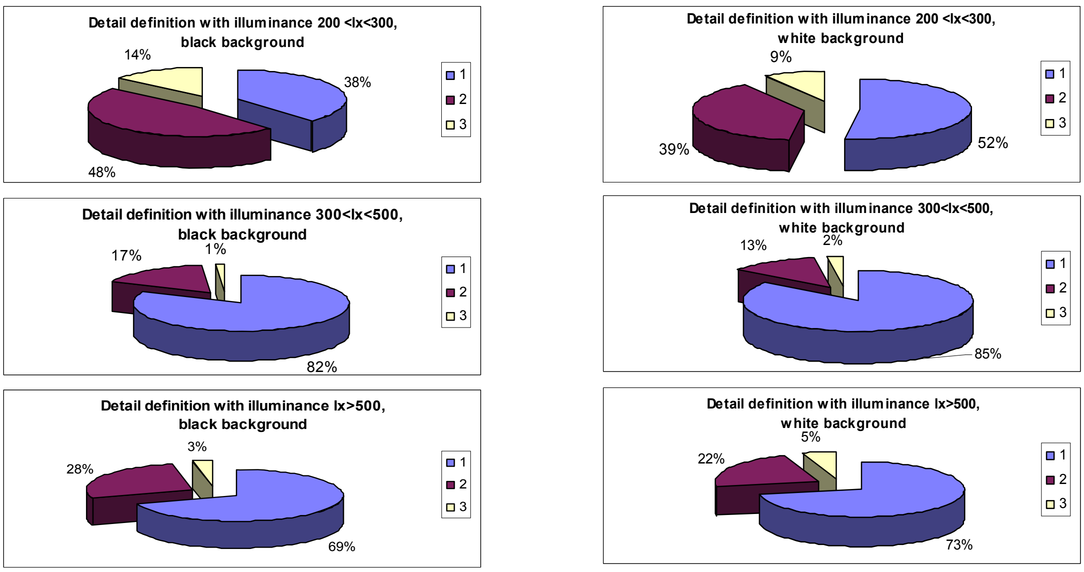
b) inside illuminance between 300 and 500 lx, in order to describe the inside illuminance level in compliance with the regulation UNI 10840 and UNI 12464-1;

c) inside illuminance >500 lx, in order to describe the inside illuminance level for possible glare conditions.

For the illuminance level (a) the percentage of the students that perceived a good detail definition is 38%, with black background, 52% with white background (Fig.6). That means that the percentage difference of the satisfied is 14%. Similar conditions have been measured for instance at 8.30, only with the natural light and the shatter completely open for the work places close to the inner wall. On the inside half part of work positions there is an illuminance level inferior to 200 lx.

For the illuminance level (b) the percentage of the students that perceived a good detail definition is 82%, with black background, 85% with white background (Fig.6). Similar conditions have been measured at 8.30, with artificial light operating and the shatter completely open or at 10.30, with only natural light and the shatter completely open. On the inside work positions there is an illuminance levels superior that 300lx.

For the illuminance level (c) the percentage of the students that perceived a good detail definition is 69%, with black background, 73% with white background. Similar conditions have been measured at 10.30, with artificial light operating and the shatter completely open.



1= it is possible to read easily | 2= it is possible to read with difficulty | 3= it is not possible to read

Figure 6 Detail definition for black and white background

Considering each different illuminance level described above and the correlated test results, it is possible to conclude that:
• black task on white background is the preferred contrast condition (negative contrast), especially for low illuminance level, often verified in the classrooms during the first and last classes;
• there is a lower difference in the detail definition between the inside illuminance condition of 300 lx instead of 500 lx than between positive and negative contrast;
• the main visual discomfort causes is the disability glare in the classrooms, perceived especially in the places closed to the windows. For this reason the shadow system is often not properly closed, so that the illuminance level could result lower than what expected.

So it is possible to define the following design guidelines for classrooms: to introduce a proper shadow system, in order to control the disability and veiling glare and at the same time in order to use the natural light contribution and to replace the old blackboard with the white, that permits a higher visibility level in different illuminance condition.

5. Conclusion

The research outputs have the following main implications.

1. Practical/technical implication: the definition of new automation lighting scenarios and their potentialities for the specific case study analyzed.
The research results demonstrate that the use of automated systems for the artificial light control can yield considerable energy savings, roughly between 40% and 60% depending on the complexity of the implemented system and of the parameters controlled, in the observed classrooms during the academic year 2005/2006.
The automated control system of the experiment could be further improved by incorporating shading control functionality. In fact, the improper use of the shading system can negatively influence the automation system efficiency and the daylight utilization.

2. Theoretic/cognitive implication: the new functions that it is possible to implement control-oriented user behavior software tools, in order to calculate energy consumption estimations more realistic.
Several studies have been and still are developed internationally to collect data on building users' interactions with building control systems and devices. Such data can bring about a better understanding of control-oriented user behavior in buildings and thus support the development of corresponding behavioral models for integration in building performance simulation applications.
The monitored data analysis has pointed out that the manual on/off probability used by Adeline doesn't correspond to the real condition in the observed lecture halls: specifically with an inside illuminance level higher than 500 lux it is still possible to have the light turn on (probability equal to 40%).
The obtained information would support the assessment of energy saving potential due to consideration of occupancy and behavioral patterns specifically in university buildings.

3. Comfort and efficiency evaluation: the relation between visual comfort perceived and the lighting system operational standard required.
Improving the energy-efficiency of lighting systems should include better use of daylight, but it will require the development of control systems that result in luminous conditions and that are suitable to occupants. Such the section 1.5 shows, what control system features would be most acceptable is not yet know, nor what range of luminous conditions the system should permit. Moreover the evaluation of visual comfort and visual ergonomic has been related mainly with the office/working places especially in reference to the use of VDT.
The analysis carried out in this research would include another application field for these concepts: the educational building, specifically the lecture halls of university building.
By the literature analysis, it is important to evaluate the correlation between productivity and satisfaction of the users on one hand and the efficiency of the lighting system on the other.

The monitoring data results could support the effective and proactive operation of building service systems for indoor environmental control. During the operation period of the automated systems, the following considerations have been pointed to a useful operation mode:
- the luminaries efficiency could be wiped up by the improper use of the blind system
- the occupancy detection in different spatial zones could bring any contribution for the energy saving, if the student are spread in classrooms even if they are a scan number in comparison with the available workplaces
- the use of the dimming regulation in classroom, where power point show has been used, could improve the students performance; it is indeed possible to maintain a balanced illuminance level that could allow simultaneously the slides vision and the writing action

In conclusion, the use of automation system guarantees a more efficient use of the artificial light and a higher visual comfort level: in fact it has been recorded that the minimum illuminance level value maintained in the traditional classrooms is low, especially in winter semester in the early morning and late in the afternoon, while on the contrary it is always guarantee in the automated classrooms.
Moreover the energy saving percentage is mainly related with the outside illuminance level; even if the disability and discomfort glare influence this trend (an improper use of the shadow system often causes the unnecessary use of artificial light).

The referred research evidences some significant results in order to better understand the effectiveness application of automated lighting systems.

Moreover, during the case study development, the following weak points have been pointed out:
- the lack of blind position data, because specific sensors were not installed in the rooms monitored
- the lack of weather data format file required by the simulation software and moreover the absence of complete weather databank for a significant monitoring period for the case study location
- the influence of the orography location (presence and dimension of the mountains) is not correctly modeled by the software simulation
- the improper use of the automation system by the users, during the first operating period, because they don't have enough familiarity with the new lighting system operation mode.

Finally, the following future steps could be developed, also in order to improve the limitations indicated above:
- the general patterns definition of user control behavior as a function of environmental parameters (indoor and outdoor), in order to develop proved models than can implement the reliability of computational building performance simulation application;
- the application of the new design tools in different building typologies: the methodological approach and the scientific rigor defined in this research could be a general praxis to be used in other case studies.

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RESTORATIVE SUSTAINABILITY, LEAN CITIES & LOW CARB MATERIALS

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Keywords: Greenhouse impacts, 'net positive' initiatives, cradle-to-cradle, restorative sustainability, green roofs, eco-balanced cities.

Summary

The current focus on energy supply sources in relation to the greenhouse impacts of current cities is only the tip of the iceberg in mitigating the societal impacts of climate change and resource utilisation. Just as we count carbohydrates to lose weight, our over-bloated cities and individual lifestyles need to go on a different kind of 'low carb' diet. Instead of counting carbohydrates, we need to count carbon outputs.

While this might smack of a single focus on energy once more, we need to realise that consumption *per se* is a major factor in itself. Just as we talk about the need for balanced lifestyles, we need to re-double and quadruple our focus on creating and utilising ecobalanced products, materials and technologies. This involves not just energy and resource use but the whole process of how we create and re-create the built environment.

This paper looks at what it will take to make ecobalanced cities and ecobalanced products that are engineered with multiple life-cycles considered before sale and how they can be re-use enabled by information flow into design, construction and higher levels of activity in physical re-sculpting at end of use. The Concept of Restorative Sustainability is presented and case study solutions provided.

1. Introduction

As 'Developed' nations', our cities, lifestyles and attitudes are the drivers of the biggest challenge humankind has ever faced and it is entirely of our own doing. There is now a real need to look beyond the superficial sound bites and the politically driven mantra that climate change is largely due to the obvious energy consumption of electricity and transport. The recent publication 'Climate Code Red' puts a very strong case for a 'climate emergency' response similar to the 'war footing response of economies' in times of war. Our response to climate change focussing on operational energy consumption has to date been superficial and slow footed.

Digging deeper we see that while the energy consumption of electricity and transport in homes and businesses is obviously a major issue there is significant carbon other resources embodied in the actual buildings, infrastructure and lifestyles as well. There are also more fundamental drivers underlying this energy consumption that are not being addressed. The 'great unsaid' in the debate to date is consumption in general and our growth economic models that recognise all economic activity as 'positive' (even if it is rebuilding from natural disasters or cleaning up after toxic spills that have devastating environmental consequences) and still more fundamentally, population growth itself.

"The economy is a wholly owned subsidiary of the environment, not the reverse."

Herman Daly, The ex Chief Economist for the World Bank, Quoted in 'The Age' May 4 2007

While it takes massive amounts of energy to run cities, it also takes vast amounts of energy to build cities, resource, feed, clean, maintain, demolish and renew them. Our commitment to buying the 'latest and greatest', means there is a need for us to change our behaviour about what we design, construct or buy, how we use, maintain and even dispose of all personal and societal 'acquisitions'.

To date, when considering how we might reduce impacts, we have, importantly tended to focus on reducing future impacts by the now common ‘3Rs’ catch phrase of actions, ‘Reduce, Re-use, Recycle’ and a range of variants promoted by such pertinent books as Lovins’ et al in ‘Factor Four – Doing More with Less’, William McDonough and Michael Braungart’s ‘Cradle-to-Cradle’, Paul Hawkins’ Natural Capitalism’ and Janine Benyus’ ‘Biomimicry’. Focussing on how we reduce past impacts has to an extent been left in the margins and to nature. It has been assumed that ‘if we reduce our impacts, nature can look after herself and will recover in time’. While the ‘Reductive Sustainability’ most discussed in the above works have a critically important role in promoting sustainability up to a point, how can we create a net positive impact to redress the past if we only ever reduce a future negative impact?

Along with all the necessary strategies dealt with in the above works, there is a need for an additional ‘enhancing nature’ focus. A focus on how we can begin to pro-actively support nature where possible, to create initiatives that have a ‘net positive’ impact that ‘put back’ more than they ‘take out’ of our ‘Natural Capital’. These are initiatives that can be described as ‘Restorative Sustainability’. This paper looks at the role of cities in our un-sustainability and explores the full spectrum of strategies and solutions as to how cities might become a pathway towards a ‘Low Carb’ future and how, using carbon as a proxy, we can move towards a more sustainable future with cities as part of a ‘5Rs’ solution.

2. The Inconvenient Truth

This paper will firstly analyse the major issues and actions within cities generating impacts that are accelerating our unsustainable demands on our Natural Capital, then look at the important ‘Reductive Sustainability’ actions that can be implemented to reduce future impacts. It will then investigate a definition of what makes something ‘restorative’ then present some examples of ‘Restorative Sustainability’ initiative and how cities can be used as part of the solution.

2.1 The Issues

When we consider the impacts of cities and the societies that live in them, it is useful to understand where the impacts are being generated and more importantly, where the potential savings are. Most studies, such as the Vatenfall study cited below when reviewing these impacts, only review recurrent operational impacts:

> *The buildings sector generates 8.2 GtCO_2 or 21% of total global CO_{2e} emission; 8% through emissions from primary fuel types (coal, gas, oil), 13% generated from power production to meet electricity demand from residential and commercial buildings.. (Vattenfall 2007)*

Furthermore, seen from figure 1 below, the growth in this sector has been astronomical over the last 50 or so years.

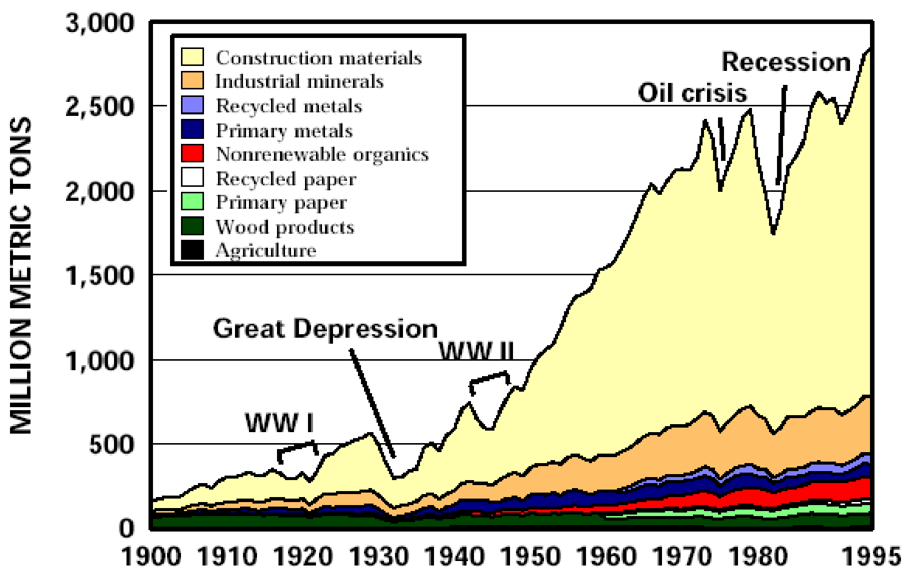

Figure 1 The growth in US materials consumption by sector 1900-1995 (Matos & Wagner, 1998)

A significant amount of embodied energy is being overlooked in the macro studies of potential CO_{2e} savings given that building and construction accounts for 40 percent of global use annually. (Roodman & Lenssen 1995)

When we look at the relevant proportions of operational vs. embodied energy in the residential sector, as exemplified by the analysis of a typical household (Treloar et al, 2000), and a 40 year analysis of 40,000m2 office building (Treloar et al, 1999), the majority of energy is consumed in operational energy. However, we also see a significant proportion of overall energy resulting from embodied energy, not just of the buildings themselves but of also of recurring consumption as part of the overall 'lifestyles' (over 50%) of occupants and commercial fitout churn.

2.3 Heat Islands: The Urban Negative Feedback Loop

A major negative global warming 'feedback loop' has emerged in the way that our cities have now been shown to heat up and retain heat compared to surrounding less densely settled surrounding areas. This 'urban heat island' effect has been identified around the world and most recently in Melbourne Australia. Melbourne has been shown to be on average 3.5-4.5 ^{o}C hotter during summer evenings and up to 10.0^{o}C hotter on still summer evenings. (Morris 2000)

3. How we can 'ecobalance' our cities

In beginning to look at how we can ecobalance or cities much has already been done to analyse what benefits can easily be found. Of the identified potential annual savings of 26.7 Gigatonnes of carbon emissions costing under €40/tonne, nearly 14% are in building alone and the influence of the buildings, materials, infrastructure and consumption can be seen throughout the rest (McKinsey 2007). A total of 3.7 $GtCO_2e$ of low-cost abatement options have been identified- 3.0 $GtCO_2e$ in the residential sector and 1.3 $GtCO_2e$ in the commercial sector which would hold emissions growth to 26% for the Construction sector by 2030. Heating and ventilation including building envelope improvements, water heating and air conditioning provide the largest potential beneifts for both residential and commercial buildings, contributing a total of 2.3 GtCO2e (62%). Lighting is potential contributor mainly in residential building, potentially leading to 0.3 GtCO2e emission reduction. Improving other appliances and reducing standby losses yields another 1.1 GtCO2of abatement (Vattenfall 2007).

3.1 The Role of Materials & Design: 'Reductive Sustainability' as Part of the Solution

If we are to reduce CO2 by 60% by 2050 to stop global warming rising beyond 1oC to the 2-2.5oC that current emissions rates would generate, (Raupach 2007) further economical CO2 savings need to identified. The role of materials has been highlighted in the above data and provides ready evidence that materials have a key role to play. The key next question is now – how can cities and their materials's potential as part of the solution be realised given they can provide benefits with little, or often no cost, sometimes even with cost savings. These focus on reducing impacts by design, cleaner production strategies, materials selection and evaluation strategies. They can all be categorised as falling within the concept described by this author as 'Reductive Sustainability' as the following strategies illustrate:

3.1.1 Materials choice
There is much to be gained from identifying the 'best of class' within any materials categories. A review of comparative embodied energy data of different residential building assesmblages by Walker Morison et al (2007) has shown there can be up to nearly a 1900% difference between the best and worst performers in some categories.

3.1.2 Industrial Ecology & 'Cradle to Cradle'
Since the early nineties, various authors including Frosch (1992), Allenby (1992) and Ayres (1994) have introduced the concept of industrial ecology where technical cycles are designed to mimic natural organic cycles in nature where there is no waste at all. McDonough and Baungart (2002) coined the term 'Cradle to Cradle' to describe how materials, products and technologies (and cities) need to be re-designed to ensure that all elements or sub-components of any product on deconstruction, to fit within one (or both) of these cyclic production/consumption/remanufacture/consumption systems. To ensure this approach works products need to be designed for disassembly.

3.1.3 Design For Disassembly (DfD)
Manufacturers and all sectors of the built environment need to design, manufacturer and incorporate materials, products and technology in cities (and the built environment generally) in ways that facilitate DfD, or

at the very least do not hinder it. The key criteria for designers relating to DfD, according to Walker Morison (2007) is to 'Start by designing with the end of life in mind'.

3.1.4 Design For Climate (DfC)
Also known as 'passive solar' design, DfC means designing buildings and incorporating materials in such as way as to maximise the use of environmental heat sinks and sources in the heating and cooling of the internal spaces for thermal comfort and daylighting. DfC is the most powerful design strategy we have to minimise the carbon footpint of operational energy consumption in buildings. We are yet to see zero-carbon footprint buildings mandated, although the UK is planning to yet they are technically feasible in most climates.

3.1.5 Buy Recycled
One of the most important initiatives to ensure that the carbon footprint of materials are minimised is the make sure that products being purchased and specified already contain recycled content. While being recyclable is important, first priority should be give to those products that already contain high levels of preferably, post consumer content and have constituent componentry clearing identified to facilitate the next recycling cycle.

3.1.6 Design for Durability
The single most important issue in life-cycle impacts of buildings and materials is durability, providing the carbon payback period is more or less, short term. It is an unfortunate reality than many (not all) highly durable materials are high in embodied energy. For this 'carbon investment' an 'avoided energy' return needs to be calculated, i.e. are the savings that accrue as a result of a material or product's durability due to avoided maintenance or unnecessary replacement,

3.1.7 Biomimicry
By using nature as a model we are finding amazing ways to reduce the impacts of how products are made and recycled. Janine Benyus in her 1997 book looks at case studies of how products are being designed using natural criteria and processes. Key lessons that can be drawn from this approach relate to how we evaluate products, how we choose beween alternatives and how we integrate industrial ecology cycles, ensuring that the materials and technology with the lowest carbon and toxics life-cycles and biodiversity impacts prevail.

3.1.8 Dematerialisation & Factor Four$^+$
Dematerialisation is about increasing the efficiency of materials e.g. the Weisacker and Lovins' Factor Four: Doubling wealth, Halving Resourse Use' is about 'doing twice as much with half as much' i.e., increased resource efficiency sometimes also known as eco-efficiency. Dematerialisation is also an issue in building design where efficient use of resources can be influenced by structural design efficiencies, detailing practices and the level of finish.

3.1.9 Renewable Inputs
Subject to where and how products are manufactured, transported and used and hence the extent of the importance of durability, the use of renewably sourced products can have a major impact on reducing overall environmental and carbon impacts..

3.1.10 Identify Carbon Sinks
Some products that bind large amounts of carbon in the materials themselves during use are called carbon 'sinks'. Provided the materials are long lived, there are significant benefits in starting to increase the use of products that are high density carbon sinks, e.g. claimed carbon sink benefits of a natural rubber based flooring over other natural and synthetic floor coverings. (Dalsouple International).

3.1.11 Embodied Water
Another emerging issue due to both lack of the resource as a result of global warming and the negative global warming impacts of the embodied energy of water is the embodied water content of products. Crawford and Treloar (2005) showed that the embodied energy content of a 11,200m2 office building ranges from 6.3 kL/m^2 using process analysis, to 54.1 kL/m^2.

3.1.12 Durability vs Greenhouse
Another key concept that has gained strong acceptance within the marketplace is that 'durability is good sustainability'. This is not always the case. In light of the case put forward by 'Climate Code Red' and recent work by the author, it is apparent that we need to study the carbon intensity of products and assess the life-cycle benefits of products and materials against much shorter timeframes than many materials and contexts will allow. The life cycle carbon intensity of external non-structural steel and aluminium components are so significantly higher than timber that the durability benefits of these metals just cannot payback within the lifetime of the products (even allowing for full recycling) in many instances.

3.2 Materials & Design: 'Restorative Sustainability' completing the solution

Along with 'Reductive Sustainability' strategies however, there is a dire need for an additional 'enhancing nature' focus. This focus on pro-actively supporting nature requires us to where possible, create initiatives that have a 'net positive' impact that 'put back' more than they 'take out' of our natural capital by integrating initiatives that 'Repair and Restore', such initiatives are described by this author as 'Restorative Sustainability', however, we first need to identify what actually constitutes sustainability from a scientific viewpoint.

3.3 Defining Sustainability'

While there are numerous literary definitions of sustainability *per se*, such as the Brundtland Commission's and Australia's National ESD Policy, that focus on mitigating impacts, maintaining intergenerational equity and working with the 'Precautionary Principle', these are very broad overarching Principles that do not really help us actually identify and implement actual strategies. In fact, we do not really have a clear idea what a truly sustainable city actually looks like or how it can operate given the extent of existing development infrastructure and systems. There is no doubt that a truly sustainable city will of necessity be radically different to what we are doing now- not just from a physical standpoint, but from a systems (transport, services, energy etc) and societal standpoint as well. According to the Australian CSIRO, the 3 'Sustainability Wedge' strategies required to deliver sustainability are, as seen in Figure 2:

1. A values based decline in consumerism
2. A dematerialisation of Product and services; and
3. Closing the Loop in Industrial Ecology.

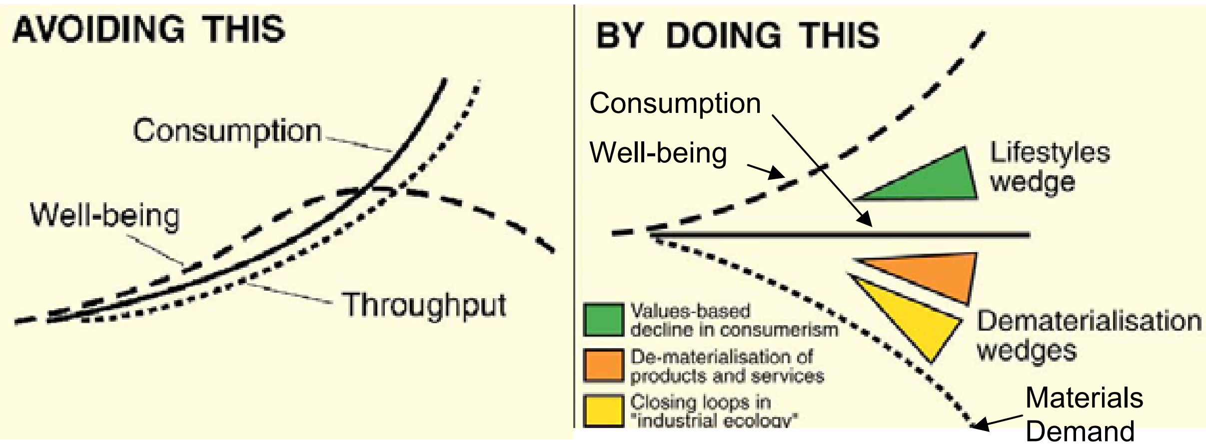

Figure 2 CSIRO vision of unsustainability and its impacts (left) and 3 proposed interventions necessary to deliver sustainability.

While there are numerous literary definitions of sustainability *per se*, The Natural Step Institute has developed 4 System Conditions for Sustainability define sustainability from a scientific standpoint and can be used as a 'compass' for setting policy in city reformation:

1. Substances from the lithosphere (within the earth) must not systematically increase in the ecosphere;
2. Substances produced by society must not systematically increase in the ecosphere;
3. The physical basis for the productivity and diversity of nature must not be systematically deteriorated;
4. The fair and efficient use of resources with respect to meeting human needs.

3.4 Defining 'Restorative Sustainability'

If we are to solve the looming global warming crisis, we need all the tools in our armoury to be fully primed and must be ready to actively implement them. The interventions needed to current consumption patterns include not only the first three Sustainability wedges shown in Fig 3 below (as adapted by Heij (2002) from Raskin (2002)) a fourth needs to be added:

1. A values based decline in consumerism
2. A dematerialisation of Product and services;
3. Closing the Loop in Industrial Ecology; and
4. Identifying and incorporating 'Restorative Sustainability';

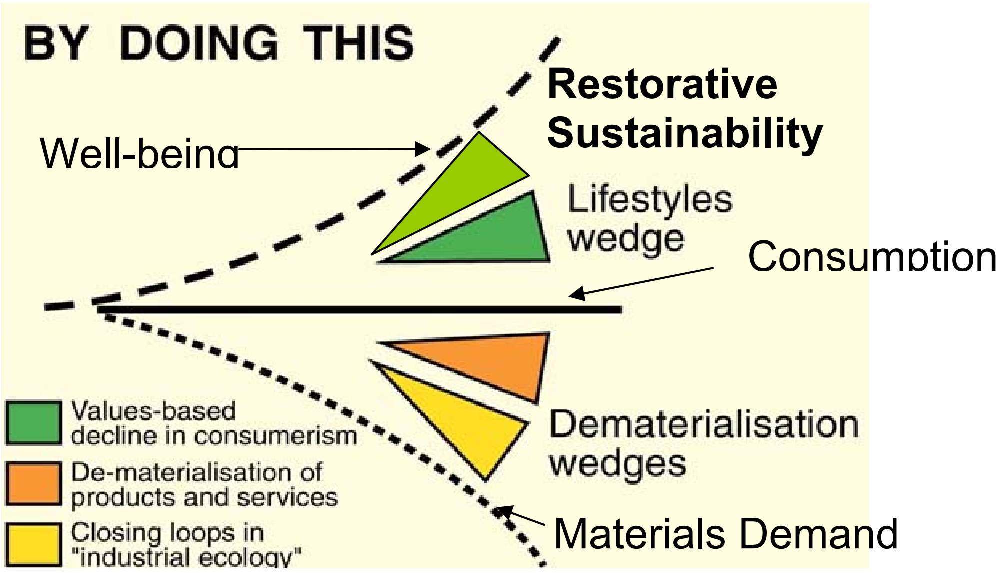

Figure 3 The full complement of 'Sustainability Wedge' Initiatives required to deliver sustainable, lean, ecobalanced cities (adapted from Heij 2002)

So what is 'Restorative Sustainability' and what constitutes a restorative solution? To be restorative a strategy, process or product would;

- meet all TNS System Conditions for Sustainability;
- be long lived perpetual or self perpetuating;
- be non maintenance or low maintenance
- likely be biological or biomimicking or ?

So far as outcomes are concerned, they create:

- net positive environmental and health outcomes
- multiple ecological benefits
- long lasting effects

3.5 'Restorative Sustainability' Solutions in Practice

A range of initiatives that have been identified as currently available and meeting the above criteria are presented below. There may well be others not yet identified and this author would welcome suggestions as to others or comments on the above proposed criteria.

3.5 1 ClimatePositive:
An Australian carbon offset organisation that focuses on tree-planting offsets. For every tonne of CO2 subscribers produce, 1.3 tonnes is offset - 1 tonne with verified emission reduction projects, and an additional 0.3 tonne over time through ecologically diverse forest restoration projects. All or part of an individual, family or company's annual CO2 emissions including travel, food, buildings and lifestyle can be offset. (ClimatePositive)

3.5.2 Green Roofs
Green roofs and earth covered buildings provide a diverse set of benefits including potential: energy savings; air pollution and CO_2 sinks; nutrient & pollutant sinks; stormwater volume reduction; biodiversity restoration; reduced urban heat island impacts; higher levels of visual amenity; Lower maintenance and longer life of roof surfaces; Dual landuse including recreation and productive urban garden potential. (Baggs et al 2007)

3.5.3 Green Walls
Plantscaping in general provides numerous benefits similar to green roofs,but to a slightly lesser extend depending on the volume of soil present: energy savings; air pollution and CO_2 sinks; nutrient & pollutant sinks; stormwater volume reduction; biodiversity restoration; reduced urban heat island impacts; higher levels of visual amenity; Lower maintenance and longer life of wall surfaces; Dual use including privacy (e.g. CH2 Building, Melbourne City Council) and productive urban garden potential (Baggs et al 2007)

3.5.4 Plantscaped Interiors
Have been shown by research to reduce air pollution and provide CO_2 absorption. They absorb and bind indoor volatile organic compounds (VOCs) and airborne pollutants including CO_2 into biological matter. This ability results from the interaction between soil, micro organisms. Plants also provide additional psychological benefits resulting in a contribution to increased worker satisfaction and potentially productivity.

3.5.5 Beneficial Microorganism Water Treatments
Are non-toxic, biodegradable, and self perpetuating, probiotic treatments which digest solid waste, transforming effluent ponds into usable water, removing any organic waste or odour control and sanitation in industrial, commercial and residential applications with the effect of multiplying the efficiency of the plants significantly – up to several times, potentially saving some large industrial or municipal waste water treatment plants 10s or even 100s of millions of dollars in avoided upgrade requirements or delayed expenditure. Whatsmore, the microorganisms continue to assist even out into the broader environment maintaining their beneficial conversion of nutrients and reduction of pathogens provided aerobic conditions exist (ecospecifier.org).

3.5.6 Microorganism-based Waterless Urinal Conversion
Waterless urinal conversion systems such as Desert ™ Cubes also contain naturally occurring microbes to turn existing trough or bowl facilities into touch-free waterless urinals. The embedded microorganisms naturally breakdown the organic matter inside the drain and interfere with the bacterial digestion that produces unpleasant odours. Reduces drain clogs and stains and reduces pathogens. Installed in any existing urinal or after construction, as above, the microorganisms continue down the pipe provided aerobic conditions exist. (ecospecifier.org)

3.5.7 Net Positive Renewable Energy
Renewable Energy sources are greenhouse emission free except for their embodied energy. Different types of systems have differing rates of embodied energy payback from 2-4 years (Baggs & Haines 2006). While ever the size of a PV or other renewable energy system is designed to replace only the emissions of a particular load, it is a 'reductive sustainability' solution. However, as soon as the embodied energy is paid back and the energy generated exceeds the annual load of the site and provides net positive energy into the grid it can be said to be a 'restorative solution'.

3.5.8 Restitution of Indigenous Plant Associations and Ecological Quality
While not relevant to every site, some sites and roofs tops may be suitable for the re-establishing of areas of plantings using locally indigenous plants and soil profiles. When grown on roofs, the benefits of green roofs (see above) would also apply.

3.5.9 Offsite Tree Planting
This strategy is being used widely as an emissions offset tool already. The benefits that accrue will actually depend on a variety of issues such as the area being planted, the planting style (monoculture or diverse), adjoining ecosystem integrity (better if diverse communities planted adjoing high quality forest with similar locally derive seedstock to allow more holistic re-colonisation of the ecosystem over time) and forestry practices (use of baits, genetically modifed seedstock or not etc).

4. Ecospecifier: a Key Tool for Implementation

One of the factors limiting the implementation of sustainability is the difficulty design and construction professionals find in locating products with *bona fide* preferential environmental and health features.

Ecospecifier.org publishes several online knowledgebase and databases in Australia, New Zealand and Middle East, incorporating verified, life-cycle based information over 5000 ecologically and health preferred products, materials and technologies that provides built environment professionals with detail needed by each market to understand how each product relates to the relevant scheme/s in each country.

The information provided is both quantitative and qualitative; life-cycle assessment based and focuses on all aspects of restorative sustainability including closed loop product cycles. Products have to meet specific entry criteria and all claims are verified by experienced professionals with enhanced listings product manufacturers required to submit third party test data to back all key environmental and health claims. Ecospecifier also reviews products against credits relating to major international Green Building Rating tools such as Green Star™, LEED® and in the near future BREEAM into product verification and search processes.

5. Conclusions

Policymakers, designers, engineers and constructors responsible for urban outcomes need to refocus their policy, design and built outcome towards ecobalanced, lean, low carb cities materials and strategies. The past 'Reductive Sustainability' mantra of the '3Rs' ('Reduce, Re-use, Recycle) needs to be expanded to include concepts of industrial ecology and 'Restorative Sustainability' and replaced by the '5Rs' 'Reduce, Re-use, Recycle, Repair + Restore' and these outcome need to actually be delivered by every new project.

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EVALUATES OF INFLUENCE OF THE SPECIFICATION OF THE GLASS OF WINDOW IN THE ENERGY CONSUMPTION OF THE CONSTRUCTIONS IN BRAZIL.

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Keywords: glass, energy efficience, window, sustainable, building.

Summary

The study evaluates the influence of the specification of the glass of window in the energy consumption of the constructions. It uses software RESFEN 5,0, developed for Lawrence Berkeley National Laboratory of California for calculation of thermal load and costs of conditioning of a construction related to the properties of the window. It was simulated a typical construction whit one floor of 100 m² in the city of Belo Horizonte and São Paulo. The evaluated glasses had been: Float 4 mm clear (reference), Float 3 mm clear, Float 6 mm clear, Float 4 mm green, Float 4 mm grey, Laminated 8,4mm clear, double glass (4 mm + 6 mm of air + 4 mm) clear. The calculations had been made for the orientation west, of bigger incidence of solar energy. They had been simulated also, the orientation north, east and south for the window with the reference glass. The variation of the thickness of the glass showed resulted modest in the energy efficiency of the window, similar in the two cities. The color of the glass produced resulted significant in the improvement of the energy efficiency of the window, also similar in both the cities. The glass systems (laminated and double glass) had produced a medium results in the energy efficiency of the window, being that, in São Paulo, the double glass had better performance of what in Belo Horizonte. The orientation of the windows showed great influence in the building energy consumption related to the window. However, the orientation east presented different results in the two cities, with small reduction in Belo Horizonte and great reduction in São Paulo.

1. Introduction

Great part of the energy consumed in the constructions is used for thermal conditioning and illumination. The solar radiation is the main agent to determine the characteristic of thermal and illumination performance of the building. It is energy that brings beyond energy in the form of visible light, energy in the form of heat for the building; therefore she must be used carefully. Design, the architectural details and the materials used in the building, have direct influence in how the building relates, appropriates and controls the solar radiation.

2. Simulation tool - RESFEN 5.0

Program RESFEN is software, developed for Lawrence Berkeley National Laboratory of California (LBNL), United States, as a tool to assist in the choice of the window whit better energy efficiency and better cost for determined residential application (figure 01). It calculates the used energy for conditioning, heating and refrigeration and associates the cost and peaks of consumption, of a determined window. The RESFEN uses DOE 2.1E (LBL 1980, Winkelmann et al. 1993) as tool of energetic balance calculation.

The RESFEN uses a custom version of the DOE-2.1E configured in dynamic link libraries (DLL) for operation in PC platforms. The DOE-2 is a term-energy program of simulation of constructions, also developed for the LBNL, known and widely used. As the DOE-2 reproduces the typical constructions characteristics of its native country, the simulation process must have a critical analysis in relation a variable adopted automatically by program. The DOE-2 did not have its basic algorithms modified. The results calculated for identical situations, are equal in the RESFEN and in DOE-2.1E.

In version 5.0, the RESFEN allows that if it defines a type of residence (one or two floor, frame or masonry), geographic localization (BIN archives), details of the core and shell of the construction (walls, floor and ceilings), type of HVAC systems (gas, electric, heat pump), cost of electricity and gas, orientation and thermal properties of the window in study. The thermal data of the window required are the U-value, SHGC and air leakage. It can be defined the solar gain reduction. The possibility of use a climatic BIN archives, together with the definition of the properties of the core, shell and windows, allows the study to use the RESFEN in other countries. Version 5.0 have library for China and Chile, beyond U.S.A. and Canada

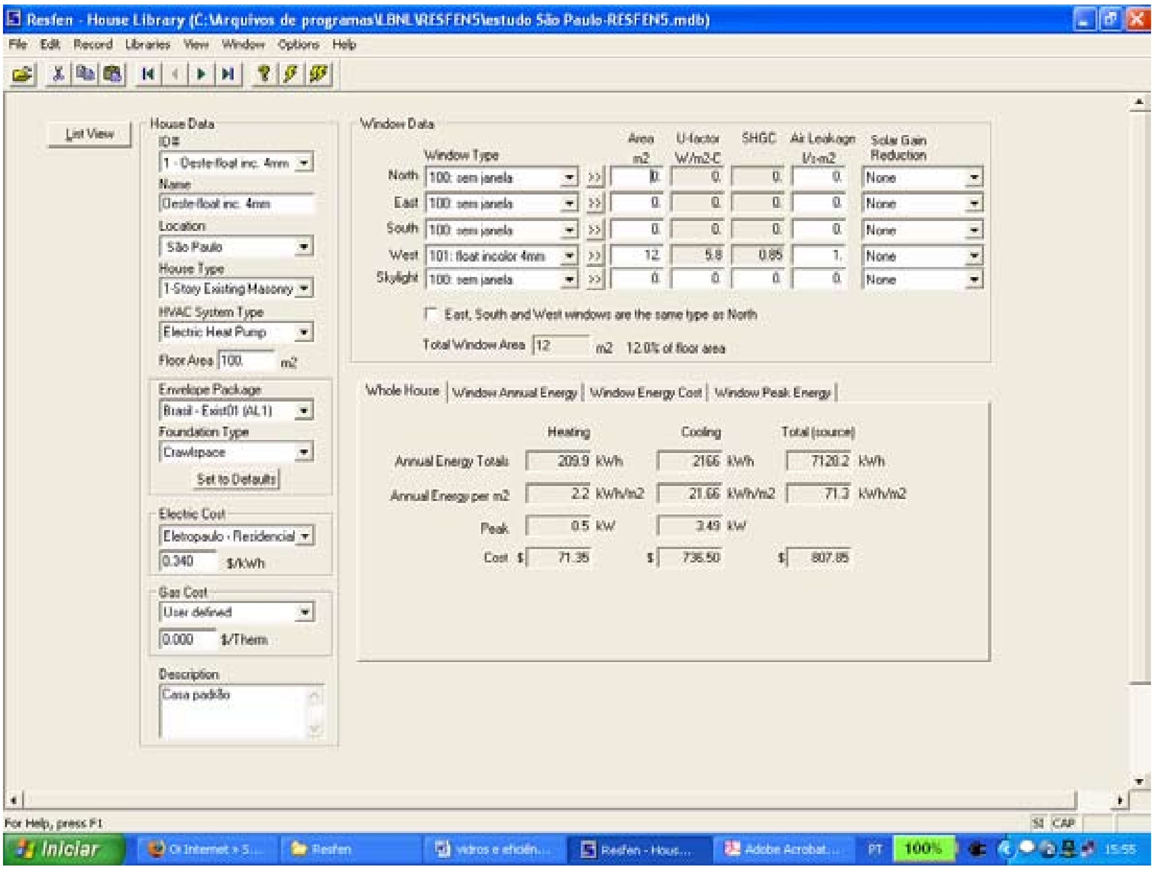


Figure 01 – RESFEN main screen.

Based in the supplied data, RESFEN generates a BDL archive (Building Description Language) for DOE-2, and then, processes the archive as an entrance module (DOEBDL). After that the module is simulated, using the defined climatic archive. The simulation generated an archive with the consumption and annual cost of the construction for heating and refrigeration, the peak demands, and how much of this consumed energy can be attributed for the window. Figure 02 presents an organization chart of the calculation method.

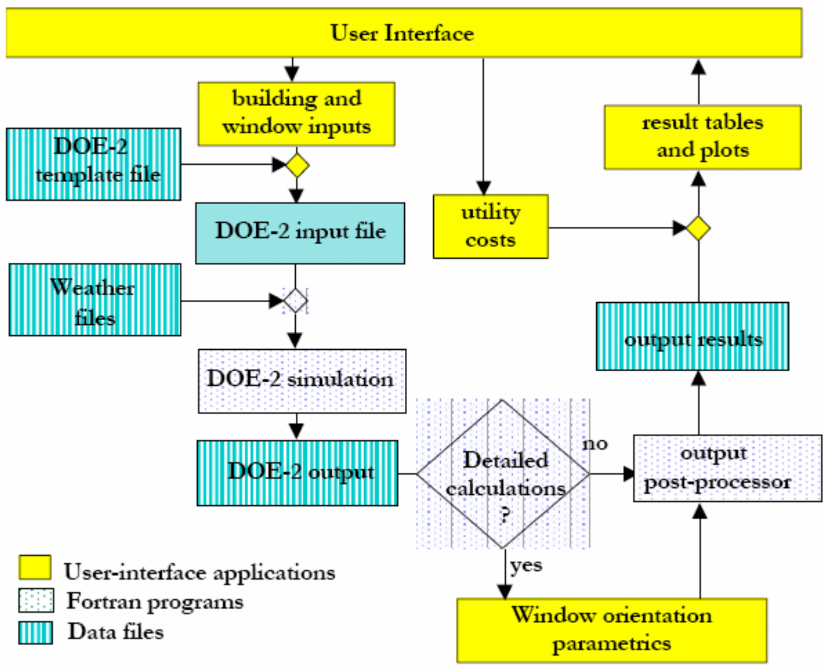


Figure 02 - Organization chart of the calculation method.

3. Data and parameters

The RESFEN was configured for the locality of Belo Horizonte and São Paulo. The entrance data in program are presented in table 01.

Table 01 – Used parameters in the RESFEN.

Parameters	Belo Horizonte	São Paulo
Floor area.	100 m^2 (inside).	100 m^2 (inside).
House type.	Existing, one floor.	Existing, one floor.
Foundation.	Crawlspace.	Crawlspace.
Thermal values – Core and shell.	Basement: R0slab (Uvalue=0.438 W/m^2K) Floor: R11flr (Uvalue=0.416 W/m^2K) Walls : R7rwall (Uvalue=0.594 W/m^2K) Roof: R11ceil (Uvalue=0.468 W/m^2K)	Basement: R0slab (Uvalue=0.438 W/m^2K) Floor: R11flr (Uvalue=0.416 W/m^2K) Walls : R7rwall (Uvalue=0.594 W/m^2K) Roof: R11ceil (Uvalue=0.468 W/m^2K)
House perimeter.	40,5 meter – RESFEN standart: (floor area/14) + 56 , in feet.	40,5 meter – RESFEN standart: (floor area/14) + 56 , in feet.
Walls height.	2,44 meter – RESFEN standard.	2,44 meter – RESFEN standard.
Roof weight.	5,06 meter – RESFEN standard: 50% bigger dimension of the house.)	5,06 meter – RESFEN standard: 50% bigger dimension of the house.)
Infiltration	ELA=1.00 ft2 (0.70 ACH)	ELA=1.00 ft2 (0.70 ACH)
Structural mass	17,08 Kg/m2 of floor area (RESFEN standard = 3,5 lb/ft^2).	17,08 Kg/m2 of floor area (RESFEN standard = 3,5 lb/ft^2).
Internal Mass Furniture.	39,06 Kg/m2 of floor area. (RESFEN standard = 8 lb/ft^2).	39,06 Kg/m2 of floor area. (RESFEN standard = 8 lb/ft^2).
Window.	100 cm (weight) x 120 cm (heigth). Frame: Aluminium, single. Glass: as table 02. No solar gain reduction. Air leakage: 1,0 l/s-m^2.	100 cm (weight) x 120 cm (heigth). Frame: Aluminium, single. Glass: as table 02. No solar gain reduction. Air leakage: 1,0 l/s-m^2.
HVAC system	Eletric heat pump.	Eletric heat pump.
HVAC system sizing.	Automátic dimension by DOE-2. (RESFEN standard). factor 1,3.	Automátic dimension by DOE-2. (RESFEN standard). factor 1,3.
HVAC efficiency	AFUE = 0.70 A/C SEER = 8.0 (RESFEN standard)	AFUE = 0.70 A/C SEER = 8.0 (RESFEN standard)
Ducts loss.	Heating: 10% fix. Cooling: 10% fix. (RESFEN standard)	Heating: 10% fix. Cooling: 10% fix. (RESFEN standard)
Part-load performance.	New DOE-2 part-load curves (Henderson 98). RESFEN standard.	New DOE-2 part-load curves (Henderson 98). RESFEN standard.
Thermostat settings.	Heating: 21,11 °C. Cooling: 25,55 °C. (RESFEN standard)	Heating: 21,11 °C. Cooling: 25,55 °C. (RESFEN standard)
Internal loads - (kBtu/day)	Sensible heat: 43,033 Btu/day + 8,42 Btu/ft^2 of floor area (illumination) Latent heat: 12,2 kBtu/day. (RESFEN standard)	Sensible heat: 43,033 Btu/day + 8,42 Btu/ft^2 of floor area (illumination) Latent heat: 12,2 kBtu/day. (RESFEN standard)
Natural ventilation.	By Enthalpic-Sherman-Grimsrud (25,55 °C / 22,22 °C – 4 day).	By Enthalpic-Sherman-Grimsrud (25,55 °C / 22,22 °C – 4 day).
Weather data	Bhrea95.BIN (LabEEE)	SaoPauloTRY1954_06.BIN (LabEEE)

The window was defined with simple aluminium frame, with dimension 1,0 x 1,2 meters each, and total area of twelve meters ². The program allows only 12% of area of window in relation to the floor area. Diverse windows had been criate, varying the glass through the determination of U-value and SHGC. Glasses with diverse thicknesses, diverse colors, lamination systems and double glass had been studied.

The U-value and SHGC of each glass had been gotten in the program Pilkington Spectrum V01.03.07 (figure 03), that it calculates the thermal and optics properties of glasses and its combinations, manufactured by Pilkington.

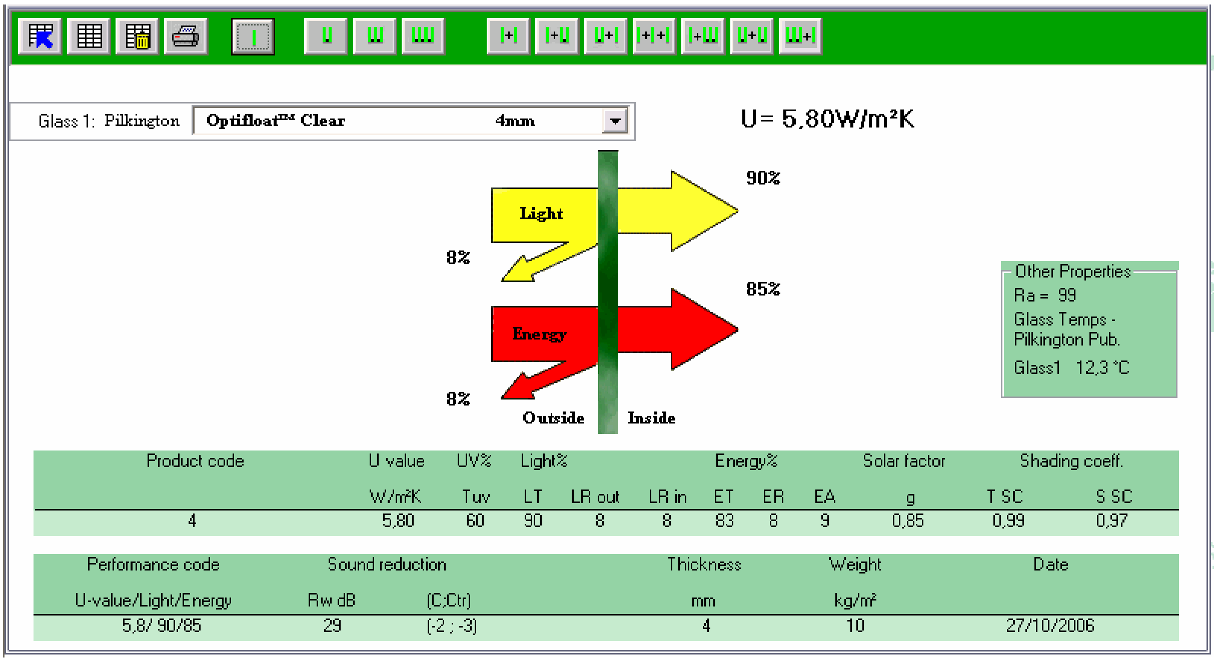


Figure 03 –Pilkington Spectrum Interface (V01.03.07.).

The properties are calculated by European Norm EN673 of U-value calculation and EN410 of solar and ótic performance of glasses. The bands of wave length considered are:

- UV Transmission - 280-380 nm.
- Visible Transmission - 380-780 nm.
- Solar Energy Transmission - 300-2500 nm.

The values of glass properties considered in Pilkington Spectrum calculation are:

- Thermal Resistivity - R = 1.0 mK/W.
- Corrected emissivity for uncoated float glass - e = 0.837.
- Temperature difference inside/outside - dT = 15oK.
- Exterior heat transfer coefficient - he = 23.0 Wm²K
- Interior heat transfer coefficient - he = 8.0 W/m²K

The U-value is calculated in glass centre. The frame effect was not incluse in the calculation. The Pilkington Spectrum program was used because its have glass data equal of glasses that was manufactured in Brazil by Pilkington. The reference window uses float glass clear 4 mm.

The electricity cost in Belo Horizonte was defined R$ 0,664 kWh, having as reference the value of 100kW residential count, inclued taxes. The electricity cost in São Paulo was defined R$ 0,340 kWh, having as reference the value of 100kW residential count, inclued taxes.

To study the thickness influence, the colour influence and the glass system influence, in the energy consumption of building, each window was simulated with orientation west, that have a bigger thermal profit for the solar radiation.

The reference window was shaped in the north, east and south orientation, to evaluate the orientation influence in the energy consumption of building.

The studied glasses and the summary of its technician data, gotten in the Pilkington Glazing Calculator program, are shown in table 02.

Table 02 – Glass technician data.

VIDRO	U-value (W/m²K)	SHGC
Float Clear 4 mm.	5,8	0.85
Float Clear 3 mm.	5,83	0.86
Float Clear 6 mm.	5,73	0.82
Float Green 4 mm.	5,8	0.66
Float Grey 4 mm.	5,8	0.67
Laminated glass clear 8,4mm.	5,7	0.77
Doble glass 4 mm + 6 mm air + 4 mm – clear.	3,3	0.76

4. Results

The summary of the results gotten for Belo Horizonte is shown in table 03.

Table 03 – Belo Horizonte results.

GLASS	ANNUAL COST DUE TO THE WINDOW (R$)	TOTAL ANNUAL COST (R$)
Float clear 4 mm - West.	1725,23	2941,77
Float clear 3 mm - West.	1745,79	2962,58
Float clear 6 mm – West.	1649,99	2866,76
Float green 4 mm – West.	1253,99	2470,33
Float grey 4 mm – West.	1276,08	2492,45
Laminated clear 8,4mm – West.	1525,74	2741,81
Doble 4+6+4 mm clear – West.	1569,48	2786,45
Float clear 4 mm – North.	1175,91	2422,09
Float clear 4 mm – East.	1640,58	2906,59
Float clear 4 mm - South.	736,36	2087,88

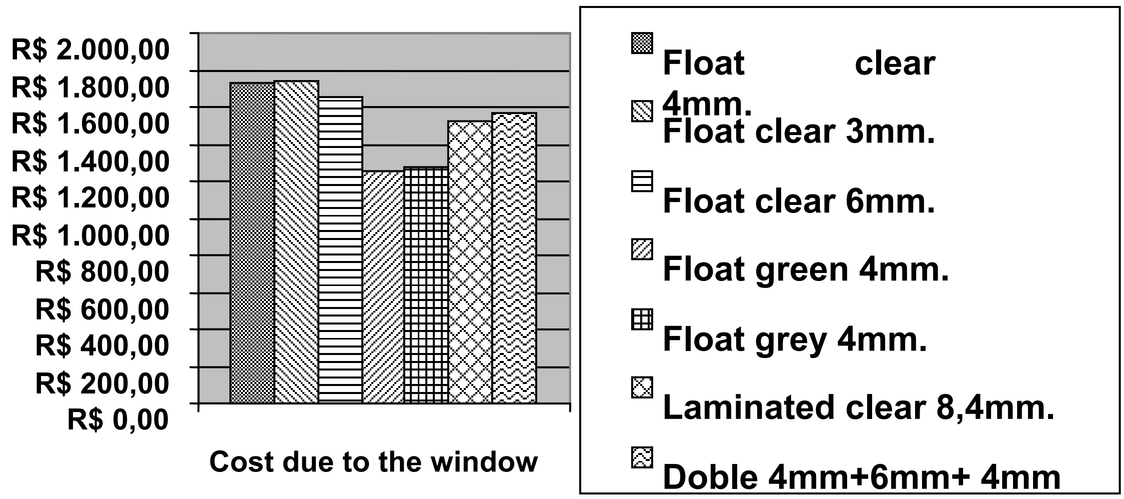
The summary of the results gotten for São Paulo is shown in table 04.

Table 04 – São Paulo results.

GLASS	ANNUAL COST DUE TO THE WINDOW (R$)	TOTAL ANNUAL COST (R$)
Float clear 4 mm - West.	551,16	807,85
Float clear 3 mm - West.	559,17	815,83
Float clear 6 mm – West.	524,28	781,19
Float green 4 mm – West.	402,69	660,16
Float grey 4 mm – West.	409,20	666,53
Laminated clear 8,4mm – West.	483,03	739,99
Doble 4+6+4 mm clear – West.	480,45	736,55
Float clear 4 mm – North.	420,20	670,24
Float clear 4 mm – East.	393,82	638,21
Float clear 4 mm - South.	228,30	484,03

5. Analysis of the Results

The Belo Horizonte annual cost of conditioning due to the window, varying the glass, is showed in graph 01.



Graph 01 – Belo Horizonte, glass variation.

Thickness:

Clear glass 3 mm showed a annual cost of conditioning due to the window, R$ 20,56 or 1,19% greater than the reference glass 4 mm.

Clear glass 6 mm showed annual cost of conditioning due to the window, R$ 75,24 or 4.36% lower than the reference glass 4 mm.

Color of the glass:

Green glass 4 mm showed annual cost of conditioning due to the window, R$ 471,24 or 27,31% lower than the reference glass 4 mm.

Grey glass 4 mm showed annual cost of conditioning due to the window, R$ 449,15 or 26,03% lower than the reference glass 4 mm

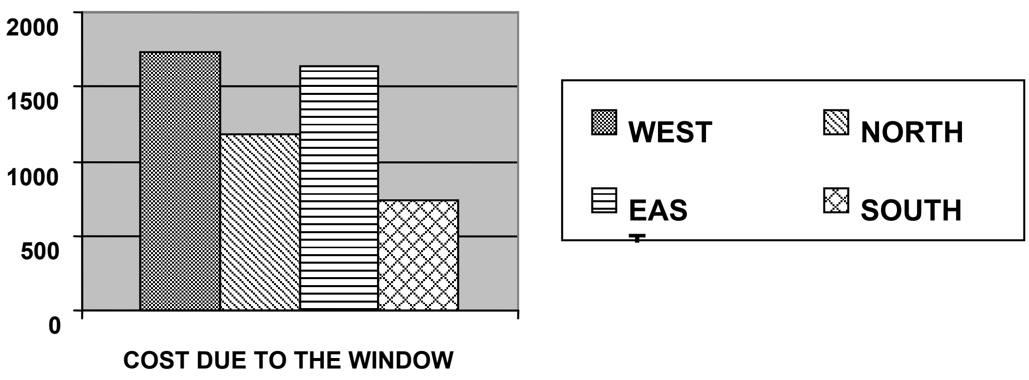
Glass systems:

The laminated glass 8,4mm showed annual cost of conditioning due to the window, R$ 199,49 or 11,56% lower than the reference glass 4 mm.

Doble glass 4 mm + 6 mm + 4 mm showed cost of conditioning due to thr window, R$ 155,75 or 9,03% lower than the reference glass 4 mm.

Window orientation:

The Belo Horizonte annual cost of conditioning by the window, varying the orientation, is showed in graph 02.



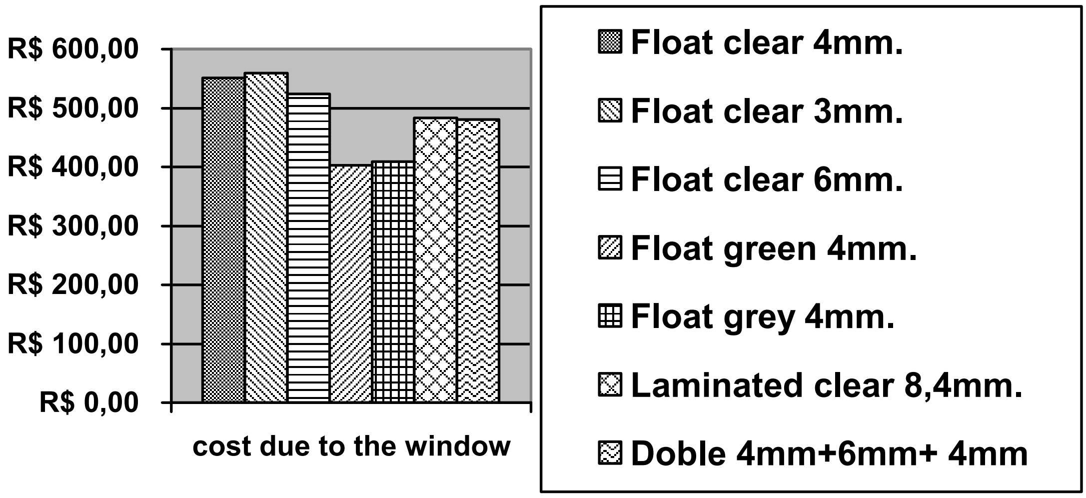
Graph 02 – Belo Horizonte, window orientation.

The orientation north presented annual cost of conditioning due to the window, R$ 549,32 or 31,84% lower than the reference glass 4 mm.

The orientation east presented annual cost of conditioning due to the window, R$ 84,65 or 4,91% lower than the reference glass 4 mm.

The orientation south presented annual cost of conditioning due to the window, R$ 549,32 or 31,84% lower than the reference glass 4 mm.

The São Paulo annual cost of conditioning by the window, varying the glass, is showed in graph 03.



Graph 03 – São Paulo, glass variation.

Thickness:

Clear glass 3 mm showed a annual cost of conditioning due to the window, R$ 8,01 or 1,45% greater than the reference glass 4 mm.

Clear glass 6 mm showed annual cost of conditioning due to the window, R$ 26,88 or 4.87% lower than the reference glass 4 mm.

Color of the glass:

Green glass 4 mm showed annual cost of conditioning due to the window, R$ 148,47 or 26,93% lower than the reference glass 4 mm.

Grey glass 4 mm showed annual cost of conditioning due to the window, R$ 141,96 or 25,75% lower than the reference glass 4 mm

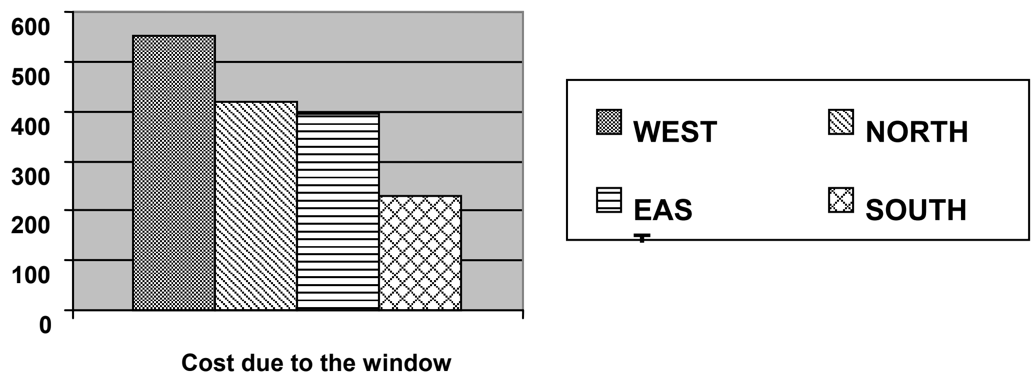
Glass systems:

The laminated glass 8,4mm showed annual cost of conditioning due to the window, R$ 68,1 or 12,36% lower than the reference glass 4 mm.

Doble glass 4 mm + 6 mm + 4 mm showed cost of conditioning due to the window, R$ 70,71 or 12,83% lower than the reference glass 4 mm.

Window orientation:

The São Paulo annual cost of conditioning by the window, varying the orientation, is showed in graph 04.



Graph 04 – São Paulo, window orientation.

The orientation north presented annual cost of conditioning due to the window, R$ 130,96 or 23,76% lower than the reference glass 4 mm.

The orientation east presented annual cost of conditioning due to the window, R$ 157,34 or 28,54% lower than the reference glass 4 mm.

The orientation south presented annual cost of conditioning due to the window, R$ 322,86 or 58,58% lower than the reference glass 4 mm.

6. CONCLUSIONS

The thickness variation maded a modest resulted in the energy efficiency of the window, in Belo Horizonte and São Paulo. An increase of 50% in glass thickness did 4,5% reduce cost of conditioning by the window.

The alteration of the glass color maded a significant results in the energy efficiency of the window, in Belo Horizonte and São Paulo. A Reduction of 27% for the green glass was gotten. However the influence of the opacity in the natural illumination must be analyzed and eventual increases of energy consumption for natural illumination.

The glass systems maded a medium results in the energy efficiency of the window, in Belo Horizonte and São Paulo. In Belo Horizonte, the laminated glass, with presence of another material (PVB-polymer) in the interior of the glass maded a reduction of 11,56%, superior than the doble glass (9,03% reduction), that it possesss air layer with 6 mm in the interior. In São Paulo, city of more cold climate, the doble glass had better performance, with reduction of 12,83%, superior than the laminate reduction (12,36%). The most cold climate, and the influence of the glass isolation, can explains the result.

The windows orientation maded a great influence in the energy consumption by the window. The south orientation showed reduction of 57,32% in the cost by the window for building conditioning in

Belo Horizonte. In São Paulo, reduction of 58,58% for south orientation was observed. The results had shown that the orientation east of the window cost different costs in Belo Horizonte and São Paulo. In Belo Horizonte, the orientation east had reduction of 4,91% and in São Paulo of 28,54%. The climate hottest and bigger solar heat, can explains the result. The orientation north also presented considerable difference, reduction of 31,84% for Belo Horizonte and 23,76% for São Paulo. Probably, it´s because the climate difference.

We can conclude that the glasses of the windows are significant for energy efficiency of the building. For a bigger energy efficiency, we must considered the place climate and the solar incidence in the construction, especially in the windows. The strong influence of the solar orientation of the window is shown by the results.

RESFEN showed adequate for the proposal situation, a fast calculation of model building thermal performance. With development of customizações for Brazil, this can be used for comparative degrees of energy efficiency of windows. A possibility is the development of Brazilian windows library, using software WINDOW 5 (LBNL), where the thermal properties of a shaped window are calculated, including glasses and frame, to be used in the RESFEN

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HOUSES OF SUSTAINABILITY

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Keywords: brick, cultural value, construction traditions, authorities, examples

Summary

Sustainable building is a very important topic in Europe at the moment. This is especially true in Belgium where a large number of initiatives are being carried out by the federal, regional and local authorities to raise the awareness of builders about the importance of designing a sustainable built environment with high technical quality.

To support those who develop sustainable construction projects, the authorities have targeted their approach on two areas. Firstly, public buildings are designed in accordance with a sustainable construction strategy. This first approach comes within the framework of the "Green Public Procurement" activity encouraged by the European Commission. Secondly, they are creating support centres to advise architects, works supervisors and building technicians.

To be credible, it is imperative that the buildings supporting this approach are perfect examples of sustainable construction. Therefore various projects are being developed to illustrate the approach implemented by the authorities.

The projects have as their common aim the promotion of the use of bricks as a sustainability vector.

1. Belgian is a country of bricks

Belgium is a country of bricks… It is also said that "Belgians are born with a brick in their stomach"... a general expression which bears testimony to the interest this country shows in construction, and more specifically the residential sector. If the brick material is at the heart of this expression it's because of its significance. We have in fact seen generations of builders shape our developed landscape by creating striking buildings made of bricks. Thanks to the material's longevity, these buildings are still, today, inescapable elements of our architectural heritage.

For generations, our country has been characterised by the great concern we attach to the architectural quality of our homes. For some years we have noticed that the interest shown by the population, construction professionals and the authorities is no longer centred solely on the aesthetic criteria but is broadening to include sustainable construction.

2. Sustainable construction and construction traditions

A considerable amount of information abounds today and we can become disorientated. In terms of sustainable construction, the emphasis is mainly on energy efficiency and the use of natural materials, renewable where possible.

These aspects are sometimes very technical and the "soul" of the building seems all too often to be forgotten. The only thing that seems to matter is the building's performance in terms of energy efficiency, waste and waste water management, adaptability, etc. These are, without a doubt, essential factors in sustainable construction, but the cultural aspect all too often becomes the poor relation in the sustainable construction debate.
This aspect forms the basis of this presentation; more particularly the exemplary role the authorities can play in terms of sustainable construction. The projects described are brick constructions which have been designed with the sustainable construction criteria in mind and which also have a strong link with their surroundings and Belgian construction traditions.
These creations go beyond the "simple" technical aspects linked to sustainable construction, offering a style of architecture which is both contemporary and in keeping with Belgian construction traditions!

3. Brick : cultural value and sustainable construction

It is first necessary to put sustainable construction in the international context of sustainable development, defined as the management of human, economic and environmental resources which meets the needs of today's society without endangering the needs of future generations.
One must therefore keep in mind this socio-economic-environmental triple dimension when talking about sustainable construction. Among the social factors, maintaining a link with construction traditions and our built heritage is an essential element. However, we notice a growing tendency to exclude anything that approaches us from the past, as though only high-tech construction solutions could support sustainable construction. Nevertheless, traditional materials have an essential role to play!

Whilst sustainable construction has become a real issue in society, brick remains the quintessential material which contributes to a sound, sustainable constructed environment which also performs on an interior comfort level! It is not by chance that brick has been shaping Europe’s constructed environment for centuries. Made from the natural raw material clay, brick is one of the highest performing construction materials, meeting all thermal and acoustic comfort, security, sustainability and building flexibility requirements.

4. The authorities : an exemplary role

Sustainable construction is a very fashionable topic in Europe. This is especially the case in Belgium where federal, regional and local authorities operate policies with the aim of making potential builders aware of the importance of creating a sustainable constructed environment of a high technological quality.

To support those who develop sustainable construction projects, the authorities have targeted their approach on two areas. Firstly, public buildings are designed in accordance with a sustainable construction strategy. This first approach comes within the framework of the “Green Public Procurement” activity encouraged by the European Commission. Secondly, they are creating support centres to advise architects, works supervisors and building technicians.

5. Buildings

To be credible, it is imperative that the buildings supporting this approach are perfect examples of sustainable construction. Therefore various projects are being developed to illustrate the approach implemented by the authorities.
These creations have the common purpose of advancing the use of terracotta materials as a means of sustainability.

5.1 Centrum Duurzaam Bouwen (CEDUBO) : "House of sustainable construction"

CeDuBo is a European Union-supported projected. Located on the former Heusden-Zolder mining site, CeDuBo is a sustainable construction information and coordination centre.

The “house of sustainable construction” was set up in 2002 in a renovated brick building as a witness to sustainable construction. The architects in charge of the renovation of the building were chosen for their significant vision of the sustainable renovation of such a historical site.

5.2 Vlaamse Milieumaatschappij (VMM)

It is not by chance that this group of offices for the "Vlaamse Milieumaatschappij"(VMM) won the Belgian Building Awards 2005. Indeed, thanks to the intervention of the De Smet Vermeulen architects, this creation is more than a group of offices; it is a unifying element between the inhabitants of the area, the various public institutions which have their offices there and the town of Aalst itself.

In order to create a feeling of acceptance of the building among all the stakeholders, the architects established a frank dialogue and an active collaboration with the management and employees of VMM, the town and the population from the outset. It was possible to take the needs and concerns of all parties into account.

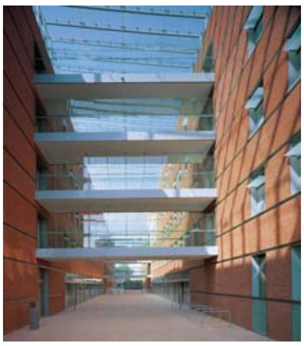
It was important, for the VMM, to integrate the environmental scale into this creation so as to reflect its commitment to the promotion of an ecological and sustainable approach. In order to meet these environmental objectives the architects used two elements: sustainability and flexibility. On the one hand, sustainable materials were used. On the other hand, the architects designed a low-energy building where every factor is managed electronically – lighting, ventilation, heating, etc. The sometimes untimely intervention of staff is no longer required and the interior climate is thus always well regulated.
The flexibility of the space inside is reflected in the common areas – reception, auditorium, and cafeteria – and the offices, which are reduced in size but functional and flexible.

This creation enriches the inhabitants' living environment. Since two areas, one public, the other semi-public, were created, they accepted the nuisance caused during the construction stage. The communication paid off as the inhabitants have taken the site into their hearts and are now its best guarantors against vandalism...

When the VMM called on the architects, their offices were already located on this site, in a former cloister with no particular architectural or historical interest and which, on the contrary, was causing the disintegration of the whole area. The proximity of Aalst station was a key element in the VMM's decision to stay on this site. The architects were immediately persuaded that demolishing the old cloister would allow them to bring the site's potentialities up to date. They then convinced the local authorities to keep only the old vicarage, which is now joined to the brick building via a glass walkway.

The architects also very soon began making every effort to work around the symbolism of the hundred-year-old tree located on the site. This was left in place to be

5.3 Vlaams Administratief Centrum (VAC)



In each of the Flemish provinces the regional council constructs an administrative centre with the aim of centralising provincial services. The "Vlaams Administratief Centrum" in Hasselt thus unites the public services of Limbourg.
This creation, as a symbol for the province, had to have an impact and set an example in terms of quality architecture incorporating the principles of sustainable construction. In order to ensure that it had a certain aura this ensemble had to be made accessible, authentifiable and open to the population.

The VAC's privileged position makes it easily accessible to the public and to the civil servants who work there. The location of the project at the entrance to the town, near to both the station and the motorway, was therefore an essential factor in its smooth running.

The VAC's quality architecture and the concept it embodies makes it without a doubt a key part of the town. Two long wings of red-orange bricks house the facilities open to the public (library, restaurant, auditorium, meeting room, etc.) on the ground floor and the offices on the upper floors. These two main buildings are linked by a glass-covered internal walkway. It is intended to be a "pathway" expressing the local government's wish to open itself up to the public. In this sense, the administrative centre completely lays itself open, lending a certain "transparency" to the activities and the working of the public services when seen from the outside.

The flooring of the internal walkway is also made of red-orange bricks and thus helps create a sense of unity.

Particular attention has been paid to user comfort. Furthermore, the architects have ensured that this public building is an example of sustainable construction. For this reason, the ventilation, lighting and heating technology used have been designed with sustainable and ecological construction in mind where each user is free to play a part in their working environment.

Through its scope, its simple volume boosted by a horizontal rhythm created by means of metal sections and the use of a brightly coloured brick, this creation gives some character back to this area surrounding the station.

5.4 Sint-Katelijne-Waver Town Hall

A town hall which would set the tone in terms of sustainable construction… such was the Sint-Katelijne-Waver local authorities' objective. This new creation had to be representative of the actions carried out by the municipality in terms of sustainable construction and, in this particular case, in terms of using sustainable materials, flexibility of space and the use of interior climate technical installations.

It is through suggesting such a striking and prestigious creation that the two architects won the competition organised by the municipality. From the beginnings of the project, facing bricks were used for their aesthetic qualities, whilst perforated bricks were then used for the interior walls for technical reasons.

The town hall consists of two buildings. The intersection of the two forms a sharp angle and the architects decided to make this the reception and public information area. One of the buildings is designed to house ticket booths for the public, the burgomaster and deputy burgomaster's offices and the boardroom. The other building houses the public services offices. The open-plan offices have a very flexible layout.

The main entrance is located at the exterior corner of the building but direct access from the car park is also planned. A second phase is expected to landscape the surroundings and the space between the two wings.

The bold architecture of this creation plays on asymmetry, on the one hand, and the internal/external contrast on the other.
A three-level building located opposite the neighbouring constructions forms the part in which the main entrance is located, whilst the height of the other building decreases gradually as it "disappears" into the ground!

The internal/external contrast consists of playing the dark, monolithic aspect of the facing off against the brightness of the inside of the building. The facing has been created using thin joint masonry. The remarkable accomplishment and the attention to detail, especially in relation to the sharp angle at the entrance to the building, should be pointed out. On the inside, the town hall welcomes visitors into a three-level area where the colour white is omnipresent.

Different elements, including the use of bricks, make this creation a success in terms of sustainable construction.

6. Cultural value and sustainable architecture

If there's one thing desperately missing from today's societies it's our roots. Without foundations, society can grow and evolve but there's a risk to lose our values.
The same goes for sustainable construction. Of course, a lot of technical equipment must be used and building physics principles applied in order for buildings to reach high performance levels whilst respecting our needs and those of future generations… But it is misleading to think that these buildings will be viable in the long run if they are not strongly linked to cultural values and local construction traditions. Without that there is nothing to relate them to society!

Using bricks in sustainable construction is in itself sustainable architecture! Far from being backward-looking, it is a question of progressive architecture… a progress rich in cultural value!

TITLE: RESEARCH ON THE DETERIORATION DEGREE EVALUATION OF NATIONAL GOVERNMENT BUILDINGS

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Keywords: repair, renovation, deterioration degree evaluation, building component

Summary

National government buildings in Japan, if they are observed from the point of asset, are enormous and aging. And those aging government buildings need to be repaired and renovated systematically to extend their service life under the tight budget circumstances. As building- related carbon dioxide gas emission is one third of the total carbon dioxide gas emission in Japan, the technologies to expand the service-life and to make effective use of existing buildings are considered very significant to the sustainability and the global environment. In this research started in 2004, GBD/MLIT has developed, 'a method for prioritizing repair and renovation' that consists of 'a deterioration degree evaluation stage' and 'a prioritizing stage', a systematic method to prioritize deteriorated building components in deferent buildings in consideration of building earthquake-resistance capacity, risk priority in disaster, security, functional continuity etc. After the development, GBD/MLIT has conducted a series of trial surveys on national government buildings to examine the effectiveness of 'the method' and reviewed and finalized it.

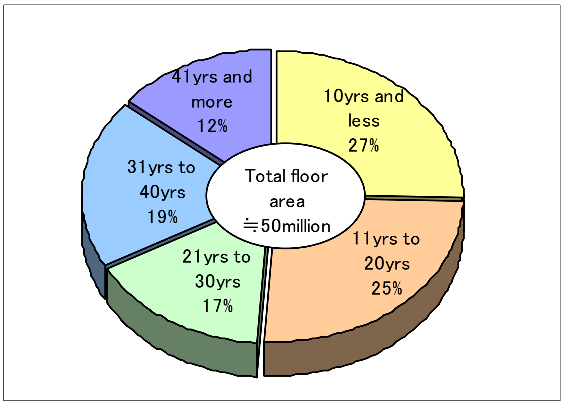
1. Introduction

1.1 What is required for national government buildings

National government buildings consist of joint-use offices, single-use offices, cultural-use buildings, educational-use buildings etc. These buildings are required to have high safety and continuous functional performance for their public use as well as to have long-term use of existing buildings for mitigating environmental impact.

1.2 Status-quo of national government buildings

Based on the data of 'national asset information system' developed by the Ministry of Finance, total floor area of national government buildings, enormous asset, is approximately 50 million m^2 and the number of buildings is approximately 19,000. Classified distribution of floor area and the number of national government buildings by their ages are illustrated in Figure 1. Buildings over 30 year after the completion are approximately 30% by floor area and 40% by the number of buildings.



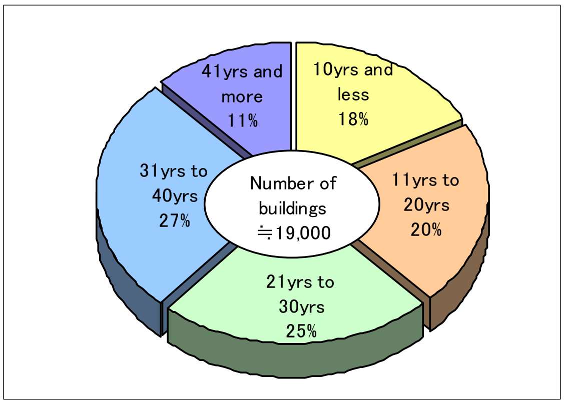


Figure 1 Classified distribution of floor area and the number of national government buildings by ages

1.3 Items needed for long-term building use

GBD/MLIT has been conducting 'periodical building condition survey' on national government buildings every 5 years to grasp the actual condition of buildings including the deterioration. But major objectives of the survey are to collect the information on judging the timing of reconstruction and to grasp rough condition of the deterioration. Therefore in order to execute the appropriate repair and renovation based on the deterioration condition, it is necessary to develop detailed survey for every component of a building.

2. Objectives

In this research, we have conducted detailed and systematic survey, analysis and evaluation on the deterioration condition of every component of government buildings and its related facilities, hereinafter referred to as buildings etc.. And with this result, we have developed 'a method for prioritizing repair and renovation' aiming at;

a) supporting to conduct appropriate guidance of maintenance

b) supporting to determine appropriate timing of repair and renovation

c) supporting budget planning and repair and renovation project

3. Development, trial survey and review of 'a method for prioritizing repair and renovation'

'A method for prioritizing repair and renovation' consists of two stages; deterioration degree evaluation stage and prioritizing stage. We have developed 'deterioration degree evaluation stage' and 'prioritizing stage' in 2004 and have conducted trial survey in 2005 to review both stages.

3.1 Identifying target components for survey

Building components for prioritizing repair and renovation, which are identical with the target components for survey, are the minimum size of the portions for budget planning. We have determined 11 major building components for 'deterioration degree evaluation stage' and for trial survey; those components are 3 for architecture and structure, 4 for electrical and 4 for mechanical.

3.2 The structure of 'a method for prioritizing repair and renovation'

To prioritize easily the surveyed building components, we have introduced a digital comparison method which is made of evaluation items, judging criteria and deterioration degree evaluation sheets for 11 building components.

3.3 Development of 'deterioration degree evaluation stage'

Evaluation system in 'deterioration degree evaluation stage' is made after 'a guideline for judging criteria of repair and renovation' developed in 1988; which is a systematized and efficient method to judge small repair and large-scale renovation by evaluating deterioration degree at the first step survey and the second step survey and if judged as small repair, detailed repair method shall be investigated in each project.In the 'deterioration degree evaluation stage', the same evaluation concept is taken from 'a guideline for judging criteria repair and renovation'.

Also, the flowchart of 'deterioration degree evaluation stage' is developed after 'a guideline for judging criteria of repair and renovation'; it means that the second step survey will be conducted by the result of the first step survey. Consequently the deterioration degree for evaluation is the score of the final step survey that is applied.

3.4 Deterioration survey method

Deterioration survey consists of the first step and the second step if necessary and the fundamental contents of survey in each step are as follows;

a) The first step survey

It is conducted by an engineer who has common knowledge on architecture, electrical and mechanical. It is conducted without scaffold and is conducted by optical observation,palpation and conventional tools.

b) The second step survey

It is conducted by a professional engineer and is conducted mainly by optical observation and palpation. It is conducted with professional investigation instrument and/or destructive investigation, if necessary.

3.5 Deterioration degree evaluation sheets and judging criteria

To conduct the deterioration survey of the first step and the second step, deterioration degree evaluation sheets with evaluation items and judging criteria are developed. A sample of deterioration degree evaluation sheets, for reinforced concrete and steel reinforced concrete structure at the first step, is illustrated in Figure 2.

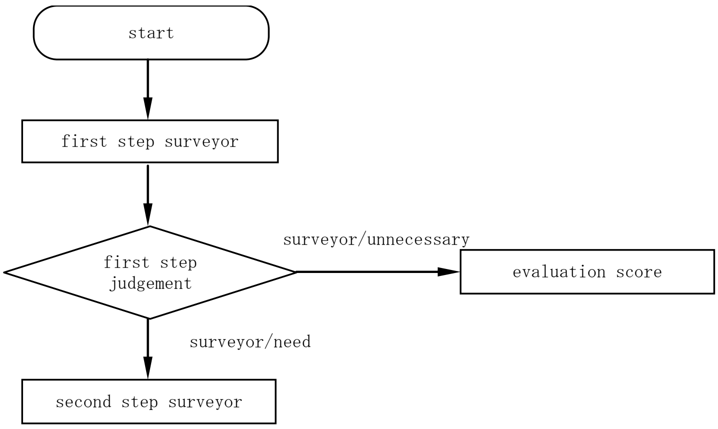


Figure 2 Flow chart

3.6 Development of 'prioritizing stage'

Based on the score of the deterioration degree evaluation sheet in the deterioration survey, 'prioritizing stage' has been developed. The priority of repair and renovation is determined not only the deterioration degree evaluation of a target component but considering items listed below to take account of high safety and continuous functional performance;

a) evaluation by the earthquake-resistance capability, including the grade for disaster

b) evaluation by the maintenance condition survey

c) evaluation by the building grade for daily use

d) evaluation by the fundamental building capability

Thus the evaluation score for prioritizing repair and renovation will be calculated by the following formula;

$$P_m=a(c_1\times Q_1+c_2\times Q_2+c_3\times Q_3+c_4\times Q_4)+b'\times \alpha_m\times L_m$$

P_m: repair and renovation priority score

Q_1: building criteria score for earthquake-resistance capability

Q_2: building criteria score for maintenance condition survey

Q_3: building criteria score for building grade for daily use

Q_4: building criteria score for fundamental building capability

a , b' , c_1-c_4 , α_m: weight coefficient

L_m : deterioration degree evaluation score

3.7 Conducting trial survey

A series of trial surveys were conducted nationwide at the regional bureau in 2005 and following issues were identified and reviewed.

a) The number of target components for deterioration degree evaluation sheets are not enough and they should be increased.

b) The number of evaluation items in evaluation sheet was so many that the average duration for survey was too long.

c) Deterioration degree evaluation sheet is so complicated that it caused many mistakes.

d) Evaluation items for different building components are not identical that it is questionable whether the evaluation sheet can maintain appropriate evaluation.

e) The second step survey took long time and high cost.

f) A formula for the evaluation score of prioritizing repair and renovation is so complicated that it is difficult to understand.

g) Prioritizing repair and renovation stage gives technical evaluation and maintenance condition survey is considered unnecessary.

Based on the issues mentioned-above, deterioration degree evaluation sheets, 'deterioration degree evaluation stage' and 'prioritizing stage' were reviewed and revised.

4. A revised method for prioritizing repair and renovation after a series of trial surveys

4.1 Increased target building components

Though at the start of the research, target building components for survey are determined 11, they should be increased to 82 as is illustrated in Table 1 to include most of the typical building components

Table 1 target building components for survey (excerpt)

construction	electric equipment	Heating, Air-conditioning and Sanitary
steel-frame reinforced concrete structure	electric light equipment(luminaire・wiring device)	direct fired absorption water heater chiller
reinforced concrete structure	clock system(time indicator)	refrigerating machine 又は chiller
steel structure	public address system	boiler
reinforced concrete block structure,other(structure)	lightning system(lightning protection system)	air-conditioner
roofing(bituminous membrane waterproofing)	telephone exchange system(private branch exchange)	cooling tower
roofing(exposed bituminous membrane waterproofing)	substation(circuit breaker)	air-conditioning duct
roofing(liquid-applied membrane waterproofing)	substation(disconnecting switch)	air-conditioning pipe
roofing(synthetic polymer roofing sheet waterproofing)	substation(transformer)	air-conditioning pump
roofing(other ( ))	substation(capacitor・reactor)	exhaust air duct
exterior wall(multi-layer finishing material)	substation(high voltage electromagnetic contactor・high voltage	fan
exterior wall(mosaic tile)	substation(cabinet)	smoke control fan
exterior wall(double sized tiles,mosaic tiles)	substation(DC power supply:rectifier)	smoke control duct

4.2 Revised survey method and 'revised deterioration degree evaluation stage'

Evaluation items in deterioration degree evaluation sheets were simplified and unified to give appropriate and equivalent evaluation as they were too complicated. And to maximize the role of the first step survey, periodical inspection record, legal inspection record, renovation and alteration record, accident and ill-condition information were added to review items for deterioration degree evaluation sheets.

With these revisions, most of the deterioration surveys on building components were completed at the first step survey. Then the first step survey and the second step survey became 'revised first step survey' and 'revised second step survey' respectively.

4.3 'Revised prioritizing stage'

Evaluation score formula for 'prioritizing repair and renovation' developed and reviewed in a series of trial surveys was revised, in consideration of issued identified in 3.7, to include building criteria, risk priority of each building components and deterioration degree evaluation score. The revised formula is;

$$P=Q+R+(a\times K)$$

P: repair and renovation priority score

Q: building criteria score for earthquake-resistance capability(35-75)

R: risk priority score of each building component in consideration of safety, disaster prevention, function and security (22-90)

a: weight coefficient (6)

K: deterioration degree evaluation score (0-45)

Varying weight coefficient (a) to investigate the appropriate relation among building criteria score, risk priority score and deterioration degree evaluation score, weight coefficient(a) was determined as 6 to present the proportional relation with repair and renovation priority score and deterioration degree evaluation score as is illustrated in Figure 3.

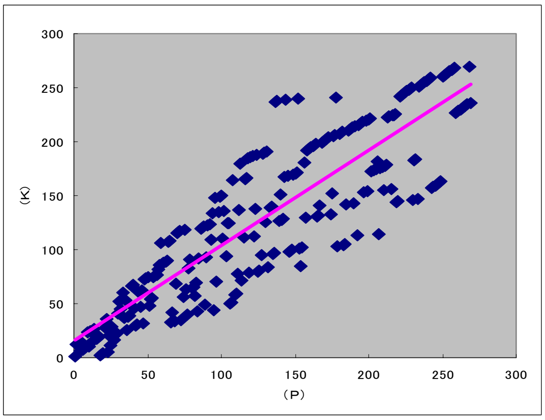


Figure 3 the relation with repair and renovation priority score and deterioration degree evaluation score

4.4 Long list

In a higher order of the scores of all the surveyed buildings and building components calculated by the evaluation score formula for ‘prioritizing repair and renovation’ evaluation, long list shall be prepared. In case repair and renovation priority scores (P) are identical, their priority shall be determined as follows;

a) in the order of higher deterioration degree evaluation score (K)

b) in the order of higher risk priority score (R)

c) in the order of higher building criteria score importance(Q)

d) in the order of larger total floor area

Table 2 example of long list

ranking	name of building	rigion	(P)	(Q)	(R)	weight coefficient	(K)
1	○○custom	exhaust air duct	333	35	40	6	43
2	○○local meteorological	electric light equipme nt	326	60	56	6	35
3	○○national government building	exterior wall(mosaic tile)	321	60	75	6	31
4	○○tax office	reinforced concrete structure	293	60	89	6	24

5. Revised second step survey(Professional survey)

Revised second step survey shall be applied to the specific building components that cannot be detected their potential defect or deterioration by the revised first step survey. Those building components are exterior walls, water supply pipes and drain pipes, and the survey methods applied are the technologies that are developed in private companies and are verified their technical credibility.

5.1 Exterior wall survey

In exterior wall survey, the revised first step survey is applicable to the portion where optical observation and palpation is applicable and the revised second step survey shall be applied to the remaining portion. Optical observation and hammer test with mobile elevating work platform is applicable to small buildings and infrared thermography method with infra-red camera is applicable to large buildings as is illustrated in Photo1 and 2.

Photo 1 hammer test

Photo 2 infrared thermography method

5.2 Water supply pipes and drain pipes survey

Though the exterior deterioration of water supply pipes and drain pipes can be detected by optical observation in the revised first step survey, the interior of them cannot be detected. As the detailed survey by cutting pipes will suspend water supply and hinder the occupants' life, X-ray photo method is applied to avoid cutting pipes.

Photo 3 X-ray generator

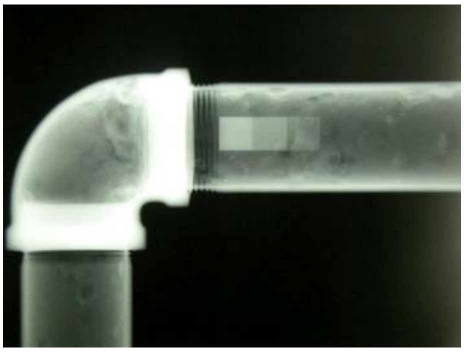


Photo 4 X-ray photo

6. Conclusion

6.1 Achieved result

The research on the deterioration degree evaluation of national government buildings has been advanced so far and the achieved result is;

a) The revised first step survey with deterioration degree evaluation sheet and optical observation, deterioration degree evaluation can be conducted by engineering staff of regional bureau of MLIT.

b) A systematic method of 'prioritizing repair and renovation method' in consideration of building grade, risk priority and deterioration degree evaluation has been developed and reviewed and confirmed to be effective.

c) As for the infrared thermography method, items listed below have been confirmed.

- Though the accuracy of the method is slightly lower than hammer test method, it can be applied for large buildings in shorter project period. As this method can be conducted without scaffold, mobile elevating work platform or hammering exterior walls, it can save the preparation period for occupant approval.
- This method cannot be applicable for the building portion where sun light is not uniform by reflection or shadow. Consequently, preliminary survey will be necessary to check obstacles and influencing buildings etc..
- This method is more applicable to voids finished with tiles or motor and cracks with water invasion than dry, fine cracks. For those deteriorations, optical observation and hammer test shall be accompanied.

d) As for X-ray photo detective method for pipes, items listed below have been confirmed.

- This method is applicable without cutting pipes or removing insulating material. As all the process of this method including developing is conducted in-situ, photos can be checked instantly and can be taken again if necessary.
- Stucks, bumps by corrosion as well as remaining thickness of pipes can be detected to forecast remaining service-life.

6.2 Issues to be discussed

MLIT is planning to conduct the first step and the second step surveys to review issues listed below.

a) Verifying the significance of deterioration degree evaluation score

As the relation of the score of deferent building components has not been discussed, following items shall be verified.

- How many score is the threshold for repair and renovation in deterioration degree evaluation score?
- Is the threshold for repair and renovation in deferent building components assumed to be identical ?

b) Additional second step survey

- For large-scale renovation, structural survey is important. Consequently, concrete compression tests and neutralization trial tests shall be conducted to review the problems and effectiveness of deterioration evaluation.

c) Feedback the second step survey to first step survey

- If the second step survey can feedback to the first step survey, it can save survey cost. Then the relation of the deterioration degree evaluation scores in the first step and the second step shall be reviewed.

DURABILITY OF BUILDING MATERIALS: MODELLING OF FREEZE/THAW PHENOMENA IN FIRED CLAY PRODUCTS

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Keywords: durability, fired clay, roofing tiles, freeze/thaw resistance, modeling, pore pressure, crystallization pressure

Summary

Fired clay products are formed by a porous media that is sensitive to frost action. During winter, products undergo several freeze-thaw cycles, sometimes associated with high water absorption. These lead to fatigue stress and progressive damage of the porous media. According to the nature of the clay and the processing method, the frost damages can take several forms, from chip to severe loss of mechanical strength. To optimize the parameters of fired clay processing and improve the frost resistance of fired clay products, a thermo-hydro-mechanics numerical code was implemented.

First, the strains in two roofing tiles were measured during freeze/thaw cycles. From the results, the pressure building up in the pores is calculated and the pressure of crystallization is identified. This step allows the pressure of the liquid phase to be deduced. For saturated products, it is concluded that the absorbed water is subjected to an overpressure during the freeze/thaw test.

By coupling the various mechanisms at the origin of the internal pressures developed in the roofing tiles, the the influence of the different products parameters (pore size distribution, permeability, modulus of elasticity and boundary conditions) is analyzed.

1. Introduction

Like all porous construction products, clay roofing tiles are sensitive to frost action and products exposed to cold climates can present progressive damage. When associated with high water absorption levels, freeze/thaw cycles provoke several forms of surface and structural damages, according to the nature of the clay and the shaping method, e.g. chips, scaling, flaking, delamination, cracking. The two latter damages traduce a severe loss of mechanical strength.

By experimentating with conditions of water absorption and temperature close to those generally found in situ, it is possible to reproduce the defaults that appear when tiles are frost sensitive. The saturation procedure, the kinetics and number of the freeze/thaw cycles are defined in a European standardized accelerated freeze/thaw test (method E from EN 539-2). In this test, a wet linen cloth is placed on the back side of the tile to create a temperature difference between the two sides of the product.

The motivation of this research is to identify and optimize the parameters of fired clay processing that are relevant for the improvement of the tiles frost resistance

The main parameters influencing the durability of fired-clay based materials submitted to freeze/thaw cycles are the characteristics of the clay body (Hansen 1988 and Maage 1984), such as porosity, modulus of elasticity, water permeability, as well as the boundary conditions imposed. The motivation of this research is, with the help of a numerical code being implemented, to determine the influence of these different parameters on the clay roofing tile ability to resist freeze/thaw cycles. In the future, optimization of the parameters will be conceivable and longer lasting fired clay roofing tiles will participate in building more sustainable houses. Moreover, minimizing energy consumption in the factory units without any loss in frost resistance will be possible.

In this work experimental results concerning the behavior of two models of fired clay roofing tiles are presented. In particular, the part of the total strains of the materials which is due to internal stresses generated by mechanical interaction between the solid skeleton and ice during its formation is determined. From it, the internal pressure generated by water and ice during freezing can be deduced.

2. Experimental study of freeze/thaw strains developed in roofing tiles

2.1 Materials

Two models of clay roofing tiles were selected on the basis of their different frost resistance and tested. They are referenced as CH3 and 2P2 (Wardeh 2004). CH3 is known for its excellent frost resistance whereas 2P2 is particularly frost sensitive.

The principal physical characteristics of the two materials were determined: they are presented in table 1.

Table 1 Physical characteristics of the tested roofing tiles

	CH3	2P2
Porosity: mercury intrusion test (%)	29.45	22.85
Mean diameters of pores (µm)	0.77	0.14
Specific area (m²/g)	0.8	3.1
Density	1.87	2.04
Modulus of elasticity (MPa)	8000	4000
Thermal conductivity (W/m.K)	0.46	0.56
Thermal expansion coefficient (K^{-1})	$6.6x10^{-6}$	$6.9x10^{-6}$
Permeability (m²)	5 to $6x10^{-15}$	2 to $2.5x10^{-16}$

The main differences between the materials are: their porosity, their chemical composition, their modulus of elasticity and their intrinsic air permeability. The porosity has been measured with a mercury intrusion porosimeter. CH3 is characterized by its greater porosity constituted of larger pores, resulting in a higher permeability. However, 2P2 has a broader distribution of relatively small pores resulting in a lower permeability.

2.2 Freeze/thaw resistance tests results

Each material was submitted to several freeze/thaw cycles according to the method E of the European standard EN 539-2 (Wardeh 2004). Two series of tests were conducted: tiles covered on the back side by a linen cloth (AT), or not (ST).

First, the roofing tiles are progressively saturated in water and covered by the cloth when needed. Then, they are placed in a freeze/thaw device where they are submitted to the freeze/thaw cycles. During each cycle, temperature of the material is first stabilized at around 15°C, dropping down to a temperature of -16°C, at a rate of approximately 7°C per hour. During the last step of the cycle, thawing is carried out by immersion in water, up to 15°C. Figure 1 represents the temperature evolution inside the CH3 tile, along with the temperature of the surrounding air, during the cycle.

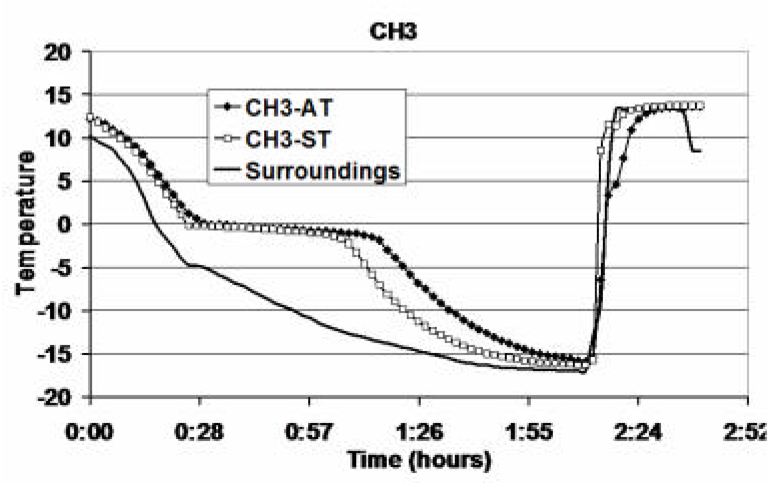

Figure 1 Temperature evolution in the CH3 tile, with (CH3-AT) and without linen cloth (CH3-ST) on its back side, along with the temperature evolution in the surrounding air (surroundings).

CH3 has a better frost resistance than 2P2: 2P2 displays more damages than CH3 after the same number of cycles. The presence of the cloth results in more cracks. The degradations occur mainly in the form of exfoliation and/or delamination. Whatever the position of the cloth on the tile, damages are always located at the same place. This observation certainly shows that the degradations show where the initial stresses concentrations are important. This factor seems to be more important than the dissymmetry induced by the presence of the cloth.

2.3 Experimental strains measured during the freeze/thaw cycles

The tiles were instrumented with strain gauges and temperature sensors in order to record the strains in all directions. During the test, the strain perpendicular to the thickness of the tiles was the more representative of the delamination of the clay body. The strains are presented in figure 2.

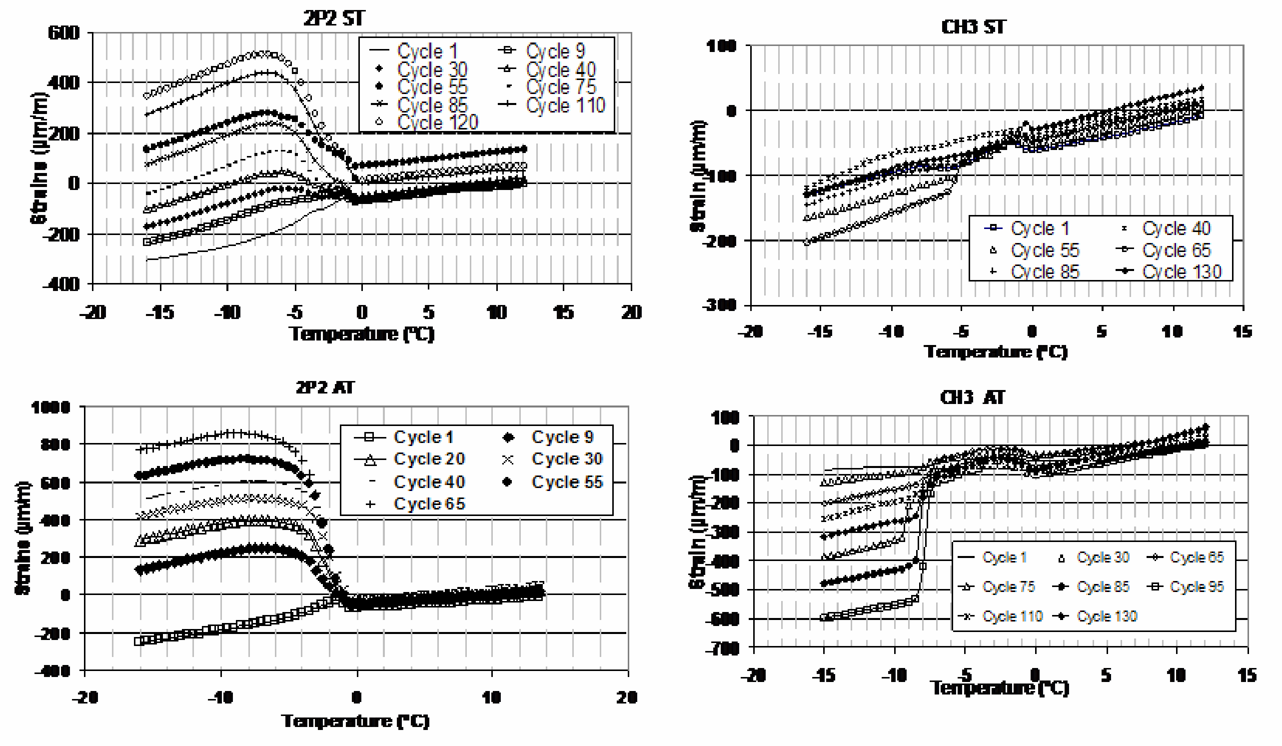

Figure 2 Strains measured in the thickness of the CH3 and 2P2 tiles, with (CH3-AT) and without linen cloth (CH3-ST) on their back sides.

The two models of tiles present very different behaviors: CH3 contracts more and more with the growing number of cycles, whereas 2P2 presents more and more expansion between the clay layers. When the back sides of the tiles are covered by the cloth, the strains are increased.

Furthermore, observation of the curves reveals the existence of three periods, corresponding to three temperature intervals.

Period 1: from 12°C to -0.5°C. Thermal contraction of the saturated material.

Period 2: from -0.5°C to -9°C. Progressive freezing of the water contained in the porous material. Large differences can be observed between the behavior with and without the cloth for both materials. At the beginning of freezing, CH3 stretches slightly from -0.5°C to approximately -2°C. After that, the strains are more or less stable according to the presence or absence of the cloth. Then there is a large contraction in the case of the material covered by the cloth, the contraction increasing with cycle number. As soon as the freezing process starts in 2P2, the gauge measures a large extension, which gradually decreases as the cycle progresses. This extension increases with the cycle number.

Period 3: from -9°C to -16°C. Linear strains due to thermal contraction of the fired clay in which all the pores are filled with ice.

3. Modeling of ice formation in fired clay materials

The model developed by Zuber (2000, 2002, 2004) was used to find the macroscopic strains starting from the knowledge of the pore size distribution. Modeling the behavior of materials during freezing implies a multi-scale approach as the occurring phenomena have to be described at both pore scale and macroscopic scale. At the pore scale, equilibrium between the phases of the interstitial solution was considered within the concepts of traditional thermodynamics. The material was then regarded as a continuous, completely saturated, porous medium. Finally, the relation between the transport mechanisms and the mechanical behavior was taken into account within the framework of the mechanics of continuous porous media.

The whole implementation scheme of the thermo-hydro-mechanics model can be found in Wardeh (2008). The physical basis of the hydro-mechanical model is the mass conservation equations of the solid matrix, water and ice. The constitutive laws of these three phases, combined with Biot's model and Darcy's law for porous media, allow the strains of the medium and the various phase pressures to be coupled. The mechanical equilibrium equation leads to the final system of equations, the resolution of which gives the space and time variations of the stresses and strains. The interest of the physical formulation is to provide an expression for the hydrostatic pressure related to the presence of the phases in the porous volume, in the form of a liquid pressure and an additional term corresponding to the presence of ice in the frozen pores which can be deduced from the pore size distribution.

3.1. Ice propagation within the pores

It is supposed that water and the ice coexist in the pores. When water freezes, the interface liquid/ice is propagating towards the not yet frozen zones. The conditions of this propagation are described by thermodynamic equilibrium between the phases liquid water 'and ice. The equilibrium conditions between the three phases present in the porosity are influenced by their interface curvatures, by the presence or the absence of species in the solution and by the pressure applied to the phases. The Gibbs–Duhem relation allows the description of the phenomenon, assuming that the medium is saturated with a non-pure solution.

It has been shown that the influence of pressure on the stability temperature as well as the degree of water purity can be neglected.

3.2. Interaction between ice and pore walls: expression of the crystallization pressure

A crystal at equilibrium, located in a large pore connected to another pore of smaller radius, neither tends to grow nor to melt. If the temperature is lowered, the crystal grows until it fills the pore volume. Consequently, it is assumed that the pressure in the crystal is controlled by the solid–liquid interface and the Laplace relation is applicable. In order to maintain mechanical equilibrium at the adsorbed layer–crystal interface, the walls of the pore have to exert a pressure on the crystal. This pressure can be expressed in the porous media by assuming that the ice–liquid interface at the entrance of the pore is spherical and that the pores have a cylindrical. The maximum pressure exerted by the fluid on the walls of a frozen pore is reached in large pores.

If a large pore is connected to several pores of different sizes, the maximum pressure will be determined by the radius of the smallest pore, because the liquid continues to flow through this channel until the crystallization starts in this small pore and blocks the flow. Therefore, the pressure in the pores is not uniform on a microscopic scale. It depends on whether the pores are frozen or not and the size of the neighboring pores.

However, at the scale of the continuous porous medium, in an elementary representative volume, this pressure intervenes only through a single value corresponding to an average value of the microscopic pressures in the elementary representative volume, called the mean pore pressure. This mean pore pressure in the elementary representative volume is obtained by weighting each pressure by the volumetric fraction of each given radius existing in the elementary representative volume.

3.3. Mechanical behavior of a saturated porous medium

The classical poroelasticity equations for an isotropic porous medium fully saturated by water were developed according to Biot. It is assumed that, at every point, the medium is occupied by both the solid and the liquid phases. Consequently, the total stress of the saturated material is divided into an effective stress carried by the solid matrix, and the stress carried by water, considered as a negative hydrostatic pressure.

The response of the medium to the applied stress is strains in the porous skeleton and the fluid. The linear elastic behavior of the drained medium (porous skeleton) is described by the traditional Hooke's law. The constitutive relation of the total strain combined with the equation of static equilibrium for a continuum gives a relation between the strains (or the displacements) in the porous skeleton, the volumetric forces, the temperature and the pore pressure.

3.4. Mass balance – constitutive relations and constitutive laws of the various phases

The former mechanical equilibrium equation contains two additional unknowns, the temperature and the pore pressure. These unknowns can be expressed by the balance equations for mass and energy. If the temperature is known, the only the average pore pressure must be determined. The resolution of the relation requires an additional scalar equation. This equation is provided by the conditions of mass conservation of the various phases present in the system under study.

The mass conservation equations are written for each phase (solid, liquid and ice). As far as the solid phase is concerned, it is considered that no solid mass creation is possible. The mass conservation equation can be simplified to the variation of porosity with time. For the liquid solution, the mass source term in the mass conservation equation is due to transformation of a part of the solution into ice during freezing. The mass rate of ice formation has to be defined, which can be done using Darcy's law. Finally, the mass conservation equation of ice is deduced assuming the medium is saturated. In this case, the mass source term is opposed to the one appearing in the liquid mass conservation equation. Moreover, it is assumed that the ice does not run out and its velocity is that of the skeleton.

Using the constitutive laws of the different phases, the state of each phase is described by a function of the temperature and pressure applied to it. This function is deduced through the expressions of the density variations of the different phases. Later, the density can be linked with the effective stress and the pore pressure.

3.5. Mathematical description of the porous media

Since the system is supposed to be saturated at all times, the general expression of the system equation can be written in the following simplified form:

$$\beta \frac{dP_l}{dt} = div\left(\frac{K_{rl}K}{\mu}\nabla P_l\right) + S - b\frac{d(tr\varepsilon)}{dt} \quad (1)$$

Where:

$$\beta = \frac{nS_l}{K_l} + \frac{nS_s}{K_s} + \frac{b-n}{K_m} \quad (2)$$

$$S = \left(\frac{1}{\rho_s} - \frac{1}{\rho_l}\right)\dot{w}_{l\to s} + \overline{\alpha}\frac{dT}{dt} - \frac{b-n}{K_m}\frac{dX}{dt} - \frac{nS_s}{K_s}\frac{dk_s}{dt} \quad (3)$$

$$\overline{\alpha} = nS_l\alpha_l + nS_s\alpha_s + (b-n)\alpha_0 \quad (4)$$

$$b = 1 - \frac{K_p}{K_m} \quad (5)$$

$\dot{w}_{l\to s}$ is the mass rate of ice formation,
a_0 is the volumetric coefficient of thermal expansion of the drained material,
K is the intrinsic permeability,
K_{rl} is the relative permeability,
μ is the dynamic viscosity of liquid,
ε is the strain,
K_p is the bulk modulus of the drained material (porous material),
K_m is the bulk modulus of the solid matrix,
b is Biot's coefficient,
n is the porosity of the porous media,
S_i is the degree of saturation of the phase i (s = solid, l = liquid),
ρ_i is the density of the phase i,
K_i is the isothermal modulus of compressibility of the phase i,
a_i is the isobaric coefficient of volumetric thermal dilation of the phase i,
k_s is the curvature of the solid–liquid interface,
X is the additional pressure due to the presence of ice,
P_l is the liquid pressure.

The major term in this relation is the term S, defined as the term responsible for the liquid pressure generation. This term integrates a number of physical phenomena such as: the difference of density between the liquid water and the ice crystal, the thermal contraction effects on the drained medium and the other components, the disjunction pressure representing the interaction between ice crystal and pore walls, and the pressure of the ice crystal.

The problem to be solved is to check that the system of equations below holds for all points and all times:

$$\begin{cases} \nabla\sigma = 0 & (6) \\ \beta\frac{dP_l}{dt} - \nabla\left(\frac{K}{\mu}\nabla P_l\right) - S + b\nabla\frac{du}{dt} = 0 & (7) \end{cases}$$

The unknowns of this problem, which can be solved by the finite element method, are the displacements and the liquid pressure at each point.

The final step is to define the boundary conditions. It is assumed that the ice is formed on the external surface of the sample and that its pressure thus remains equal to the atmospheric pressure. The liquid pressure consequently undergoes a depression given by the following relation:

$$P_l = -\frac{2\gamma_{ls}}{R_{eq}} \quad (8)$$

Where γ_{ls} is the surface tension of the ice–liquid interface and R_{eq} is the radius of the interface at equilibrium.

The physical characteristics of the materials studied as well as of water and ice, are necessary in order to solve this system.

4. Numerical simulations, results and discussion

The objective of this study was, on the one hand, to study the influence of the physical parameters such as porosity, permeability and modulus of elasticity for a standard material and, on the other hand, to test the aptitude of this numerical model to describe the behavior of fired clay materials.

4.1. Influence of the different parameters of the porous media

4.1.1. Pore size distribution

Five different pore size distributions giving the same total porosity were tried. The modulus of elasticity, the permeability, and the coefficient of thermal expansion were taken to be the same for the five distributions and fixed at representative values of the physical characteristics of fired clay materials.

It can be seen that, as the pore diameter decreases, the temperature of ice formation decreases while the medium undergoes an increasingly significant relative dilation and the magnitude of variation of the average liquid pressure increases. Everything else remains unchanged.

For a given distribution, the liquid pressure reaches its minimum at the same time as ice begins to form. As the liquid pressure increases with temperature, a cryo-suction phenomenon can be induced. It appears as if the temperature is not uniform. Water then moves from high pressure (and high temperature) towards low pressure (and low temperature), where it transforms to ice first. During the progressive development of ice, the pressure in the liquid in contact with the ice crystals increases, and an opposite water movement must then occurs. The ice volume increase controls the water movements thereafter.

4.1.2. Permeability

When the permeability is low, the average pressures become significant after ice formation. The apparition of hydraulic pressure involves a water flow opposed to the water pressure gradient. If the low permeability impedes the water movement, the resulting strains and liquid pressure will be significant.

4.1.3. Porosity

The S term responsible for the liquid pressure generation is strongly influenced by the value of the porosity. The higher the porosity, the more significant the S term. This phenomenon is simply explained by the fact that, as the porosity increases, the quantity of water increases, and the quantity of ice formed during freezing is also increased.

Concerning the X term, that is to say the additional pressure due to the presence of ice, it shows no variation since it is directly related to the radius of the pores and not to the porosity.

The strains and the average pressures become higher as the porosity increases.

4.1.4. Boundary conditions

The influence of the boundary conditions was evaluated by varying the magnitude of the liquid pressure imposed on the surface of the porous media. The tested values correspond either to water or to ice at atmospheric pressure. An intermediate situation was also evaluated.

The results of the numerical simulations show that the behavior is strongly related to the pressure imposed at the surface. The change of state of the liquid at the boundaries of the porous media implies a change of behavior of the medium, with accentuated strains.

4.2. Application to clay roofing tiles

As far as the two tested models of tiles CH3 and 2P2 are concerned, the pore size distribution, the porosity, the kinetics of ice formation and the strains developing during the freeze/thaw test were experimentally characterized and recorded (figures 2, 3 and 4). It can be observed that the pressure exerted on the pore walls of the 2P2 is higher than the one exerted in the case of the CH3 since the pores of the 2P2 are smaller.

The mechanical and hydraulic characteristics and the pore distribution being identified, it remained to impose the boundary conditions during ice formation. As the numerical code does not consider all the phenomena involved at the boundaries (e.g mass exchanges between the environment and the tiles such as water absorption), it cannot provide a realistic resulting liquid phase pressure. Therefore, it was chosen to impose on the external border of the tile the liquid pressure deduced from the experiment. The results are presented in figures 5 and 6.

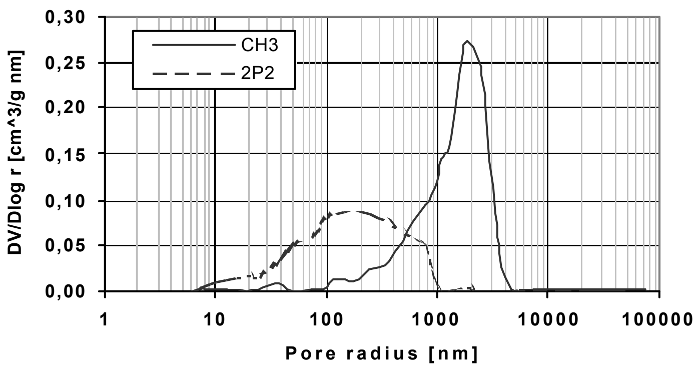

Figure 3 Pore size distributions of the two tested tiles: 2P2 and CH3.

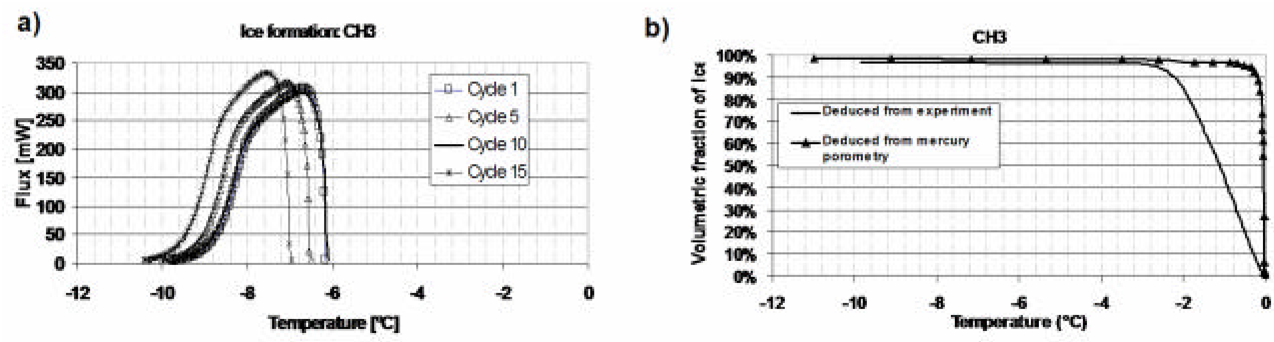

Figure 4 Ice formation: a) in CH3 tiles for different freeze/thaw cycles as obtained by DSC – b) Volume fraction of ice as a function of temperature, deduced from experiments and mercury porometry.

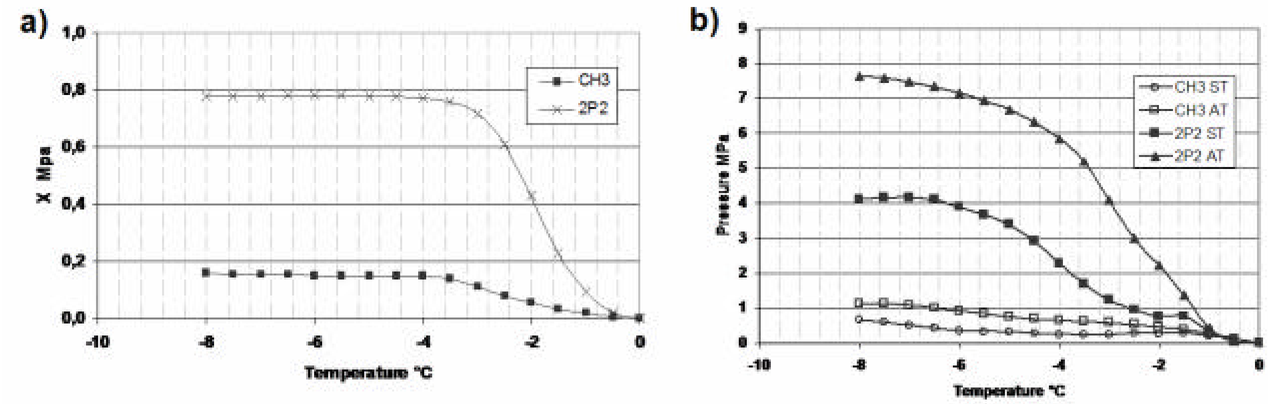

Figure 5 Numerical results obtained by the system for the two tested tiles: a) Additional pressure due to ice formation (e.g. X term) – b) Liquid phase pressure (e.g. corresponding to the S term).

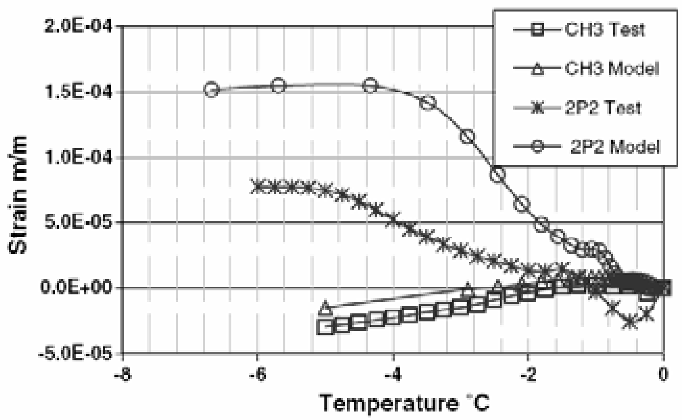

Figure 6 Numerical strains obtained by the system for the two tested tiles by imposing on the boundaries of the liquid the pressure deduced from the experiment.

The numerical model shows difficulty in reproducing exactly the experimental behavior. However, it is a very interesting qualitative tool for studying the behavior of porous media such as fired clay subjected to freeze/thaw cycles. Threfore, the study of the influence of the most significant parameters (e.g. pore size distribution, modulus of elasticity, and liquid permeability) becomes possible.

5. Conclusions

The implemented numerical code constitutes a very interesting qualitative tool for studying the behavior of media subjected to freeze/thaw cycles. Therefore, it was possible to study the influence of the most relevant parameters, such as pore size distribution, modulus of elasticity, and liquid permeability on a material with fictitious porosity but displaying mechanical characteristics close to those of the tiles. Its implementation for the tested 2P2 and CH3 tiles does not yet correctly reproduce their experimental behavior during freeze/thaw cycles. Although the physical model on which the code is based is one of most complete currently in existence, it still has some limitations related to the simplifications it contains. Indeed, in the case of saturated media, the code does not take into account all the exchanges at the boundaries of the material. Finally a comparison between calculations and experiment highlighted the importance of the boundary conditions, as well as the liquid permeability of the medium. Complementary experiments are currently being done at the CTMNC to improve the code and compare the results of the numerical simulations with experimental data from fired clay tiles displaying a wide range of characteristics. The objective is to obtain a quantitative tool to predict the freeze/thaw behavior of fired clay roofing tiles.

Once the code has been validated, it will be possible to estimate the freeze/thaw resistance of fired clay products and to optimize their characteristics in order to produce longer lasting roofing tiles, to build constructions with longer lifespan. Moreover, by adjusting the physical properties of the fired clay to respond to their intended use, minimization of the energy consumption in the processing unit will become conceivable.

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REPORT ON STUDIES CONDUCTED TO IMPROVE THE QUALITY OF AIR TIGHTNESS IN MASONRY BUILDINGS FOR SUSTAINABLE BUILDINGS

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Key words: Sustainable, building, masonry, clay, block, monomur, air tightness

Summary

1. Research objectives

Construction choices and interfaces between components that make up the outer walls of a building have a major influence on its global thermal performance, especially in the case of masonry structures (ADEME *Agency for the Environment and Energy Management* study "test campaign of housing air tightness 1999-2000").

A further study conducted by the CTMNC (TECHNICAL CENTRE FOR NATURAL BUILDING MATERIALS) consisting in numerous measurements of air tightness in individual houses built all over France since 2000, aims to make a strong contribution to the design and creation of energy and resource efficient habitats with low environmental impacts. Wall construction systems consist in either clay Monomur blocks (Clay monolithic block without added insulation) with no additional insulation or masonry walls lined with a clay backing wall covered on the inside with plaster.

Test campaigns have enabled the definition of recommendations concerning the choice of masonry finishes, treatment of window junctions, weatherproofing of rolling blinds, the wall/roof junction and all other openings in the walls. These measures allow us to achieve today a permeability of less than 0. 65$m^3/h/m^2$ under 4Pa.

This quality approach to air tightness of buildings has translated today into a demand for certification of compliance with new French thermal regulations (decree of 24th May 2006, appendix VII) supported by technical specifications that enable us to achieve a level of permeability inferior to 0.65$m^3/h.m^2$ under 4Pa.

2. Permeability test campaigns

From June 2000 to December 2007 the CTMNC conducted, with joint research teams from the CETE of Lyon -Laboratory of Autun (specialised in technical tests of equipment), 8 test campaigns concerning air

permeability of individual house envelopes using a significant sample of more than 40 housing units located all over France.
The tests concerned air permeability of the overall building envelope based on measurements obtained using a "blower door" system. Tests were carried out using a test protocol in compliance with European and French standard NF EN 13829. The principle consisted in artificially depressurising premises and then measuring leakage. The "blower door" is set up in place of an outside opening (front door…). It is installed in such a way as to ensure the air tightness of the opening. Test preparation is completed by blocking all voluntary openings in the envelope of the different houses. Permeability of a house's envelope can be measured once the "blower door" is completely installed with a ventilator as well as a control unit and data acquisition system.

Example of report	**Intervention site and ID N°**	**Intervention date**	**Type of construction**
Case N°12671	**CUGAND (85) France B2000-5**	**27th June 2000**	**Monomur**

Individual single-story house located at Le hameau des Giraudelles, 85610 Cugand FRANCE
Private construction client: Mme XXXX
This house is not totally finished.

Heated volume in m³ (1)	**Heat loss areas in m² (2)**	**Area of openings in m² (3)**	**(1) (2)**	**(3) (1)**	**(3) (2)**	**Permeability under 4 Pa[1] m³/(h.m²)**	**ACH (10)[2]**	**Equivalent leakage area (in cm²)**
211	196.72	11	1.07	0.052	0.056	0.14	0.25	52

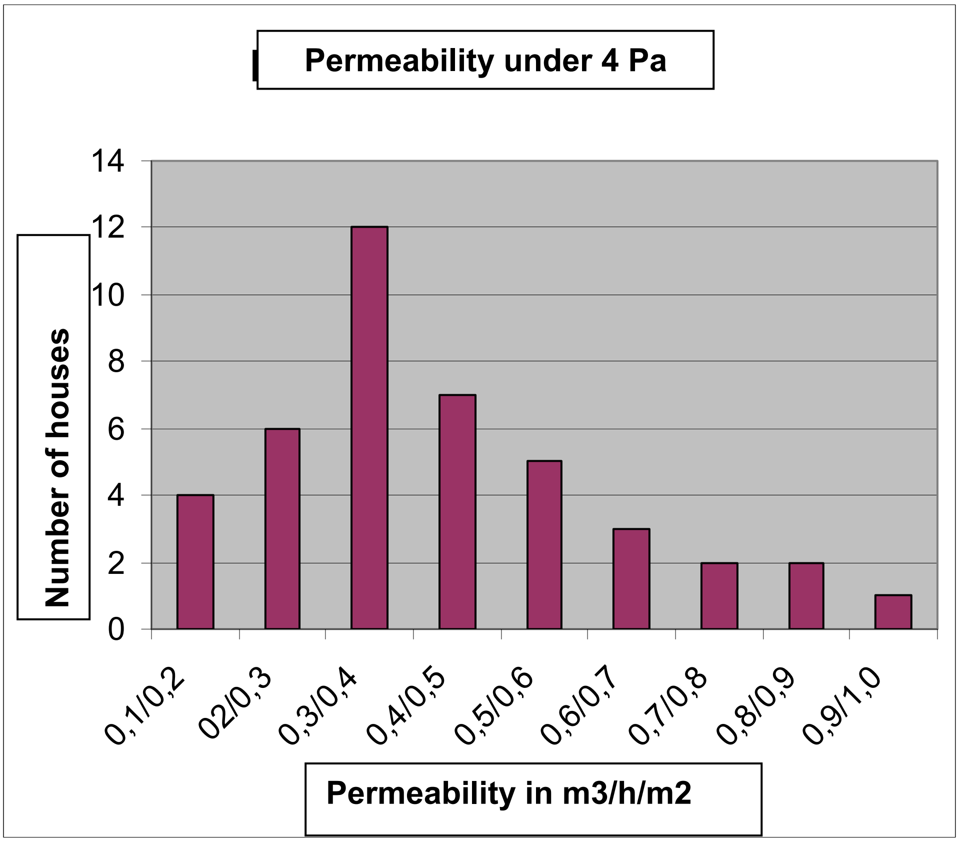
P≤0.2	0.2<P≤0.4	0.4<P≤0.7	0.7<P≤0.9	0.9<P≤1.3	P>1.3
Excellent	**Very good**	**Good**	**Average**	**Poor**	**Unsatisfactory**

Excellent permeability under 4 Pa =0.14 m³/(h.m²)	**Regulatory threshold = 0.8 m³/(h.m²)**
Location of outside air penetration points	**Type of leakage[3]**
-Living room: wall-mounted lighting fixture	!
-Water pipe in living room (30 cm x 5 cm hole), wall/floor junction The hole was filled during the tests; this defect will be repaired	!!!
-Kitchen electrical outlet	!

[1] According to article 15, decree of 29/11/2000.
[2] Air renewal rate under 10 Pa
[3] Intensity of leakage: ! Low !! Medium !!!Strong !!!Very strong

Important remark: the measurements of the air tightness value used in calculating regulatory compliance were made in houses that had no special treatment except that the walls had been plastered on the inside (either Monomur or with clay backing). Measurements were carried out in several regions and houses were only selected according to "availability" during the CETE test campaigns. They are therefore representative of typical French constructions.

Test campaign synthesis;
Values obtained by the CETE (*Centre d'Etudes Techniques de l'Equipement*). These values were also obtained using ALDES equipment.



The mean of these 42 values is 0.43m3/h.m2
The fractile 85 is 0.65m3/h.m2

3. Establishing quality standards for air tightness of buildings

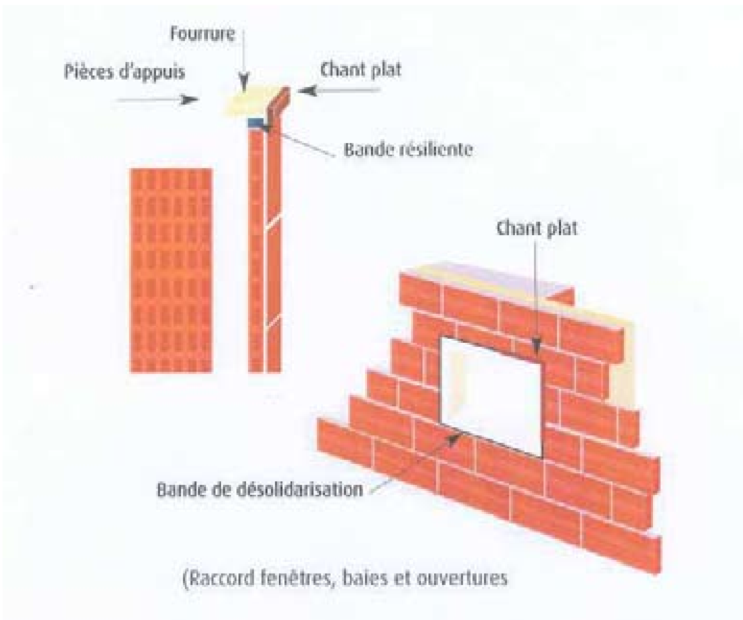
The standards proposed by the CTMNC and the FFTB (French Federation for Roofing Tiles and Bricks) aim to deal with the most common forms of leakage encountered in the construction of individual homes all over France. Wall construction systems consist either in Monomur brick walls or masonry walls lined with clay backing.

For the construction of an individual house, the customer or builder specifies at the start of construction that the building will be carefully monitored for air tightness. He agrees to provide craftsmen with the complete list of standards even if they are only concerned by part of these measures. Indeed, we believe it is important that all parties involved in the construction project are aware of their roles as well as the roles of others so as not to hinder each other's work. The customer, or his representative, will check these measures himself.

The following measures will be applied:

- Monomur clay blocks or clay backing walls will be plastered on the inside in order to prevent air leaks at structural junction points.

- Windows will be classified A*E*V* level A*2 minimum with improved permeability (French AEV classification in compliance with standard FD P 20-201 indicated the air tightness of the window (A), water tightness (E) and wind resistance (V) on a scale from 1 to 3, 3 being the highest level of efficiency).
- For installation of flush or recessed window casings, the inside or reveal must be levelled if the evenness does not comply with standard DTU 20.1. The weatherstripping joint must always be placed at the junction of the window frame and the carcass.
- Housings for rolling blinds: weatherstripping is placed at the junctions of the housing and the carcass and the window/door frame.
- Wall/roof junction
  There are two possible cases:
  The ceiling is also plastered: no special measures required
  The ceiling is in plasterboard: taping between the board and masonry before applying plaster.
- All openings in walls providing access to the outside or an unheated room will be finished with weatherstripping.



These measures enable us to obtain a value of 0.65m3/h.m2 without testing at the end of construction.

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BUILDING CERTIFICATION SYSTEM ACCORDING TO SUSTAINABLE BUILDING TOOL: ITALIAN EXPERIENCE

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Keywords: Sustainable Building Certification System, Accreditation System, Green Building Challenge, ITACA Protocol, Italian Regions, SBTool, Standardization

Summary

The assessment systems which are available, can define the level of the sustainability of the buildings but do not guarantee the private and public stakeholders with a defined responsibility for the certificate.

It is necessary to develop a certification system which identifies the process, the roles and responsibility in order to assess and certify, and define the certification procedures to obtain the certificate.

In Italy many certificates are issued both in the private and public sectors in accordance with the SB Method and the certification system which is available.

ITACA is a Federal Organization of the Italian Regions, which approved an assessment tool named "ITACA Protocol" in accordance with the SB Method that is used in assessment and certification systems by many Regions. The performance levels of sustainability in buildings are used to promote and finance public and private building.

This Tool should assess sustainability of residential buildings at 3 levels of complexity. The "ITACA Protocol" identifies criteria divided into two important areas, resources consumption and environmental impact, in accordance with European and Italian regulations and norms.

The structure of the Certification Scheme identifies the process and the roles of ITACA, the Italian Regions and iiSBE Italy.

ITACA should define strategic guidelines, supervise certification systems and guarantee the upgrade of the assessment tools.

Italian Regions should define their own procedures of certification and accreditation systems and identify the responsibility to issue the certificates.

iiSBE Italy established a written agreement with ITACA in order to support the Italian Regions to define and apply the assessment and certification system.

1. From the Assessment to the Certification

The Assessment Systems which are available, can define the level of the sustainability of the buildings but do not guarantee the private and public stakeholders with a defined responsibility of the certificate.

It is necessary to develop a Certification System which identifies the process, the roles and responsibility in order to assess and certify, and to define the certification procedures to obtain the certificate.

The Accreditation Scheme promotes the adoption of a process approach when developing, implementing and improving the effectiveness of a certification system.

The Accreditation Scheme guarantees that the Certification Process and the Evaluating Team's competences meet the requirements defined to assess and certify the Sustainability of the Built Environment.

In Italy many certificates are issued both in the private and public sectors in accordance with the SB Method and the available certification system.

ITACA is a Federal Organization of the Italian Regions, which approved an assessment tool named "ITACA Protocol" in accordance with the SB Method that is used in assessment and certification systems by many Regions. The performance levels of building sustainability are used to promote and finance public and private residential building.

ITACA has established an agreement with iiSBE Italy to support the Regions to develop and maintain the public certification system.

1.1 Sustainable Building Assessment System

The Sustainable Building Assessment System is performed through Assessment Methods to define the potential environmental impacts of the building.

The Guidelines to define a Sustainable Building Assessment System identify two important instruments:

- Assessment Tool
- Assessment Process

The design and implementation of an Assessment Tool is influenced by several needs: the particular destination of the building, the building phase, the local context and the size and structure of the building.

The application cases can be:

- design of a new building,
- refurbishment of an existing building,
- improvement of operations,
- operating building
- planning for modernization
- planning for demolition and waste management.

The Assessment Process includes the review of the documentation, the definition of the tool requirements data, the application of the assessment procedures and an analysis and report.

The Assessment Process, that uses the Assessment Tool, shall be organized in an Assessment System which can be improved in order to verify the results of the application experiences.

The stakeholders of the Assessment System can be investors, owners, developers, designers, builders, suppliers of building materials, users, occupants, facility managers, operators, sponsors, insurance companies, real estate brokers and governmental agencies.

The application of an Assessment Process to measure the building sustainability should be a strategic decision made by customers or interested parties.

The results of the Assessment Process provide a reference as a common basis for owners, design teams, contractors and suppliers who can define effective performance strategies.

The design process can be assisted by the Assessment Process to define the key environmental considerations and support the team to a results.

Another important issue is to be able to communicate and promote the built environmental quality, which is useful to design the certification system as activities and procedures to get a certificate.

1.2 Qualification Process of the evaluating team

The Evaluating Team should be a group of individuals who seek to have all relevant knowledge and skills available to the Assessment Process.

The competences of the evaluating team should allow to be able to use the Assessment Tool and apply the Assessment Process.

The training process of the evaluation team should be designed in order to develop and maintain the theoretical competences and practical applications.

The periodic re-qualification process of the team guarantees the assessment process quality results over time.

In order to qualify the trainers, the training process should be specified and designed according to the contents and methodologies to manage the Assessment System.

The courses for the evaluation team, followed by a final exam, shall be organized and held by the local chapters.

The accreditation system manages the qualified evaluators register and identifies the process of the supervision of the evaluators' re-qualification process.

1.3 Certification System

The Certification System is an structured ensemble of methods, tools, procedures, roles and responsibilities to give performance measures, to apply the assessment system, to get a certificate and to communicate the results.

The diffusion of sustainable building and the recognition of the best works for performance and cost reduction are two such good practices.

Gathering and organising information on good works can be used to lower operating, financing and insurances costs and can increase marketability.

The administration of public housing can check and evaluate building performances to finance public housing programs aimed at the socially and economically weaker segments of the population.

The availability of a certification system shall permit the estate market to tweak the market demand towards high performance buildings that can guarantee a higher return on investment and lower management costs.

In order to design and develop the certification system many important characteristics to meet requirements shall be identified.

The assessment method shall be based on scientific elements, depending on the climatic, social, economic and cultural context of the nation and region where the building is located.

The correlation to an internationally recognized system aims to bridge the gap between national and regional methods and provide a common framework for their expression.

The best practices concerning the assessment and certification system which exist in a regional context can be taken into consideration to improve the national system.

The certification system must be designed and developed in order to ensure that all of the scientific and technical characteristics, the methodology and procedures, the organizing system and the process should achieve very high levels of performance.

The indicators for the assessment process may be either qualitative or quantitative information and the quality of entry data must be checked because it will influence the results.

The certification system should be economically, financially, technically, environmentally, and socially sustainable.

The success of a certification system depends on its own capability to involve common stakeholders in the process and lead all parties to the results. The procedures must be easily applicable and available and the management control must be effective.

The cost of the system must be correlated to the activities and the resources needed. Continuous improvement activities must be planned to reduce the costs and improve the efficiency of the system.

The certification system must be able to maintain and improve its characteristics over time. The process of monitoring the performance and of the evaluation of the effectiveness of the system must be available.

For this document, a Certification Body is a qualified organization accredited by an Accreditation Scheme to perform the assessment process of sustainable built environment evaluation and to register the audited buildings.

Certification Bodies should meet the requirements of accreditation guidelines. The most important roles of the Certification Body are to design and maintain the certification process, provide technical support in the adaptation of the assessment tool to the local context and support the upgrading of the tool.

The roles of the Certification Body are to manage the contract whit the customer, identify the evaluation team, do assessment activities, validate the certificate through an accrediting body and update the certificate register.

The contribution of the Certification Bodies should focus on the continuous improvement of overall performance and efficiency, as well as the effectiveness of the system.

2. Accreditation Scheme Guidelines

For this document, an Accreditation Body is an organization with authority to accredit Certification Bodies to issue sustainable built environment certificates.

The roles of the accreditation body shall be to define the following strategic guidelines, develop certification and accreditation procedures and apply the process to qualify and re-qualify evaluation teams and procedures to monitor and evaluate the effectiveness of the certification system in meeting customer requirements.

The Accreditation Body shall update the Register of accredited bodies and oversee the certification bodies' activities.

The Accreditation Scheme promotes the adoption of a process approach when developing, implementing and improving the effectiveness of a Certification System.

The Accreditation Scheme concerns 4 main steps defined in a structured process which include roles and responsibilities of the accreditation and certification bodies:

Step 1 – Define Assessment Process

Step 2 - Define qualification process of the Evaluating Team

Step 3 – Identify Certification Body roles

Step 4 – Identify Accreditation Body roles

2.1 Step 1 - Define Assessment Process

The activities to define Assessment process are:
define the Strategic Guidelines. Identify assessment tool and procedures of the Sustainable Built Environment Assessment Process. Upgrade the assessment tool. Oversee the application of the Tool and procedures.

2.2 Step 2 - Define qualification process of the Evaluating Team

The activities to define qualification and re-qualification process of the evaluating team are:
define the competences of the Evaluating Team. Specify training process of the Evaluating Team. Qualify the trainers. Design the training process (Contents and Methodology). Hold the courses followed by final exam. Oversee the Qualified Evaluators Register. Supervise Evaluator's Requalification Process.

2.3 Step 3 - Identify Certification Body roles

The activities to identify the certification body roles are:
define minimum requirements of the Certification Body. Define process and procedures to obtain the Certificate. Identify Roles and Responsibilities in order to Assess and Certify. Define the Guidelines for Certification System. Guarantee that the Guidelines are followed.

2.4 Step 4 - Identify Accreditation Body roles

The activities to identify the accreditation body roles are:
define Accreditation Process to accredit Certification Bodies. Define Roles and Responsibility for the accreditation Process. Define the Procedures of Accreditation Scheme. Upgrade Register of Accredited Bodies. Monitor the Certification Bodies' activities. Define the Guidelines for Accreditation Scheme. Guarantee that the Guidelines are followed. Monitor and Evaluate the Accreditation Scheme.

3. Italian Certification System

At the present in Italy we have issued many important certificates for sustainable built environment.

These certifications have been of two types :

1. SB Method Certification System for Private Buildings
2. "ITACA Protocol" Certification System for Public and Private Buildings

3.1 iiSBE Certification System

The Scheme of the Certification System based on SB Method covers the iiSBE certification process applied in Italy to private buildings.

The model of a process-based certification system shows connections between the customer and iiSBE Italy.

The Customer characterizes the building on the basis of its construction and dimension data, function and life state and provides requested documents and data.

The document review determines if the documentation of the building meets all requirements of the assessment tool defined for each particular application with regard to the data input required. If the data are not satisfactory, the customer makes the necessary revisions.

The assessment process determines the degree and effectiveness of the performances of the building. In this phase it is necessary to establish the evaluation team's competences, organize the team, plan the activities and conduct the assessment. If the assessment is not satisfactory, the evaluation team repeats any necessary activities. After analysis and report reviews of the assessment procedures, the accreditation body shall confirm the process. The validation procedures are a confirmation by examination and provision of the evidence that the performance requirements of the building have been fulfilled.

Fig. 1 shows the certificate issued to one of most important commercial organizations located in Italy. This organization, named Coop, manages locations all over Italy and planned the certification process of its Sesto Fiorentino plant, near Florence. The building had been in use for two years. The GBC tool defined 6 areas of assessment and identified many criteria according to the Italian regulations and norms. iiSBE Italy was supported by two scientific partners: ITC-CNR, Italian Research Council and Environment Park of Turin, to define the context and apply the assessment tool.

The certificate issued identified the performance level of the building and established the date of issue and the date of expiry (5 years from issuing). To keep the certificate valid over time, it is necessary to repeat the assessment before this expiration date.

iiSBE Italia is collaborating with the most important stakeholders from the private sector performing building assessment on office buildings, hypermarkets, schools, etc...

At this moment it is in charge of the certification of the two major new skyscrapers that will be constructed in Italy (Turin) in the next 5 years. The first tower will be the Regional Government Headquarters, and the second one will be the Intesa-San Paolo banking Group Headquarters. The certification process will be performed on design, construction and operation phase.

The application of SB Method and ITACA Protocol is generating a demand of training and education from professionals, from technicians of the private and public sectors. iiBSE Italia, in cooperation whit several architectural and engineering institutes and with educational institutes is carrying out training courses on Green Building and ITACA Protocol application in several Italian Cities.

An Information Center on Green Building for public and private organizations is available to provide technical support for the Sustainable Building Certification process. A web-site provides the collection of all data of Italian and international information related to sustainable building.

Conferences, seminars and workshops on Green Building are organized by iiSBE Italy in cooperation with other public and private organizations to spread and promote Sustainable Building in Italy.

Fig. 1 Italian Hypermarket GBC Certificate

GREEN BUILDING CHALLENGE

iiSBE ITALIA

Certificato numero 01-IT

Certificazione di sostenibilità ambientale

Fase di verifica:	ESERCIZIO

Tipo di edificio
Centro Commerciale

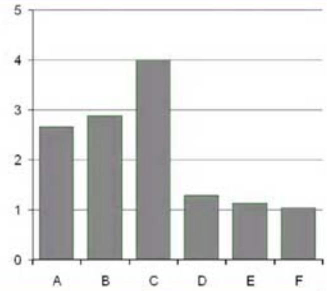
Anno di costruzione
2003

Ubicazione
Via Petrosa 19/21/23
Sesto Fiorentino (FI)
Italia

Superficie lorda
45.173 m^2

Superficie sito
104.450 m^2

Prestazione relativa



Il complesso valutato è composto da tre sotto - aree: ipermercato COOP e condominio, punto vendita OBI, uffici amministrativi.

Il ciclo di vita dell'edificio è stato assunto pari a 30 anni.

Sul sito erano presenti edifici esistenti, parzialmente riutilizzati nella nuova edificazione.

Classe	Prestazione	Punti
F	Prestazione inferiore alla pratica corrente	-1
D	Pratica corrente	0
C	Moderato miglioramento della prestazione rispetto alla pratica corrente	1
B	Sostanziale miglioramento della prestazione rispetto alla pratica corrente	2
A	Migliore pratica corrente	3
A+	Incremento della migliore pratica corrente	4
A++	Eccellenza	5

	Aree di valutazione	Pesi	Punteggi
A	Scelta del sito, sviluppo dell'area	13,6%	2,7
B	Energia e consumo delle risorse	22,7%	2,9
C	Carichi ambientali	22,7%	4,0
D	Qualità ambientale interna	18,3%	1,3
E	Funzionalità	9,1%	1,1
F	Prestazioni a lungo termine	13,6%	1,0
G	Aspetti socio - economici	0%	0,0
	Punteggio pesato dell'edificio		2,4

classe **B**

Prestazione assoluta

		Per area
1	Consumo netto complessivo di energia primaria inglobata, GJ	7,63 GJ/m^2
2	Consumo netto annuo di energia primaria inglobata, MJ / anno	254,3 MJ/ m^2
3	Consumo netto annuo di energia (delivered) nell'esercizio dell'edificio, MJ / anno	1209 MJ/ m^2
4	Consumo netto annuo di energia primaria non rinnovabile nell'esercizio dell'edificio, MJ / anno	1463 MJ/ m^2
5	Consumo netto annuo di energia primaria inglobata e di energia primaria nell'esercizio, MJ / anno	1618 MJ/ m^2
6	Quantità di energia rinnovabile impiegata nell'esercizio dell'edificio, MJ / anno	82% (idroelettrico)
7	Consumo netto annuo di acqua potabile nell'esercizio dell'edificio, m^3 / anno	0,4 m^3 / m^2
8	Impiego annuo di acque grigie e piovane nell'esercizio dell'edificio, m^3 / anno	2432,03 m^3 / m^2
9	Emissioni nette annue di gas serra nell'esercizio dell'edificio, kg. CO_2 equivalente per anno	44,2 kg./ m^2
11	Percentuale dell'area lorda di edifici esistenti riutilizzata nel nuovo intervento	33 %
12	Percentuale dell'area lorda dell'edificio da riuso di edifici esistenti	18 %

PRIMA EMISSIONE 4 GENNAIO 2007

VALIDO FINO AL 3 GENNAIO 2012

iiSBE

iiSBE ITALIA

iiSBE ITC ENVIRONMENT PARK

Il presente certificato è soggetto al rispetto del regolamento per la certificazione del livello di sostenibilità ambientale definito da iiSBE

3.2 ITACA Protocol Certification Scheme

ITACA is a Federal Organization of the Italian Regions which is competent for Sustainable Building. In 2004 ITACA approved an Assessment Tool named "ITACA Protocol" in accordance with the GBC and SB Method. This Tool should assess sustainability of residential buildings at the different levels of complexity.

For the Italian Constitution, energy and environment fall in to the competence of the Regions and a regional law on energy and environment has priority on national ones.

That means that the ITACA Protocol is a national labeling system recognized from all the Italian Regions as appraisal system both for public and private context.

The Ministry of Environment and the Ministry of Productive Activities are including the ITACA Protocol as a reference labeling in the national guidelines for the Energy Certification System.

The ITACA Protocol is used in Assessment and Certification Systems by many Italian Regions to define the performance levels of sustainability and to promote and finance public housing.

In the public context, the ITACA Protocol is used to define policies and to promote sustainable building through financial incentives, building codes, urban plan and guidelines.

The Protocol has been used by Italian Regions in different applications:

- Piedmont: funding program for social housing for several million Euros
- Lombardy: guidelines and urban plan
- Tuscany, Veneto, Friuli Venezia Giulia, Liguria, Lazio, Basilicata, Calabria: guidelines and social housing program
- Marche: its own Certification System and the founding program for social housing
- Apulia: reference labelling system, regulations and Certification System

In the private context the ITACA Protocol is used to promote financial products aimed to award green building, such as "Aedifica bioedilizia" by Intesa - San Paolo Banking Group, and insurance products by RAS (Alliance Group). iiSBE Italy acts as scientific support to promote and spread these initiatives in the Italian Market.

Through the ITACA Protocol rating system a major impact on the building sector in Italy is underway, with the beginning of a market transformation.

The well known ITACA Protocol for residential buildings identifies 12 criteria divided into two important areas, resources consumption and environmental impacts, in accordance with Italian regulations and norms (Synthetic ITACA Protocol for Residential Building, Edition 2, approved in 2007). Assessment tools are available as criteria set, appraisal scheme, application manual and software.

The structure of the Certification Scheme for Italian Regions, shown in Fig. 2, illustrates the process and the roles of ITACA, of the Italian Regions and of iiSBE Italy.

ITACA should define strategic guidelines of the Certification Scheme and guarantee that the certification system is based on scientific elements, correlated to an internationally recognized system, solid and sustainable, user friendly and easily applicable, suitable, cost efficient and reliable.

ITACA should establish the Assessment System and provide the upgrade of the Assessment Tool in order to follow the evolution of national regulation requirements.

ITACA should oversee and supervise certification systems and guarantee the quality of the results.

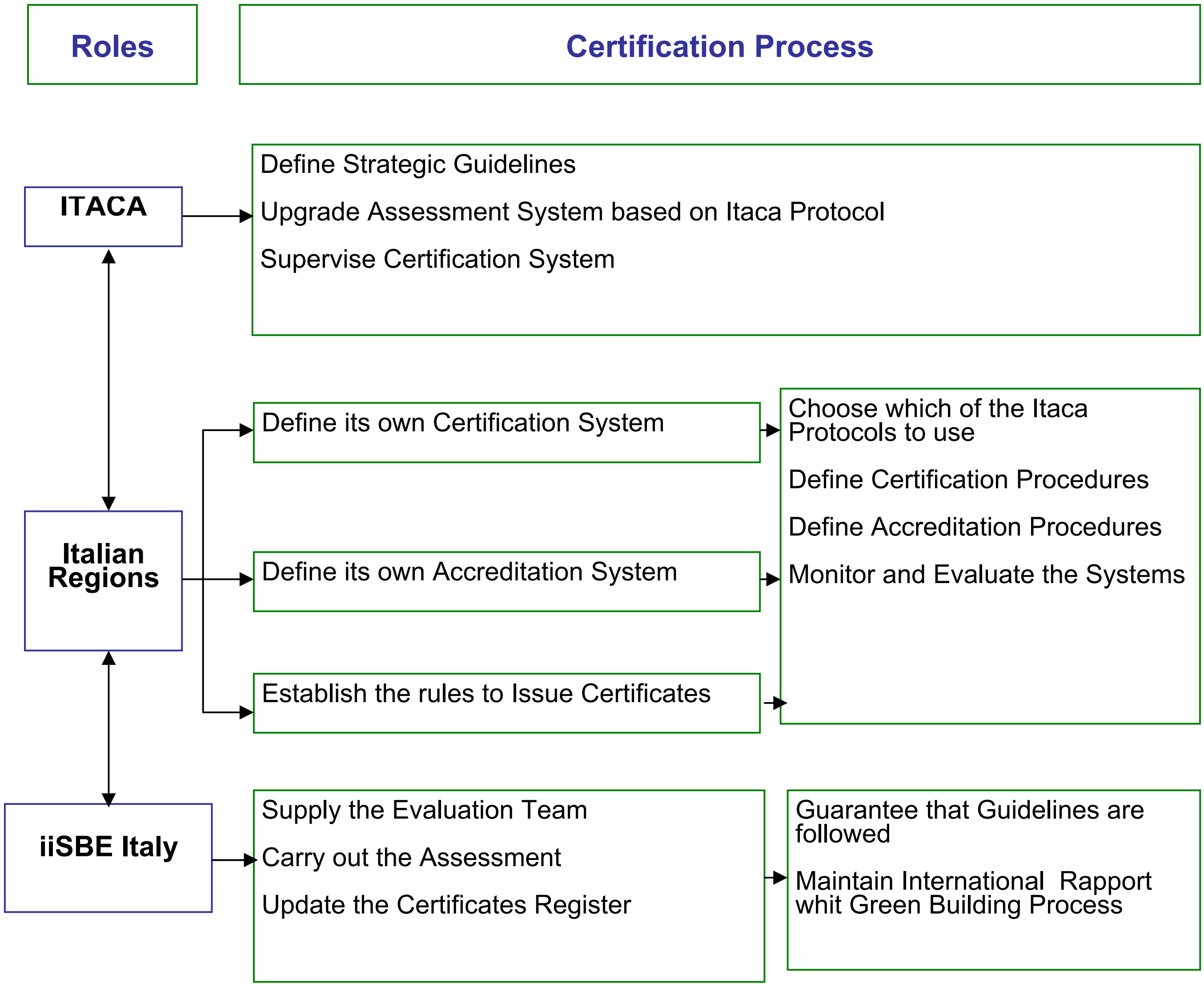
Italian Regions should define their own certification and accreditation systems and establish the rules to issue the certificates. They choose which type of the protocol to use, and define certification and accreditation procedures. They monitor and evaluate the certification and accreditation systems.

iiSBE Italy is the National Control Body of the ITACA Protocol, provides technical support to ITACA, supplies the evaluation team, carries out the assessment and updates the certificate register.

In several regional founding programs, iiSBE Italy has the important role of Certification Body in the Certification Scheme.

The role of iiSBE Italy is to establish and maintain the relationship with the international Sustainable Building Challenge process.

Fig. 2 Certification Scheme for Italian Regions



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DEVELOPMENT OF RING-PANEL CONNECTION METHOD FOR REUSE OF STEEL MEMBERS

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Keywords: Reuse of members, Steel structure, Rigid connection, Non-welding, Ring-panel, structural behavior, Loading test, Disassembling test

Summary

To realize the environmentally sustainable society, the development of building construction methods for reuse of structural members is required these days. The Ring-panel connections, newly developed in this paper, makes the steel members more possible to be easily disassembled and consequently to be reused.

The Ring-panel consists of a steel pipe with outer diaphragms and beam brackets, and with a little larger size than connected steel columns. The steel columns are inserted into the Ring-panel, with "disassembling steel plates" inserted into the gap. Mortar is filled into the gap, and then the rigid connection is formed.

The authors verified the structural performance of the Ring-panel connections by experiments, and derived the evaluation method for the strength of the Ring-panel connection. On the other hands, the authors tested the disassembling procedure using full-scale specimens, and could disassemble easily the all members without any damage.

1. Introduction

A sustainable social system has been one of the urgent themes for global environment in the 21st century. In construction fields, the energy saving measures has been discussed much more especially from the viewpoint of building machinery engineering. However, it is also important to approach the global environment issues from structural engineering.

One of the approaches from structural engineering is to reuse the steel structural members and decrease the CO_2 emissions in the member production stage. The authors have proposed a sustainable building system called "adaptable building" as shown in Photo 1. This system allows easy assembling and disassembling, and helps reuse the building members. The authors realized the adaptable building by applying the "Ring-panel connection method". The Ring-panel connection can be realized by non-welding connection method, maintaining high construction performance and disassembling performance of the steel members. This paper reports outlines of the Ring-panel connection and the experimental studies on the structural behaviors of the Ring-panel connection.

Photo 1 Adaptable building

2. Outlines of Ring-panel Connection

An outline of the conventional Ring-panel connection is shown in Fig.1 (a). The Ring-panel consists of a steel pipe with outer diaphragms and beam brackets, and with a little larger size than connected steel columns. The steel columns are inserted into the Ring-panel. Mortar is filled into the gap between the columns and the Ring-panel. The stress transfer mechanism in the connection is shown in Fig.2. The connection resists against the shear force and moment from columns with the leverage reaction force and compressive strut. The compressive strut occurs between the flat bars attached to both ends of the Ring-panel and the columns. This mechanism consequently forms the rigid connection.

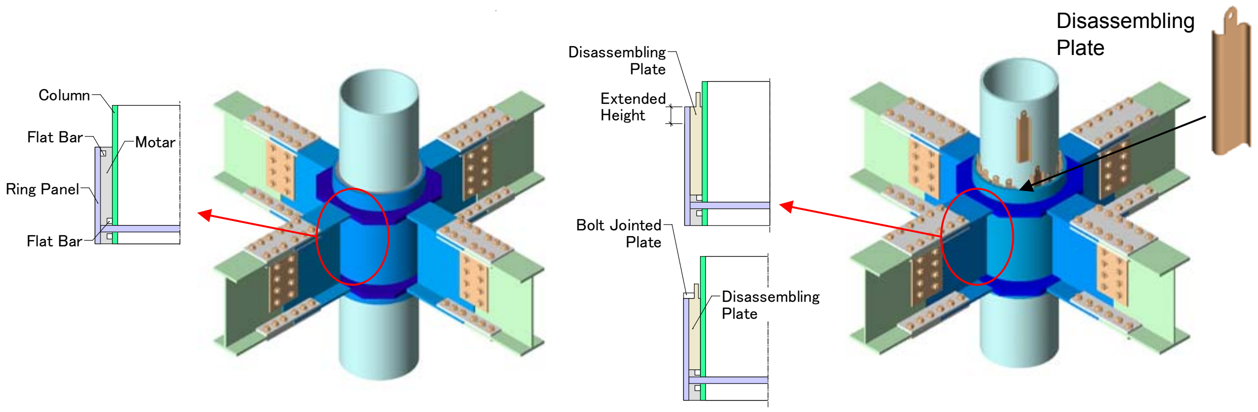
An outline of the reuse type of Ring-panel connection is shown in Fig.1 (b), which can disassemble all members without any damage. The reuse type of Ring-panel connection has disassembling plates inserted into the gap, which are placed in advance to where the mortar is supposed to be filled. When the structure is disassembled, the plates are removed to make voids in the mortar, leading to easy disassembling. In the conventional Ring-panel connection, the flat bars at end of the Ring-panel would obstruct disassembling. Therefore, in the reuse type the flat bars are removed, and instead the Ring-panel is made longer in a vertical direction to increase the friction resistance and leverage reaction force. If the flat bars are fixed with bolts, the Ring-panel height can be made lower.

3. Structural Test

3.1 Outline of Test

In order to verify the structural behaviors of the Ring-panel connections, loading tests were carried out using 2/3 scale specimens. The specimen configurations are showed in Fig.3 and Fig.4, and the test parameters are showed in Table 1.The specimen J1 is designed as the conventional Ring-panel method and its Ring-panel height “h” is 600mm. The specimen S1 is designed as the reuse type Ring-panel that has flat bars fixed with bolts, and the Ring-panel height “h” is identical to that of the conventional type. For the specimen S2, the Ring-panel height “h” is taken as 800mm; 1.3 times of the conventional type because of no flat bars. These specimens are designed to ensure the beam yielding prior to any other parts. The mechanical characteristics of steels and mortar used in the specimens are shown in Tables 2 and 3.

A shear force of inverse symmetry is applied to each end of the beam. The top and bottom ends of the column are simply supported. A cyclical loading is conducted with the story drift angle once for 1/120, twice for 1/60 and 1/30, and once for 1/20. After the cyclic loading, specimens are loaded up to 1/15 of story drift angle in one-way direction.



(a) Conventional Ring-panel connection *(b) Reuse type of Ring-panel connection*

Figure 1 Outline of Ring-panel connection method

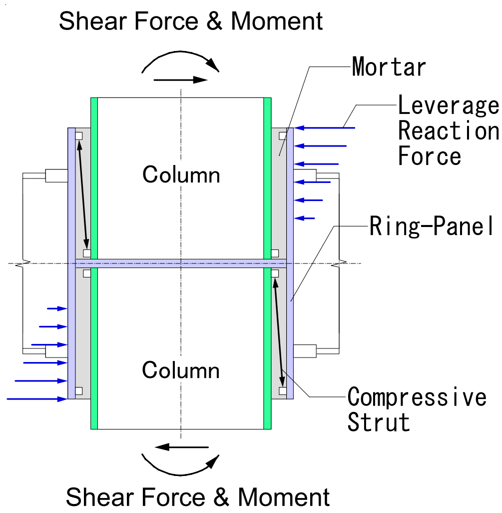


Figure 2 Stress transfer mechanism of Ring-panel method

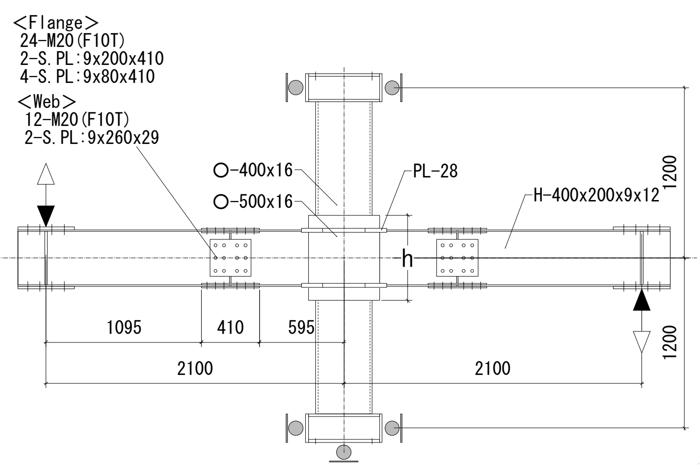


Figure 3 Configuration of specimens

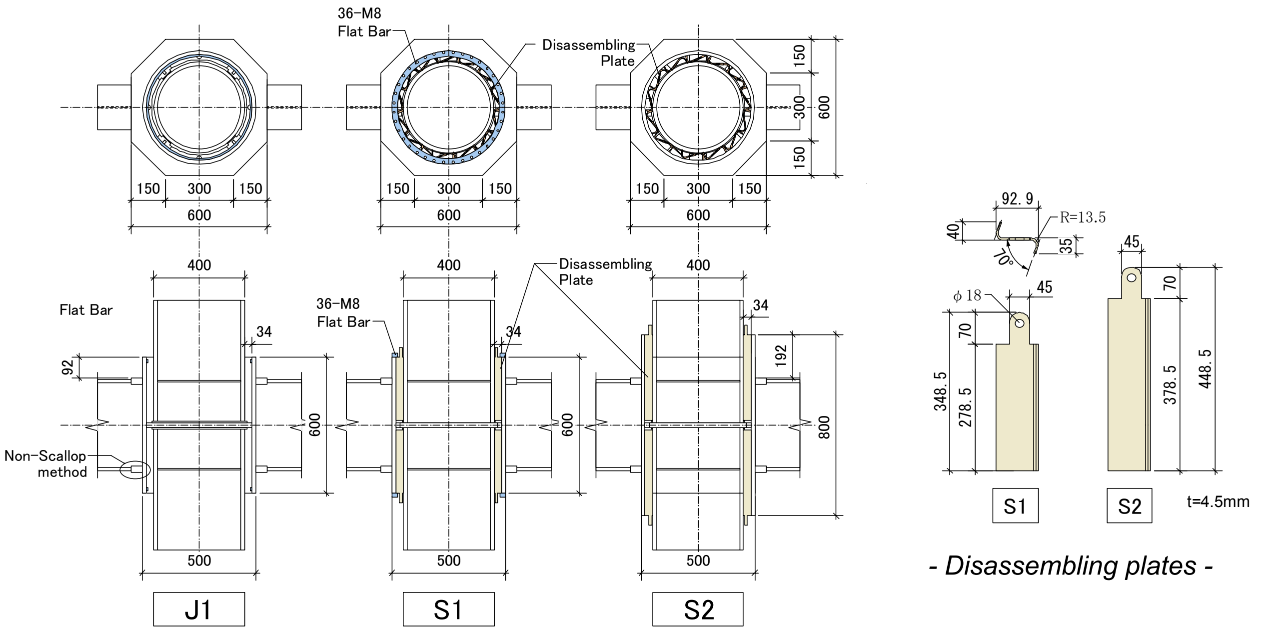


Figure 4 Details of beam to column connections of specimens

Table 1 Specimens and test parameters

Specimen No.	Ring Panel Heigth [mm]	Disassembling Plate	Flat Bar for Strut
J1	600	×	○
S1	600	○	○
S2	800	○	×

Table 2 Properties of steels

Part		Materials standard	Yeild Strength [N/mm²]	Tensile Strength [N/mm²]	Uniform Elongation [%]
Column		STKN490B-ELG	389	541	46
beam	Flange	SN490B	383	532	26
	Web		408	541	26
Ring Panel		STKN490B-ELG	370	534	46
Diaphragm		SN490B-ELG	378	536	34
Disassembling Plate		SS400	325	412	32
Flat Bar for Strut		SN490B	382	528	28

Table 3 Compressive strength of mortar

Specimen No.	Age [Day]	Compressive Strength [N/mm²]
J1	23	72.3
S1	17	55.9
S2	32	78.1

3.2 Result of Test

The relationship between the shear force of columns and the story drift angle is shown in Fig.5. The failure example of the specimens at final loading stage is shown in Photo 2. The local buckling was found at each beam end in all specimens, and then the maximum load was reached. The reuse type specimens S1 and S2 showed a slight slippage in the shear force vs. drift angle curves, however no significant difference was shown compared to the conventional specimen J1.In the specimen J1, cracks occurred on the surface of the mortar, but there was no crush in the mortar inside the connection. In the specimens S1 and S2, the slippage out of the disassembling plate and the crush on the surface of the mortar occurred at the loading cycle of 1/30, but there was no crush in the mortar inside the connection as in the specimen J1. In all specimens the columns, Ring-panels, and diaphragms all remained elastic.

A comparison of skeleton curves based on the shear force vs.drift angle curves for all specimens are shown in Fig.6. As shown in Fig.6, the reuse type Ring-panel connections have almost the similar structural performance to the conventional Ring-panel connections.

The potential strengths when each part of the specimens would yield are shown in Table 4. For calculation of the strength of mortar crushing, the stress distribution in the Ring-panel as shown in Fig.7 is assumed. The calculation values based on the yield strength and the ultimate for all specimens met a good agreement with the test results.

4. Disassembling Test

In order to confirm the disassembling performance of the reuse type Ring-panel connections, disassembling tests were carried out using full-scale specimens. The specimens consisted of a column (Pipe-609.6x22mm), a Ring-Panel (Pipe-711.2x22mm), 20 disassembling plates (Length: 450mm), and mortar (compressive strength: 48N/mm^2).

Each disassembling plate was pulled out from the mortar. The pull-out force was about 10kN at maximum for each plate. And the time required for disassembling was about a minute for each plate. After all plates pulled out, since the consequent voids made the column and the Ring-panel separated, the column was easily removed from the Ring-panel. The total time for disassembling was about 30 minutes, and it was confirmed to disassemble all the members without any damage.

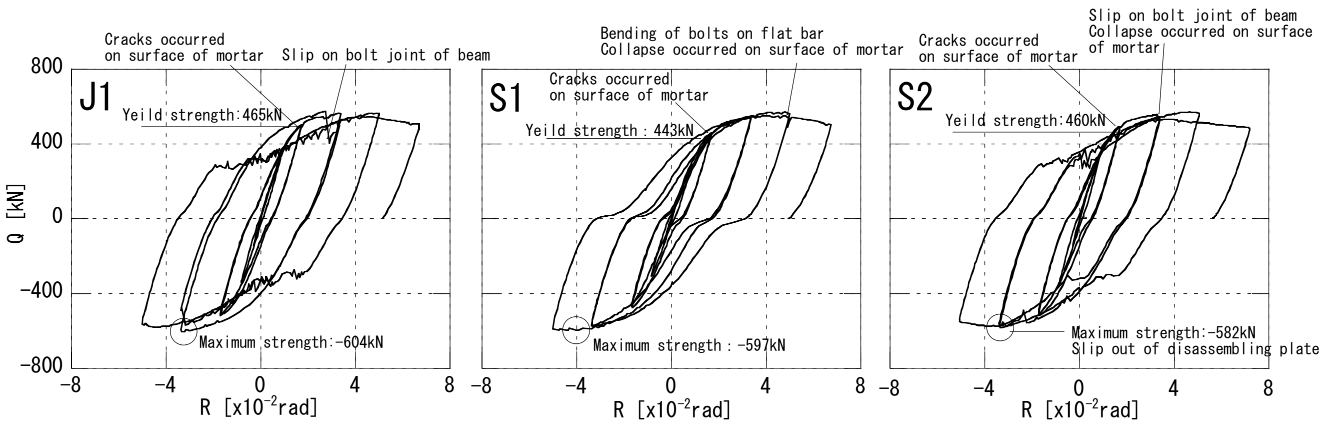


Figure 5 Relationships between column shear force and story drift angle

(a) The local buckling of the beam (J1) *(b) The slippage out of the disassembling plate (S2)*

Photo 2 Failure examples of specimens at final loading stage

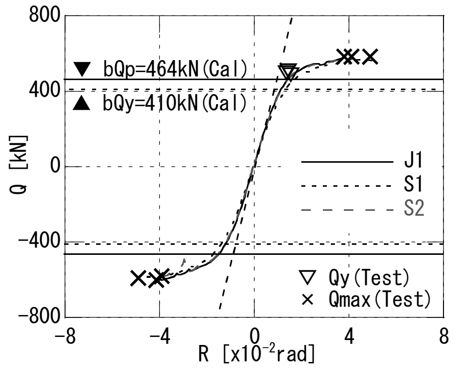


Figure 6 Comparison of skeleton curves

Table 4 Test results and calculation results

Specimen No.	Calculation Results				Test Results			Test/Calculation	
	Beam		Column	Mortar	eQy[*1] [kN]	eQu [kN]	Yeilded part	eQy /bQy	eQp /bQu
	bQy [kN]	bQp [kN]	cQy [kN]	mQp [kN]					
J1	410	464	771	851	465	604	Beam	1.14	1.30
S1	410	464	771	658	443	597	Beam	1.08	1.29
S2	410	464	867	1634	460	582	Beam	1.12	1.25

*1 eQy: calculated by the 1/3 slope factor

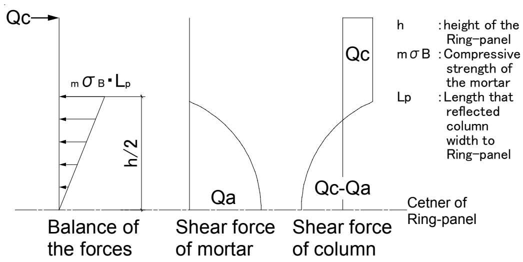


Figure 7 Stress distribution in Ring-panel

5. Conclusion

The authors proposed the Ring-panel connection method for the reuse of steel members. According to this method, the steel members can be easily disassembled without any damage. The structural performance of the Ring-panel connections was verified through the loading tests. And the disassembling performance was verified through the disassembling tests using full-scale specimens.

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RUNNING PERFORMANCE OF SPLIT-TYPE AIR CONDITIONING SYSTEMS INSTALLED IN A UNIVERSITY CAMPUS AND AN OFFICE BUILDING IN TOKYO AND ITS SUBURB

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Keywords: EHP, GHP, air conditioning, cooling, heating, heat pump, performance, COP, part load

Summary

Split-type air conditioning systems or heat pump systems with multiple indoor and outdoor units are becoming very popular for air conditioning and room heating of small or middle-sized non-residential buildings in Japan. However, their running performance is yet to become known due to the difficulty of measuring actual amount of heat transferred by the system. Mixed irregular flow of vapor and liquid refrigerant has prevented building engineers from obtaining accurate amount heat flow between indoor and outdoor units.

This study introduces alternative methods to calculate heat transferred by the system from air volume and enthalpy measured with simple sensors attached to the indoor units as well as measuring amount of heat exchanged by outdoor units. Results at a national university building in suburban Tokyo and an office building in central Tokyo showed unexpectedly low COP values mainly due to the capacity of the systems far exceeding actual heat demand and imbalance between summer and winter heat demand both resulting in the prevailing low part load factors especially in winter which is under 20% of the system capacity.

1. Introduction

Recent rise in environmental consciousness and deteriorating state of the earth combined with approaching deadline for public commitments to reduce CO2 emissions and increasing energy consumption at private sectors have intensified importance of developing and promoting methods for conservation and efficient use of energy.

Somewhat irrelevant to these situations, multiple-unit electric and gas heat pump (EHP/GHP) systems have been rapidly spreading from the aspect of cost saving and convenience and installed even in the buildings with several tens of thousand square meters of floor area in major Japanese cities. From the aspect of energy efficiency, however, it is suspected that their high rated COPs based on the Japanese Industrial standard do not necessarily represent actual values in use. It is also suggested that EHP/GHP may constitute a primary source of heat island, because unlike centralized air conditioning systems equipped with cooling towers which primary discharge latent heat, EHP/GHP exclusively discharge sensible heat into the urban canyon directly rising its air temperature. Their efficiency therefore is also a primary interest from the aspect of urban environment. In order to obtain state of the art knowledge to these pending questions, series of researches have been conducted in cooperation with three universities and Tokyo Gas, a major GHP distributor, to measure energy efficiency of a typical EHP and GHP system under actual operating environment. The results will help us in designing and installing them in a better way.

2. Indoor Measurement at an University Campus Building in Suburban Tokyo

A multiple type EHP system consisting of 7 indoor and 4 outdoor units installed on a national university campus in west suburb of Tokyo was the site of the first measurement. For this system, multiple points indoor measuring method was applied to examine its system efficiency (i.e. COP: Coefficient of Performance) in daily operation. Summer measurement was conducted from August 26 through September 5, 2005 with the indoor setting temperature of 27deg. and winter measurement from February 14 through 22, 2006 with the setting temperature of 24deg. (February 14 through 16), 22deg. (17 through 19) and 20deg. (February 20 through 22). Climate during summer measurement was normal ranging between 21.9 and 33.1 degrees and warmer during winter between 2.2 and 18.5 degrees. Throughout measurement, airflow of the indoor units was set at strong mode while airflow direction was set no swing with middle low angle blowout position.

2.1 Measurement Specification

2.1.1 Specification of Measured Units

Measured units are specified in Table 1 and 2. The total cooling (i.e. air conditioning without humidity control) capacity of indoor units is 50.9kW (at 50Hz, same hereinafter) while heating capacity is 57.0 kW, 11% exceeding cooling capacity. Outdoor units consume 21.18kWh of electricity to remove 56kWh of heat for cooling and consume 18.3 kWh of electricity to provide 53kWh of heat for heating. Including small power consumption by indoor units, rated COP for the system is 56/(21.18+0.63) = 2.57 for cooling and 53/(18.3+0.63) = 2.80 for heating. Electricity consumption of all 7 indoor units, 4 outdoor units and their control systems were measured every minute by attaching clamp watt meters to the grid power line.

Table 1 Specification of indoor units (50Hz/60Hz)

Name		ACM 8-1 (1 Unit)	ACM 8-2 (2 Unit)	ACM 8-3 (4 Unit)
Electric source		Single phase 200V, 50/60Hz		
Capability	Cooling	4.5kW	9.0kW	7.1kW
	Heating	5.0kW	10.0kW	8.0kW
Electric power consumption	Cooling	0.07/0.08kW	0.11/0.12kW	0.085/0.09kW
	Heating	0.07/0.08kW	0.11/0.12kW	0.085/0.09kW
Power current	Cooling	0.35/0.4A	0.55/0.6A	0.425/0.45A
	Heating	0.35/0.4A	0.55/0.6A	0.425/0.45A
Air volume system		Very Strong(15m3/min), Strong(12), Week(10)	Very Strong(20m3/min), Strong(15), Week(12)	Very Strong(16m3/min), Strong(13), Week(11)

Table 2 Specification of outdoor units (50Hz/60Hz)

Name		ACM-5,7,8,11
Electricity		Three phase 200V, 50/60Hz
Capacity	Cooling	56.0kW
	Heating	53.0kW
striking current		Cooling 168/155A, Heating 166/153A
Electric power consumption	Cooling	21.18/22.48kW
	Heating	18.30/20.10kW
Power current	Cooling	67.6/72.1A
	Heating	59.3/65.1A

2.1.2 Thermal Flow through Indoor Units

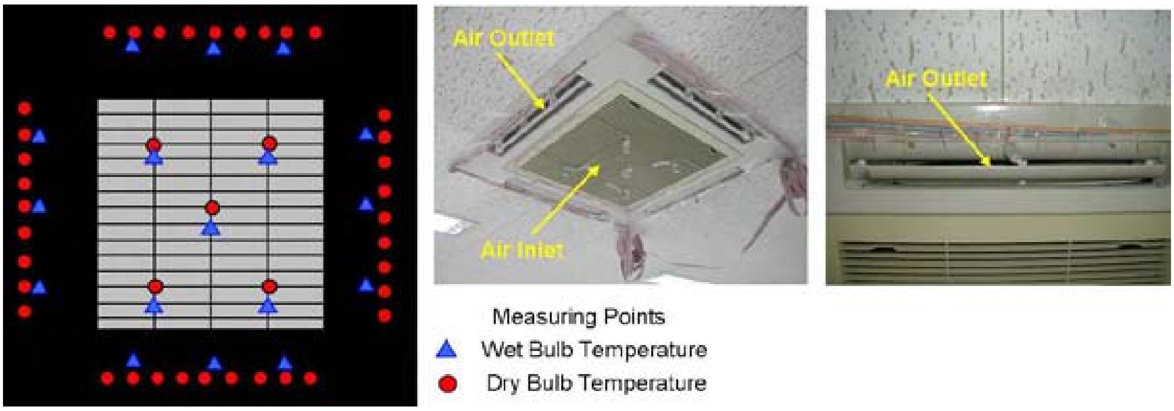


Figure 1 Temperature and humidity summer measurement points of a indoor unit

For all indoor units, 9 dry and 3 wet bulb temperatures were measured at each air inlet while 5 dry and wet bulb temperatures were measured at outlet with thermocouples and a data logger as shown in Figure 1. Airflow velocity at air inlets and outlets were pre-measured with a traverse unit reproducing the same airflow as during the measurement. Heat exchange quantity was calculated by multiplying inlet and outlet enthalpy difference and airflow volume calculated by the airflow velocity distribution described later. Measured items on indoor units are specified on Table 3.

Table 3 Measurement specification of indoor units

Position	Item	Sensor	Specification	Points (Summer)	Points (Winter)
Air outlet	Temperature	Thermocouple 0.32T-G		9 x 4=36	9 x 4=36
	Humidity	Thermocouple 0.32T-G	Wet-bulb temperature measurement with moisture gauze	3 x 4=12	1 x 4=4
Air inlet	Temperature	Thermocouple 0.32T-G		5	5
	Humidity	Thermocouple 0.32T-G	Wet-bulb temperature measurement with moisture gauze	5	1

2.1.3 Indoor and Outdoor Thermal Environment

In order to measure indoor temperature distribution, 15 representing points were designated each with three vertical measurements making up 45 altogether as shown in Figure 2. In addition, outdoor temperature, humidity, solar radiation, airflow direction, airflow velocity, atmospheric pressure and precipitation were measured with a portable weather station.

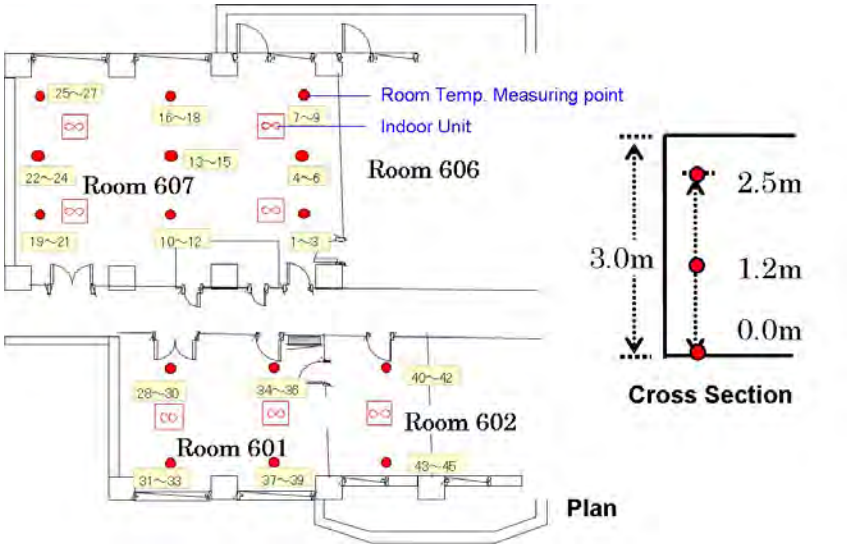


Figure 2 Horizontal and vertical location of thermo-hygrometers set around indoor units

2.2 Airflow Volume Calculation

Airflow velocities in and from an indoor unit were measured with a traverse unit" designed by Professor Shigeki Kametani for the study (Figure 3). A scalar and a vector anemometer traverse across an indoor unit by a tenth of an inch precisely measuring three dimensional airflow velocities in and from it creating accurate airflow velocity distribution curve (line graphs of Figure 4). Airflow

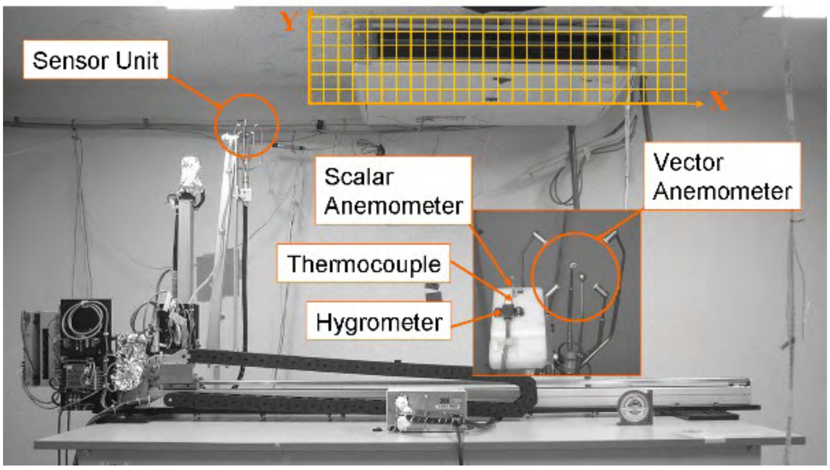


Figure 3 Kametani Traverse Unit

velocity at each measuring point was calculated by modeling these charts (bar graphs of Figure 4)

Airflow volume at each measuring point of an air outlet was calculated from modeled airflow velocities. Inlet airflow volume was calculated according to the representing area of each measured point (Figure 5). A sum of calculated airflow volume was adjusted to match the rated airflow volume for strong airflow mode and distributed to each measuring point.

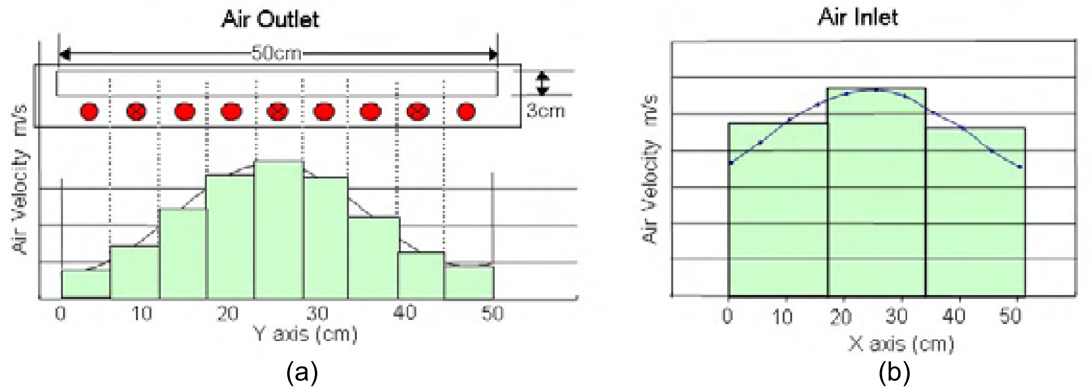


Figure 4 Airflow velocities distribution of air outlet (a) and inlet (b) with approximation at each measuring point

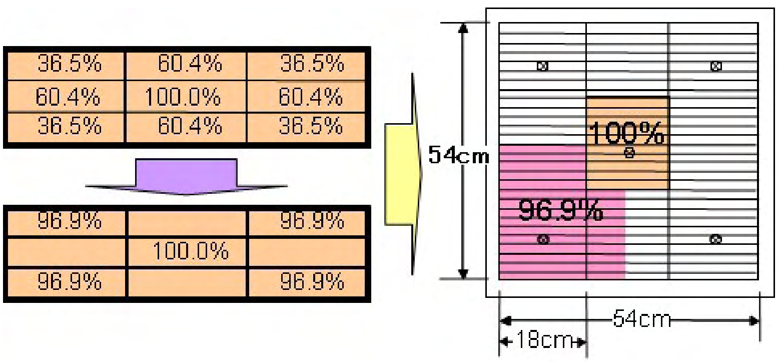
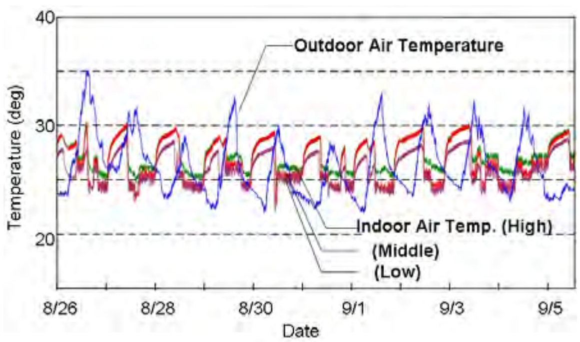


Figure 5 Air inlet volume distribution at each measuring point

2.3 Results

2.3.1 Summer Measurement

Outdoor air temperature and room temperatures at three vertical measuring points are shown in Figure 6. During most of the operating time (10am-9pm), room temperatures stayed well at the preset temperature or a little below identifying cooling were properly functioned.



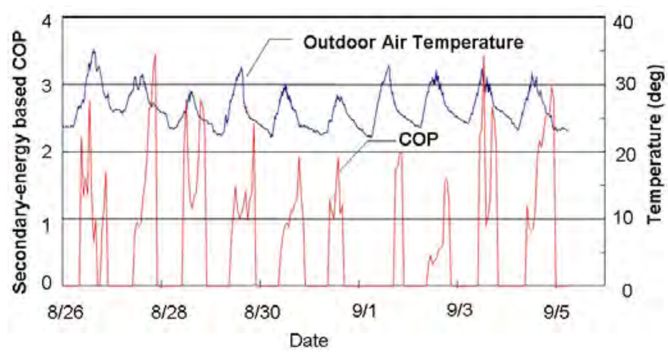


Figure 6 Outside air and room temperature (Summer measurement)

Figure 7 Change of COP (Summer measurement)

The change of COP during operating time in summer measurement is shown in Figure 7. Average COP calculated by formula (1) was considerably lower than the rated COP of 2.57. Figure 8 and 9 show distribution of load factor. Most of the load is concentrated under 30% of the capacity. It is assumed that the system has excess capacity.

$$COP = \frac{\text{Quantity of heat exchanged by the indoor units}}{\text{Electric power consumption by indoor and outdoor units}} \quad (1)$$

= 715.806 [kWh] / 411.382 [kWh] = 1.74 (10am-9pm, August 26-September 5, 2005)

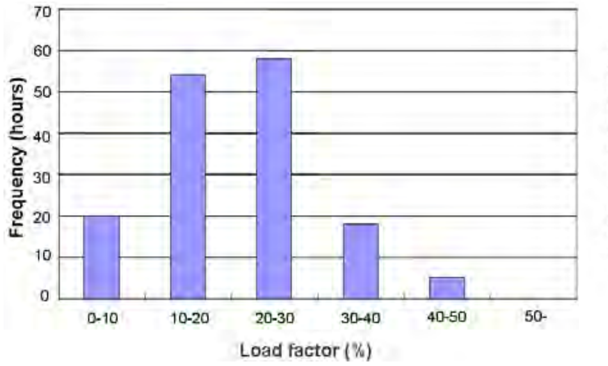


Figure 8 Frequency distribution of load factor (summer measurement)

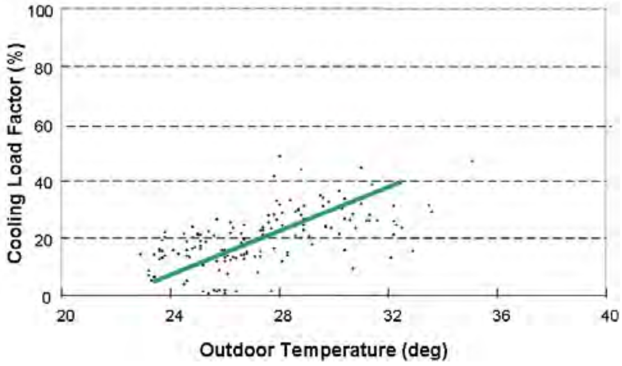


Figure 9 Relation between outside air temperature and load factor (summer measurement)

2.3.2 Winter Measurement

Outdoor air temperature and room temperatures at three vertical measuring points are shown in Figure 10. During operating time (10am-9pm), room temperature stayed well around the preset temperature identifying heating was properly functioned.

The change of COP during operating time in winter measurement is shown in Figure 11. Measured COP calculated by formula (1) was much lower than the rated COP of 2.80. One of the reasons for such low COP in winter is the use of oil heaters adding to the stand-by power consumption.

COP= 92.700 [kWh] / 153.898 [kWh] = 0.60 (10am-9pm, February 14 - 22, 2006)

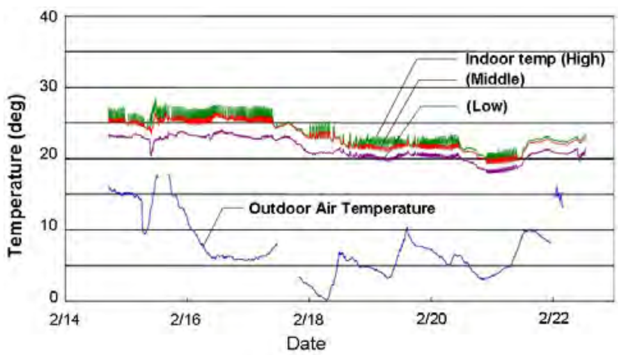


Figure 10 Outdoor air and room temperature (winter measurement)

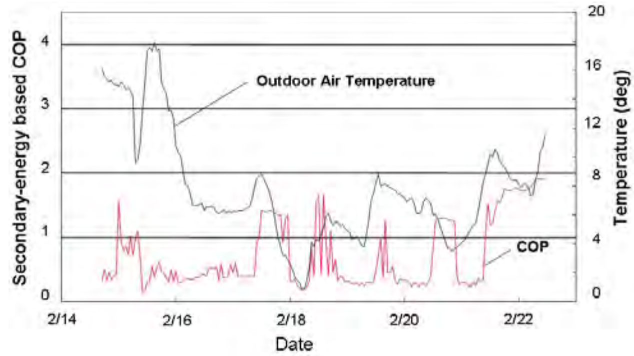


Figure 11 Change of COP (winter measurement) (winter measurement)

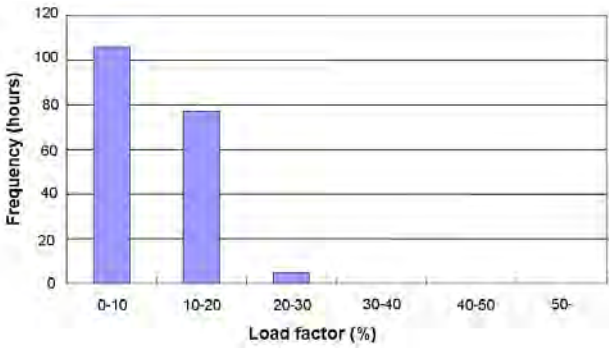


Figure 12 Frequency distribution of load factor (winter measurement)

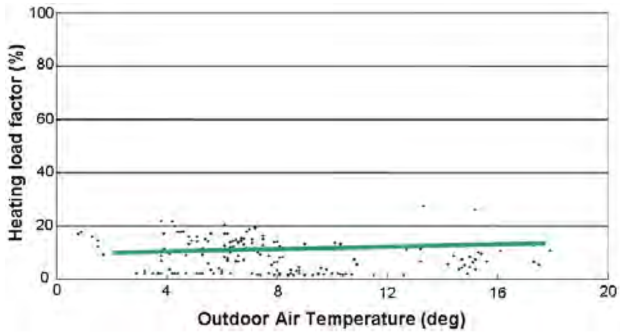


Figure 13 Relation between outside air temperature and load factor (winter measurement)

Load factor distribution during winter measurement is shown in Figure 12 and 13. Most of the load is concentrated under 20% of EHP's capacity. Load Factor was lower in winter than in summer because relatively high outdoor air temperature prevailed during the measurement had worsened imbalance of summer and winter heat demand in addition to its excess capacity. It is observed from the measurement that for a building with more daytime and less night time use, load factor can stay very low for the most of winter except for a few snowy cold days because in Tokyo metropolitan area heating demand maximizes at night and early morning hours when outdoor temperature falls and hit the bottom.

3. Outdoor Measurement at an Office Building in Tokyo

A multiple type packaged gas heat pump (GHP) unit installed in an office building in central Tokyo was the alternative outdoor unit measurement site. The measured system consists of an outdoor unit driven by a 30HP gas engine fueled by city gas and 11 indoor units each with 7.1kW of cooling and 8.0 kW of heating capacity. Rated COP of this unit is 1.25 for cooling and 1.37 for heating at primary energy basis. Referring to an EHP, its secondary-energy based COP is 3.39 for cooling and 3.71 for heating. Probing sensors insertion method exclusively developed for this measurement was applied for the first time to measure the amount of heat exchanged through heat exchange chambers of outdoor units in daily operation. The measured system installed on rooftop of three stories building provides primary heat source of cooling and heating of 384 m^2 of office floor. Measurement was conducted from July 11, 2007 through February 13, 2008 without interruption. Neither indoor measurement was conducted nor measurement informed to workers on the object floor.

3.1 Measurement Specification

Figure 14 shows how probing sensors as well as airflow velocity sensors were fitted on the outdoor unit. Each probing sensor consists of two T type thermocouples, one of which is put on the exterior of heat exchange fins and the other penetrates through fins into exhaust air chambers so that temperature of before and after heat exchange could be measured at one time. Figure 15 shows the works of sensors fitting through heat exchange fins (a), a penetrated sensor appeared in an exhaust chamber (c), CPU fans for PCs are placed over the exhaust air fans to measure velocity of exhaust air (b). To make good representation of total heat exchanged by the system, total of 27 probing sensors were fitted on three sides of the outdoor unit (shown in round dots in Figure 14). Velocity of exhaust airflow was measured on each fan unit (shown in oval dots in Figure 14) so that volume of air through heat exchange fins can be calculated with the performance curve supplied by the manufacturer. Assuming all the heat was exchanged only as sensible heat, amount of exchanged heat was simply

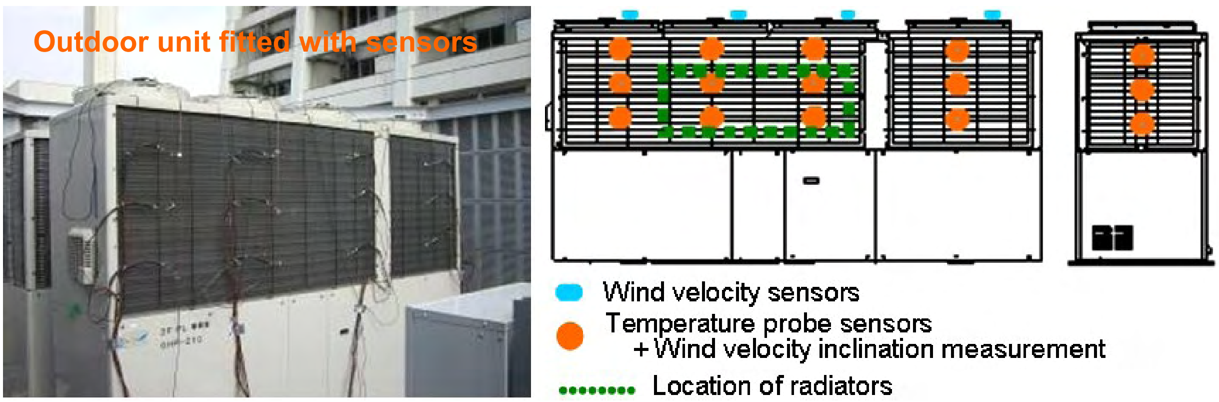


Figure 14 Location of sensors set on the outdoor unit

Figure 15 Sensors fit into (a) and penetrate through (c) heat exchange fins and placed on exhaust air fans (b)

calculated by multiplying temperature difference between exterior and interior sensors and volume of air came through heat exchanging fins.

Electricity consumption of both outdoor and indoor units was measured with cramp power meters not disturbing daily operation. To measure gas consumption, however, an additional gas meter had to be installed halting the operation for half a day. Measurement was conducted at 10 minutes interval throughout the term. All the measured data were automatically sent wireless by cellular phone radio wave to a data center and accumulated for later analysis. Weather condition throughout the measurement was observed by a portable weather station.

Table 4 Measured contents

Measured Item		Sensor or sensor method
Exchanged heat through outdoor unit		Probing sensor insertion method
Power consumption	Indoor units	Cramp power meter
	Outdoor units	Cramp power meter
Gas consumption		Gas meter, Pressure gauge
Exhaust gas heat value		T type thermocouple
Outdoor climate		Weather Station

3.2 Results

3.2.1 Heat Exchange and Primary Energy Consumption

Upper part of Figure 16 shows amount of heat exchanged daily both for cooling (left half) and heating (right half). It is easy to recognize that there is big difference between cooling and heating demand presumably due to Tokyo's worsening heat island and to the global warming. It is also easy to understand that if we decide the capacity of the system by cooling demand, then in winter we must operate it under lower part load because all heat pumps have structurally more than 10 % larger heating capacity than cooling capacity as was the case on measured GHP: 7.1kW for cooling and 8.0 kW for heating per indoor unit. Lower part of Figure 16 shows primary energy use, which is a sum of

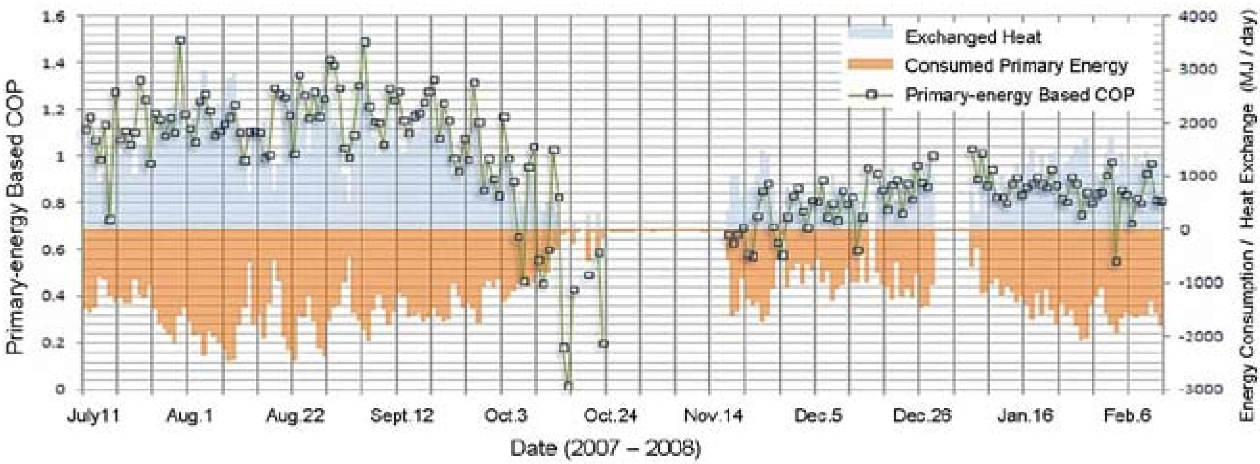


Figure 16 Daily heat exchange, primary energy consumption and COP

gas and electricity consumption. By simply dividing amount of heat exchanged by total amount of primary energy consumed, COP of the GHP unit was calculated and shown in line graphs. It is clear that COP for heating is much lower than the rated value staying between 0.6 and 1.0. These values were a little higher in comparison with indoor unit measurement, but it is likely that low part load was preventing the unit from running at expected efficiency not only at a university campus but also at an office building.

3.2.2 COP Classified by Outdoor Temperature

It has been observed that efficiency of heat pumps varies much with the change in outdoor temperature. Thanks to continuous measurement over seasons, relation between climate and COP has been clearly disclosed in this measurement. Bar graphs of Figure 17 show accumulated time length of operation classified by outdoor temperature, the left bars show total heating and the right bars show total cooling hours. Line graphs with colored background show part load factors for corresponding temperature. Line graphs with dots and numbers are the average primary-energy based COP at corresponding outdoor temperature. It has become clear from figure 17 that during cooling operation, COP rapidly drops as outdoor temperature rises beyond 30 degrees because the unit has an excess capacity and never runs over 50% of the capacity even on summer peak days. It has to be investigated how far COP can rise if a system with proper capacity and better part load is installed. For heating season, fall of COP by outdoor temperature is moderate for GHP because it can choose operation between heat pump cycle and direct heating by burning gas. EHP without such alternative operation should demonstrate worse performance.

From this measurement it has become clear that EHP/GHP is sensitive not only to the part load but to the outdoor climate and their performance varies with the inlet air temperature much grater than our recognition. Therefore more attention must be paid to its capacity and climate of the site before the installation of an EHP/GHP.

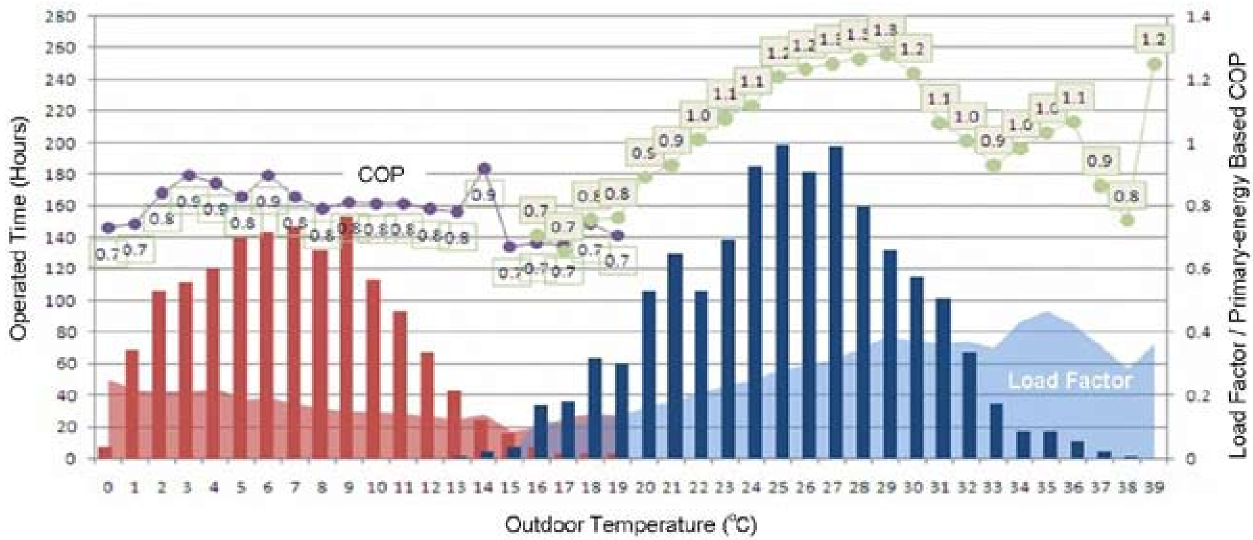


Figure 17 Change of primary-energy based COP classified by outdoor temperature

4. Conclusion and Discussion

Running performance of split-type electric and gas-engine multiple-unit heat pump systems were measured under actual operating environment at a university campus building and at an office building in metropolitan Tokyo. For the measurements, classic indoor measuring method and probing sensors insertion method for outdoor units originally developed for the study were applied respectively. Both results showed considerably low COP compared to the rated values of the systems because cooling and heating capacities were far exceeding actual load resulting in operation under low part load throughout measured period. Fall of COP values were also explained by the difference of air temperature from that of peak COP. Therefore more attention should be taken to the operating climate all year around especially to the cooling at 30 degrees centigrade or above and 25 degrees or below. COP was lower for heating than for cooling because imbalance of summer and winter heat demand is increasing probably due to urban heat island and global warming. To solve these problems, more accurate load calculation and proper designing with reliable data and software must be conducted. And also, a technological breakthrough to integrate heat load into fewer outdoor units to operate them at higher part load is expected.

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THE ENERGY CONSERVATION BENEFIT FOR PUBLIC ELECTRIC FACILITIES OF EXISTING HIGH-RISE RESIDENTIAL BUILDINGS

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Keywords: sustainability, energy conservation, public electric facilities, high-rise residential buildings

Summary

This study analyzed the electrical consumption of the public building services at residential buildings with 15 floors or more for the possibilities of saving energy. The review of literature, the on-site measurement, and the summarization and spreadsheet of the energy-saving technology are employed to understand the features of electrical consumption of public utilities and the possibility of saving energy. The cases are the buildings in Tainan and Kaohsiung cities in Taiwan. There are three main results (1) The average electrical consumption is 27.3% for elevators, 28.8% for power plants, 33% for the lighting, 4.1% for the air-condition, and 6.8% for the other items. (2) To save energy for the residential buildings, the rationalization of the contract capacity, the increase in the power factor, the adoption of efficient running water pumps and lighting, and the adjustment in the operation time of exhaust fans are helpful. The ratio of energy saving is 17.9% and the PBY is five months to 5.3 year.

1. Introduction

1.1 Research Motive

Since the government actively promoted the energy saving measures to the industries with high energy consumption and the commercial buildings in recent years, the benefits of those measures have gradually appeared. Residential buildings consumes 20% of the national electrical consumption in Taiwan, but the benefits of the energy saving measures at these buildings type are not to be noticeable. In another way, the less electricity is consumed, the less CO2 (carbon dioxide) is emitted. So decreasing the electrical consumption of the residential buildings is very important. Then, there are two main purposes of this research:

（1）We will analyze the composition and characteristic of electric consumption of the public building services at the residential buildings.

- To collect and analysis the public electrical consumption features from the past electrical receipts.
- To measure and analyze the public electrical consumption features including operating and standby mode of building services.

（2）We will evaluate the electricity saving benefit in the public building services that assume to adopt the energy saving products.

1.2 Research Range

The research focuses on the electrical consumption of the public building services at the buildings of at least 15 floors or those of at least 50 meters high. The public building services exclude those consuming other kinds of energy like natural gas and heavy oil. The building services includes water supply and drainage system, air-condition, elevators, ventilation system, and fire escape equipment. The investigated areas are Tainan and Kaohsiung (Cities and Counties included).

1.3 Research Method

The study chooses 50 residential buildings of at least 15 floors in Tainan and Kaohsiung as the investigating samples, whose records of electrical consumption and relative information (the floor, household numbers, the total floor area, the building age, and the occupancy rate) for the previous year are collected.

The research conducts the on-site measurement of electrical consumption for the elevators, power, air-condition, and lighting individually at 10 of the 50 samples in order to calculate the KWH. The records of electrical consumption from the 50 samples do not indicate large variation in the monthly consumption. Consequently, the measurement for this study lasts only one week for the understanding of the consumption features and for the prevention of interference from the measurement devices installed too long for the residents' daily life.

2. Composition of Public Electrical Consumption

The public electrical consumption is influenced by the level of the residential building in construction and the use frequency & behavior of the public building services in daily life. This research divides the 50 cases into three categories, which are luxurious, normal, and economical residential buildings. In Table 1, the public electrical fee of luxurious buildings per household each year can be up to NT$ 10,701, while the fee of economical buildings is only NT$ 887. The difference among different categories is up to 4.9 times.

When the households is fewer (or the floors is higher or the more luxurious or comfort), it results in the higher public electrical consumption. The electrical consumption of public building services is a stable load which does not fluctuate significantly according to season. Only in few of the cases, the increase in electrical consumption is found in the summer, due to the increase in the electrical consumption of air-condition.

62% of the cases made the very high contract capacity of power supply, leading to the increase in the public demand charge. Taiwan Power Company imposed penalties on 6% of the cases with the very low contract capacity. The company imposed penalties on 44% of the cases with the power factor lower than 80%.

Table 1. Classifying Public Electrical Consumption according to building level

Category	Public facilities	Number	KWH per Household	Fees per Household
Luxurious	1) High hall 2) Movie theater 3) Conference room 4) Classroom of rhythmic gymnastics 5) Gymnasium 6) Movie theater 7) Banquet hall & Audio-visual room 8) Play room 9) Reading room 10) (Warm) swimming pool 11) SPA & Saunas 12) Scene lighting 13) Atrium scenery building 14) Parking space on B3F 15)Fountain 16) Computer game room 17) Air-condition in all indoor public space	9	4,345 (KWH/year)	10,701 (892NTD/month)
Normal	1) Normal entrance hall 2) Caretaker room 3) Movie theater & conference room 4) Gymnasium 5) Reading room 6) Simple atrium facilities 7) Parking space of two floors underground	24	1,540 (KWH/year)	3,731 (311 NTD/month)
Economical	1) Simple entrance hall 2) Parking space of one floor underground 3) Lighting for staircases and elevators	17	887 (KWH/year)	2,467 (206 NTD/month)

Luxurious: for luxurious, magnificent, and comfortable demands
Normal: for elementary demands of daily life and recreation
Economical: for elementary demands of daily life

3. Workable Measures to Save Energy

This study expects the energy saving technology for the public building services. The technology shall be (1) fully developed to provide enduring products (2) economically efficient to save the daily electrical consumption and to reduce the high price for maintenance (3) able to overcome the on-site problems.

3.1 Improving the Building Services Efficiency

3.1.1 Running water pumps and control devices

So far, the standing, lying, and sinking running water pumps are highly efficient. Generally speaking, brands such as Ebara, Tsurumi, EMU, and Groundfos (with efficiency up to 75%) are more efficient than Taiwanese brands (with about 40%). What's more, the durability of brands like Ebara usually is better and the rate of breakdown is low. When we select highly efficient equipments, both of the operation electricity consumption and the contract capacity of the public electricity will reduce.

3.1.2 Air-condition

The investigation results demonstrates that the ratio of electrical consumption of the air-condition is only 3.93% (compare with the electricity consumption for public building services). The common air-conditioners are window-type or split-type, without large installed capacity or high use frequency. All the window-type and split-type air-conditioners have met the EER (energy efficiency ratio) standards required by the Bureau of Energy as the conditioners were produced in that time. As a result, the old air-conditioners shall be replaced with the efficient products carrying energy labels to save the energy.

3.1.3 Lighting, Evacuation Lamps, & Floodlight

Traditional Fluorescent lamps that consist of T9 fluorescent tubes and traditional ballasts is popular. If they are replaced with T5 fluorescent tubes and electronic ballasts, the electrical consumption can be reduced by 25% for ballasts and 30% for tubes. With the high rendering average (Ra≧84, T9'Ra is 61%), T5 tubes contain less mercury for environmental protection and last longer. As spiral lamp holders of the original lamps are replaced by energy saving bulbs, the electrical consumption of incandescent lamps can be reduced by 60%. 10W fluorescent lamps, used by most pilot lamps for emergency exits and for evacuation routes and turned on for 24 hours a day, should be replaced by LED's ones to save energy. Most floodlights are charged with constant currents, but floodlights charged with constant voltage consume less electricity.

3.1.4 Fans at Underground Parking Space

Most of the fans are controlled by timers. The first energy saving measure is to prevent the simultaneous operating time in different floor of fans. Because different exhausting zone should take turns their fans, the contract capacity will be reduced. The second measure is to replace the domestic fans (used in most cases and with less than 50% efficiency) with foreign fans (with up to 70% efficiency) like Nicotra, Kruger, ABB. The third measure is to replace the duct system (the fan and duct system) with the fan and inducer fan system. The inducer fans averagely arranged in space can induce out the air surrounding the outlets in order that the bad quality of air common for the duct system should be improved. Besides, the removal of old ducts can improve the clear height and offer a better view of the whole underground parking space.

3.1.5 Fire Fighting Transformer

Transformers ranging from 37.5 to 50 KVA are installed in all the cases to provide electricity for the fire fighting sockets. The transformers, only to be driven at fire, do not have to be in standby mode, which wastes electricity for the iron losses and the consumption of the power lines despite the no-load power connection. Given the capacity of transformers at 50 KVA, the annual standby electrical consumption can be reduced by 2155 KWH. Therefore, the automatic and manual switches should be installed on one side of the transformers and connected with the switch of the automatic fire alarm system.

3.1.6 Elevators

The elevators driven by the variable-frequency & transforming motors and by the spiral gear windlasses, consume at least 15% of energy less than traditional elevators. In addition, floor buttons should be able to change the pressed buttons, the fans should be turned off automatically 30 seconds after the stop, and the lighting should be turned off automatically 10 minutes after the stop. These measures can save energy.

3.2 Improvement of Building Services Management

3.2.1 Management of Contract Capacity & Power Factor

60% of the studied cases do not manage the contract capacity or the power factor well and thus order the most suitable contract capacity. As the Governing Rules for User Premise Power Line Placement of Taiwan Power Company require, the power factor must be higher than 80%. The 0.3% more of electric fees as penalty for 1% less of the power factor and the 0.15% discount for 1% more of the power factor are ideal and economical improvements.

3.2.2 Lighting Control

Besides the manual lighting switch, the two-wire lighting control system, the infrared ray sensors, the timers, and the daylight sensors are automatic control measures.

3.3 Evaluating Efficiency of Energy Saving for Cases

This study evaluates the energy saving efficiency before and after the improvement in six cases. The evaluation includes the annual electrical consumption, the reduced electrical consumption, the saved electrical fees, the electricity saving efficiency, and the PBY of investment. The annual electrical consumption is evaluated to be 615,800 KWH/year. The energy saving measures are(1) the rationalization of the contract capacity, (2) the increase in the power factor, (3) the adoption of efficient running water pumps, (4) the adoption of efficient lighting fixtures and lighting control systems, and(5) the adjustment in the operation time of exhaust fans.

This evaluation shows that the average electricity saving efficiency can be up to 17.9%, and that the PBY ranges from five months to 5.3 years. Therefore, the energy saving measures of this research are beneficial enough to recommend to the management committee. The energy saving measures and efficiencies of the studied cases are listed in Table 2.

Table 2. Evaluating Efficiency of Energy Saving for Cases

Case No.	Floor	Household No.	Energy saving measures	Annual electrical consumption (KWH/year)	Reduced electrical consumption (KWH/year)	Saved electrical fees NTD/year	Electricity saving efficiency (%)	PBY of investment (Year)
1	B2F~16F	235	1、2、3、4	442,920	65,248	370,998	14.7	3.8
2	B3F~17F	578	1、3、4	784,720	129,552	365,094	16.5	5.3
3	B7F~41F	143	1、2、4、5、6	869,040	180,102	487,327	20.7	5 month
4	B2F~21F	246	3、4	283,360	62,280	194,305	22.0	5.2
5	B2F~21F	180	1、3、4、7	267,280	62,365	204,193	23.3	4.4
6	B3F~24F	521	1、4	1,047,480	161,160	476,249	15.4	3.9
Average				615,800	110,118	349,814	17.9	--

1. energy-saving measure
（1）Rationalization of contract capacity（2）Increase in power factor（3）Adoption of efficient running water pumps
（4）Adoption of efficient lighting fixtures（5）Efficient lighting control systems
（6）Adjustment in operation time of exhaust fans（7）Improvement of emergency lighting fixtures
2. Electricity saving efficiency ＝ （Reduced electrical consumption / Annual electrical consumption）× 100%

The reasons why some energy saving measures are not adopted during the evaluation are as follows:

1） Some cases already have some of the energy saving measures. For example, the infrared ray sensors have shortened the use of the lighting. When the lighting adopts electronic ballasts, the electrical fees can be reduced but the energy saving efficiency is not high.

2） PBY of some cases is longer than five years: The PBY of investment in Taiwan ranges from five to seven years, which can motivate the committees of management to improve their public utilities. New pilot lamps for emergency exits at emergency doors and for evacuation routes can reduce the electrical fees. Nevertheless, it is not recommended to replace old pilot lamps since the cost cannot be paid back within five years. In the future, the lighting fixtures should be gradually phased out and replaced with electricity saving lighting fixtures. Furthermore, the energy saving elevators and the fans at the underground parking space have the PBY of longer than five years.

4. Conclusion

This study, analyzing the features of the electrical consumption and the efficiency of the energy saving measures in the high residential buildings in southern Taiwan as the cases, comes to the following conclusion:

1） The main public building services that consume electricity are elevators, power plants, and lighting. The average electrical consumption is 27.3% for elevators, 28.8% for power plants, 33% for the lighting, 4.1% for the air-condition, and 6.8% for the other items

2） The main factors for the electrical consumption of the public building services are the building scale, the building layout, the natural daylighting, the building services efficiency, and the users' demands.

3） High efficient lighting and running water pumps , rationalization of the contract capacity, the increase in the power factor and the adjustment in the operation time of exhaust fans are the most economical measures to save public electric consumption.

4） The average ratio of energy saving is 17.9% and the PBY is five months to 5.3 year.

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(Paper No. SB953)
A GOVERNMENT BUILDING AS A SHOWCASE VENUE FOR SUSTAINABLE TECHNOLOGIES IN HONG KONG

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Abstract

Since 2005, the Electrical & Mechanical Services Department (EMSD) Headquarters Building has been used as a showcase venue to demonstrate to the public the application of sustainable building technologies. The building is an eight-storey high building with offices, vehicle workshops and data centres. Installed on the roof is a 350 kW solar photovoltaic panel system, which is the largest of this kind in Hong Kong. Ten sun pipes utilizing natural lighting for illumination are also installed on the roof. These renewable energy technologies can be seen by visitors in a glass-made viewing gallery fitted with integrated photovoltaic glass panels. Moreover, various energy efficient technologies and green features have been incorporated in the building design. Motion and daylight sensors automatically turn off or dim down lights when artificial lighting is not required. Water-cooled ammonia chillers, with zero global warming potential, are used to minimize electricity use. Other sustainable features include sunshade screens installed outside the building facade, green roof gardens, grey water recycling system and thermal storage utilizing "slurry ice" etc. The building has been a persuading case of utilizing sustainable building technologies. It will continue to be used for demonstrating the successful application of advanced energy efficient and renewable energy technologies under local conditions.

1. Introduction

The EMSD Headquarters building is situated at Kowloon Bay and in the old Kai Tak Airport site. The building was formerly a cargo terminal building. It has been designed to make full use of the concrete structure of the former cargo terminal building as far as possible without demolition of the old building structure, resulting in a saving of HK$600-$700 million. By retaining most of the concrete and steel structure of the old building, the conversion has greatly reduced the use of energy and construction material as well as construction waste created in the process. The volume of construction waste saved can fill a four-storey building of the size of a football pitch.

The building is an eight-storey building. The lower floors are vehicle workshops, electronics workshops and car parks. The top two floors are offices of nearly 20,000 square metres. Also, a fully equipped computer data centre and staff canteen is located on the first floor.

Various renewable energy technologies, energy efficient technologies and green features have been incorporated in the building design as described in details in the following paragraphs.

Figure 1 The EMSD Headquarters Building

2. Application of Renewable Energy

This building has utilized various kinds of renewable energy resources including solar and wind for contributing electricity and hot water for use in the building.

2.1 Grid Connected Photovoltaic Panels

Rows of photovoltaic panels nearly cover the entire roof space of the building. With an installed peak capacity of 350 kW, the photovoltaic panels system is one of the largest of its kind in Hong Kong. The installation consists of more than 2,300 photovoltaic panels and has a total surface area of about 3,100m^2. The panels are grid connected to the electricity distribution network, contributing around 350,000 kWh of electricity per year from solar energy which helps to avoid annual emission of about 250 tonnes of CO_2, 860 kg of SO_2 and 430 kg of NO_x into the atmosphere.

Figure 2 Photovoltaic Panels installed at the roof of the building

2.2 Micro-wind Turbines

To demonstrate the applicability of wind technologies on top of a building located in an urban area, two types of micro-wind turbines including a 1-kW horizontal axis wind turbine and a 1.5-kW vertical axis wind turbine are installed on the roof of the building. The two wind turbines are also grid connected to electricity network and contributing over 1,000 kWh of electricity for the building annually.

Horizontal-axis wind turbine

Vertical-axis wind turbine

Figure 3 Micro-wind Turbines installed at the roof of the building

2.3 Solar Water Heating System

The solar water heating system installed on the roof of the vehicle reception office building is of high efficiency evacuated tube type solar collectors. It is used to pre-heat incoming water for hot water supply for canteen and the showering facilities in the workshop. The system can provide hot water for shower of around 40 persons. It is estimated that the annual solar energy absorbed by the system and converted into useful heat energy is 25,000kWh, equivalent to avoiding emission of about 18 tonnes of carbon dioxide from the power plant.

Figure 4 Evacuated tube types solar collectors installed on the roof of vehicle reception office building

2.4 Sun Pipes

Utilisation of natural light can minimize the artificial lighting demand in a building. In the building, ten sun pipes are installed on the roof to use daylight to provide illumination to part of the lobby at 7/F.

Sunlight is captured through dome shaped collector at the roof top of each sun pipe. It then travels down the sun pipe's highly reflective tube to illuminate the corridor. The ray bender inside the dome helps capture and reflect light that is not directly above the tube. The light captured is then channeled through a highly reflective shaft and diffused indoor.

On a sunny day, the brightness of each sun pipe is equivalent to the brightness of about 4 nos. of 11W compact fluorescent lamps.

Daylight collector

Sun pipes illuminating the lobby

Figure 5 Sun pipes

3. Intelligent Lighting System

3.1 Description and Working Principle

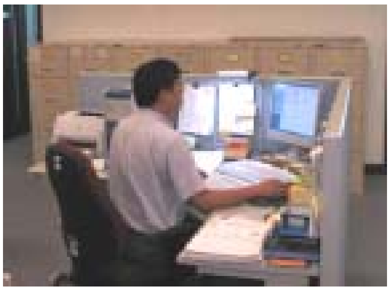
The lighting system installed in the Building is an Intelligent Lighting Control System consists of a Lighting Control Server which interfaces with the building Central Control Monitoring System (CCMS).

The control system saves energy by automatic light switching. It switches off the lighting automatically when the occupancy sensor detects no people in the space for a preset time period. The delay time for switching off the lighting fittings is 7.5 minutes in office areas and 2.5 minutes in circulation areas. It can be adjusted to suit the activity pattern of the occupants. On the other hand, the occupancy sensors in the open space offices will switch on the light fittings automatically once people are detected and keep the illumination at adequate illumination level. It will be topped up by task light for intensive reading and other specific activities.

Integrated light and motion sensors are also installed in cellular offices. The light sensors will monitor the resultant illumination on desk top of the cellular offices and adjust the light output of the dimmable lighting fittings so that daylight enters into the rooms can be fully utilized to minimize the energy requirement for artificial lighting.

To evaluate the actual energy saved by using this system, the power consumption of the light fittings on an office floor recorded by the CCMS was compared with the calculated total rated power and gear loss of conventional lighting system. In a weekly power consumption analysis, the energy consumption recorded by the CCMS is 6,380 kWh. The calculated power consumption of the same number of lighting fittings using conventional lighting switches is 8,130 kWh. It is found that the energy saving by the Intelligent lighting System at an office floor per week is 1,750 kWh or about 20% of the conventional lighting system.

Occupancy sensor



Task light

Figure 6 Occupancy sensors and energy efficient task lamp

3.2 Installation of Sensors and Automatic On/Off Controls for Lighting in Toilets

In order to conserve more electrical energy, occupancy sensors will be installed in toilets as well. At present, there are 56 nos. of toilets in the building, in which, the light fittings are operated by manual switches. The proposed control strategy is that half of the lighting fittings in the toilet would be switched off automatically if the sensors detect no movement in a preset time (say 30 minutes). The remaining light fittings would be switched off automatically if the sensors further detect no movement in another 30 minutes. As such, around 43,000 kWh of electricity would be saved annually.

4. Air-conditioning and Ventilation System

Four nos. of 1,055 kW ammonia chillers are installed at the building to cater for a cooling load of 3,500KW in summer. An ice-maker of rated cooling capacity of 700kW is installed in the chiller plant room to produce iced glycol solution at night and the iced solution were stored in 5 nos. 110m^3 thermal insulated bulk tanks with total storage capacity of 19,000 kWh to supplement the cooling capacity of the air-conditioning central chilled water system at day time. A heat rejection system which consists of 4 nos. of freshwater evaporative condensers is employed for the chiller plant. The air-conditioned spaces are served by VAV/AHU with under-floor air delivery system.

4.1 Ammonia Chillers with Evaporative Condensers

Ammonia is an environmentally friendly refrigerant as its ODP is zero and it has no green house effect. Its chemical components are nitrogen and hydrogen which are gases naturally exist in the environment. To minimise the disturbances to the building, the plant room for ammonia chillers is located outside the building area and a water scrubber system for emergency exhaust of ammonia refrigerant is provided.

4.2 Thermal Storage Using Slurry Ice

The coefficient of performance of the entire ice-storage system, from the chiller to the heat exchanger output, is about 3.5. At daytime, the iced glycol solution "slurry ice" in the ice storage system absorbs heat from the central chilled water system via heat exchanger and therefore reduces the maximum cooling load of the central chiller plant.

As the ice-maker is operated at nighttime, the peak load demand can be reduced. The ice-maker can produce a daily cooling capacity 8,300 kWh. This is about the full load capacity of an ammonia chiller. The peak load demand is reduced by about 250kVA.

Figure 7 Ice storage tank at the entrance of the building

4.3 AHU Equipped with Free Air Cooling Facility

Free air cooling (FAC) utilises cool outdoor air to provide space cooling in lieu of mechanical cooling thus saving energy. An air handling unit (AHU) fitted with FAC has 3 operation modes: (1) normal operation with full mechanical cooling, (2) fully free air cooling, and (3) partially free air cooling supplemented with mechanical cooling. A controller will continuously compare the temperature, relative humidity and enthalpy of outdoor air and indoor air with their design values. It will then determine the fresh air, return air and exhaust air quantities required to achieve the designed indoor conditions, and adjust the dampers accordingly.

One of the air handling units serving the office floors of the building has been modified to be equipped with FAC facility. The supply air quantity of this selected AHU is 5m^3/s and the outdoor air intake, before FAC modification, was 1m^3/s. To make provisions for FAC operation, alterations and additional works including additional outdoor/exhaust air ducts, exhaust air fan completed with variable speed drive, sensors and control devices, and modification of existing CCMS programme have been carried out.

The real time operating data of the modified AHU and another AHU without FAC control with the same cooling load profile and operating hours have been measured. It was found that the energy saving for each FAC hour could be as high as some 60%.

5. Other Sustainable Features

5.1 Grey Water Recycling System

The Grey water Recycling System installed in the building is for treating the wastewater discharged from showers and wash hand basins in the kitchen and toilets. The treated grey water is used as toilet flushing water for the entire Building.

The water treatment process comprises three stages:

(i) Biological treatment - Micro organisms consume nutrients and transform suspended and dissolved organic matter in the water into acceptable end products. The surplus activated sludge will then be stored and removed regularly.

(ii) Micro filtration - After biological treatment, the water is pumped through submerged microfiltration membrane sheets that filter out particles including bacteria.

(iii) Disinfection and adjustment - After filtration, chemicals are added to disinfect the water, adjust the pH value (acidity) and to maintain residual chlorine in the treated water.

The average daily designed flow of the grey water recycling system is 26,000 litres per day, which is capable of serving a maximum of 2,500 persons in the building.

5.2 Double-layer Curtain Wall

The office uses double-glazing serves as heat insulation and noise insulation. The void between the two glasses minimizes the radiant heat transmission from outside and therefore reduces the amount of energy consumed by the air-conditioning system

5.3 Sunshade Screen

Sunshades screens are installed at the south-east and south-west portion of the building facade which minimize direct sunlight penetrating into the building in the summer and thus reduce the energy required for providing air conditioning.

Figure 8 Sunshade screen

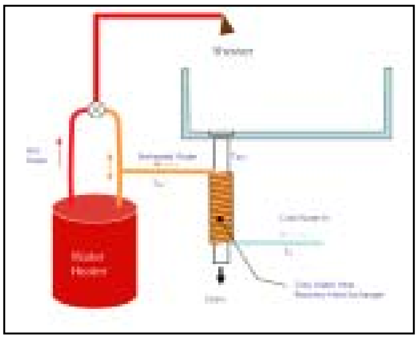
5.4 Solar Control Window Films

Solar control window films can reduce solar heat gain through fenestrations and result in energy saving in air conditioning. The windows at the corridor of the roof garden where there is large area of fenestration exposed to direct sunlight have been fixed with window film. The window film reduces about half of the solar heat gain through fenestration and lowers the average space temperature by 1-2 °C.

Fig. 9 Corridor with large fenestration area exposed to direct sunlight are fixed with window film.

5.5 Grey Water Heat Recovery System

Grey water heat recovery system has been installed as a pilot installation in the building. The system recovers thermal energy from the drains of 12 shower cubicles to preheat cold water supply to one of the bath rooms in the building. The system recovered about 2,300 MJ of thermal energy from the drain in a year.



Operating principle

Heat recovery pipes

Fig. 10 Operating principle of grey water heat recovery system

5.6 Green Roof Garden

Forming part of the sustainable building design, a green roof has been built into this building. The green roof not only provides a simple landscaped rest area for the staff, it can also keep down the roof surface temperature in summer.

Figure 11 Green roof garden

6. Education Path

An Education Path has also been built in the building to offer on-site public education tours for students and the public on sustainable building design. It comprises 2 exhibition galleries and a rooftop viewing gallery.

At the roof viewing gallery, the visitors can see the renewable energy features including the photovoltaic panels, wind turbines and sun pipes.

There are 17 sets of interactive exhibits in the exhibition gallery on ground floor. The exhibits provide comprehensive information on energy issues, renewable and clean energy technologies, energy efficiency schemes, energy efficient building services features, energy data, etc. The exhibition area on 7/F contains 4 nos. exhibits to introduce the safety of electrical, amusement rides, gas and lifts and escalators installations.

Figure 12 Roof viewing gallery and the photovoltaic panels

Figure 13 Interactive exhibits at the ground floor exhibition gallery

Figure 14 Exhibits introducing electrical and mechanical safety

7. Summary and Conclusions

Intelligent lighting control system, energy efficient chillers, cooling towers and variable air volume control air-conditioning system are effective energy efficient technologies applicable for buildings in Hong Kong. The EMSD Headquarters building is on the leading edge to use these energy efficient technologies as well as others including energy saving lamps, solar window film, thermal storage system and heat recovery systems. The building has put forth much emphasis towards incorporation of renewable energy technologies including photovoltaic panels, wind turbines, solar water heating system and sun pipes. Together with the incorporation of other green features including green roof garden, sunshade screen and grey water recycling system, the EMSD Headquarters building has won the Grand Award of the Green Building Award 2006 organised by the Professional Green Building Council, Hong Kong.

The Education Path provides an on-site public education tours for students and the public on sustainable building design. It promotes awareness and provides education on energy efficiency and renewable energy through the use of interactive exhibits and physically shows the innovative energy efficiency and renewable energy features of the building to the public.

The building has been a persuading case of utilizing sustainable building technologies. It will continue to be used for demonstrating the successful application of energy efficient and renewable energy technologies under local conditions.

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ANALYSIS AND REVIEW OF TOOLS FOR ASSESSING CONSTRUCTION SUSTAINABILITY IN SPAIN.

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Summary

Four different tools used to assess construction sustainability are reviewed and compared, namely LEED, GBTool-SBTool-es, the Regional Guide edited by the Basque Country (Spanish acronym GCAPV) and CALENER. The effect of the Technical Building Code recently implemented in Spain on sustainable construction is likewise analyzed.

Housing construction in the Autonomous Community of Madrid is of major importance to the region's economic and social development, accounting for nearly 10% of regional GDP and employing around 15% of the workforce. The industry's growth indicators have remained strong for over ten years. While this bonanza has indisputably contributed to regional economic development, it has also generated a series of adverse effects: a substantial rise in the volume of construction and demolition waste, urban sprawl, need for a larger water supply and, of course, intensified energy demands, which have grown seven-fold in the last forty years. The paper submitted forms a part of a research project whose primary aim is an in-depth analysis of HOUSING CONSTRUCTION SUSTAINABILITY in the region of Madrid.

1. Introduction

According to UNEP and OECD data on global environmental impact (UNEP SBCI, 2006), buildings account for 25 to 40% of total energy demands, 30 to 40% of solid waste and 30 to 40% of GHG emissions.

The need to quantify, classify and clarify this domain of sustainability has led to the development of a series of models and tools of varying scope.

The present article analyzes several tools for evaluating building sustainability, taking account of the various factors involved in the respective assessment methods such as Annex 31 of the IEA (2004), Green's EGBF File (2001), or the Final report of the EU Working group Sustainable Construction Methods and Techniques (2004): social, economic and environmental dimensions, the scale of the impact (global, regional or local), the agents and processes involved, the environmental loads considered and their effects (in a given timeframe), the requirement evaluated and the existing legislation.

2. Methodology

2.1 Tools selected

Three evaluation tools were selected on the grounds of availability, variety of structures and scope: Guía CAPV (EVE, 2006), LEED NC (USGBC, 2006), SBTool-es (IIsbe, 2007), y Calener VyP (Ministerio de Vivienda, 2007), the tool most representative of Spanish legislation on energy efficiency and certification, was evaluated but not actually used in the comparison.

The Guía CAPV, *Guía de edificación sostenible para la vivienda en la Comunidad Autónoma del País Vasco* (Guide to building sustainable housing in the Basque Country, Spain), contains nearly eighty measures or good practice recommendations that can be applied throughout the life of a building.

LEED (US Green Building Council) evaluates a series of technical requirements for building and facility construction; a building's overall rating is computed as the sum of the credits awarded for compliance with these requirements. In addition, certain minimum pre-requisites must be met to opt for certification. While it has been applied primarily in the United States, this scheme has been used to certify buildings in other countries, making it one of the most commonly used tools of its kind in the world.

In SBTool (iiSBE, Green Building Challenge) buildings are compared to two references, one representing normal practice and the legislation in force and the other the best possible practice given the technology available. While an international tool, SBTool-07 is presently in place, a version here called SBTool-es, that incorporates methodological adaptations and regional parameters is being developed specifically for Spain. This tool assesses buildings on the grounds of the impact reduction achieved with best practice.

Calener VyP is the benchmark tool for energy certification in Spain. It addresses the existing requirements (Technical Building Code – March 2006) on the limitation of energy demands and includes emissions data for different types of equipment for comparison with the standard building used as a reference.

2.2 Framework for comparison

In most cases, the analytical and methodological approach adopted in the various tools is unclear or unknown. The models used for internal calculations, specific system limits, scope of the life cycle analysis, technological scenario assumed and, most importantly, the analytical method and environmental model used for the assessment, are issues addressed below in the discussion of the entry data required and results or output.

In light of the variety of methodologies and parameters used, the indicators or criteria proposed by the different tools were taken as the starting point and organized in accordance with the categories defined in SBTool.

The comparison focuses on the design stage, the most strategically complete phase and the one that foresees many of the actions implemented during building construction and end of life. Only the criteria applicable to residential building in Spain were analyzed.

The areas and categories were weighted on the grounds of the weights applied in the tools themselves, which often differ depending on the country or region involved. Since as a rule this type of evaluation is conducted in response to political or commercial tendencies or even to the difficulty involved in estimating certain data, the parameters studied may vary widely. Climate change, for instance, or high CO2 emissions have become a priority in recent years both nation- and world-wide, and yet waning biodiversity, fertility and the depletion of the ozone layer, very topical issues only five years ago, are now accorded only secondary importance.

2.3 Organization of criteria and assignment of values

The procedure used to break down the maximum possible values allocated by each tool and distribute the different criteria by categories is described below.

The area distribution proposed by was used (see Table 1). The categories within each area defined by the international tool were included and the different criteria were grouped as a supplement to this study.

Area H (Other) was added to consider questions difficult to assign to any other area.

When several criteria were assigned to a given indicator, their weights were added. Where, on the contrary, a single criterion was assigned to several indicators, its weight was divided equally among them.

Guía CAPV. In this tool, the indicators for the pre-building stages were chosen, namely special subdivisional plan, development plan, preliminary design, design brief and full construction design.

Each item was weighted as specified in the Guide. Criteria appearing in several stages were counted in only one.

LEED. All the criteria described in LEED NC were considered. The requirements applicable during construction and use are established in the design stage.

Since this tool scores each criterion, the values were simply converted into percentages. The prerequisites (PR) specified for the various areas are shown but were not weighted.

SBTool-es. The criteria proposed in were included directly in the respective category. The phase for selecting criteria was the design stage. This included pre-building decision-making.

Although in this tool the raw scores are based on a scale of 0 to 5, it specifies the weight given to each area and criterion in percentage. For this reason, only the percentages were used to determine the maximum possible value.

Calener VyP. This tool, which assesses efficiency on a scale of A to E, was not used in the comparison because it only covers energy efficiency-related issues. In the energy and atmosphere category, however, it was taken as a proxy for Spanish legislation. Since most of the tools are based on existing legislation and grant a premium for strategies that improve on standard sustainability criteria, a score of “E” (minimum) was adopted as the reference for possible design improvements in this case.

2.4 Standardization of allocated values

In a first approximation, all the categories and criteria and their relative weights were used in the weighting exercise. This provided an overview of how areas and categories are weighted in the various tools. Subsequently, the areas containing criteria not shared with any other tool were set aside and their weights distributed proportionally among the rest of the areas. Broadly speaking, the areas set aside were G (economic and social factors), H (Other) and some of the categories in area F (Service quality). The results are given in Table 1.

Table 1. Summary of values by category and areas (%) and mean.

		G-CAPV		LEED NC			SBTool-es		Mean
		*	**	*	**		*	**	**
A	**Site selection, p. planning and development**	**17,9**	**17,9**	**20,3**	**21,9**		**33,4**	**36,7**	**25,5**
	Site selection	11,6	11,6	12,8	13,8	PR	15,3	16,8	14,0
	Project planing	3,2	3,2	3,1	3,4		13,5	14,8	7,1
	Urban design and development	3,1	3,1	4,3	4,7		4,7	5,1	4,3
B	**Energy and atmosphere**	**36,5**	**36,5**	**24,6**	**26,6**		**14,3**	**15,7**	**26,3**
	Renewable energy and GHG emissions	36,2	36,2	23,2	25,0	PR	12,4	13,6	24,9
	Other atmospheric emissions	0,3	0,3	1,4	1,6	PR	1,9	2,1	1,3
C	**Potable water**	**6,2**	**6,2**	**7,2**	**7,8**		**2,9**	**3,2**	**5,7**
	Potable water	3,8	3,8	4,8	5,2		1,7	1,8	3,6
	Rainwater, stormwater and wastewater	2,4	2,4	2,4	2,6		1,2	1,4	2,1
D	**Materials**	**17,4**	**17,4**	**15,9**	**17,2**		**12,0**	**13,1**	**15,9**
	Materials	8,7	8,7	13,0	14,1		12,0	13,1	12,0
	Solid wastes	8,7	8,7	2,9	3,1	PR	0,0	0,0	3,9
E	**Indoor environmental quality**	**5,7**	**5,7**	**16,7**	**18,0**		**14,3**	**15,7**	**13,1**
	Indoor air quality	2,6	2,6	10,9	11,7	PR	2,2	2,4	5,6
	Ventilation	2,7	2,7	1,4	1,6	PR	2,2	2,4	2,2
	Air temperature and relative humidity	0,0	0,0	1,4	1,6		2,2	2,4	1,3
	Daylighting and ilumination	0,0	0,0	2,9	3,1		3,3	3,6	2,2
	Noise and acoustics	0,4	0,4	0,0	0,0		4,4	4,8	1,7
F	**Service quality**	**16,2**	**16,2**	**8,0**	**8,6**		**14,3**	**15,7**	**13,5**
	Safety and security during operations	0,0		0,0			0,0		
	Functionality and eficiency	0,0		0,0			0,0		
	Controllability	2,6	2,6	4,3	4,7	PR	4,4	4,8	4,0
	Flexibility and adaptability	3,9	3,9	0,0	0,0		5,5	6,0	3,3
	Commisioning and manteinance of facility syst.	9,8	9,8	3,6	3,9		4,4	4,8	6,2
G	**Social and economic aspects**	**0,0**		**0,0**			**8,8**		
	Social aspects	0,0		0,0			4,4		
	Cost and economics	0,0		0,0			4,4		
H	**Others**	**0,0**		**7,2**			**0,0**		

* Relative weightings including all cathegories and areas
** Relative weightings not including special cathegories and areas

3. Comparative analysis

3.1 Areas

Areas G and H are associated exclusively with the SBTool-es and LEED tools, respectively. Despite their higher relative weight (8.8% and 7.2%, respectively) than found for other areas such as *potable water*, this singularity disqualified them for the comparison.

Area G – economic and social factors – places the same weight on social factors such as accessibility, construction site accidents and privacy, as on economic factors such as building costs and selling or rental prices. This area does not cover criteria related to perceived or local cultural values, some of which are included under other areas in SBTool-es.

Area H – Other – encompasses innovation criteria proposed by LEED, which take into consideration both exceptional performance in any of the other criteria and innovative performance in categories not specifically addressed by the tool.

As Figure 1 shows, *energy and atmosphere* is the area most heavily weighted, followed very closely by choice of site. Between them, they account for around 50% of the total. *Potable water*, at 10%, is the area assigned the lowest weight. The rest of the areas accounted for abut 14% each.

This area classification is not directly related to type of impact. While *energy and atmosphere* are directly associated with greenhouse gas emissions, the relationship is more ambiguous in other areas. Moreover, many of the criteria included in other areas are also directly associated with this same type of impact: transport or materials, for instance. This is the logical outcome of regarding energy to be a key parameter in the environmental impact generated by buildings.

As a rule, these assessment tools evaluate the environmental load on water, air, soil, landscape and plant and animal life in terms of the resources used and the waste generated (in the broadest sense of both). Building habitability, however, covers other types of parameters such as the items included under the heading *indoor environmental quality* that affect health, hygiene and comfort. This approach deals with factors relating to people's quality of life.

Figure 1 shows the weights by cathegorys of each of the tools and the mean after the redistribution following the removal of areas G and H and some of the service quality categories.

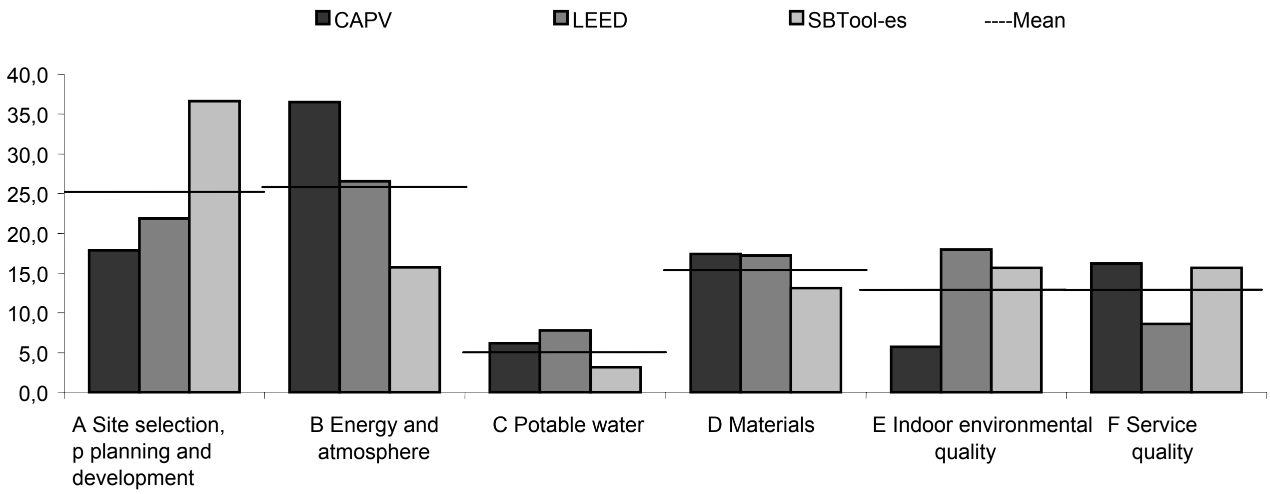

Figure 1 Weights by area

In the draft Green Paper on the Environment for urban Spain (Libro verde de Medio Ambiente Urbano para España – Ministerio de Medio Ambiente 2007) were identified as the main causes of non-sustainability in the building: the unbridled growth, inefficiency in the use of resources, and the rigidity of housing supply. All are linked directly to the medium in which they are engaged.

3.2 Categories

In the following discussion, the areas and categories are broken down into the respective criteria for a more detailed comparison.

3.2.1. A- Site selection, planning and development (mean weight, 25.5%)

The area is subdivided into three categories:

- A1 Site selection. Intended for the agent choosing the building site. It includes the criteria determined by the site and type of existing planning, such as development density and community connectivity.
- A2 Planning. Associated with the specific circumstances of the site to be chosen, such as its orientation or value as prime farmland.
- A3. Urban design and area development. Including design strategies applicable to the site chosen, such as the reduction of light pollution or fitting the building with a waste separation or water recycling facility.

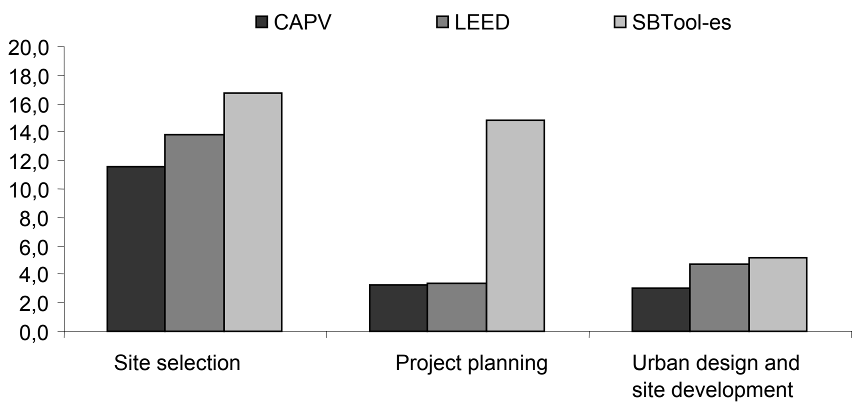

Figure 2 Category weighting in area A – Site selection

This area stresses the interdependence between the building and its urban surroundings. The difficulty lies in precisely defining and delimiting the surroundings.

The criteria used by the various tools are approximately similar in this regard, the most prominent of which are the inclusion of provisions in the design for mixed use or to avoid the possible shading of adjacent lots.

The relationship between the design and the existing landscape, compatibility with local cultural values or property value are features specific to SBTool-es.

Some of the criteria included in this area are also considered in others, such as trees with shade potential or site orientation, which have a direct effect on energy efficiency.

Differences can be identified between the requirements of the various tools, however. In LEED, for instance, the maximum allowable distances to public transportation are 800 m (for underground or similar) and 400 m (at least two bus lines), while the Guía establishes a maximum distance of 500 m to some form of public transportation providing service at 20-minute intervals or less.

As a rule, many of the criteria are directly related to their impact on climate change which, as noted above, is the chief priority.

This area contains only sparing recommendations with respect to the legislation in force, although account must also be taken of the type of urban design or planning processes and proceedings presently in place.

SBTool-es is the application that attaches most importance to this area, which at 37% nearly doubles the weight allocated by the other two tools (LEED, 22% and the Guía, 18%).

After the redistribution exercise, category weighting in SBTool-es is: 15% for planning, another 15% for choice of site and only 5.1% for urban design.

The agricultural and ecological value of the undeveloped area and the impact on surface and underground water are assigned very little weight in general. Acording to Naredo (1997), the urban sprawl of the last twenty years, has used more land than the land used two thousend years before.

3.2.2. B- Energy and atmosphere (mean weight 26.3%)

The area is subdivided into two categories:

- B1. Renewable energy and GHG emissions. This includes the type of energy source used and greenhouse gas emissions.
- B2. Other emissions. Emissions with other types of environmental effects.

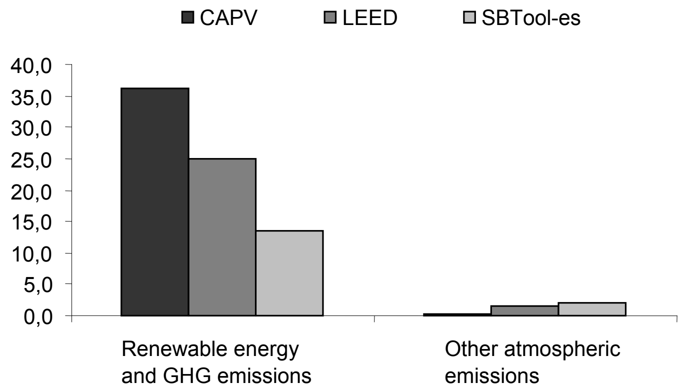

Figure 3. Category weighting in area B – Energy and atmosphere

This is the area where tool criteria and Spanish legislation on energy efficiency and renewable energy are most closely correlated. Essentially, the difference consists in the type of requirements. Improvements on minimum standards are rewarded and possible strategies are recommended, such as the design of passive systems.

The main enhancements with respect to the existing legislation are found in the provisions on the use of local products to avoid having to ship materials and on the amount of energy needed to produce them. This is directly related to area D (Materials), where reuse or recycling entails the reduction of waste as well as of the demand for resources.

Here it is the Guía CAPV (which, it will be recalled, was developed at the same time as the new legislation) rather than SBTool-es that weights the area most heavily. Improvements in the envelope and heating and air conditioning systems are the most relevant factors for the former tool.

The reduction of the amount of equivalent CO2 emitted by HVAC systems is the basic consideration, even though such emissions are addressed in the present legislation, specifically in the Technical Building Code and energy certification standards. Initially, the differences lie in the improvements over the standard requirements: many of the criteria set out in the Guía are included in the legislation, while in LEED the reference standard is ASHRAE and SBTool-es takes account of improvements over Spanish legal requirements.

The graph by areas also shows the importance attached to greenhouse gases over other types of emissions. The distribution of consumption (heating, cooling, hot water, ilumination, and others), and the type of energy suply in residential buildings, variate depending on the region and climate area studied, and consecuently, the potential impact reduction (UNEP 2007).

3.2.3. C- Potable water (mean weight 10%)

The area is subdivided into two categories:

- C1. Potable water. Focused on reducing consumption.
- C2. Rain-, storm- and wastewater. This category considers the use of these types of water as a source of supply.

The criteria applied to water, similar in all the tools, consist basically in lowering consumption through reduced use (highest score) and the deployment of alternative sources where potable water is not needed. Criteria such as water quality or the water content in materials are not addressed.

Spanish legislation contains a number of recommendations in this regard, but no specific measures for minimizing the associated impact.

SBTool-es associates these criteria with the loss of aquatic life and the depletion of resources.

3.2.4. D- Materials (mean weight 15.9%)

The area is subdivided into two categories. As the two are closely related, the subdivision clarifies little in this case:

- D1. Materials. Reused, reusable, recycled, recyclable. Composition and origin are other factors considered here.
- D2. Solid waste. Generated essentially during construction or demolition, but also during the building's service life.

This area focuses essentially on products containing harmful substances and their possible active re-entry into the environment through recycling and reuse. Production criteria for certain materials such as certified wood are also covered.

The Guía is the only tool that takes account of waste generated during construction and demolition, although these items could be included in the databases used by the other tools or in the type of strategies proposed for construction and demolition in the site development stage.

Both LEED (14.1%) and SBTool-es (13.1%) score reuse or recovery as a basic strategy higher than recycling and propose the use of existing elements and precast/prefabricated or industrialized elements.

3.2.5. E- Indoor environmental quality (mean weight 13.1%)

The area is subdivided into five categories:

- E1. Indoor air quality
- E2. Ventilation
- E3. Temperature and relative humidity
- E4. Daylight and lighting
- E5. Noise and acoustics

The legislation is more closely patterned to the requirements laid down in this case. Ventilation, temperature, humidity, light and noise are directly reflected.

However, differences are again encountered in the stringency of the requirement. In this case, as well as in service quality as discussed below, monitoring and controllability play an important role.

The air quality criterion contains no reference to outdoor air quality, that in some areas exceeds the levels of pollution limits for the protection of human health (OSE 2007).

The Guía is the tool that attaches least importance to this area, while focusing on the quality of indoor air and ventilation. LEED also takes this approach, but places less weight on temperature, humidity and lighting. SBTool-es distributes the values more or less evenly across the various areas, with greater weight going to noise and acoustics than in the other tools. In light of the new legal requirements respecting noise, this emphasis proves to be excessive.

3.2.6. F- Service quality (mean weight 13.5%)

The area is subdivided into five categories. The first two (F1- *Safe usage* and F2- *Functionality and efficiency*) were eliminated from the comparison because they are addressed in the legislation and do not score in any of the tools:

- F3 Controllability

- F4. Flexibility and adaptability
- F5. Commisioning and manteinance of facility system.

SBTool-es assigns similar values to system controllability, flexibility and maintenance, while LEED attributes no value to flexibility and the Guía attaches greater importance to system delegation and maintenance.

Since *controllability* and *building delegation and maintenance after completion* are closely related, the inter-tool differences are not significant.

3.2.7. G- Economic and social aspects (relative weight excluded)

The cost per square meter-hour of building use is an indication of the long-term efficiency of solutions.

The cost of land is not considered.

3.2.8. H- Other (relative weight excluded)

Area H – Other – encompasses innovation criteria proposed by LEED, which take into consideration both exceptional performance in any of the other areas and innovative performance in categories not specifically addressed in the tool.

4. Discussion, conclusions and proposals

4.1. Output or results

In the Guía and SBTool-es, the results are displayed on fact sheets showing the relevance of the impact generated. In LEED, by contrast, the result is the rating level obtained. The fact sheet display, which shows partial and total results, affords a more complete overview of the multidimensional assessment. The final score is an addition of different partial issues, like health, CO2, security or NOx, and it leads to mistake the score weight for its relevance, so clarity in fact sheet layout and differentiation depending on the degree of detail desired are other important features.

In the Guía, project scores are given in percentage and shown on a graph. The weighting factors and breakdown by categories are also visible, providing a broader view of the domain affected by the load (materials, soil, potable water…). The inclusion of the partial results obtained on every one of the pages as the form is filled in is extremely useful.

In SBTool-es, scoring is based on impact prevention and each of the criteria within the categories refers to the type of impact involved. This method is similar to the procedure followed in the Guía, although the scores reflect the effects caused by specific loads and an attempt has been made to use these loads as the unit of measure.

Energy certification is clear and revealing, but is not intended as a design aid.

Generally speaking, the rationale for criterion weighting is difficult to understand. While the value assigned to the volume of harmful gases is conceptually comprehensible, for instance, there is no notion of the scale of their significance. Much the same can be said of materials and waste. The quantities by content in material recycling or the degree of recycling possible are often hazy or ill-defined.

A more complete view of local, regional and global impact, reflecting the beneficial and adverse effects of the process studied, would be highly useful. Moreover, the inclusion of the real impact associated with the various requirements would lead to more responsible decision-making.

In housing construction, it would be helpful to have results in terms of the number of persons or users for which a building is intended. Broken down by areas, such results would indicate, for instance, the number of kg of material used or the amount of land deteriorated and/or reclaimed *per capita*.

4.2. Design process

The tools analyzed are geared to design decision-making. As such, they set out a series of guidelines referred to present construction practice. One final outcome provides an indication of the degree of compliance with requirements, which is useful where the objective is merely to obtain a certificate or a high score. As reference tools for selecting specific strategies, or as educational tools, however, they clarify very little.

For the design process it will be helpful and efficient, to synchronize the assessment with other modelling tools and building databases, in order to simplify the management of the building cycle, exchanging and integrating construction information, legislation or documentation and involve the various actors. This may improve the evaluation of sustainable options and quality of solutions.

4.3. Regionalization

When tools are regionalized, they are adapted to a greater or lesser degree, fortifying non-regulated sustainability criteria or criteria of greater regional or local relevance. Some of the criteria excluded from the comparison, therefore, are not being taken into account because they are included in the existing legislation. Regional adaptation is one of the features that distinguishes and adds value to these tools.

4.4. Legislation

Both the Guía and SBTool-es are based on energy certification under Spanish legislation, directly adopting this (or some similar) assessment as a criterion.

Spanish legislation should promote or include the points where the tools clearly and decidedly concur.

4.5. Type of criteria and organization

The areas, categories and criteria of the tools analyzed are imprecise and their limits blurry. The structure could mirror the sustainability model used for the assessment.

Where social and economic factors are – exceptionally – considered, the treatment is cross-sectoral. This is odd, when users' lifestyles and habits are so closely related to buildings and have such a long-term impact, and when a new order is being proposed for the production system on which construction is based.

The cost-sustainability ratio should be reviewed. The e*nvironmental profitability* conceit, i.e., the savings in the cost of water and energy throughout the service life of a building, could be extended to other categories. Sustainable buildings are more costly than buildings erected using standard practices and procedures. And yet cost increases in this type of practices are widespread.

In light of land development and occupancy in Spain, the need to develop tools for rehabilitation would appear to be inescapable. Criteria might also be included on the necessity of construction: second homes as opposed to housing for disadvantaged communities, for instance.

The inclusion of regional data on outdoor air quality, urban complexity, noise or the location of recycling sites and the orderly reference to systems recommended for their sustainability would facilitate decision-making.

The surroundings where buildings are sited and the way they contribute to the formation and use of cities are directly related to construction *per se*. A review of the indicators used in urban systems reveals analogies and differences with the tools analyzed here. Generally speaking, they have much in common, but there are fields where the tools could go into deeper detail, such as participation, reduction of inequalities and social inclusion, furtherance of local employment or facilitation of integrated design, defining the areas that correspond to the various actors involved and specifically addressing issues as closely related to building as quality of life, public space, diversity and complexity.

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MONUMENT PROTECTION VERSUS CLIMATE PROTECTION? SUSTAINABLE DISTRICT DEVELOPMENT AS A SOCIO-ECOLOGICAL TOOL

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Summary

As a result of structural change, new inner-city conversion areas are increasingly emerging in European cities (due to the relocation or closure of facilities and properties used for industrial or military purposes). Using the tool of prospective project development and integral planning, taking account of demographic development and different lifestyles, the goal of sustainable district development can be achieved.

The task and goal that we set ourselves was to use best practice models, in other words projects we have implemented, to set an international example of the sustainable, energy-efficient renovation of listed buildings, backed up by scientific measurements.

We will be reporting on fully or partially completed property renovation projects carried out by a network that we set up. The future residents, who are at the centre of the action, receive comprehensive advice and support from us.
We involve the residents in planning right from the redesign phase. They receive competent advice from experienced architects and economists, alongside a financing option tailored to suit the concept at hand. This option, which encompasses grants for sustainable renovation and cooperation contracts, enables communal areas and multi-purpose areas to be established, thus enabling individuals with a lower level of income to also own their own property within these units.

1. Rediscovering the city – sophisticated living

The charm and appeal of inner-city districts in European cities comes from the historical structures that have evolved over time.
This is what sets European cities apart from many of their American or Asian counterparts and defines their identity.
People are now rediscovering inner cities as places to live. City centres are becoming increasingly attractive to single people, young couples, families and older people who no longer wish to live “away from the action”, and who consider the city with its unique supply structure the best place to live.
As a result of structural change, new inner-city conversion areas are increasingly emerging in European cities (due to the relocation or closure of facilities and properties used for industrial or military purposes). These areas and buildings that have lost their original function now offer space for individual, sustainable living concepts.
The German government introduced guidelines for sustainable construction back in 2001. However, what is missing in Germany is a clear label that makes the recording and assessment of economical, ecological and socio-cultural factors transparent and traceable. The “Future Construction“ research initiative from the German Federal Ministry of Transport, Building and Urban Affairs is set to present a label of this type in 2008.

1.1. Re - thinking the city

This was one of the contributions from the European Commission conference in October 2007 entitled "Towards a post-carbon society – European Research on economic incentives and social behaviour".
Taking account of climate change, the EU's aim of achieving a "post-carbon society" by 2020 as well as the need to not only save energy in buildings but also provide energy, it is evident that intelligent, decentralised solutions are required. Innovations should result in legal obligations with high benchmarks so they can be implemented across Europe in the mid-term.

In decades to come, societies will be faced with two main challenges:
– Economic and social adaptation to climate change, which has already begun
– Economic and social development alongside ever-increasing prices for energy resources.
The economical and social costs in this area are immense. In cash terms, these costs are estimated at more than one hundred billion euros per year. This, of course, has a detrimental impact on the well-being of society as a whole and on quality of life.

The aim of the European Union is to incorporate research on social adaptation into climate research in order to bring about the consciousness required for a "post-carbon society". Jean-Michel Bear, Director of the European Commission DG for Research, Science, Economy and Society has explained that humanists and social scientists urgently need to get involved in the debate and define new forms of responsible leadership in the business world or in cities.
The necessary social contact in city districts brings together people who do not live in the form of the "classic" family. City living also offers a lot more freedom to those with children.

1.2. National urban development policy

In climate protection, particular attention is also paid to urban development policies.
In Germany, three quarters of inhabitable buildings are deemed in need of renovation. However, due to insufficient attention paid to energy efficiency, etc., the aim of sustainable construction has not yet been reached for existing buildings. In addition, 40% of energy used is needed for running buildings. In the last 10 years, building heating costs have risen by around 90%. On one hand, all parties involved need to change their way of looking at things. On the other hand, sustainability must be made measurable and comprehensible to everyone so that it becomes a new competition factor in the housing industry.
One of people's primary needs is healthy and safe living or working in an enclosed space. Positive changes in behaviour regarding health protection, ecological protection and conservation of resources are becoming apparent through living or working in "sustainable" buildings.
The advantages of city living are obvious. These advantages, including a short journey to work, cultural entertainment, educational facilities, medical care and other benefits, are in high demand.
Are consumers responsible for paving the way towards a "post-carbon society"?
Will new social values lead to rapid and lasting changes in behaviour (similar to the way in which smoking has negative connotations in today's society, for instance)?
Could *Passivhäuser* (ultra-low energy buildings) or low-energy houses accelerate the change process, and lead to changes in the way consumers think?
The answer to these questions is a resounding YES. As economist Franz-Josef Radermacher states in his book *Welt mit Zukunft* (World with a future), a balanced world can only be achieved by all people making a change in their immediate surroundings.

Figure 1 aerial view of Ludwigshafen Hemshof 2003, building Rohrlachstr. 79 front and courtyard view.

Regional diversity and identity give rise to major urban development and profiling potential in terms of the Leipzig Charter. Including listed buildings in the 2020 outlook is of great importance in achieving the aim of energy-independent, energy-efficient houses and districts without a loss of their identity.
Adapting existing properties to contemporary user requirements and demographic change, while taking sustainability into account and using existing architecture as a resource, requires changes be made more rapidly to existing properties.

2. Project implementation

Using the tool of prospective project development and integral planning, taking account of demographic development and different lifestyles, the goal of sustainable district development can be achieved.
The task and goal that we set ourselves was to use best practice models, in other words projects we have implemented, to set an international example of the sustainable, energy-efficient renovation of listed buildings, backed up by scientific measurements.

The aim of the projects run by Osika GmbH is to achieve sustainable district development – meaning development that is socially open, that spans generations, that is committed to cultural heritage, that is functionally differentiated, that is ecological, that is ambitious in construction terms, that networks various urban areas and that opens up public spaces. This aim is proven by examples of the company's projects in Ludwigshafen-Hemshof, Mannheim-Schwetzingerstadt and the "Quartier Normand" in Speyer.

These examples demonstrate how to go about carefully protecting existing buildings that are worth preserving, while adapting them to suit future development challenges in districts.
In Ludwigshafen-Hemshof, the old town, which is around 50 hectares in size, has been given a new lease of life through involving both public and private individuals and property owners.

2.1. Sample project Quartier Normand, Speyer

In Speyer, an area of land that has been isolated by military use for 120 years is being reincorporated into the city as an inspirational "city building block".

Figure 2 historical picture 1900, Quartier in 2003, district development in 2004

The individual measures that have been taken or will be taken are as follows:

- Interdisciplinary development of a district strategy
- Reaching a consensus in committees and public authorities
- Selective deconstruction
- Static reinforcement
- Renovation of listed properties
- Energy-saving modernisation of constructional and technical structures:
    - Interior insulation of building fronts
    - Controlled ventilation with heat recovery
    - Incorporation of elements of passive houses
    - CO_2-neutral heating system with a heating network based on biomass and solar power

Figure 3 innovative interior insulation, CO_2- neutral heat supply,ventilation with heat recovery

- more than 80% reduction in the primary energy requirement
- Buildings with a heat requirement of fewer than 60 kilowatt hours per square metre per year
- Division into manageable owner communities (house-in-house principle)
- Addition of individual free areas for each unit of use
- Various housing offers for different user groups
- Development of individual planning designs from a 1-room apartment to a loft apartment
- Combined commercial and residential use
- Sophisticated grounds as an integral part of the project

In this way, these new, “old” parts of the city are not only being sustainably renovated and developed for their own benefit, but are additionally setting an example that is being followed in neighbouring districts.

Starting with integrated planning and incorporating networks of all those involved, such as project developers, utilities, councils, specialist planners, investors and users, and using best-practice procedures supported by the German energy agency DENA and the national urban development policy, higher-level sustainability targets can be reached in many areas within a short space of time.
In the case of individual historic buildings, for instance, these targets are being met by renovating the building to make it energy efficient, mainly by using passive-housing components. In the case of districts, these targets are being met by decentralised, autonomous provision of renewable energy.

Figure 4 Visualisation 2005 of the historical building in Speyer, Quartier-Normand

2.2. Sample project Transformation at Luther Square, Ludwigshafen

The aforementioned goals are being pursued as part of a project in Ludwigshafen to transform Luther Square.
The project, “Living at Luther Square”, can be viewed as a pilot project for the planned city redevelopment measures in Ludwigshafen.

Future inhabitants are looking for:

- Sophisticated living and a return to the city
- A tranquil living environment
- Adaptable concepts
- *Bauhaus* architecture
- Life in a place with historical flair
- Life in energy-efficient buildings
- Accommodation suitable for families

- Independence in old age
- Proximity to work/amenities and a good infrastructure
- Cultural diversity
- A mix of generations
- Houseshares
- The young and the elderly helping each other
- Childcare for small children
- Care for the elderly or the ill, if required
- Increased quality of life though a sense of community
- People of a similar mindset, regardless of their income

The following terms can be used to describe the concept strategy:

- Establishing desirable places to live
- Unique selling propositions
- Diversity of usage
- Developing a neighbourhood
- Expanding and renovating existing structures
- Promoting community, civil participation and social communication
- Dealing with empty properties and wasteland
- Prioritising internal development over external development
- Improving the habitability of inner cities
- Modernising existing housing, adapting it to suit current needs
- Establishing new forms of housing
- Increasing the living quality of properties, creating green areas, creating open spaces between housing blocks
- Stabilising the social structure
- Increasing the amount of condominiums
- Making the city a more attractive place to live
- Developing a positive image

Good project management enables all types of homeowners and homeowners' associations with different financial arrangements to participate positively in finding a solution to meet everyone's needs.

Figure 5 Visualisation 2008 Building Berlinerstraße/ Lutherstraße

Revitalisation of areas in terms of sustainability, energy efficiency, inspiration and flexibility to suit the lifestyle of people of all ages is expressed by the transformation at Luther Square in Ludwigshafen as follows:
The imposing former council house can be split into numerous small properties that are grouped into various owner communities in line with the house-in-house principle.
Each owner community has its own entry door to the main building, some have lifts and are accessible to the disabled. Each community has balconies overlooking the courtyard. It is possible to change the living arrangements and communal spaces if required.
33 residential units and units for offices and cultural use ranging in size from 40 square metres through to 200 square metres of effective useable floor space can be created in this building.

This means that the building, which lends identity to its area, is an attractive example of the overall concept of inner-city renovation.

Figure 6 Cancellation of the inner block area, planed inner courtyard situation

3. Data and evaluation

Our own annual empirical data dating from 1994 onwards has been analysed in terms of energy efficiency and energy-saving potential. This data concerns a total of 160 residential and office units with a total of 17.200 square metres effective useable floor space in the Rhine-Neckar Metropolitan Region, including larger cities such as Ludwigshafen, Mannheim, Heidelberg and Speyer. This data shows how on the one hand primary energy needs and the energy required for living change over time, and on the other hand how the people residing in these units behave regarding the environment and climate protection in their immediate setting.
The project in Speyer for the revitalisation of a former barracks compound was used as the basis of a lifecycle analysis, and analysed using the LEGEP tool in connection with the other two contributions from Germany to the World Sustainable Building Conference 2008.

The following data analysis are predicated on the evaluation of the project Quartier – Normand Speyer with the LCA,LCC tool LEGEP:

The graphic shows the Final Energy consumption before (left) and after (right) the renovation of the building.
The heating energy consumption with only 21.629 kWh/m^2/a after the refurbishment shows the reduction of 94% of the heating energy.

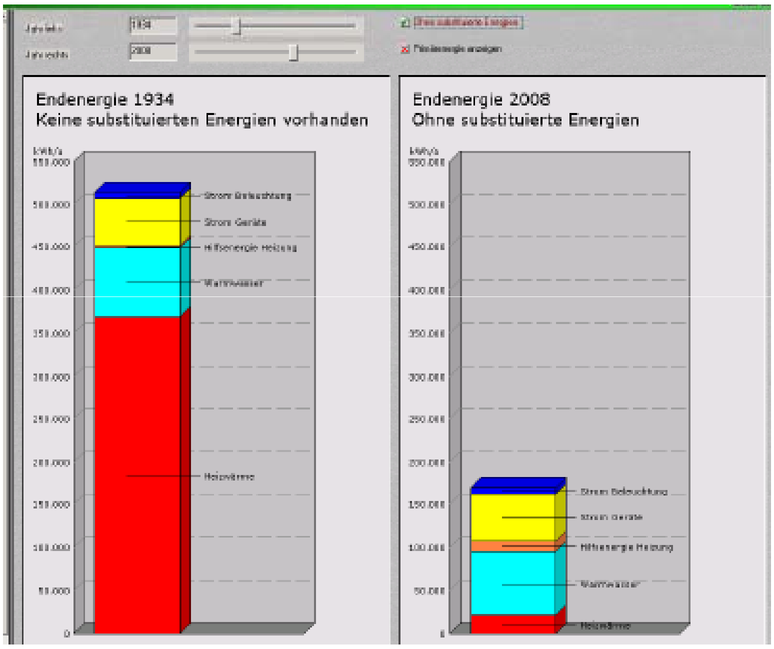
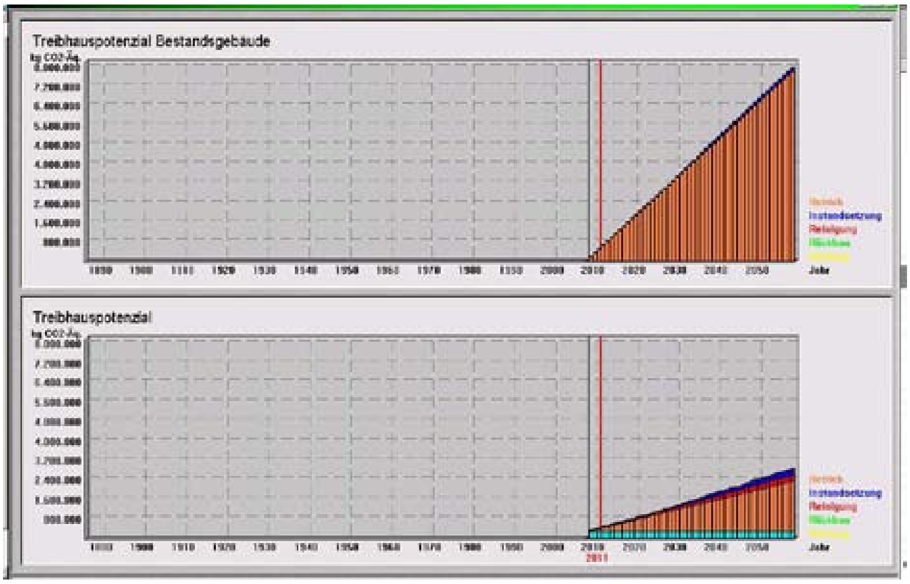


Figure 7 Final Energy consumption

The changes of the enviromental impact, (kg CO_2 – equivalent) shows that the amortisation occurs after 3 years in 2011.

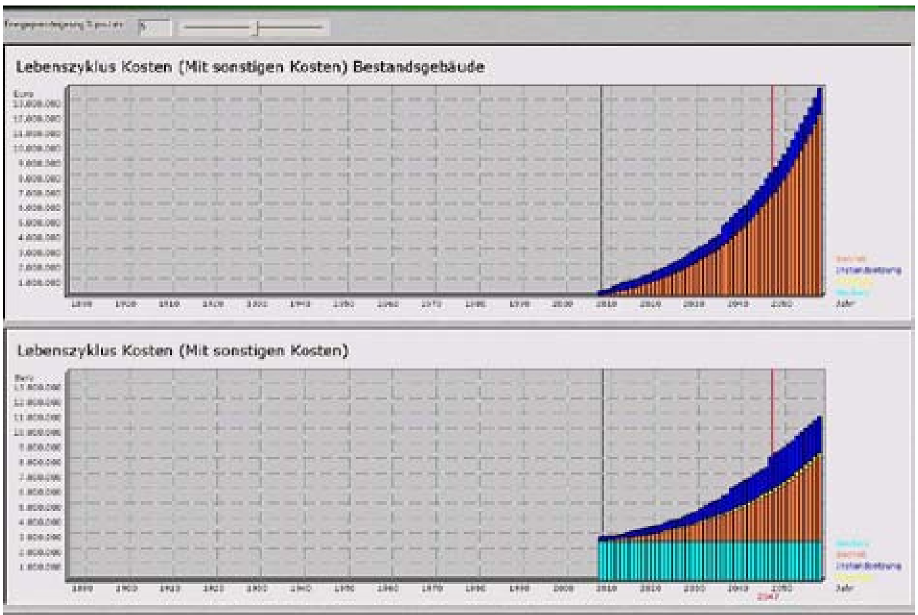


before renovation

after renovation

Figure 8 -kg CO_2 - greenhouse gas emmissions

This graphic shows the values of Life Cycle Costs if the energy prices increases about 6%/a over a period of 50 years



before renovation

after renovation

Figure 9 LCC with energy price increase of 6%/a during 50 years

4. “Homes for living” initiative

The floor plans of the individual residential units can be adapted to suit the needs of the residents. Here, the owner communities also form small mutual support communities, so that a family with 3–4 children, for instance, can also afford a large home, as the part of the purchase price that exceeds the family’s budget is financed by the other residents through a cooperative model. Competent specialist advisors who can think innovatively in terms of both legal and economical issues are required to support and run this process. That’s why in 2007, we launched the “Homes for Living” initiative – sustainable buildings for more quality of life.

Figure 10 Impressions entrance and indoor Quartier Normand, Speyer

5. Successful and sustainable networking – connected, viable, liveable

The Rhine-Neckar Metropolitan Region, with an area of 5,637 square kilometres and 2.4 million inhabitants, is the seventh largest urban agglomeration in Germany. Networked structures in business, science, politics and administration allow successful collaboration at all levels with a view to taking increased regional responsibility in these areas.
Following acceptance in the group of European metropolitan regions on 28 April 2005, the Minister-Presidents of the Federal States of Baden-Württemberg, Hessen und Rhineland-Palatinate clearly expanded the leeway of the region and its players with a new state treaty on 26 July 2005.

More than 100,000 companies operate in this region. Key issues and areas of action for the various players are sustainability but, in particular, energy efficiency, and sociocultral values.
Faced with global competition, the regions that will be successful will be those that consolidate their strengths and communicate a clear profile both within and outside the region.

Alongside this large network, there are numerous smaller networks, which are held in high regard in terms of their impact and acceptance.
Examples here include EnergieEffizienzAgentur Rhein Neckar gGmbH, the Stiftung für Ökologie und Demokratie e.V. foundation and the Energieagentur Speyer Neustadt Südpfalz energy agency, which even makes a key contribution in conjunction with German national urban development policy.

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INTERNATIONAL SURVEY OF "HIGH RISE" SUSTAINABLE OFFICE TOWERS CAN A HIGH RISE OFFICE BUILDING BE SUSTAINABLE?

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Keywords: Environmental Building Assessment, High Rise Building, Sustainable Building, efficiency, Office Buildings

Summary

The French Ecology and Sustainable Development and Planning Ministry contracted with CSTB in order to get aware of and to take benefit from the existing examples of "sustainable" high rise offices towers all over the world

The study has been a two step process:

- A description and a comparison of the main existing sustainability/environmental assessment methods of offices buildings, has been developed as a follow-up of a previous study, with a specific focus on the low energy performances.

- An international survey of. high rise "sustainable" office buildings has been carried out. An overall analysis methodology was proposed in order to collect and take the most of relevant data, firstly based on bibliography and internet sources, and secondly on direct contacts with the concerned people.

This paper focuses on the survey. It first explains the analysis methodology, and reports on the results at the different steps. At the final stage, five towers selected from the initial inventory have been deeply investigated, with a special attention towards the climate, energy and ventilation concepts and the real performances in use. Main objectives were to elaborate a state of the art of the "sustainable" technologies used, and to collect performances in use and feed back from the owners and users, in order to make choices based on actual experience.

At the end, we try to provide a partial answer to the following question: Can a high rise office building be "sustainable"? The debate has to be initiated at the early stage of the process, with only the programme in hand.

1- Introduction

Among all the office towers which have been erected recently, or which are planned in different cities in the world, some projects have been designed with the concern of sustainability. The aim of the study ordered by the French Ministry for Ecology and Sustainable Development and Planning was to get an overall view of the best examples, together with a good knowledge of the tools enabling the assessment of the sustainability of the works.

The study has been performed in two steps:

- A description and a comparison of the main existing sustainability/environmental assessment methods of offices buildings, has been developed as a follow-up of a previous study, with a specific focus on the low energy performances.

- An international survey of. high rise "sustainable" office buildings has been carried out. An overall analysis methodology was proposed in order to collect and take the most of relevant data, firstly based on bibliography and internet sources, and secondly on direct contacts with the concerned people.

The following development focuses on the second part, the survey. We first describe the methodology, then present the results. The second part of the paper is dedicated to the lessons learned, with a more developed section on the energy consumption aspects. The study was conducted in close contact with an advisory committee composed of technical experts together with national authorities' representatives, who commented our results in terms of transposition feasibility.

2- International survey on high rise sustainable office buildings

2-1 Methodology

Objective of the study was firstly to inventory some remarkable high rise office buildings in term of sustainability.

The survey has been performed in two steps:

- a bibliography enquiry has been made by CSTB, using mainly internet sources, which procured plenty of information
- a mobilization of the international CSTB network in order to collect complementary and real information.

To collect data and analyze information, CSTB made different types of questionnaire and analysis and evaluation documents which were discussed and validated with the ministry. The questionnaires were sent to out international contacts with a document describing our study in order to get one or two references in each country.

A simplified questionnaire was focused on project characteristics, actors of the project (owner, architects…), state of the work, operation description, site characteristics (surfaces, high of the work, usage), economic data, principal objectives of the work in term of sustainability and environmental quality, thermal performances expected and in use, space organization and some others aspects of sustainability matter.

In order to analyze deeply five towers of this preliminary inventory, a detailed questionnaire was made which focused more precisely on the sustainable and environmental quality issues, on the space organization, on the comfort in use of the building, on the innovating solutions and systems in order to get the performances of the building, and on the real performances in use.

We have been confronted to difficulties to get completed questionnaires returned from our contacts. The difficulties came from the short delay to respond to our enquiry, and from the fact that real performances in use of "sustainable towers" are not always known by the owner, and not always communicated. The expected performances are set up by the architect and engineers teams of the project, but not often evaluated when the building is in used, and if known, not communicated. This study pointed that expected performances of a high rise building are not often matched when the building is in used, a special point about the usage of the tower which does not correspond with the expected use during its design.

2-2 Results

This non exhaustive inventory showed that there is a lot of high rise office buildings around the world, lot of them with "supposed" sustainable characteristics. Our analysis focused on 25 towers, most of them in Europe and USA, and few in Asia, in order to get more confident and transposable information. In a second part of the study, five selected projects were deeply investigated and analyzed.

This inventory showed that environmental preoccupations are not a design priority for older towers. Nevertheless, the sustainable principles are more and more taken into account, and become inescapable in the design and construction of new towers.

The five deeply investigate projects have been chosen with the ministry for:

- the sustainability preoccupations, and especially environmental and energetic concept and performances,
- the climatic, cultural and social criteria, in order to get usable and transposable information for the ministry,
- towers in used in order to get experiences returns and real performances in used.

The five selected towers are:

- Commerzbank Tower (Germany)
- Conde Nast Building (USA)
- Post Tower Bonn (Germany)
- St Mary Axe (or "Swiss Re" in GB)
- Highlight Business Tower (Germany)

Commerzbank Tower is located in Frankfort and has been made by Foster and Partners for Commerzbank AG. This triangular building has been delivered in 1997 and is 259 meters high (300 m with antenna). It has been considered by many as the first "green" high rise office building in Europe. Four storey gardens spiral up the tower and are linked to a 200m central and triangular atrium.This building has been designed in order to optimize daylight penetration utilize natural ventilation for a large proportion of the operating cycle, using mechanically assisted air conditioning only under extreme conditions.

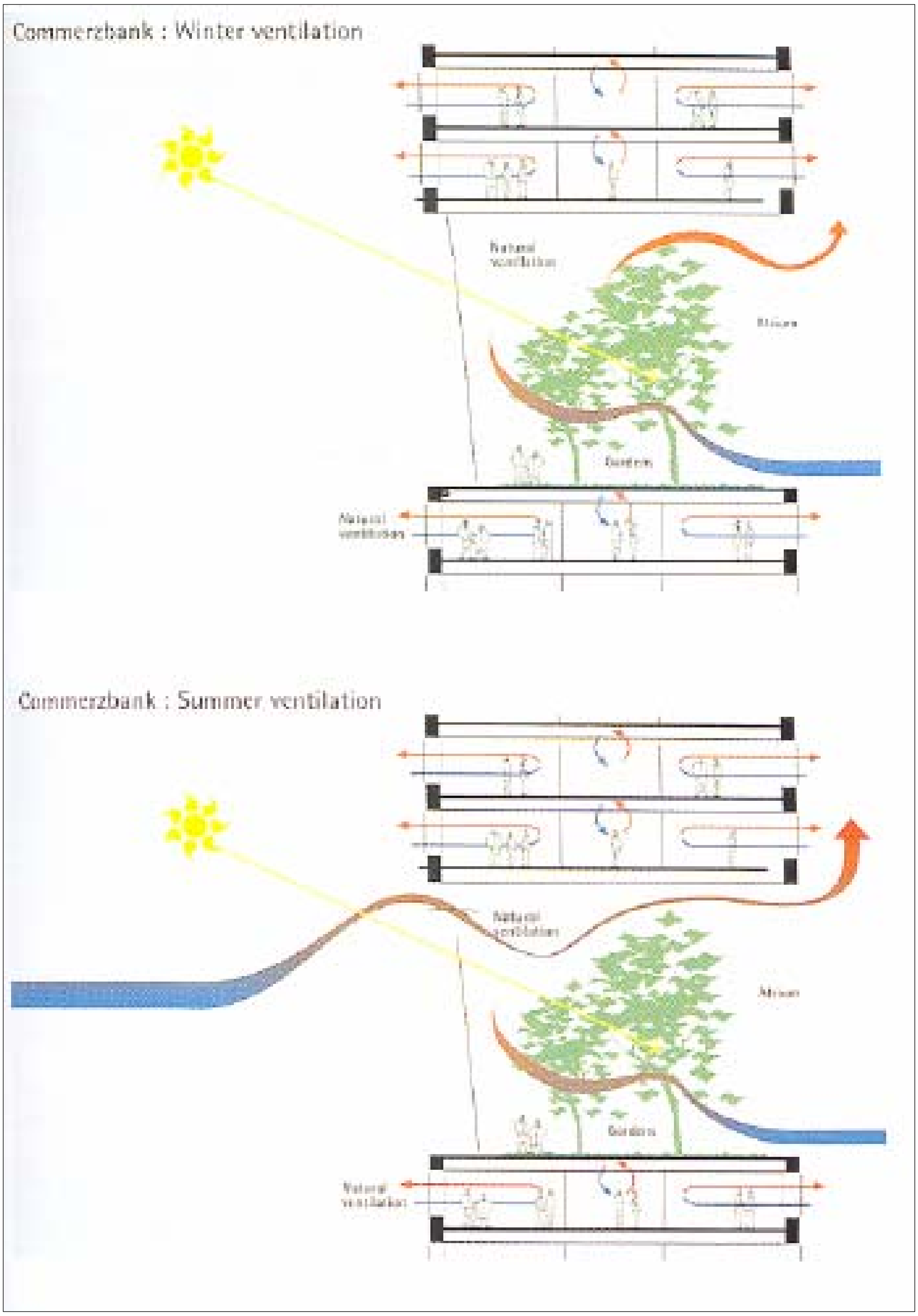

Figure 1 Commerzbank : functioning scheme in summer and winter (Michael Wigginton and Jude Harris, 2002 Intelligent skins)

Conde Nast Building is located in New York and has been made by Fox and Fowle architects for the Durst Organization. It has been delivered in 1999 and is 247 meters high (264 m with antenna). It was the first “green” high rise building in New York with high consideration in terms of energetic performances of the building and renewable energy

. Post Tower Bonn is located in Bonn in Germany and was conceived by Helmut Jahn for Deutsche Post and was delivery in 2002. This 161 meters high building is composed by two twin towers connected by glass bridges at each floor. This building develops a double skin façade in glass. At the design stage, energy demand of Post tower Bonn was evaluated at 117 kWh/m²/year, compared to 390 kWh/m²/year of a standard office building. Measures done in 2003 showed a real energy demand of 166 kWH/m²/year (source TRANSSOLAR), 66% higher of the estimated figures

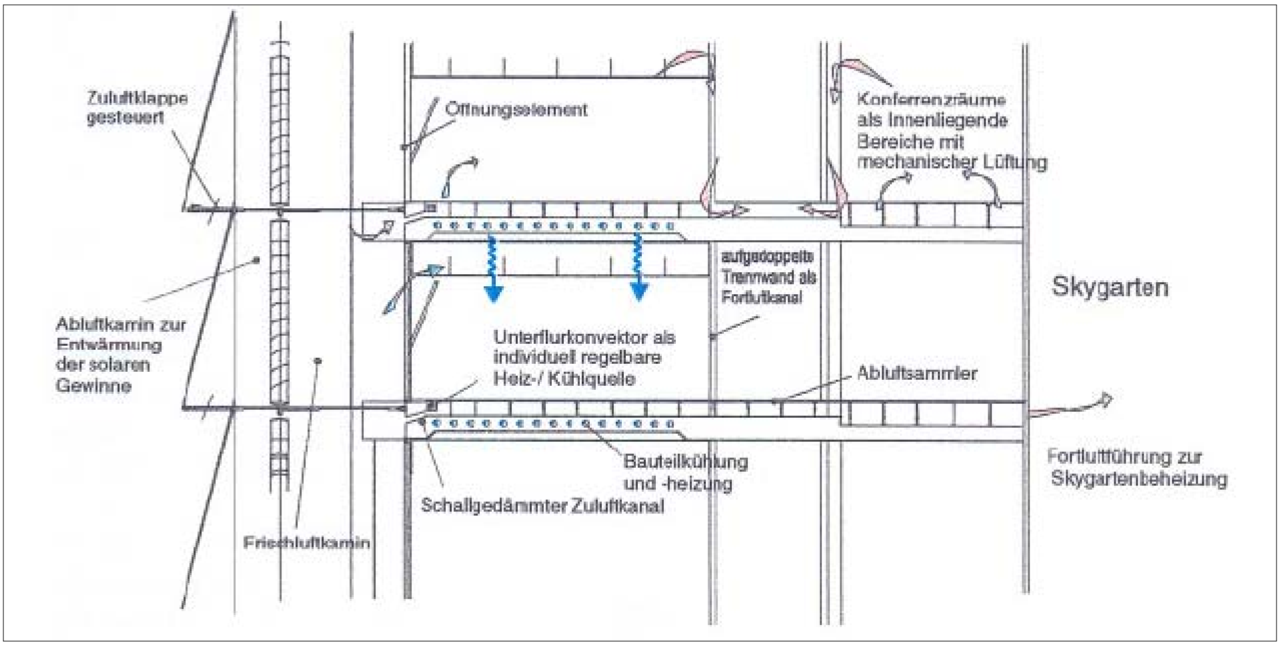

Figure 2 *Post Tower Bonn: Conditioning and ventilation scheme (TRANSSOLAR Energietechnik GmbH)*

St Mary Axe is located in London in UK and was conceived by Foster and Partners architects for Swiss Re. This 180 meter high tower is helical shape and has a double skin ventilated façade in glass. This building was conceived in order to reduce energetic consumption and to optimize natural daylight inside. It was supposed to work with hybrid ventilation, but this concept is not used in the fact. The consumption target was 150 kWh/m²/year but the real figure (not communicated) is supposed to be about 400 kWh/m²/year in reality.

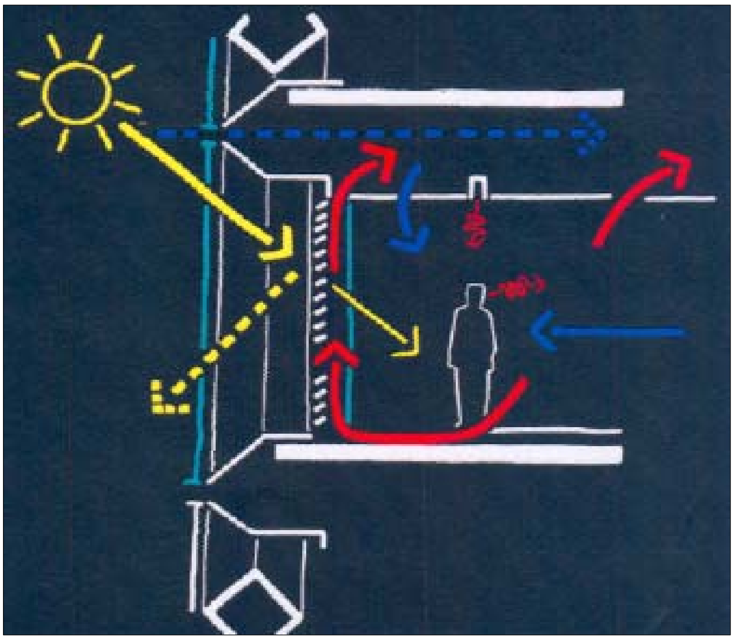

Figure 3 *St Mary Axe: Façade scheme (document Swiss Re)*

Highlight Business tower is located in Munich in Germany and was conceived by Helmut Jahn for Kan Am International GmbH. This building is composed by two twin and thin entirely glassed towers, which are connected by glass bridges at the 9th, 10th and 20th floor. It was build with the objectives to be the most transparent, and to reduce energy consumption and cost constructions. The façade is in triple layer glass. This building optimizes daylight penetration.

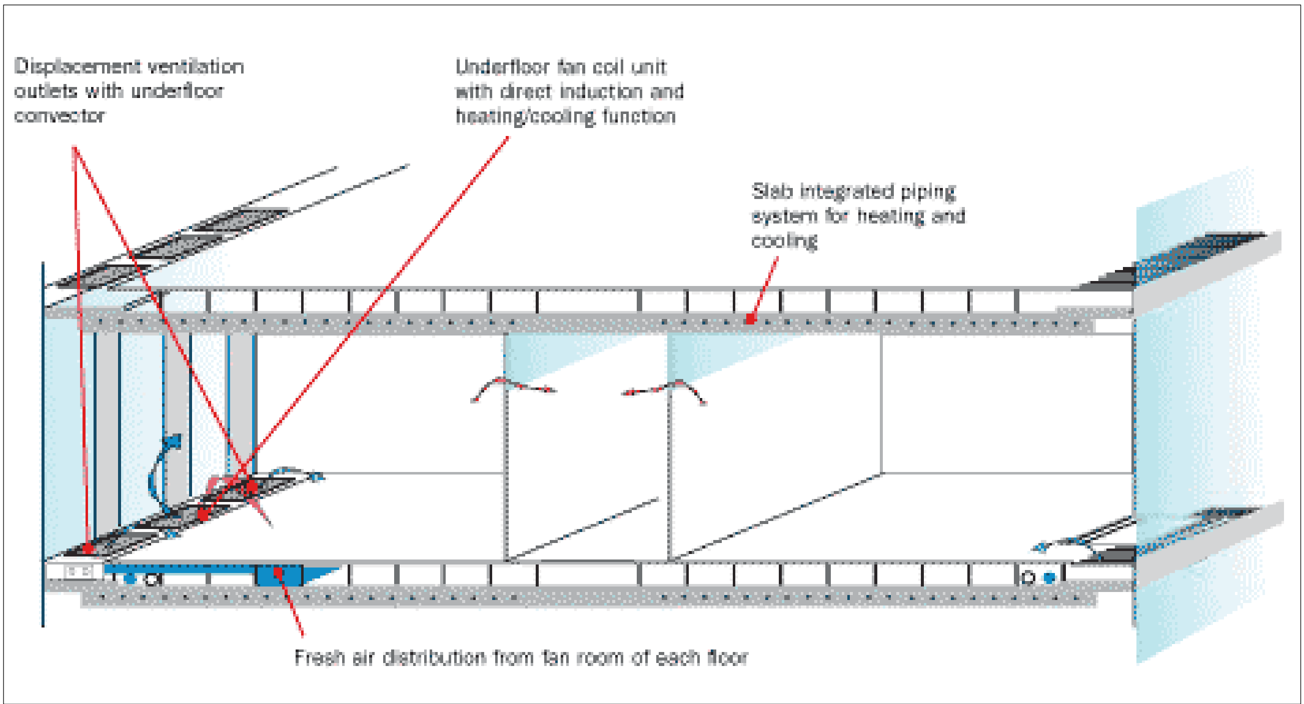

Figure 4 Highlight Business Tower : Heating/ventilation system diagram

3. Main points and lessons learned from the study

3.1 Why towers?

Nowadays, the problematic of the towers can't be considered without the sustainability concern, and even the sustainable urban development approach. Towers are seen to be the building with the largest energy consumption. One of the major stake is to reduce it. It is nevertheless a solution to the densification of the city, territories are not inexhaustible. A joined reflection has to be done on the transport on site, in order to reduce transport of the user, and favor the use of public transportation. Four issues have te be together considered: the high rise performances, transportation ways, optimal use of the land, and biodiversity.

The tower configuration can be an answer to some sustainable problematic (densification, use of public transportation) but a special attention has to be carried out on the environmental characteristics and energetic performances which are more difficult to obtain

3.2 Spaces

3.2.1 Public spaces

Most of new office towers are looking toward offering large and quality public ground spaces in a very constraint environment. The possibility for the public to circulate in the ground floor is a necessity to not cut towers from public space and external world. The immediate surrounding is also very important in the implantation of new towers.

In regards to very constraint sites for the implantation of new tower, interrogation on the choice of the site and relation of the tower towards surrounding environment with creation of public space at ground have to be taken into account as soon as possible, at the beginning of the project.

3.2.2 Space organization

Most of new office buildings are looking to offer more flexible and progressive floor plans of variable surface in order to answer the needs of all users.

Flexibility, modularity and adaptability of building in long term have to be considered at the design stage. Partition of office space has to be adaptable to different organization and technical systems have to be modifiable and adaptable. Cores and circulation have to be though in order to obtain this flexibility. Quality meeting and relaxing places are also a necessity for users.

3.2.3 Thermal and visual comfort

Guarantee thermal and visual comfort, in summer and winter, in office high rise buildings is a primordial stake. Users want more and more a real comfort in their office space.

In order to obtain thermal an visual comfort in office high rise buildings, a special attention has to be taken to the following points:

- The façade performance, with a maximum glazed part of 50%, providing external pleasant views
- A good solar gain and dazzle control and management with automated and effective solar blinds
- A good artificial lighting control and management with repartition of the intensity of lighting, presence sensors, and natural daylight sensors in order to control the artificial light need.

A special attention has to be taken on real use of the building and its interior fitting up has to be thought in order to best adjust the different systems to the real needs. The individual management by the user of his working environment has to be thought and limited in order to prevent drifts due to the use of the building.

Users of the building have to be associated at the design stage in order to explain its functioning, and allow some user behavior change and explain why limiting user management of its working environment.

3.2.4 Vertical displacement

One of the stakes in tower is to allow user to move up and down in a limited time, with a high speed and a limited number of lifts. Elevators are also a high consumption energetic post. Innovations in elevators are the double deck lift, sky lobbies, and intelligent management of elevators call. Some buildings now have lifts which deserve only one floor on three.

3.3 Energetic performances and innovations

3.3.1 Office buildings in use

Studies done in 2001/2002 in Frankfort showed that primary energy demand for office buildings can vary between 200 and 1000 kWh/m²/year, with a mean value of 500 kWh/m²/year.

Since 1990, the construction of energy efficient office building, towers in particular, became a very important stake. Energy efficiency is more and more important, design methods changed with innovative technologies.

In efficient high rise office buildings, heating demand is limited, especially due to high internal load with densification of working area, and lighting demand. However, other posts are more energetic consumer. In relation to a low rise office building, specificities of a tower rise its energy demand. As a matter of fact, a large building increases energy consumption for some posts:

- Ventilation: large building rise ventilation systems losses and their energy consumption. The setting up of hybrid ventilation with natural ventilation becomes more complex.
- Cooling needs: cooling via natural ventilation becomes complex for large buildings. Internal loads are higher, due to working post densification and office equipment, and artificial lighting
- Lighting: artificial lighting demand is higher due to large floor surfaces.

3.3.2 Integral design

Most effective way to reduce energetic consumption in office buildings is “integral design”.

The different parts and systems of the office building were typically separately conceived, by different design teams.

Integral design allow to conceive simultaneously different parts of office building, as the façade, heating, cooling, ventilation and lighting systems, office equipments and energy provider system in allow to optimize the dimensioning of all this posts.

Integral design method allows investment and functioning cost reductions, as environmental impacts (limitation of carbon dioxide emissions, air quality…)

Studies showed that energy demand can be reduced by 30 to 50% with integral design.

3.3.3 Double skin façades

Double skin façade means a system composed by two glass skins separated by a significant air space. Those two skins can act as a thermal insulator. The buffer space between the two skins can also allow ventilation, permitting a good air circulation between the two skins. The double skin façade allows better thermal and acoustic performances, a space for blinds protections, and allow natural ventilation with openings of windows of the double skin. However, many different types of those façades exist and there is only few knowledge and experience returns on the real functioning of this type of façade.

3.3.4 Hybrid ventilation

Some towers were and are conceived with natural ventilation for a part of the year, with the possibility for the user to open the window when the climatic conditions allow it. When the windows are opened, heating, ventilation and cooling systems are automatically shut, reducing the electricity use. In the fact, most of the existing high rise buildings don't use natural ventilation mode, because the final office floors fitting up with partition don't allow it..

Mixed mode ventilation can reduce energetic consumption of a building. However, such a solution has to be considered with the final fitting up of the office floors, taking into account the partition spaces in the system dimensioning.

3.3.5 Reduction of internal loads

In high rise office buildings, increasing of internal loads due to office equipments and lighting induce higher cooling needs of the building.

Within the perspective of a building that should be build in few years, consumption of office equipments in this perspective of time.should be taken into account

The need of cooling is high in regards to those internal loads, and the just dimensioning of the cooling system has to be considered with limited lighting installed power and evolution of office equipment.

Electricity consumption of building can be reduced a lot by the setting up of advanced office equipments, and by limited installed lighting power. This consequently will also reduce cooling demand.

3.3.5 Renewable energy use

Before renewable energy integration, the building has to be low energy conceived. The use of renewable energy became necessary to compensate for energetic consumption in building. Local production of energy is dependant of site potential. However, local production of photovoltaic electricity can only cover a few part of electricity demand, due to tower configuration which only offers a low surface of façade and roof in regards to floor area. Pertinence and efficiency of wind electricity has not been proved until now.

The energetic performance of a high rise office building can't be achieved without the reduction of its energy consumption. Local production of renewable energy can then represent a higher part of its energy consumption.

3.3.6 Cogeneration

Some experiments in Frankfort showed that new office buildings should have cogeneration or tri-generation systems, which reduce by 30% primary energy consumption and dioxide carbon emission.

4- Conclusion

Most of the teaching is focused on energetic performances of offices towers, with the objective of "low consumption building" (BBC label) . One can notice that for high rise office buildings, energetic transportation consumption could be introduce in the global energetic assessment of the building. However, energetic performances oh high rise office buildings can't be compared and reach energetic consumption of low rise office buildings, due in particular to their higher need of ventilation, conditioning, lighting, and the necessity to have efficient lifts.

Optimization can be get with integral design of the building, efficient façades, joined with efficient heating, ventilation and cooling systems, and hybrid ventilation if possible. A special attention has to be taken on office equipments and a limited lighting power.

A refection at the design stage has to be initiated with the management and maintenance actors and the final users of the building, in order to explain the building functioning and allow some behavior change in order to optimize building performances.

The consideration of other environmental characteristics as products choice, energy contained in products, health preoccupations and water management are never considered as a priority in building design, but are nevertheless present in the design of new office towers.

Others aspects of sustainable development as social and economic matter are until now never really considered.

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SUSTAINABILITY@HOME: DRIVING CHANGE BEYOND COMPANY WALLS

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Keywords: sustainability, sustainable living, employee, customer, education, engagement, website

Summary

At a time when corporate sustainability programs have become almost ubiquitous, one often marvels at how quickly change can occur. In a matter of years, corporate sustainability has brought issues such as climate change, water scarcity, and resource consumption to the forefront of the public and corporate psyche, particularly in the building sector.

Considering the outstanding capacity to achieve sustainable outcomes within the corporate world, one must ask, what role can corporations play in driving sustainability beyond company walls? How can the lessons learnt in our board rooms be translated into connected, viable and liveable communities? This paper examines the Mirvac Sustainability@Home Program, as an example of an extended corporate sustainability program, which reaches beyond the normal scope of operations, and promotes meaningful changes in the broader community.

The Mirvac Sustainability@Home Program provides staff and their families with useful information, practical knowledge and meaningful support, to promote a culture of change and a lasting shift towards more sustainable living. The hub of the program is the Sustainability@Home website; providing tools, and information on sustainable living, while doubling as a sustainability forum, spreading ideas and knowledge among Mirvac communities.

By partnering with various eco-product and service providers, Mirvac staff and their families have access to energy efficient appliances, low volatile organic compound carpets and paints, recycled office supplies, biodegradable cleaning products and more at preferential rates. This way, previously unattainable tools for promoting sustainable living and creating viable communities have become a real possibility for many homes.

1. Mirvac's Sustainability Strategy

Since mid 2007 Mirvac has worked hard to develop and consolidate its sustainability strategy, the cornerstone of which includes clear performance objectives, targets and measures that provide the necessary structure for the Group's forward planning and expansion.

Important milestones in this journey to date include a detailed review of current business activities to clarify sustainability related impacts and opportunities; defining Mirvac's sustainability values – how will Mirvac judge its long-term sustainability performance; identifying sustainability priority areas considered 'most significant' to Mirvac and its stakeholders; structuring objectives for sustainability performance against each of these priority areas; and, establishing performance targets for all areas of activity.

Guiding principles have been established in-line with Group values which set the vision for sustainability performance.

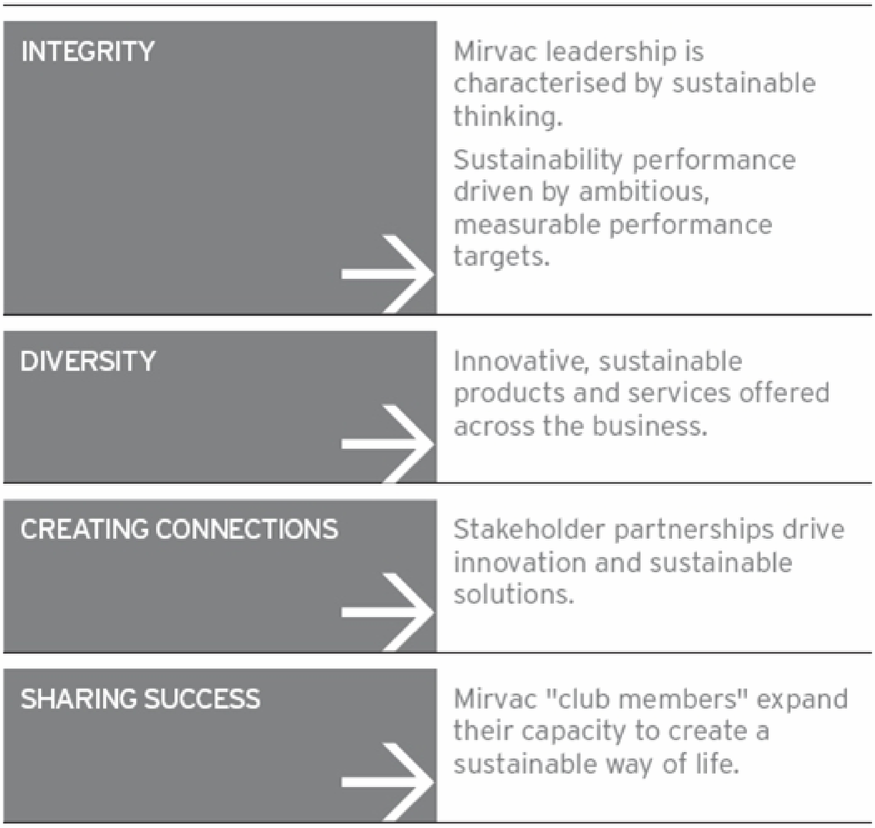


Figure 1 Mirvac's Sustainability Guiding Principles

Six sustainability priority areas are identified as 'most significant' to Mirvac and its stakeholders. Against each of these priority areas, objectives have been developed and performance targets established for all areas of activity. They are under constant review and may change as Mirvac, and the world in which it operates changes.

Priority Area	What does this include?	Objective
BUSINESS CONDUCT	Management of Sustainability	To effectively manage sustainability performance across the Group.
	Corporate Governance	To maintain a high standard of honest, ethical and legal business behaviour in accordance with Mirvac policies at all times.
	Industry Advancement	To contribute to advancing the sustainability of the Real Estate Investment Trust sector.
MIRVAC PEOPLE	Health and Safety	To minimise risk and prevent harm to people or the environment.
	Corporate Culture	To foster a high performance culture committed to sustainability
STAKEHOLDERS	Customers	To provide Mirvac customers with an experience that delivers excellence, meets or exceeds expectations of sustainable performance and engenders loyalty.
	Investors	To provide Mirvac investors with an experience that delivers excellence, meets or exceeds expectations of

Priority Area	What does this include?	Objective
		sustainable performance and engenders loyalty.
	Community	To enhance the communities in which Mirvac operate through active engagement, innovative design and giving programs.
SUPPLY CHAIN		To include companies in Mirvac's supply chain who have a commitment to sustainability in line with our own.
ENVIRONMENTAL IMPACT	Management	To ensure appropriate systems to minimise environmental impacts of all Mirvac activities.
	Energy	To optimise the productivity of all energy employed in Mirvac activities.
	Water	To reduce the consumption of water and impacts on water quality of all Mirvac activities.
	Waste	To reduce waste produced and maximise recycling and resource recovery from all Mirvac activities.
	Ecosystems	To minimise the impact of all Mirvac activities on local ecosystems.
	Transport	To minimise environmentally detrimental transport dependency of Mirvac operations and products.
	Materials	To minimise the environmental impact of materials used by Mirvac.
	Indoor Environmental Quality	To provide for healthy indoor environment quality.
CLIMATE CHANGE ACTION		To position Mirvac for optimum performance in a changing climate and carbon constrained economy.

Figure 2 Mirvac's Sustainability Priority Areas

Full details of Mirvac's commitments and targets can be found at www.mirvac.com.au.

1.1 Mirvac People – Part of the Commitment to Sustainability

Mirvac's commitment to fostering a high performance culture committed to sustainability extends beyond the company walls, and into the homes and communities of our employees. By promoting the message of sustainability not only at work, but also more broadly, we aim to make a meaningful impact in the lives of our employees.

Central to this aim, is the Mirvac Sustainability@Home Program, providing our staff with information and resources to drive change in their own lives.

2. Mirvac Sustainability@Home Program

The Mirvac Sustainability@Home Program aims to provide staff and their families with useful information, practical knowledge and meaningful support, to promote a culture of change and a lasting shift towards more sustainable living. The hub of the program is the Sustainability@Home website; providing tools, and information on sustainable living, while doubling as a sustainability forum, spreading ideas and knowledge among Mirvac communities.

The interactive website is based around a Mirvac designed home layout, allowing users to navigate to each room, and the outdoor areas. The information on the site is layered, to provide varying degrees of detail and complexity depending on user interest and need. Each room has a number of 'clickable' items, such as stoves, waste bins or taps, which when selected provide simple and straightforward tips and ideas including cooking efficiently, reducing waste and saving water.

Figure 3 The Mirvac Sustainability@Home website homepage

Figure 4 The Mirvac Sustainability@Home website – room view

To learn more, users can follow links at the bottom of each pop-up, or the top of the page, which directs them to detailed fact sheets on more complex topics, such as choosing efficient appliances, comparing electric, gas and solar hot water systems, improving home insulation, and reducing toxins in the home.

Figure 5 The Mirvac Sustainability@Home website – fact sheet listing screen shot

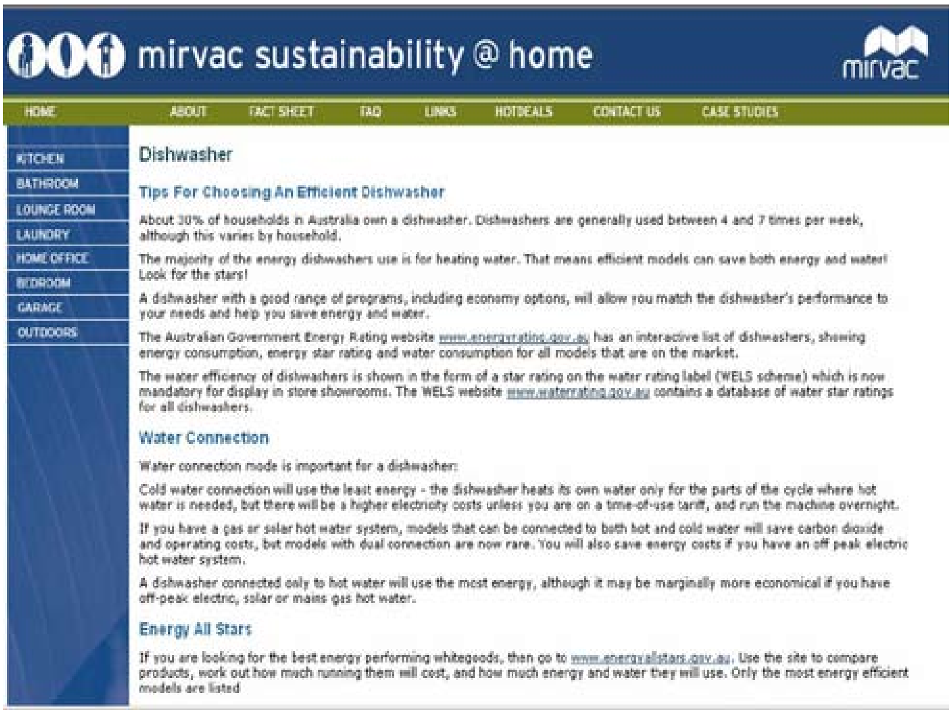


Figure 6 The Mirvac Sustainability@Home website – dishwasher fact sheet screen shot

2.1 Research – Sources and Challenges

In many cases, information on sustainable living already exists in the public domain. One of the key challenges in delivering this program is collating credible and accurate information, and providing it in a format accessible to beginners and technical specialists alike.

The information included on the website has been gathered through extensive and careful research, primarily from Government Departments or research institutions. Often, these sources provide highly technical information, which required extensive editing to be suitable for the lay reader.

In some cases, information was sourced from non-Government organisations, industry groups and businesses. Here the challenge was ensuring that information and claims were robust and transparent, with enough detail to suit the technically-minded reader. Links and references are provided throughout for users to learn more.

With much research yet to be done in the field of sustainability, this process is certainly imperfect. As interest in sustainability grows, and online and other resources abound, it is important that constant review is undertaken to maintain the accuracy of information listed on the site.

2.2 Sustainable Living Case Studies

In late 2007, Mirvac ran the first initiative of the Sustainability@Home program – a competition challenging staff to provide an interesting and compelling case study of how they have incorporated sustainability into their own life. The focus was not on the most expensive, nor the most extensive initiatives, but rather those that inspire and educate, and show that simple steps can make a meaningful difference.

The prize for 9 lucky winners, were tickets to see former US Vice President, and renowned environmentalist Al Gore speak on the future of energy, thinking green, and how climate change will affect corporate economic strategy for the 21st Century.

A high standard of entries were received, with staff presenting both simple and complex steps that they had taken to incorporate sustainability into their lives. The winning entries ran full spectrum, with initiatives including car pooling, shopping with green bags, buying local, water efficient gardening and home renovations.

These case studies are now hosted on the Sustainability@Home website, to showcase to Mirvac staff how simple steps can lead to big changes.

Mirvac received such a positive response to this contest that it intends to run similar events annually.

2.3 Supplier Agreements

Mirvac also uses the Sustainability@Home website as a means of promoting a number of key supply chain agreements, offering staff preferential rates on a range of products and services which assist in moving towards sustainable living.

Mirvac has a large number of preferred supplier agreements, covering a wide variety of products and services across our Group, including our development, hotels and corporate services activities. These agreements often extend to Mirvac staff, giving them access to products and services at discounted or wholesale rates. In many cases, these agreements cover categories with clear linkages to sustainable living, such as appliances, carpets, paints, rainwater tanks and more. This way, many tools for promoting sustainable living and creating viable communities have become a real possibility for many homes.

By educating our staff about the benefits of water and energy efficient appliances, low volatile organic compound (VOC) paints and carpets, saving water and so on, and providing access to discounts on these specific products, Mirvac hopes to positively influence the purchasing decisions of our people, to turn ideas into positive action promoting sustainable living.

3. The Next Steps

Mirvac plans to continue developing and expanding the Sustainability@Home website over time, including new ideas, technologies and knowledge as the property industry, and the broader community continue to learn about sustainable living.

Logically, Mirvac will move to include the knowledge and lessons learned from our projects and developments in this website, linking specialist sustainability practitioners within the organisation, to the broader Mirvac community.

Similarly, as additional supplier agreements are negotiated, they too will be added, broadening the scope of products available to Mirvac communities.

The most significant next step for the Sustainability@Home program is rolling it out to Mirvac customers, as a home operators guide.

3.1 Home Operators Guide

In the residential development field, marketing materials tend to focus on traditional areas, such as location, lifestyle, and design. Certainly these are key inclusions; who would buy a home without these prerequisites?

However, as we design and deliver increasingly complex 'green' homes, complete with water and energy savings features, passive cooling, on-site energy generation, water-efficient landscaping and so on, we transfer greater responsibility to the home buyer and occupier to make sure these design features are utilised to their full potential. Without adequate explanation and training, these outstanding design features are at risk of being misused or under-utilised.

To counter this, Mirvac is working to include the Sustainability@Home website as a companion to the existing information in the Mirvac Home Buyers packs. By educating our customers on the design, and operation of their homes, and providing them with sensible and readily understandable tips on reducing their ongoing impact, we aim to ensure that our designs function appropriately, and that our positive influence does not end when we hand over the keys to the door.

Conclusion

A key consideration in any corporate social responsibility initiative is to understand and take full advantage of your strengths. Mirvac has aimed to do just that, by leveraging the existing knowledge and experience from within our company, and combining it with external research, to deliver a simple, yet comprehensive program to educate our people and promote sustainable living. By creating linkages between the Sustainability@Home Program and standard corporate operations, sustainability moves farther away from the periphery, and towards the core of Mirvac business activities.

While still in its early days, Mirvac hopes to grow the Sustainability@Home Program to broaden our role as educators, and add value to our people, our customers and the community.

ENERGY MANAGEMENT IN EXISTING BUILDINGS-ONE SIZE DOES NOT FIT ALL!

Lidia Rozman, Associate
Connell Wagner

INTRODUCTION

Ecologically Sustainable Design (ESD) does not only apply to new buildings. Existing buildings can be improved to have a more sustainable ecological footprint. The status quo has been challenged for occupational health and safety reasons. **Now** is the time to challenge the way things have been done for sustainability reasons.

Water reduction, energy efficiency, indoor environment quality, maintenance, materials, waste management, and the outdoor environment are just some of the issues to be addressed.

One size Does NOT fit all!

Each building is unique and requires a solution that is tailored to the needs of the building and its occupants. This applies equally to new and existing buildings.

Effective sustainable design concept development must be based on a sound understanding of engineering detail **and** operational building imperatives. Pragmatic solutions that respect future operations and facilities management objectives are required.

Environmentally sustainable principles need to be adopted, in line with the objectives of the building owner/ occupants, in a cost effective manner and which **enhance** both staff use of the facility and improves the health of the building.

NEW BUILDINGS

There is a strong emphasis on good passive design right from the start of the design process. We all understand that to get best value from every dollar spent, ESD needs to be embedded in the construction in an integrated manner. This can only be achieved by all of the team members working closely together to achieve multiple benefits from single pieces of construction. By optimising orientation and the use of thermal mass; savings in mechanical and electrical capital and operating costs can be achieved.

It is important that appropriate energy benchmarks are set at the start of any project and are monitored using energy models at each project stage.

Indoor air quality and the indoor environment is becoming even more important to owners because we spend so much of our time indoors, that issues such as, the amount of outside air, avoidance of off gasing materials, good air filtration etc. are carefully considered as well as maximising opportunities for views to outside. These all impact on client well being.

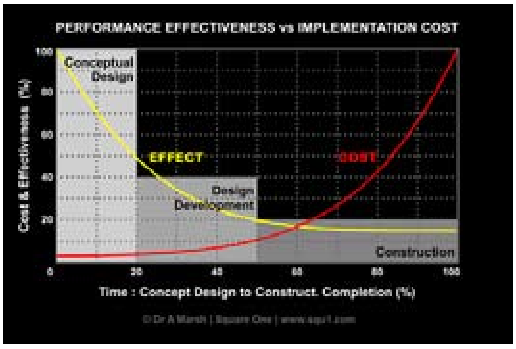


Fig 1 Performance effectiveness vs Implementation cost at various project stages

From the Proceedings of the World Conference SB08 - ISBN 978-0-646-50372-1
www.sb08.org

PRACTICAL APPLICATIONS OF ESD INCLUDE:

The following elements are essential components of a sustainable project:

- Energy Conservation
- Minimising Greenhouse Gas Emissions
- Water Conservation and Reuse
- Material selection
- Design for disassembly and reuse
- Recycling materials
- Minimising waste, reduction in emissions
- Whole of life cycle assessment

Fig 2 Margaret Tobin Mental Health facility at FMC

CASE STUDY 1- MARGARET TOBIN MENTAL HEALTH WARD AT FMC

This example is of a site where it was not possible to reorientate the building as the site was a long narrow site that faced south west. It has fantastic views from the site to the beach. The lower floor is a laboratory floor, while the upper floor is mental health inpatient accommodation.

By working together with the Architect at the very early stage of the project, we came up with the concept of the angled walls, which effectively have north facing glass, which was easy to shade. Due to the geometry it actually became fully shaded glass, yet the views to the sea were retained.

But best of all, the cost savings in the mechanical plant were almost enough to pay for the angled walls, and they will of course enjoy significantly less running costs for the life of the plant.

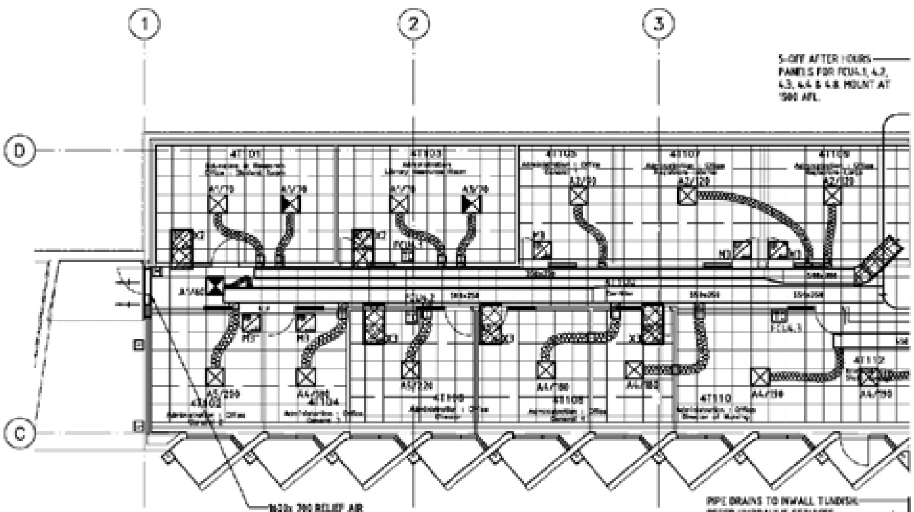


Fig 3 Plan view of Margaret Tobin Mental Health facility at FMC showing the angled window shading

EXISTING BUILDINGS

Many people are concentrating on new buildings, but what about the existing building stock? Have they kept up with the energy revolution or are they still in the last century chewing up energy as if it was cheap?

Energy efficiency is not only about new designs, it is equally important to be looking at existing installations and evaluating opportunities to save energy, running costs and the environment, as well as improving the amenity for the building occupants.

There are great opportunities to save energy in existing buildings. Many companies are able to save up to 20% on their energy bills by putting an energy management program into practice.

Energy management starts with an understanding of where your building is currently benchmarked by calculating an energy use base line and understanding which tenants or systems are the high energy density users.

Systems can then be evaluated to determine where changes can be implemented most effectively to reduce energy consumption without affecting the operation of the building's functional requirements.

Substantially improved performance and energy savings have been demonstrated by some buildings for a comparatively small investment by fine tuning the building systems and getting the systems working as designed.

SO HOW DO I GREEN MY EXISTING BUILDING?

Buildings should be evaluated based on their projected energy requirements and emission of refrigerants. Heating, Ventilation, Air Conditioning and Refrigeration (HVAC&R) systems contribute to greenhouse gas releases indirectly through energy-related effects and directly through the effect of refrigerant losses.

Energy-related impacts (contribution to CO_2 releases) are addressed by reducing the energy consumption of equipment, systems, and buildings and by modifying user behaviour. HVAC&R technologies provide the tools for the design and application of comprehensive energy-savings techniques in buildings and for the selection and proper use of energy efficient equipment and system integration.

ENERGY AUDITS

The first step is to take stock of where the building is performing. This can best be achieved through an energy audit. This draws the line in the sand so to speak.

An energy audit generally includes:

- Audit of historical data
- Walk-through audit
- Detailed investigation and analysis.

Audit of historical data requires the auditor to identify and quantify each of the energy forms as well as establish a general trend or pattern in energy use over a number of years.

The walk through audit is used to identify any immediate opportunities to reduce energy costs. This step will also establish the feasibility for potential cost savings in each area of energy consumption and the priority for allocating resources.

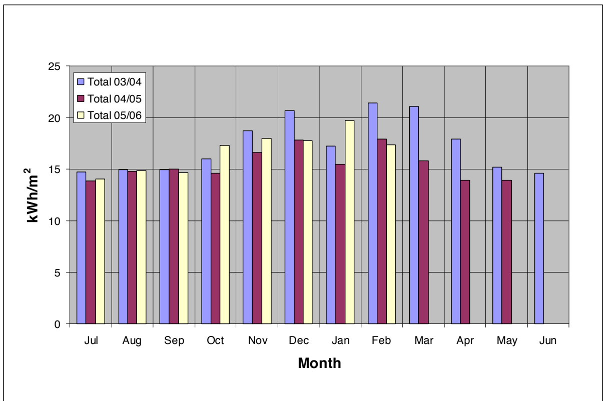


Fig 4 Typical energy audit data output

A simple survey including a walk around the work place will identify areas where there seems to be excessive energy usage. Spot checking soon find areas where equipment or lights are left on when not required. There is generally an opportunity to save energy, particularly in older installations.

The major step in an energy audit is the detailed investigation and analysis, based on the areas that were identified in the walk through audit as requiring further investigation.

Australian Standard AS 3596 Energy management programs - Guidelines for definition and analysis of energy and cost savings would be the basis of the investigations. With results from this step and those obtained in the walk through survey a detailed energy management program for the business can be developed, or an existing program reviewed.

Once a program or policy has been put in place it needs to be reviewed on a regular basis to make sure that it is achieving the objectives that were set in the energy management plan.

A level 2 energy audit is a good start, this will then identify which areas should be further investigated with a level 3 energy audit. There is no point in wasting resources in conducting intensive level 3 energy audits of everything, this will just frustrate everyone.

It is important to have a good consultant that can identify the energy wasting practices that occur in the buildings. From this you will be able to identify the areas that can be improved through opportunities for energy reduction. Some of these will be easy to implement, others will be more expensive or more difficult.

It is good practice to outsource this investigation because you get a fresh set of eyes looking at the systems and the problems. This can often challenge the “way we've always done things”.

Once the audit is complete then you can then set the targets for energy reduction.

The building owner will also understand whether the building has potential to be upgraded.

EXISTING PROBLEMS

So what are the likely problems that your buildings could experience?

MECHANICAL SYSTEMS

- **Noisy plant**, vibration is often passed through the building structure and causes disruption to tenants. It is often an indicator that there are significant losses and inefficiencies occurring within the plant or equipment.
- **Infiltration** through old window seals or poorly sealed facades. This is a problem as infiltration allows unconditioned unfiltered air to enter the air-conditioned space; adding significant load to the plant and discomfort for occupants.
- Old plant is generally **inefficient.** Technology has improved efficiencies of modern plant to the point that significant energy and cost savings can be made if the old plant is replaced.

Fig 5 Typical old chillers are inefficient and often contain ozone depleting substances

- Old plant is generally more **costly to maintain.** As plant ages spare parts are more difficult to source and the breakdown costs become more frequent.
- Old plant, such as chillers and refrigeration units often contain **Ozone depleting substances.**
- **Pneumatic controls = poor controls**. The range of control strategies available with pneumatic controls is very limited. Unless well calibrated and maintained, the controls may not actually be doing what they were designed to.
- **Old BMS systems = glorified time clocks**. Many older style BMS systems only report status points and turn plant on/off at pre-determined times. There are no "smarts" in the controls.
- **Calibration of sensors** and controls? If these are out of calibration- well what are you controlling?
- **Averaging temperature sensors**- that is a sure way of ensuring that everyone is unhappy!
- **Insufficient air movement**- stuffy stale environment are often complaints in older buildings where air quantities were often too low to provide comfort.
- Old cooling towers- do they comply with AS 3666? Are they a **Legionella Risk!** How much water do they waste?
- Outside air quantity may not comply with AS 1668 and can lead to **sick building syndrome**

Fig 7 old cooling towers pose potential health problems and are high in maintenance costs

Fig 6 Dust and mould growth accumulate inside ducts

- **Dirty ducts and mould?** These are a particular problem in tropical environments where moisture encourages mould growth. Moulds are often toxic and can cause significant irritation to the building occupants.
- Is there **economy cycle?** Many older buildings did not have economy cycles (free cooling) or if they did, then often include seized dampers and can not operate.
- **After hours use** of plant- does the entire building need to run to keep one tenant cool after hours?
- **Rogue zones** eat energy- these are spaces that are not compatible with the rest of the building load, and always require cooling when no other areas do, therefore driving systems needlessly into cooling modes.
- **Reheat strategy?** Many old buildings had one perimeter cooling coil and then reheated each zone to meet the load requirements for that zone. In one such building where the cooling valve was 60% open, and the four reheat coils heating valves ranged from 40% to 80% on a mild 18C ambient day.
- **Hot and cold decks**- these are so inefficient the BCA has now outlawed them.

ELECTRICAL SYSTEMS

- **Over lighting-** many old buildings have light levels much greater than necessary. This is to cover the poor efficiencies of the older style lamps.
- **Inefficient lighting-** magnetic ballasts and losses through these are significant.
- **Poor lighting control-** does anyone know where the light switches are? Do they turn on/off the entire floor on one switch? Why are the lights on when no one is in the room or the sun is coming in through the windows.?
- **Lack of energy monitoring-** No one has any idea how much energy is being used and where.
- **Spaghetti in the ceiling space?** Changes over time can result in a mess such as this one where live wires were found even after the switchboard was isolated.

HYDRAULICS

- **Inefficient fixtures and fittings**- these can waste lots of water- particularly through flushometers or full size WC cisterns.
- **Inefficient irrigation**- what are you really watering?
- **Water heating systems** are there more losses in your hot water system than the energy used to heat the water actually used?

- **Water leaking from existing pipes and fixtures**- how do you know there are no leaks?
- **Old storage tanks at top of buildings?** When did you have these checked out- are they at risk of failure?

OTHER

- **Asbestos?** This should be removed wherever possible if there is any way that it can be dislodged into the airstream.
- **Inefficient façade treatment-** many old facades are very inefficient. The aluminium frames often had no thermal breaks. Have you tried putting your hand on the window frame when the sun is shining on them? You can burn yourself! That is all heat that the air conditioning system has to remove.
- **Imperial ceiling tile grid-** it is difficult to source new light fittings and fixtures that suit the old grids?
- **Outdated fitout, base building toilets, foyers-** there may be nothing wrong with them, but they are not going to attract the high level tenants.
- **Leaking facades-** allow both moisture and air to enter the conditioned space. This is particularly serious in tropical areas where mould growth and condensation are a problem.
- **Inefficient lifts-** some lifts are very inefficient, use significant amounts of energy, yet are also inefficient at serving the building occupants with long waiting times, bumpy rides and jerks.
- **Non compliance with disability act requirements-** any building upgrade required the installation of access toilets, accessible lift buttons and equitable access to the buildings entry.
- **BCA compliance issues-** Do the fire and life safety elements of your building still comply with the BCA? Often not and a major upgrade will require a BCA compliance check.
- **Have you been on those vacant floors lately?** Just look at the picture- could this be your building?

Fig8 A pile of bird excrement- it obviously liked to roost on the door

POSSIBLE SOLUTIONS

MECHANICAL

- Replace major plant with energy efficient state of the art equipment
- Non ozone depleting refrigerants

- Service and overhaul all remaining plant
- Clean all ductwork
- Install Outside Air Economy Cycle
- Recommission and recalibrate all systems
- Maintain Control Systems
- Install heat recovery systems
- Install variable speed drives and floor isolation dampers
- Install monitoring equipment to monitor energy and water consumption
- Remove rogue zones such as meeting rooms onto a separate system and control with occupancy sensors
- Review flaws of existing air conditioning systems and resolve
- Install state of the art BMS system and replace all pneumatic controls
- Check integrity of insulation on systems

Does your building contain a diesel generator that never gets used apart from testing time?

Evaluate the savings that can be made through peak electrical demand lopping by running it on peak days

Convert it to a green fuel; bio-diesel or gas on diesel. This will save the environment and your energy bills.

Fig 9 Cogeneration can save on greenhouse gas emissions

Cogeneration- provides standby power capacity independent of the grid. Natural gas has much lower rate of greenhouse gas emissions than electricity, so CO_2 savings can be made. Also utilise waste heat recovery through

- absorption chillers
- Heating system
- Saves energy and greenhouse gas emissions

CONTROL SYSTEM MAINTENANCE

- Control systems need to be maintained over time
- Re-calibration of sensors
- Complete commissioning of plant and controls
- Optimisation of systems
- Valves that do not shut off tightly by-pass fluid
- Leaking dampers can introduce excess outside air
- Check for temperature sensor locations that do not represent conditions etc
- Significant energy savings achieved by properly setting up and maintaining control systems.
- Consider some PV

FULL OUTSIDE AIR ECONOMY CYCLE

Provides a building's cooling requirements via full outside air when ambient conditions permit. (30% or more of plant operating hours). This works better in dry places like Adelaide, Melbourne etc.

If your building does not include outside air cycle, consider how this can be installed. It also enables other energy saving strategies such as night purge, where the building is flushed out at night (summer time) with cooler night time air, leaving the building fresh and removing the heat from the thermal mass of the building.

VARIABLE SPEED DRIVES ON FANS

Air flow can be optimised to match the required duty or reduced during periods of low load eg at night, significant energy savings can be achieved. Install dampers on floor by floor basis to enable floors to be isolated if unoccupied.

HEAT RECOVERY

- Used where air recirculation is not possible to recover heat and 'coolth'

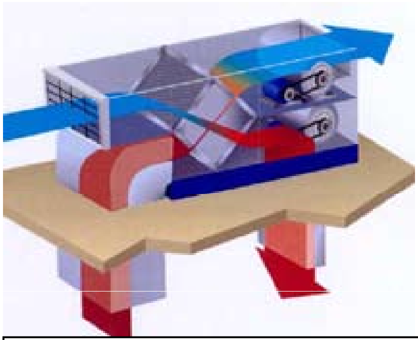


Fig10 A typical air to air heat recovery system

- Run around coils used where enthalpy wheels and Plate heat exchangers do not fit
- Good energy savings but cost and space can be barriers

VARIABLE SPEED DRIVES ON PUMPS

Oversized pumps are usually installed in practice, these can be up to 10% excess water flow, resulting in a higher than necessary energy requirement all the time!

Excess water flow is removed by closing balancing valves, leading to unnecessary pressure drops and high pump power requirements.

Variable Speed drives on Pumps should be incorporated in new and refurbished systems.

Rebalancing and amended controls strategies are necessary for efficient pump operation.

WATER SAVING FEATURES

WATER IS OUR MOST PRECIOUS RESOURCE

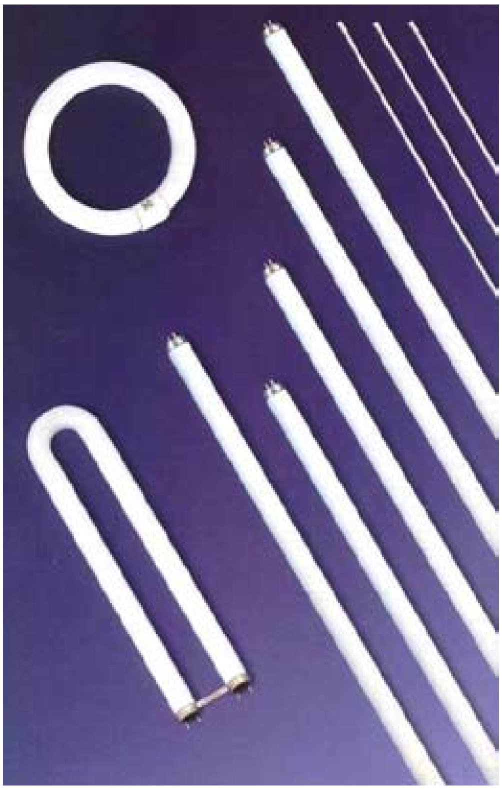
- Install Low Flow tap ware. Low flow tap ware using aerators can provide the required flow with equivalent comfort and/ or performance.
- Replace existing tap ware and fixtures with 4 star WELS. Current water efficient tapware (labelled as AAA-rated) uses up to 50% less water than older products.
- Do not use flick mixer taps, these use hot water when you do not want to (lever set in middle)
- Capture rainwater for reuse in toilet flushing and irrigation
- External gardens and water features create cooler micro climates.

Domestic hot water (DHW) is used in many areas of buildings, including showers, wash basins, kitchens and laundries.
Reductions in total water usage has benefits including reductions in:

- Water Usage
- Hot water (and other) energy consumption
- water supply
- Sewer disposal costs
- Investigate long DHW piping runs these also create losses
- DHW Storage and generation
- Install Solar Hot Water generation
- Check insulation on pipe work and tanks to minimise losses.

LIGHTING

- Lighting uses approx 30% of total electricity in a building.
- Install occupancy sensors particularly for intermittently used rooms like meeting rooms.
- Modify switching to have smaller switching groups to enable lights to be switched off when not required.
- Provide electronic control gear.
- Replace lighting with low glare T5 fittings.
- Add an indirect lighting component
- Provide automatic lighting controls
- Sensors within the various areas measure the amount of natural light and dim the high efficiency internal lights to save energy.



POWER FACTOR CORRECTION

- Power factor is a measure of effective use of energy supplied by utility.
- There are a number of options for improving power factor including:
    - Selection of equipment on demand side
    - Installation of power factor correction
- Although the energy utility sees the majority of financial benefits, the environmental benefits are universal and paybacks for 3 to 7 years are achievable.
- The supply arrangement will affect the ease of implementation, but retrofits can be successful.
- Day to day operations won't be affected, however the life of plant is increased, and the capacity of the electrical infrastructure is increased.

HIGH EFFICIENCY MOTORS

- Many electric motors are used throughout a building for pumps, fans, lifts and escalators.
- High efficiency motors attract a small cost premium, but savings will be rapidly achieved. Particularly where systems operate many hours per day.
- Government MEPS now require the use of high efficiency motors.
- Typical paybacks of 1-3 Years are achievable, where failed motors are replaced with HEMS.
- Longer paybacks (14 Years) for replacement of existing operating motors within High efficiency motors.
- Don't take the small capital cost saving by not putting them in!

STAFF AWARENESS

- Instigate an education program which make staff aware of energy saving opportunities and encourages and empowers them to participate in Energy saving.
- The paybacks are immediate.
- Options range from simple 'posters and e-mail campaigns' to formal staff training.
- Added benefits include increased staff morale, and support for the engineering team.
- Updates are essential for longevity.
- Older buildings have more 'manual' controls and would benefit greatly from staff awareness. New buildings would also benefit, as they would 'run properly from the beginning'

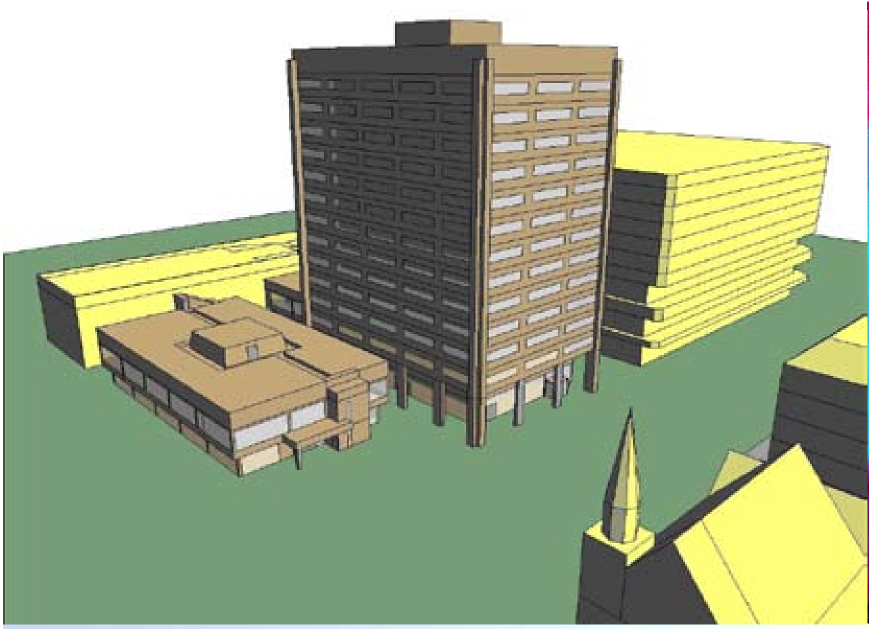
CASE STUDY 2 -40 ALBERT RD, MELBOURNE

6 star GreenStar- office design world leadership. Building refurbished to include

- 1200 m^2 over 4 levels faces E-W
- New glazing, atrium natural ventilation, daylighting
- Greenhouse gas neutral
- Gas engine driven air conditioning
- 1kW fuel cell
- Solar power and water heating
- Central vacuum system
- Low VOC materials throughout
- Lighting control system

CASE STUDY 3- EXISTING CBD BUILDING

- Existing Adelaide CBD 14 storey building, built in the 1970s
- Investigate different options for glass types
- Include veil ventilated façade



Above left: IES model of the existing building

Above: Photograph of the existing building

Left: IES model of the building with full height windows and veil

The existing building incorporates double glazed punch windows with reflective bronze glass and integral internal blinds sandwiched between the panes. The window frames are dark aluminium with no thermal breaks. When the sun shines on them, you can almost burn your hand on the internal faces of the frame. This significantly increases the cooling load required for the building. Additionally there is a 100mm thick uninsulated concrete spandrel below the windows which has a very poor U value and does not comply with the current BCA requirements.

The architect was keen to explore "opening up" the building to create a visual connection between the internal and external environments. We were asked to evaluate a number of scenarios including the addition of a glass veil incorporating additional shading structure at each level that would enable the cleaning of the glass as well as providing additional shade to the façade.

We evaluated the following glass types using IES computer modelling software.

Table 1 – Glazing Properties Comparisons

Glass Type	U Value (W/m^2K)	SHGC	SC	VT (%)
Single Glazing	5.8	0.81	0.94	87
Clear Low E Single Glazing	3.7	0.7	0.76	82
Existing Glazing (without Venetians)*	3.42	0.46	0.53	-
Existing Glazing (with Venetians)*	3.42	0.36	0.41	-
Low E Double Glazing (inner clear)	1.9	0.66	0.76	73
Clear Low E Single Glaze + Low E Veil	1.9	-	0.58	-

Properties estimated

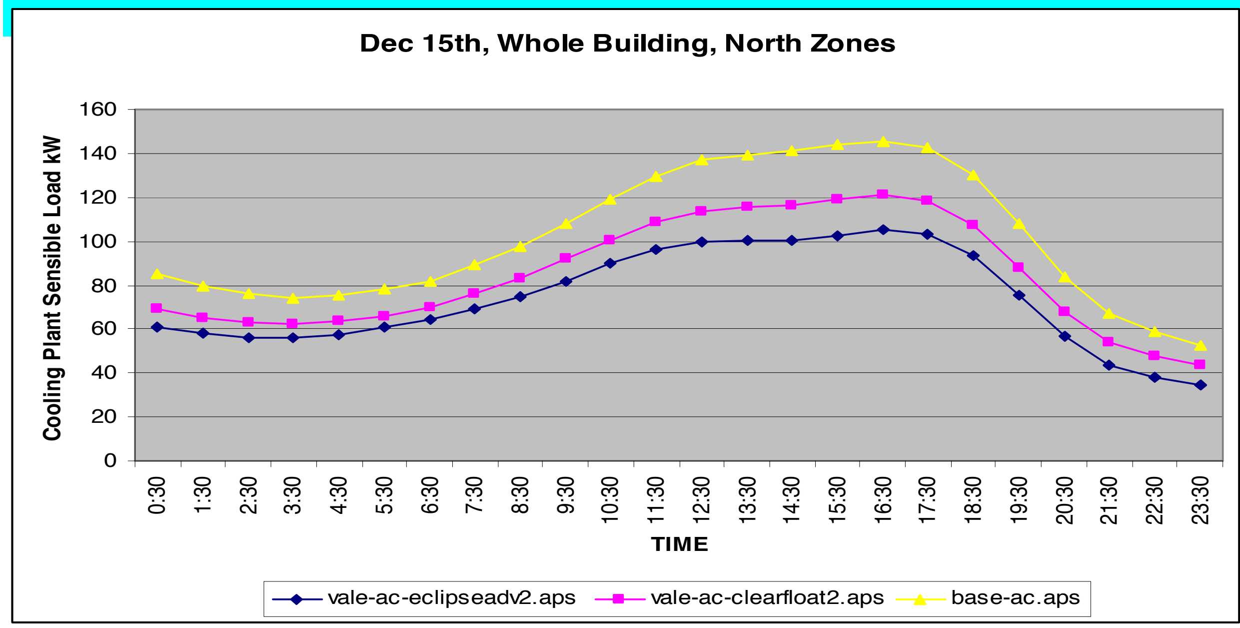
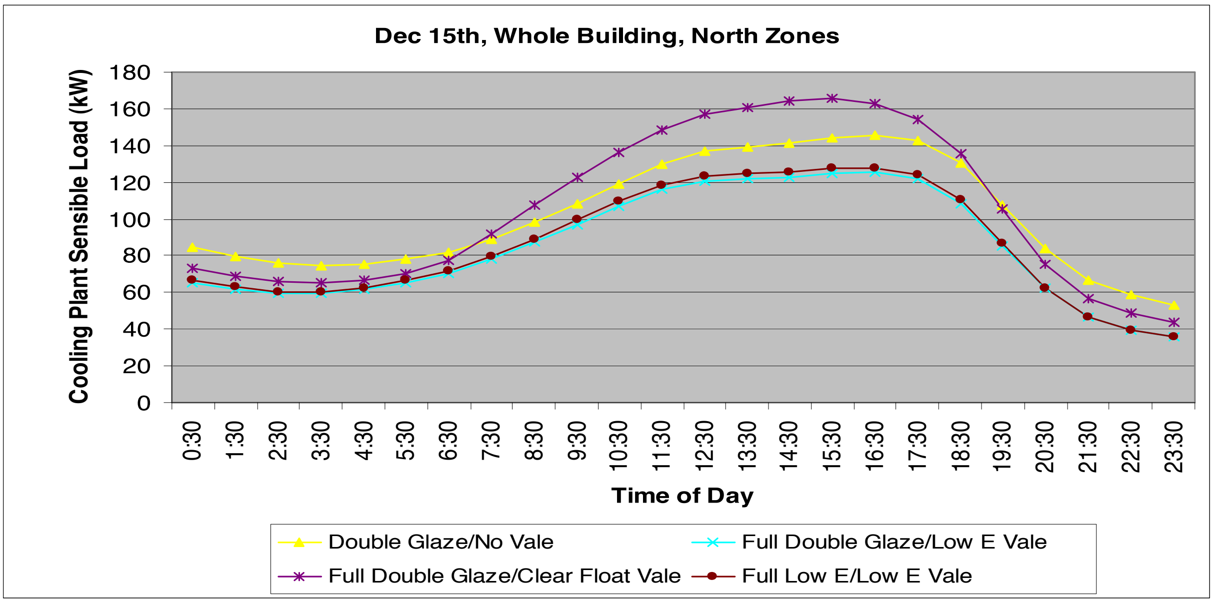


Fig 11 Results for the peak day on the entire North Zone of the building –punch windows

Fig 12 Results for the peak day on the entire North Zone of the building –full height windows



As expected, the addition of a clear float veil reduces the peak cooling load, changing this to a low-E glass veil reduces the cooling load even further. A total of 40kW energy reduction can be achieved in the size of the plant at the peak day.

Increasing the windows to full height double glazing with a clear veil increases the cooling load required during the day time, when compared with the existing façade. Utilising a low-E glass in the veil makes a significant difference to the cooling load, much more than the addition of a double glazed vs single glazed low-E glass.

The graphs indicate that the worst performing facade is a full height infill double glazed window with a clear float veil. The best performing facade is the existing double glazed windows with a low-E Veil. All other options have a lower maximum cooling load than the base case (yellow line).

It is obvious however that the veil needs to be low –E glass, particularly if the infill glass option is considered.

Unfortunately the budget did not stretch to replacing the façade, however it is interesting to note that much larger clear looking (i.e. Low E) windows could be installed in the building and actually reduce the energy demand of the plant.

CONCLUSION

ONE SIZE DOES NOT FIT ALL!

FOR NEW BUILDINGS

ESD considerations must be included early in design development.
The right solution will depend on the building and its occupants

FOR EXISTING BUILDINGS

The first step is understanding what you've got by conducting a base line audit.

What you do and how far you go will again depend on the building, the existing systems and your budget.

BRINGING THE INDUSTRY UP TO SPEED – MASTER BUILDER GREEN LIVING, AN EDUCATION PROGRAM FOR DOMESTIC BUILDERS.

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Keywords: building, sustainable, accreditation, training, industry, engagement, education

Summary

When contemplating the construction of new houses or renovations, many consumers only contact with the building industry is through a builder. The Master Builder Green Living program is designed to provide builders involved in the residential sector with a suite of improved management and business skills to enable builders to pursue energy innovations in their constructions. They will be issued with the necessary tools and information to identify the design features of energy efficient structures that not only meet minimum standards but set a new benchmark in the housing sector for energy innovation. This will result in a positive for the builder by improving their customer service ability by providing informative advice to clients about sustainable solutions in the design and construction of their dwelling.

By identifying builders that view sustainability issues as an important part of their business, consumers interested in addressing sustainability issues during the construction or renovation of their homes have the ability to seek out these builders. By bringing together like minded individuals the chances of improved sustainability outcomes for everyone are increased.

1. Introduction

Often the first point of contact for people contemplating the construction of new houses or renovations is through a builder. Domestic builders have experienced an increase in questions from their clients about sustainability issues, helping to raise the awareness amongst builders of the importance of incorporating sustainability into their operations. This has subsequently driven the demand for increased information from Master Builders which led to the development of the program.

The question then becomes one of presenting the required information in a format that is accepted by participants that usually do not have a strong academic background. While there is a large amount of information available on improved sustainability outcomes in the construction sector the challenge is to be able to translate this information from the academic to a series of goals, strategies and techniques understandable to and accepted by builders.

The Master Builder Green Living program is designed to provide builders involved in the residential sector with improved management and business skills to enable them to pursue energy innovations in their constructions. These include the necessary tools and information to identify design features of energy efficient structures that not only meet minimum standards but set a new benchmark in the housing sector for energy innovation. The builder is also able to improve their customer service by providing informative advice to clients about sustainable solutions in the design and construction of their dwelling.

This innovative program focuses on sustainability issues relevant at all stages of the construction process from important design considerations through materials selection and site management to interior fit out and health considerations. The information is easy to digest and focuses on common sense, practical solutions that are not necessarily expensive.

The other benefit for the builder is the linking of the program and work practices with a unit of attainment from the national training system which encourages further training for a nationally recognised qualification.

The program was developed by the Institute of Sustainable Futures for Master Builders through an Australian Greenhouse Office grant in 2005. Since then the program has been further developed by Master Builders Victoria. Over the last 2 years, Master Builders Victoria has seen over 150 builders complete the 2 day training program and sign a written commitment to incorporate sustainability objectives into their day to day operations. The program has also been presented by other Master Builders in Western Australia, Tasmania, New South Wales and the Australian Capital Territory.

By identifying builders that view sustainability issues as an important part of their business, consumers interested in addressing sustainability issues during the construction or renovation of their homes have the ability to seek out these builders. By bringing together like minded individuals the chances of improved sustainability outcomes for everyone are increased.

2. The Program

The Master Builder Green Living Program consists of a 2 day course, an accreditation system and the provision of a number of resources. It focuses on the often used, reduce, reuse and recycle message and considers the need to reduce impacts, energy and water use in the first place. It then explores a group of ideas that have a big impact on minimising the environmental impact of the house, without necessarily imposing an increased cost by using what we call deadest winners.

2.1 The training course

The training course is structured in a manner that follows the building cycle. It commences with a look a number of environmental issues such as greenhouse gas production and biodiversity loss and the impact of construction on these issues.

It then looks at the importance of project planning by emphasising the importance of thinking about sustainability features right from the beginning of the project. This is where features can be easily incorporated into the building project at minimal additional cost as they are integrated at the design phase.

The importance of design is then introduced, in particular passive solar design ideas. Once again the focus is on providing ideas that will reduce operational energy use and environmental impact without necessarily introducing additional costs.

The next few topics cover the environmental issues to be considered during the construction phase such as on site management, waste management and erosion and sediment control. Materials selection used in the framing and structure and the building envelope becomes important when we consider, where these materials come from, their recycled content and embodied energy. Concepts such as sustainably sourced and grown timber resources are also introduced.

Methods to reduce water and energy use are then explored by focusing on the big users and easy methods to reduce consumption. The importance of design considerations are not forgotten as a series of activities allow the participants to apply the ideas to real plans. These practical activities deliver a number of other outcomes such as group work and the sharing of ideas

Once the construction of the building is completed the issues to be considered during interior fitout are explored. As well as again looking at the importance of materials selection and embodied energy, indoor air quality is introduced as a topic that an increasing number of people are concerned about when they think about the emissions given off by solvents, glues, carpets and paints used in their homes.

The final topic covers business strategy and discusses methods to incorporate what they have just learnt into their day to day operations to make the whole process as easy as possible. In order to sell their increased knowledge of sustainable construction the accreditation process is discussed and a number of ideas of how to best to use the brand to differentiate their business from others in the market are introduced.

2.2 Resources

The goal of the program is to increase the chances of builders incorporating sustainability considerations into their developments. A number of resources are issued to participants during the course in order to make this process as easy as possible.

As well as a set of training notes a checklist is distributed as part of the Green Living domestic builder course. It is designed for the builder to use with their client to determine the range of environmentally friendly options to be incorporated into their development. This not only helps to remind the builder of the options available but also helps to clarify the client's requirements. The checklist follows the construction process and considers outcomes concerned with passive solar design, materials selection (environmental impact and embodied energy), water and energy conservation, recycling and indoor air quality.

All participants are also issued with a list of useful resources which is continually updated on the Master Builder Victoria Green Living webpage (www.mbav.com.au/training/greenliving.html). This list of useful suppliers and resources is once again designed to make the process of finding environmentally preferable materials as simple as possible. If the sourcing of a product or service becomes too difficult it is likely to be dismissed by the builder.

They are also given a copy of the "Your Home" manual (Australian Greenhouse Office 2005) a technical guide to environmentally sustainable homes. The guide provides them with additional information that they can read at their leisure or use as a future reference.

Once builders complete the program they continue to be supported through e-newsletters and an annual workshop. The newsletter, which is sent out tri-monthly, is able to keep Master Builder Green Living builders updated on regulatory changes, events that may be of interest and useful new products and resources. A one day workshop is also held annually which includes guest speakers from government who are able to provide insight into proposed regulatory changes, industry speakers and useful product suppliers. There is an opportunity for the builders seek clarity by having their questions answered. Each year a number of builders are also asked to speak about their own developments. This is often well received by the attendees as they are able to hear from a real builder about some exciting projects, how they overcame various problems and what they found useful along the way.

Accreditation

Only Master Builders members who complete the 2 day training program and sign a written commitment are able to refer to themselves as Master Builders Green Living Builders and to use the associated branding. The signing of a written commitment significantly increases the chances of the person putting a verbal commitment into action (McKenzie-Mohr and Smith 1999). The commitment includes:

- submission of an annual report to Master Builders that includes information and details on the total number of residential projects and Master Builder Green Living projects (including checklists) completed,
- an estimate of the amount of material recycled or diverted from landfill
- an assurance that sand, soil, screenings, concrete and chemicals were confined to the building site (completion of annual report declaration).

The annual report is required from the builder in order to continue to maintain their accreditation and is considered to be evidence of sustainable strategies being put in place. On provision of this evidence participating builders can continue their accreditation and also be eligible to receive a nationally recognized statement of attainment for the unit of competency demonstrated - BCGBC4020A Build thermally efficient and sustainable structures (domestic).

3. Achievements and Results

As of March 2008 152 builders have completed the Master Builders Green Living program in Victoria. Importantly 88% of those who complete the course have signed a written commitment to incorporate sustainability objectives into their day to day operations. Results compiled from reports submitted by the builders as part of the accreditation process indicate that;

- on average each of these builders are working on 8 projects per year covering 1072 building sites.
- 73% of these sites are recycling 47% of their waste.
- all these sites are controlling discharges to the storm water system.

4. Conclusion

Feedback from course participants has been excellent indicating that the information is presented in a format that they respond positively to. In evaluations completed at the end of each course 99% of participants rate the course as very good or excellent. There are also numerous comments on how useful they found the discussions and ideas shared with other like minded builders.

Providing training in a practical easy to follow format that is complemented by a variety of tools, ensures that builders feel more confident when discussing environmentally friendly practices with their clients. Providing improved training for builders in a format they are comfortable with and identifying builders, who have an interest in providing more sustainable housing, increases the chances that consumers who want these outcomes make contact with the appropriate person.

This approach results in an improved level of cooperation between client and builder which in turn increases the range and likelihood of these practices being incorporated into new developments. A builder who is not confident in dealing with sustainability issues is likely to be dismissive of questions asked by their clients.

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SUSTAINABLE CONSTRUCTION - COMMERCIAL. A PROGRAM DESIGNED TO IMPROVE THE KNOWLEDGE OF SMALLER COMPANIES AND WORKERS INVOLVED IN COMMERCIAL CONSTRUCTION.

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Summary

There has been an increased importance in the incorporation of sustainability practices into commercial building construction due to the increased inclusion of sustainability requirements in tender documents. This has resulted in the need for companies tendering for projects and their subcontractors to be more aware of sustainability issues and the methods of addressing them during the construction process.

Master Builders Victoria through its membership has identified a need for improving the knowledge base of commercial builders, site managers and other employees. It has addressed this by developing a practical program and an associated DVD which clarifies sustainability issues and methods to address them as simply as possible. An improved understanding of developer and tender requirements will enable site managers and contractors to improve compliance with environmental requirements on site.

1. Introduction

Master Builders' members are increasingly recognising the importance of sustainability in construction due to the popularity of "Green Buildings" and the Greenstar rating system, and the inclusion of sustainability criteria in government tender documents in the commercial property market. This demand is being driven by major companies wanting to be seen as good corporate citizens by housing themselves in "Green" buildings; because of the realisation that there are staff retention and productivity benefits associated with the improved working conditions due to better natural lighting and indoor air quality; minimum ABGR and Greenstar requirements from Government for leased office space and a realisation from developers that "Green" buildings are better investments (Green Building Council of Australia 2006).

This has resulted in the need for builders to respond to an increasing number of tenders that have a range of sustainability requirements in them. Builders have had to start thinking about the types of materials included in their buildings and the importance of incorporating sustainability into their operations. This has subsequently driven the demand for increased information from Master Builders on environmental policies, environmental management plans and materials suppliers, which led to the development of the program.

The Master Builder Sustainable Construction - Commercial program is designed to provide builders involved in the commercial sector with improved management and business skills to enable builders to better respond to sustainability requirements in tender documents, source information on appropriate materials and to incorporate these requirements into their day to day operations.

This innovative program focuses on sustainability issues relevant at all stages of the construction process from important design considerations through materials selection and site management to interior fit out and health considerations. The information is easy to digest and focuses on common sense, practical solutions.

The other benefit for the builder is the linking of the program and work practices with a unit of attainment from the national training system which encourages further training for a nationally recognised qualification.

The program was developed by Master Builders Victoria with the aid of funding provided by Sustainability Victoria and the first course was run in May 2007. The program was further enhanced by the production and incorporation of a DVD, developed in conjunction with Kestrel Media with the aid of funding provided by Incolink (a building industry redundancy payment fund). The DVD clarifies a number of sustainability issues and methods to address them via on site management practices as simply as possible.

An improved understanding of developer and tender requirements will enable site managers and contractors to improve compliance with environmental requirements on site.

2. The Program

The Sustainable Construction - Commercial course consists of a 2 day course, some audio visual resources and a range of activities that leave the participants with a simple environmental policy and management plan that they can then adapt for their own requirements. It focuses on the often used, reduce, reuse and recycle message and considers the need to reduce impacts, energy and water use in the first place. It then explores a group of ideas that have a big impact on minimising the environmental impact of construction, without necessarily imposing an increased cost.

2.1 The training course

The training course commences with a look at the concept of sustainability, a term that builders often hear about, but may not necessarily be aware of its exact meaning. This abstract term is given a concrete meaning by using the Ecological Footprint concept (Environment Protection Authority Victoria 2006). The concept attempts to determine just how much land is required to meet the resource requirements of a population in relation to their lifestyle. The concept is reinforced by using information from the group on their travel habits, food and lifestyles to determine just how many earths would be required to meet this need if everyone on the earth lived as they did. It then explores a number of environmental issues such as greenhouse gas production and biodiversity loss and the impact of construction on these issues.

The reasons for the increasing popularity of Green Buildings and the increasing requirements for builders to respond to sustainability requirements in tenders are then explored. Market drivers for sustainable buildings are then discussed. These drivers include;

- major companies wanting to be seen as good corporate citizens by housing themselves in "Green" buildings;
- the realisation that there are staff retention and productivity benefits associated with the improved working conditions due to better natural lighting and indoor air quality;
- a move to minimum ABGR, Greenstar and sustainable development requirements from Local, State and Federal Government for office space and
- a realisation from developers that "Green" buildings offer better investment returns (Green Building Council of Australia 2006).

This is followed by a familiarisation exercise looking at the various sustainability scorecards such as GreenStar and the Sustainable Development Scorecard used by a number of Victorian councils. The goal is to introduce participants to the manner in which they operate and the methods by which developments are scored according to the methods used to reduce the environmental impact of the building.

It then looks at the importance of project planning by emphasising the importance of thinking about sustainability features right from the beginning of the project. This is where features can be easily incorporated into the building project at minimal additional cost as they are integrated at the design phase.

The importance of design is then introduced, in particular passive solar design ideas. Once again the focus is on providing ideas that will reduce operational energy use and environmental impact without necessarily introducing additional costs.

The next few topics cover the environmental issues and legal requirements to be considered during the construction phase such as on site management, waste management and erosion and sediment control. The DVD is used to clarify a number of sustainability issues and provides practical examples of on site management practices filmed on building sites to address the issues as simply as possible. The participants are then issued with a series of site plans and asked to complete an environmental management plan for that site.

Materials selection used in the framing and structure and the building envelope becomes important when we consider, where these materials come from, their recycled content and embodied energy. Concepts such as sustainably sourced and grown timber resources and certification systems are also introduced.

Methods to reduce water and energy use are then explored by focusing on the big users and easy methods to reduce consumption. This material is backed by a number of case studies where real examples are used to show exactly how much energy and water use can be reduced. The importance of design considerations are not forgotten as a series of activities allow the participants to apply the ideas to real plans.

Once the construction of the building is completed the issues to be considered during interior fit out are explored. As well as again looking at the importance of materials selection and embodied energy, indoor air quality is introduced as a topic that an increasing number of people are concerned about when they think about the emissions given off by solvents, glues, carpets and paints used in their workplaces. The benefits to workplace productivity, staff retention and decreased absenteeism are also discussed.

The final topic covers business strategy and discusses methods to incorporate what they have just learnt into their day to day operations to make the whole process as easy as possible. In order to sell their increased knowledge of sustainable construction, methods to highlight this knowledge in tender documents are also outlined.

2.2 Resources

The goal of the program is to reduce the mystery around sustainability and to increase the chances of builders incorporating sustainability considerations into their developments. A number of resources are used by participants during the course in order to make this process as easy as possible.

The Sustainable Construction – Commercial DVD, is used to provide real examples filmed on building sites of methods to reduce the environmental impact during construction. A series of activities completed during the course ensure that participants leave with their own example of an environmental policy and an environmental management plan which they can adapt to fit their own requirements.

All participants are also issued with a list of useful resources which is continually updated on the Master Builder Victoria Green Living webpage (www.mbav.com.au/training/greenliving.html). This list of useful suppliers and resources is once again designed to make the process of finding environmentally preferable materials as simple as possible. If the sourcing of a product or service becomes too difficult it is likely to be dismissed by the builder.

Link to National Training Scheme

As a Registered Training Organisation, Master Builders Victoria is able to provide participants who complete the 2 days training and submit their environmental management plan for assessment with a nationally recognized statement of attainment for the unit of competency demonstrated;

- BCGBC5011A Manage building or construction, environmental management practices and processes (commercial)

This links the program and work practices directly in with the national training system and encourages further training for a nationally recognised qualification such as a Diploma of Occupational Health and Safety.

3. Conclusion

The Sustainable Construction – Commercial program was first delivered in March 2007. As of March 2008, 39 building industry professionals have completed the program.

Providing training in a practical easy to follow format that is complemented by a variety of tools, ensures that builders feel more confident when responding to sustainability issues and tenders. Providing improved training for builders in a format they are comfortable with increases the chances of an improved level of cooperation between developers, designers, builders and sub-contractors.

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REDUCING THE ENVIRONMENTAL FOOTPRINT: MORNINGTON PENINSULA SHIRE COUNCIL CASE STUDY

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Summary

The Mornington Peninsula Shire Council, located just outside the City of Melbourne in Australia, has taken significant steps in implementing a range of initiatives to become a sustainable shire. The Shire appreciates that a number of benefits exist for reducing their impact on the environment including the potential for cost savings. They have demonstrated leadership by example, by managing their own assets.

To ensure that sustainable practices are adopted by contractors responsible for maintenance and refurbishment of council owned properties, a checklist of items including whitegoods, heating and cooling units and some building materials was developed. The intention of this checklist was to incorporate sustainability criteria wherever possible when existing items needed to be replaced or new items ordered as part of renovations/refurbishment of Shire assets. Criteria in the development of the checklist included considerations such as energy and water impacts, materials choice and indoor environmental quality. Due consideration was also given to practical issues such as place of manufacture, availability/servicing capability within the Shire and costs.

1. Introduction

The built environment has a significant impact on the natural environment, both in Australia and globally. The OECD (2002) reported that buildings are estimated to consume 30 - 50% of available raw materials and account for 25 - 40% of final energy consumption. They generate about 40% of waste to landfill in OECD countries (OECD 2003). There is therefore an untapped opportunity for the built environment to help reduce environmental impacts through their design and use.

Buildings in Australia have a turn over rate of about 2% per year (Horne R 2007), meaning that it will be 50 years or more before current building stock will be replaced and sustainability features of new buildings rolled out across all buildings. It is therefore important to focus on implementing sustainability into current buildings through refurbishments and renovations so that we can make an impact on reducing the built environments impacts on the natural environment.

The UNEP (2007) found that internationally, operational energy of buildings tends to be around 85% of the total energy of the life of a building. As reported by McKinsey & Company (Bressand et al 2007, p. 13) large opportunities for improving energy efficiency exist across the different sectors. The potential demand reduction in 2020 through enhanced energy productivity can create 10% opportunities in commercial sector, and 30% in industrial sectors. It is noteworthy that most council assets would fall within these sectors.

Also reported by McKinsey & Company is that the commercial sector offers more opportunities for boosting energy productivity (Farrell et al 2008).There is an opportunity of 20 to 30 percent in the commercial sector in the US (Bressand et al 2007). The commercial sector is generally dominated by lighting and other electricity powered appliances, followed by space heating (Bressand et al 2007, p. 109). It is expected that the figures in Australia would be very similar. Efficiencies in heating and cooling offer large energy productivity opportunities, leading to attendant greenhouse gas abatement. Therefore, it is strategic to focus on opportunities where energy efficiency policies and programs can be developed and implemented.

The checklist developed for the Mornington Peninsula Shire Council (MPSC) offers another way of reducing our impact on the built environment. By preparing a prescriptive checklist for council contractors and designers, the Shire is making some in-roads into dropping its use on operational energy, and attendant greenhouse gas emissions. This paper outlines the process undertaken in the preparation of the checklist and presents findings. It also presents feedback from the council contractors in the use of the checklist and offers recommendations in the development and implementation of such types of checklists.

2. Mornington Peninsula Shire Council

As organisations around the world and in Australia are starting to realise the benefits of 'going green' they are starting to look for every opportunity where they can make reductions to their overall environmental footprint. In Australia, many local councils are taking a leadership role and leading by example in their efforts to be sustainable.

The Mornington Peninsula Shire, located south just over an hour's drive from Melbourne, is the most popular informal recreational area in Victoria. The Mornington Peninsula is a boot-shaped promontory separating two contrasting bays: Port Philip and Western Port and has over 190kms of coastline.

3. Aim of the project

To ensure that sustainable practices are adopted by their contractors responsible for maintenance and refurbishment of council owned properties, the Mornington Peninsula Shire Council (MPSC) decided to use a checklist of items including whitegoods, heating and cooling units and wherever possible, provide opportunities for reducing environmental impact through choice of building materials and products. Due consideration was given to practical issues such as place of manufacture, availability/servicing capability within the Shire and costs.

The checklist was deliberately aimed to be prescriptive rather than a decision making tool. An underlying reason for this was to make it easy for contractors and other players in the refurbishment process to adopt sustainability practices. It was recognised, that as a result of this, the checklist will have a rather short shelf life.

4. Scope of the project

MPSC wanted to create a checklist of sustainably preferable products and materials across a range of costs and performances and they also required a contractor compliance sheet. The specific deliverables were:

- Developing a ESD Building Refurbishment Checklist
- Tailoring the existing Contractor Compliance Sheet for ease of use and appropriate information provision.

The Checklist needed to:

- Be a simple and easy to use document
- Provide a list of objectives and targets for each of the subheadings
- Provide additional product options within the range described
- Identify purchase price and local availability within the Mornington Peninsula
- Calculate payback time for major appliances (this was later refined further for application)
- Provide an indication of the percentage increase to the maintenance budget associated with using product alternatives. This was to be achieved by identifying the cost difference between typical existing products and their eco-preferred option identified on the checklist. The price difference was to allow for a calculated percentage variation to the budget.
- Provide a checklist induction session with the Shire

The Contractor Compliance sheet was designed to be used by the contractors when replacing, upgrading or installing new appliances or selected materials. It is to be used as a check to make sure that appliances are replaced only when necessary and replaced with one of the recommended options to maximise water and energy savings.

The Contractor Compliance Sheet needed to:

- Be a simple and easy to use document
- Indicate relevant information: for example - existing conditions (site, building element and existing in-situ product/s) and replacement activity (identify checklist product/s, price, changed conditions etc.). The scope of compliance sheet requirements outside these parameters was to be evaluated in discussion with relevant council members and contractors if possible.

The checklist and contractor compliance sheets were to be used for renovations and refurbishments of projects within MPSC.

5. Research Design

The checklist was developed in two parts. The summary sheets at the front end of the checklist with detailed information following, and the raw data sheets. The summary sheet, as the name implies, provided a summary of the information contained in the detailed sheets. The summary sheet consisted of the recommended product in each of the different product and material areas and each of the different size requirements. Each of these products and materials contained the following information: cost, warranty, dimensions, energy/water ratings and consumption rates.

The detailed information contained the following information: cost, warranty, dimensions, product description, energy/water ratings, energy/water consumption rates, energy/water ratings and consumption rates for average (not-specially energy/water efficient) products and a weblink to further product information.

The raw data sheets contained the same information as the detailed information but also contained payback periods for the different products. The payback period was worked out by using the cost difference (if any) of the more energy/water efficient appliances compared to an ‘average’ product and working out the payback period based upon the costs of those utilities.

Desk research provided most of the information. Two main areas of information were used to populate the spreadsheets: products and materials. Products were those that were usually replaced during renovations or refurbishments. They contained:

- Products – Air conditioning, bathroom appliances, dishwashers, dryer, hot water system, lighting, ovens and stoves, refrigeration and freezers and washing machines.
- Materials – Cement, insulation and paint

Two different approaches for used for each of the above. Products were grouped under different categories such as air conditioning, bathroom appliances, dishwasher etc, (see Development of Checklist section below). Within these categories, information included the physical dimensions of the product, the prices, and web links for information. Wherever possible, product descriptions included water savings and consumption information. Likewise, they also contained energy savings and consumption information. Each category required 4-6 products (where possible) which covered a range in environmental performances as well as durability and costs.

Materials information contained descriptions regarding recycled content, Volatile Organic Compounds (VOC) information and recycability information.

Durability and costs were included for both products and materials.

After an initial list of products was put together, further research into each product was carried out. Local suppliers were contacted and asked about the availability of these products and if there were any others they would recommend. Information such as costs, dimensions and warranty was also gathered and the spreadsheet populated. Information about an ‘average’ product was also gathered for comparison to the more environmentally friendly products.

Material information was gathered by calling different suppliers and requesting information about their materials as well as using sources such as Ecospecifier (2008). Sustainability information such as recycled content, low Volatile Organic Compound (VOC’s) and recycability was then recorded about their products.

Lists such as WELS (2008) and Energy Rating (2008) were researched for appliances which were in the highest water and energy star rating categories. The energy star rating categories included products from the very highest star ratings to those with the lowest star ratings. Other sources such as Choice Magazine were also researched for recommended and non-recommended products.

6. Development of checklist

It was agreed at the outset between the MPSC and the Centre for Design that there may be elements of the checklist that would be iterative. As a starting position, it was agreed that the checklist include the following subheadings for products:

- Product name
- Brief product description
- Dimensions, where applicable
- Water saving rating and consumption rates
- Energy star rating and consumption rates
- Price
- Weblink for further product information
- General cost and energy and water consumption for an ‘average’ product (for a comparison)

And not included on the final checklist itself but calculated and provided with the raw data sheet:

- Pay back periods for the more sustainable products compared to the ‘average’ product
- Water and energy savings compared to the ‘average’ product

The product categories and subheadings were set up in a spreadsheet so it could easily be populated with the required information. Once the spreadsheet was set up, desk research was undertaken to populate the checklist.

Once all this information was collected, each product and material category was narrowed down to 4-6 products which covered the size requirements and desired performance. The best couple of environmentally performing products and materials in each category were kept along with the products and materials with the lowest price (regardless of environmental ratings) and some that were recommended by other credible sources such as Choice Magazine or Ecospecifer.

Pay back periods were calculated for each of the products for their energy and water saving features compared to the extra cost over an ‘average’ product of similar size and requirements. This payback information was used to show how long it would take for the more environmentally friendly products to come out ahead of an ‘average’ product based upon capital and operational costs.

From these lists, one product or material was recommended for each of the categories and subcategories based upon the following:

- Preference was given to the best environmentally performing product or material;
- Where the top environmentally performing product or material was significantly more expensive than the second place product or material, then consideration was given to the cheaper option as long as its environmental performance was not significantly less
- Consideration was also given to warranty length and type, as well as payback periods and any other relevant information.
- Where there was too great a range to narrow down to one product such as for lights or tap fittings (as these will differ depending on requirements and style), a general guiding principle was given and targets to aim for (for example taps – aim for 6 stars rating, 1.5L/min to 6L/min).

These chosen products and materials were then compiled into two A4 pages as a summary for contractors to quickly check (refer Figure 1). All relevant information such as product, product description, capacity size, dimensions, warranty, price and energy and water ratings and consumption rates was provided. Payback periods and other attendant information was not provided with this overview as this was considered part of the detailed information. The contractors were encouraged use this list when purchasing products or materials. If the product or material was not available for whatever reason, then a product of equal environmental performance was recommended to be purchased.

	Size	Product	Product Description	Dimensions (w,d,h) m	Warranty	Price	Energy star rating and consumption	Water rating and consumption
Airconditioning	Single split system up to 5kWh	Fujitsu (ASTB12LDC)	3.5kW cooling capacity	0.79x0.23x0.28	5 years	$1,650	Cooling: 6 star, 0.91kWh Heating: 6 star, 1.22kWh	NA
	Single split system above 5kWh	Fujitsu (ASTA 30LCC)	8kW cooling capacity	1.30x0.23x0.32	5 years	$2,300	Cooling: 4 star, 2.55kWh Heating: 4.5 star, 2.64kWh	NA
Dishwasher	12 place setting	Fisher and Paykel DW60CGX1	12 place setting dishwasher	0.50 x 0.60 x 0.85	2 years	$625	NA	3 star, 257kWh/365 washes
Dryer	Small load (up to 4.9kg)	Simpson 39P400M	4kg capacity	0.50 x 0.46 x 0.79	1 year	$349	1.5 star, 159kWh/52 uses	NA
	Medium load (5-6.9kgs)	Kleenmaid KED600	6.5kg capacity	0.50 x 0.64 x 0.84	5 years	$1,499	3 star, 247kWh/52 uses	NA
	Large load (7kgs plus)	Fisher & Paykel DEIX1	8.0kg capacity	0.59 x 0.71 x 1.06	2 years	$1,499	2 star, 339kWh/52 uses	NA
Hot water system	Solar gas boosted (1 to 2 person)	Rheem Solar Premier Hiline - 52H180-G	180 L	1.50 x 2.80 for panels	1 to 5 years	$4,276	NA	NA
	Solar gas boosted (2 to 5 person)	Rheem Solar Premier Hiline - 52H300-G	300 L	2.20 x 2.80 for panels	1 to 5 years	$5,391	NA	NA
	Solar electric boost (1 to 2 person)	Rheem Solar Premier Hiline - 52H180	180 L	1.50 x 2.80 for panels	1 to 5 years	$2,737	NA	NA
	Solar electric boost (2 to 5 person)	Rheem Solar Premier Hiline - 52H300	300 L	2.20 x 2.80 for panels	1 to 5 years	$3,881	NA	NA
	Gas immersion DHWS (1 to 3 person)	Rinnai Infinity V series INF16	16-26L/min	0.35 x 0.20 x 0.53	3 to 10 years	$880	5.5 star, 15MJ/h	NA
	Gas immersion DHWS (3 to 6 person)	Dux Endurance Plus Gas Continuous Flow	26L/min	NA	3 to 10 years	$1,120	5.5 star, 17MJ/h to 199MJ/h	NA
	Electric immersion DHWS (1 to 3 person)	Rheem Optima - 411250	250 L	0.55 x 0.71 x 1.39	1 to 10 years	$1,350	4.8kW	NA
	Electric immersion DHWS (3 to 6 person)	Rheem Optima - 411400	400 L	0.67 x 0.71 x 1.88	1 to 10 years	$1,746	4.8kW	NA
Oven/stove units	Gas oven/stove unit	Kleenmaid FEG605X		0.60 x 0.60 x 0.90	5 years	$3,499	29.5MJ/h	NA
	Electric oven/stove unit	Westinghouse PPN776S	80L oven capacity	0.60 x 0.57 0.60	2 years	$1,379	NA	NA
Refridgerator	Bar fridge	Fisher and Paykel P120 EZKlean	115 L Fridge	0.53 x 0.57 x 0.82	2 years	$307	2.5 star, 291kWh/yr	NA
	Small 150-300L	Fisher & Paykel E249T	248L (191 L fridge, 57 L Freezer)	0.38 x 0.61 x 1.63	2 years	$809	4 star, 387kWh/yr	NA
	Medium 301 - 450 L	Fisher & Paykel Active Smart Elegance E440T	447L (342L Fridge, 105L Freezer)	0.79 x 0.73 x 1.72	2 years	$1,649	4 star, 476kWh/yr	NA
	Lage 450L +	Simpson 520L STM5200WA	250L Fridge&Freezer	0.80 x 0.73 x 1.72		$1,199	4.5 stars, 510kWh/yr	NA
Washing machines	Small load (up to 5.5kg)	Simpson 45S556E	5.5kg capacity	0.60 x 0.59 x 0.85	2 years	$600	2.5 star 368kWh/365 wash	4 star, 56L/wash
	Medium load (5-7kg)	LG WD-8015C	7kg capacity, front loading	0.60 x 0.55 x 0.85	2 years	$906	4 star, 235kWh/365 wash	4 star, 69.5L/wash
	Large load(7.5kg plus)	LG WD-1238C	7.5kg capacity, front loading	0.60 x 0.55 x 0.84	2 years	$1,249	4.5 star, 205kWh/365 wash	4 star, 70L/wash

Figure 1: A screen shot of a summary page of the best value products for each category. Products were rated on environmental performance as most important with cost and durability also considered as secondary importance.

A more comprehensive list of all the products and materials including all information was compiled into a booklet for MPSC to use as a reference (Figure 2). The booklet provided details on where contractors could find further information if they required it. It also provides a comparison between all the products and materials in terms of environmental impacts and cost so it can be seen why the preferred product or material on the summary sheet was chosen.

7. Feedback on the checklist

Almost a year after the checklist was developed, the authors sought feedback from MPSC on the use of the checklist. The checklist was distributed to consultants for the building refurbishment program ($2 million pa). It was also distributed to a number of other councils, however whilst some of these councils found it useful, others found its use very limited.

The general feedback was that the checklist was helpful for selecting some appliances and is one of a number of tools the Council were using to improve the sustainable design of their buildings. It must be noted that the champion in the organisation whose idea it was to develop the checklist in the first place no longer worked for the organisation, therefore, the uptake of the checklist was expected to be quite modest. It was also reported that the document had been useful for the selection of some appliances and products for the refurbishment program.

A designer appointed by the Shire to work on refurbishments found the checklist very useful. Feedback from the designer indicated that the checklist assisted in specification of refurbishment works for the Shire.

The main criticism, however, was that the appliances in the checklist was suitable more for domestic rather than commercial use. This was not surprising as this was flagged while preparing the checklist, and the needs for commercial use is often "tailor made" rather than being generic – contrary to the approach taken in the development of the checklist.

Specific comments included that while selecting air conditioning brands, the checklist was useful. While the information for instantaneous gas hot water units was useful, the checklist did not address adequately larger units. The information covered in the checklist for bathroom, insulation and paint was very useful. The information for ovens and stoves was helpful, but more information was needed for commercial fridges.

It was suggested that the checklist, while limited in its application worked quite well with other tools available within the local government sustainable buildings program such as the Sustainable Design Scorecard (SDS) developed by Moreland and Port Phillip councils in Victoria.

DISHWASHER

For a complete list of dishwashers registered with Australian Government accredited Water Efficiency Labels (WELS), see www.waterrating.com.au

For a complete list of dishwasher registered under the Australian Government accredited Minimum Energy Performance (MEPs), see www.energyrating.gov.au

Product	Dimensions (w,d,h) m	Product description	Warranty	Water rating and consumption	Energy star rating and consumption	Price		Weblink
Miele G 1220 SC	0.60 x 0.60 x 0.85	12 place setting dishwasher, has energy saving function	2 years	3 star, 13L/wash	3 star, 274kWh/365 washes	$1,599	Bottom of the range - 1 star dishwasher can use up to 24L per wash and up to 600kWh/year (approx $550)	http://www.miele.com.au/index1.asp
Asko D3900	0.60 x 0.60 x 0.85	14 place setting dishwasher, marked for recycling. ISO 14001 compliant	2 years	4 star, 14L/wash	2.5 star, 334kWh/365 washes	$2,130		http://www.asko.com.au/index.cfm/en_au/our_products/dishwashers030506/d3900/
Fisher and Paykel DW60CDX1	0.60 x 0.60 x 0.85	12 place setting dishwasher	2 years	3 star, 13.6L/wash	3 star, 267kWh/365 washes	$825		http://www.fisherpaykel.com.au/global/kitchen-products/dishwashing/dishwashers.cfm?productUid=A6B45D00-CFD1-E242-AE5D0D06B77818F4&section=feat
Westinghouse SB925SJ	0.60 x 0.58 x 0.82	12 place setting dishwasher	2 years	2.5 star, 16.2L/wash	2.5 star, 315kWh/365 washes	$960		http://www.westinghouse.com.au/productdisplay/model/SB925SJ
Bosch SGS46M78AU	0.60 x 0.55 x 0.85	14 place setting dishwasher	2 years	3 star, 20L/wash	3.5 star, 269kWh/365 washes	$1,390		http://www.boschappliances.com.au/content.asp?document_id=386
Kleenmaid DW35X	0.60 x 0.60 x 0.85	12 place setting integrated dishwasher	5 years	3.5 star, 14.3L/wash	4 star, 212kWh/365 washes	$2,899		http://www.kleenmaid.com/products.asp?pageID=4&cat=9
Electrolux EX600ISC	0.60 x 0.59 x 0.82	12 place setting integrated dishwasher	2 years	3 star, 14.1L/wash	3.5 star, 257kWh/365 washes	$1,375		http://www.electrolux.com.au/node38.aspx?productId=2335

Figure 2: A screen shot of a complete category listing. It shows all the products which were researched across the spectrum of cost, size and durability as well as environmental performance.

8. Conclusion and recommendations

The development of the checklist, while a time consuming exercise, offers yet another resource to key players in the building industry. An underlying reason for developing the checklist was to ensure that the players involved in the Shire's refurbishment process would not have to "think about it". They would simply pick out the appropriate appliance/product from an existing document, making it as simple and easy as possible.

The checklist's reasonable short shelf life was recognised. Resources would need to be directed at appropriate intervals to ensure that the information contained in the checklist was current. The checklist alone was not enough, it needed to be part of a range of resources available to the Shire and their building industry stakeholders.

A decision making checklist would add value to this document. A decision making checklist would provide an educational value and enable contractors, designers and other building industry players to base their product/material choices on broader considerations such as: energy and water efficiency and conservation both in its manufacture and use, reuse/recyclability, toxicity, supply chain stewardship and other similar environmental considerations.

A potential next step for this project would be to expand the existing checklist, and prepare a decision making one suitable for all Councils in Victoria, containing a greater range of products and materials. This could then be updated at appropriate intervals to keep abreast of changes to products and new products entering the marketplace. A web based system may also provide a quick, easy to use reference document for not just councils, but also other professionals in the building industry.

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PROBE INSERTION METHOD FOR ON-SITE EVALUATION OF VRV SYSTEMS

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Keywords: coefficient of performance, variable refrigerant volume, long-term measurement, electric heat pump, gas heat pump

Summary

This report describes a probe insertion method for on-site evaluation of variable refrigerant volume (VRV) systems and evaluation results for VRV systems using a gas heat pump (GHP). This method allows calculation of production calories for outdoor units based on the energy balance and measurement of exchange heat. The former is to determine input energy and output energy of the VRV system. The latter measures air temperature before and after the outdoor unit heat exchanger to determine the amount of heat exchange. A sheath-type thermocouple is inserted from the outside of the heat exchanger, and air temperature after heat exchange is measured. This method is able to evaluate four types of VRV system operations [cooling while using an electric heat pump (EHP), heating while using an EHP, cooling while using a GHP, and heating while using a GHP]. Result of an on-site evaluation for a VRV system using a GHP clarified characteristics of energy consumption. This evaluation was conducted from July 2007 to February 2008. The results showed that the VRV system was operating under an extremely low load.

1. Introduction

In Japan, the use of VRV systems in small and medium-sized office buildings is widespread. This situation also is becoming common worldwide. These VRV systems are considered to provide good performance. However, the characteristics that affect performance of the equipment during actual operation are not well understood, and how energy is used is uncertain. This is a disadvantage for facility designers and users. This report describes how energy is consumed by an actual system using a probe insertion method.

In addition, a simultaneous test using a method generally done in an examination room without disturbances exist was conducted to verify the accuracy of this method. This result showed that the system coefficient of performance (COP) error margin of this method was +19% in cooling with EHP use, and, +6% in cooling with GHP use.

Practical operation conditions of a VRV system installed in building K were investigated using the probe insertion method during a 30-week investigation period over summer and winter. A GHP outdoor unit with specifications of 30 HP was installed. This system managed temperature control for a 384 square meter office.

Results of on-site evaluation of a VRV system can help predict the success or failure of a facility design, and demand of the indoor unit.

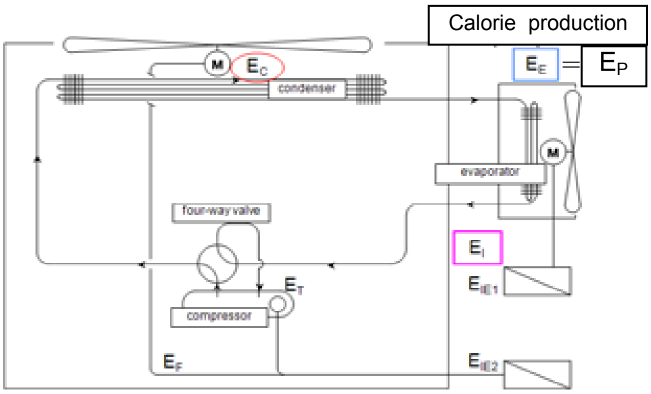
2. Probe insertion method

2.1 Calculation of calorie production on an outdoor unit

The energy balance in each system is shown in Figures 1-4. The outdoor unit was considered as heat source equipment for this research, with the evaluation based on calorie production of the outdoor unit. The following energy balance is assumed to have calorie production on the outdoor unit (E_P) correspond to calorie use of the indoor unit. This method disregards the influence of heat loss in the refrigerant pipes.

For EHP cooling and heating, calculation of calorie production can be done on the outdoor unit. Figure 1 (cooling) and Figure 2 (heating) show the energy balance. Energy to the compressor of total input energy on outdoor unit is shown by equation (1). Moreover, energy balance in the refrigeration cycle is shown by equation (2), and calorie production of the outdoor unit during cooling is described by equation (3), derived from equations (1) and (2). Calorie production of the outdoor unit during heating is described by equation (5). Therefore, COP of the whole system is described by equations (4) and (6).

Figure 3 (cooling) and Figure 4 (heating) show energy balance at cooling and heating with a GHP. Each energy balance during cooling operation is described by equations (7) and (8). Energy balance during heating operation is described by equations (11) and (12). Energy to the compressor and total input energy of the outdoor unit are described by equations (7) and (11). Moreover, energy balance during the refrigeration cycle is shown by equation (8), and heat production of the outdoor unit during cooling is described by equation (9), derived from equations (7) and (8). Heat production of the outdoor unit during heating and is described by equation (13), which is derived from equations (11) and (12). Therefore, system COP is shown by equations (10) and (14).



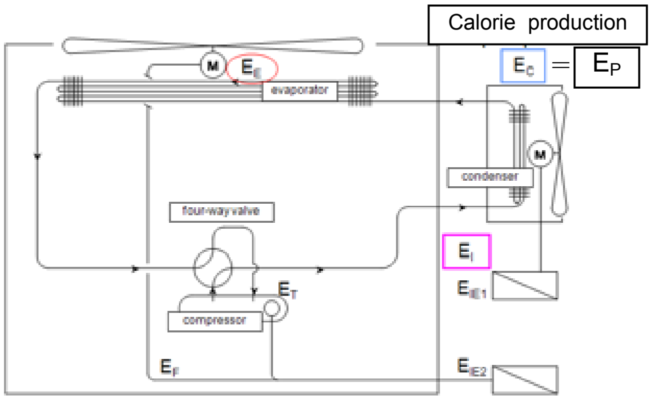
$$E_T = E_{IE2} - E_F \quad (1)$$

$$E_E = E_C - E_T \quad (2)$$

$$\therefore E_E = E_P = E_C - E_{IE2} + E_F \quad (3)$$

$$COP_S = \frac{E_P}{E_{IE}} = \frac{(E_C - E_{IE2} + E_F)}{(E_{IE1} + E_{IE2})} \quad (4)$$

Figure 1. Energy balance during cooling with EHP



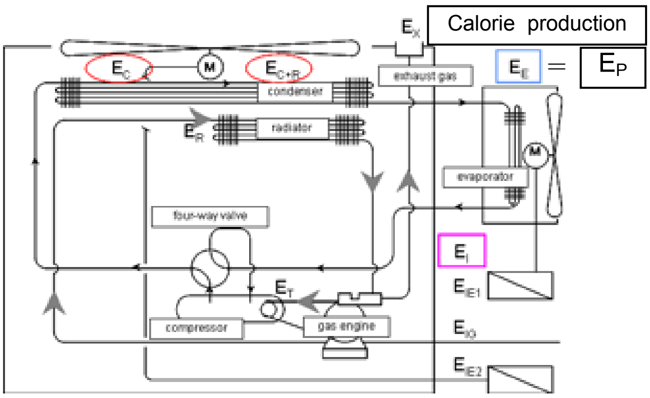
$$E_T = E_{IE2} - E_F$$

$$E_C = E_E + E_T$$

$$\therefore E_C = E_P = E_E + E_{IE2} - E_F \quad (5)$$

$$COP_S = \frac{E_P}{E_{IE}} = \frac{(E_E + E_{IE2} - E_F)}{(E_{IE1} + E_{IE2})} \quad (6)$$

Figure 2. Energy balance during heating with EHP



$$E_{IG} = E_T + E_X + E_R$$

$$\therefore E_T = E_{IG} - E_X - E_R \quad (7)$$

$$E_E = E_C - E_T$$

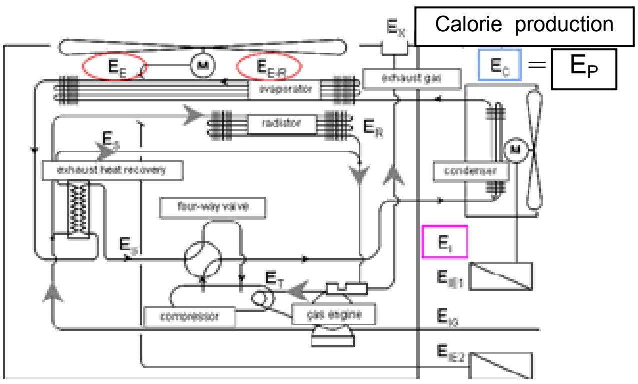
$$\therefore E_T = E_C - E_E \quad (8)$$

$$\therefore E_{IG} - E_X - E_R = E_C - E_E$$

$$E_E = E_P = E_C + E_R + E_X - E_{IG} \quad (9)$$

$$COP_S = \frac{E_P}{E_{IE}} = \frac{(E_C + E_R + E_X - E_{IG})}{(E_{IE1} + E_{IE2} + E_{IG})} \quad (10)$$

Figure 3. Energy balance during cooling with GHP



$$E_{IG} = E_T + E_X + E_R + E_S$$

$$\therefore E_T = E_{IG} - E_X - E_R - E_S \quad (11)$$

$$E_C = E_E + E_T + E_S$$

$$\therefore E_T = E_C - E_E - E_S \quad (12)$$

$$\therefore E_{IG} - E_X - E_R - E_S = E_C - E_E - E_S$$

$$E_C = E_P = E_E - E_R - E_X + E_{IG} \quad (13)$$

$$COP_S = \frac{E_P}{E_{IE}} = \frac{(E_E - E_R - E_X + E_{IG})}{(E_{IE1} + E_{IE2} + E_{IG})} \quad (14)$$

Figure 4. Energy balance during heating with GHP

E_T : compressor energy
E_E : evaporation calorie
E_C : condensation calorie
E_P : production calorie
COP_S : systemCOP
E_I : total input energy
E_{IG} : input gas energy
E_{IE1} : electric power indoor
E_{IE2} : electric power outdoor
E_R : radiation calorie
E_X : exhaust calorie
E_S : exhaust heat recovery calorie

2.2 Measurement of exchange heat on the outdoor unit

Figure 5 shows a schematic of the probe insertion method. To calculate calorie production of the outdoor unit based on equations (3), (5), (9), and (13), it is necessary to measure exchange heat of the outdoor unit. For example, in equation (3), the calories correspond to E_C. In addition, other items can be measured. For GHP [equations (9) and (13)], measurement of E_R is difficult. Generally, a radiator is set up in parallel with the heat exchanger. Therefore, the amount of heat exchange of the radiator and heat exchanger is added based on equations (9) and (13).

Air that flows into the heat exchanger passes through a fan for heat exchange promotion. Therefore, the amount of heat exchange of the outdoor unit is calculated by measuring the change in temperature of the air.

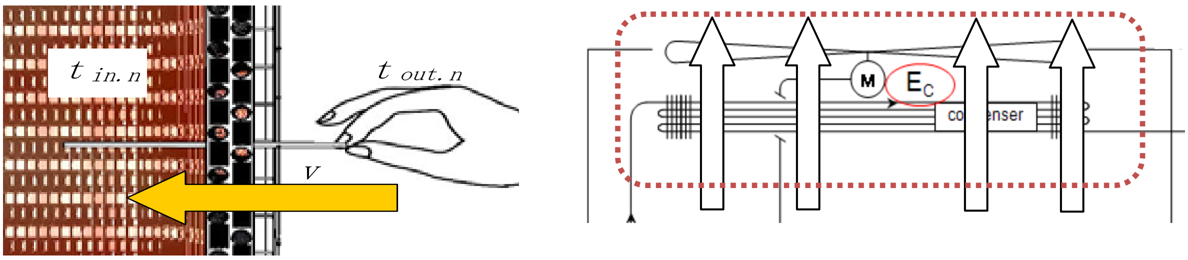


Figure 5. Probe insertion method idea

Equation (15) describes the basics of this system. It calculates the state of air under fixed pressure conditions. To calculate the amount of heat exchange, air temperature before and after the outdoor unit heat exchanger is measured. A sheath-type thermocouple is inserted from the outside of the heat exchanger, and air temperature after heat exchange is measured.

$$Q = v \times s \times \rho \times C_p \times (t_{before} - t_{after}) \qquad (15)$$

In addition, the amount of air that passed through the heat exchanger also is measured. Here, equation (16) excludes serious disturbance. Exhaust air speed from the fan (V_{FAN}) and air speed past the heat exchanger (v_n) are proportional. Then, v_n is a target variable, and V_{FAN} is assumed to be an explaining variable. Thus, *α* is derived from equation (17) and calculated from measurements.

$$\frac{v_{n.2}}{v_{n.1}} = \frac{V_{Fan.2}}{V_{Fan.1}} \qquad (16)$$

$$v_{n.2} = \alpha \times V_{Fan.2} \qquad \alpha = \frac{v_{n.1}}{V_{Fan.1}} \qquad (17)$$

Figure 6 shows the measurement points of the probe insertion method. Exchange heat is measured by all points simultaneously while considering distribution of air speed currents. More measurement points are preferable. Actually, the representative area is allocated and totaled, with the assumption of exchange heat on the outdoor unit [equation (18)].

outdoor unit heat exchange

$$q_{all} = \sum_{n=1}^{n} \alpha_n \times V_{FAN.t} \times s_n \times \rho \times C_p \times (t_{after.n} - t_{before.n}) \quad (18)$$

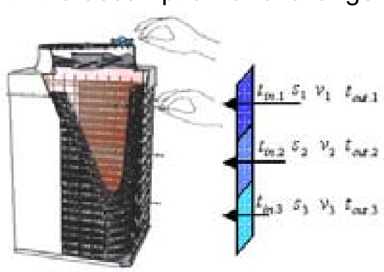


Figure 6. Measurement points of probe insertion method

$V_{FAN.t}$: Exhaust air speed $[m/s]$
s_n : Representative area n [m2]
ρ : Specific weight [kg/m3]
C_p : specific heat [kJ/kg K]
$t_{after.n}$: Air temperature after heat exchanger n $[^0C]$
$t_{before.n}$: Air temperature before heat exchanger n $[^0C]$

3. Measurement example in VRV system by probe insertion method

3.1 Outline of building K and object system

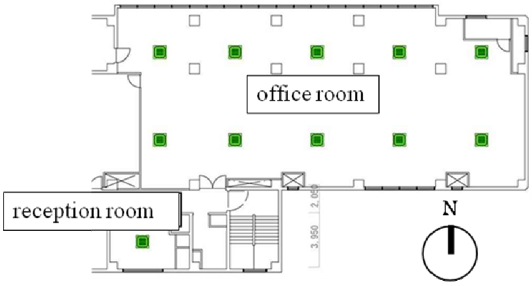


Figure 7. Building K 2F plan

Table 1. Outline of building K and object system

Position	Tokyo in Japan	
Object floor	second floor	
Use	office room	reception room
Space	360m^2	24m^2
Indoor unit	7.1[kW]/8.0[kW]×10	7.1[kW]/8.0[kW]×1
Outdoor unit	GHP	
Refrigerant	R410A	
Controller	indoor	
systemCOP	1.25/1.38	

※cooling/heating

Measurements were taken using the probe insertion method from July 13, 2007 to February 11, 2008.

Rooms include a reception area and office with a large north-facing window (Figure 7). Table 1 shows characteristics of the VRV system using a GHP. Specifications included 203 square meters [W/m^2] in cooling mode and 229 [W/m^2] in heating mode. In addition, room temperature could be set with an indoor controller. This is a generalized facility design common in Japan.

3.2 Measurement point

Figure 8. Appearances of object

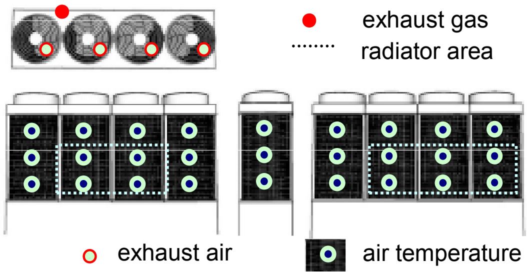


Figure 9. Measurement points

Air temperature before and after the heat exchanger was measured at 27 points, while exhaust air speed was measured at 4 points and the temperature of exhaust gas was measured at 1 point, as shown in Figure 9.

Object system energy consumption was measured. The power consumption and consumption of gas of the outdoor unit system were measured. Additionally, indoor unit power consumption was measured from the second floor distribution panel.

3.3. Results and discussion

3.3.1 Outside air temperature and humidity during the experimental period

Figure 10 shows daily average outside temperature and humidity. The maximum daily average temperature was 33.0°C, recorded on August 16, 2007; the minimum daily average temperature was 1.7°C, recorded on February 3, 2008.

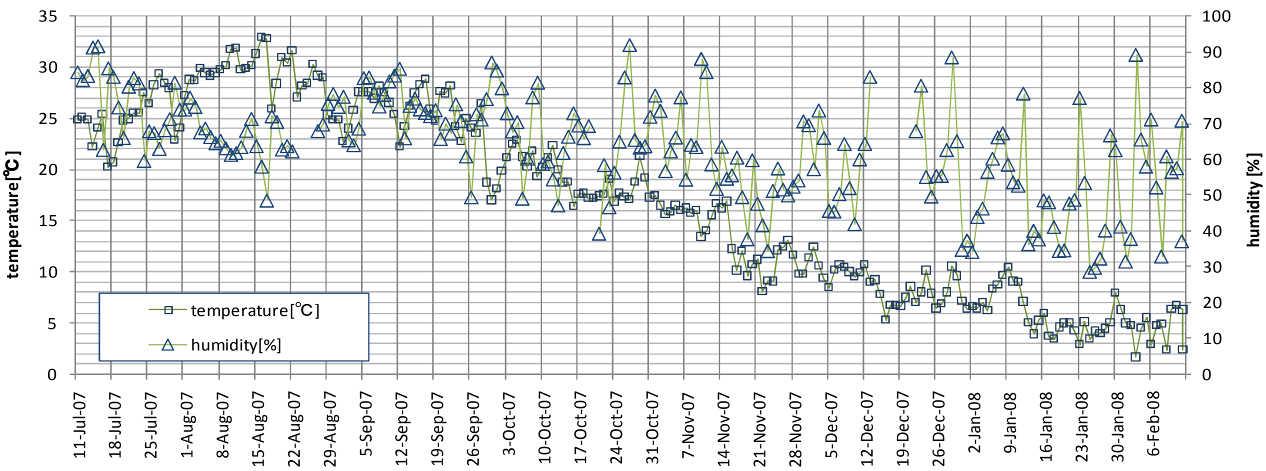


Figure 10. Daily average outside temperature and humidity

3.3.2 Multiple energy consumption by day, calorie production per day, and system COP per day

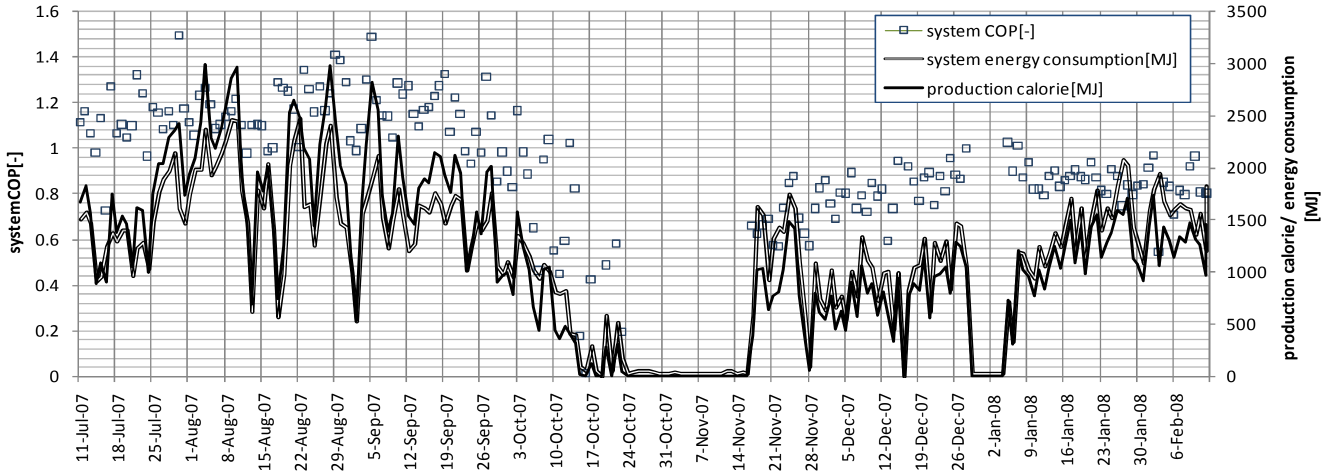


Figure 11. Multiple energy consumption per day and system COP per day

Figure 11 shows multiple energy consumption by day and system COP by day. The time from July 13, 2007 to October 24, 2007 was a cooling period, while the time from November 17, 2007 to February 11, 2008 was a heating period. The daily maximum energy consumption while cooling was 2851 [MJ/day] recorded on August 9, 2007; the maximum recorded during heating was 2066 [MJ/day] recorded on January 27, 2008. Average energy consumption while cooling was 1389 [MJ/day]; average while heating was 1223 [MJ/day]. Thus, more energy was used during the cooling period than during the heating period. Indoor heat generation rate from any equipment is assumed to be related. Average system COP during cooling was 1.05, while that during heating was 0.82. Generally, when the outside air temperature is low, system COP improves at the same load during a cooling period. However, Figure 11 does not show this trend, because the load of the object system was changing.

3.3.3 Object system characteristic

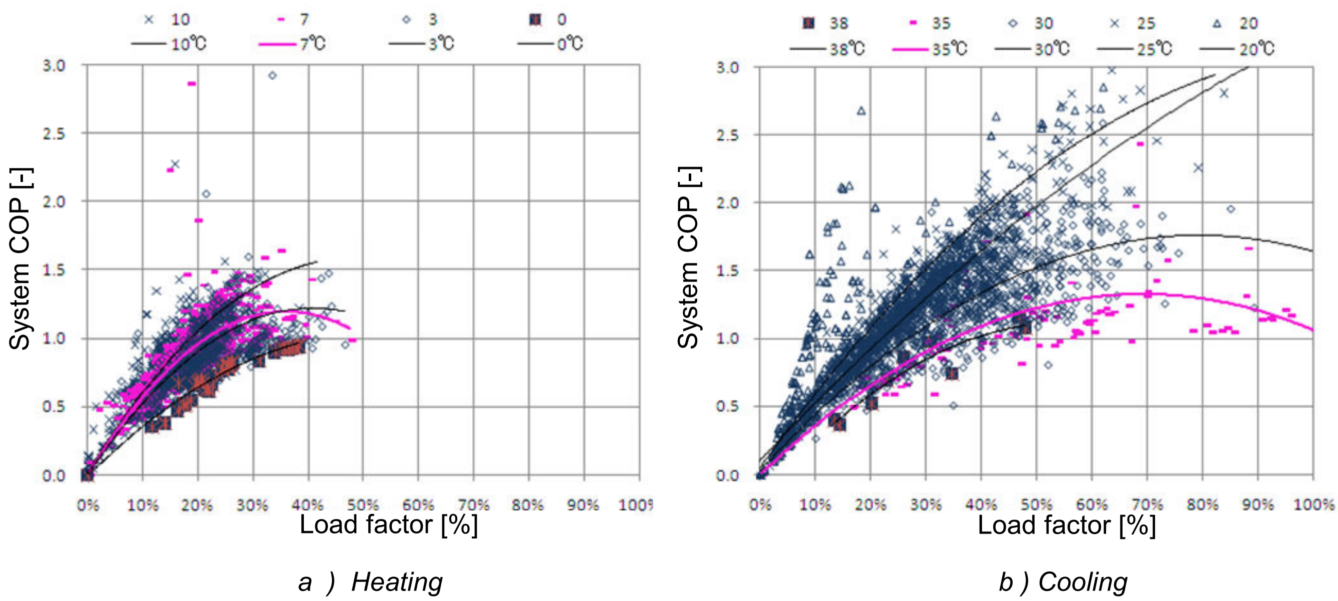
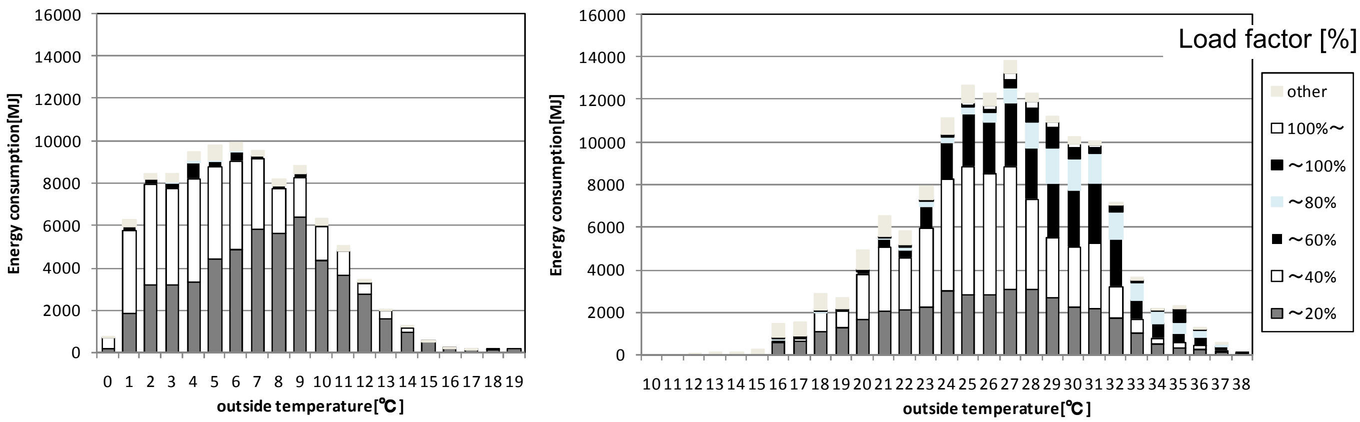


Figure 12. Object system characteristics during: a) Heating b) Cooling

Figure 12 shows object system characteristics. System COP and load factor are plotted every ten minutes for each typical outside temperature. Load factor is a value for which calorie production is divided by specified ability. In Japan, specified ability in cooling is determined at an outdoor temperature of 35°C and indoor temperature of 27°C. And, specified ability in heating is determined at an outdoor temperature of 7°C and indoor temperature of 20°C. At the same load factor, system COP improves with a low outside temperature during a cooling period. Similarly, system COP improves with a high outside temperature during a heating period. Additionally, system COP is high too, when load factor is high at any outside temperature. However, during the cooling period, the load factor of 25% or less increased to 44%. And during the heating period, the load factor of 15% or less increased to 43%. At these low load factors, system COP also is low.

3.3.4 Energy consumption according to outside temperature



a) Heating *b) Cooling*

Figure 13. Energy consumption according to outside temperature a) Heating b) Cooling

Figure 13 shows the amount of multiple system energy consumption at each outside temperature. The bars are classified by load factor and were divided group into categories of 20%, 40%, 60%, 80%, and 100%. Ventilation mode of indoor unit and standby power are classified as "other." The energy consumed reached a maximum of 13850 MJ at an outside temperature of 27°C during cooling, and a maximum of 9946 MJ at an outside temperature of 6°C during heating. Additionally, during cooling, most of the system energy consumption was at a load factor of 40% or less. As mentioned earlier, during heating, indoor heat generation rate from any equipment may ease object system load. Generally, energy is used for driving that load factor and system efficiency is not high. Moreover, energy use at low load factor is not lost to outside temperature.

4. Conclusions

This study describes a probe insertion method for on-site evaluation of VRV systems and demonstrates the usefulness of actual measurement. The object VRV system operation does not interfere with the probe insertion method, which is highly advantageous. In addition, this method is easy to apply and perform.

The measurement example clarifies the actual operation of the VRV system. First, the evaluation period included 30 weeks covering both summer and winter, with system COP demonstrating actual performance. The performance was not maintained by a relative increase in low load factor. Second, the object system characteristics show the possibility of high-performance VRV system operation. However, most actual operation was at a low load factor and low system COP. Third, energy is used at a low load factor, and low load factor exits at each outside temperature. These data suggest a lack of stability in VRV system operation, possibly due to facility design and the demand of the indoor unit.

This study demonstrates that it is very difficult to achieve a high-performance VRV system (according to the catalog) over the long term.

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PROBE INSERTION METHOD FOR ON-SITE EVALUATION OF VRV SYSTEMS

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Keywords: coefficient of performance, variable refrigerant volume, long-term measurement, electric heat pump, gas heat pump

Summary

This report describes a probe insertion method for on-site evaluation of variable refrigerant volume (VRV) systems and evaluation results for VRV systems using a gas heat pump (GHP). This method allows calculation of production calories for outdoor units based on the energy balance and measurement of exchange heat. The former is to determine input energy and output energy of the VRV system. The latter measures air temperature before and after the outdoor unit heat exchanger to determine the amount of heat exchange. A sheath-type thermocouple is inserted from the outside of the heat exchanger, and air temperature after heat exchange is measured. This method is able to evaluate four types of VRV system operations [cooling while using an electric heat pump (EHP), heating while using an EHP, cooling while using a GHP, and heating while using a GHP]. Result of an on-site evaluation for a VRV system using a GHP clarified characteristics of energy consumption. This evaluation was conducted from July 2007 to February 2008. The results showed that the VRV system was operating under an extremely low load.

1. Introduction

In Japan, the use of VRV systems in small and medium-sized office buildings is widespread. This situation also is becoming common worldwide. These VRV systems are considered to provide good performance. However, the characteristics that affect performance of the equipment during actual operation are not well understood, and how energy is used is uncertain. This is a disadvantage for facility designers and users. This report describes how energy is consumed by an actual system using a probe insertion method.

In addition, a simultaneous test using a method generally done in an examination room without disturbances exist was conducted to verify the accuracy of this method. This result showed that the system coefficient of performance (COP) error margin of this method was +19% in cooling with EHP use, and, +6% in cooling with GHP use.

Practical operation conditions of a VRV system installed in building K were investigated using the probe insertion method during a 30-week investigation period over summer and winter. A GHP outdoor unit with specifications of 30 HP was installed. This system managed temperature control for a 384 square meter office.

Results of on-site evaluation of a VRV system can help predict the success or failure of a facility design, and demand of the indoor unit.

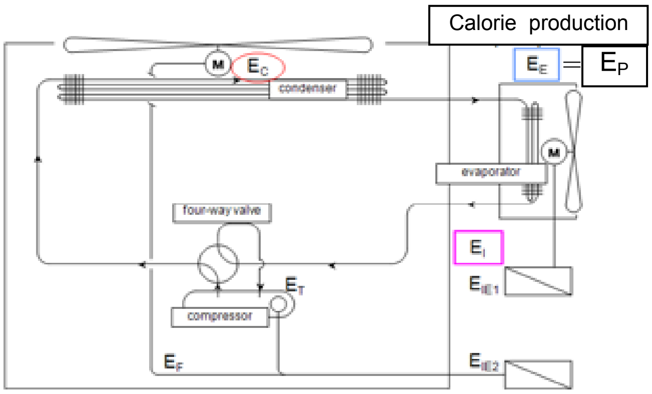
2. Probe insertion method

2.1 Calculation of calorie production on an outdoor unit

The energy balance in each system is shown in Figures 1-4. The outdoor unit was considered as heat source equipment for this research, with the evaluation based on calorie production of the outdoor unit. The following energy balance is assumed to have calorie production on the outdoor unit (E_P) correspond to calorie use of the indoor unit. This method disregards the influence of heat loss in the refrigerant pipes.

For EHP cooling and heating, calculation of calorie production can be done on the outdoor unit. Figure 1 (cooling) and Figure 2 (heating) show the energy balance. Energy to the compressor of total input energy on outdoor unit is shown by equation (1). Moreover, energy balance in the refrigeration cycle is shown by equation (2), and calorie production of the outdoor unit during cooling is described by equation (3), derived from equations (1) and (2). Calorie production of the outdoor unit during heating is described by equation (5). Therefore, COP of the whole system is described by equations (4) and (6).

Figure 3 (cooling) and Figure 4 (heating) show energy balance at cooling and heating with a GHP. Each energy balance during cooling operation is described by equations (7) and (8). Energy balance during heating operation is described by equations (11) and (12). Energy to the compressor and total input energy of the outdoor unit are described by equations (7) and (11). Moreover, energy balance during the refrigeration cycle is shown by equation (8), and heat production of the outdoor unit during cooling is described by equation (9), derived from equations (7) and (8). Heat production of the outdoor unit during heating and is described by equation (13), which is derived from equations (11) and (12). Therefore, system COP is shown by equations (10) and (14).



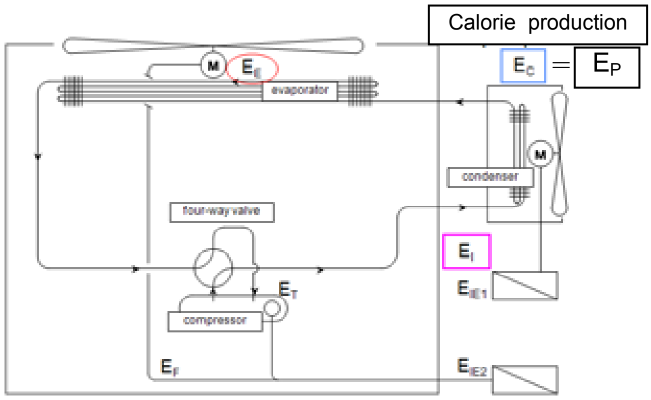
$$E_T = E_{IE2} - E_F \quad (1)$$

$$E_E = E_C - E_T \quad (2)$$

$$\therefore E_E = E_P = E_C - E_{IE2} + E_F \quad (3)$$

$$COP_S = \frac{E_P}{E_{IE}} = \frac{(E_C - E_{IE2} + E_F)}{(E_{IE1} + E_{IE2})} \quad (4)$$

Figure 1. Energy balance during cooling with EHP



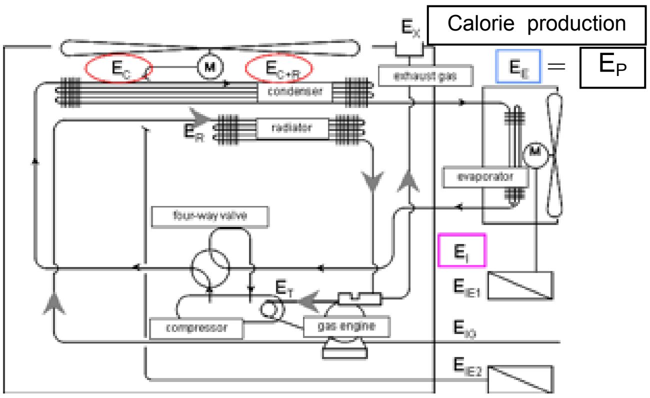
$$E_T = E_{IE2} - E_F$$

$$E_C = E_E + E_T$$

$$\therefore E_C = E_P = E_E + E_{IE2} - E_F \quad (5)$$

$$COP_S = \frac{E_P}{E_{IE}} = \frac{(E_E + E_{IE2} - E_F)}{(E_{IE1} + E_{IE2})} \quad (6)$$

Figure 2. Energy balance during heating with EHP



$$E_{IG} = E_T + E_X + E_R$$

$$\therefore E_T = E_{IG} - E_X - E_R \quad (7)$$

$$E_E = E_C - E_T$$

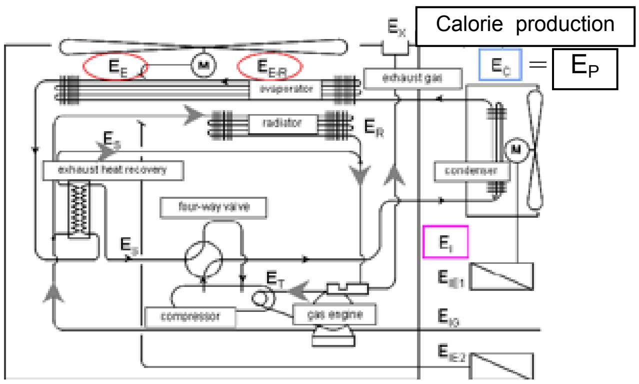
$$\therefore E_T = E_C - E_E \quad (8)$$

$$\therefore E_{IG} - E_X - E_R = E_C - E_E$$

$$E_E = E_P = E_C + E_R + E_X - E_{IG} \quad (9)$$

$$COP_S = \frac{E_P}{E_{IE}} = \frac{(E_C + E_R + E_X - E_{IG})}{(E_{IE1} + E_{IE2} + E_{IG})} \quad (10)$$

Figure 3. Energy balance during cooling with GHP



$$E_{IG} = E_T + E_X + E_R + E_S$$

$$\therefore E_T = E_{IG} - E_X - E_R - E_S \quad (11)$$

$$E_C = E_E + E_T + E_S$$

$$\therefore E_T = E_C - E_E - E_S \quad (12)$$

$$\therefore E_{IG} - E_X - E_R - E_S = E_C - E_E - E_S$$

$$E_C = E_P = E_E - E_R - E_X + E_{IG} \quad (13)$$

$$COP_S = \frac{E_P}{E_{IE}} = \frac{(E_E - E_R - E_X + E_{IG})}{(E_{IE1} + E_{IE2} + E_{IG})} \quad (14)$$

Figure 4. Energy balance during heating with GHP

E_T : compressor energy | E_I : total input energy | E_R : radiation calorie
E_E : evaporation calorie | E_{IG} : input gas energy | E_X : exhaust calorie
E_C : condensation calorie | E_{IE1} : electric power indoor | E_S : exhaust heat recovery calorie
E_P : production calorie | E_{IE2} : electric power outdoor
COP_S : systemCOP

2.2 Measurement of exchange heat on the outdoor unit

Figure 5 shows a schematic of the probe insertion method. To calculate calorie production of the outdoor unit based on equations (3), (5), (9), and (13), it is necessary to measure exchange heat of the outdoor unit. For example, in equation (3), the calories correspond to E_C. In addition, other items can be measured. For GHP [equations (9) and (13)], measurement of E_R is difficult. Generally, a radiator is set up in parallel with the heat exchanger. Therefore, the amount of heat exchange of the radiator and heat exchanger is added based on equations (9) and (13).

Air that flows into the heat exchanger passes through a fan for heat exchange promotion. Therefore, the amount of heat exchange of the outdoor unit is calculated by measuring the change in temperature of the air.

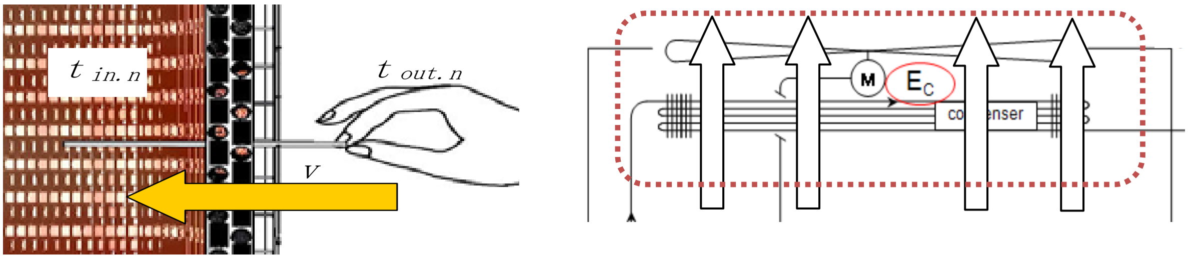


Figure 5. Probe insertion method idea

Equation (15) describes the basics of this system. It calculates the state of air under fixed pressure conditions. To calculate the amount of heat exchange, air temperature before and after the outdoor unit heat exchanger is measured. A sheath-type thermocouple is inserted from the outside of the heat exchanger, and air temperature after heat exchange is measured.

$$Q = v \times s \times \rho \times C_p \times (t_{before} - t_{after}) \qquad (15)$$

In addition, the amount of air that passed through the heat exchanger also is measured. Here, equation (16) excludes serious disturbance. Exhaust air speed from the fan (V_{FAN}) and air speed past the heat exchanger (v_n) are proportional. Then, v_n is a target variable, and V_{FAN} is assumed to be an explaining variable. Thus, α is derived from equation (17) and calculated from measurements.

$$\frac{v_{n.2}}{v_{n.1}} = \frac{V_{Fan.2}}{V_{Fan.1}} \qquad (16)$$

$$v_{n.2} = \alpha \times V_{Fan.2} \qquad \alpha = \frac{v_{n.1}}{V_{Fan.1}} \qquad (17)$$

Figure 6 shows the measurement points of the probe insertion method. Exchange heat is measured by all points simultaneously while considering distribution of air speed currents. More measurement points are preferable. Actually, the representative area is allocated and totaled, with the assumption of exchange heat on the outdoor unit [equation (18)].

outdoor unit heat exchange

$$q_{all} = \sum_{n=1}^{n} \alpha_n \times V_{FAN.t} \times s_n \times \rho \times C_p \times (t_{after.n} - t_{before.n}) \qquad (18)$$

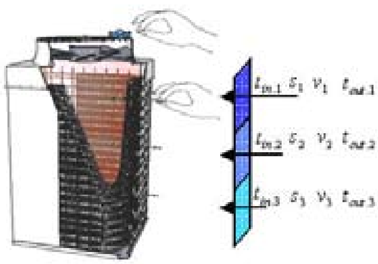


Figure 6. Measurement points of probe insertion method

$V_{FAN.t}$: Exhaust air speed $[m/s]$
s_n : Representative area n [m2]
ρ : Specific weight [kg/m3]
C_p : specific heat [kJ/kg K]
$t_{after.n}$: Air temperature after heat exchanger n [^{0}C]
$t_{before.n}$: Air temperature before heat exchanger n [^{0}C]

3. Measurement example in VRV system by probe insertion method

3.1 Outline of building K and object system

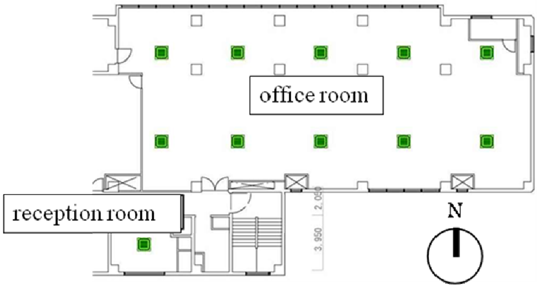


Figure 7. Building K 2F plan

Table 1. Outline of building K and object system

Position	Tokyo in Japan	
Object floor	second floor	
Use	office room	reception room
Space	360㎡	24㎡
Indoor unit	7.1[kW]/8.0[kW]×10	7.1[kW]/8.0[kW]×1
Outdoor unit	GHP	
Refrigerant	R410A	
Controller	indoor	
systemCOP	1.25/1.38	

※cooling/heating

Measurements were taken using the probe insertion method from July 13, 2007 to February 11, 2008.

Rooms include a reception area and office with a large north-facing window (Figure 7). Table 1 shows characteristics of the VRV system using a GHP. Specifications included 203 square meters [W/m^2] in cooling mode and 229 [W/m^2] in heating mode. In addition, room temperature could be set with an indoor controller. This is a generalized facility design common in Japan.

3.2 Measurement point

Figure 8. Appearances of object

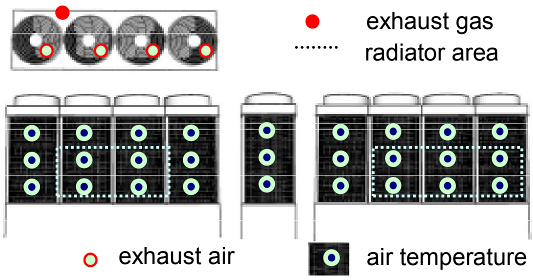


Figure 9. Measurement points

Air temperature before and after the heat exchanger was measured at 27 points, while exhaust air speed was measured at 4 points and the temperature of exhaust gas was measured at 1 point, as shown in Figure 9.

Object system energy consumption was measured. The power consumption and consumption of gas of the outdoor unit system were measured. Additionally, indoor unit power consumption was measured from the second floor distribution panel.

3.3. Results and discussion

3.3.1 Outside air temperature and humidity during the experimental period

Figure 10 shows daily average outside temperature and humidity. The maximum daily average temperature was 33.0°C, recorded on August 16, 2007; the minimum daily average temperature was 1.7°C, recorded on February 3, 2008.

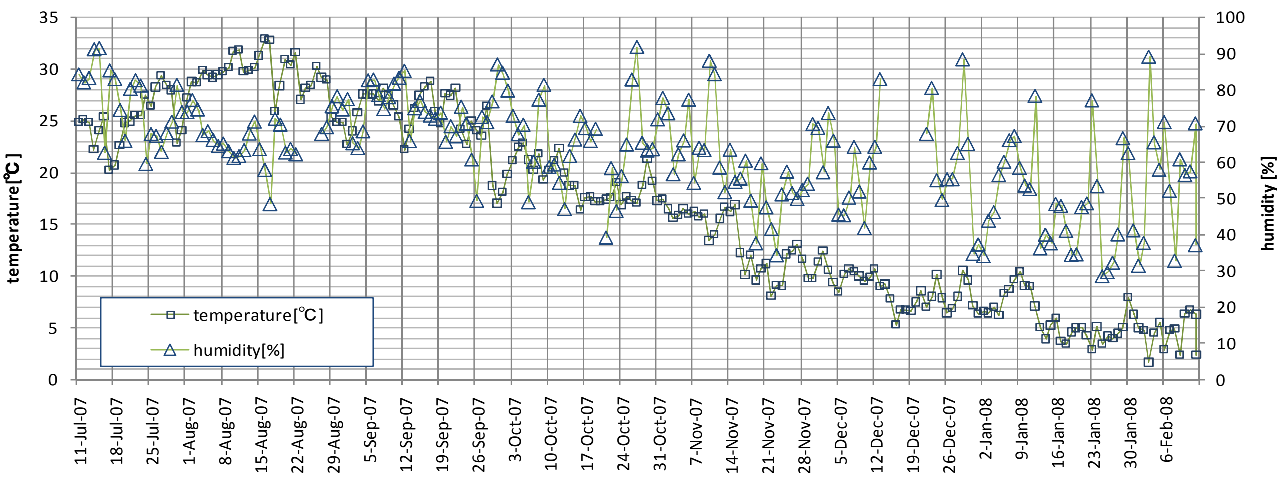


Figure 10. Daily average outside temperature and humidity

3.3.2 Multiple energy consumption by day, calorie production per day, and system COP per day

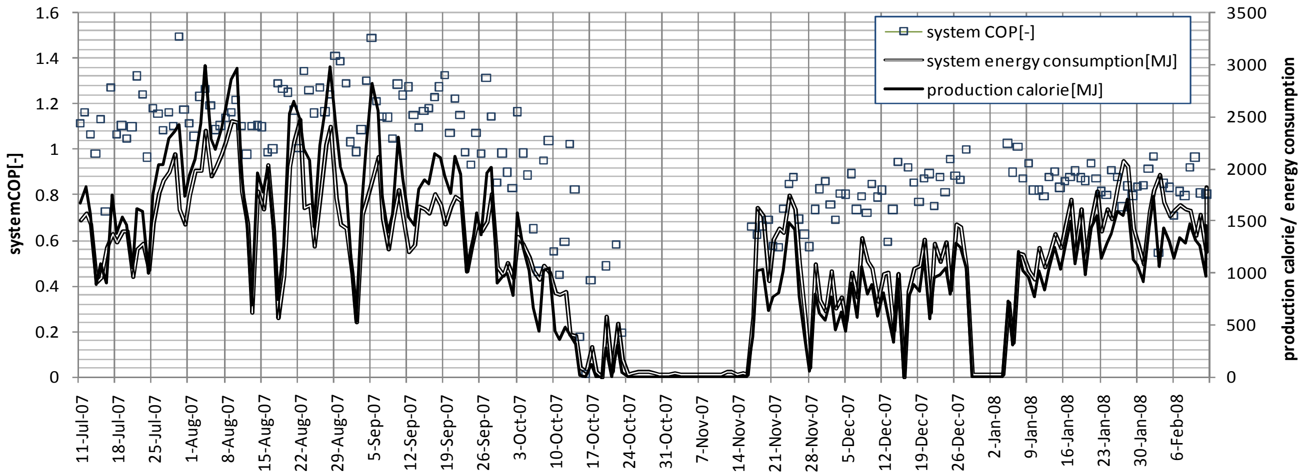
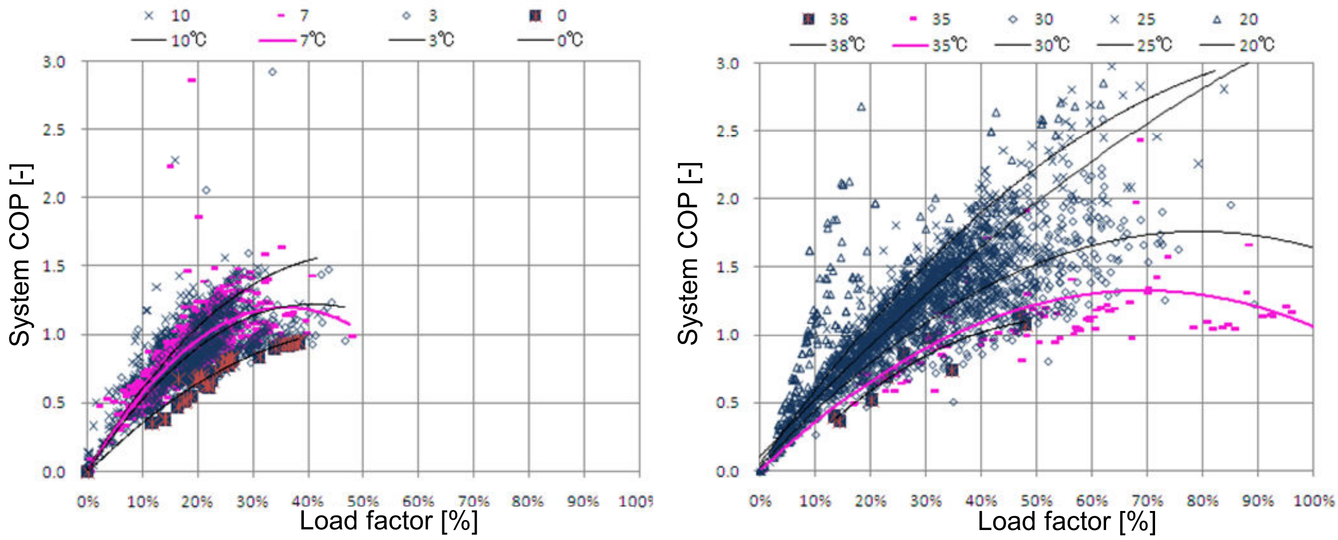


Figure 11. Multiple energy consumption per day and system COP per day

Figure 11 shows multiple energy consumption by day and system COP by day. The time from July 13, 2007 to October 24, 2007 was a cooling period, while the time from November 17, 2007 to February 11, 2008 was a heating period. The daily maximum energy consumption while cooling was 2851 [MJ/day] recorded on August 9, 2007; the maximum recorded during heating was 2066 [MJ/day] recorded on January 27, 2008. Average energy consumption while cooling was 1389 [MJ/day]; average while heating was 1223 [MJ/day]. Thus, more energy was used during the cooling period than during the heating period. Indoor heat generation rate from any equipment is assumed to be related. Average system COP during cooling was 1.05, while that during heating was 0.82. Generally, when the outside air temperature is low, system COP improves at the same load during a cooling period. However, Figure 11 does not show this trend, because the load of the object system was changing.

3.3.3 Object system characteristic

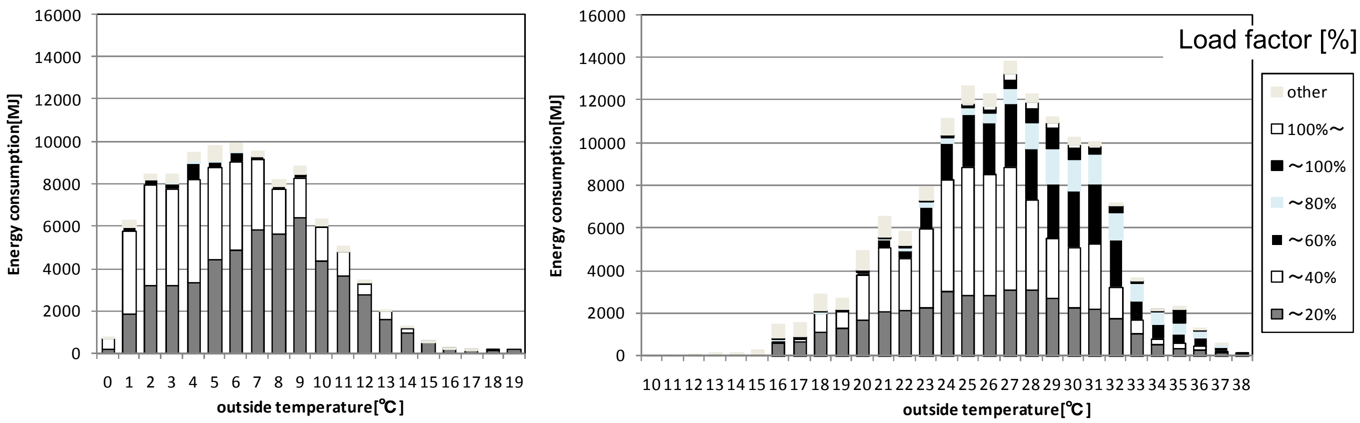


a) Heating *b) Cooling*

Figure 12. Object system characteristics during: a) Heating b) Cooling

Figure 12 shows object system characteristics. System COP and load factor are plotted every ten minutes for each typical outside temperature. Load factor is a value for which calorie production is divided by specified ability. In Japan, specified ability in cooling is determined at an outdoor temperature of 35°C and indoor temperature of 27°C. And, specified ability in heating is determined at an outdoor temperature of 7°C and indoor temperature of 20°C. At the same load factor, system COP improves with a low outside temperature during a cooling period. Similarly, system COP improves with a high outside temperature during a heating period. Additionally, system COP is high too, when load factor is high at any outside temperature. However, during the cooling period, the load factor of 25% or less increased to 44%. And during the heating period, the load factor of 15% or less increased to 43%. At these low load factors, system COP also is low.

3.3.4 Energy consumption according to outside temperature



a) Heating *b) Cooling*

Figure 13. Energy consumption according to outside temperature a) Heating b) Cooling

Figure 13 shows the amount of multiple system energy consumption at each outside temperature. The bars are classified by load factor and were divided group into categories of 20%, 40%, 60%, 80%, and 100%. Ventilation mode of indoor unit and standby power are classified as "other." The energy consumed reached a maximum of 13850 MJ at an outside temperature of 27°C during cooling, and a maximum of 9946 MJ at an outside temperature of 6°C during heating. Additionally, during cooling, most of the system energy consumption was at a load factor of 40% or less. As mentioned earlier, during heating, indoor heat generation rate from any equipment may ease object system load. Generally, energy is used for driving that load factor and system efficiency is not high. Moreover, energy use at low load factor is not lost to outside temperature.

4. Conclusions

This study describes a probe insertion method for on-site evaluation of VRV systems and demonstrates the usefulness of actual measurement. The object VRV system operation does not interfere with the probe insertion method, which is highly advantageous. In addition, this method is easy to apply and perform.

The measurement example clarifies the actual operation of the VRV system. First, the evaluation period included 30 weeks covering both summer and winter, with system COP demonstrating actual performance. The performance was not maintained by a relative increase in low load factor. Second, the object system characteristics show the possibility of high-performance VRV system operation. However, most actual operation was at a low load factor and low system COP. Third, energy is used at a low load factor, and low load factor exits at each outside temperature. These data suggest a lack of stability in VRV system operation, possibly due to facility design and the demand of the indoor unit.

This study demonstrates that it is very difficult to achieve a high-performance VRV system (according to the catalog) over the long term.

References

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PHYSIOLOGICAL AND PSYCHOLOGICAL EVALUATION OF SOUND AND LIGHTING ENVIRONMENT IN TAIWAN' S EXPERIMENTAL SUSTAINABLE BUILDINGS

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Keywords: Ryodoraku, physiological and psychological evaluation, sound environment

Summary

The reduction of energy consumption on air conditioning in sustainable buildings of subtropical areas is a critical issue. However, noises can be transmitted easily in semi-open living space due to the necessity to utilize natural ventilation in buildings. In order to avoid the noise and promote the privacy of Inhabitants in a semi-open living space, a specific type of Background Music(BGM)+Soundscape system was applied into this experimental sustainable building (Symbiosphere1Center). Furthermore, the physiological and psychological evaluation of Background Sound+Lighting(BGS+L) system for symbiotic living environment were carried out. The project was carried out by four participants who live in the urbanization area, but they were situated in Symbiosphere 1 Center for experiment. The evaluation of experiment was measured for 3 days after their arrival. In order to compare the difference, the other two long-term residents were as the contrast group. The evaluation of experiment was measured in the length of 60 min. per test at immobile time for 3 days. The psychological evaluations were obtained by the 6 semantics analyze that are included comfortable, relaxed, etc. Moreover, the physiological reaction is measured by using a Ryodoraku detector of Traditional Chinese Medicine. The results show a positive effect of psychological reactions in BGM environment. The participants' reactions become more comfortable, stable, relaxed, and joyful of the psychological assessment. However, the Ryodoraku reactions are affected after 30 min exposed but not in the long-term exposed. The evaluations of Ryodoraku values of four short-term exposed participants were obtained and exceeded the health range at the first day, but their Ryodoraku values of meridians were obviously improved and recuperated to the health status in Symbiosphere 1 Center at the second and third day. However, the Ryodoraku values of two long-term exposed participants whose Ryodoraku values of meridians are within the health range. The results show Symbiosphere 1 Center provides the possibility for living in health in comparison with the situation of living in the urbanization area.

1. Introduction

Taiwan is located in subtropical zone as sustainable building that the natural ventilation is typically designed for a semi-open living space(Chiang,2002). Under such condition, the sound is very freely to emit. Therefore, the conversation of residents will be the interference to each other in the living space. On the other hand, there is no privacy and perplexed for the sound disseminating(Lin,2005).

This research carries out the establishment and operation evaluation of Background sound (BGS) system (consist of Soundscape and BGM), and carry out an psychological evaluation to identify the usefulness of BGS system. Life and environment sound (Soundscape) system contains four sets of microphone in order to collect the sound sources from life and the environment in Symbiosphere 1 center. The sound sources were mixed adequately by microphone mixer and broadcast to the public area in order to receive the message from the life, environment and the weather immediately. BGM system broadcast Background Music (BGM) by central DVD player and speakers in individual rooms, residents can adjust volume or turn off the music in individual rooms. Effect of mixed-sound can increase the abundance of the life sound environment, mask the noise and promote the privacy of residents.

2. Evaluation of BGS System

After operation for two months, an psychological evaluation of BGS system was carried out. The evaluation scale was divided into 7 with a mean of 4. The analysis of the questionnaire for Soundscape system appears that it is satisfied highly with the users (the average evaluation is 5.6 points). The analysis of the questionnaire for BGM system appears that it is satisfied highly with the residents (the average evaluation is 5.8 points). The style of the broadcasted music of the BGM system was piano music. Most of the users were satisfied with this kind of BGM. The results of the questionnaire analysis for BGS system appears that The residents were satisfied with the BGS system (including the Soundscape and BGM) , the average point is

5.6. It appears that this system can be accepted by the residents (as shown in Table 1). Furthermore, the physiological and psychological influence evaluation of BGS+L system for symbiotic living environment were carried out.

Table 1 The integral satisfaction evaluation of BGS system

evaluation of system	average point of satisfaction
Soundscape system (life and environment sound)	5.6
BGM system (background music)	5.8
BGS system (consist of Soundscape and BGM)	5.6

3. Physiological and Psychological Evaluation of Sound and Lighting environment

3.1 Laboratory environment

The testing location is one of the living units in Symbiosphere 1 Center (*Figure 1*). During the testing, the indoor temperature 19• ; relative humidity 75%, the indoor table lamp and headlight were open at the average 408Lux. The indoor background noise was measured around 43 dB(A), and 56 dB(A) with BGM broadcast.

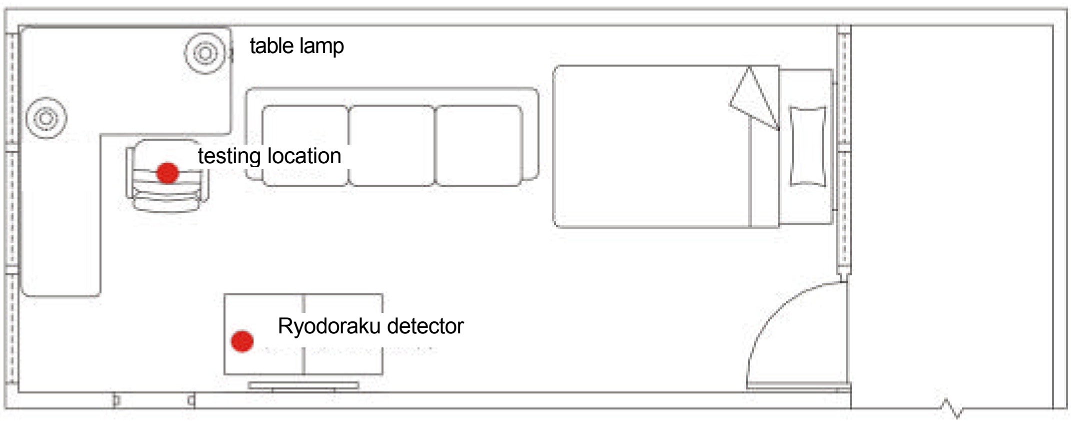

Figure 1 The plan of laboratory and test arrangement.

3.2 The Evaluation Methods

The psychological evaluations were obtained by the 6 semantics analyze that are included comfortable, relaxed, stable, awake, and weary of the psychology assessment criterion. Moreover, the physiological reaction is measured by using a Ryodoraku detector of Traditional Chinese Medicine. The value of Ryodoraku reaction is depended on the electric resistant of the object. The Ryodoraku is increased with the resistant decreasing.

The physiological reaction is measured by using a Ryodoraku detector of Traditional Chinese Medicine(Kobayashi,1986).The project was carried out by four participants who live in the urbanization area, but they were situated in Symbiosphere 1 Center for experiment. The evaluation of experiment was measured for 3 days after their arrival. In order to compare the difference, the other two long-term residents are as the contrast group. Piano music (56dB(A)) was used as BGM sound source. The evaluation of experiment was measured in the length of 60 min. per test at immobile time for 3 days.

4. Results and Discussions

4.1 The Influence of BGM on the psychology and physiology of human

4.1.1 Reaction of the percipience of human psychology

The influence of BGM broadcast (after playing, 15 min and 30min) was investigated (*Figure 2*). The results show a positive effect of psychology sensation. The tester's sensations become more comfortable, stable, relaxed, and joyful of the psychology assessment in BGM with a piano music.

4.1.2 The Ryodoraku reaction

The Ryodoraku is measured in the varieties BGM broadcast conditions results were shown in *Figure 3~4*. There are significant effects on the meridian and channel reaction (such as Pericardium Meridian, Heart Meridian, Sanjiao Meridian, Large Intestine Meridian, and Bladder Meridian) in the both 15 min. before and simultaneous BGM broadcast. However, the human body adapts the BGM condition and the Ryodoraku reaction recuperates to the original status after 30 min. BGM broadcast.

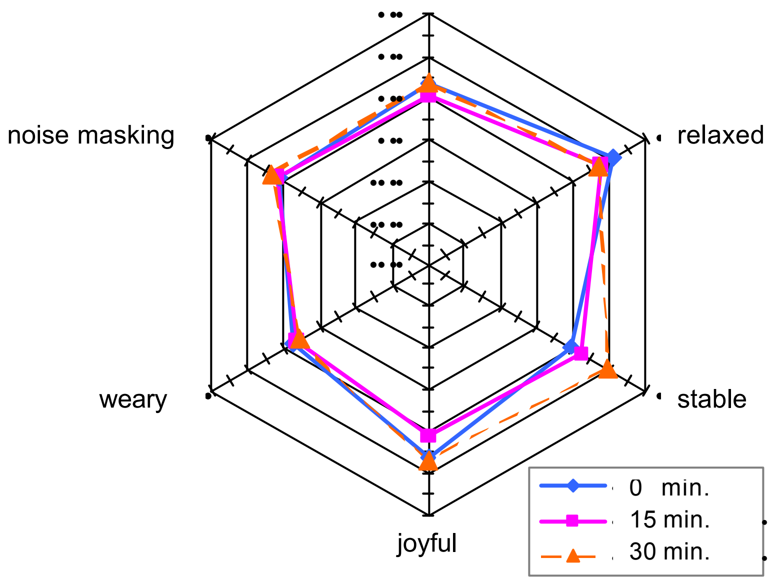

Figure 2 Overall evaluation of influence of BGM

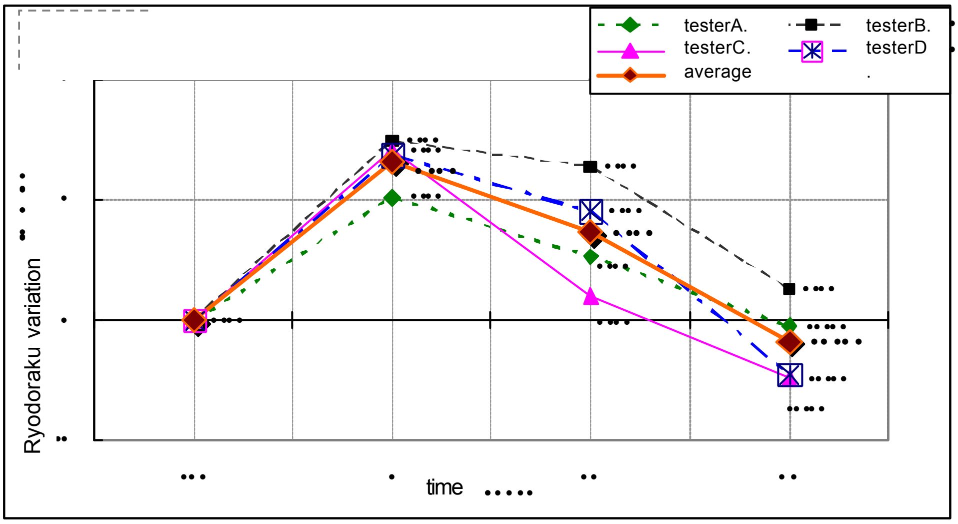

Figure 3 The time average of Ryodoraku reactions were measured at varieties BGM broadcast conditions

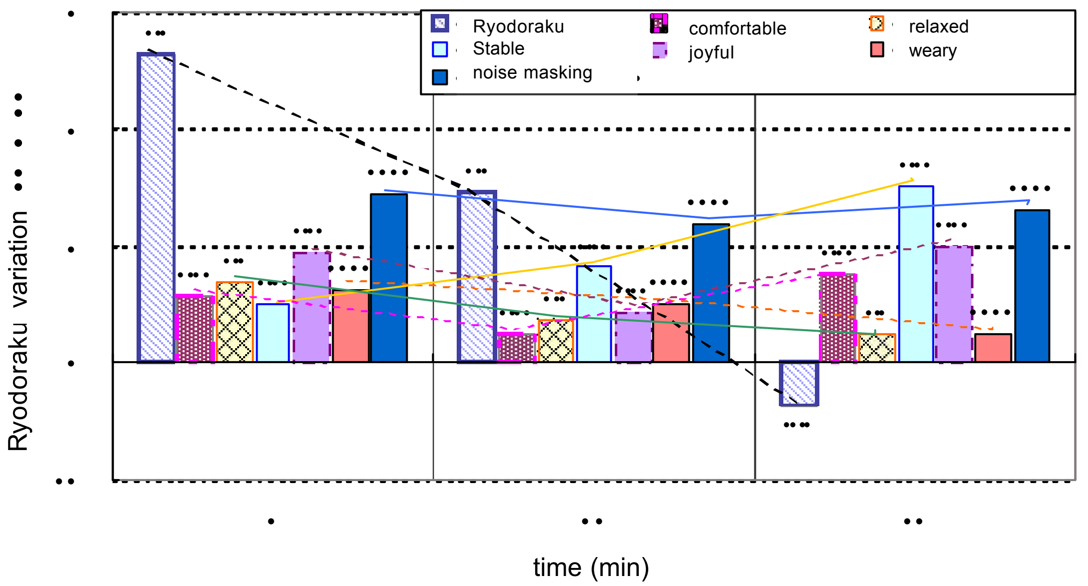

Figure 4 The time average of Ryodoraku reactions and the psychology were obtained at varieties BGM broadcast conditions

4.2 The trend of Ryodoraku of the short-term residence

The average Ryodoraku values for four testers in 3 days period of the measurements were shown in *Figure 5~8*. For Tester A ,the Ryodoraku values (Sanjiao Meridian, Left-side Liver Meridian, and Right-side Gallbladder Meridian) are exceeded the health range•• ••• • • in 1st day. Furthermore, all Ryodoraku values recuperate to the health status in 2nd and the third day.

For Tester B ,the Ryodoraku values (Sanjiao Meridian) are exceeded the health range in 1st day. However, the Ryodoraku values of Pericardium Meridian, Heart Meridian, Liver Meridian, Kidney Meridian and Bladder Meridian are at upper limitation. The Ryodoraku values of Pericardium, Heart, Liver, Kidney, and Bladder Meridian are recuperated to the original status in the third day. Furthermore, the Ryodoraku value (Sanjiao Meridian) is drew back to the health status.

For Tester C, the The Ryodoraku values (Sanjiao, Bladder, and Stomach Meridian) are significant exceeded the health range in 1st day. However, the Ryodoraku values of Pericardium Meridian, Heart Meridian, Liver Meridian, Kidney Meridian and Bladder Meridian are at upper limitation. The Ryodoraku values of Sanjiao, Large Intestine, and Stomach Meridian are significant improved and recuperated to the health status in the third day. Furthermore, others Meridian Ryodoraku values are drew back to the original status.

For Tester D, the The Ryodoraku values (Lung, Pericardium, Liver, and Stomach Meridian) are exceeded the health range in 1st day. However, The Ryodoraku values of Lung, Pericardium, and Liver Meridian are significant improved and recuperated to the health status in the third day.

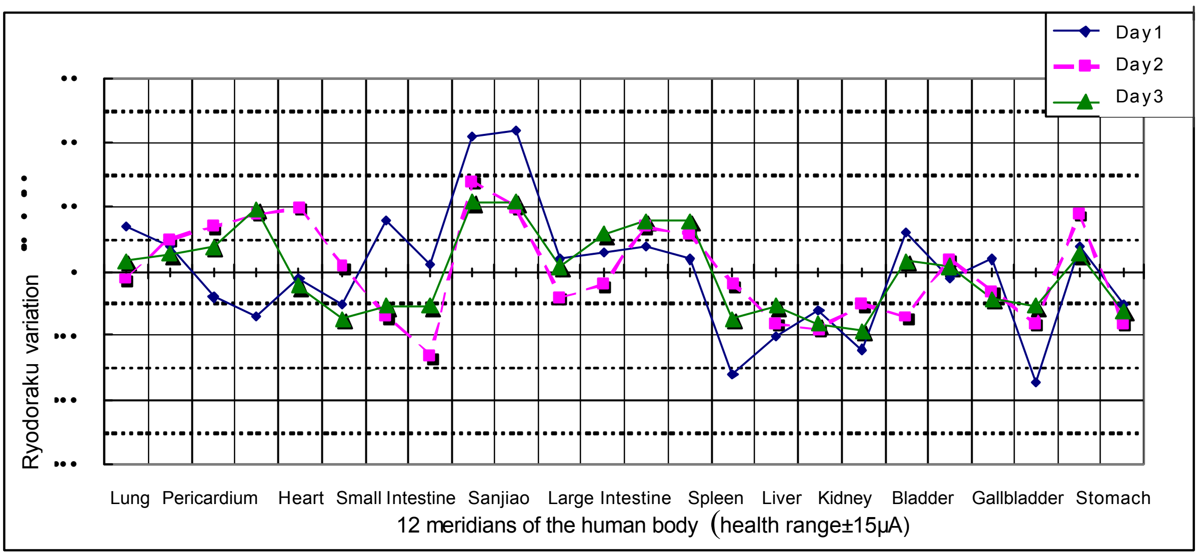

Figure 5 The Ryodoraku reactions of Tester A who lived in Symbiosphere 1 Center for 3 days

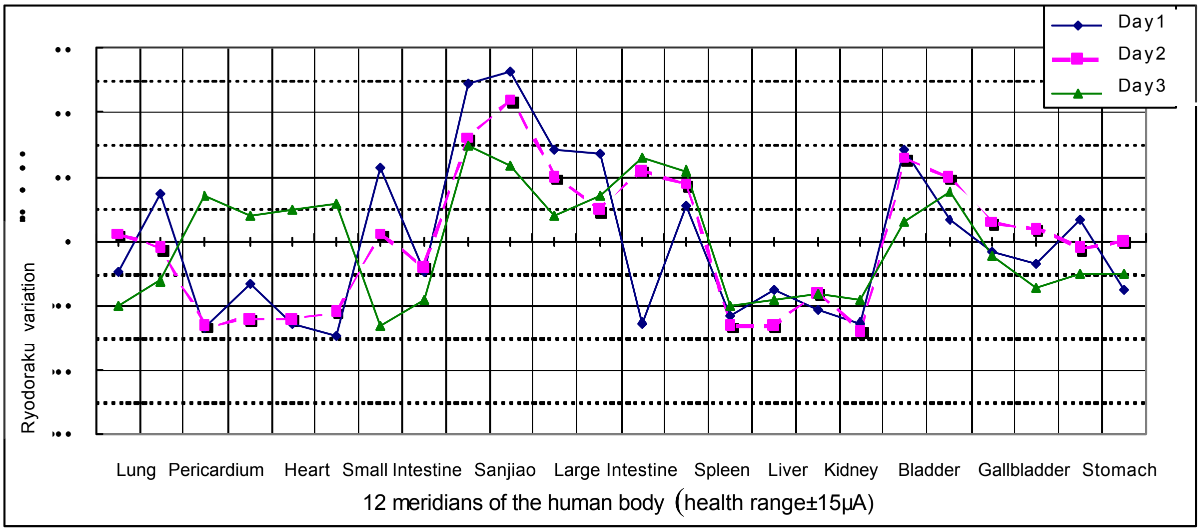

Figure 6 The Ryodoraku reactions of Tester B who lived in Symbiosphere1 Center for 3 days

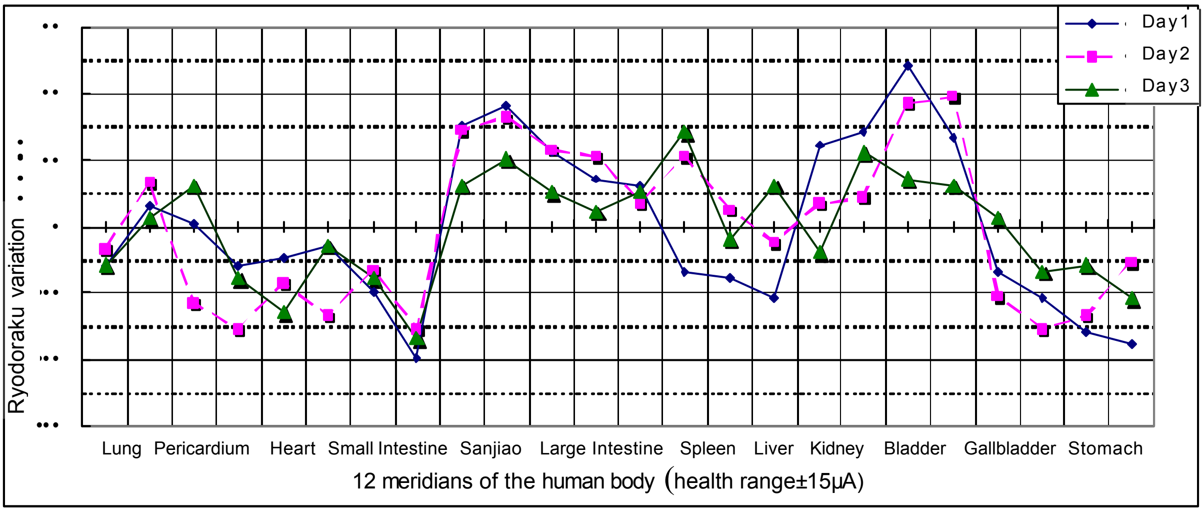

Figure 7 The Ryodoraku reactions of Tester C who lived in Symbiosphere1 Center for 3 days

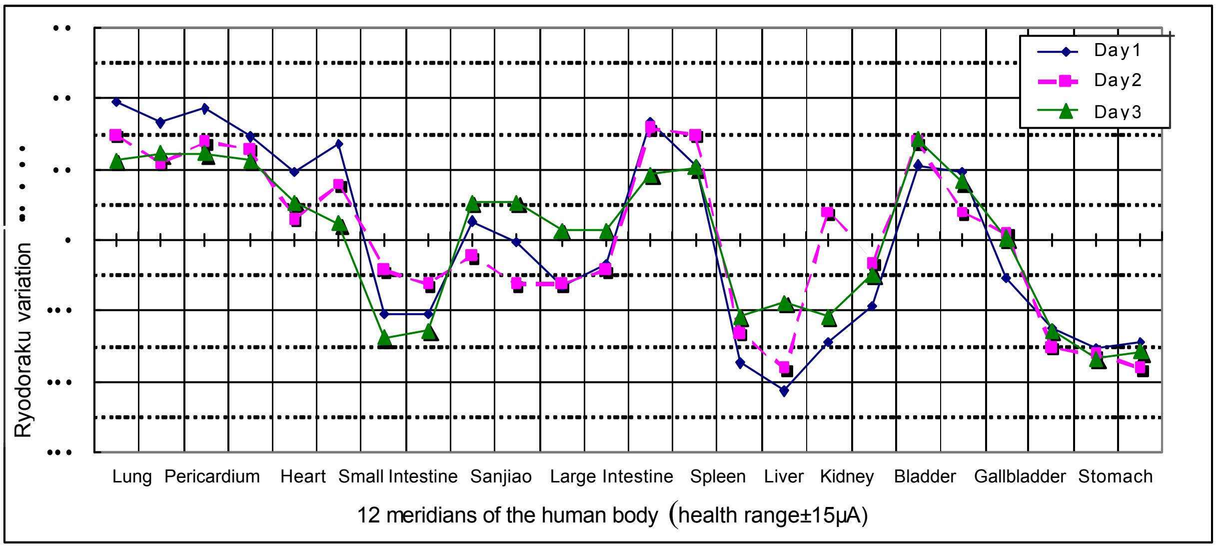

Figure 8 The Ryodoraku reactions of Tester D who lived in Symbiosphere1 Center for 3 days

4.3 The trend of Ryodoraku of the long-term residence

The average Ryodoraku values for two long-term living participants were shown in Figure 9. The Ryodoraku values of two long-term exposed participants whose meridians are under the health status. Symbiosphere 1 Center environment provides the better health in long-term living participants than comparison with the situation of short-time living participants.

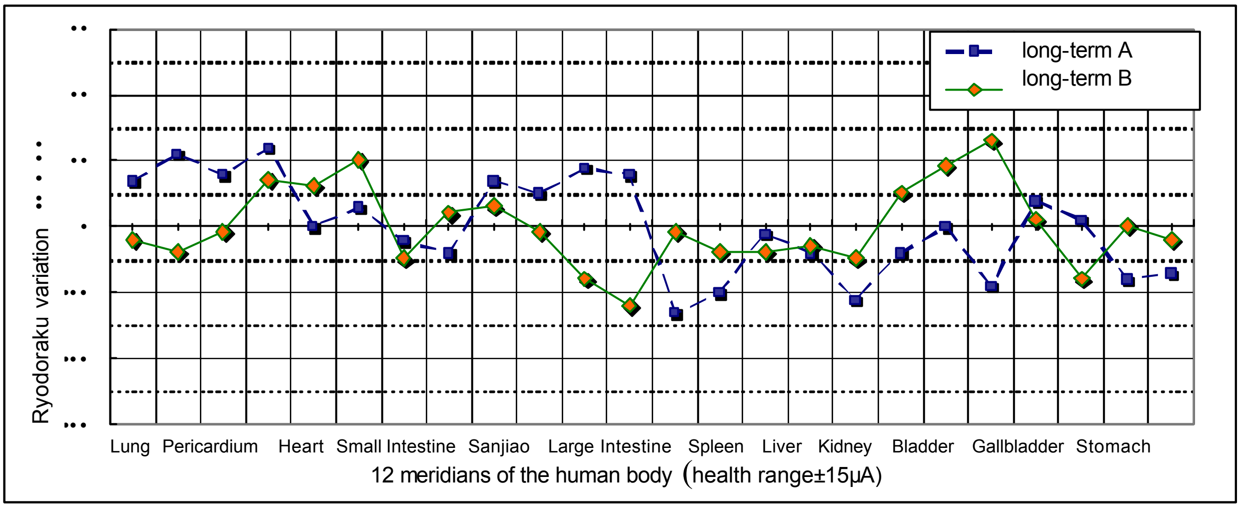

Figure 9 The Ryodoraku reactions of participants who lived in Symbiosphere 1 Center for long-term exposed

Conclusion

The results show a positive effect of psychological reactions in BGM environment. The participants' reactions become more comfortable, stable, relaxed, and joyful of the psychological assessment. However, the Ryodoraku reactions are affected after 30 min exposed but not in the long-term exposed. The evaluations of Ryodoraku values of four short-term exposed participants were obtained and exceeded the health range at the first day, but their Ryodoraku values of meridians were obviously improved and recuperated to the health status in Symbiosphere 1 Center at the second and third day. However, the Ryodoraku values of two long-term exposed participants whose Ryodoraku values of meridians are within the health range. The results show Symbiosphere 1 Center provides the possibility for living in health in comparison with the situation of living in the urbanization area.

Acknowledgements

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MODULAR STRAW BALE BUILDINGS PREFABRICATED IN A "VIRTUAL FACTORY"

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Keywords: virtual factory, renewable resources, sustainable building, industrialized series production, mass customization

Summary

As a result of research and development in straw bale building technology, the need for a modular, prefabricated straw bale building system has been recognized.

The production itself is organized in a so called "Virtual Factory", which makes the best use of already existing small-scale local players like carpentries and farmers (for raw material), while marketing and logistics are organized centrally. The main benefit of this structure is its flexibility caused by the network of local actors. Furthermore the application of prefabricated systems produces higher profitability resulting from less construction failures. Design can be also customized. The system is anticipated to be competitive over big players based on the strength of professional central planning and logistics.

1. Background: Growth of Sustainable Building Solutions

In many countries, especially in Western Europe, sustainable building solutions have been widely introduced in the market (e.g. a thousand passive houses in Austria). Through research and development programmes supported by governmental institutions, a wide range of new construction materials and building components as well as efficient engineering methods have been developed especially in consideration of sustainability.

The "S-HOUSE (www.s-house.at)" is an extraordinary example of a passive house. Profound basic research on the materials and the reflective design and construction which consider economic and environmental consequences were done by the Centre for Appropriate Technology (GrAT). The whole project was funded by the government of Lower Austria, the Austrian Federal Ministry for Transport, Innovation and Technology (BMVIT) through the "Building for Tomorrow" programme and the EU-LIFE Environmental programme. The paramount achievement of the S-HOUSE is the integration of all relevant aspects of sustainable building methods, from selection of materials to disposal. As a result, the building is below the high standard of energy consumption for passive houses with approximately 6 kWh/m²year. Material and energy consumption were minimized during the construction of the S-HOUSE by a Factor of 10, compared to conventional constructions applying state-of-the-art technology (tested in cooperation with IBO, the Austrian Institute for Healthy and Ecological Building). The building demonstrates appropriate use of building materials derived from renewable raw materials. In addition, a large number of suitable solutions have been developed that enable problem-free reuse of all building materials after completion of their lifespan. During the entire development of the project, close cooperation between experts in different fields resulted in achieving innovative technical solutions, such as a particular screw for straw bale mounting and biomass stoves. Specific building engineering techniques led to significantly reduced energy consumption.

Other excellent practices supported by the "Building for Tomorrow" program demonstrate how resources can be saved, and how innovations can be realized. Renewable building materials like straw, reed and clay show reliable physical properties, highly effective heat insulating ability and safety levels (e.g. fire resistance). They ensure simple rebuilding and optimum reusability after application in constructions. Furthermore in terms of social benefit these materials can contribute to the enhancement of the regional economic growth.

Today, there is a wide range of high quality products made from renewable raw materials available. Growing numbers of clients are interested in sustainable and environmentally sound solutions. As an indicator, the number of energy efficient buildings in Austria rose from 154 in 2002 to 950 buildings in the year 2005. However, the limitation of these sustainable building solutions was recognised developing the S-HOUSE project. As mentioned earlier, this building is remarkable as it combines the whole spectrum of sustainable building solutions. Extensive studies were required to search for and figure out right materials among the great variety. Also, harmonious amalgamation of those alternatives was another important task of all partners involved. Therefore, as a follow-up scheme of the S-HOUSE project, the series production of those construction materials, engineering knowledge and dissemination strategies was suggested.

2. Limit of sustainable building solutions in the market

In spite of the increasing market awareness and acceptance of sustainable building alternatives, related players (i.e. architects, research centers, companies) still remain in the non-mainstream group. If one builds a house without making particular efforts, it will be provided by the majority of housing enterprises with materials and methods that do not sufficiently consider the economic and environmental performances. Why are the companies specialized in sustainable building solutions not competitive enough in the market? There are a number of obstacles to market expansion, and they are linked one way or another. The following points explain those factors:

- Cost

For many years there has been a continuous increase of building costs in the industrialized countries in Europe. Most of material products such as food, cars and many other artifacts are mass-processed or mass-produced. Through the economy of scale effect, these outputs can be sold at a lower price. However in Europe houses are rather individually designed and constructed. Therefore design and building costs are still at a high level. In these circumstances, a single house remains a prototype.

- Quality consistence

Currently, prefabricated systems are scarcely used. The main parts of the building are erected at site which results in time losses caused by a lot of manual work combined with unpredictable weather risks. When the shell is finished, wiring and plumbing risks to destroy the airtight construction. Production today is characterized through 'one by one' prototyping, spontaneous finishing on site, inconstant quality problems, and informal dissemination of construction techniques. Partly or completely prefabricated systems are more efficient as they are standardized and not manufactured at site. Also, the prefabrication level results in lower costs, lower weather risks and lower probability of critical failures.

- Limited research efforts

Building companies often lack research with which they can improve building and construction qualities, in terms of materials, energy efficiency, air tightness, heating systems and so forth. The disconnection between the upfront technologies and actual application delays progress of the industry. One of the major reasons is that training for workers is too expensive. On the other hand, the new skills of workers are generally not noticed, relevant information is handed down orally and only among workers. Systematic evaluation of the state-of-the-art in technological development and training of workers will accelerate business growth and improve quality.

- Lack of cooperation among stakeholders

Numerous companies are related to building and construction business. However, their cooperation is extremely limited. For example, producers of building parts can not control the application of the products. Workers on site do not pay enough attention to the product application in order to achieve optimal performance. This may lead to significant loss in utilization of specific product features. Being concerned with cost increase, builders often hesitate to involve new expertise. For best outcome, however, engagement of relevant stakeholders seems highly required. Customers/building users are important players. Their specific needs and wants need to be taken into account in planning, designing and constructing as much as possible. Lack of sufficient communication between actual users and builders may bring additional work as well as degradation of customer satisfaction.

- Absence of institutional framework

Environmentally friendly building materials are sometimes not certified, therefore not generally accepted in the marketplace. For example, straw bales are hardly obtainable as a building material despite their large amount available in the field as a by-product of cultivation. There is no official quality control standard of straw bales to be used in buildings and there are few reliable suppliers. This is a burden for the customer who wants to build a straw bale house, especially if he also has to convince skeptical building companies, who have no experiences in building with straw. The material is 'new', not standardised, and varies in its dimensions.

To summarise, an industrial evolution is urgently needed in the sustainable building area. Currently, many of ecological building materials and techniques are far from series production and standardization, in spite of their excellent ecological performance (Wimmer et al. 2001). The proliferation is strongly dependent on motivated and idealistic owners and architects. As mentioned earlier, the hindering factors above are fairly related to each other. With a small number of solutions most of the problems can be solved.

3. Market analysis: prefabricated production and construction

In the building sector in general the following three production methods are commonly used:

1) Fully industrialized mass manufacturing. Buildings are prefabricated in factories in large quantities. High quality is guaranteed by standardization and prefabrication of the construction elements. Professional marketing, extensive official achievements or additional equipment distinguish the suppliers.
2) Highly individualized manufacturing. Small companies, for example carpentries or master builders, carry out the whole planning and production processes. The building is mainly constructed on the building site.
3) The partial prefabrication of components, like a wall segment. These standard components are mounted at the building site.

It is clear that prefabricated construction can reduce building costs, as companies can manufacture at a cost-effective volume of production and increase the quality level.

There is an emerging trend of prefabrication for building materials and parts in the global scale. In terms of the total number of prefabricated buildings, Japan is the leading country in the world. Considering their strong prefabrication technologies in the car industry it is not surprising that they expanded the application of prefabrication into housing. The number of prefabricated houses in Japan in 2005 was 156.254, and the market share (rate of occupying in all residences) is 12.6% (Prefab Club 2005). Among the 1.230.000 residential houses newly built, about 1 in 8 houses is a prefabricated house. One of the market leaders in Japan, the company Sekisui Chemical Co. Ltd. started its unit-housing business in 1970 with more than 80% of its houses being manufactured under quality control on assembly lines in the plants. The total number of Sekisui unit houses in Japan today is more than 400,000 and on average each house comprises 15 units, so there are about 6,000,000 structural units (Iwahara, Suzuki 2005).

The growing ratio of prefabricated houses is seen in European countries as well. For example in Austria, the market demand for pre-manufactured houses has constantly increased for many years (Kreutzer, Fischer & Partner 2007). An international comparison shows that the highest share of prefabricated (single family and semidetached houses) houses can be found in Sweden followed by Austria with 33 %, Great Britain with 15%, Switzerland with 12% and Hungary with 3.9 %. In Austria, the number of prefabricated houses has increased from 400 in 1970 to 5,350 in 1998. Approximately 31% were sold in Lower Austria. Prefabrication for parts has been growing but is mainly used for office buildings or hotels.

Nonetheless, there is a clear difference between prefabricated housing companies in Japan and Europe. Japanese housing companies are mostly large enough to produce the whole prefabricated houses including the interior decoration at the factory. They can standardize dimensions of parts, and therefore, relatively easily integrate them under one roof system. A remarkable point is that some of them (e.g. Sekisui Chemical) are highly devoted to environmental performances of their business and they try to provide such products and services.

In contrast to this, housing companies in Europe are dominated by small- and medium- sized enterprises (SME). Especially, those who are environmentally conscious are often very small. Contrastingly, large housing entities do not pay enough attention to sustainable issues. When considering this specific situation in Europe, a different approach is required to make prefabricated sustainable housing system possible.

4. Industrialised Serial Production

Industrialized serial production using the "Virtual Factory" is the solution GrAT suggests. This new concept for production and logistics for sustainable building components and technologies can make the sector more competitive in the market. The key strategies are as follows.

4.1. Virtual Factory: Centralized Planning and Localized Production

The title "Virtual Factory" describes the characteristics of the partnership. SME in a certain regional boundary form a membership-based association to provide customers with a range of sustainable building solutions. The Virtual Factory consists of two parts by large. At the centre is a group of organisations in charge of strategic planning, basic element design (e.g. modularization), quality control, logistics, R&D, and marketing. Production, delivery, and construction of components itself is processed by registered members individually or collectively. The members are mostly already existing small-scale players like carpentries and farmers (for raw materials supply). They are linked via the virtual network and share the strategic functions from the umbrella organization. Similar business models have been already successfully implemented in other branches such as furniture, fashion and other design related industries. Within building industries, however, the system will lead to a shift of paradigms. The following picture illustrates the envisaged transition processes in the Virtual Factory.

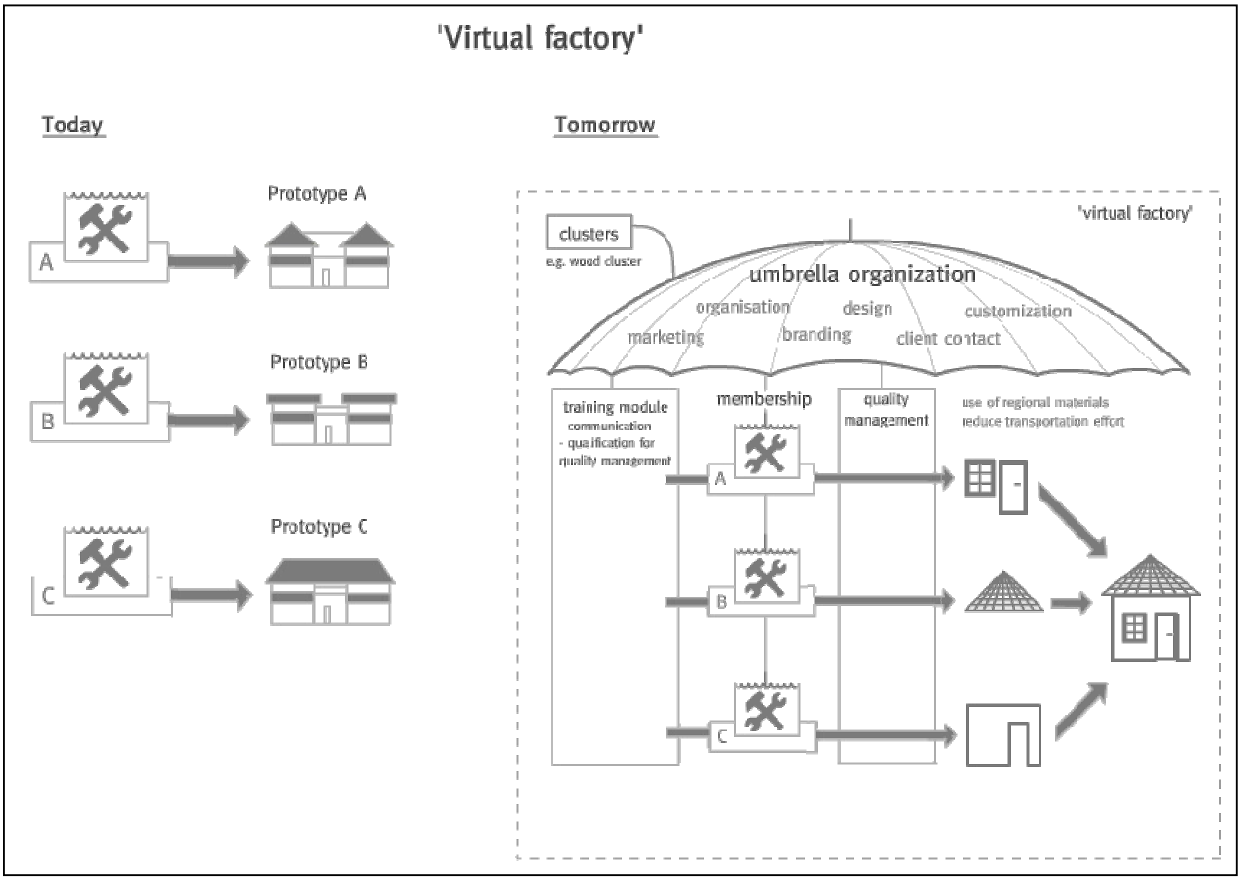

Figure 1 Industrialized production and construction through "Virtual Factory"

Today, if customers want to build sustainable houses, they need to organize each building element from different producers and combine them into one house by workers who are not specialized in sustainable building techniques. This approach demands a lot of time, energy, and money. Moreover, the result could be unsatisfying due to incompatibility of components and poor quality control. In the Virtual Factory system, they can order high quality houses with lower costs and within a short time.

4.2. Units and functions

The system of the Virtual Factory is characterized by the intensive segmentation of business functions and the strong quality control.

- Umbrella organization

The umbrella organization includes all the companies which participate in the planning, designing, construction, and marketing processes. As local companies produce and assemble prefabricated systems according to the order from this organisation, their role in the virtual network is highly important. They need to establish an intelligent modular system which allows flexible assembly of various components produced by different producers. The communication between the umbrella organization and the producers should be systematized precisely and efficiently. In a sense, this umbrella organization can be understood as an enhanced unit of coordination, marketing and Single Point of Contact for the customer.

- Quality management and training

Quality control and training modules are vital as many of small building companies are yet lacking awareness and knowledge of renewable building materials. Sometimes these materials (e.g. straw bales) require specific treatment and sophisticated application. The quality of the building has to be strictly examined (e.g. thermo-graphical analysis, blower door tests, etc.) to guarantee the energy efficient performance, not only during the production processes but also during construction. Advanced training on the basis on the state-of-the-art technologies and skills will improve the overall quality level of the outcomes.

- Logistics

The key to the success of the system lies above all in a centrally steered efficient logistics. Managing logistics is necessary to enable companies to work together and to avoid long transport distances. The chance arises to minimize the distance of transport as a result of the dispersion of the production plants. This is especially relevant in terms of the large quantity and rising transportation at the building industry.

- Purchasing association

To raise the market share a competitive price and customer acceptance is important. Therefore the umbrella organization functions as a buying syndicate to achieve lower prices for passive housing components. Buying syndicates are common in the sports or electrical goods branch. Such an association enables lower wholesale prices by means of its higher purchase power. Thus small shops, especially those in rural areas, can compete with large franchise shops. It seems that this kind of syndicate could be a feasible way for them to achieve higher profitability whilst sustaining their original scale.

4.3. Benefits

The benefits of this structure are manifold:

- Low capital investment for establishment

Creating a virtual network among existing units costs far less than establishing a large firm. With relatively small amount of initial capital, internal infrastructure (e.g. communication media, shareware, etc.) can be set up. On the other hand, individual companies also have benefit in terms of initial investment. They do not need abundant expense for planning, customer contact, and marketing for new businesses. For example, a farmer can become a member of the Virtual Factory, and provide other straw bale producers with straw. From his point of view, straw is a by-product from his major business, i.e. farming, yet he can contribute to the sustainable building industry with some profit.

- Increased market competitiveness

Finally, such small players are able to compete with large companies with the strength of central planning, quality control, and viable costs. It is considerable that the local small enterprises will keep their traditional forms, yet evolve towards industrialised processes through the virtual partnership. Such cooperation will guarantee higher profitability and a higher market share of sustainable building solutions. Also, this concept is economically beneficial as a certain level of a feasible scale (i.e. number of production unit) can be achieved. Available production capacities can be used more efficiently. In terms of public advertisement, a common brand representing the partnership can be known in a far easier way. The great number of members can be already such a powerful marketing instrument.

- Independence of local members

The small companies who are members of the Virtual Factory can continue their current local business. They can get involved in the network, in order to provide their special knowledge and skills. In return, they gain not only financial payment, but also competitiveness by getting to know the latest research and technology information.

4.4. Design

The design of the construction plays a vital role regarding environmental and economic performances. The following principles need to be taken into account.

- Avoidance of mixture of building elements concerning durability and material composition

Currently, most of building materials are extensively mixed with renewable resources (e.g. wood, straw), mineral building products (e.g. clay, stone, glass), and synthetics (e.g. plastic, chemical substances). In sustainable building, it is important to separate these materials as far as possible to optimise reuse and recycling after the lifespan of the building.

- Customized design

Mass customization[1], the business model well-established in the car production, is one of the principles the Virtual Factory is based on. It enables the companies to sell customized products and at the same time using efficient production methods. Customers can choose their preferred options within a given range.

The customization centre discusses the type of construction as well as the price, planning and design with clients. There are several construction types and materials available. The selection is up to the customer and s/he can also to some degree modify structures. This individually customized planning is based on prefabricated components. By using computer applications, customers can already design their own buildings. They can choose desired size, exterior and interior design, and the location of doors and windows. During this process, prices for each application are already shown. Moreover, within the given structure and materials, the amount of energy and resource savings can be calculated.

Local prefabrication systems, for example, can produce kitchen units, staircases, heating facilities, electricity, ventilation, and plumping systems which satisfy the customers' preference. As far as they follow specific dimensions for modular assembly, they can provide diverse alternatives. A modular design enables high flexibility in architectural design.

- Modularised and standardized components

To make the sequential production and assembly feasible, the building components need to be modularised and standardised. Establishing module standards deserves a long-term investigation, development, monitoring and improvement.

- Detachable joining techniques

Detachable connections, especially of resource intensive building parts (e.g. concrete cellar) can dramatically reduce waste generation as well as construction time on the building site. Furthermore they can be refurbished and used for new buildings after its life time. The expansion and downsizing of buildings to address the changing customer needs (e.g. number of family members, various ambient) should also be taken into account.

- Accessibility of the installed equipment

Appropriate and timely maintenance and modernisation of parts can considerably expand the useful life time of buildings. For example, some facilities like heating, ventilation, and lighting can be upgraded. Therefore easy access to such units is desired.

The following table shows many advantages arise through the design principles along the life cycle of a building respectively.

Table 1 Advantages of modular, detachable constructions

Stage	**Advantages**
Planning	Clients can design various parameters within limited options according to their prioritised preferences and given budget. The basic construction stays the same.
Prefabrication	Standardized building components allow quick and seamless assembly on the spot, though multiple companies were involved in the production of different components.
Construction	Detachable joints allow short construction of the building shell and wiring.
Use of the building	The building can be easily expanded or downsized according to the needs of the owners.
Deconstruction and disposal	The detachable joints allow a non-destructive disassembly, and therefore facilitate further reuse of whole or partial components. Parts which are of no use can be sold, or environmentally disposed, owing to the clear separation of material types to be controlled in the early phase of fabrication.

[1] Mass customization refers to a customer co-design process of products and services which meet the needs of each individual customer with regard to certain product features. All operations are performed within a fixed solution space, characterized by stable but still flexible and responsive processes. As a result, the costs associated with customization allow for a price level that does not imply a switch in an upper market segment. (Piller 1998)

5. Discussion

The initiative of the Austrian Federal Ministry for Transport, Innovation and Technology (BMVIT) and rising prices for fuel boosted the development of energy efficient buildings in Austria. To reach low level of energy consumption a combination of air tightness, insulation, orientation of the building and ventilation technology is needed. The most material intensive part is the higher level of insulation to reduce heat loss. When designing sustainable building solutions, the materials used should be considered to minimize the amount of carbon dioxide emitted and the waste after the life span of the construction. In this context straw bales seem to be an ideal product because of their low thermal conductivity and their low impact on the environment.

In spite of the increasing awareness and acceptance, the main hindering factors to use straw bales are low availability, irregular dimensions and no professional marketing strategies to advertise the advantages of straw bales as building material. These problems are topics of other research projects addressed by GrAT.

Another hindering factor is the low prefabrication and standardization rate of sustainable buildings. They are mainly prototypes and therefore cannot compete with prefabricated houses.

In this context the Virtual Factory seems to be the most promising solution for the Austrian situation above all because it enables small companies to act as one network, share resources and gain more market power.

Geissler and co-authors (2005) highlighted the importance of large scale post-industrial production and trans-national marketing for the residential construction in the future. However, in the Austrian building industry which is characterised with small companies, it is not simply feasible. In this dilemma the Virtual Factory can be an intelligent compromise.

This concept addresses the business profile of building industry in Austria and many European countries: Instead of setting up a new large company, creating a virtual production sequence over a number of small companies can be a clever strategy in such SME dominant areas.

As a follow-up task of the successful demonstration of the S-HOUSE, an industrial series production concept has been elaborated. Materials and technologies taken in passive housing, including straw bales, will be further standardized and marketed by the Virtual Factory system. Because of the larger scale of production and centralized management power, higher economic and environmental efficiency will be achieved. Customization can be achieved within a number of options based on a modular configuration.

To prove and improve the concept of the Virtual Factory the first step will be to enhance the system of the Virtual factory whilst building a Zero Carbon Village (ZCV) with 30 to 40 units in Austria. The Virtual Factory will be put into practice, using mainly locally available resources derived from renewable resources, regarding logistics (reduction of transport), quality control, reducing transport, and achieving a high level of living quality. Additionally the ZCV will be energy autonomous due to reducing drastically the amount of especially electric and thermal energy through innovative ways of energy supply by renewable resources.

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STUDY ON CHARACTERISTICS OF MULTIFUNCTIONAL DOUBLE SKIN SYSTEM AND ITS EFFECT ON ENERGY CONSERVATION IN BUILDINGS

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Keywords: facade design, double skin, natural energy, thermal performance, cost performance

Summary

A multifunctional double skin system called NEXAT has been developed to minimize the thermal skin load of buildings while maintaining the perimeter area as comfortable as possible. NEXAT consists of a double glazing window unit equipped with Venetian blinds and an air flow control system comprising ducts, dumpers and fans. It can be installed in all building floors. It has five mode patterns depending on flow channel change and its relationship to the air-conditioning system. It improves energy saving because it has functions in addition to those of the conventional Japanese double skin system. Constant thermal performance was achieved for every mode in laboratory model tests, and confirmed by full size field tests from annual measured data. NEXAT was applied on a large scale on the west side facade (about 1,500 m^2) of an office building completed on January 31st, 2007. This paper describes the thermal characteristics of NEXAT and its effect on energy conservation in buildings.

1. System figure and feature

1.1 Schematic diagram

Figure 1 shows an example of an air-conditioning system incorporating NEXAT.

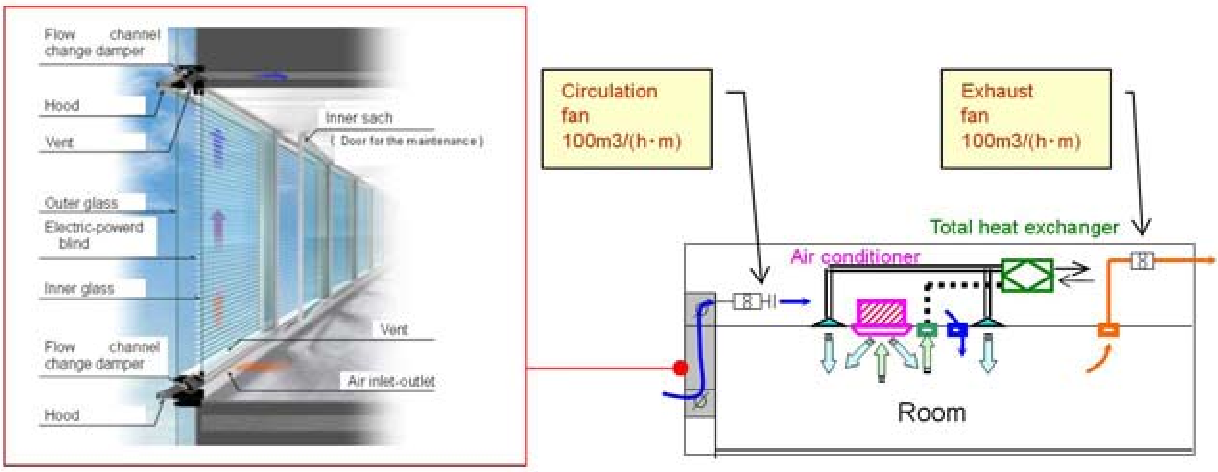


Figure 1 Schematic diagram of NEXAT

1.2 System feature

NEXAT provides an opening in the top and bottom of a double skin sash separated at each floor and has the mechanism of opening and shutting using a flow channel change damper. It adjusts the slat angle of the electric blind installed in the double glazed window so that it can introduce as much indirect natural light as possible while interrupting a direct solar radiation. It thus achieves air-conditioner energy saving while maintaining a comfortable thermal environment in the perimeter area throughout the year by self-adjusting the air flow according to the outdoor climate and the indoor thermal environment. It thus improves cost performance by reducing running costs (annual air-conditioner energy consumption) compared with that of the conventional double skin system. It reduces annual air-conditioner energy consumption by about 14%, and the initial cost by about 2.5%. As a result, NEXAT achieves a simple payback period of about 9 years. In addition, it is compact (20 cm deep) and can be used to retrofit existing buildings.

Figure 2 shows a mode pattern by flow channel change. In summer, the space within the double-glazed window is ventilated by letting outside air enter from the bottom and exit from the top by natural ventilation, which reduces the effect of solar radiation. In winter, the space is completely closed or ventilated by room air to reduce the window's thermal transmittance. When the solar radiation intensity is strong, this system can recover solar energy. In spring and autumn, outside air can be taken from the openings at the top or bottom of the window system, which results in ventilation cooling or night purging. This system provides three additional modes other than the summer sun shading mode and the winter insulation mode not provided by the conventional double skin system. These have the advantage of energy saving. Figure 2 also shows the restraint value of the energy saving effect. The annual energy reduction percentage becomes 34% that of the single skin sash system that uses a float glass due to the model building restraint.

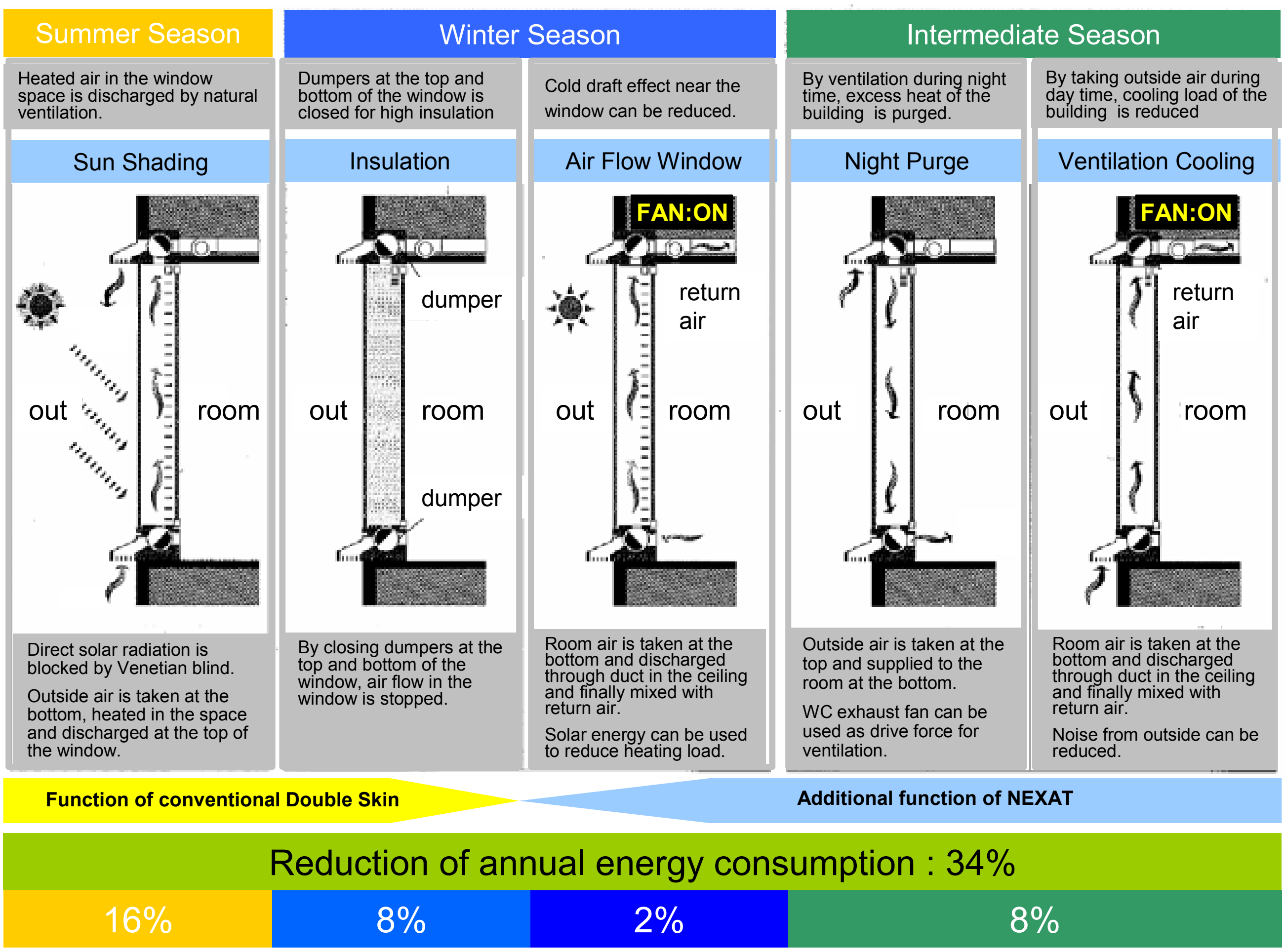
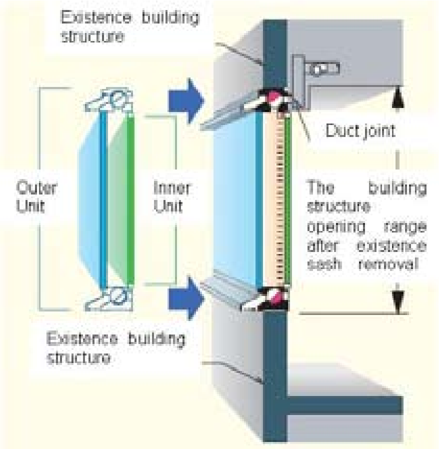


Figure 2 Example of effect of NEXAT on reduction of annual energy consumption of a building in Japan

Figure 3 shows two retrofitting methods for existing buildings. The field test discussed later is based on case 1.

Case 1



↑ (Case 1)

Remove existing sash and attach new inner and outer units.

Apply when there is no distance between the building's outer wall and the site boundary.

→ (Case 2)

Leave existing sash and attach only outside unit.

Case 2

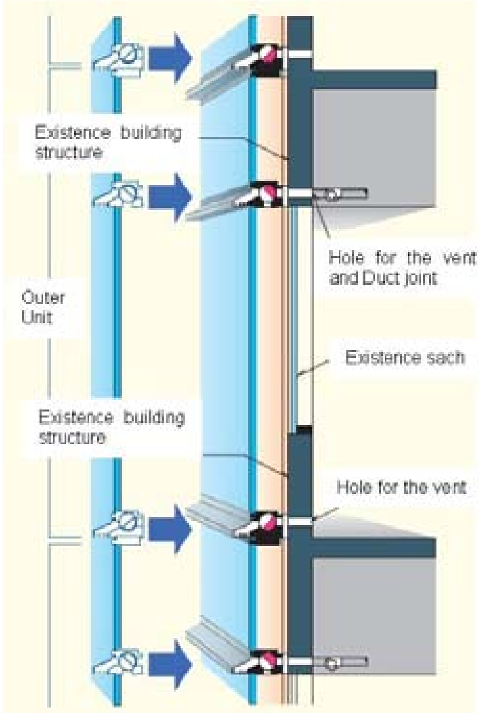


Figure 3 Concept of application to retrofitting of existing buildings

1.2.1 Thermal characteristics

Laboratory testing of thermal performance (Figure 4) confirmed that the sampler achieved the performance goal (solar shade factor 0.2) as shown in Table 1.

[Test apparatus]

Across the middle division wall installed in the sampler, the outdoor side comprises a low-temperature room and the indoor side comprises a constant-temperature constant-humidity room.

Sunlight is irradiated by the sunlight equipment from outside the room. (The irradiation is adjusted by changing the distance between the sunlight equipment and the irradiation surface.)

Temperature and wind speed are measured by a thermocouple and an anemometer installed in the sampler.

The sunlight equipment uses sunlight lamps (metal-halide lamp 150W×48) near the relative spectral energy distribution of the sunlight. The maximum irradiation becomes 600W/m^2 at 360 mm.

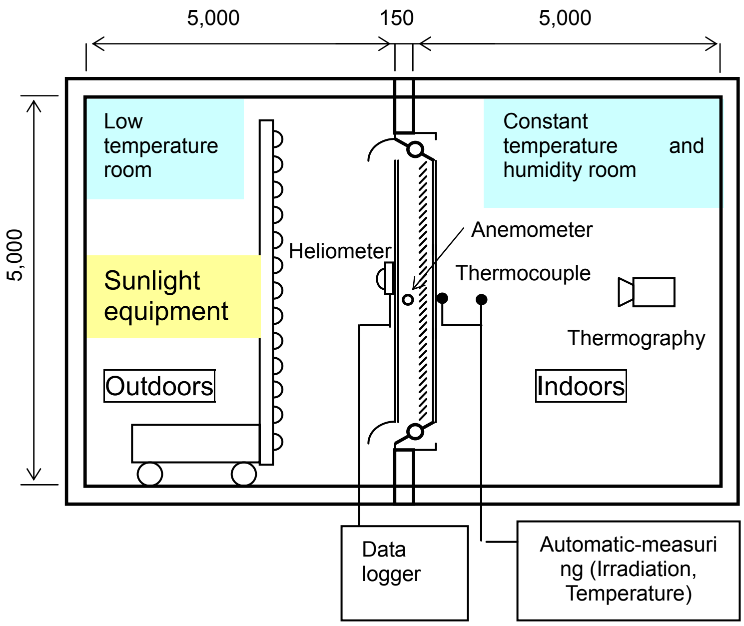


Figure 4 Thermal facility to performance test

Table 1 Thermal characteristics

Test item	Testing condition	Test outcome
Coefficient of heat removal	Mode：Sun Shading Outside air temperature：35℃ Room temperature：26℃ Irradiation：600w/m^2 （Equivalent to afternoon sun in summer）	Air flow rate(natural ventilation)：111m3 / (h/m) Heat extraction：704.0W Coefficient of heat removal：26.4%
Overall coefficient of heat transfer	Mode： Ventilation Cooling Outside air temperature： 35℃ Room temperature： 26℃ Air flow rate： 105.0m^3/(h･m)	Heat flow rate： 18.78W/m^2 Overall coefficient of heat transfer： 2.15 W/（m^2･k）
	Mode： Air Flow Window Outside temperature： 0℃ Room temperature： 22℃ Air flow rate： 105.0m^3/(h･m)	Heat flow rate： 23.9W/ m^2 The value of the appearance(Overall coefficient of heat transfer)： 1.07 W/（m^2･k）
	Mode： Insulation Outside air temperature： 0℃ Room temperature： 22℃ Air flow rate： 0m^3/(h･m)	Heat flow rate： 38.2W/m^2 Overall coefficient of heat transfer： 1.81W/（m^2･k）
Solar shading coefficient	Mode： Sun Shading Outside air temperature： 35℃ Room temperature： 26℃ Irradiation： 600w/m^2	Solar shade factor： 0.19 To calculate a value above, it assumed that the radiant heat transfer coefficient is 4.7W/(m^2･k) and that the convective heat transfer coefficient is 7.79W/(m^2･k).
Ventilation resistance,	Mode： Air Flow Window Air flow rate： 105.0m^3/(h･m) Mode： Ventilation Cooling Air flow rate： 108.4m^3/(h･m)	The delta-pressure between the air inlet is provided for the indoor side at the bottom and the duct joint part at the top： 9.5Pa The delta-pressure between the hood is provided for the outdoor side at the bottom and the duct joint part at the top：22.5Pa

2. Field test

2.1 Overview

We began a field test in the building in October, 2005 to confirm thermal performance, durability and maintenance requirements. The sampler under test was installed for case in the outer wall (1 span) on the 3rd floor southeastern surface of the institute building (gross floor area 1, 291m^2) in Kiyose City, Tokyo. Figure -5 shows the outward appearance and the introspection of the building. We varied the operating controls of window A and window B.

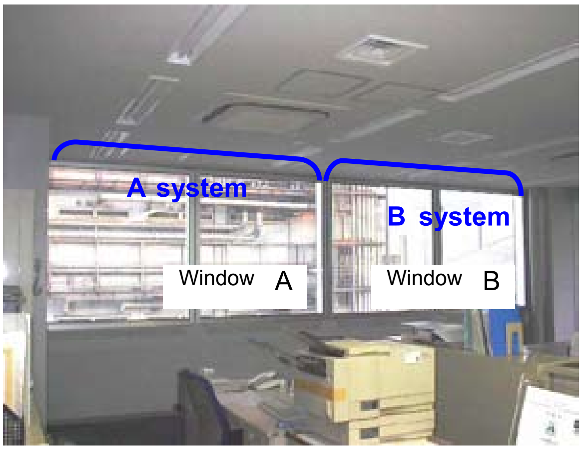


Figure 5 Exterior (the left figure) /interior view (the right figure) of the building

2.2 Measurement results

Figure 6 shows the solar shade factor estimated from data of experiments carried out from August to September 2006, comparing the performances of the single skin and the double skin. This factor was calculated by the standard for 10mm heat absorbing glass comprising the outside glass. It was estimated to be 0.26 from linear regression. This performance was approximately the same as that achieved in the laboratory test because the solar shade factor of 0.2 in the laboratory test is calculated by the standard for 10mm float glass. Figure 7 shows the assessed value with the overall coefficient of heat transfer in winter. The overall coefficient of heat transfer in the midnight hours in February was 1.43 W/m^{2}K. This was equivalent to about 1/4 of the value with the overall coefficient of heat transfer of the 10 mm float glass and the high insulation performance of the multifunction double skin of the development article.

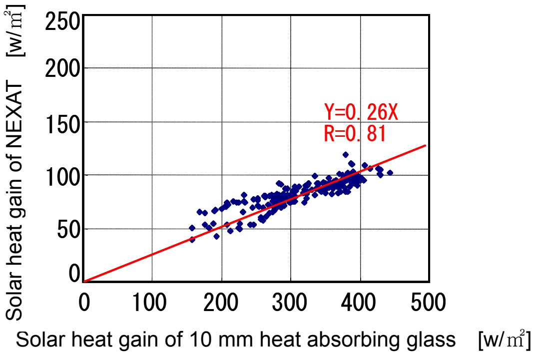


Figure 6 Solar shade factor (August- September, 2006)

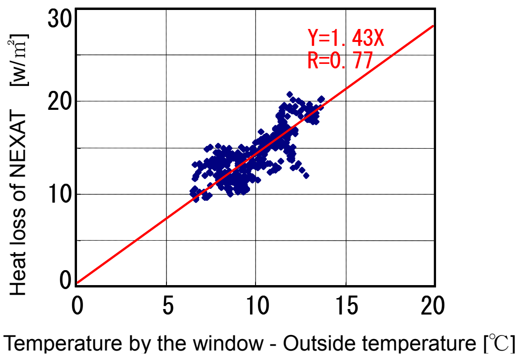
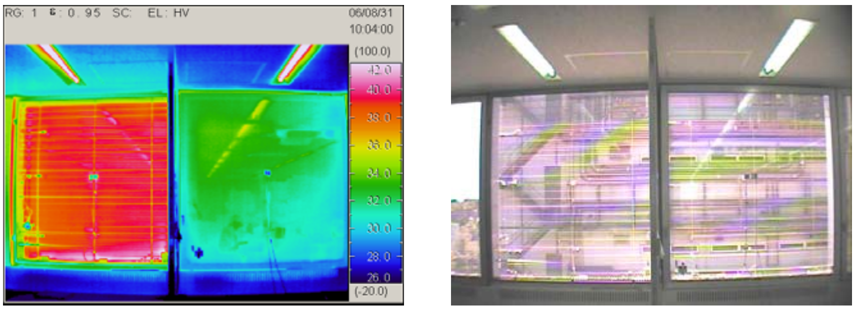


Figure 7 Overall coefficient of heat transfer (February, 2007)

2.3 Comparative test

There is a great effect of spaciousness and comfort when the slats level compared with the case where the blinds are closed. Figure 8 shows the heat image and the visible image when the direct solar radiation becomes a maximum on a fine day in summer. The window on the left side forms a single skin when the inner glass is opened. When the slats are level, as for the single skin, the window inside surface temperature reaches 39°C.
However, the multifunction double skin of the development article (the window on the right side) falls to 32°C. Thus, the thermal environment is aggravated.



(blind slat is level)

Figure 8 Thermal image and visible image of single skin (left window) and double skin (right window) in case of the summer fine weather (10:00 August 31st,2006)

3. Implementation application

3.1 Overview

An overview at the building equipped with NEXAT on the facade on the western surface on a large scale, and annual operating data in March, 2007, are described. The left of Figure 9 shows the building's outward appearance of its northwestern surface. The right shows the status of the installation of the opening hood of NEXAT installed in the building. A mutual short circuit is avoided by arranging an approaching opening among the floors with a staggered layout. Table 2 shows the building overview. Table 3 shows the specification of double skin sash.

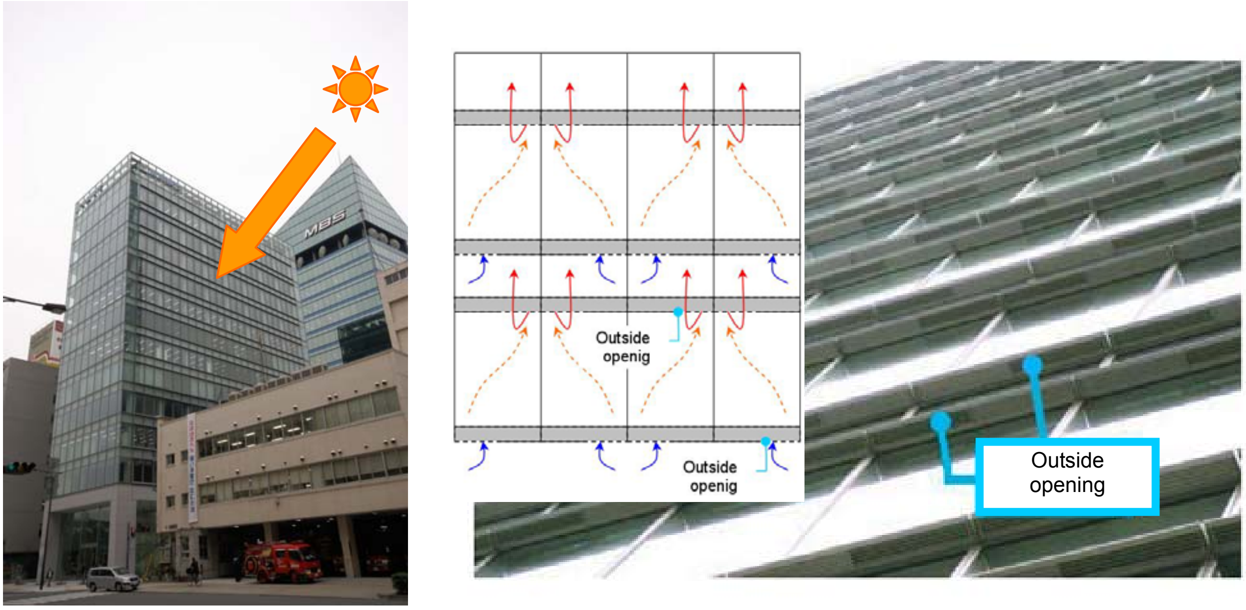


Figure 9 Exterior of building

Table 2 Building overview

Building name	Oosaka-Umeda Ikeda Bank Building
Building structure	Skeleton-construction, Reinforced-concrete-construction (the part),
Building scale	The 13rd floor the ground, the 1st floor the basement, the 1st floor penthouses
Site area	1,248.91 ㎡
Building area	686.25 ㎡
Total floor area	8,781.67 ㎡
The roof height	56.5 m
Construction period	The middle in July, 2005-the last day in January, 2007

Table 3 Specification of double skin

Size	Width：1,500mm Height：4,180mm
Glass	Tempered glass 12 mm (The outer side)
	Float glass 10 mm (The inner side)
Operator	The drive according to the top and the bottom

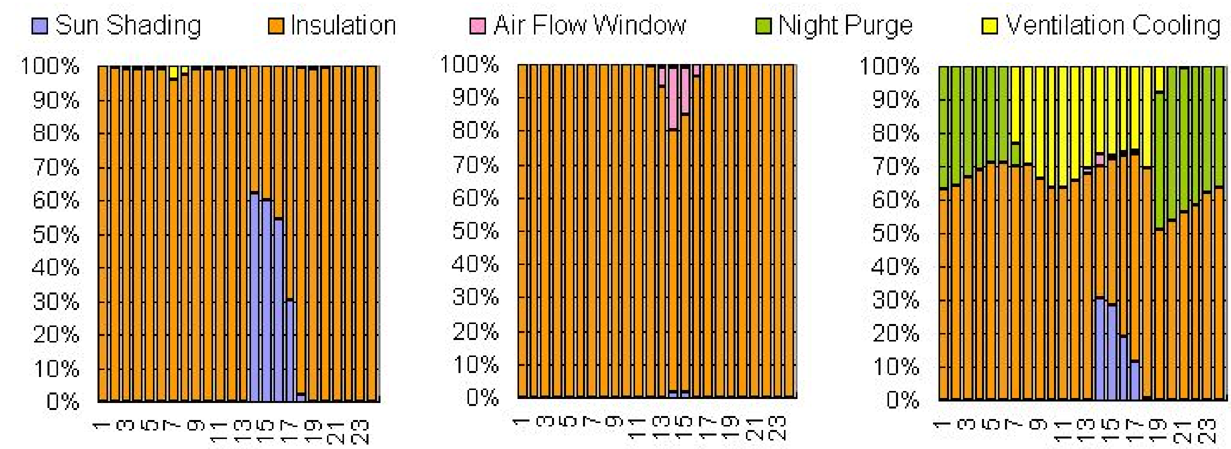
According to the logic shown in Table 4, the mode that realizes energy saving while ensuring comfort is chosen from the sensor information in each place. The adjustment of the slat angle is controlled to ensure as much sight as possible while it interrupts direct solar radiation based on the sunlight incidence angle which was calculated every month and time in the annual schedule.

3.2 Actual result data

The left of Figure 10 shows the results of the operation mode from July to September, 2007. When under the influence of afternoon sun, NEXAT switches over to Sun Shading mode, and at other times it is set to the insulation mode and improves energy saving. Also, in night, because the outside temperature is high throughout this period, without the Night Purge mode, it is sets to the Insulation mode. Incidentally, when comparing it with the air flow rate of natural ventilation measured in the Sun shading mode and the result of the experimental data, it is confirmed that NEXAT achieves fixed sun shading performance approximately.
The center of Figure 10 shows the results of the operation mode from December, 2007 to February, 2008. It is operated mainly in Insulation mode through this period.
Also, it performs heat recoveries by Air Flow Window mode. The right of Figure 10 shows the results of the operation mode from March to June and from October to November, 2007. Using cool fresh air, Ventilation cooling mode in the daytime and Night Purge mode in night are actively operated. Also, because the outside temperature is high from the afternoon, under the influence of the afternoon sun, when the ventilation cooling with outside air is invalid, it is controlled by the Sun Shading mode.

Table 4 Logic for mode change

Weather		Noon-night	Afternoon sun	Amount of insolation	Condition of temperature, enthalpy and so on	Mode	Circulation fan	Exhaust fan
Bad weather	In case of the cloudburst (Above fall 10mm/h) or In case of strong wind (The equal to or more than 15m/s wind speed)	Noon 7:00-19:00	—	—	Set value (5℃)< Outside temperature < Set value (15℃) and Air temperature at the top of the space in the double glazing window > Room temperature	Air Flow Window	Operation	Stop
					When missing from the above	Insulation	Stop	Stop
		Night	—	—	—	Insulation	Stop	Stop
Good weather	When missing from the above	Noon 7:00-19:00	existence 14:00 ～ 18:00	—	Set value (15℃)< Outside air temperature < Set value (25℃) and Outside air dew point < Set value (18℃) and Air enthalpy at the top of the space in the double glazing window < Room air enthalpy	Ventilation Cooling	Operation	Operation
				> Set value (100W/㎡)	Outside air temperature > Set value (15℃)	Sun Shading	Stop	Stop
				—	Set value (5℃)< Outside air temperature < Set value (15℃) and Air temperature at the top of the space in the double glazing window > Room temperature	Air Flow Window	Operation	Stop
				—	When missing from the above all	Insulation	Stop	Stop
			non-existence	—	Set value (15℃)< Outside air temperature < Set value (25℃) and Outside air dew point < Set value (18℃) and Air enthalpy at the top of the space in the double glazing window < Room air enthalpy	Ventilation Cooling	Operation	Operation
				—	Set value (5℃)< Outside air temperature < Set value (15℃) and Air temperature at the top of the space in the double glazing window > Room temperature	Air Flow Window	Operation	Stop
				—	When missing from the above all	Insulation	Stop	Stop
		Night	—	—	Set value (15℃)< Outside air temperature < Room temperature and Outside air dew point < Set value (16℃)	Night Purge	Stop	Operation
			—	—	When missing from the above	Insulation	Stop	Stop



Summertime in July - September, 2007

Winter in December, 2007 - February, 2008

March - June, 2007 and October - November, 2007

Figure 10 Operation mode rate of each season

3.3 Restraint of the effect

We estimated the annual energy saving effect of Ventilation Cooling and Night Purge. In case of restraint, the air-conditioned energy amount reduced by these was calculated, assuming that the coefficient of performance of the air conditioner is 4.0～5.0. Figure 11 shows the annual air conditioner power consumption and energy saving quantity by Ventilation cooling and Night Purge at the 7th standard floor office. The energy saving quantity of Ventilation Cooling and Night Purge is 11%, 11% of the annual power consumption (the one to have added the assumed power consumption when not performing Ventilation Cooling and Night Purge) respectively and is 22%. We found that this exceeded the 8% of the restraint example of Figure -2 and that the NEXAT application of this building contributed to the energy saving effect.

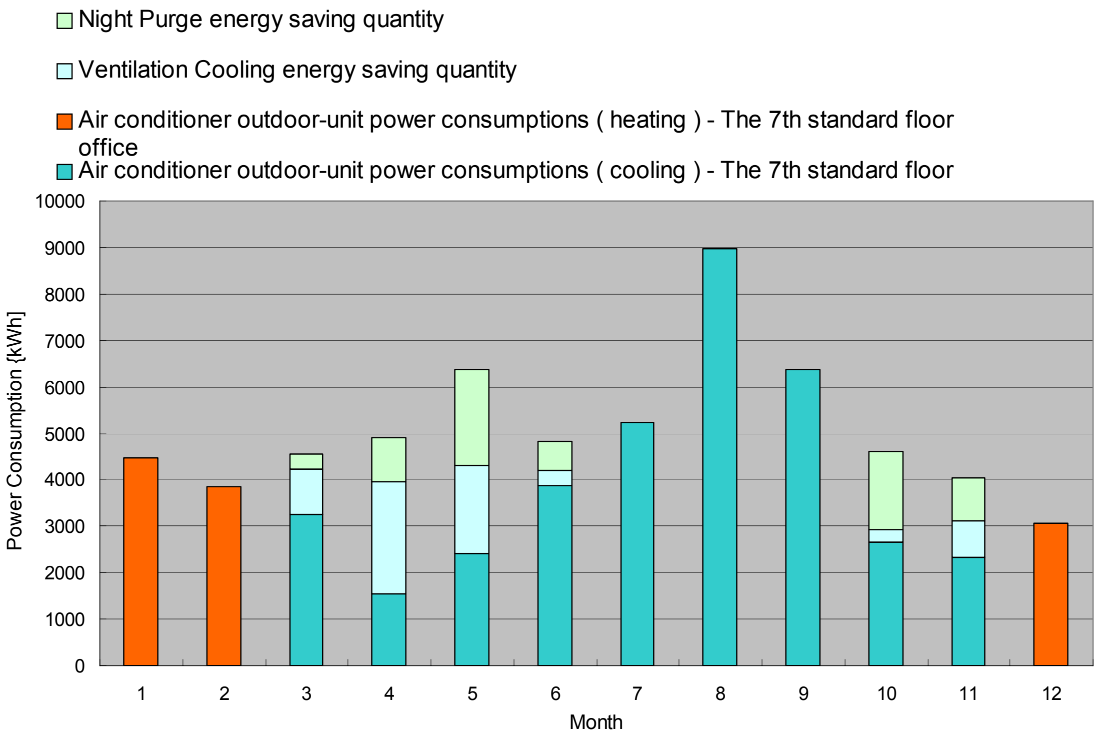


Figure 11 Energy saving effect about Ventilation Cooling and Night Purge

4. Conclusion

This study and development was implemented from 2003 to 2005 to realize a multifunction double skin system with higher energy saving performance than the conventional Japanese double skin system. As a result, the unitization could verify improvement of applicability to a building. Moreover, while considering the balance of performance and cost reduction, we made a product. Thus, while reducing annual air-conditioner energy consumption by about 14% by the model building restraint, the initial cost could be suppressed by about 2.5% compared to that of the conventional double skin system. Then, NEXAT achieves a simple payback-period of about 9 years. To confirm its performance, we carried out performance testing of a sampler in the laboratory. We confirmed that the performance was achieved by collecting annual data from field testing. Moreover, the field test confirmed that the control (the mode change) of the air flow according to the conditions of the weather outside functioned in the validity of energy saving and comfort, in addition to confirming the thermal performance achieved in the laboratory. By applying it to a large scale test on the west side façade of the office building, we verified that reliability was improved.

YOUR DEVELOPMENT: CREATING SUSTAINABLE NEIGHBOURHOODS

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Keywords: sustainable development, urban planning, web portal

Summary

To assist the development sector produce more sustainable infill and greenfield developments, the Department of Environment, Water, Heritage and the Arts (DEWHA) in partnership with CSIRO's Division of Sustainable Ecosystems is undertaking a project called Your Development. This project will provide a national 'one-stop-shop' technical Web resource that is based on the latest research and real-life case studies, with the potential to demonstrate the business case for sustainable subdivisions through the consolidation of available knowledge.

Your Development will provide an information base to assist urban development practitioners incorporate sustainable solutions into their planning, design and construction of new residential developments. The resource will cover a range of topic areas including estate design, site ecology, materials and recycling and sustainable energy services and provide national and international best practice examples. The central information resource for creating sustainable suburbs will have such spins-offs as strengthening the industry and research relationship while importantly building industry's capacity in sustainable knowledge transfer and implementation.

Your Development complements existing DEWHA projects including Your Home and Your Building that focus on environmentally sustainable housing and commercial buildings respectively. Your Development bridges the gap between these two resources by considering predominantly residential, low-rise developments.

The final Your Development resource will initially be a set of integrated web-based materials packaged for use by specific groups of practitioners, including urban planners and developers, designers, industry associations, financiers, utility providers and government. The material will be updated on a regular basis to meet demand and will cover the impact on the environment, society and costs of decisions at all stages of new residential developments including concept, design, implementation and operation.

1. Introduction

People have been living in cities and neighbourhoods for many millennia. Indeed, formal city planning is attributed to the Greeks and in particular Hippodamus who designed cities such as Miletus around 450BC. This early city designer was fully aware of how the natural environment should interact with the urban environment and Hippodamus designed Miletus so that the winds from the mountains and the sea could flow through the city and provide cooling during the hot summer. The city also uses a grid plan, with public buildings located in the centre and neighbourhood zones located around this centre, allowing for easy access by all residents to the city's heart. The grid plan was also intentionally laid out with a north/south axis to allow houses to have good solar access during the winter and shading from the sun in summer, a building practice that had been occurring in Greece since 400BC (Lahanas 2008).

This early understanding of a sustainable neighbourhood unfortunately did not last and subsequent civilisations and societies allowed cities to be developed in highly unsustainable ways. As populations grew so did the cities. The industrial revolution saw unprecedented levels of growth in cities as rural people flocked to the booming city economies. For most industrial cities their existing infrastructure was not capable of supporting such large populations and consequently disease and overcrowding was common. These overcrowded and polluted cities created the catalyst for a change in how cities were planned and saw the start of recreating healthier and more sustainable neighbourhoods.

The Garden City Movement was started by British planner Ebenezer Howard who published a book in 1898 entitled *Tomorrow: A Peaceful Path to Real Reform*, which was then republished in 1902 as *Garden Cities of Tomorrow*. Howard proposed a move away from industrialised cities to communities that combined the social and public conveniences of towns with the healthy aspects of rural living (Friedman 2007). Industry was located at the town centre and surrounded by a ring of parkland. Around the park were shopping areas and the next layer out were the houses with attached gardens. At the periphery were rail lines and larger farms. This segregation of land use would later be seen as the contemporary model for town planning.

Howard's ideas were not necessarily new and indeed he had Australian inspiration from Colonel William Light, who designed Adelaide's layout in the 1830's (Figure 1). Howard include a sketch of the Adelaide plan in his book and Light's design for splitting the city into smaller sections surrounded by parklands was a major influence on the idea of the green belt (National Library of Australia 1995). Howard's garden city idea inspired the development of Letchworth, located in Hertfordshire just out of London, in 1903. This was Britain's first planned garden city and its designers, Raymond Unwin and Barry Parker, also planned Hampstead Garden Suburb in London in 1907.

Figure 1 Adelaide's city layout with gardens ringing the two city sections

The post World War 2 era saw suburbs expand rapidly, mainly due to the rise in use of private cars. Planning of these new areas was also driven by earlier desires to separate out dwelling, industrial, commercial and retail areas from each other, but the desire from residents to have large lots, the typical quarter acre block, created large sprawling suburbs that no longer had the density to support much of the infrastructure and services required for a sustainable suburb. Consequently the infrastructure and services now need to draw their user base from a much larger land area, diminishing the ability for residents to access them by walking and thus the need for the private car has become mandatory in these suburbs. The need for the car has itself only exacerbated the problem, requiring more land for wider roads that have to deal with peak loadings, larger homes that need to house increasing number of cars and larger carparks to carter for the increasing number of single person trips.

Like with the industrial cities, many residents in our modern cities are now seeking change and realising that the way we are living is not sustainable. Developers and regulators are also grappling with the problems of the ever increasing sprawl and are starting to reinvent our modern suburbs to become less car dependant, more self reliant, better linked to the natural environment and generally lower the overall impact that our suburbs have on the environment.

2. Sustainable neighbourhoods

Outline the new trends towards creating green suburbs – following on from the green building movement. List some examples like Currumbin, etc.

The move to creating the modern sustainable neighbourhood probably first begun with creating a more sustainable house. Energy and water efficient homes, using low embodied energy materials and employing the principles of passive design, have been built for many years. Like the idea of the garden city, the principles of sustainable building design have been in existence for decades and have remained virtually unchanged. Indeed, many of the principles are taken from traditional building practices that can date back centuries. Before the advent of mechanical climate control systems and artificial lighting, dwellings had to be designed to deal naturally with the environment in which they were located. For example, Eskimos in Alaska for centuries built semi earth covered homes that used the soil as a highly effective insulating barrier against the extreme cold of an Alaskan winter. Early European settlers reported that these traditional homes remained between 15 to 20 degree Celsius using only two or three seal oil lamps and that the homes employed a natural ventilation system that ensured that fresh air was always circulating through the dwelling (Seifert 2007).

In Australia, the idea of building structures designed for the climate is also not new. Early 19th century settlers quickly saw the need for wide verandahs to provide shade and elevated light weight homes, such as the 'Queenslander', have been present for over a century in the warmer climates. In the cooler southern states too, the use of thermal mass has long been well understood and homes using mud brick and *pise de terre* type construction were introduced into Australia in the early 1930's by Justus Jorgensen who founded the Montsalvat artists' colony at Eltham in Victoria and whose work would later influence designers like Alistair Knox.

Moving from the individual sustainable house level to the sustainable suburb level has been slower to evolve, which is hardly surprising given that many more stakeholders are involved. Within Australia some early attempts were made, usually tackling a specific aspect of sustainable development. For example, the Kingsley With The Sun development in Wannaroo, Western Australia, was developed in 1986 and was the first subdivision in Australia which sought to protect solar access (Issac 1989). The establishment in 1994 of the Global Eco-Village Network (GEN) was probably the first modern organised movement for developing sustainable neighbourhoods. Foundered by Ross and Hildur Jackson, who were also founders of the Gaia Trust, GEN has the aim to "support the development of sustainable human settlements". The inaugural meeting saw representatives from eight communities from around the globe, including Crystal Waters Permaculture Village which is located in Queensland (Garden 2006).

Although the eco-village movement has seen many villages established around the GEN principles, there has also been criticism of the apparent elitism of the GEN movement. Garden (2006) argues that the GEN movement implies that ecological living is not possible in mainstream society and that it does little to directly address ecological or environmental crises. More recent eco-villages have taken a more proactive stance, engaging with a range of stakeholders and addressing the challenge of creating sustainable developments for mainstream society. The Ecovillage at Currumbin, located in Queensland's Gold Coast hinterland, is an excellent example of the new breed of eco villages that are developer driven but which prioritise community and social ecology along with economic and environmental sustainability on an equal basis with standard development practice. This development has received numerous awards, including the 2007 Urban Developers Institute of Australia national award for best environmental development. This recognition by the mainstream development industry demonstrates how the modern eco village can not only exist within the mainstream development industry, but also influence and demonstrate how modern neighbourhoods can be developed sustainably.

Figure 2 Newly completed house within the Ecovillage at Currumbin

3. Your Development

The rise in awareness of sustainability issues within the built environment has also lead to the need for knowledge on how this is best achieved. Numerous books, magazines and web sites have been devoted to a range of sustainability issues related to buildings. One of the best known is the acclaimed Your Home web site (www.greenhouse.gov.au/yourhome/), developed by the Australian Greenhouse Office in consultation with the building industry, it has established itself as the primary source for sustainable residential building information within Australia. The success of Your Home owes much to how it was organised and authored. A series of over 60 fact sheets authored by many of the leading experts within Australia on a range of sustainability topics including water, energy and material use and site related impacts. These fact sheets are then supported by an extensive range of real world case studies to demonstrate how the principles discussed are put into practice. Your Home has a wide ranging user base from the building professional through to the home purchaser and has allowed many in the industry as well as the home owner to understand the basic principles of sustainable housing.

The success of Your Home has lead to the development of two sister projects, Your Building, which focuses on sustainability issues related to commercial buildings, and Your Development, which focuses on sustainability issues of residential land development. The Your Development project has been a partnership project between the CSIRO's Division of Sustainable Ecosystems and the federal government's Department of Environment, Water, Heritage and the Arts and is complimentary to the Your Home web site in that it addresses the missing information set in the sustainable residential building world. Your Development realises the importance that the land developer has in ensuring that not only houses, but entire neighbourhoods are built sustainably.

3.1 Industry's role

When land is developed for residential housing, there is usually a once only opportunity to instil sustainability principles within that development. The way the natural topography is addressed in the development, how waterways are incorporated into the design, the positioning of roads, paths and building lots will usually be locked into that development forever once construction has been completed. If these aspects are done poorly, then it is virtually impossible for many to be undone. Unlike houses, it is very difficult to retrofit a subdivision. The layout of roads and building lots once completed are unlikely to be significantly altered in the future and if they were it would involve enormous costs. Consequently, those involved in the land development industry, including developers, planners and the various levels of government have an obligation to ensure that these developments are done in a way that will minimise their impact on the environment and encourage sustainable development.

Many of the large land development companies are now well aware of the sustainability opportunities that are available to them and many have incorporated these opportunities into their developments. Newington, the former Sydney Olympic village, Koolamara Waters, Wallarah Peninsula and Aurora are just some of the developments created by large development companies that have won national and state based environmental awards. However, small to medium sized developers often do not have the resources or knowledge that these large firms have available and consequently are often unaware or lack sufficient information to employ sustainability features within their developments. The same is often true of local government councils, who ultimately often have the final say on whether a development will proceed. Innovative developers putting forward concepts that local regulators only have limited knowledge of will often result in councils taking the conservative "business as usual' approach and rejecting any schemes that may contain a perceived higher degree of risk.

The perceived risk of some sustainable development strategies is often just that, perceived! In reality, there is often the same level of risk as the normal approach and in some cases it may even be a lower risk. The whole area of risk, who ultimately carries that risk and risk mitigation is a complex area and one that cannot be covered here, but often risk is used as an excuse for lack of knowledge. Addressing that knowledge gap is the main aim of the Your Development project. Additional aims of the Your Development project include:

- to create a one-stop-shop resource that explains the 'why' and 'how' of sustainable urban development and influence changes in market behaviours
- to bring together industry and research expertise, skills and knowledge to develop best practice and innovative content
- to build the capacity of the industry to respond to sustainable knowledge transfer and implementation
- to demonstrate the benefits of sustainable developments in terms of the triple bottom line, that is, environmental, economic and social benefits.

3.2 Structure

Your Development is structured as an online web based information portal. Like Your Home and Your Building, the content of the site is arranged as a series of fact sheets written by experts from research and academic organisations and backed up by industry knowledge and experience. The topics that the fact sheets cover and how they are organised was initially addressed in a scoping study that was carried out in 2005 by the Institute for Sustainable Futures (McGee & Partridge 2005). This scoping study identified a range of stakeholders involved in the development process and then carried out a series of surveys and workshops with these stakeholders to identify the topic areas that would be required. This preliminary list was then reviewed and refined into the following nine topic areas:

- **Site Ecology** – site issues, landscaping, biodiversity, soil and water management, ecological footprint.
- **Place Making and Social Sustainability** – housing stock, affordability, community issues and facilities, connection to facilities, heritage and safety, community education, community health and wellbeing.
- **Estate Design** – street and lot layout, urban density, mix use, open space provisions and infrastructure provisions.
- **Access and Transport** – public transport and bicycle infrastructure, pedestrian environments, innovative transport modes, transport integration and linkages.
- **Materials and Recycling** – life cycle assessment of materials, waste minimisation, waste management and recycling and healthy materials.
- **Integrated Urban Water Management** – water sensitive urban design, water sources, water efficiency and water quality.
- **Energy Management** – energy supply, distributed energy and energy efficiency.
- **Climate Change Adaptation and Mitigation** - greenhouse abatement and adapting to climate change.
- **Sustainability Management** – whole of life costing, financial models, partnerships, post occupancy evaluation, governance, industry education and sustainability assessment.

Under each topic area there is a series of fact sheets that cover different aspects of the topic theme. The fact sheets themselves are structured in a consistent style across all topic areas which allows a matrix style approach to finding relevant information. For example, each fact sheet covers a series of key issues that were identified as essential elements that developers would want to consider before implementing any sustainability initiative. These key issues are:

- Benefits – why should I do this? Environmental, marketability, economic and social benefits.
- Costs – what is the cost? Includes financial, time and other "costs".
- Savings – are there potential savings? Also covers financial and time related savings
- Risks –what risks might be involved? May be political, marketability and financial risks
- Barriers – what barriers might exist? Includes regulatory, government and public perception barriers.
- Benchmarks – what should I aim for? What are the national and international benchmarks that exist and what is "best practice" for a particular sustainability initiative.

In addition to these key issues, the fact sheets also aim to address how and, importantly, when in the development process sustainability initiatives should be implemented. Opportunities to implement certain features will only be possible through careful planning and scheduling during the whole development process. As work progresses, these opportunities may become more difficult, if not impossible, to implement. Consequently, the fact sheets break the development process into six phases:

- Feasibility – the initial project scoping stages;
- Planning – preliminary planning, legislative requirements, initial community consultation, etc;
- Design – formal design stages, master plan creation, layout, permits, etc;
- Construction - major construction phases, road and infrastructure placement, earthworks, community facilities, parkland development, etc;
- Lot Creation – construction of dwellings and ongoing lot release and development; and

Each fact sheet covers what actions are required at the various phases allowing developers to plan how best to implement their sustainability initiatives.

3.3 Case studies

Backing up all the fact sheets is a series of case studies demonstrating how a particular sustainability initiative has been implemented in the real world. Case studies are an essential part of the Your Development portal and provide all users with practical examples of how others have succeeded in their sustainability aims. Each fact sheet has a series of case study "snap shots" that highlight that specific feature. These "snap shots" are then linked backed to a comprehensive case study database that contains hundreds of case study examples from Australia and around the world. The powerful search engine included with Your Development allows users to search for a case studies in certain locations, that focus on particular sustainability aspects and then obtain the case study details and further contact information.

It is envisaged that over time, this database will grow to become the primary reference point for Australian residential land developers. The Your Development portal is designed to allow easy updating and addition of new developments providing all in the development industry the opportunity to showcase their development's sustainability achievements.

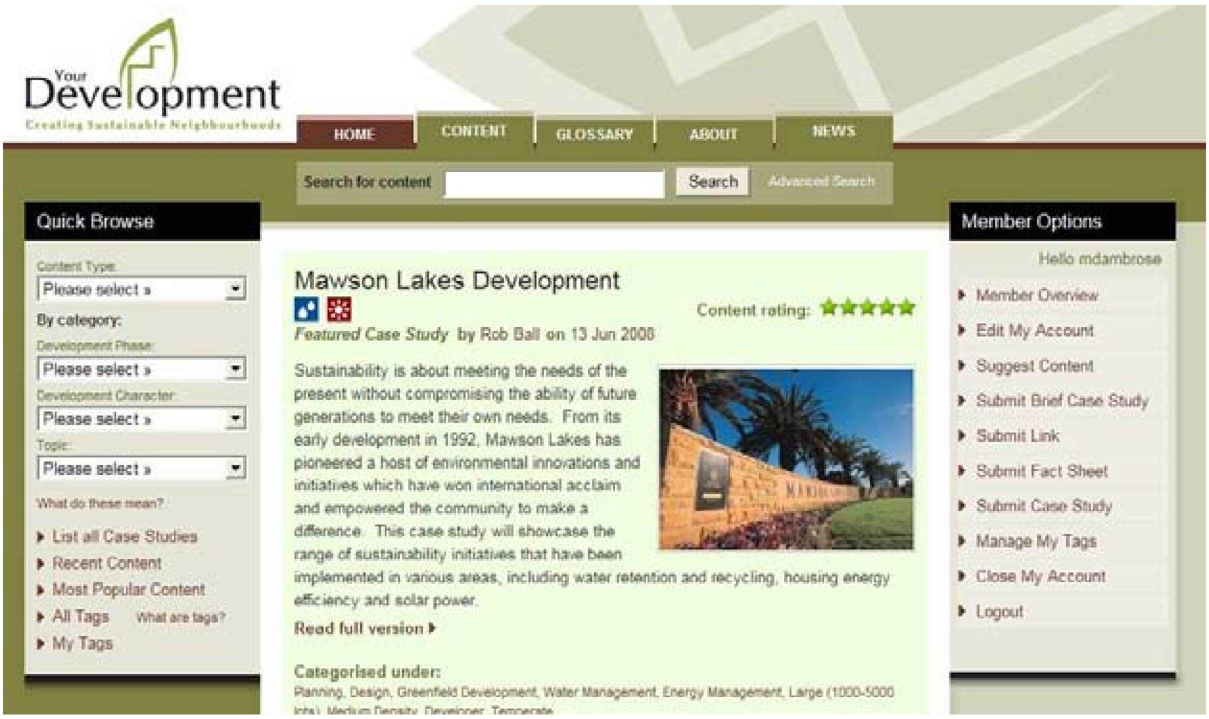

Figure 3 Screen shot from the new Your Development web portal

3.4 Web portal

The actual web portal has been designed to take advantage of the latest web based opportunities. Figure 3 shows how Your Development employs a "wiki" style interface as pioneered by Ward Cunningham on his WikiWikiWeb site in 1994 (Wikipedia 2008). Wikipedia, the online encyclopaedia is probably the best known example of a wiki based website. Wiki websites are collaborative websites allowing users to add new information and edit existing information. There are both advantages and disadvantages of this approach, but it is generally believed that the advantages far outweigh the disadvantages. The main advantages of the wiki approach are that information is continually updated and added to and errors in the information can be easily corrected by any user. It also allows new fact sheets to be easily added to the system allowing the whole site to become a dynamic repository of sustainable development information. Of course, allowing any user to edit content does mean that fact sheets run the risk of being vandalised and manipulated to push a certain user's personal opinions and/or bias. The original content authors for Your Development were instructed to write fact sheets that did not contain personal opinions and to avoid being prescriptive. The aim has always been to create fact sheets that are relevant, factual, unbiased and informative.

Initially, it is expected that editing rights to existing fact sheets will be restricted to the authors themselves and trusted others. New fact sheets will be encouraged by registered users and initially trialling of the editing process will help determine the speed that wider editing rights are enabled. Experience from other web sites that utilise this approach, including Wikipedia, suggest that new content needs to be independently reviewed and assessed before making it publically available on the main web site. Your Development will develop this group of reviewers that will vet content and ensure that information that is presented meets the objectives of the Your Development portal.

4 Future of sustainable neighbourhoods

The Australian Federal Government has made a commitment to reduce Australia's greenhouse gas emissions by 60% on 2000 levels by 2050 (Department of Climate Change 2008). As part of a package of initiatives are financial incentives, strengthened energy efficiency regulations and targeted information at households to use less energy and water while saving money. The government has indicated that it is planning to not only strengthen existing energy efficiency regulations, but move to a more holistic sustainability focus by creating standard nationwide requirements. Such a move would require significant industry education and access to the latest knowledge and methodologies for achieving new sustainability goals. Our new and existing neighbourhoods will become key parts of achieving a more sustainable country, which is becoming more urbanised every year. Indeed, a recent United Nations report predicts that by 2050 93.8% of Australians will live in urban areas, up from 88.2% in 2005 (Edwards 2008). Ensuring that our new urban developments cater for this increase sustainably will be a significant challenge.

The Your Development web portal and its companion portals Your Home and Your Building, are valuable resources for an industry that is being increasingly challenged to provide developments, buildings and related infrastructure more efficiently and sustainably while still retaining high quality and affordability to the general public. Your Development's collaborative based structure means that users from all stakeholder groups have the opportunity to share their knowledge and ensure that information provided is both relevant and accurate. Access to a broad range of case studies helps both developers and regulatory agencies understand how sustainability initiatives have been implemented in the real world and helps ease the reluctance and trepidation that often accompanies the take up of innovative solutions.

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Sustainability through Prefabricated Construction in Hong Kong Public Housing Projects

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ABSTRACT: Prefabrication offers cleaner, more efficient and safer construction and makes a significant contribution to sustainability in housing development. The key benefits from these methods are the conservation of construction materials, savings in overall resources and energy, minimizing construction waste, providing a clean and healthy working environment and shortening the overall construction time. Upon completion, there are also life cycle cost benefits when compared with the hitherto more traditional approaches to design and construction.

The Hong Kong Housing Authority (HA) has been a pioneer in developing prefabrication in the territory. In the early 1980's, the HA initiated a programme to encourage prefabrication and mechanized construction technology through well known international contractors. In the late 80's, leading local contractors were encouraged to develop their own pre-casting systems to suit the Hong Kong context. The follow-up contractual, procurement and quality assurance measures were then developed and implemented in building contracts. In parallel, new technological initiatives have been introduced one by one and a very comprehensive prefabrication system for high rise residential buildings has evolved.

This paper will share the experience in the evolution and development of prefabrication initiatives in the public housing programme, for the benefits to be appreciated by the industry as a whole and for the advancement of the sustainability in the construction industry.

1. INTRODUCTION

In the mid 1960's, due to the influx of immigrants from Mainland China to Hong Kong, the majority of these immigrants lived in squatters or very old buildings. A large number of flats had to be built speedily to meet the massive demand for housing. At the same time, rapid industrial development meant people had begun to receive stable incomes, and hence higher expectations in the supply of better housing.

On the other hand, the construction industry in Hong Kong in those years was still relatively primitive, low skills and labour intensive. The public housing blocks then developed could only serve the functional requirements, but not on durability and sustainability.

2. SUSTAINABILITY OF EARLIER HOUSING STOCK

Starting in the early 1970's, because of the growing population in HK, medium rise reinforced concrete buildings were the normal mode of accommodation for the citizens at large, in particular those living in public housing. Concrete material was adopted basically due to the abundance of granite rock from the excavation of local quarries and from Mainland China, instead of importing structural steel from abroad which was more expensive. Concrete was deemed to be more durable under the subtropical humid climate in Hong Kong.

Resettlement Blocks in mid 1970's

However, at the technological level in the 1970's to 1980's, there were some critical shortcomings in the quality of construction workmanship at that time:-

a) The method of construction was by traditional in-situ construction, using timber formwork. The finished profile and in particular the concrete cover protecting the reinforcement from corrosion were very much subject to the carpentry skills of the workers.

b) The other aspects of workmanship such as steel fixing, compaction of concrete, finishing of concreting works, all operated in a very labour intensive and congested working site and generally with unskilled labour. This had worsened the corrosion protection to the concrete elements.

c) The secondary infringement by water seepage at joints (e.g. at windows), water ponding in slabs (e.g. roof, cantilever corridor), water leakage at pipe connections (e.g. exterior of kitchen and bathroom), also led to the deterioration of the building structural frame and fabric.

Traditional Method of Construction of Housing Blocks during 1970's

In Hong Kong, there were over 250 nos. of public housing blocks constructed in this way during the period of 1970's to 1980's, ranging from 7 stories to 20 stories buildings. These blocks have been under an extensive maintenance programme over the years in tackling concrete spalling, recasting of concrete elements and even substantial strengthening works. The table below shows the repair cost trend of the housing blocks constructed in different periods in the past.

Table 1: Cost Trend of Concrete Repair

Age of Blocks (years)	Handover Year	No. of Blocks Completed	Cost of Repair per flat per year (HK$)
31 -- 35	1972 ~ 1976	60	301
26 -- 30	1977 ~ 1981	194	158
20 -- 25	1982 ~ 1987	219	15

The life cycle of the earlier domestic blocks have been typically in the range of 40 to 50 years when the maintenance cost is continually increasing. Because of the need to go for more high rise redevelopment due to the scarcity of land and the upgrading of living standard through enlarged flat sizes, the majority of these earlier blocks have been progressively demolished under the Housing Authoriity's Comprehensive Redevelopment Programme. From the sustainability point of view, compared with other structures like bridges which have the life of over 100 years, this is a significant cost tag to the society and should be improved.

In Table 1 above, it is clear that maintenance expenditure on the older buildings is greater. It can also be seen that the repair cost drops significantly in the 1980's which was the time when mechanization and prefabrication was introduced.

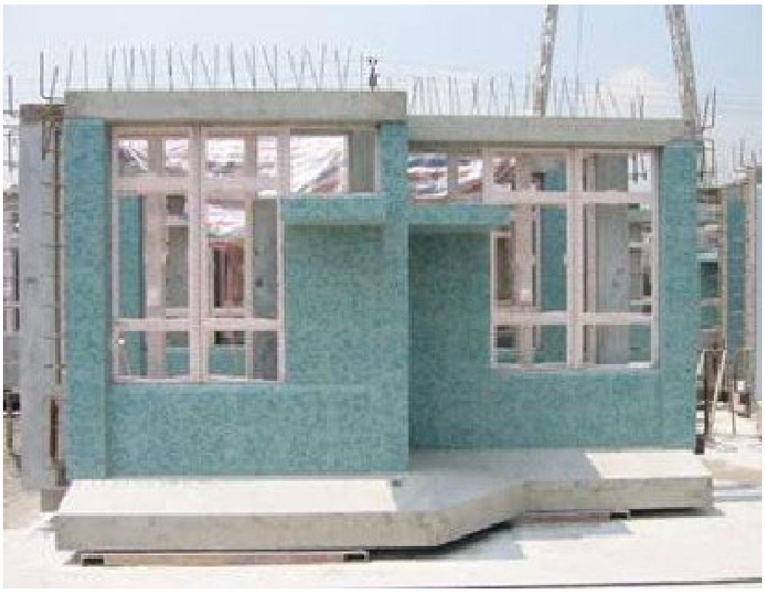
3. ENHANCEMENT OF QUALITY AND WORKMANSHIP OF STRUCTURAL WORKS

With a strong strive to enhance the quality and workmanship of structural works, the Housing Department responsible for the construction of the public housing had mandatorily introduced the use of large panel steel formwork and associated mechanized construction in the mid 80's

Mechanized and Prefabricated Construction

This is not only a pioneer environmental initiative to reduce the use of timber, but also gives assurance to the accuracy in lines and profiles of the structural elements. The surface finish of off-form concrete is also much enhanced with no more uneven surfaces and/or left-in peeling off timber pieces in concrete.

In the early 1990's, another great step forward in the public housing construction was the mandatory use of precast facades. The main purpose of the move was to prefabricate the complicated concrete profile of the facades in a factory instead of casting them at the working floors and to cast-in the windows in the facades to avoid water leakage at the window/façade interfaces.


Precast Facades

From a sustainability point of view, the immediate benefits of precast concrete construction are:

a) Great reduction in use of timber for formwork.

b) Assurance of concrete cover to reinforcement as a front line defence to corrosion.

c) More robust and reusable steel formwork/steel mould which facilitate better compaction of concrete.

d) Better surface finishes to greatly minimize the touching up with repair materials which might detach in the longer term.

4. PROCUREMENT OF MECHANIZATION AND PREFABRICATION

During that period, the HA has also initiated a programme to encourage prefabrication and mechanized construction technology by inviting well known international contractors to participate. The outcome was promising. Stakeholders in the industry began to be exposed to these new technologies both in design offices and on site. However, in the later years, not many of these international contractors could sustain their business because of the higher overhead costs and their difficulty in managing local subcontractors. In the early 1990's, leading local contractors were encouraged to develop their own precasting systems to suit the Hong Kong context, drawing experience from the international contractors and from experience in Singapore which has a similar form of construction of medium rise buildings.

5. MORE PREFABRICATION IN DESIGN

Following the design of precast facades, more prefabrication had been developed. These precast components are reckoned to be "for a purpose" within their different locations and contexts, which are elaborated as follows:-

a) Semi-precast slabs, tie beams and staircases

To prefabricate these components in factory instead of constructing it at working floors. The latter would require relatively substantial formwork/falsework on site, which might be vulnerable to poor workmanship and have severe safety concerns.


Semi-precast Slab


Precast Tie Beam


Precast Staircase

b) Volumetric precast bathroom/kitchen

To precast a box-type structure to be installed to each flat unit. With this volumetric set up, it could embody numerous pipeducts, fittings, tiles, waterproofing membranes, etc. It could also incorporate cast-in pipe sleeves instead of box-outs which are vulnerable to leakage. A lot of wet trade could be transferred to the factory which is a better controlled working environment. From past experience, bathrooms and kitchen areas are locations which call for frequent maintenance throughout their life spans.

Precast Bathroom

c) Precast structural walls

A pilot project in Kwai Chung Flatted Factory has been launched successfully to extensively try out the use of precast structural walls. This innovative approach has opened up a new era for high rise precast construction which could further reduce the operations on site. Their applications are currently being reviewed for their effectiveness and opportunity cost.

Precast Structural Wall

d) Prefabrication along the building perimeter

Prefabrication not only enhances construction workmanship but also enhances safety construction at height. In normal mechanized construction, it is prudent for the contractor to make provisions for safe working platforms at open edges along the building perimeter. Metallic working platform with robust railings are required. Nonetheless, there is still a risk of workers falling out of the railings. By adopting precast facades and semi-precast walls (also called 'lostforms'), the perimeter could basically be surrounded by precast 'walls' and workers are not required to step outside into the working platforms. Hence, all activities are confined within the building enclosure. This approach is becoming popular in the private sector in Hong Kong and has also been tried out in our Kwai Chung Flatted Factory pilot project.

Semi-precast Wall (Lostform)

6. PREFABRICATION FOR HIGH RISE CONSTRUCTION

Prefabrication and modular construction have been widely used in European countries like France, UK, Sweden and many others. They are usually adopted, however, in low rise houses or medium rise blocks up to around twenty stories. These countries do not have the need to construct high rise residential blocks like those in Hong Kong. The precast technology in Hong Kong is therefore somewhat unique though reference have been made to similar usage in Singapore. In Singapore, not until recent years, their building heights has been up to 30 stories with column beam structures as their main stream. In Hong Kong our residential blocks are 40 stories or above, where the structural forms are essentially shear wall structures.

Prefabrication in high rise construction in Hong Kong demands special considerations for buildability: -

a) Symmetry of Block Layout

Blocks are designed with symmetry to allow for more repetitiveness in the components and to facilitate the rotary construction by tower cranes .

b) Modular Flat Unit

The flat units are designed to be in modular types, including one bedroom, two bedroom, three bedroom, etc. These have a lot of benefits in terms of unifying the flat unit components, including the building and structural components, and allow the repetitiveness in prefabricated production.

c) Weight of Precast Components

Weight of components is critical. Heavier items may require greater carnage of the tower crane, hence jacking up the construction cost. Similarly, volumetric precast components have to be carefully located in the layout to ensure that the tower crane has sufficient capacity to lift them during construction.

d) Monolithic Connections

Connections of precast elements with the insitu structure should be through monolithic construction. Post-fixing with brackets and grout/mortar infill are not desirable for tall buildings, mainly because of to the high cyclic wind load which may render the connections unstable and/or lead to cracking of infill grout, hence water leakage.

e) Dimensional Tolerance

In high rise construction in which precast components are interlocking with insitu structural components like shear walls or columns, dimensional accuracies are very important. Only very tight tolerances could be allowed for the components to be fitted into, otherwise the construction cycle would be disrupted.

7. QUALITY ASSURANCE OF PREFABRICATION

Prefabrication off-site was an activity rather new in our contract procurement. It has also triggered the establishment of another sector of suppliers to invest in setting up factories in region of South China next to the Hong Kong. This is because Hong Kong has a scarcity of land for accommodating large factories and the cost of labour is also high. With the introduction of extensive prefabrication, many of our main contractors have the incentive to set up factories and inject management staff to undertake the factory production.

One of our major concerns is the quality assurance in these remote factories. The HA has now established a series of QA measures as elaborated below:-

a) Independent consultants have been appointed to supervise the production of these factories, with full time staff stationed at the factories.

b) Each factory has to carry out internal audits at regular intervals. The independent consultant is required to conduct monthly external audits and the HA would also carry out regular audits to the performance of the consultants.

c) A Performance Assessment Scoring System (we called the PASS) is also imposed to these factories, with particular focus on the workmanship of the production. Scores obtained from the PASS would be related to the performance of the main contractor employing the precast supplier and affect the tendering eligibility of the main contractor.

d) At the initial set up of the factory, it has to be accredited to ISO standards. In addition, the supplier has to carry out a pilot production run to demonstrate its competence before it is approved for production.

8. CONCLUSION

Prefabrication offers cleaner, more efficient and safer construction and makes a significant contribution to sustainability in housing development. The key benefits from these methods are the conservation of construction materials, savings in overall resources, including energy, minimizing construction waste, providing a clean and healthy working environment and shortening the overall construction time. Upon completion, the result is an aesthetically pleasing, versatile and highly durable development. There are also life cycle cost benefits when compared with the hitherto more traditional approaches to design and construction.

The prefabrication experience gained by the HA is indeed very rewarding. Private sector in Hong Kong are following suit and are developing further in breadth and in depth because of their affordability to use more luxurious components. Compared with the earlier housing blocks in Hong Kong, this approach has brought about longer life buildings for our next generation to continue to live in.

POWERLINK QUEENSLAND EDISON BUILDING
A CONNECTED, VIABLE, AND LIVEABLE
SUSTAINABLE BUILT ENVIRONMENT

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Keywords: sustainable building, environmental, refurbishment and recycling

Summary

In 1997 the Edison Building complex was completed. An asbestos cement clad steel framed industrial building, constructed for Queensland Rail in 1955 in an oil contaminated site, was recycled into a state-of-the-art office building for Powerlink Queensland.

In November 2008 the facility will be in continual operation for 11 years.

The Powerlink Queensland office building case study is a living example of best practice achieving excellent results in all the factors driving decision making in the built environment. It has stood the test of time.

Powerlink has experienced increased workplace productivity through innovative design and implementation, and uplifting cultural change and behaviour in the workplace as a direct result of the environment created in this building.

The visionary working environment brings people and plants together in a symbiotic relationship of calm offices and rainforest greenery. Central to the office is an 850 sq.m. landscaped atrium surrounded by 2 levels of open plan office space.

The award winning building complex utilises methodologies developed at the Johnson Space Centre by NASA[(1)] for the international space station now in orbit, where selected species of plants are used to clean the air and remove contaminates and generate positive ions into the built environment. The extensive water features and plants are an integral part of the air conditioning system, as all return air is directed via the rainforest for cleaning, and humidity control during its cycle.

(A) *(B)*

Main entrance facing northwest (A) in 1997 (B) in 2008.

Introduction

Powerlink Queensland is a Government Owned Corporation providing electricity transmission facilities for the State of Queensland. The Corporation was established under the GOC Act 1994 and commenced operation on 1 January 1995.

Prior to this, the Queensland Electricity Commission carried out the function of transmission. In this context, the QEC was a monopoly organisation managing the Generation and Transmission businesses as well as future generation and transmission planning for the State of Queensland. Staffing for that business was over 3000 people and the structure and operation were bureaucratic and control oriented.

The challenge for the Board of Powerlink Queensland from 1 January 1995 was to shed the management philosophies and overly bureaucratic trappings of the former QEC and build a streamlined commercially focused business comprising 500 employees.

In 1995 the Powerlink Board inherited a business that was operating from :

- A depot in Richlands on Brisbane's southside with high overheads;
- A large under-utilised and high cost workshop complex on Brisbane's northside;
- A Head Office located in the Brisbane City centre plagued by high rents and overheads.

The new workforce was drawn together from disparate groups with different goals and ambitions.

A key aspect of building the business was the creation of an identity that was not linked to the former role of the transmission business as part of the Queensland Electricity Commission.

In mid 1995, the Powerlink Board undertook to establish a headquarters that would be the focal point for the future. We were appointed to assist in identifying options for new headquarters, including:

- Leasing central business district offices;
- Leasing near city buildings;
- Building near the city (eg. Southbank);
- Utilising existing assets.

In November 1995, the Board decided that the best option was the consolidation of its business activities at its workshop site at Virginia. The plan included the relocation of all of Powerlink's business activities to a single location in Brisbane.

The option had many commercial benefits for the Corporation. It meant that the business was able to reduce its overheads by avoiding high CBD rents, obtain better utilisation of the workshops property at Virginia, and close down and sell a commercial property on the southside. It also meant that there was an opportunity to create a new employee culture to build a business that had to compete in a commercial arena without the benefits of the protection of the State.

The workshop complex at Virginia comprised two buildings. One was the major workshop building constructed in the mid 1950's and used for transformer repairs since the mid 1960's; the other was built in the early 1950's and used for administration, trade training and instrument workshops activities. The former building was still required as an integral part of the business, but the latter was under utilised, in a parlous state of repair, and its future use in the existing context was economically not viable.

The essential structure of the old railway shed was maintained when the building was recycled into a lush interior landscape surrounded by open-plan offices.

The decision taken was to refurbish the workshop building and redevelop it into the headquarters of Powerlink Queensland.

The fifty year old former Queensland Rail industrial building has been recycled into a modern office building set into a park-like landscaped setting, and named Edison Building.

The conversion of the harsh industrial site was seen by Powerlink Queensland as an important reinforcement of its corporate mission to practice responsible environmental actions and to be a good neighbour. The provision of a quality working environment for Powerlink Queensland's staff was also high on the development agenda.

The Edison Building

A detailed cost benefit analysis was prepared which analysed cost scenarios of several building options, including complete demolition and rebuild. Approximately 10% of the construction cost of a new facility was saved by re-use of the existing ground floor slabs and steelwork.

When the existing 13 bay saw-toothed shed was stripped of its asbestos cement cladding a well engineered and honest expression of steel industrial engineering was found. Features such as the 70m x 80m floor plan, large column spaces, and 7m height clearance lent themselves to recycling the shed into a two storey office building.

South facing clerestory windows in the saw-tooth roof allow ideal light for atrium plants – 1997.

In order to provide prime office space, i.e. – no one more than 9 metres from an outside window or a view, an 18m wide rectangular plan-form evolved. Wide overhangs were possible at the perimeters, and a landscaped atrium, integral with the office space, allowed the creation of a unique workplace environment. The existing structure, evident throughout the project, has been extended and embellished by the use of metallic forms and cables. Structural integrity is evident both internally and externally.

(A)

(B)

Wide verandahs (A) in 1997 (B) in 2008.

The project is a significant example of sustainable design, which has had an extraordinary impact upon Powerlink Queensland's organisation, and the neighbouring community. It has set a new benchmark for non-CBD office design in a healthy working and living environment.

The west elevation faces busy Toombul Road – 2008.

Because of the economy of structure and general economic sense to recycle rather than demolish and rebuild, the project has been able to afford some unique features such as extensive advanced landscaping, incredible staff amenities, and the spectacular cantilevered hydraulic lift – unique in its design.

We designed a cantilevered lift, which caters for a stretcher and also conveys disabled persons from ground to first floor with ease. Disabled persons have 100% accessibility to all staff areas at non-discriminatory locations.

Central landscaped Atrium – 2008.

The optimum human requirements of air quality, temperature and humidity in the office building were delivered in a unique way by exploiting the finding of new scientific evidence from NASA[(1)], that plant species can help mitigate indoor air pollution and improve greatly the aesthetic quality of spaces to be inhabited by human beings.

The central landscaped atrium and waterways is an integral part of the office environment. All return air is directed through the plants for pre-cleaning. The waterways add “white noise” to the office and help humidity levels to remain constant. South light has resulted in healthy plant growth and has given the office an unusual outdoor quality. Seating areas are provided in the garden where people can unwind to relaxation music, watch fish and frogs in the stream, or just enjoy the natural setting.

Co-ordination of the Facility Changes

This involved two aspects. Firstly the architectural changes to recycle the old building into a modern office complex, secondly the cultural changes to relocate a workforce in excess of 500 people, from cellular offices to an open plan environment.

There are no partitioned offices in the facility. Everyone, from office junior to the C.E.O. is in a workstation, and all workstations are the same size. Quiet rooms, with acoustic treated full height workstation screen walls are provided at a ratio of one per 10 people. All spaces such as these are available to all staff at all times.

There are over 450 workspaces and only 8 do not conform to the standard. These 8 workstations are different not because of status but because the people need special facilities to do their job. The way that facilities are provided will limit the future costs arising from the churn factor. Because everyone is in the same size workstation, when any changes are required, we move people not workstations. These are 'briefcase' moves.

All trappings of status in the workplace were removed to reinforce the new flattened management and team-based work ethic of the corporation.

In order to foster greater inter-departmental communication and socialisation, small cafes or refreshment nodes have been scattered throughout the facility where staff are encouraged to pause over a cup of coffee during the day.

We have also created numerous meeting places where staff experience unexpected encounters, for an enriched work experience.

Informal meeting areas are scattered around the office and atrium areas – 2008.

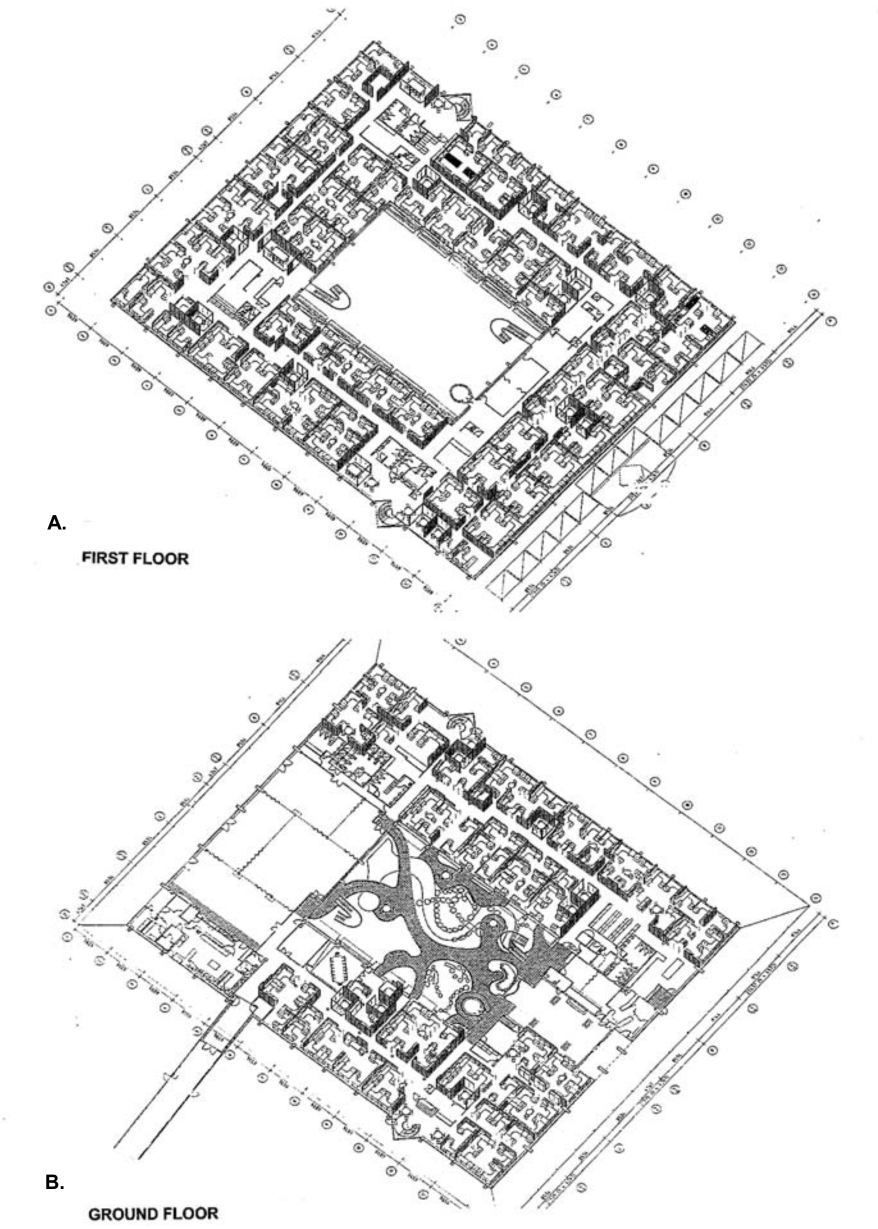
Conclusion

The opportunity to recycle Powerlink's redundant industrial building into a state-of-the-art modern building has delivered considerable cost savings to the Corporation. It has also delivered to its employees accommodation that provides cohesion in meeting the targets of the business, and placed in the hands of employees a creative, innovative and effective working environment.

As the landscaped atrium and waterways are an integral part of the buildings ecosystem, they have been regularly maintained and today have matured with the buildings systems, so that the Edison Building is as vibrant and energy efficient today as it was in 1997.

Innovative features used over 10 years ago such as solar collectors for hot water, air cooled AC condensers and heat exchange systems, P.E. cells controlling light circuits and rain water harvesting are now becoming common place in 'green' buildings.

The Powerlink Edison Building is a true pioneering sustainable building, that has stood the test of time, and which still has a considerable future ahead of it.



Edison Building Floor Plans

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CREATING POSITIVE OUTCOMES FROM OUR BUILT ENVIRONMENT

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Keywords: living buildings, positive building outcomes, sustainable, energy efficiency, reduced resource demand

Summary

Our generation is demanding more from our built environment. Not only do we want healthy buildings which are energy efficient; we no longer accept these as independent from the surrounding environment. In the global market we expect buildings and the organisations operating within them to interact with their community and share responsibility for supply and use of our resources. The more aware we are of our environment and the challenges we face, the greater expectation we place on building design and their outcomes. Globally we are challenging the design brief for the built environment in the move towards providing a better lifestyle for all; whilst facing global challenges of climate change, resource depletion and population growth.

Australia whilst only recently competing in 'world leadership' sustainable building design is producing some valuable additions to the built environment, yet is this enough?

Can our future built environment generate and renew the resources our communities require such as positive energy, water, material, food and social outcomes? We have the opportunity to create a new way of living in urban communities and new opportunities for large-scale renewable energy creation.

We explore future visions of how our built environment and sustainable communities could operate through changing values, reduction of resource requirements and our potential to create not just a self sufficient community but an abundant community model for all to share and adopt – the living building model.

Can we create a new breed of built environments that not only operate passively, generating and renewing resources onsite but in addition create enough renewable clean resources to supply themselves and their local community?

We review outcomes from current best practice built environments providing leading design solutions. What do our organisations and their buildings provide back to the community and what should we expect from them?

1.0 Living Built Environments

It would appear that in a frenzy of excess, consumerism and global neighbourhoods we have failed to appreciate the importance of taking responsibility for the resources and waste generated within our regions. Instead we have transported our polluted resources to other regions for disposal out of our sight. Whilst western society is attributed with the creation of much of today's consumer products we are also responsible for much of the earth's pollutions and waste. *How did we become so irresponsible in regards to our own needs and our planet?* The well referenced acronym 'NIMBY' - 'Not in My Back Yard' should perhaps be replaced by 'NIMP' - 'Not in My Planet'. Many older cultures / indigenous cultures value and respect the lands resources, believing they are one with the land, not through ownership but through spirituality and respect for our finite resources. We need to (re)create this respect in all who develop, design and manage our built environment; our community. We need a new understanding within our communities in respect to our environment and our resources.

For people in our community to change their behaviour, education and awareness is required, illustrating how much we waste our resources and pollute our communities through a cradle to grave approach to our resources and buildings. The alternative is to integrate a cradle to cradle approach whereby resources and waste are safe and reused within our community, self generating and creating abundance.

We need to question not only our communities' values but the values and benefits of our large organisations. How much benefit does a large organisation really provide to our community? Should we accept organisations providing a single product alongside many toxic outputs; thereby creating an additional health and resource burdens on our community? If they were a human cell they may be defined as cancerous and we would invest in research on how to rid society of them. As a community we need to demand organisations operate utilising clean inputs and outputs in the process of providing a product/commodity for the community? For too many years we have accepted building and manufacturing processes emitting toxic air, water and waste emissions as part of the necessary evil of modern day living. This has contributed to health problems globally that are related to toxic building materials and wastes; contributing to the enormous and increasing health costs for today's society.

We also have the critical challenge of significantly reducing our greenhouse emissions globally across a number of sectors but specifically from transport, manufacturing and buildings. This is globally understood, reported and supported by organisations such as the World Building Council of Sustainable Development (WBSCD), United Nations Environment Program (UNEP), World Health Organisation (WHO) and the International Program on Climate Change (IPCC).

Due to many current day health, environmental and climate change issues we now look to the design and management of our buildings to create a more holistic environment that will support our ongoing health and community needs. Responding to the needs of today's global community, a new model for the built environment is required, a further evolution from current best practice designs that look at significantly reducing energy and water demands; a new built environment model which not only reduces energy, water and materials demand but generates onsite clean and reusable resources to create building self sufficiency and positive outcomes for the local community.

1.1 The New Model

A new model is being suggested for the built environment which treats the building as a living organism with inputs and outputs operating within a larger ecosystem - our cities, continents and earth. The building itself can be viewed as a finely tuned environment within a delicately balanced ecosystem. Tipping towards an extreme overuse of energy, water and toxic outputs as we have already experienced in the 20th century causes chronic fatigue of the system, leading to more acute conditions globally such as excessive increase in greenhouse gas emissions, warming of the oceans, and melting of the arctic ice. We would do well to perceive the earth as human containing many living organisms. When diseased we need to find the causes and rebalance the system, just as we need to for buildings, cities and regions.

The living built environment model is based upon the concept of clean inputs, clean reusable outputs and mutually beneficial symbiotic relationships with the community. In a similar way to a 'cradle to cradle' approach to individual product design, a living built environment should adopt a cradle to cradle model. This will require living buildings accessing a responsible amount of clean inputs of air, water, energy and people resources, utilising these resources and providing these resources back in to the community to be reused in other ways. By all built environments responsibly utilising community resources and recharging them for use back into the community we can create balanced and abundant resources as demonstrated in Figure 1.

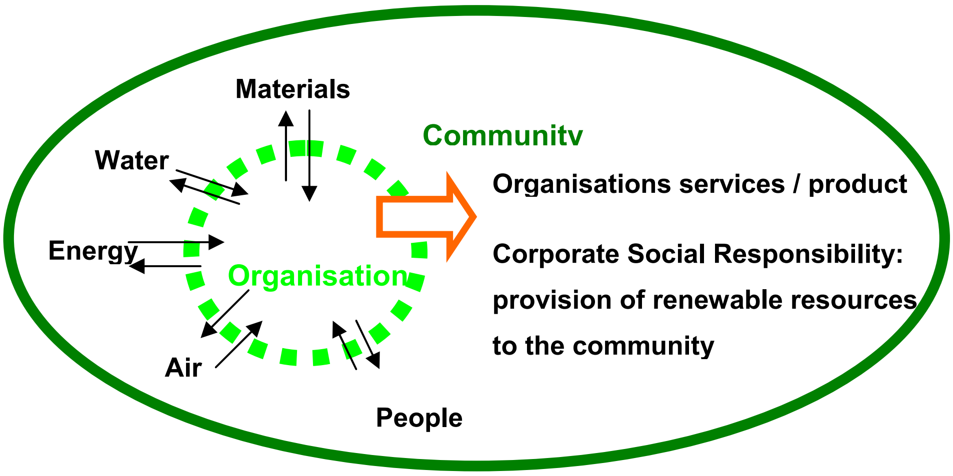


Figure 1 Model organisational operation within a community/planet.

This change to a new model requires business communities and organisations to change their approach from current practices of:

- Overuse of available resources thereby draining resources others require and upsetting the fine balance; and
- Creation of toxic outputs which can no longer be used within the community and only serve to disease the community.

It is the ongoing responsibility of our community to ensure that our buildings are not only designed as positive built environments utilising a cradle to cradle model but that they operate as positively within the community.

1.2 Greater Passive – Energy Building Design

A key objective of 'living buildings' is to minimise building energy use and provide onsite renewable energy generation through the design and operation of the built environment, thereby creating a low energy / self sufficient or energy positive built environment. The rebirth of energy efficient onsite renewable energy solutions such as trigeneration, wind, and solar becomes more viable for part or full onsite energy generation once we have a low energy built environment.

The following concepts consider how we may first minimise our building energy usage.

Passive and complimentary Active Systems: Our buildings need to be designed and operated for passive operations for the majority of occupation. New low energy building models propose annual building operation as 80% passive and as low as 20% active. The previous practice of operating buildings with 100% active systems running 24/7 for convenience is now seen as irresponsible and worst practice. If we are to significantly reduce our greenhouse gas emissions and maintain current rising world population levels we need to design and operate our buildings for general passive operation, with onsite energy generation.

Thermal Comfort / Ventilation Systems: There exists today the technology and expertise for buildings to be designed with both thermal insulation and significant ventilation as required to provide a thermal comfort level (subject to region/climate) for the majority of the year. The provision of separate heating and cooling systems to ventilation systems also allows further energy efficiencies when outdoor conditions are suitable for the internal comfort level. In this case natural ventilation methods or, if required, active ventilation methods may be utilised without activating the heating and cooling system. By creating a thermal building skin and compact building shape we may provide a more uniform indoor temperature allowing further efficiencies, and thereby decreasing the requirement for active heating/ cooling systems.

Whilst the heating load of an older building is approx. 200kWh/m2, more recent buildings designed with sustainable building principles can operate with a heating requirement of around 80kWh/m2. The use of solar passive and thermal design and an appropriate ventilation system with heat recovery can bring down the heating requirements to as little as 15kWh/m2. Buildings with such a low heating requirement are referenced as passive-energy buildings.

Natural /Artificial Lighting Systems: More recent buildings and workplaces are designed with sufficient daylight in the workplace or indoor environment to allow minimal or no artificial lighting during 'good' daylight hours. Artificial lighting needs and energy demand are therefore significantly reduced. This also occurs in modern housing where generally artificial lighting is not required in daylight hours.

In a number of commercial buildings low level artificial lighting and/or task lights are individually switched so end-users can operate lighting on demand when natural daylight is insufficient. Considering many of our built environments occupied by businesses/organisations are only occupied 8-10 hours per day (general daylight hours) and 5/7 days per week, the ability to significantly reduce lighting energy demand by naturally lighting indoor environments for the majority of occupied hours exists.

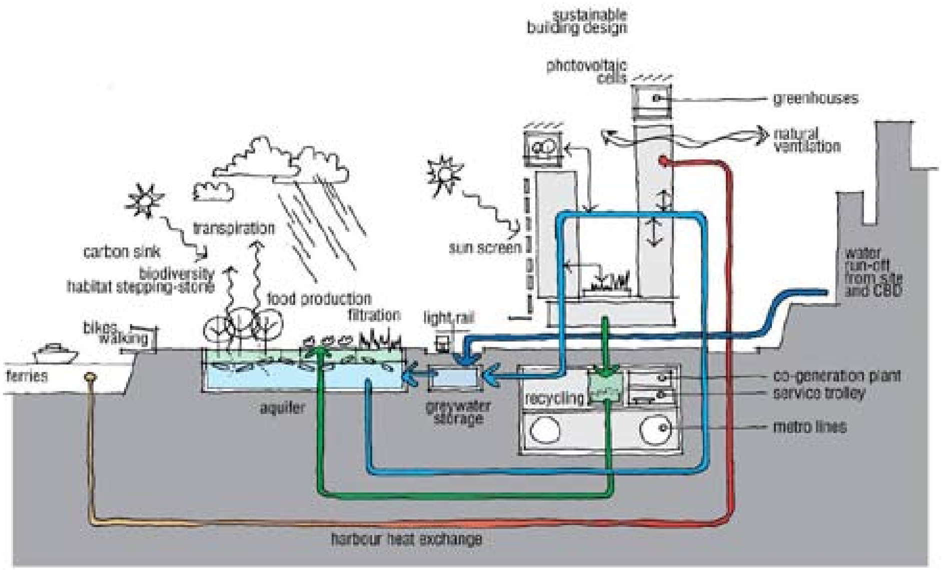
Vertical movement approach: The practice of providing compact low rise buildings with passive vertical movement (stairs) to reduce the need for energy driven movement (lifts) is commonly utilised world wide. Low-rise buildings provide benefits to organisations operating across a number of floors. The increased movement of people across and up floors provides exercise and enhanced communication interaction spaces. The more businesses/organisations encourage a sense of community with employees the greater the flow of natural communication and engagement within an organisation.

We need to choose to build zero energy / positive buildings that are low energy demand and will generate renewable energy for building operation and the community.

1.3 Creating Positive Outcomes – The Other Side Of Zero Demand

If we look at the commercial built environment as a biological process its purpose must be to contribute to the health and prosperity of the community it operates within: a cell (organisation/building) is only successful when the organism (community/planet) it operates within is successful. They have a mutually symbiotic relationship. To be successful the cell will provide a function within the community; it draws on resources to carry out its purpose, but it must also provide back to the community (reusable/non-toxic) resources as a bi-product of performing its role within the community.

Therefore the built environment and the organisations that occupy it must be required to provide the community with outcomes that assist with the success of the community through a balance of give and take of resources. The building/organisation should be required to provide back to the community clean resources from that which they utilised from the community. For example, CH2 Melbourne has been designed to draw black water from the passing street sewer, treat it onsite within the building, utilise treated water for the building operation and recirculate treated water to surrounding community/council gardens for watering purposes. In the 'Living Built Environment' sketch below we consider the inputs and outputs of our built environment in relation to the building operation and surrounding community operation. To achieve successful outcomes for the community the built environment must be fully integrated with the surrounding community and provide a balanced use of resource demand and re/generation.



Sketch 1 Living Built Environment - interrelationships with the environment and community. (HASSELL)

1.4 Future Indicators Of Success

So what do our built environments require to operate as a living built environment? There are a series of resources required as inputs and a series of outputs. To evaluate these we need to create key resource equations and indicators which will define the success of the living built environment. These must be used to continuously check against the design and management of the built environment to ensure a balance of resources is maintained and that the built environment performs a mutually symbiotic relationship with the regional and thereby global community.

Responsible use of local resources:

Each organisation / built environment must be required to demonstrate their positive contribution to society and equilibrium of clean input and output resource demand through a series of equations such as:

Energy Equation

Onsite renewable energy generation	+	Energy capture through building systems /reuse	=	Operational energy demand and renewable energy supply to community

Water Equation

Rain water collection	+	Grey water treatment system	+/or	Black water treatment system and sewer mining	+	Potable water resource from community	=	Operational Water demand and clean water supply to community

Air Equation

Clean indoor air quality with zero off gassing of toxins, pollutants or contaminants from equipment furniture or materials	+	Passive and active ventilation - air input from natural ventilation and active building systems, clean air outputs form building systems	=	Clean / healthy air provision for building occupants and local community

There must be clean and balanced inputs and outputs of energy, air and water resources of the built environment or organisations, as opposed to unbalanced and high resource demand of energy, air and water resources and toxic emissions. This is then extended and applied to all resource use and output. Organisations must ensure they generate clean bi-products throughout their operation. Products and services must begin to capture the cost of emitting clean bi-products / resources for the communities use.

The following criteria apply not just to the built environment operation but to an organisations operation within the built environment. These measures require an organisation to share community responsibility for the balanced use of community resources: ensuring clean inputs are balanced with clean outputs and that theirs is a self generating cycle of resources and materials within our built environments and each community.

Procurement of materials input: Procurement of simple products produced with clean/reusable emissions from recycled non toxic content and recyclable; cost of removing material to include disassembly ready for reuse in other products

Procurement of equipment input: Procurement of simple equipment and systems that are produced with no emissions/toxicity from recycled non toxic content and recyclable and produce no toxins in operation; Cost of removing equipment to include disassembly ready for reuse in other products

Recycling of materials and equipment: Procurement of equipment and materials to take into account long term usage, ability to be repaired/maintained/upgraded; and simplicity of systems to enhance long-term usage and maintenance

Food Input: Source local, seasonal and responsibly grown / produced fruit and vegetables, meats and legumes; source food produced without toxins, grown in suitable areas where toxic industry does not exist, and soil is non toxic.

Food Cycle: Ability to grow seasonal produce onsite or contribute to local production for local community consumption.

Food Output: Share / Compost food excess with business/ local community growers / community garden

Transport Input: Support and sponsor equitable public transport free from toxic emissions. Encourage and support pedestrian and bicycle transportation for employees and local community.

Transport Cycle: Support consumer availability of low cost/ no emission private transport options; Provision of cycling and pedestrian safe paths onsite and in community; provision of work within proximity to affordable sustainable housing communities**;** provision of onsite cycle storage and onsite charging of zero emission shared and private vehicles (such as electric/compressed air vehicles).

Transport Outputs: Investment into vehicles creating no emissions in operation and fully recyclable

Community / Social Output: Provide community services / support as appropriate for the region/ community size in physical environment or voluntary assistance through a range of community sectors (this already includes the provision of community facilities such as meeting spaces, shared fitness facilities, parklands, education and conferencing, community volunteering etc).

Corporate Social Responsibility (CSR) Community / Social Input: Source employees from region; incorporate/sponsor training and education within the region to ensure skills base; source experts and advisors from the region.

Due to the pressing need for cleaner energy and water resources organisations may focus social program opportunities on assisting the entire community to balance resource demand with resource availability. This requires business/organisations to ensure they minimise energy and water demand through reduced intake, provision of onsite generation and excess generation for community use.

2.0 ACHIEVEMENTS OF COMPLETED BUILT ENVIRONMENTS

2.1 Reductions, baselines and operational management

In the past 10 years Australian organisations and the building industry have made significant changes in the way we operate, manage and design our built environments. In response to a number of growing concerns, international standards and corporate best practices, we have increased our building efficiencies and moved toward a more environmental and sustainable building model.

Over this time a number of organisations have contributed significantly to our understanding and increasingly sustainable approach. The establishment of the NABERS Energy tool (previously ABGR – Australian Building Greenhouse Rating) by the NSW state government in the late 1990's provided benchmarking and baseline data on building and tenancy energy usage. This has been further developed to provide water, waster and indoor air quality benchmarking tools under the NABERS rating scheme. With the commencement of the Green Building Council of Australia in early 2000 and subsequent creation of the Green Star Rating system, Australian design and building professionals finally have a suite of rating tools to evaluate the built environment. This has inspired the Australian building industry and provided centralised resources, benchmarking and case studies for our built environment and industry professionals.

The establishment of Australian building environmental rating tools was further assisted by both State and Federal Government Green Star/ABGR mandatory benchmarking requirements. The referencing of these tools by the Property Council of Australia in the PCA commercial building rating has ensured further implementation by the Australian commercial built environment.

More recently we have seen the uptake of Environmental Management Systems (EMS) for many organisations as part of their environmental initiatives to operate with a more responsible use of resources and provide continual improvements. With impending Emissions Trading Schemes, Carbon Reporting is also implemented within organisations. This will enable an organisation to be well prepared to both monitor and reduce the greenhouse gas emissions. We envisage these operational and organisational indicators will become critical for building designers in the future.

Ongoing education, training and case study information from International and Australian rating tools and contributing organisations assists in the further evolvement of Australian sustainable and energy efficient buildings. Data and Case Studies from these two Australian rating tools have provided benchmarks and best case scenarios for much of what we design and build today.

2.2 Success against current indicators

Benchmarking sustainability initiatives and outcomes allows us to better understand areas of building design and operation requiring improvement. Australian buildings show a range of success against standard energy building measures where benchmarked against he NABERS tool. Measures utilised reference electricity density measured in MJ per m2 area and kWh usage. Current Best Practice for a building or tenancy currently sits between 5 and 5 + 40% ABGR (refer www.nabers.com.au).

The referenced buildings discussed in Section 3 reference current benchmarking measures provided by the Australian environmental building tools. Whilst only small samples of Australian buildings are referenced in this paper the results are indicative of what we find in the broader built environment in Australia.

Through the use of the ABGR/NABERS Energy tool many new buildings are achieving 30-60% savings in their energy rating as compared to a standard commercial building. Through the use of the Green Star rating scheme we have seen significant improvements in potable water reduction and air quality/ventilation rates.

Through the process of utilising these rating tools and the follow-up case studies industry benchmarks are created. Measuring environmental benchmarks thereby provide the feedback mechanism to the community for improvements to building design, informing and educating the community about what is being achieved and what more we can do. With these built environment tools and organisational Environmental Management System's (EMS) we as a community are seeing reduced energy demand from Australian buildings.

3.0 PREDICTED ACHIEVEMENTS OF CURRENT BUILDING DESIGNS

3.1 Reductions and New Initiatives

Current sustainable building design undertaken has lead to a greater understanding of sustainable building models suited to our region and changing climate. As our designs improve in respect to energy and more recently water resource use, we begin to introduce a new set of measures that are becoming more consistent and drive improvements in not only design but organisational commitments to the environment. The design, construction and operation of the following two buildings raise current best practice built building standards, providing alternative building system combinations, consistent benchmarks and case study references by further reducing energy and water demand and integrating new initiatives in building design.

CH2 Council House 2 Little Collins Street Melbourne

The CH2 building completed in 2007 by Melbourne City Council has been successful in lifting current best practice building standards in Australia. Through published research, building case studies and Productivity study outcomes, CH2 has contributed greatly to our building measures and perception of what is possible in our built environment.

The building is a 10 storey commercial office building with underground car and bicycle parking and ground floor retail space providing community engagement and activation. The building has a commercial office net lettable area of 9373m² and retail net lettable area of 500m².

The building systems utilised are non-conventional and challenge our notion of low energy technology.

The 'energy system' comprises: a cogeneration unit providing 60kVA of electricity which is estimated to supply 30% of buildings need; a Photovoltaic (solar) system supplying 3.5kW of electricity; solar hot water heater supplying 60% of hot water requirements; and wind turbines[1].

The 'water system' comprises: sewer mining and black water treatment of 100KL capacity per day to A grade quality; and a rainwater harvest capacity of 15KL. The estimated water usage reduction in comparison to existing building standards is 72%. The water system is designed to enable the council to utilise recycled water fro the building for use on local council parks and gardens, creating a positive benefit to the community.

The 'heating and cooling' system comprises: chilled ceiling panels within the office ceilings and radiant heating panels, along with shower towers to the southern façade to cool air used back into the building. Purge windows used in summer nights reduces cooling requirements by an estimated 20%.

The ventilation system allows for 100% fresh air intake.

The lighting system comprises: low level general lighting (150 lux supported by task lighting which is estimated to save 66% of lighting energy use.

The building is designed to maximise benefits from climatic conditions with individual façade design based on building orientation.

CH2 is a certified 6 star Green Star Office Design rating by the Green Building Council of Australia, and has achieved an ABGR (NABERS Energy) 5 star +20% reduction in carbon dioxide emissions. CH2 nominates on their website they are currently registered to achieve Green Star As-Built rating for the building also. The key success of this building would be the council's openness and transparency of the design process and building outcomes and the contributions to low energy building design research and case studies internationally which inspires our global community.

VS1 Victoria Square Adelaide

The VS1 building will house SA Water from November 2008 and has already generated much interest in the sustainability principles applied to the laboratory component and the building design overall. The building has already achieved a 6 star Green Star Office Design rating by the Green Building Council of Australia, and is registered for the Green Star As-Built rating and Green Star Office Interior rating. Through conference presentations and case study publications of the building design and predicted outcomes, VS1 has already contributed to the current understanding of building design and systems required for sustainable buildings. Productivity studies are underway which will add to current understanding of sustainability principles and productivity links.

The building is a 10 storey commercial office building with underground car and bicycle parking and ground floor information centre for SA Water providing community engagement and activation. The building has a commercial office net lettable area of 12000m^2 and laboratory net lettable area of 5000m^2.

The building has been designed with open stair ways and a central atrium to create greater internal daylighting, views and interaction between the commercial, laboratory and retail component of the building. The building systems utilised are conventional and non-conventional commercial building systems and together challenge our notion of low energy technology.

The 'energy system' comprises: a gas fired co-generation utilising a combined heat and power unit to generate power, heat hot water and run an absorption chiller; generates 25% of the base electricity load; and a photovoltaic (solar) system on the roof; and solar hot water. The 'energy system' for the laboratories includes: risk assessment approach to validate the use of ganged fume cupboard ductwork allowing significant reduction in fan energy; energy recovery from return air stream; demand reduction; and laboratory equipment efficiency. The building is estimated to achieve a reduction of approximately 50% in comparable greenhouse gas emissions and energy costs compared to a typical office building.

The 'water system' comprises: black water treatment to A grade quality; cooling tower water is recycled; fire test water collected and re-used; and rainwater harvested (from the roof of the building and the school roof next door). Due the significant focus placed on water reduction and recycling the office building is estimated to use a reduction of approximately 70% in potable mains water consumption compared to a conventional office building – a saving of 11 million litres per annum.

The 'heating and cooling' system comprises: high efficiency underfloor displacement ventilation system with individual control to occupants; and night purge of air removes heat and cools the building structure. The ventilation system uses 100% fresh outside air under most operating conditions.

The lighting system comprises: 75% of the office area lies within 8m of windows and the atrium; increased natural daylight and 18% less base building general fittings.

The building is designed to maximise benefits from climatic conditions with individual façade design based on building orientation. A fritted western veil in front of the building skin reduces the solar load on the western facade while still retaining views and daylight. High performance double glazing is utilised for the north, south and east facades.

VS1 has been developed as a commercially viable building that brings together many developed technologies to create a low energy building systems. The key success of this building would be the organisations commitment to leading low energy design and best indoor environment quality including improved air quality and design for the laboratories areas. The building and its operation will be monitored after completion with the outcomes providing further benchmarking indicators to ensure continual improvement in our building design and management.

3.2 Success Against Living Building Indicators

Obtaining consistent measurable indicators which can be used universally will allow us the greatest ability to move forward quickly and achieve our greenhouse gas emission and water reduction targets whilst achieving a built environment which achieves our community requirements.

The CH2 building design explores non-conventional building methods and systems to create a low energy, positive building which is successfully communicated to the community from the building construction process to occupation in 2007. Since then we have seen a greater uptake of commercial buildings demonstrating the viability of low-energy buildings in today's market demand. VS1 demonstrates the ability to use sustainable building design and conventional systems to create a commercially viable low-energy building only a year later than the completion of CH2. IN addition to this both organisations operating these buildings are progressive and demonstrate a commitment to improved environmental outcomes which includes an environmental policy, Environmental Management System and the creation of carbon reduction targets and carbon management.

What more can we expect from our leading buildings in the next couple of years? Benchmarking sustainability initiatives and outcomes from current and future building designs against the indicators of success for 'living buildings' will allow us to better understand our most recent improvements and move us closer to creating a low energy - positive living building model.

4.0 WHAT WILL IT TAKE TO CREATE THE LIVING BUILT ENVIRONMENT?

As in all areas, we cannot manage and improve upon that which we do not measure. Whilst we have the vision and technology to design living buildings which operate partially self sufficient of community infrastructures and provide recycling of resources and positive community outcomes, we are still developing consistent measures and benchmarking of built environments required to provide the understanding and improvements required at an international level.

What we must work towards now is the sharing and implementing of consistent benchmarking across all built environment key indicators. Whilst we understand holistically the principles required we all must take ownership of this issue and provide international measures.

So what will it take to create the model of living built environment? Technology is already available to create positive living as such. It will require education, expertise will power and cultural change to drive this. It also requires each individual, community, organisation, Government and Non Government Organisation to take responsibility for the resources they use and commit to sharing resources and the generation and reuse of clean outputs which supports mutual symbiosis within our entire community.

Our built environments, organisations and sustainable communities can and should operate to create not just a self sufficient community but an abundant community model for all to share and adopt – the living building model.

Footnote [1]The electricity generation from the CH2 rooftop wind turbines are unknown at time of publication. Information on CH2 has been obtained form published case study information available for the Melbourne City Council website. Refer www.melbourne.vic.gov.au

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CASE STUDIES OF COMPREHENSIVE ASSESSMENT SYSTEM FOR BUILDING ENVIRONMENTAL EFFICIENCY (CASBEE) FOR HOME

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Keywords: CASBEE, detached house, environmental quality, case study

Summary

In Japan, approximately 500,000 detached houses are constructed per year. In order to improve the quality of houses, the “Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) for Home (Detached House)” was introduced in 2007.

Since the CASBEE for Home is expected to be used by various stakeholders in the housing construction industry, such as clients, designers, contractors, and builders, it is designed to be easy to use. The structure of the CASBEE for Home" is similar to that of other CASBEE tools, and it can be used to evaluate both quality and environmental loads. The evaluation criteria are divided into 6 categories— Q1: comfortable, healthy, and safe indoor environment; Q2: sustainability to service life; Q3: regional contribution for view and ecology; LR1: energy and water conservation; LR2: resource conservation and reduction in construction waste generation; and LR3: contribution to improvement in regional and global environment. The assessment also includes 54 evaluation criteria that are based on the standards established in Japan. The comprehensive assessment considers not only the features of houses but also the features of their surroundings, the home appliances used by the occupants, the information provided to the occupants by the house owners, and the techniques used in the building material production and house construction.

The results for the case studies were obtained by using the CASBEE for Home. A total of 25 case studies were conducted at several construction sites from Hokkaido (northern part of Japan) to Kyusyu (southern part of Japan). For the case studies, 15 wooden (columns and beams) houses and 10 prefabricated houses comprising lightweight steel framework or wooden panels were selected. In addition, case studies of model houses that were built without taking the environment into consideration, taking the environment into consideration to some extent, and taking the environment into consideration in detail.

1. Introduction

The CASBEE evaluates the environmental load from various viewpoints. With the future of mankind being threatened by advancing global warming, it is necessary to build environment-friendly houses by reducing their environmental load. The use of CASBEE to evaluate houses is a very effective technique for reducing the environmental load. If the CASBEE is used extensively, environmental load of houses can be reduced to a large extent. The CASBEE also assesses the environmental quality of houses from various viewpoints, which aids in improving their quality. Builders are expected to construct comfortable houses, maintain them assuming them to social assets, and hand them over to their owners.

CASBEE tools for new buildings, old buildings, buildings in urban districts, etc. have already been developed. The CASBEE for Home was introduced in 2007. It evaluates the general environmental conditions on the basis of the two indices Q and L. Index Q is used to assess the improvement in the environmental quality within a hypothetical enclosure, and index L is used assess the negative impact on the external environment of the hypothetical enclosure. The BEE for a virtual enclosure is evaluated as shown in Figure 1. Each factor related to Q and Load Reduction (LR) shown in Tables 1 and 2 is evaluated. In this paper, we report the results of the case studies of the CASBEE for Home (Detached House). L indicates the environmental load and is evaluated on the basis of LR. The BEE chart is shown in Figure 2. Houses are given grades 1–5 on the basis of their BEE, and their grades are indicated by stars. Figures 2–4 present the results of the evaluation obtained using the CASBEE. The radar chart shows the equilibrium between the 6 criteria, Q1–Q3 and LR1–LR3. The warming effect chart shown in Figure 4 presents the $LCCO_2$ of a simple detached house and shows the reduction rate comparing to referenced general houses. The bar charts show the grades assigned to the houses on the basis of 21 additional criteria, which elucidates the equilibrium between the criteria. Using these criteria, detached houses can be evaluated precisely, and the results of the evaluation can be presented effectively through charts.

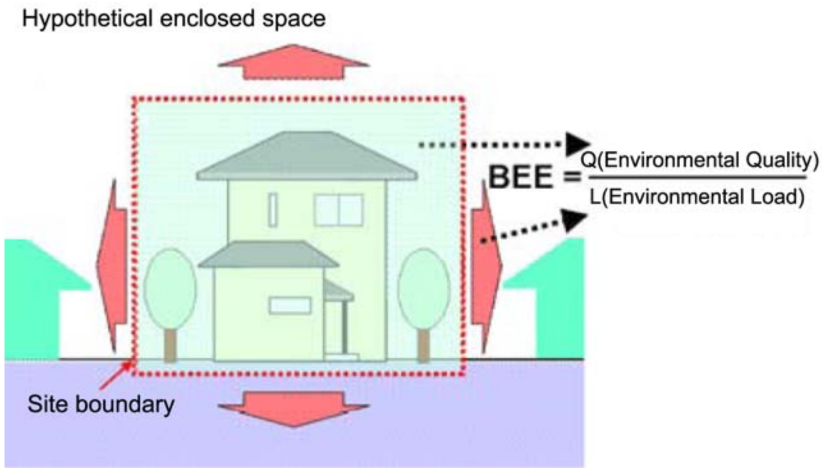


Figure 1 Concept of Hypothetical Enclosure in CASBEE for Home

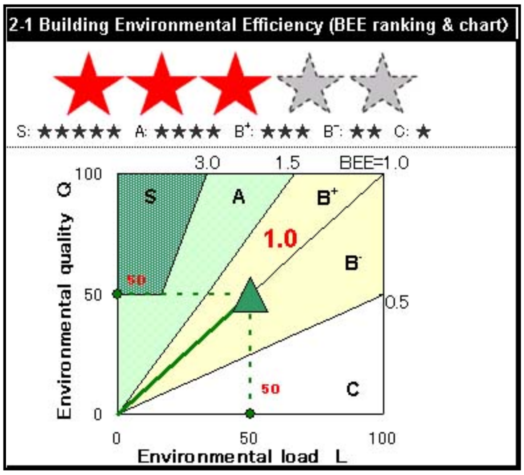


Figure 2 BEE Ranking & Chart

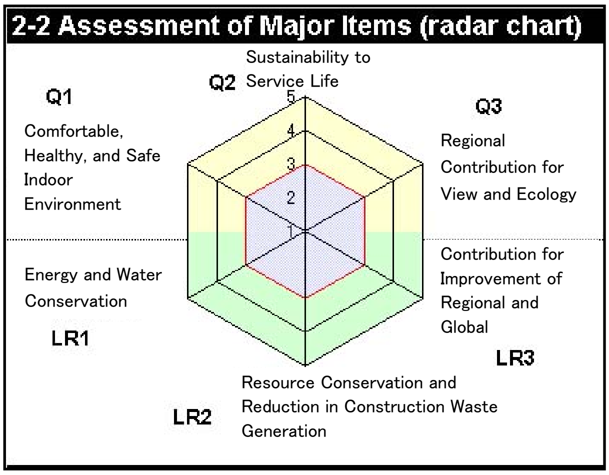


Figure 3 Assessment Based on Main Criteria (Radar Chart)

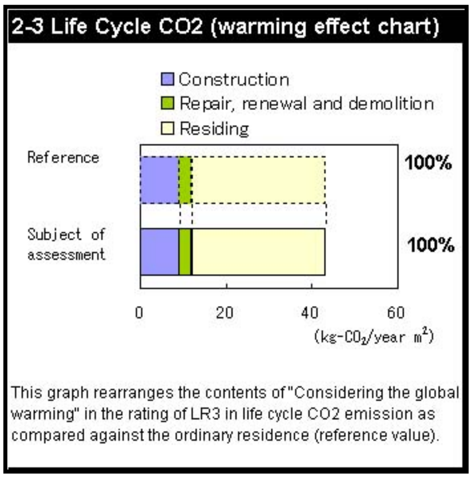


Figure 4 Life Cycle of CO_2 (Warming Effect Chart)

Table 1 Criteria for Q

Main Criteria	Additional Criteria
Q1 Comfortable, Healthy, and Safe Indoor Environment	1. Hotness and Coldness
	2. Health, Security, and Safety
	3. Brightness
	4. Peaceful Atmosphere
Q2 Sustainability to Service Life	1. Basic Life Performance
	2. Maintenance
	3. Functionality
Q3 Regional Contribution for View and Ecology	1. Consideration of Townscape and Scenery
	2. Creation of Biological Environment
	3. Safety and Security in Region
	4. Utilization of Regional Resources and Assimilation of Regional Culture

Table 2 Criteria for LR

Main Criteria	Additional Criteria
LR1 Energy and Water Conservation	1. Energy-saving Design of Buildings
	2. Energy Conservation by Use of High-efficiency Equipments
	3. Water Conservation
	4. Devices of Maintenance and Management
LR2 Resource Conservation and Reduction in Construction Waste Generation	1. Use of Materials that Aid in Resource Conservation and Reduction in Waste Generation
	2. Reduction in Waste Generation in Production and Construction Stages
	3. Promotion of Recycling
LR3 Contribution to Improvement in Regional and Global Environment	1. Consideration of Global Warming
	2. Consideration of Regional Environment
	3. Consideration of Immediate Environment

2. Range of Evaluation Criteria and Outline of Results

A total of 25 case studies were conducted on houses located in the region from Hokkaido to Kyusyu; these houses were constructed by using various methods and included both conventional wooden houses and modern houses. The list of case studies is provided in Table 3. In the case studies, 15 conventional wooden houses and 10 prefabricated houses comprising lightweight steel frameworks or wooden panels were considered. The case studies also included model houses that were built without taking the environment into consideration (Case 26), taking into consideration the environment to some extent (Case 27), and taking into consideration the environment in detail (Case 28). The specifications of the model houses are listed in Table 4.

The results of BEE are shown in Figure 4. Because we have chosen relatively good cases in which energy is conserved and/or the quality of environment is improved, we obtain relatively high grades. It can be observed from the results that the model houses have received high grades, which indicates that people are increasingly growing concerned about environment (Cases 26–28).

3. Results of Evaluation

The results of the evaluation are presented according to the evaluation criteria adopted in the case studies.

3.1 Q1: Comfortable, Healthy, and Safe Indoor Environment

The assessed houses in general got high ranks for insulation quality because approximately 90% of them satisfied the Next Generation Energy-Saving Standards established in Japan, and the air conditioners and heating systems were appropriately designed. However, a grade was low for the model house and for the case in which the air-conditioning units were not selected when evaluation. With respect to the building material, most of the houses got grade 5, which was the highest grade given in the evaluation, because they were made of ☆☆☆☆ building materials, which emit a low amount of VOCs. In the meantime, more than 50% of the houses got grade 3 with regards to prevention of house break-ins. In some cases such as Case 14 had laminated glass panes.

3.2 Q2: Sustainability to Service Life

The assessed houses in general got the highest grades for their earthquake-proof designs and natural-disaster-proof designs. The design of houses is the primary factor on which the strength of houses in Japan depends on. However, more than 50% of the houses got grade 3 with regard to the quality of outer wall and roof. With regards to barrier free, 50% of the houses got only grade 2 nevertheless there is a standard set in the law for promotion to secure the quality of house in Japan.

3.3 Q3: Regional Contribution for View and Ecology

Most of the houses got above grade 4 with regards to the arrangement of the building and the surroundings taking into consideration the landscape or safety. With regard to the use of local resources and the cultural heritage of houses, most of them got grade 3 because of the efficient use of the appropriate building materials or consciousness of use. However, the houses in Case 1, in which local building materials were extensively used, got grade 5.

3.4 LR1: Energy and Water Conservation

As mentioned previously, the assessed houses had high-quality insulation. However, most of them got grade 1 with regard to the efficient use of natural energy. With regards to the performance of air-conditioning units and hot-water supply systems, around 50% of them got grade 5 for air-conditioning units and around 80% of them got level 5 for hot-water-supply system. This was because most of the hot-water-supply systems is served together with house and easy to serve with explanation about effectiveness of the saving energy equipment. However, more than 50% of them got grades lower than grade 3 with respect to the insulation in bathrooms and piping. With respect to the effective use of energy, 2 cases had combined heat and power systems and 13 cases had photovoltaic power generation systems. They got high grades with respect to water conservation because most of them had water-saving-type equipments, but only 3 cases have rainwater tanks. Fifty percent of the houses served as model houses providing information on the ideal way of living and house maintenance and management.

3.5 LR2: Resource Conservation and Reduction in Construction Waste Generation

The houses generally got grade 3 with regards to the use of building materials taking into consideration resource conservation and reduction in the generation of construction waste. They got low grades because recycled building materials such as wood-based composite board or plasterboard for the finishing material were not used extensively although they use for back materials of both exterior and interior. On the other hand, most of the houses got grade 5 for their contribution to reduction in the waste generation during production of the building materials or construction. Thus, it is evident that environmental issues have been seriously taken into consideration by designers and builders.

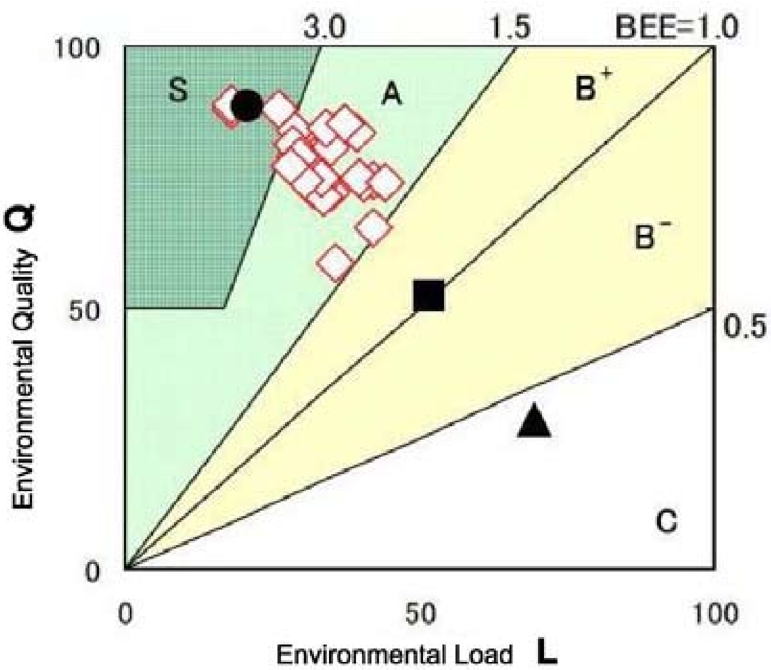
3.6 LR3: Contribution to Improvement in Regional and Global Environment

Most of the house got high grades with regard to the contribution to the improvement in the surrounding thermal environment through appropriate building arrangement or tree plantation. With respect to the conservation of natural environment, more than 50% of them got grade 3.

4. Conclusions

The CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) is an environmental labeling tool for buildings and is based on the assessment of the environmental parameters with respect to the building design. In Japan, approximately 500,000 detached houses are constructed per year. In order to improve the quality of houses, the “CASBEE for Home” was introduced in 2007.

The results for the case studies have been obtained by using the CASBEE for Home". A total of 25 case studies have been conducted at several construction sites from Hokkaido (northern part of Japan) to Kyusyu (southern part of Japan). It can be observed from the results that the model houses have received high grades, which indicates that people are increasingly growing concerned about environment. The results of the evaluation have been presented according to the evaluation criteria—Q1, Q2, Q3, LR1, LR2, and LR3—adopted in the case studies.



Legend ◇: Result of Case Studies, ▲: Case 26, ■: Case 27, and ●: Case 28

Figure 4 Distribution of BEE in Case Studies

Table 3 List of Case Studies

	Area	Structure/Construction	BEE
Case1	Hokkaido	Conventional Wooden Structure	2.0
Case2	Saitama	Conventional Wooden Structure	3.3
Case3	Saitama	Conventional Wooden Structure	4.8
Case4	Tokyo	Conventional Wooden Structure	4.8
Case5	Tokyo	Conventional Wooden Structure	2.2
Case6	Tokyo	Conventional Wooden Structure	2.6
Case7	Tokyo	Conventional Wooden Structure	1.5
Case8	Tokyo	Conventional Wooden Structure	2.2
Case9	Tokyo	Conventional Wooden Structure	1.8
Case10	Tokyo	Conventional Wooden Structure	2.4
Case11	Kanagawa	Conventional Wooden Structure	2.1
Case12	Kyoto	Conventional Wooden Structure	2.4
Case13	Kyoto	Conventional Wooden Structure	1.6
Case14	Fukuoka	Conventional Wooden Structure	2.2
Case15	Fukuoka	Conventional Wooden Structure	2.3
Case16	<Supposed> Metropolitan Area	Wooden Prefab	4.8
Case17	<Supposed>	Wooden Prefab	2.1
Case18	Ibaraki	Wooden Prefab	2.8
Case19	Ibaraki	Steel Prefab	2.7
Case20	Tokyo	Steel Prefab	2.8
Case21	Kanagawa	Steel Prefab	2.0
Case22	<Supposed>	Steel Prefab	1.8
Case23	Chiba	Steel Prefab	1.7
Case24	Aichi	Steel Prefab	1.6
Case25	Fukuoka	Steel Prefab	2.2
Case26	<Supposed>	Conventional Wooden Structure	0.4
Case27	<Supposed>	Conventional Wooden Structure	1.0
Case28	<Supposed>	Conventional Wooden Structure	4.2

Table 4 Specifications of Model Houses

	Case 26 Environment not taken into Consideration	Case 27 Environment taken into Normal Consideration to some Extent	Case 28 Environment taken into Consideration in Detail
Insulation Quality	Former Energy-saving Standard	New Energy-saving Standard	New Energy-saving Standard
Natural Energy Use (Solar/Wind Energy)	Not Considered	Not Considered	10% Reduction in Heating
Windows	Single Glass + Drapes	Double Glass + Drapes	Low emissivity Glass + External Sc reen
Arrangement of Windows	No Windows in Two Directions	Windows in Two Direction in Most Rooms	Two Windows in Directions in All Rooms
Proportion of Windows	<20%	>20%	>20% + South Window
Prevention of House Break-ins	No Consideration	Consideration for Enterable Openin g	Effective Consideration for Enterable Opening
Air-conditioning Units	Inefficient Air-conditioning Units	Efficient Air-conditioning Units	High Efficient Air-conditioning Units in Entire Building
Photovoltaic Power Genera tion System	Not Used	Not Used	4 kW
Water Conservation	Not Considered	Dishwasher	Dishwasher + Water-saving Toilet
Level of Chemical Pollution	Quality Security (Level 1)	Quality Security (Level 3)	Quality Security (Level 3)
Structural Durability	Standard Level	Standard Level	Quality Security (Level 3)
Structural Strength (Earthquake)	Standard Level	Standard Level	Quality Security (Level 3)
Durability of Exterior Material	del 50 years	del 50 years	del 100 years
Use of Recycled Exterior Material	GW for Insulation	Shown left + Wooden Board under Roof	Shown left + Wooden Board under Wall
Use of Recycled Interior Material	Plaster Board under Wall and Ceiling	Plaster Board under Wall and Ceiling	Shown left + Wooden Board under Floor + Natural Wood for covering Wall and Floor
Barrier-free Housing Design	Not Considered	Quality Security (Level 2)	Quality Security (Level 3)
Trees	<20%	<30%	<40%
Safety and Security in Region	Not Considered	Clear View	Clear View + Easy to Evacuate
Use of Local Resources	Not Used	Not Used	Partial Use of Local Material
Improvement in Thermal Environment	Appropriate Arrangement of Building	Appropriate Arrangement of Building	Appropriate Arrangement of Building + Many Trees
Reduction in Load on Infrastructure	Not Considered	Penetration System of Rainwater into Ground	Shown Left + Garbage Separation
Environmental Conservation	Preservation of Geographical Features and Topsoil	Preservation of Geographical Features and Topsoil	Shown left + Local Trees

5 STAR PLUS - POLICY AND REGULATION RESPONSES TO POLITICAL AND INDUSTRY PRESSURES FOR ENHANCED SUSTAINABILITY STANDARDS.

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Summary

Building standards in Australia are controlled under an Inter-Government Agreement (IGA) between the Commonwealth Government and the governments of the states and territories. The IGA provides for an Australian Building Codes Board (ABCB) to create and manage the Building Code of Australia (BCA). Traditionally, building codes in Australia, and the BCA as first developed, have been concerned with minimum life-safety standards. The introduction of sustainability standards into the BCA has brought many challenges, not least of which are how to determine sustainability standards for energy and water use in buildings, and how to deliver them in a contentious political environment.

This paper outlines the introduction of energy-use standards for housing into the BCA, and then deals with the technical and political issues faced in Western Australia in going beyond the coverage of the BCA to introduce standards for greenhouse gas reductions in water heating and reductions in potable water use. It shows the rationale of the Western Australian Government for introducing these measures and gives an insight to the complex decision-making issues that surround public policy development in sustainability.

1 Introduction

Sustainability has been a key focus of the Western Australian State Government since 2003 when the introduction of the State Sustainability Strategy officially acknowledged its importance. The Strategy set out a range of actions under six major headings - governance, global sustainability, natural resource management, settlements, community and business. This was then supplemented by various other strategies that furthered sustainability in the State. These include the Greenhouse Strategy 2004, the State Water Strategy 2003, the State Water Plan 2007, the State Water Recycling Strategy 2008 and the Premier's Climate Change Action Statement 2007.

Sustainability has also been a key feature in the expansion of the scope of the BCA. Emerging environmental, social and economic trends have driven the momentum for increased sustainability measures in buildings. The Western Australian policy development experience in this area is unique in that two separate policy options were developed in parallel, a Western Australian version of the New South Wales' BASIX assessment tool and the BCA. This situation has led to the introduction of 5 Star Plus, which brings water efficiency measures into the BCA for the first time. This has preceded national policy development by the ABCB, which is just starting to research possible options for water efficiency and energy use in water heating.

2 Energy Standards in the Australian Building Regulations

In the late 1990s it became obvious to Australian governments that energy use in buildings was increasing significantly, and this was causing both greater greenhouse gas emissions from power stations and substantial infrastructure costs in delivering enhanced electricity and reticulated gas supplies. Of particular note was the rapid increase in use of reverse-cycle air conditioners during summer in Australia at a time when traditional "Californian bungalow" house designs were being superseded by Georgian and Tuscan styles with no eaves and exposed windows. These "M^{c}Mansions" were often poorly insulated, badly oriented and offered little scope for natural ventilation. By 2001 there was a growing belief that regulation through appropriate building standards was needed to ensure an adequate level of thermal performance in housing, as well as in commercial buildings.

In 2001 the ABCB was asked to prepare energy use standards for buildings. The first BCA energy provisions for detached houses were introduced in 2003, and steadily extended to cover all classes of buildings by 2006. These provisions addressed energy use in heating and cooling by requiring appropriate insulation, reduced heat gain and loss through windows and provision of adequate natural ventilation (ABCB, 2007a). In 2006 the standards for detached houses were increased to what is colloquially known as the "5 Star" standard. As is the case with all BCA standards, these provisions are set out as a performance requirement which can be met by using any scientifically valid building solution, or by adopting "deemed to satisfy" building solutions that are set out in the BCA (ABCB, 2007b)

In parallel to the development of these BCA standards, the New South Wales Government developed a sustainability tool known as BASIX. BASIX adopted energy provisions similar to the BCA to deal with thermal comfort, but added provisions to deal with water heating, appliance use and water use in houses and for landscaping. BASIX is applied through the planning system using an on-line certification process that allows a designer or owner to try different combinations of energy or water saving strategies to meet the required target reductions, before obtaining an online compliance certificate (New South Wales Government, 2007).

Increasing BCA energy provisions to the 5 Star standard, and in New South Wales the introduction of BASIX, proved politically contentious. A great deal of debate occurred about the true cost of introducing these sustainability provisions into houses, with suggestions ranging from no cost if a house is properly designed, to upwards of $20,000 for full compliance with all the energy and water saving requirements of BASIX. Because of industry lobbying, and because of their own concerns about housing affordability, some governments remained cautious about adopting the BCA 5 Star standards, while others were keen to go further and include provisions for water saving and water heating.

The IGA that governs the operations of the ABCB and the ABCB's commitment to best-practice regulation require each proposal for new regulation to be subjected to an appropriate Regulatory Impact Statement (RIS). This looks in detail at the costs of the proposed regulation, the benefits that flow to both consumers and the community, and whether non-regulatory approaches are a better alternative. Because of the differing views of possible cost, the 5 Star RIS was subjected to a high level of scrutiny and review. The final RIS demonstrated a small but positive benefit over cost.

At the November 2005 meeting of the ABCB board, the final decision was made to include the 5 Star provisions in the BCA for 2006. This decision was contentious. The ABCB noted that a number of governments were committed to proceeding with the 5 Star standards, whether they were included in the BCA or not. The Board believed that it was better to publish the standard as part of the BCA, with those governments not wishing to adopt it able to "vary it out" rather than not adopt it, and run the risk of some governments developing their own standards that were not compatible with the BCA proposals or similar proposals in other jurisdictions.

3. Water Use Requirements in Buildings

There are at present no sustainability provisions in the BCA dealing with water use, in the same way that energy provisions have been included. Studies are under way for the development of water use standards (ABCB, 2007c). Sustainable water use in housing relates to water used inside the house for cooking, washing and flushing of toilets and to water used outside the house for landscaping, swimming pools and the like. Normally BCA provisions would relate only to the fabric of the building and it is debatable whether BCA standards should regulate water use in landscaping where a building permit is not required.

Potable water is typically delivered through reticulated pipes by centralised water utilities. Conditions of drought in Australia, coupled with expanding urban areas and limited access to new water supplies or dam sites, have limited the amount of potable water available for household use. Most governments have responded to these conditions by imposing restrictions on how water can be used for landscaping, and some governments have gone further in trying to reduce water use within the house. Strategies for reducing water consumption are based on the use of reduced-flow fittings or appliances, or by substituting alternative water supplies for reticulated potable water. These strategies have not been uniformly applied across Australia, in Queensland, for example, the State Government has introduced building standards in addition to the BCA to deal with water use. In New South Wales, BASIX deals with both internal and external water use, as well as energy use.

4. The Western Australian Context

Western Australia is a large state with climatic and geographical conditions ranging from tropical monsoons in the north, through deserts in the centre to temperate woodlands in the south. Perth, the major city, is located on the south west coast and has a Mediterranean climate with high temperatures in summer and most rainfall concentrated in winter. Perth and the south western region of Western Australia have been subject to a step-change in rainfall since the mid-1970s as shown in Figure 1.

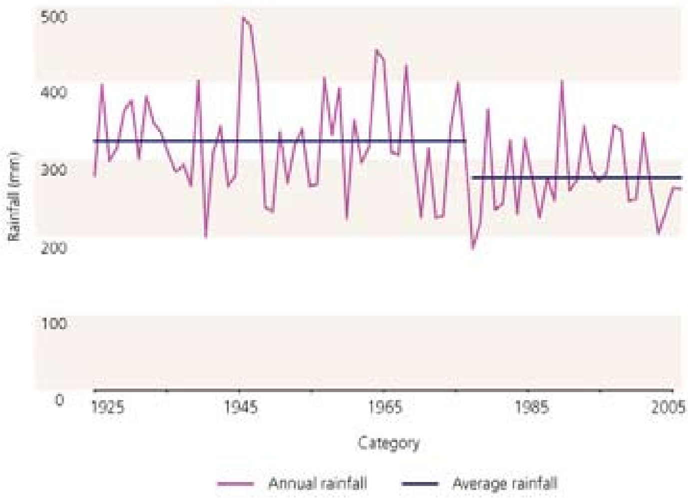

Figure 1: How our rainfall has changed – the South West (Indian Ocean Climate Initiative, 2005)

4.1 Western Australian Separation of Building and Planning

Political responsibility for building standards and applying the BCA falls to the Minister for Housing and Works while responsibility for the planning system falls to the Minister for Planning and Infrastructure. This is different from some other states that combine building standards and planning within the same ministerial portfolio.

Western Australia adopted the BCA 5 Star standard in 2006. A transitional provision in the State's building regulations allowed this to be phased in over a 12-month period with minimal adverse affect on house prices or industry capacity to deliver.

4.2 BASIX and the BCA

While the introduction of the BCA 5 Star Standard was under control of the Minister for Housing and Works, the Minister for Planning and Infrastructure became an enthusiastic supporter of the New South Wales BASIX system and commenced feasibility studies for the introduction of BASIX in Western Australia. The advantage of BASIX was that it goes further than the BCA and deals with energy use in water heating and appliances, and with water use for internal purposes as well as landscaping (Pracsys, 2006). Because BASIX requires an estimate of likely energy and water savings from a pre-determined benchmark it also provides a measure of potential energy and water savings that can be monitored and used for infrastructure planning (Pracsys, 2006). The disadvantage of BASIX was that it required considerable technical work to make the computer systems and website applicable to Western Australian requirements, required amendments to either planning or building legislation and introduced an additional step in the building approval process. Industry associations were wary of any regulation that would change the way houses and land were delivered in Western Australia At the same time many environmental groups and local governments agitated for early adoption of enhanced sustainability standards.

It was clear to all stakeholders that the energy provisions in the BCA did not go far enough and further regulation would be needed to deal with issues such as water use and water heating. In late 2006 the housing industry began to lobby government to make a clear statement on whether it was to use the BCA or BASIX as its sustainability tool for houses, and reiterated its opposition to increasing sustainability standards that only applied to new houses. In particular the industry emphasized its preference for "deemed to satisfy" standards rather than complex assessment tools such as BASIX. In early 2007 representatives of the housing industry approached the Government with a proposal to adopt a simple checklist of standards, coupled with rebates and educational campaigns focused at existing housing. Eventually the State Government adopted a position that it would quickly introduce additional "deemed to satisfy" provisions through the existing building regulation system. These were implemented by the Department of Housing and Works as "5 Star Plus". Further consideration of BASIX was deferred until a national working group had clearly delineated what sustainability measures should be managed through the planning or building regulatory processes, and what sustainability tools should be adopted for national use.

5. What is 5 Star Plus?

5 Star Plus was launched in May 2007 as part of the *'Premiers Climate Change Action Statement'*. It addresses the energy and water efficiency of the building stock in the State via two new codes: the *"Energy Use in Houses Code"* and the *"Water Use in Houses Code".* The Energy Use code applied from 1

September 2007. The Water Use code is split into two stages (Department of Housing and Works, 2007). The first stage was also applied from 1 September 2007 with the second stage to be introduced from 2008.

The *Energy Use in Houses Code* confirms the 5 Star energy rating provisions within the BCA, and requires low greenhouse hot water systems, which must be either a:

- Solar hot water system;
- 5 star gas system; or
- Heat pump system.

The *Water Use in Houses Code*, Stage 1 requires:

- Water efficient fixtures and fittings – 3 star WELS rated showerheads, 4 star WELS rated taps (except bath and garden taps) and 4 star WELS rated dual-flush toilet;
- Swimming pool and spa covers; and
- The pipe from a hot water system to the furthest hot water outlet cannot be more than 20 metres long, or 2 litres internal volume.

Stage 2 proposed:

- All new houses be arranged or pre-plumbed to allow an alternative internal water supply (rainwater tank, bore water, third pipe) to be fitted at a later stage without breaking into the fabric of the house;
- New houses on suitable lots be arranged or pre-plumbed allow a grey water diversion system to be fitted at a later stage without breaking into the fabric of the house;
- Those houses that are likely to use large amounts of scheme water internally to install an alternative internal water supply; and
- Those houses on lots of a size likely to use large amounts of scheme water on landscape watering to install an alternative internal or external water supply, or greywater system.

6. Developing 5 Star Plus

As outlined above, 5 Star Plus was required to be a "deemed to satisfy" set of building solutions that delivered useful sustainability outcomes within the current building approval process, and did not require variation from the BCA. The philosophy that underpinned the development of the standards was that energy (and particularly energy that involved emission of greenhouse gases) and water were scarce resources that should not be wasted, and that where possible, high quality energy (for example grid electricity) or potable water should not be used for low quality uses. A scan of existing or proposed regulations in other jurisdictions, including BASIX and the proposals from the housing industry, provided a menu of possible responses. These had to be confirmed with stakeholders before they could be adopted.

In principle 5 Star Plus was a compromise position between government, wishing to make early progress in dealing with greenhouse gases and water shortages, and industry seeking simple, easily implemented solutions that would not impact on housing prices and affordability. Because of the short time-frames available, consultation during the drafting of 5 Star Plus primarily occurred with industry peak bodies and core government agencies. Because of this limited consultation a number of more adventurous possibilities were not taken up, and the responses adopted are very much a minimum standard.

7. Drafting the Codes

A key factor in drafting the 5 Star Plus codes was to establish a framework that could be used at a later date by the ABCB to accommodate all state and territory additions to the BCA that covered water heating and water use. Also the codes had to read logically as a self-contained document. The key to writing the codes was to adopt the hierarchy and terminology of the BCA that works from an ***objective*** via a ***functional statement*** to a set of ***performance standards***. It is permissible to adopt any building solution that can be demonstrated to meet the performance standards, or the ***deemed-to-satisfy*** building solutions contained within the codes (ABCB, 2007b). In practice most builders will adopt the deemed-to-satisfy solutions, and it was these that required the most consultation and adaptation.

8. The Energy Use in Houses Code

The Energy Use in Houses Code has the objective to reduce greenhouse gas emissions. In order to reduce greenhouse gas emissions a building, including its services, is to be capable of efficiently using appropriate sources of energy. Two of the performance standards set out in the code repeat the BCA 5 Star provisions for energy efficiency of a building and its services. The third performance requirement is that a building's hot water systems, including any associated components, must have features that produce low levels of greenhouse gas when heating water.

8.1 Deemed-to-Satisfy Provisions —Hot Water Systems

For domestic hot water, the common aim was to replace electric hot water systems, ultimately dependent on fossil fuel-fired power stations, with solar hot water (preferred) or high-efficiency natural gas systems. Reticulated natural gas is widely available in Perth and the south-west region and gas hot water systems are standard fittings in most project homes. Bottled gas is popular in regional areas where gas is not reticulated. Although the capital cost is higher, the climate in Western Australia is highly favourable for solar hot water and there is good market penetration and supply by local manufacturers. Electrically driven heat pump water heaters are new on the market, but have been proven in remote areas where gas or solar have proven uneconomic. They provide an alternative that is perhaps more suitable for replacement of existing electrical storage hot water systems, and are particularly economical when used at off peak electricity rates. There was little debate in requiring new homes to have either a:

- Solar hot water system; or,
- “5 star” gas hot water system; or,
- Heat pump hot water system.

9. Water Use in Houses Code—Stage 1

The Water Use in Houses Code’s objective is to reduce water demand by efficiently using water, minimising the waste of water and facilitating the efficient use of alternative sources of water. To reduce potable water demand a building must enable the efficient use of potable water, prevent the excessive loss of potable water, have the capacity to connect to alternative sources of water supply and use alternative sources in situations of high water demand or restricted availability of potable water. Reducing demand and minimising waste were not controversial matters and there was a high level of support for provisions adopted to deal with these. As a result these were implemented as part of Stage 1. The problematical provisions for alternative water supplies were held over to Stage 2. The three Stage 1 performance requirements relate to water use efficiency, water loss prevention and hot water use efficiency.

9.1 Deemed-to-Satisfy Provisions—Water Use Efficiency

Useful water savings can be made by requiring low flow rate taps or shower fittings in appropriate areas. Such fittings are labelled in Australia under the Water Efficiency Labelling Scheme (WELS) and are normally installed as part of new construction. Dual flush toilets have been mandatory for new houses in Western Australia for many years. However continuous improvement in the design of toilet systems made it feasible to increase the efficiency rating as part of 5 Star Plus. There were, however, some constraints on reducing the water flow in toilets, and these are discussed below.

9.2 Deemed-to-Satisfy Provisions—Water Loss Prevention

Private swimming pools are very popular in Western Australia, where the Mediterranean climate supports an outdoor lifestyle during summer. Evaporation from swimming pools in Perth is estimated to equate to about 2.8 gigalitres per year (1 gigalitre equals a million kilolitres) (Premier’s Water Foundation, 2006). As a result, mandatory provision of pool blankets as part of the installation of new swimming pools was identified as a useful strategy for water saving.

9.3 Deemed-to-Satisfy Provisions—Hot Water Use Efficiency

During consultations, builders in Western Australia stated that a common issue raised by prospective purchasers of project homes was the time taken, and water wasted, for hot water to come to a tap from a distant hot water system, and were keen for this to be considered for inclusion in 5 Star Plus. Research suggested the maximum pipe length should be between 10 and 20 metres. Discussion with industry indicated that the longer length would be able to be introduced at minimal cost, whereas the shorter lengths might require the fitting of two hot water systems or the use of a recirculating pump at a cost of up to $1,000. In order to allow some flexibility, and to limit waste from larger diameter pipes, a volume limit of 2 litres was also adopted. This equates to about 20 metres of 13 mm copper piping.

10. Water Use in Houses Code—Stage 2

A key response to drought in many parts of Australia has been the introduction of restrictions on the use of scheme water for landscaping and other external purposes and the requirement to fit new houses with rainwater tanks to provide an alternative water supply. Most major cities are coastal and built on rock or clay soils so that any runoff in suburban areas runs quickly into the sea, and causes a stormwater disposal problem to authorities. Rainwater tanks plumbed directly into toilets reduce the draw on scheme water, with consequent savings in infrastructure costs, while also reducing the amount of runoff to be dealt with. In catchments where runoff is already below minimum needs, the water from a tank can be used on landscaping, thus preserving ecological flows.

Perth is in a different situation from the eastern states capitals, in that the majority of the metropolitan area is built on deep strata of saturated sands, and there is little or no effective rainfall over the summer (Environment Protection Authority, 2007). Rain falling in winter is not lost by running directly over the surface and into the rivers and the sea, but instead soaks into the aquifers (Environment Protection Authority, 2007). This groundwater is widely used, after treating, for scheme water, or directly on landscaping through domestic bores. State water policy had for many years encouraged householders to install bores for landscaping use (Department of Water, 2008). One of the difficulties in adapting BASIX to Western Australian use was its requirement for rainwater tanks, and the difficulty in adapting the water use aspects to include the use of bores as alternative water supplies.

Research commissioned by the Department showed that in Perth a modest sized rainwater tank could be used to flush toilets for nine months of the year, with useful savings in scheme water and infrastructure costs. Although the relatively low cost of water makes this hard to justify on purely cost grounds, pressures on the existing dams and groundwater sources were forcing water utilities into more expensive alternatives, such as desalination and it is foreseeable that the price of water will rise (Department of Water, 2008). The generally high quality of Perth groundwater suggested that there was no reason why water from domestic bores could not also be used for toilet flushing, and some new land developments in Perth are starting to provide a "third pipe" supply from a community bore, although Department of Health does not currently encourage this water to be used internally in the house.

There are therefore several options for an alternative water supply including rainwater tanks, bores and third pipes. A review of these options uncovered a number of issues, including the high cost of this water for householders compared to scheme water, Health Department concerns, and that the plumbing regulations do not require a licensed plumber to install an alternative water supply. Despite this there was strong support from the community and government for greater choice in the use of alternative water supplies for both internal and landscaping use.

The performance requirements of Stage 2 have two objectives – to 'future proof' all new houses to allow connection of an alternative water supply or grey water diversion system at a later date, thus allowing householders choice as to if or when they do so. It also requires houses that are likely to use large volumes of scheme water to connect to an alternative water supply or grey water diversion system for either internal or external use. To be suitable for adoption into the BCA these performance requirements cover all alternative water supply options available anywhere in Australia.

10.1 Deemed-to-Satisfy Provisions—Alternative Water Supply Use Capacity (Future Proofing)

Toilets and washing machines must be capable of being connected to an alternative water supply without breaking into the fabric of the house. This requires toilets and washing machines to be either located against an external wall, or to pre-install a second pipe in internal walls that runs either into the ceiling space or to an external wall.

10.2 Deemed-to-Satisfy Provisions—Grey Water Use Capacity (Future Proofing)

Bathrooms and laundries must be capable of being connected to a grey water diversion system without breaking into the fabric of the house. This requires the pipes from bathrooms and laundries to run directly outside the house to where they can be cut into, before the water is mixed with wastes from toilets, kitchens and the like (black water). The most effective grey water systems distribute the water through buried trickle irrigation pipes, and to avoid build up of contaminants in the soil the grey water must be diluted over a minimum area of suitable soil. This requirement therefore only applies to houses on a minimum lot size where sufficient dilution of grey water can take place.

10.3 Deemed-to-Satisfy Provisions—Alternative Internal Water Supply (Mandatory Supply)

New houses with more than two toilets or showers are required to connect an alternative water supply for toilet flushing. The requirement to install an alternative water supply to houses with more than two toilets or showers was a compromise that targetted potentially high users of water, where the savings would be greater, and avoided the lower end of the market aimed at first home buyers. The requirement was expressed as an alternative water supply, rather than a rainwater tank, so that third pipe and suitable bore water could also be used, subject to health regulations.

10.4 Deemed-to-Satisfy Provisions—Alternative External Water Supply (Mandatory Supply)

New houses on lot sizes on large lot sizes are required to connect an alternative water supply or grey water diversion system for landscaping purposes. The most common alternative water supply used for landscaping in Perth is a domestic bore. The requirement to install an alternative water supply to houses with large areas of landscaping was a compromise that targetted potentially high users of water and also avoided the lower end of the market used by first home buyers, who tend to buy on smaller lots. To provide more flexibility for builders and homeowners this requirement can also be met by providing an alternative internal water supply.

11. Implementing 5 Star Plus

The Water Code provides for two stages. Stage 1 consists of the least problematic measures that have been agreed upon by all stakeholders, and are low cost in nature, such as low-flow tapware. The more controversial items have been left for stage 2 to enable further consultation. In October 2007 a Technical Advisory Group (TAG) was convened to discuss various technical issues that became apparent through desktop research. The group provided recommendations which went on to inform a public consultation document. In addition a regulatory impact assessment was undertaken which provided an analysis focussing on economic issues and high-level discussions were held across government agencies. Meanwhile, there has been rapid evolution of State Government policy on water with the release of the Western Australian State Water Recycling Strategy. This has made parts of Stage 2 problematical, with an overlap in policy objectives creating possible perverse outcomes. An example of this is the large-scale greywater recycling project being proposed by the state water utility, which will treat and inject waste water into aquifers. The removal of greywater at the household level would reduce the quantity of waste water available for this purpose.

These developments highlight the dynamic nature of policy development and have led to a revised, pragmatic policy position that endeavours to increase the sustainability of new houses through the BCA, without impeding other government jurisdictions from meeting the same objectives as Stage 2 but at a lower cost to the individual and society. The policy position also takes into account the advice from the TAG that there may be impacts on infrastructure by reduced waste water flows into household and municipal sewer lines, which have been designed to function assuming a particular flow rate.

The revised policy position, therefore, is that 5 Star Plus, Stage 2 will proceed with the future proofing requirements of the alternative water supply and greywater use capacity detailed above, but will only require the mandatory supply provisions in Regional Water Plans, as they are developed. They will not be required in the Perth and Peel regions where sandy soils allow aquifers to be filled directly by rainfall and accessed by domestic bores or water utilities. This is in line with the majority of feedback from all the stakeholders consulted and the State Water Recycling Strategy.

The staged implementation has given the Western Australian Government time to progress various policy options and has provided time for extensive consultation. This has meant that 5 Star Plus is aligned with government strategies, will prove more effective and will have a reduced chance of creating perverse outcomes for industry and individuals.

11.1 Bringing 5 Star Plus into legislation

The simplest way of bringing the 5 Star Plus standards into effect would have been to publish them as a Western Australian addition to the BCA. Unfortunately the annual update cycle for the BCA meant it was too late to incorporate any standards in BCA 2007, and it was not acceptable to wait until BCA 2008 came into effect in May 2008. Building standards are set in Western Australia through the *Building Regulations 1989* that allow the adoption of a “code” either in whole or in part. The Regulations adopt the BCA as the primary building code. It was therefore decided to set out the 5 Star Plus standards as “codes” that could be adopted by the Building Regulations 1989 as an interim measure before being published in BCA 2008. The way the codes were set out and worded followed where possible the precedent of the BCA. In this way, the energy measures and Stage 1 of the water measures were applied in Western Australia as from 1 September 2007. From 1 May 2008, these requirements were transferred to the WA appendix of the BCA. The same approach can be adopted for Stage 2..

12 Evaluation of 5 Star Plus

A key aspect of good policy making is evaluation of policy to ensure that it is providing the outcomes that were intended. This will be part of the policy development of 5 Star Plus, and will help to inform and focus further sustainability policy. Data on water use and energy use will be available through various agencies and industry associations.

13 Conclusion

The policy development of 5 Star Plus is a case study in how to deliver better sustainability outcomes, whilst ensuring key stakeholder support. Without key stakeholder support it is politically very difficult to introduce new regulations or legislation. Lack of industry support was a key factor in the decision to not proceed with BASIX.

5 Star Plus has managed to get the support of environmentalists and sustainability practitioners as well as industry, without placing a significant burden on society, particularly on those least likely to be able to afford it (e.g. first homebuyers). It fits well within existing regulatory mechanisms and has pushed the overall agenda within the BCA, helping raise the minimum standards of housing throughout the State and Australia.

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CLIMBING K2: THE DESIGN AND OPERATION OF A SUSTAINABLE PUBLIC HOUSING PROJECT

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Summary

The K2 Apartments development is a public housing project in Melbourne. It departs from the norm in Melbourne public housing by incorporating a range of sustainable features including passive solar design, natural cross- ventilation, photovoltaics, solar thermal heating systems, rainwater and grey water recycling, and stormwater remediation using on site swales. It has been occupied from May 2007 and is undergoing a post-occupancy study. This paper reflects on the design process, evaluates how well the design has met its environmental and social objectives, and comments on how this might inform the design of future public housing in Melbourne.

1. Introduction

The K2 Apartments development is a 96 unit public housing project for the Victorian Office of Housing (OoH), located in Windsor, Melbourne. The project was initiated by an open competition, which challenged applicants to design a housing development which was at the forefront of sustainable design, including the following key aspirations:

- Produce net zero CO_2 emissions in use.
- Use no non-renewable energy for operations.
- Reduce mains water use by 50%, when compared to a similar conventional building.
- Have a design life span of up to 200 years.

Arup, in collaboration with DesignInc architects won the competition in 2001, and were engaged to carry out full engineering design services for the project, including structural, mechanical, electrical, hydraulics, vertical transportation, acoustics, fire safety, performance based fire engineering and civil engineering. Design commenced in 2001, construction in 2005 (by Hansen Yuncken) and practical completion was achieved in May 2007.

Public housing supports people who cannot access the private rental or ownership markets. It is funded, wholly or in part, by government and rented at lower than market rates to people who meet eligibility requirements.

Today, the needs of the Victorian community have changed and the OoH is refocussing its approach. More than 30 per cent of public housing is over 30 years old and was constructed to meet the needs of a community that has changed. When public housing was built 30 years ago, public tenants were commonly families who could not afford private housing. As such, a high percentage of existing public housing is two and three bedroom houses and apartments. However, over the last ten years, the proportion of tenants seeking pubic housing who are single, elderly or smaller families has significantly increased.

K2 was designed to meet the changing social mix of our communities whilst significantly improving environmental performance compared to past public housing.

This paper reflects on the engineering design process, evaluates how well the design has met its environmental and social objectives, and comments on how this might inform the design of future public housing in Melbourne.

2. Engineering Design Approach

The following design approach was adopted in order to structure the engineering design to meet the OoH objectives for the project.

2.1 Establish design criteria

It was important to identify design criteria by which to assess and appraise engineering solutions. With the OoH and the architect, the engineering design team identified the following assessment criteria for engineering solutions:

- low maintenance
- proven and robust
- suitable to the tenant profile – potentially of poor health, born outside of Australia, or elderly
- exemplar
- environmentally sustainable
- long lasting
- low risk
- replicable in future housing projects.

2.2 Define team structure

The team structure for this project was based around incorporating sustainable design responsibility into each discipline, rather than tasking sustainable design to one 'champion' or advisor. This ensured ownership of sustainable design principles rested in each discipline and that there was a smoother transition from aspiration to design and documentation.

As many of the sustainable principles were interrelated between disciplines, team communication and coordination were important. For example a decision to expose concrete walls for thermal mass affected acoustic design for noise isolation, structural design for concrete finishes, electrical and hydraulics design for services routes and mechanical design for heating and cooling system design. Regular communication was important to facilitate meeting objectives in all disciplines, which was assisted by having all engineering design completed under the one roof.

2.3 Services approach

Building services systems were designed on the basis of the following:

1. Attempt to remove the demand for servicing.
2. Minimise the demand for servicing.
3. Service the demand as efficiently as possible.

Following this approach, the thermal performance of the building was optimised to remove or reduce demand. Efficient appliances were specified and tenant education encouraged to further reduce demand. Finally efficient services were specified to ensure consumption of water and energy was minimised. Detail on how this was achieved is discussed further in the report.

3. Feasibility assessment

Prior to commencing design, studies were undertaken to determine the feasibility of achieving the four project aspirations identified above.

3.1 Renewable energy feasibility study

Using no non-renewable energy on site and having net zero CO_2 emissions were challenging targets, particularly when combined with other design criteria of low risk, low maintenance and proven solutions - characteristics not often associated with large scale urban renewable energy systems.

To assess feasibility, Arup initially carried out an estimate of building energy consumption under various scenarios. Energy estimates were based on the services approach outlined above. Electricity consumption for the tenants depended on the efficiency of tenant appliances and the extent of time that they were used. Potential electricity consumption was estimated to range from 680MWh/yr for inefficient appliances with uneducated usage to 80MWh/yr for efficient appliances with educated usage. This highlighted the difficulty in controlling energy consumption when the level of control over the tenant's behaviour was limited. It also highlighted the extent to which positive education programs could have a drastic impact on energy consumption.

Domestic hot water heat energy requirement was estimated to be 165MWh/yr, space heating heat energy requirement estimated to be 160MWh/yr and base building electrical energy consumption estimated to be 245MWh/yr.

Due to the concurrent demand for electricity and heat, a combined heat and power (CHP) system was identified as potentially the most suitable renewable energy technology for the development. A solar powered organic rankine cycle (ORC) CHP system was initially investigated. Such a system would require up to 2000m^2 of solar collector area and up to 200kL of hot water storage to provide electricity and hot water self sufficiency annually. At the time of the study a suitable supplier was not available in Australia, and this together with the large space requirement for solar collectors, and potentially high cost for the system, led the design team to rule out this option.

Following the design criteria of low risk, low maintenance, proven solutions, more conventional photovoltaic (PV) and solar thermal systems were investigated for suitability. This study determined that zero CO_2 emissions could potentially be achieved with a large PV array, but natural gas would be required for hot water and heating demands, meaning that fossil fuel energy would be used. The system also came at a high cost which exceeded the available budget for the project.

A pragmatic balance of 170m^2 of crystalline PV and 130m^2 of flat plate collector based solar thermal systems was agreed upon. This would provide at least 50% of the expected domestic hot water energy demand annually and approximately 10% of the base building electrical energy demand annually.

3.2 Water feasibility study

The average daily water consumption within an Australian dwelling was estimated to be 350 litres per person, although for a unit this would typically be much lower, at approximately 250 litres per person. The water feasibility study determined that with water conservation measures such as low flow showers and aerated taps, along with the education of residents, water consumption could be reduced by 27%. This would result in an average usage of 193 litres per person per day. Further reductions in mains water demand could be made through rainwater collection, treatment and use and wastewater collection, treatment and reuse. Treating wastewater on site was not a new concept, although for residential developments had rarely been put into practice and reusing the residency’s wastewater was basically unheard of. This presented challenges to the design team, however none that were insurmountable. The study therefore concluded that the 50% potable water reduction target could be met.

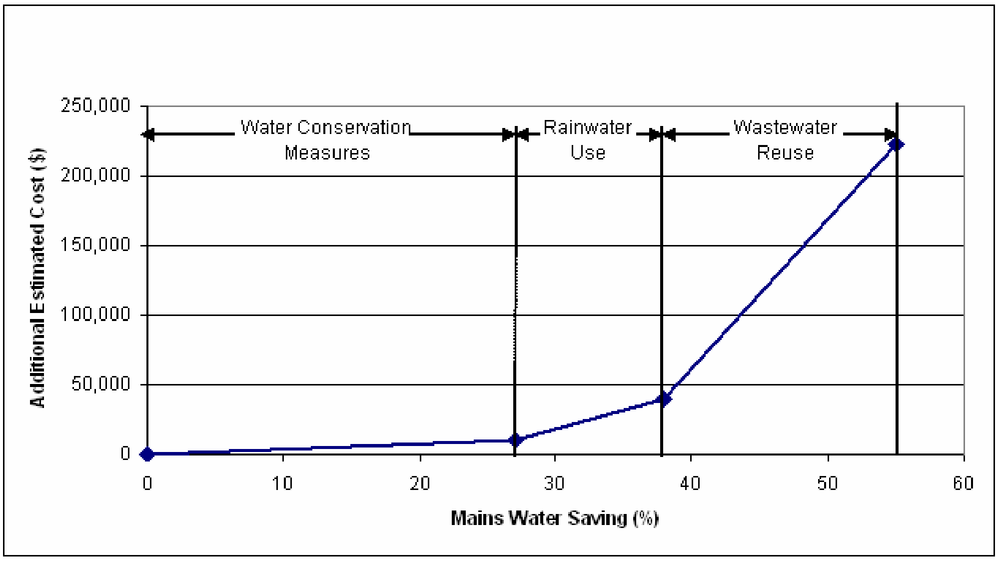

Figure 1 The additional cost of mains water saving initiatives at the Windsor development.

3.3 Design life feasibility study

Designing for a structural design life of greater than 50 years requires the determination of a specific loading regime, corrosion protection systems and durability requirements which are all more onerous than specified in the Australian Standards. It would lead to designing the buildings for higher loads and would increase member sizes, concrete cover, and the size of the foundations.

Assuming that at the time of refurbishment of the development in the future, an inspection of the structure is undertaken and any necessary remedial works completed, the structure integrity of the structure should be maintained well beyond 50 years.

In consultation with the OoH it was therefore decided that the structural elements of the buildings would be designed and detailed to the normal Australian code requirements, which assume a design life of 50 years.

4. Design Features

Specific design features implemented to achieve high levels of environmental sustainability are outlined below.

4.1 Energy

4.1.1 Passive thermal design

The engineering design team was involved very early on during the competition stage of the project to help inform building geometry, orientation, massing and solar access, and coordination with active engineering components. Passive thermal design was fundamental to reducing energy consumption and maximising design life. All design features were developed in such a way that the building would passively default to thermally comfortable conditions. This meant minimising the complexity of features and reducing the need for user control.

The development was designed with a 12 metre maximum depth to all four building blocks, which in conjunction with secure openings at the front and back facilitated effective wind induced cross ventilation of each unit for physiological cooling. This departs from the more common deep plan public housing tower design with units accessed off a common double loaded corridor.

The engineering team proposed insulation values for external fabric which were challenging at the time and far exceeded code requirements, whilst fitting within the allowable budget. Minimum U-values of 0.2W/m^{2}K and 0.4 W/m^{2}K were recommended for roof and wall constructions respectively.

All units were north facing, with windows to east and west minimised. Fixed external shades were provided to the north elevation, sized to minimise summer solar gain whilst allowing winter sun to enter the unit. Every unit was provided with a balcony and the design team assessed the benefit of enclosing the balcony in operable glass to create an indoor/outdoor winter garden space. This strategy was not adopted however given the potential for tenants to operate the glass incorrectly leading to overheating in summer and cooling in winter.

Figure 2 North elevation of rear building block showing solar shading and balconies (© Peter Hyatt)

Exposed thermal mass was provided in every unit to give thermal stability, reducing internal air temperature fluctuations. The diurnal range in Melbourne is often around 10-15^{o}C in summer, which makes night cooling an effective passive cooling strategy. To meet acoustic criteria only one side of each inter-tenancy wall was exposed, with the other lined with insulation and plaster, also providing a services distribution route. Approximately one third of the concrete soffit was also exposed - a balance between mass, servicing distribution routes and aesthetics.

Dynamic thermal modelling was carried out to assess and optimise the performance of all design features. This showed that comfortable conditions would be expected for most of the year without need for active heating or cooling. An average internal air temperature of approximately 20°C would be expected in winter, and peak summer internal air temperatures at least 4°C less than ambient temperatures, and rarely higher than 30°C. Summer modelling assumed the onerous scenario where windows would be left open during the day and night. In practice educated tenants would close their windows during the hot summer days, improving summer performance.

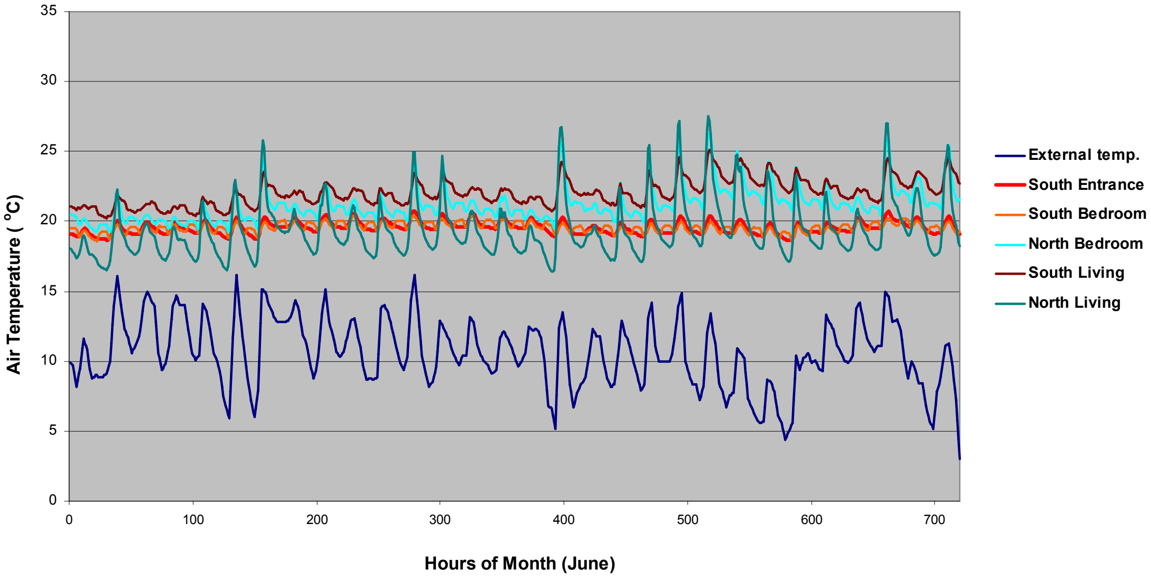

Figure 3 Internal air temperatures for a range of spaces within a typical unit during winter

As a result of the passive design measures, active cooling was not required to the units. For most tenants active heating would also not be required, however given that the tenant mix would include a significant number of elderly or physically disabled residents, the design team decided that mechanical top up heating should be provided.

4.1.2 Efficient systems and equipment

Lighting energy consumption was minimised through the use of T5 fluorescent luminaires for base building areas and efficient compact fluorescent luminaires for tenancies.

Toilet ventilation and kitchen exhaust systems were required in each unit to remove odours and control humidity. Individual tenant fans were provided so that fans only operated when required, not continuously. Fans discharged into risers which were ventilated by roof mounted wind ventilators rather than the more common roof mounted fan system, further reducing fan energy.

Top up heating was provided to units by a hydronic heating hot water system served by gas fired boilers. This was far more efficient than other common alternatives including electric radiators, heat pumps, electric fan convectors and portable oil heaters.

4.1.3 Solar hot water

A solar hot water system was recognised as good value for investment, and a focus was placed on providing sufficient roof space for solar thermal collectors over the less financially attractive PV system. Using flat plate solar collectors the solar hot water system was used to preheat make up water to the domestic hot water (DHW) system, providing an expected 50% energy savings for DHW annually.

4.1.4 Photovoltaics (PV)

Crystalline grid connected PV arrays were provided to the roof and façade of buildings 1, 2 and 4 to reduce reliance on mains electricity. The array comprised 134 off 160W panels, giving a peak power output of 21.4kW, and an expected annual energy yield of 25MWh/yr. The area of PV was dictated by available roof and façade space once solar hot water was optimised; and budget constraints.

Figure 4 Image showing photovoltaic panels (foreground), solar thermal collectors (background) and wind ventilators on exhaust risers. (© Peter Hyatt)

4.2 Water

4.2.1 Stormwater

The stormwater system on the site was designed to minimise pumping while capturing runoff from landscape elements through the site. The landscape design included elements such as bio-trenches along the entry and exit drives to treat run-off from hardstand areas while also detaining flows to restrict the peak outflow from the site and reduce any downstream impacts. Most impervious surfaces drain across vegetation strips before entering the stormwater system to allow for maximum opportunity for infiltration and vegetation uptake to reduce the total runoff volumes from the site.

A gross pollutant trap was incorporated at the discharge point to the council system to ensure all larger pollutants and any oil that enter the stormwater system were not allowed to enter the council system.

4.2.2 Grey water

A treated recycled water supply system was provided throughout the development, the first of its kind in Victoria. Black water recycling was not included as Authority approvals may not have been forthcoming and grey water recycling met the targets for recycled water established in the feasibility report. Separate grey water stack systems were provided in buildings 3 and 4 to supply grey water to a Membrane Bioreactor treatment plant for reuse as toilet flushing and irrigation supply.

Based on advice from the Victorian Department of Human Services the greywater system was treated to the same degree as blackwater would be for this type of development. This was due to the fact that controlling the quality of the greywater (laundry, shower and kitchen wastewater) within a multi-dwelling development such as the K2 Apartments would be difficult as residents cannot be made to take responsibility for what enters the system.

The grey water system was expected to reduce mains water consumption by 14%.

4.2.3 Rainwater harvesting

Rainwater is collected from the roofs of all four buildings and connected to tanks located in a central courtyard. The rainwater collection system was designed to capture 98.7% of average rainfall, with the remaining 1.3% overflow draining to stormwater. The capture of roofwater runoff equates to an estimated reduction of over 40% in the total runoff from the site to the council system. All rainwater is filtered and disinfected by a UV sterilisation unit and an automatic chlorine dosing unit, before being provided to the domestic hot water system as make-up water. The rainwater harvesting system was expected to reduce mains water consumption by 11%.

4.2.4 Water smart appliances

Water smart appliances such as low flow showers and aerated taps were recommended for the development, contributing to an expected reduction in mains water consumption of 27%.

4.3 Materials

4.3.1 Cement content substitution with fly-ash

Cement production is energy intensive, with one tonne of CO_2 produced per tonne of cement manufactured. To reduce the environmental impact of concrete, cement content was designed to be reduced by substituting it with fly-ash or slag. Fly-ash (FA) is finely divided ashes produced by burning pulverised coal in power stations. FA has been used in concrete since the 1930s. In the sustainability context, FA is beneficial in reducing the quantity of Portland cement (PC) in concrete with a consequent lowering of total CO_2 emission in production from the PC component. It also utilises a by-product that would otherwise have to be stored or disposed of.

The concrete specification identified primary objectives that were to be met and gave the contractor ESD objectives which they were challenged to maximise.

The range of percentages of fly-ash/slag given varied, as follows: Insitu beams and slabs: 10% to 40%, insitu columns and walls: 20% to 50%, precast walls: 10% to 30%, insitu retaining wall: 10% to 40%.

4.3.2 Recycled concrete aggregate (RCA)

Global demand for recycled construction products has increased substantially during the past decade. At the time of design in the state of Victoria, most of the demolition concrete waste generated was successfully recycled as fill material for road construction and related applications. As such, RCA was not a viable alternative for consideration to be used for structural applications, and was therefore not used.

4.3.3 Recycled steel reinforcement

Ninety five percent of steel reinforcement used within the structure was designed to be from recycled steel. A recycled quantity of 50% was specified for structural steel elements.

4.3.4 PVC minimisation

The use of PVC for hydraulic services elements was significantly reduced by specifying alternative products for sanitary drainage, cold water and rainwater systems such as HDPE and ABS plastics.

4.3.5 Embodied energy

Minimising embodied energy was not a key project goal and therefore did not form part of the engineering design criteria.

4.4 Education

4.4.1 Metering

As identified in the feasibility study, a potentially significant contributor to energy consumption was the extent of education of the tenants regarding resource use. In an effort to assist tenants to understand the impact their actions have on resource consumption, energy meters were provided to all units. The meters record heating energy and domestic hot water energy and store data at a central head end. Electrical check meters were also provided for each unit, allowing all energy data to be recorded and reported for each unit. The OoH can use this data for tenant education and as useful benchmark information for future housing developments.

4.4.2 Tenant briefing guides

Tenant briefing guides are provided to all tenants by the OoH, describing the environmental strategies designed into the development. This guide allows tenants to optimise thermal comfort and encourages tenants to consider appliance efficiency and sensible usage to reduce resource consumption.

4.5 Cost

The cost premium for sustainable design features, compared to a conventional public housing development of equal size, was estimated during design to be approximately $3m. Out of a $32.3m project cost, this equates to approximately 10%. This includes the following features: higher levels of insulation, exposed thermal mass, solar shading, double glazing, timber framed windows, building massing – four separate narrow plan buildings rather than one deep plan, solar hot water, photovoltaics, energy metering, efficient lighting, substitution of fly ash for cement, and grey water and rainwater treatment and reuse systems.

5. Building Performance

Since practical completion, the building has undergone monitoring of resource consumption to enable comparison to design targets, to assist with demand reduction via tenant education, and to inform future public housing design. As the building has not been occupied for a full year, complete building performance data is not available at this stage.

The following interim feedback provides an indication of the performance of the development.

5.1 Thermal performance

During summer, the OoH advised that internal air temperature in one unit was measured to be 30°C at occupied level on a 40°C day. This represents a 10°C temperature reduction from outside which is much improved from the 4°C temperature difference estimated during design. This was due to the tenant taking an active part in thermal control by closing windows during particularly hot weather and opening them overnight.

The OoH received only one complaint relating to the space heating system from a tenant during the winter period of 2007, which was much less than their experience on previous public housing developments.

5.2 Materials

5.2.1 Cement content substitution with fly-ash

During construction, the slower strength gain of concrete incorporating fly ash impacted on construction time. The concrete had to have sufficient strength the day after pouring to be able to fix masonry anchors into the top of the slab for the props to support the next level of precast walls. If there wasn't enough strength, then the placement of the walls would be delayed a day, which could have meant a delay of 4-5 weeks overall. To avoid this the amount of fly ash was adjusted according to the weather, so that in winter less fly ash was used, but as the weather got warmer, helping strength gain, the amount of fly ash was able to be increased. Overall 30% of cement was replaced with fly ash in insitu elements, which was in the middle of the design range.

The precaster was initially hesitant about including flyash for precast walls in the mix as they were concerned about early strength gains and achieving colour control and consistency. By the design team and contractor discussing this and working together, a mix with 20% flyash was achieved which was in the middle of the range specified.

5.2.2 Recycled steel content

The recycled content of reinforcement steel was 100%, in line with the design target. The recycled content of structural steel was reported by the builder to be 32%. This was due to the lack of availability of recycled steel at the time of construction. This percentage of recycled steel was considered to be acceptable, and a reasonable figure to have been able to achieve. This was not a project to force the industry to provide outside its current capacity, but more to work to achieve the highest level of recycling possible by the industry at the time.

6. Lessons Learnt

The K2 Apartments development was the first large scale multi-storey residential development in Victoria to incorporate sustainable features to such a great extent. As such there were some lessons to be learnt and aspects which would be designed differently on future projects.

A defined framework such as Green Star would have been very helpful for developing and assessing sustainable design elements. This was not available at the time, but is now available in pilot version for multistorey residential projects.

The metering strategy initially centred around education of tenants in their use of energy, and was not a whole building, end use defined metering strategy. To assist in reporting and assessing building performance, the OoH would like to interrogate all end uses. A more comprehensive metering framework would be established on future projects of this kind.

7. Future Public Housing

One important aspect of the K2 Apartments development was to provide an example for future public housing developments. All of the sustainable design principles applied to K2 Apartments could be reproduced in other developments, once tailored for site and end use conditions. Metering data will assist in understanding resource demands for future developments. The tenant feedback which is currently being sought by the OoH will also inform future designs.

The release of the K2 competition brief seven years ago had an immediate impact. TAS Housing and Homes West both requested to use it as a basis for their similar undertakings. Importantly, K2 has given the OoH the confidence to develop and proceed with other sustainable design and engineering pilots, targeting new and existing housing stock. The realisation of K2 has influenced the organisation to improve environmental performance in future redevelopment projects. The outcomes and learnings from this project are directly applicable to other medium and high rise residential buildings around Australia, not just public housing. This is a worthwhile precedent and offers lasting benefit for K2's residents and the wider community.

8. Conclusions

The K2 Apartments development demonstrates that it is possible to incorporate comprehensive sustainability features across all engineering disciplines within multistorey residential design. Indeed the particular demands of this type of development offer unique opportunities to apply sustainable design principles, such as water recycling, natural ventilation, passive thermal design and renewable energy systems. Such buildings demand close coordination, communication and commitment from all parties, and greater cost (approximately 10% in this case) but can result in very low environmental impact, affordable accommodation.

A STUDY ON THE MEASUREMENT OF THE VENTILATION PERFORMANCE OF THE NATURAL VENTILATION WINDOW SYSTEM WITH ATTACHABLE WINDOWS

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Keywords: Natural ventilation window system, Blower door test, CFD simulation, Ventilation performance

Summary

In recent years apartments are becoming more insulated and airtight in an effort to save energy, and as the high airtightness makes the inflow of outside air difficult, the quality of indoor air was deteriorated with the conventional natural ventilation system due to the lack of fresh air and poor ventilation.

Accordingly, the Ministry of Construction and Transportation enacted the 'Indoor Air Quality Control in Public-use Facilities, Etc. Act' in January 2006, and selected apartments with more than 100 households for installation of ventilation systems. In February 2006 the Ministry amended the ‘Rules on the Facilities Standards of Buildings, etc.’ and determined the required ventilation of new or remodeled housing as 0.7 ACH, and made it mandatory to install a natural ventilation system or a mechanical ventilation system.

However, as the mechanical ventilation system increases energy consumption, and it cannot be replaced when it is inadequately managed or fails, it is highly likely to cause the building syndrome, fan noise and a mental disease like claustrophobia.

The purpose of this study is to develop open-module-type natural ventilation windows, install them in actual apartments, and evaluate the ventilation performance. They can be installed monolithically without deteriorating the view, insulation and airtightness of the windows, and can control ventilation 0.1~2 ACH by means of constant continuous ventilation. They can be used with any window and door types.

The ventilation performance was measured according to the 1) blow door system method, and 2) simulation analysis method.

1. Introduction

In recent years apartments are becoming highly insulated and airtight as part of the effort to save energy, and as the high airtightness makes the inflow of outside air difficult, the quality of indoor air has deteriorated with the conventional natural ventilation systems due to the lack of fresh air and poor ventilation. Especially the CO_2 from the respiratory system of residents, the Volatile Organic Compounds, and high concentrations of formaldehyde (HCHO) emitted indoors due to their content in construction materials and paints causes sick house syndrome which gives rise to respiratory symptoms and disharmony in the human body, and the main cause of this is known to be the lack of ventilation.

Accordingly, the Ministry of Construction and Transportation enacted the 'Indoor Air Quality Control in Public-use Facilities, Etc. Act' in January 2006, and selected apartments with more than 100 households for installation of ventilation systems. In February 2006 the Ministry amended the ‘Rules on the Facilities Standards of Buildings, etc.’ and set the required ventilation of new or remodeled housing at 0.7 ACH, and made it mandatory to install natural ventilation systems or mechanical ventilation systems.

However, as the mechanical ventilation system increases energy consumption, and it cannot be replaced when it malfunctions or is inadequately managed, it is highly likely to cause sick house syndrome, fan noise and mental illnesses like claustrophobia.

The purpose of this study is to develop open-module-type natural ventilation windows and doors applicable to all fittings, install them in actual apartments, and evaluate the ventilation performance. They can be installed monolithically without disrupting the view, insulation and airtightness of the windows, and can control ventilation to 0.1~2 ACH by means of constant continuous ventilation.

The ventilation performance measurements were taken using the 1) blower door test and 2) CFD simulation.

2. Outline of the Developed Natural Ventilation System with Attachable Windows

In developed countries natural ventilation systems are already being used in diverse forms for commercial and residential buildings. A representative case would be the system where the air is ventilated by preheating with the onset of outside air during the heating periods and blockage of the outside air during the cooling periods using the double structure of the windows. Also, window attachment type ventilation systems and wall penetration type ventilation systems which are both economical and highly applicable have already been incorporated in many buildings.

One of the ventilation systems noted recently in Korea for being economical and easily applicable is the natural ventilation system with attachable windows. Originally, along with the large scale supply of high apartments in the 80s, the natural ventilation system with attachable windows was used as a simple ventilation device installed on the lower part of the balcony window. However, the recently developed natural ventilation system with attachable windows enables precision ventilation control without opening or closing the window, and possesses the following features and properties, as well as having the advantage of securing maximum ventilation performance with the use of little equipment and energy. Moreover, the wind velocity, pressure, and the resulting noise of wind, sudden fluctuations of outside air infiltration etc. can be counteracted by detailed technology factors incorporating specific advanced technologies, and taking into account the domestic climate features, the probability of dew condensation occurrence was minimized.

The features of the natural ventilation system with attachable windows developed in this study are as follows.

- Addition of natural ventilation control capability to the fitting system (0.1 ~ 2ACH)
- Apart from natural ventilation, addition of minimal mechanical ventilation function when required (1 ~ 3ACH)
- Addition of regular ventilation function (small amount of continuous ventilation)
- Improved architectural appearance (system that suits the functions & appearance of the existing fittings)
- Open module type easy applicability (open module type that can be applied to any fitting)

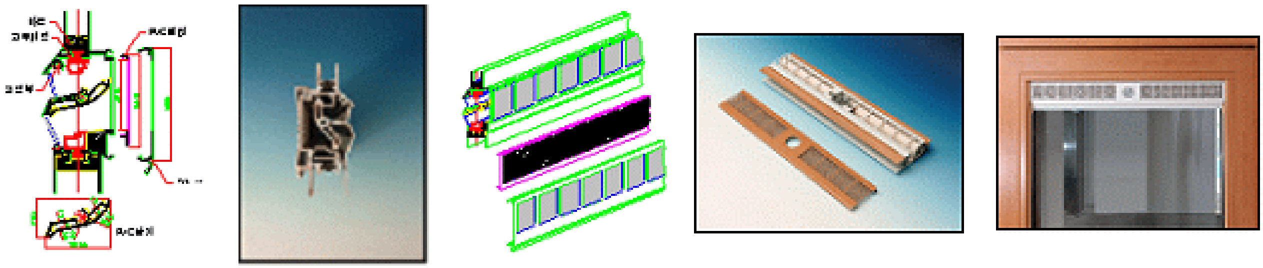

Figure 1 Developed Natural Ventilation System

2. Ventilation Performance Measurement Method

Building ventilation performance measurement methods include the Trace Gas method, Blower Door Test, and CFD simulation.

Firstly, the measurement method for the Tracer gas method is explained in KS F 2603 (indoor ventilation measurement method- carbon dioxide method) and ISO 12569 (Tracer gas dilution method). Depending on the particular injection & sampling methods there is the Concentration decay method, Constant concentration method and the Constant injection method. Of these, the Concentration decay method is the most simple and widely used, and in the beginning a standard amount of tracer gas is injected and after the inside air is mixed, the initial concentration is measured. After a certain time has passed, the natural ventilation amount is obtained by the index formula using the concentration decay value.

Secondly, the Blower Door Testis a pressure difference measurement method and is prescribed in the ASTM E779-87(Standard test method for determining air leaking rate by fan pressurization) and ISO 9972(Determination of building airtightness – fan pressurization method). As a method to measure the building ventilation performance, the decompression test is performed as a standard which exhausts the indoor air and maintains lower than the atmospheric pressure, and the pressure difference measurement points are taken from high pressure differential to low pressure differential points. The maximum pressure differential varies depending on the volume and form of the building, but usually 50Pa or above is seen as the measurement point. The pressure measurement method using the Blower door is not affected significantly by fluctuations in the outside air compared to the Tracer gas method, and is advantageous due to its easy & simple installation and measurement methods.

Thirdly, with the CFD simulation method, when analyzing temperature, air current speed & direction, concentration of pollutants etc. in relation to complex air currents in the building, the subject zones are divided into numerous control volumes and dynamic relationships between the very small volumes are calculated by which air movement is interpreted. Through a computer the CFD interprets the Navier-Stokes equation, a differential equation that governs fluid flow, and the indoor temperatures, air current & pressure distributions can be derived under steady and transient states. Strengthened by the recent development in computer interpretation technology, this method can obtain a more economical outcome compared to methods requiring much cost and time, so it enables estimation of effective results in a relatively short period of time, and many evaluations are being conducted using this method.

3. Ventilation Performance Test

3.1. Test Outline

As shown in Figure 2, the test was performed on the 84m² test apartment unit owned by Korea Institute of Construction Technology, and in order to determine the ventilation effects of the natural ventilation system with attachable windows 1) the aperture ratio of the natural ventilation system was set as the variable at 0, 12.5, 25, 50, 75, & 100%, and the 6 cases were measured 2) the length of opening was set as the variables and 3 cases were measured. This is summarized in Table 1. The Blower door system was used as the measuring equipment as it has simple onsite application.

Figure 2 Test Model

Figure 3. Ventilation Performance Test using the Blower Door System

Table 1 Test Conditions

Measurement case	Length of Opening [m]	Aperture Ration [%]	Pressure Conditions [Pa]
case 1	11.15	0%	10Pa 15Pa 20Pa 30Pa 40Pa 50Pa
case 2	11.15	12.5%	
case 3	11.15	25%	
case 4	11.15	50%	
case 5	11.15	75%	
case 6	11.15	100%	
case 7	5.60	100%	
case 8	4.10	100%	
case 9	3.50	100%	

3.2 Test Method

Under steady state, the indoor/outdoor pressure difference is approximately 1~4Pa, and in this condition ventilation performance measurement is extremely difficult. Thus, the indoor/outdoor pressure difference was raised from 10Pa to 50Pa in 5Pa and 10Pa intervals, and the wind volume was measured for each pressure difference. Based on the results, the ventilation under Pa steady state was indirectly estimated as shown in formula (1).

$$Q=C(\Delta P)n \qquad (1)$$

Here, C: air movement coefficient, ∆P : indoor/outdoor pressure difference, n : air movement index

The effective pressure difference measurement scope of this measurement device is 10Pa ~ 100P, and in the test measurements were taken for up to 50Pa. In accordance with the ASTM standards of America, the indoor/outdoor conditions on measurement were set with wind speed 0~2m/s and outside temperatures 5~35℃, and all air inflow areas were blocked except for the natural ventilation system.

3.3 Ventilation Performance Measurement Results in Accordance with Aperture Ratio

Table 2 shows the ventilation volume (㎥/h) measurements according to the indoor/outdoor pressure difference under the measurement conditions. The results revealed that wind volumes were proportional to the increase in aperture ratio and indoor/outdoor pressure differences rising in a linear fashion. Table 3 shows the conversion to air change rate by applying a K factor of 20 to the wind volume. The results suggest that in order to secure air change rate of 0.7ACH in a 84m² apartment unit, the natural ventilation system must be 50% or more opened.

3.4 Ventilation Performance Measurement Results in Accordance with the Length of Opening

Tables 4~5 and figures 5~6 show the air volume and ventilation performance in accordance with the lengths of openings in Cases 6~9. When the length of opening is 11.15m the air change rate is 1.43ACH, for 5.6m length it is 1.06ACH, for 4.1m length it is 0.83ACH, and for 3.5m length it is 0.84ACH.

In this study the data is insufficient and limited to determine the relationship between air volume and ventilation performance in accordance with the length of opening, so there is a need to obtain more data through following tests and simulations in order to establish the relationship between air volume and ventilation performance in accordance with the length of opening.

Also, the Blower Door test measures ventilation by forcibly creating indoor/outdoor pressure difference using a fan, and because it injects and extracts air through all openings, it has limitations in that there are differences to the natural conditions. Thus, comparison of ventilation performance must be conducted in natural conditions using the Tracer gas method, and to activate the supply of natural ventilation systems, there needs to be additional research on ventilation performance according to the length of the inflow and outflow sides.

Table 2 Air Volume in Accordance with Aperture Ratio [unit : ㎥/h]

Pa / case	10	15	20	30	40	50
1case	544	697	833	1,155	1,317	1,461
2case	612	765	951	1,240	1,444	1,614
3case	722	917	1,172	1,427	1,665	1,835
4case	1,189	1,444	1,665	2,039	2,243	2,464
5case	1,665	1,920	2,209	2,854	3,406	3,908
6case	1,971	2,294	2,684	3,568	4,078	4,587

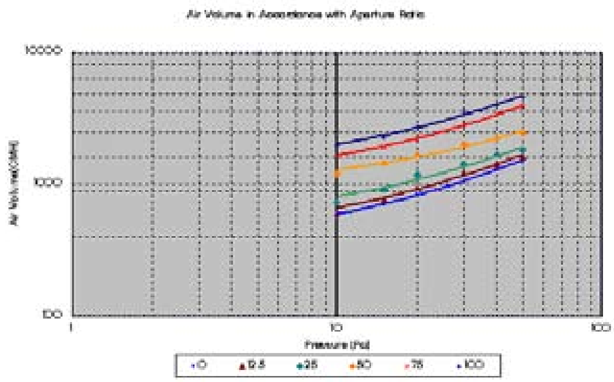

Figure 3 Air Volume in Accordance with Aperture Ratio

Table 3 Air Change Rate in Accordance with Aperture Ratio

case	A/C [ACH = ACH50 / 20]
1case	0.46
2case	0.50
3case	0.57
4case	0.77
5case	1.22
6case	1.43

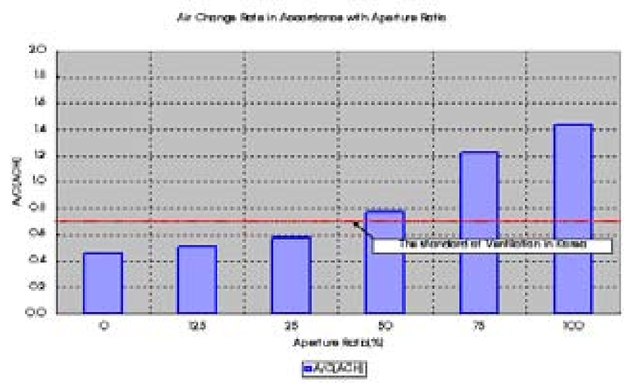

Figure 4 Air Change Rate in Accordance with Aperture Ratio

Table 4 Air Volume in Accordance with Length of Opening [unit : ㎥/h]

Pa / Case	10	15	20	30	40	50
case6	1,971	2,294	2,684	3,568	4,078	4,587
case7	1,478	1,818	2,039	2,498	2,888	3,398
case8	1,189	1,495	1,750	2,107	2,413	2,667
case9	1,087	1,461	1,750	1,954	2,209	2,498

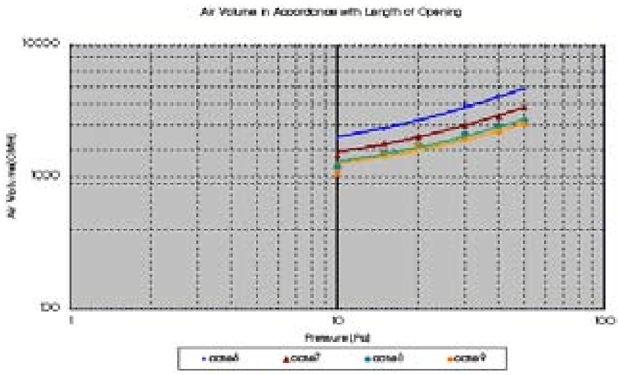

Figure 5 Air Volume in Accordance with Length of Opening

Table 5 Air Change Rate in Accordance with Length of Opening

case	Length of Opening [m]	A/C [ACH = ACH50 / 20]
case6	11.15	1.43
case7	5.60	1.06
case8	4.10	0.83
case9	3.50	0.78

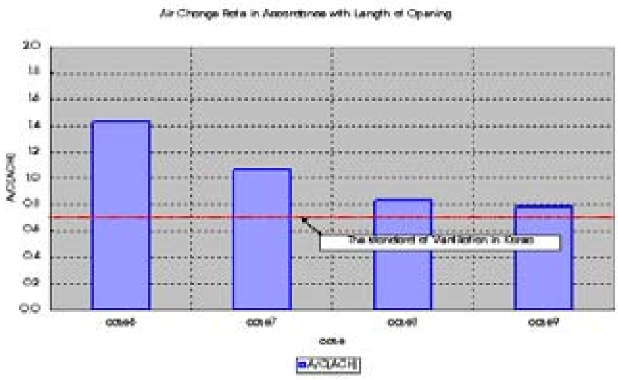

Figure 6 Air Change Rate in Accordance with Length of Opening

4. Ventilation Performance by CFD Simulation

4.1Outline of simulation

The simulation model is identical to the test model in Figure 2, and the position was set at the medium floor. In terms of the boundary conditions, the natural ventilation system was set at 100% opening, outside velocity at 1m/s, wind direction south, outside temperature at -2℃, and floor heating was set for the interior with floor temperature at 29℃. Prior to the ventilation simulation on the apartment with natural ventilation system, item interpretation was conducted on the natural ventilation system and used the results as the boundary conditions for ventilation simulation on the apartment. The boundary conditions are as shown in Table 6, and the computational method is shown in Table 7.

Table 6 Boundary Conditions

Aperture Ration of the Natural Ventilation System	100%
Outside Velocity	1m/s
Outside Wind Direction	Southerly
Outside Temperature	-2℃
Interior Floor Temperature	29℃

Table 7 Computational method

Solver	STREAM
Convective term	Upwind(1nd order)
Pressure correction	SIMPLEC
Turbulence model	MP k-ε model

4.2 Results of Simulation

When the CFD simulation was conducted in relation to ventilation on application of the natural ventilation system under the above boundary conditions, the ventilation performance was revealed to be 0.74ACH which satisfies the ventilation rate required for apartments in Korea.

Figures 7~8 show the item interpretation results of the natural ventilation system. When the outside velocity was 1m/s, the indoor/outdoor pressure difference was 51Pa, and centering on the PVC blades of the natural ventilation system, it was found that the positive pressure was relatively greater on the upper section than the lower section. Accordingly, it was also found that the speed of outside air inflow on the upper section was approximately 2m/s faster than the lower section.

Figures 9~10 show the outside pressure and air current distribution. According to the outside pressure distribution in Figure 9, positive pressure occurs in the position perpendicular to the wind direction, and to the rear of the positive pressure belt a low pressure belt is formed. Apart from the point of air current inflow, it was found that low pressure belts were formed in most sections.

Figures 11~12 show the air current distribution and stream line within the apartment unit. According to the stream line, the ventilation flow within the unit was smooth, so it can be assumed that no dead zones would have existed.

Figure 13 shows the inside temperature distribution within the apartment unit. Because the speed of the inflowing air current was fast, it was seen to move along the ceiling and drop towards the floor in the center section of the lounge room. Accordingly, there is the advantage of the occupants being able to breathe fresh air with low age of air, but as cold drafts can occur attention must be given to interior thermal comfort.

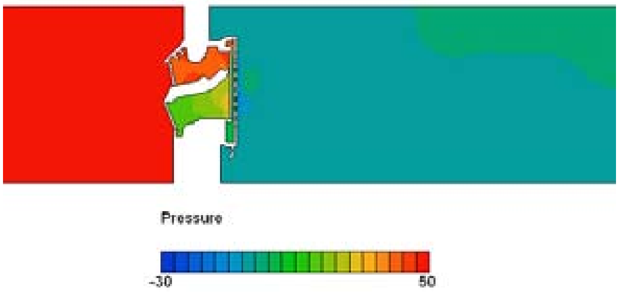

Figure 7 Natural Ventilation System Internal Pressure

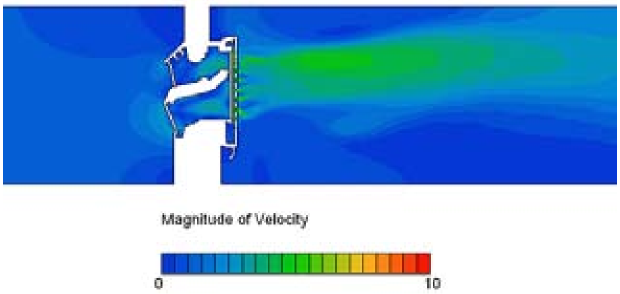

Figure 8 Natural Ventilation System Internal Velocity

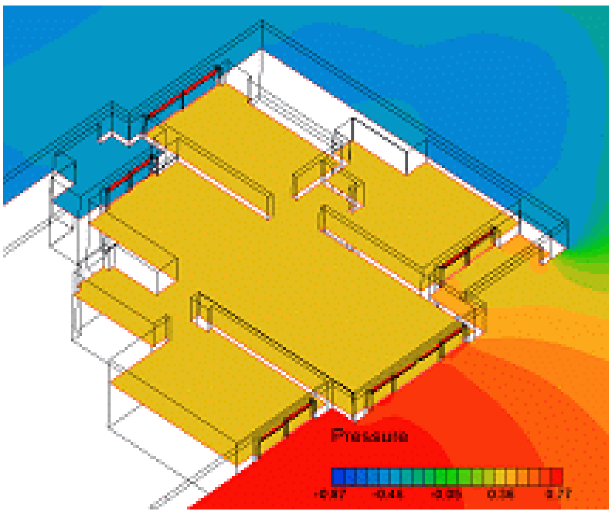

Figure 9 Outside Pressure Distribution

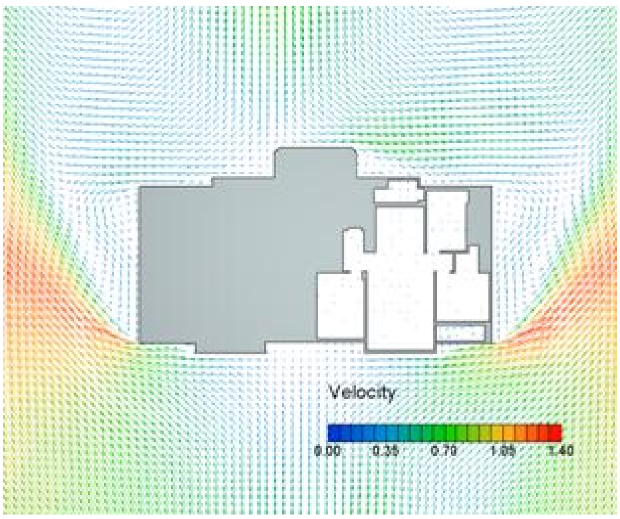

Figure 10 Outside Air Current Distribution

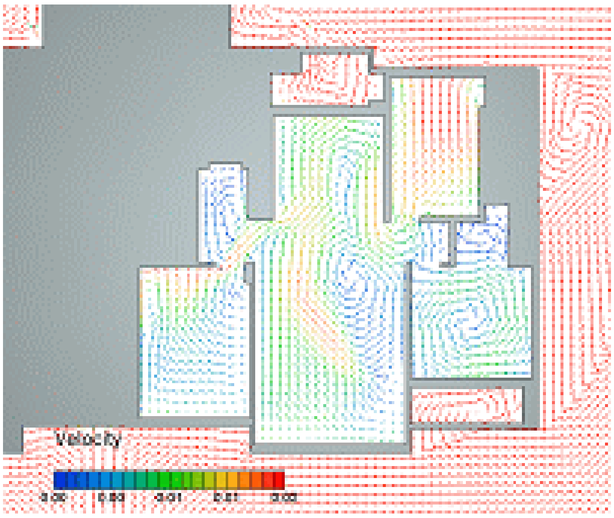

Figure 11 Unit Interior Air Current Distribution

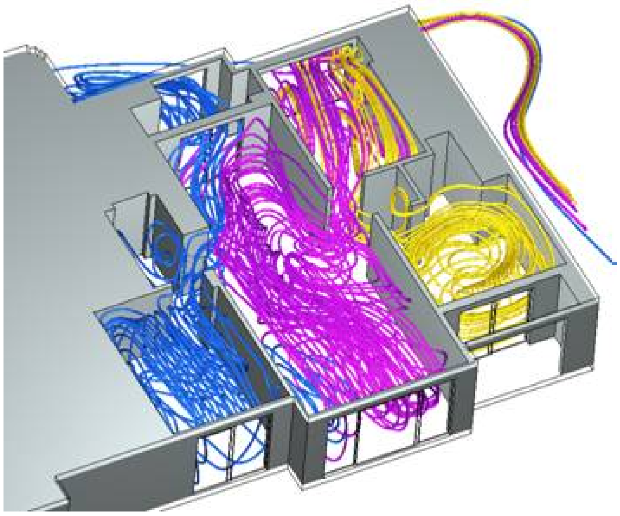

Figure 12 Unit Interior Stream Line

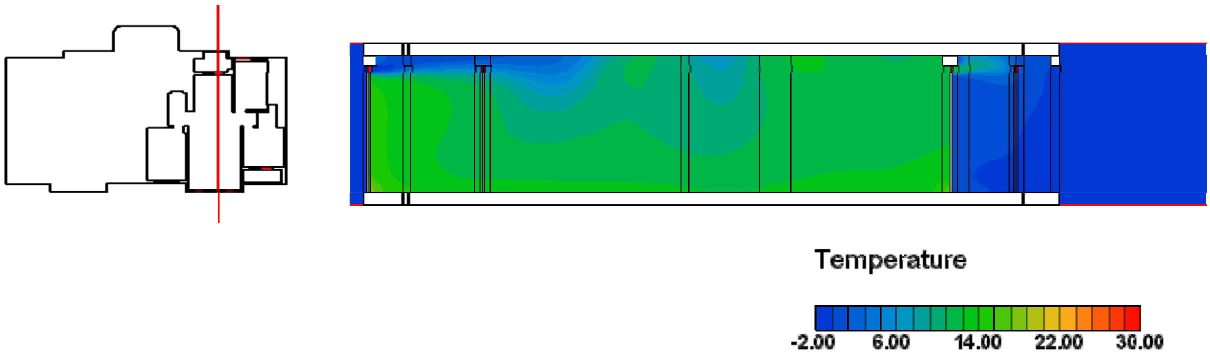

Figure 13 Unit Interior Temperature Distribution

5. Conclusion

In this study the ventilation performance of the natural ventilation system was measured using blower door test and CFD simulation.

The results of ventilation performance measured in an actual test apartment using the blower door test are as follows.

(1) With the increase in the aperture ratio of the natural ventilation system with attachable windows and the indoor/outdoor pressure difference, air volume also increases proportionately in a linear fashion. Moreover, the results suggest that in order to secure ventilation frequency of 0.7ACH in a 84m² apartment unit, the natural ventilation system must be 50% or more opened.

(2) With the natural ventilation system with attachable windows, when the length of opening is 11.15m the air change rate is 1.43ACH, for 5.6m length it is 1.06ACH, for 4.1m length it is 0.83ACH, and for 3.5m length it is 0.84ACH. However, in this study the data is insufficient and limited to determine the relationship between air volume and ventilation performance in accordance with the length of opening, so there is a need to obtain more data through following tests and simulations in order to establish the relationship with the air volume in accordance with the length of opening.

The results of the CFD simulation are as follows.

(1) When outside velocity was 1m/s, ventilation performance was 0.74ACH which satisfies the ventilation rate required for apartments in Korea.

(2) The ventilation flow within the apartment unit was smooth, so it can be assumed that no dead zones in air current would have existed.

(3) The air current flow within the unit was seen to move along the ceiling and drop towards the floor in the center section of the lounge room. Accordingly, there is the advantage of the occupants being able to

breathe fresh air with low age of air, but as cold drafts can occur attention must be given to interior thermal comfort.

In order to activate the future supply of this system, additional research must be conducted on ventilation performance of the natural ventilation system in accordance with size and shape of the apartment units, ventilation performance in accordance with the opening length of the air current inflow & outflow sections of the natural ventilation system, and ventilation volume calculation methods when there is simultaneous inflow & outflow through which data required for ventilation system design must be accumulated. Also, by conducting research on energy consumption with the incorporation of diverse outer systems, economic analysis must additionally be performed including comparisons with mechanical ventilation systems.

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SUSTAINABLE WORKPLACES AND CULTURAL CHANGE

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Keywords: sustainable workplace, productivity, cultural change, indoor environment quality, energy efficiency

Summary

The potential marketing and cost benefits generated from sustainable workplaces have created significant interest within commercial organisations. Whilst this has been a key selling point for sustainable workplaces business leaders today are more aware of the broader benefits of a sustainable workplace. In particular the opportunities and value successful sustainable workplaces provide in terms of employee and community engagement with sustainability and emerging opportunities for highly sustainable outcomes alongside changing community values.

In this paper a number of recent Australian sustainable workplaces are reviewed. In addition we discuss the organisations that inhabit these workplaces and their commitment to progressing sustainability within their community. The workplaces reviewed include: Sustainability Victoria, Melbourne; HASSELL Studio Melbourne; and Investa, Sydney. Two of these projects have undertaken productivity studies utilising Business Outlook and Evaluation (BOE) to further evaluate outcomes. The productivity studies are compared for perceived employee and organisational outcomes to determine if they achieved cultural change in employee values. The 'lessons learned' are also reviewed in terms of endeavours to improve culture change needed to support sustainable communities. Finally, we consider how we can affect a more meaningful future workplace utilising the designed environment and cultural change.

1. Introduction

Entrenched cultural expectations are driving building energy demand beyond sustainable consumption. Fueled by tighter parameters of workplace 'comfort', increasing use of information and communication equipment and expectations of 24/7/365 operation our expectations have created exponential demand for workplace lighting, ventilation, heating and cooling; which in turn puts upward pressure on both electricity resources and global greenhouse gas emissions.

As with all cultural change, awareness and education of the challenges and opportunities is critical to creating the change in community attitudes and actions. Whilst the demand for sustainable workplaces is driven by the need for healthy and environmentally responsive workplaces, the process of creating a sustainable workplace requires employee engagement and a level of awareness and education. There is an opportunity to provide not just a workplace that reduces operational costs whilst increasing staff productivity – a sound business case; but to engage the community in pursuing a responsible approach to our environment; providing the opportunity to change cultural behavior on a daily/life basis throughout the workplace and broader community.

In the growing global movement towards corporate social responsibility the incentive to reduce the demand on our finite earthly resources and share the benefits with our community is a global imperative and something increasingly aware employees demand in a potential business employer. Through education and awareness Generation X, Y and Z employees seek employers who are environmentally responsible and provide a healthy supportive workplace allowing them to function at their optimum ability. Gen X, Y and Z expect their employees to provide a workplace that operates on a minimum carbon footprint with an optimum indoor environment quality which includes fresh air, no indoor toxins, renewable onsite energy and low energy demand.

1.1 Sustainable Workplaces – Sustainable Organisations?

Sustainable workplace outcomes are maximised when designed and operated as integrated components of living buildings. This requires not only that the workplace is designed to operate as a sustainable workplace; but for the workplace to be located within a building that is designed to operate sustainably; and for the organisation to apply sustainability principles to their organisational values and operations. A successful sustainable workplace lives within a sustainable built environment, within a sustainable community.

Sustainable workplace design will incorporate:

- A healthy indoor environment i.e. the provision of clean, fresh air; flexible and appropriate lighting and heating and cooling solutions; comfortable thermal conditions (protected against weather extremes); a safe and community-orientated environment; and
- The provision of amenities which support equitable and accessible local transport and encourage physical and mental health and wellbeing.

Living Building design will incorporate:

- Solar passive designed building with building façades built to suit the climatic conditions and aspect of the building;
- Building systems which operate passively as well as actively, and are flexible to allow reduced energy demand;
- Onsite renewable energy generation;
- Onsite water capture and recycling; and
- Onsite reuse / recycling of waste.

Organisations sustainable operations will incorporate:

- An environmental management system (EMS) that is transparent, responsive to local environmental needs and takes a cradle-to-cradle approach for energy, water, materials procurement and waste;
- Carbon Reporting, Sustainability Reporting and a commitment to a zero carbon strategy for the organisation;
- Support and engagement with the local and global community to pursue sustainable resourcing i.e. Corporate Social Responsibility (CSR).

To achieve sustainable workplaces as integrated components of living buildings we need to do more than change the way we design, create and use our workplaces: we need to change our community values, lifestyles and culture.

Successful, sustainable workplaces require:

- Visionary clients who are in touch with changing values and current global and regional needs;
- Business leaders, regional and global leadership engaging/driving the transition to a more sustainable community;
- Passive and active design elements which support the health and wellbeing of employees while minimising toxins and emissions; and
- Passive and active building operation which is allied to the local environment in terms of energy, water and waste.

1.2 Local Resources

Australian and regional research has done much to stimulate the uptake of sustainable activity.

At a national level, the Green Building Council of Australia (GBCA) is a key industry body in terms of the provision of education, rating tools and policy for sustainable commercial buildings. The 'Your Building' website is an national online forum providing research information and case studies on sustainable built environments throughout Australia and internationally.

At the local level the Melbourne City Council (MCC) and Sustainabiltiy Victoria (SV) offer fast turn around programs and education for facility managers, building owners and tenant representatives with the objective of reducing energy demand in existing Melbourne tenancies/buildings. For example, the Melbourne City Council's Sustainable Lighting Guide and associated seminars enables interested parties to understand the sustainability rationale and financial incentives behind improving lighting systems. It also provides funding to facilitate early uptake. SV actively educates and provides financial incentives to businesses to reduce their energy and water demand and to reduce waste outputs and impacts.

1.3 Global Issues and influences

It is the global and regional challenges of our time which drive the transition to a more sustainable community. The critical challenges of global climate change, provision of drinkable water, greenhouse gas emissions reductions and the issues we face in relation to the health of our people as well as our planet are seen as keys drivers.

International research has contributed significantly to the body of knowledge required to demand behaviour and cultural change in relation to the procurement of the built environment. International targets for the reduction of carbon emissions globally have been proposed over the last 30 years. The development of living buildings integrated with their environment will further support a reduced onsite energy demand and onsite renewable resource generation. Operational cost savings enabled through reduced energy and water demand in addition to reduced waste resource management have recently been proven.

With the advent of new research and better understanding of global climate change and Emission Trading Schemes (ETS) the business case scenario of purchasing carbon credits to offset carbon emissions is seen as beneficial for short term goals only. The long term view requires we change our cultural expectations and dramatically reduce energy and greenhouse gas emissions.

Sustainable workplaces utilise passive and active design elements to support the health and wellbeing of employees and their local community through the provision of increased indoor environment quality for improved health and productivity.

Current research demonstrates the link between productivity and indoor environment quality and the disproportionate organisational costs of sick leave compared with the provision of environmental 'comfort' i.e. employee salaries exceed building energy and maintenance costs by a factor of approximately 100 and exceed annual construction or rental costs by almost as much (Woods, 1989 USA). Even the achievement of a 1% increase in productivity should be sufficient to justify an expenditure equivalent to a doubling of energy or maintenance installation costs or large increases in construction costs or rents. Productivity increases of 1% correspond to reduced sick leave of two days per year, reduced breaks from work or increased time at work of 5 minutes per day, or a **1%** increase in the effectiveness of physical and mental work (Fisk and Rosenfeld, 1998).

With improvements in employee health come improvements in overall community health easing the burden on our communities and economy. Whilst this is not an obvious economic incentive for companies, it is an economic incentive for governments and local communities. An improvement in overall health of our community will contribute to stronger and greater global economic capability.

2. Sustainable workplaces

2.1 Cultural expectations within the workplace

Changes to lifestyle and culture have a rapid and sustained uptake if underpinned by education. Low cost changes with demonstrated benefits and little lifestyle impact can be absorbed rapidly in both the work and private arenas. However to affect the degree of change required lifestyle and cultural changes must occur.

The question from the broader community is "will these changes improve our lifestyles?" In many instances the changes required actually improve the quality of our natural and built environment, offering a better lifestyle; the challenge is whether we can affect change quickly enough for the planet.

Cultural change will occur where the community is educated, actively engaged and can influence the process and outcomes. It will occur fastest if the community is aware of the current opportunities and benefits to their lifestyle if they make immediate changes.

2.2 Current sustainable measures for workplace

So what are the measures of a successful sustainable workplace? Here caution is required, for any review of a sustainable workplace design and construction is but a snapshot in time; and we know that sustainable workplace design and the way the workplace is operated evolves with time dependant on the organisation. So when we review a sustainable workplace of an organisation it is important to review the organisation and any changes occurring within it.

The sustainable workplace performance review looks at the base building selection and a number of organisational sustainability measures.

Key base building measures include:

- energy efficiency, water efficiency and sustainability rating (and/or certification)
- commitment to achieving greenhouse has emission reduction/neutrality
- renewable energy generation.

Key organizational measures include:

- Environmental Management System (EMS)
- Occupational Health &Safety System (OH&S)

— Carbon accounting and Sustainability reporting

— Commitment to achieving a carbon balance (carbon neutrality/zero carbon).

2.3 Sustainable Workplace Performance

When large, multinational organisations embrace the need for sustainable workplaces the opportunities for cultural change can occur rapidly with a global reach. The importance of grasping these opportunities and delivering successful outcomes is critical.

Since 2000 in Australia opportunities for cultural change due to sustainable workplaces have been growing. Table 1 below outlines the sustainability initiatives by workplace, building environment and organisation. Two organisations have undertaken productivity studies conducted by Business Outlook and Evaluation, which is discussed in Item 2.5. SA Water is currently under construction and, in this review, is used as a current comparison of sustainability initiatives to the earlier workplaces (refer to Table 1 of the Appendix).

In addition to reviewing Sustainability initiatives and the use of rating tools Table 1 below looks at two additional components: the selection of the base building and respective Sustainability rating and initiatives; and the ongoing commitment to sustainable business management practices.

2.4 Sustainable Workplace Outcomes

Of the workplaces/organisations reviewed the majority have implemented key Sustainability initiatives in respect to indoor environment quality and in the provision of supportive amenities. Many organisations referenced or applied the Green Star rating tool for both fitout AND base building which improves overall energy, water and waste reductions. Sustainable buildings have the potential to minimise toxic emissions, provide more flexible building operating systems; increase fresh air rates; provide monitoring of resources and thereby allow improved energy, water and waste efficiency. Sustainable buildings provide greater opportunities for the creation of a sustainable workplace with potentially less cost.

In addition to building design considerations many organisations demonstrate a commitment to sustainability within the broader community through thought leadership, community education and engagement programs. For example, Investa has gone on to produce the Green Lease Guide in conjunction with a number of other local organisations. This publicly available document assists business in understanding how they too can create a sustainable workplace. SV and HASSELL have implemented Environmental Management Systems certified to Australian/International standards. Both have also conducted productivity studies and have implemented carbon reporting with a commitment to achieve carbon neutrality (Zero Carbon) in the near future. These initiatives have occurred since the establishment of their sustainable workplaces. Whether this is a direct outcome of sustainable workplace initiatives or the continuing evolution of a sustainable organisation is not clear from this review. What is clear, and fundamentally important, is that the continual process of education and awareness which occurs in the process of establishing a sustainable workplace does not stop. It continues through the organisation via the employees to create a sustainable community.

2.5 Productivity Study Outcomes for Melbourne Sustainable Workplaces

All reviewed workplaces indicated a high level of end-user satisfaction. Productivity studies conducted on three workplaces/buildings included both preoccupancy and post occupancy evaluation. This allowed a more detailed evaluation of employee satisfaction health and productivity indicators. In these surveyed workplaces, many employees indicated the new work environment was a major contributing factor to improvements in their job satisfaction.

The productivity survey results from HASSELL and Sustainabiltiy Victoria (which include indoor air quality and HR data) are compared in Table 2 below Productivity survey results from a tenant within 500 Collins Street (also undertaken by Business Outlook and Evaluation) offer a third set of comparative indoor environment Sustainability initiatives within the Melbourne context. In this context the survey was undertaken within the same building, pre and post base-building refurbishment (the tenant temporarily relocated within the building during this period) Refer Table 2. The 500 Collins St building is also reviewed in context of the new Melbourne office of the GBCA (see Table 1).

Investa did not conduct an independent pre and post occupancy productivity studies. Instead they conducted internal qualitative surveys which identified significant benefits had been achieved by implementing sustainable workplace initiatives. These included decreased absenteeism, increased productivity and staff satisfaction. Investa is currently participating in a University research project on productive and sustainable workplaces which will, in the near future, provide further data on this subject.

The three productivity studies of sustainable workplaces found significant improvements across a range of workplace indicators including staff health, productivity, reduced sick leave, and better staff concentration and engagement in meetings. Table 1 clearly shows that within SV and HASSELL both organisations have ongoing commitments to sustainability, including the management of their workplace and resource usage and the ongoing education and engagement of staff. From the outcomes of the productivity studies we can see a clear indication that where an organisation successfully implements Sustainability initiatives within their workplace, they will also see improved employee satisfaction, and improved employee productivity and engagement.

Attraction and retention of staff is also increasingly important in an era of professional skills shortage. The benefits of a sustainable workplace in attracting and retaining employees through the provisions of a healthy and environmentally responsible workplace are also implied through the productivity study results.

However the ability to activate cultural and behavioural change within a short space of time is most critical particularly as cultural change can take one or more generations to occur. We do not have the luxury of an extended timeframe. Many would say that the requirement to change our cultural behaviour and reduce our energy consumption and greenhouse gas emissions has been known by a section of our community for the last 30 years. Environmentalists and scientists have been conducting research and publishing reputable papers on this topic for most of the second half of the last century i.e. the Kyoto Protocol was activated in 1990 and the current definition for Environmentally Sustainable Development drawn from the Bruntland Commission in 1988.

3.0 The Cultural Change in Sustainable Workplaces, Organisations and Communities

Many of the organisations reviewed here have fulfilled their early vision by creating a more sustainable workplace, supporting the health and productivity of their employees and minimising their resource demand and environmental impacts. A number of organisations however have continued to evolve along their path towards greater sustainability by committing to carbon neutrality, incorporating carbon reporting mechanisms, certifying their Environmental Management System (EMS) and creating meaningful cultural change within their employees, client and industry groups.

Organisations commencing the process to deliver better productivity and lower operational costs for the business should seize the opportunity for the organizational culture to influence broader community change. Large employers in particular have the ability to affect change in thousands of employee households. In this way organisations demonstrate corporate social responsibility and assist the government in their educative role.

4.0 Conclusion

If we are to change our communities' mindset towards an environmentally responsive culture and lifestyle we need our governments and organisations to educate and support the changes for all of our community. Leadership by Governments, organisations and industry professionals is critical to make the policy and cultural changes required to significantly reduce our energy usage, greenhouse gas emissions and provide us with a healthy and sustainable lifestyle.

Sustainable workplaces, like sustainable buildings act as a mechanism for broader cultural and behavioural change within our community. To ensure we as a community move forward at the speed which is now imperative, we need to populate the creation of sustainable workplaces globally as a catalyst for cultural change – change to an abundant and promising future.

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Appendix 1

Table 1: Sustainable Workplaces[1] including building and organisational impacts

SUSTAINABLE WORKPLACES	Investa Sydney 2005	HASSELL Studio Melbourne 2006	Sustainability Victoria Melbourne 2006	ARUP Melbourne 2007	GBCA Melbourne 2007	SA Water Adelaide 2008
Area	2,880 m2	1,500m2	1,650 m2	1,400m2	140m2	16,600 m2
Energy	Certified 5 Star Green Star Office Interiors Certified 5 Star ABGR; Achieved an approx 60% energy reduction (5 star plus 30% predicted ABGR rating)	Registered Green Star Office Interiors Aim 5 Star ABGR; energy reduction program; Energy Resource: 100% Accredited Green Power. Full Lighting load 6-7 watts per m2. Addressable lighting system with motions and daylight sensors activated.	Registered Green Star Office Interiors Aim 5 Star ABGR; energy reduction program. Addressable lighting system with motions and daylight sensors activated.	Registered Green Star Office Interiors Aim 5 Star ABGR; energy reduction program.	Designed to Green Star Office interiors best practice Aim 5 Star ABGR; energy reduction program.	Registered Star Office Interiors Aim 5 Star ABGR; energy reduction program Addressable lighting system with motions and daylight sensors activated.
Water	Efficient fittings and appliances	Water efficient sanitary fittings and appliances	Water efficient sanitary fittings and appliances	Water efficient sanitary fittings and appliances	Water efficient sanitary fittings and appliances	Water efficient sanitary fittings and appliances
Waste	80% construction waste recycled; waste reduction program	Portion of construction waste recycled; Waste reduction program: Landfill/comingling/ compost – worm farm /mobile phones, corks and CD's and DVD's/ procurement and catering policy	80% construction waste recycled; Waste Wise – waste reduction program: Landfill/recycled paper and cardboard / recycled glass and plastics/ compost / procurement policy	Waste Reduction program	Waste Reduction program Workplace designed to be packed up and relocated easily. Product / material minimalisation	Aim: 80% construction waste recycled; Waste Reduction program
Environmental Management System	Implemented Staff awareness and education on sustainability and energy usage	Implemented / Certified Staff awareness and education on sustainability and energy usage	Implemented/Certified Staff awareness and education on sustainability and energy usage	Staff awareness and education on sustainability and energy usage	Staff awareness and education on sustainability and energy usage	Implemented Staff awareness and education on sustainability and energy usage
Indoor Environment Quality	50% improved ventilation rates, planting, low toxicity materials and environment, improved views and daylight	50% improved ventilation rates, planting, low toxicity materials and environment, improved views and daylight	50% improved ventilation rates, planting, low toxicity materials and environment, improved views and daylight	50% improved ventilation rates, planting, low toxicity materials and environment, improved views and daylight	50% improved ventilation rates, planting, low toxicity materials and environment, improved views and daylight	100% fresh air, planting, low toxicity materials and environment, improved views and daylight

Appendix 1

Table 1: Sustainable Workplaces[1] including building and organisational impacts

Productivity Outcomes / End user satisfaction	Preoccupancy end-user survey; Post occupancy Survey underway End User Satisfaction High (Internal Survey)	Productivity study Complete End User Satisfaction High	Productivity study Complete End User Satisfaction High	n/a End User Satisfaction High (Anecdotal)	n/a End User Satisfaction High (Anecdotal)	Commitment to pre and post occupancy study Awaiting project completion
SUSTAINABLE BUILDING	**Deutsche Bank Place,** **126 Phillip Street, Sydney** (New Build)	**61 Little Collins Street, Melbourne** (Refurbishment of derelict 1800's warehouse)	**Urban Workshop, 50 Lonsdale Street, Melbourne** (New Build)	**Spring Street, Melbourne** (1980's building, refurbished recently)	**500 Collins Street Melbourne** (1980's building refurbished in 2005)	**VS1, Victoria Square, Adelaide** (New Build)
Sustainability / Energy Benchmark	Certified 4.5 Star ABGR; Energy reduction program	Sustainable lighting program; Submetering; addressable lighting systems	Aim 4.5 Star ABGR		Certified 6 Star Green Star Office Design Energy reduction program, Improved heating /cooling systems - Passive and Active Chilled Beam System	Certified 6 Star Green Star Office Design Aim - approx 60% energy reduction
Water	Efficient fittings and appliances	Efficient fittings and appliances	Black water recycling treatment plant, water efficient fittings and appliances	Efficient fittings and appliances	Efficient fittings and appliances	Approx 70% less mains water consumption
Waste Reduction	Operational Waste Reduction Program: 79% per month landfill diversion building/tenancy waste	Operational Waste Reduction Program: Refurbishment of derelict warehouse; reuse of building envelope	Operational Waste Reduction Program: Landfill/recycled paper and cardboard / recycled glass and plastics/		Operational Waste Reduction Program: Landfill/recycled paper and cardboard / recycled glass and plastics/	Over 90% recycling of construction and demolition waste
Client Community	Green Lease Guide; Greenhouse Guarantee.	Sustainability Research, Papers and industry presentations; Sustainable Futures Unit/ Sustainable Communities; Sustainable Design and Planning	Sustainability Funding Program; Design for Sustainability; Solar Cities; Smart Energy Zones.	Global Foresight & Innovation Group Sustainability research	Green Star Rating tool Green Star training and education Sustainability research and publications	Save Water Program; Environmental Improvement Programs
Greenhouse Gas Emissions / Carbon Neutrality	Sustainability Reporting;	Carbon reporting and reduction program Commitment to carbon neutrality by 2010	Carbon reporting and reduction program Commitment to carbon neutrality by 2010			Sustainabiltiy Reporting

1 All sustainable workplaces referenced in Table 1 were designed by HASSELL.

Appendix 2

Table 2. Sustainable Workplace Productivity Study[2] Outcomes.

PRODUCTIVITY STUDY	**HASSELL** Sustainable Workplace	**Sustainability Victoria[1]** Sustainable Workplace	**500 Collins Street** Sustainable Building Refurbishment
Satisfaction index	Previous office -16; new office +46	69% more comfortable office(light, air quality/temperature, ergonomics)	Previous office -11; new office +16
Air quality	Previous office: -42 rated as stuffy or variable; New office: +24 rated as normal or fresh	Meeting room Air Quality index rose15%; meeting room ambience rose 19%.	Previous office: 73% rated as stuffy or variable; New office: 77% rated as normal or fresh
Temperature	Previous office: 50% rated as too hot or too cold; 60% rated as normal		Previous office: 45% rated as too hot; 59% rated as normal and none rated it too hot
Workplace ambience	Previous office 43% found it tiring; New office 48% of staff found it 'invigorating'	Meeting room concentration index rose 43%; Meeting room engagement index rose 41%	Previous office 64% found it tiring; New Office 40% of staff found it 'invigorating'
Health / Sick leave:	Significant falls (8-27%) in the frequency of headache, sore throats, sore eyes, fatigue, colds and flu and feeling 'off-colour'. Sick leave fell by 0.2 days per employee/per year. (Sick leave in conjunction with significant increase in project workloads experienced in the first 8-10 months this is seen as a successful reduction.	Sick leave fell by approximately 2 days per employee per year. Or by 30% in average sick days per employee Sick leave reduction represents a financial saving of approximately $76,080pa	Significant falls (10-25%) in the frequency of headache, sore throats, sore eyes, fatigue, colds and flu and feeling 'off-colour'
Staff self-assessment of productivity:	Increased by 3%. (productivity improvements occurred at a time of increased workloads / administrative requirements)	Increased workplace performance 13%	Increased by 11.7%
Business impact	Consulting work increased by 20% in the first 8-10 months after relocation. Staff involvement in sustainability programs increased significantly.	Significant savings in other sectors of the new fitout were achieved. 96% of respondents say the new workplace represents the Sustainability Victoria values.	

1 The Sustainability Victoria Productivity Study utilised two productivity measures: Sick leave as a quantitative indicator of organisational performance; and self assessed staff performance in meetings. Air quality measures were undertaken separately utilising Deakin University's MABEL technology.

2 Productivity Studies were conducted by Business Outlook and Evaluation (BOE).

PHYSICAL PROPERTIES OF THE ENVIRONMENT-FRIENDLY PAPER FOAM INSULATOR BY CELLULOSE AND STARCH, POLYPROPYLENE

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Keywords: Foam Insulation, Recycled Paper, Thermal Conductivity, Physical Properties

Summary

The annual CO_2 emission in Korea is 4.1 million tons (CO_2 tons)/year. It increased by 75.5% during the past 10 years, and by 6.5% on average annually. Accordingly, in consideration of high oil prices and for the purpose of reducing the environmental load on Earth, it will be necessary to establish energy-saving policies and develop energy-saving technologies.

The main ingredients of the foam insulator suggested in this study are cellulose and starch. Cellulose comes from recycled paper, and starch is natural. Unlike other insulators, the foam is made using the steam foaming technique which does not use foam gas. Accordingly, this foam insulator has little environmental load occurring in the production process, and is environmentally friendly from product distribution to scrapping.

Foamed products show a vertical texture, but most cells are close types. It is low in absorptiveness, and high in moisture permeation resistance, i.e. 0.07 g/m3 hr mmHg. This foam insulator can be easily processed at a density of 20 kg/m3~ 30 kg/m3, and the thermal conductivity under this condition was 0.034 W/mK ~ 0.037 W/mK.

1. Introduction

With the insulation materials recently used in buildings there have been extensive developments in diverse technologies and materials, and many new products with increased insulation performance have been released into the market. The paper foam insulation proposed (hereinafter referred to as "paper insulation") in this study consists mainly of cellulose and starch. The cellulose is extracted from the incinerated paper and used as foam material, and plant materials are used as starch.

The cell formation to secure insulation properties in the paper insulation, that is, the foam to form very fine spaces is produced using the steam foaming method unlike the standard insulation production process which uses foam gas.

Thus, the environment load arising from the raw materials in the production process is low and possesses environment friendly properties from product distribution to the disposal process.

This study seeks to examine the physical properties of the environment friendly paper insulation made from recycled paper as insulation for buildings, and to devise application possibilities.

2. Paper Insulation Overview

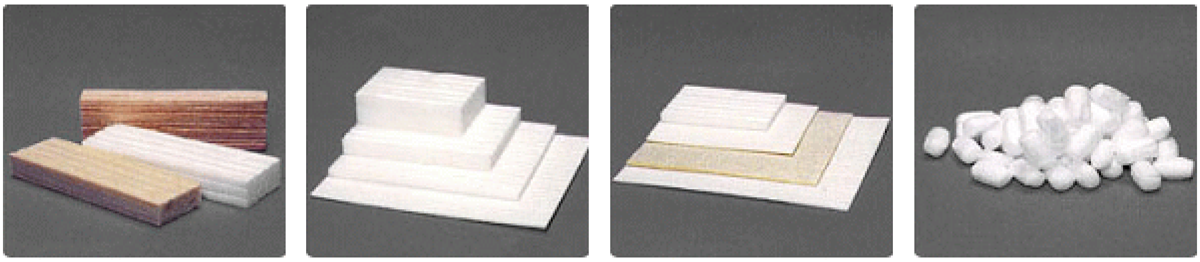
The core material of the paper insulation proposed in this study is cellulose extracted from paper. Cellulose can freely be extracted from waste paper in which the fiber is destroyed or grinded, that is, paper that cannot be recycled and is normally incinerated. To summarize the production process, firstly the waste paper and starch are mixed, and then polypropylene resins are mixed in, and after the expansion using steam and the press molding process, it is produced into insulation material in the form of a board or filling type particles.

The cell structure of the paper insulation is comprised of elements that act as the nucleus during expansion and the outer cover that covers the nucleus, and possesses the advantage and characteristics in which the cell image and membrane do not physically or structurally change after expansion.

The expanded product shows a perpendicular direction grain, but the cell is in a closed form which has low absorption while possessing high water vapor resistance of approximately 0.07 g/m3.hr.mmHg. The paper insulation has relatively easy density control depending on the expansion proportion, and as a building insulation material, a density of 20 kg/m^3 ~ 35 kg/m^3 would be the most economical for application.

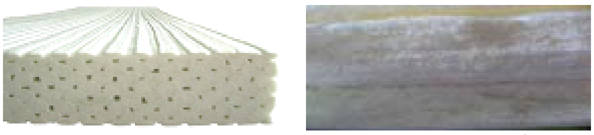
Apart from the polypropylene resin additive, the paper insulation comprises mostly of natural materials, so it is free from harmful gas emissions in the case of fires during the summer season, and it does not contain harmful substances such as formaldehyde, VOC etc.

Figure 1 shows the density and molded image of the product sample, and Figure 2 shows the product as a building insulation and a detailed sectional diagram. Figure 3 shows the application of both the internal insulation system and the external insulation system on an actual building.



a) Low density board　b) Medium density board　c) High density board　d) Filling type particles

Figure 1. Images of paper insulation materials



a) Paper insulation product diagram　b) Detailed image of the perpendicular cut side

Figure 2. Paper insulation product sectional diagram

a) Internal insulation system　b) External insulation system

Figure 3. Paper insulation installation

3. Performance of Paper Insulation

3.1 Thermal Conductivity Test Overview

For the thermal conductivity measurement the test methods of ASTM C 518(Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus), ISO 8301(Thermal Insulation-Determination of Steady-State Thermal Resistance and Related Properties), KS L 9016 (thermal conductivity measurement method for heat insulation materials) were applied. Table 1 and Figure 4 show the measurement principles and composition of the heat flow meter.

For the thermal conductivity test the high-end temperature was set at 33℃ and the low-end at 7℃ while the average test temperature was set at 20± 0.5℃, and measurements were taken of the high-end & low-end temperatures in the insulation sample (T_u, T_l), the heat flow quantity using the heat flow meter (Q_t), and the thickness of the insulation sample (d). The measurements were taken 5 times in 10 minute intervals after the temperature and heat flow reached normal conditions.

Subsequently, 4-6 types of samples were used for each of the 5 paper insulation types, and by conducting 5 repetitive tests on each sample, a total of 115 tests were performed. The test was conducted in a constant temperature & humidity room with the test temperature set at 23± 1℃ and relative humidity at 50 ± 5%.

3.2 Heat Conductivity Test Results

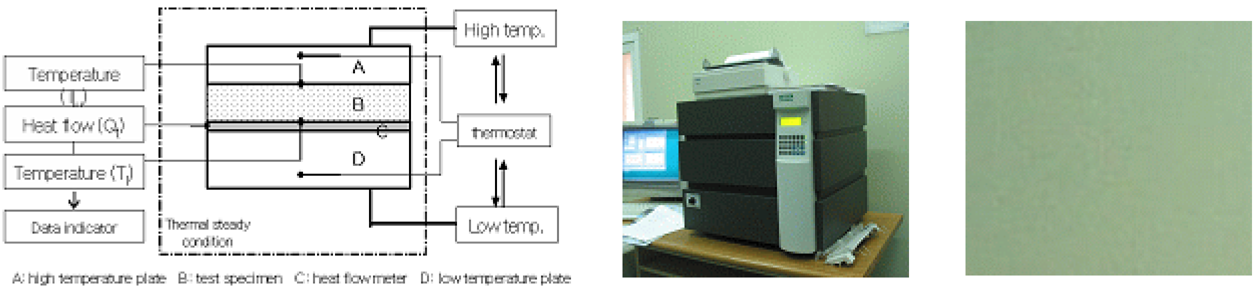
In order to determine the physical properties according to the foam composition & proportion of the paper insulation, the heat conductivity test was performed twice on the samples after setting each foam composition & proportion. Table 2 & Figure 5 show the test results of the paper insulation produced through the phase 1 expansion process.

3 sample types with densities 0.02 g/㎤, 0.026 g/㎤, and 0.031 g/㎤ were produced for phase 1, and the average thermal conductivity rates according to density were 0.037 W/mK, 0.035 W/mK, and 0.034 W/mK respectively.

The densities of the 2 phase 2 sample types after setting foam composition & proportions were approximately 0.024 g/㎤ and 0.026 g/㎤, and the average thermal conductivity rates according to density were 0.035 W/mK and 0.034 W/mK respectively. Table 3 & Figure 6 show the test results of the paper insulation produced in the phase 2 expansion process.

Table 1. Outline of the Thermal Conductivity Measurement Device

Thermal Conductivity(λ) Measurement Scope	0.015 ~ 0.43 W/mK
Precision	± 2% ~ ± 5%
Reproducibility	± 1%
Measurement Sample Size	300mm(W)×300mm(L), 30 ~ 50mm(H)



a) Composition of the Heat Flow Meter b) Test Device c) Constant Temperature & Humidity Room

Figure 4. Test Device & Test Room

3.3 Insulation Performance Estimation & Comparison

Figure 7 shows the thermal conductivity correlation of the paper insulation according to density based on the phase 1 & 2 test results. The thermal conductivity according to the densities of the phase 1 & 2 samples in the figure reveal a largely different fluctuation pattern, and in the case of the phase 2 sample there was a decline in thermal conductivity with the increase in density, so this shows improved thermal performance compared to the phase 1 sample.

Thus, when the foam composition and proportion is optimized, thermal conductivity of 0.032 W/mK or less can be secured under a density condition of 0.031 g/㎤.

Table 4 makes a comparison between the thermal conductivity of the paper insulation calculated from the correlation graph in Figure 7 and the thermal conductivity of the EPS insulation prescribed in the current KS standards. As shown in the table, the paper insulation shows more superior thermal performance than the EPS-1 insulation for both the phase 1 & 2 samples when density was 0.015 g/㎤ or higher, and with density of 0.03 g/㎤ or higher it had similar thermal performance to EPS-2 (graphite content) number 4 (density 0.015 g/㎤). In the case of the high density paper insulation with density over 35 g/㎤, the thermal conductivity is estimated to be under 0.030 W/mK, and this level of performance can secure overall superiority over the performance of existing insulation materials.

4. Physical Properties of the Paper Insulation

Figure 9 shows the test process to examine the absorption properties of the cell interior and perpendicular texture of the paper insulation. In the absorptiveness test the paper insulation was immersed for 68 hours into a container with coloring materials, and by cutting a section, the degree of water penetration and absorption was examined by the capillary tube phenomenon on the perpendicular grain.

Test results showed that no water was absorbed within the cell as the entire paper insulation had closed cells rather than open cells, and especially, there was no water penetration through the openings between the cells. However, there was water penetration between the openings of the perpendicular grain, but there was no water absorption past the water penetration boundary surface due to the capillary tube phenomenon.

Table 5 shows the results of gas composition when fire was applied to the paper insulation. There was CO 130mg/g, and CO_2 610mg/g, but other harmful gasses such as Cyan, hydrogen chloride, ammonia, nitrogen oxide, sulfur oxides etc. were not detected.

In the meanwhile, quantitative tests are currently in progress for other physical properties required in building insulation materials such as tensile strength, compressive strength, combustibility, permeability, and emission of chemical substances that can affect air quality.

Table 2. Phase 1 Thermal Conductivity Test Results

TYPE	density (g/㎤)	Average Thermal Conductivity (W/mK)
1 - 1	0.0222	0.036
1 - 2	0.0221	0.036
1 - 3	0.0219	0.036
1 - 4	0.0218	0.036
2 - 1	0.0258	0.035
2 - 2	0.0270	0.035
2 - 3	0.0275	0.035
2 - 4	0.0268	0.035
2 - 5	0.0266	0.035
3 - 1	0.0304	0.034
3 - 2	0.0307	0.034
3 - 3	0.0307	0.034
3 - 4	0.0320	0.034

Table 3. Phase 2 Thermal Conductivity Test Results

TYPE	density (g/㎤)	Average Thermal Conductivity (W/mK)
4 - 1	0.0239	0.035
4 - 2	0.0233	0.035
4 - 3	0.0230	0.035
4 - 4	0.0238	0.035
4 - 5	0.0245	0.035
4 - 6	0.0240	0.035
5 - 1	0.0270	0.034
5 - 2	0.0252	0.034
5 - 3	0.0247	0.034
5 - 4	0.0251	0.034

Table 4. Comparison of Standard Insulation Performance Values

Insulation Type / Density [g/㎤]	EPS-1	EPS-2 (Graphite Content)	Paper Insulation Phase 1	Paper Insulation Phase 2
0.015	0.043	0.034	0.038	0.039
0.020	0.040	0.033	0.037	0.036
0.025	0.037	0.032	0.035	0.034
0.030	0.036	0.031	0.034	0.032
0.035	-	-	-	0.030

Table 5. Gasses Produced with Fire Application on the Paper Insulation

Gas Composition	Quantities produced
CO	130mg/g
CO_2	610mg/g
Cyan	-
Hydrogen Chloride	-
Ammonia	-
Nitrogen Oxide	-
Sulfur Oxides	-

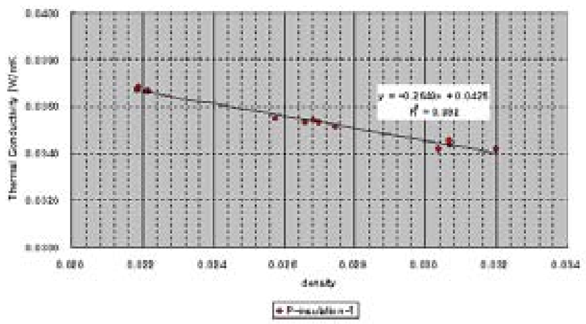


Figure 5. Phase 1 Thermal Conductivity Test Results

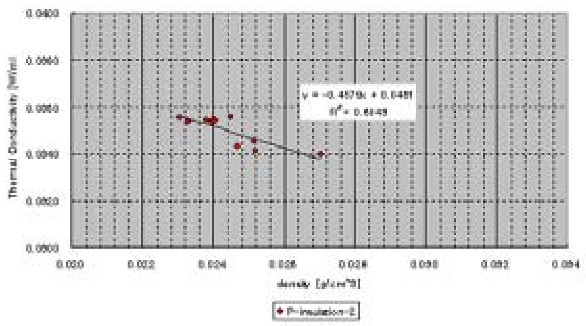


Figure 6. Phase 2 Thermal Conductivity Test Results

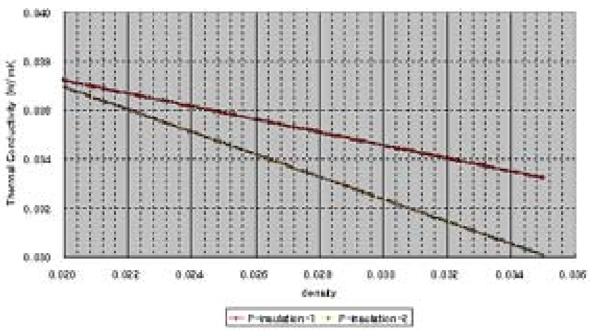


Figure 7. Correlation of Density & Thermal Conductivity

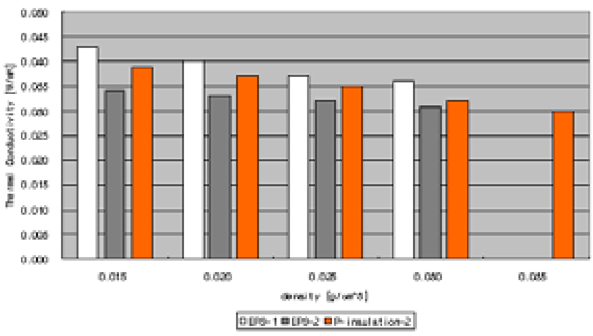


Figure 8. Thermal Conductivity Performance Comparison

a) Sample Preparation

b) After 68 Hours of Immersion in Water

c) Sectional Cut of the Sample

d) Section Under the Immersed Surface

Figure 9. Water Penetration Test Results

5. Conclusion

The total annual emission of CO_2 in Korea is approximately 410 million CO_2tons/year. There was a 75.5% rise over the past 10 years which is an annual average increase of 6.5%. Thus, with the high oil prices and to reduce global environmental load, developments are required for energy related technology, as well as technologies for resource regeneration and recycling.

The results of this study are as follows.

1) The paper insulation is comprised of closed cells, so absorptiveness is low and resistance to water penetration is relatively high. Also, there is no absorption due to the capillary tube phenomenon in the openings between the perpendicular grains.

2) Results of analysis for gases on combustion revealed that apart from CO and CO_2 there were no emissions of harmful gasses such as hydrogen chloride, sulfur oxides etc.

3) The paper insulation density control according to the expansion multiple is relatively easy, and a density range of 20 kg/㎥ ~ 35 kg/㎥ was found to be applicable as building insulation materials.

4) Thermal conductivity of the paper insulation has high correlation to density, and the test results showed thermal conductivity of 0.034 W/mK ~ 0.037 W/mK according to density.

Physical property tests are currently in progress in relation to diverse items required in building insulation materials, and especially because paper insulation is comprised mainly of recycled materials and no global warming related gasses are emitted in the expansion process, comprehensive direct & indirect economic evaluation taking into account these physical properties and analysis of the environmental load reduction effects will continually be conducted.

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EVALUATION OF THE THERMAL PERFORMANCE AND ENERGY CONSUMPTION CHARACTERISTICS OF THE SLIM ONDOL(FLOOR HEATING) SYSTEM USING SMALL-DIAMETER HYDRAULIC HEATING PIPES

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Keywords: small-diameter hydraulic heating pipes, slim ondol system, thermal performance, energy consumption

Summary

Ondol, the Korean traditional floor heating system for houses has undergone many changes, and has been used as the heating system for most residential buildings until now. The biggest change to Korean ondol was the introduction of the hot water ondol system with pipes in the mid-1970's. The structure and heat-supply principle of the ondol system greatly changed, but few comprehensive and systematic studies have been conducted to improve the technologies related to the design, construction and operation thereof. Accordingly, typical examples of unreasonable installation of the current floor heating system are the excessive heat collection capacity, the imbalance of the floor surface temperature, and the insistence on the wet construction method, which in turn result in the increased structural load, the difficulty of renovations and maintenance, and the waste of resources and energy.

Meanwhile, the energy-saving policies of the government to reduce the environmental load, such as global warming caused by greenhouse gases, and the high oil prices in recent years are highlighting the importance of the energy consumption and efficiency of the ondol system. Accordingly, various studies are underway to develop a new ondol system and increase on-site application with the aim of reducing the energy consumption of buildings which account for about 30% of domestic energy consumption.

The purpose of this study is to develop an energy-efficient ondol system capable of heating at a relatively lower temperature by eliminating the imbalance of floor temperature, which is the weakness of the most common wet-type ondol, and by increasing the radiation capacity per unit area. In this study small-diameter hydraulic pipes (Ø 8mm), which replace the existing hydraulic pipes 20mm in diameter, were installed at intervals of 75mm. A unit model experiment was conducted to evaluate the thermal performance and energy consumption characteristics by examining the radiation characteristics according to the hot water supply temperature and supply flux.

1. Introduction

Ondol, the Korean traditional floor heating system for houses, has undergone many changes over the years, and has been used as the radiation panel heating system for most residential buildings until now. Currently most high-rise apartments have the district heating system or the local heating system using city gas, and the heating system most widely used for houses in Korea is the hot water circulating ondol. This is a wet type. That is, an insulating resilient layer is installed at the bottom. After the filled layer based on autoclaved light-weight concrete is installed above the insulating resilient layer, heating pipes are installed and mortar is applied. Then, boards, room carpets or ondol floors are laid.

Meanwhile, the national energy-saving efforts to reduce environmental loads in response to the continuation of high oil prices and global warming due to greenhouse gases highlight the importance of energy consumption and efficiency of ondol. Accordingly, diverse researches are being conducted to develop new high-efficiency ondol systems and to increase their application as part of the effort to reduce building energy consumption, which accounts for about 30% of domestic energy consumption. In addition, it will be necessary to develop a 3R (Reuse, Reduce, Recycle) ondol system capable of reducing environmental loads and pollution by using environment-friendly building materials derived from waste materials.

With the purpose of developing a slim ondol system capable of eliminating the imbalance in floor temperature, which is the shortcoming of an ordinary wet-type ondol system, and heating with relatively less warm water and improving energy efficiency by increasing the radiating capacity per unit area, this study evaluated the radiation and energy consumption characteristics of unit model test specimens in relation to the temperature and flow rate of supplied hot water.

2. Outline of the slim ondol system using small-diameter hydraulic pipes

2.1 Core technology

1) A 3R-type ondol system that substitutes the key component materials of the ondol system with wood, plastics and rubber by replacing those materials hard to recycle and reuse, such as autoclaved light-weight concrete and cement mortar.

2) Using dry-type and industrial members for on-site assembly to lengthen the life of apartments, and turning the structure of the ondol system into infill when the design is variable.

3) Adopting small-diameter hydraulic pipes (Ø 8mm) to improve the radiation capacity of the conventional dry-type ondol.

4) The entire ondol system, including slim panels, will have an ultra light-weight structure so that the load of the ondol layer will be reduced to 1/5 or less when the structure of the building is designed.

5) A dry-type ondol system which is comparable to the wet-type cured with cement mortar in terms of amenity and sensitivity of walking.

2.2 Outline of the system

The slim ondol system, using small-diameter hydraulic pipes, replaces the XL pipes of the existing wet-type ondol and places small-diameter hydraulic pipes on modular panels at narrow intervals of 75mm. It is a dry-type/prefabricated modular radiation panel system that increases energy efficiency by maximizing the radiation area and thus increasing the radiation capacity per unit area. The cross-section and unit panel of the slim ondol system are shown in Figures 1 and 2 respectively.

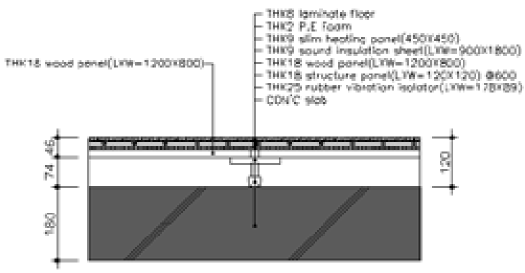


Fig 1. Cross-section of the slim ondol

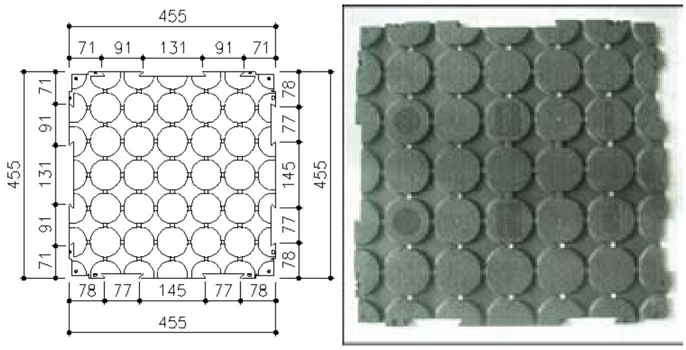


Fig. 2 The dimensions and shape of the slim ondol panel unit

3. Evaluation of the thermal performance and energy consumption characteristics

In an artificial weather laboratory where precise control of thermal environment elements, such as indoor temperature, humidity, air velocity and air distribution, the performance of the slim ondol system, i.e. the heat release and energy consumption characteristics, was evaluated against the heating conditions (room temperature, supply water temperature, etc.) of the apartment ondol system.

1) Evaluation of the changes and uniformity of the floor surface temperature in relation to supply water temperature and flow rate under continuous and intermittent heating conditions,

2) Evaluation of the energy consumption properties vs the wet-type ondol

A heatproof cover is installed in the ondol system to be measured to ensure its temperature is different from the temperature of the temperature setting (20℃) inside the laboratory. The energy consumption necessary for maintaining the same indoor temperature was measured to compare and evaluate the energy consumption characteristics of the wet-type ondol and the slim ondol system.

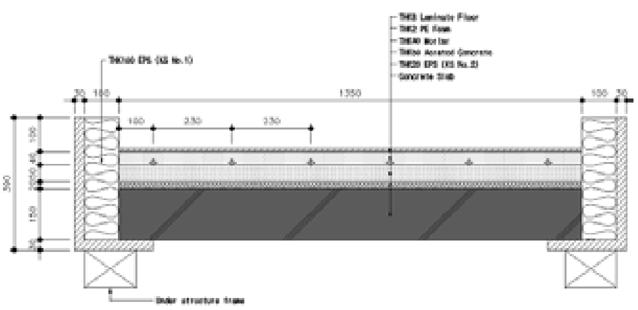


Fig 3. Wet-type ondol test specimen

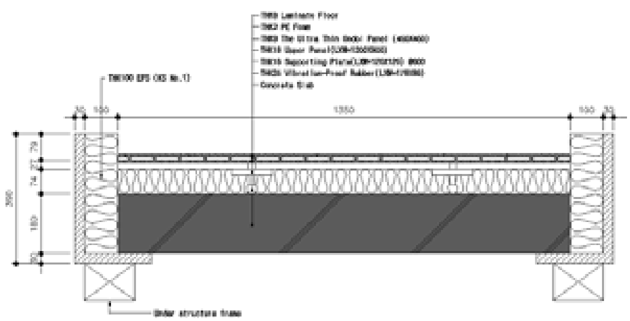
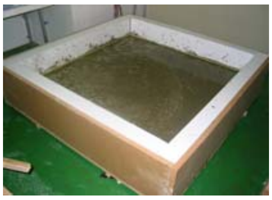


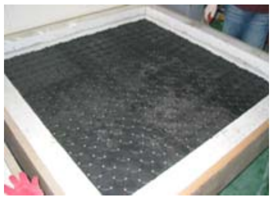
Fig 4. Slim ondol system test specimen



(a) slab construction

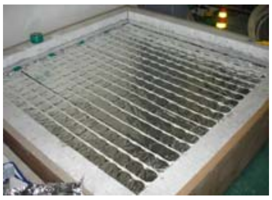
(b) insulated (GW) construction

(c) double floor upper panel construction



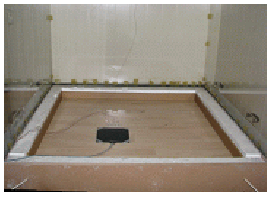
(d) slim ondol panel construction

(e) aluminum radiation panel construction



(f) hydraulic pipe construction

(g) laminate floor construction



(i) making the test specimen and installing the sensor

Fig 5. Photographs depicting the installation of the ondol system test specimen for evaluation of thermal performance and energy consumption characteristics

3.1 The results of the evaluation of thermal performance in case of continuous heating

On condition that 45℃ water is supplied continuously at the flow rate of 3 Lpm, Figure 6 illustrates the changes of the mean floor surface temperature directly above (0/4 pitch, 4/4 pitch), in the middle (1/4 pitch, 3/4 pitch) and the center (2/4 pitch) of the wet-type ondol system and the slim ondol system, whereas Figure 7 illustrates the changes of the floor surface temperature in different parts of the pipe.

Table 1 shows the changes of temperature from 8 hours after hot water supply till the stop of hot water supply (floor surface temperature stabilization) in the thermal performance experiment in case of continuous heating. The mean temperature difference (ΔT) directly above and in the center of the pipe was 0.6K for the slim ondol system and 3.9K for the wet-type ondol system. The ΔT of the slim ondol system was about 3.3K smaller than that of the wet-type. Overall, the mean temperature of the floor surface of the wet-type ondol was about 1.5K higher than that of the slim ondol system.

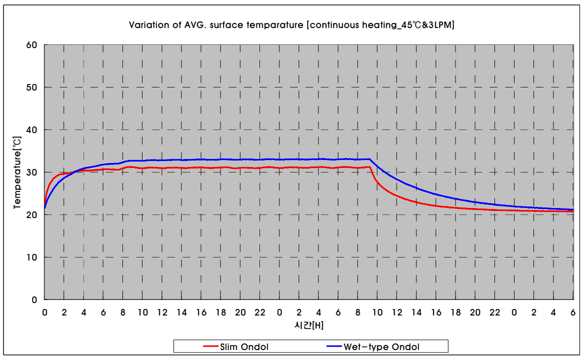


Figure 6. Changes in the mean floor surface temperature (continuous heating)

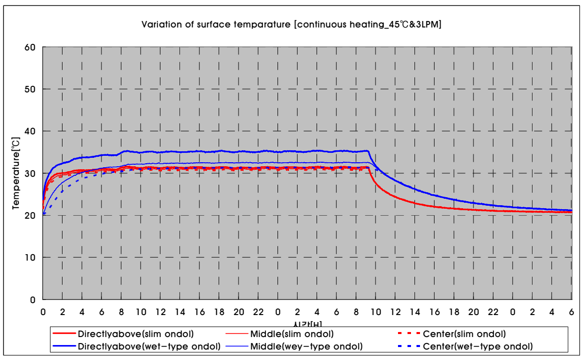


Figure 7. Changes of the floor surface temperature in different parts of the pipe (continuous heating)

Table 1. Changes of temperature under continuous heating conditions

Classification		Minimum	Mean	Maximum
Wet-type ondol	Directly above	34.8	35.1	35.4
	Middle	31.7	32.4	32.6
	Center	30.5	31.2	31.4
	Mean floor surface temperature	32.4	**32.9**	33.1
	ΔT (directly above-center)	4.3	**3.9**	4.0
Slim ondol system	Directly above	31.2	31.4	31.6
	Middle	30.8	31.0	31.2
	Center	30.6	30.8	31.0
	Mean floor surface temperature	30.9	**31.0**	31.3
	ΔT (directly above-center)	0.6	**0.6**	0.6

3.2 The result of the evaluation of thermal performance in case of intermittent heating

On condition that the 45℃ water is supplied for two hours at the flow rate of 3Lpm, and then cooled down for two hours, i.e., hot water was supplied intermittently three times in total (stage 1; 0 ~ 2 hours, stage 2; 4 ~ 6 hours, stage 3; 8 ~ 10 hours), Figure 8 illustrates the changes of the mean floor surface temperature in the wet-type ondol system and the slim ondol system. In case of intermittent heating with 45℃ water, 2 hours after hot water supply, the floor surface temperatures directly above, in the middle and center of the pipe were 32.48, 27.52 and 25.23 ℃ respectively for the wet-type ondol system. The temperature difference between the part directly above the pipe and the center was 7.25K. In case of the slim ondol system, the floor surface temperatures were 30.27, 29.77 and 29.40 ℃, showing a temperature difference of about 0.87K. The hourly increase of the mean floor surface temperature of the slim ondol system was 8.15 ℃/hour, while the hourly temperature decrease was 6.09 ℃/hour, whereas the hourly increase of the mean floor surface temperature of the wet-type ondol system was 7.20 ℃/hour, and the hourly temperature decrease was 2.60 ℃/hour.

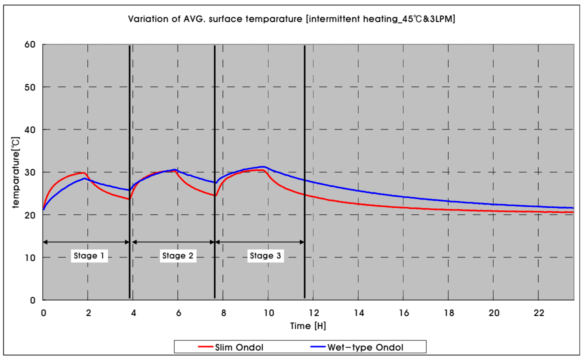


Figure 8. Changes of the mean floor surface temperature (intermittent heating)

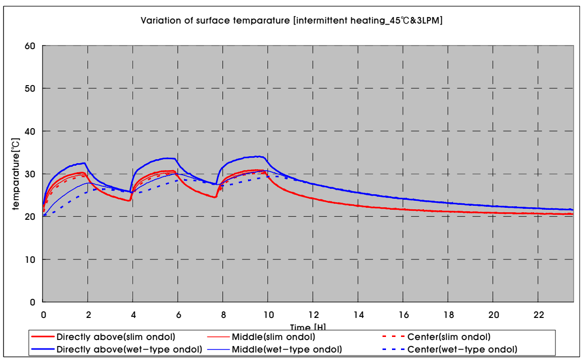


Figure 9. Changes of the floor surface temperature in different parts of the pipe (intermittent heating)

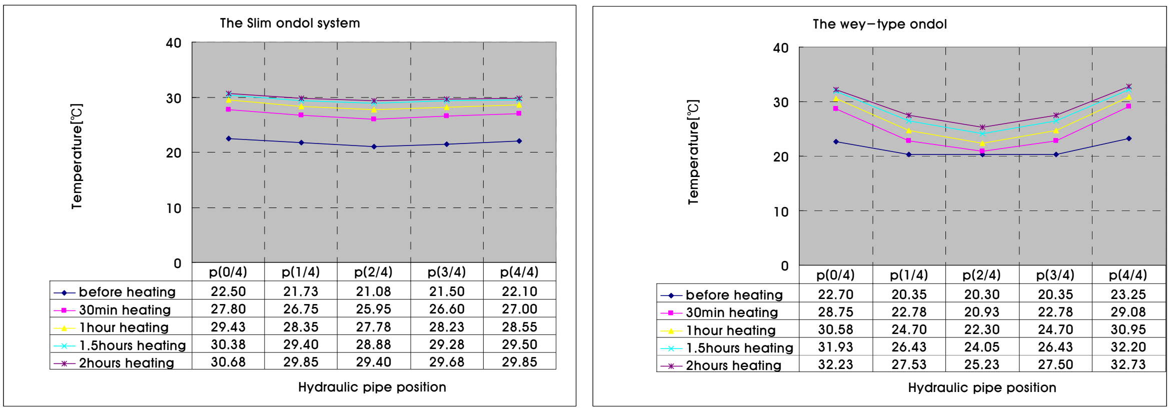


Figure 10. Slopes of the floor surface temperature (for stage 1 of intermittent heating)

3.3 The result of the evaluation of energy consumption characteristics

60℃ water was supplied for the wet-type ondol, and 45℃ for the slim ondol system to ensure that the indoor temperature of the artificial weather laboratory (outer room) was 20℃. The heatproof cover was installed in both the wet-type ondol and the slim ondol system, and the heating energy consumption necessary for keeping the indoor temperature inside the heatproof cover at 24℃ was measured. It was 8.60kW/h for the slim ondol system, and 9.10 kW/h for the wet-type ondol system. The heating energy consumption of the slim ondol system was about 5.5 % less than that of the wet-type ondol system. At this time, the indoor temperature inside the heatproof cover was almost the same for both ondol systems: i.e. 24.0℃ for the slim ondol system, and 23.8℃ for the wet-type ondol system.

Table 2. The result of the heating energy consumption characteristics experiment

Classification	Slim ondol system			Wet-type ondol			Remarks
	Minimum	Mean	Maximum	Minimum	Mean	Maximum	
Indoor temperature (℃) inside the heatproof cover	19.9	24.0	24.5	20.4	24.1	24.6	
Directly above (℃)	20.1	29.6	30.5	20.1	32.0	36.7	
Middle (℃)	20.1	29.6	30.5	20.1	29.4	30.3	
Center (℃)	20.2	29.3	30.3	20.1	28.7	29.0	
Mean floor surface temperature (℃)	20.1	29.6	30.5	20.1	30.0	31.6	
Heating energy consumption (kW. h)	8.60			9.10			24 hours

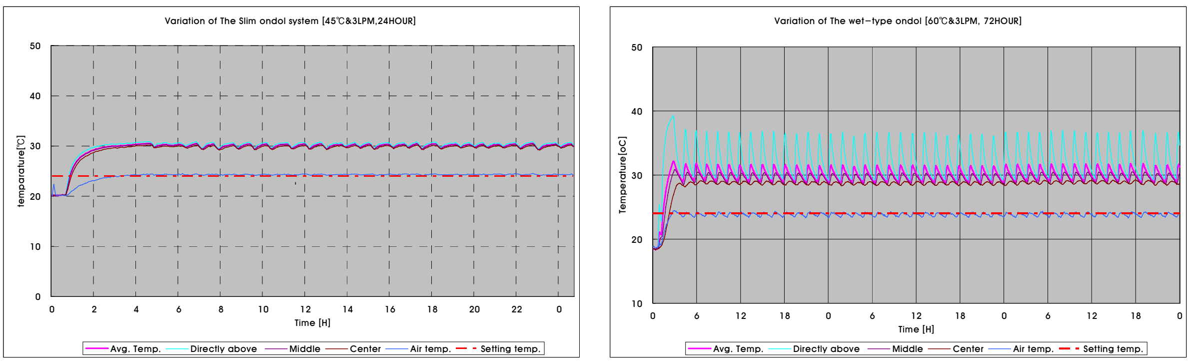


Figure 11. Changes of surface temperature in different parts of the pipes

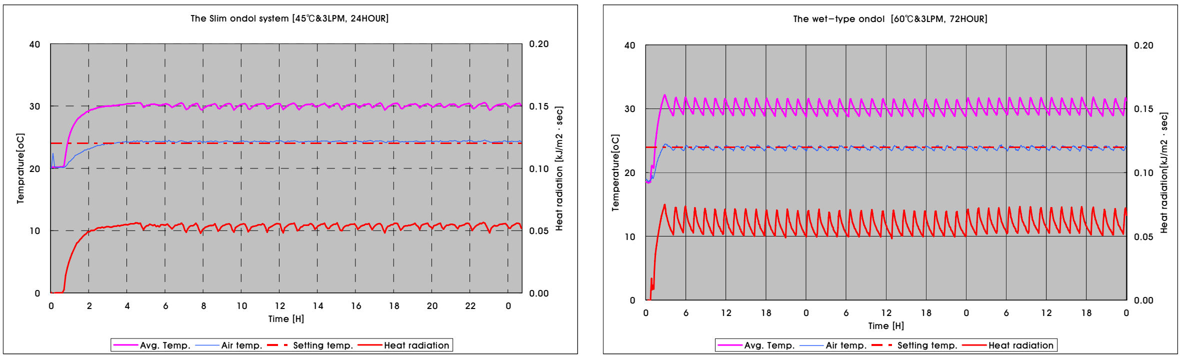


Figure 12. Changes of the mean floor surface temperature and heat radiation of the upper part

4. Conclusion

This study evaluated the radiation and energy consumption characteristics of the unit model test specimen, which is capable of heating with relatively lower-temperature water and increasing energy efficiency by solving the problem of the general wet-type ondol system, i.e. the imbalance of the floor temperature, in relation to supply water temperature and flow rate.

1) The mean radiation capacity of the upper part of the slim ondol system was 0.057 kJ/㎡ sec, better than or equal to that of the conventional wet-type ondol system. Meanwhile, the floor surface temperature difference of the slim ondol system was less than 2.5K for the entire floor surface, solving the uneven floor surface temperature distribution (over 6K) of the conventional wet-type ondol system, and the temperature deviations of the dry-type ondol system (over 10K).

2) On condition that the supply water temperature is 45℃, the mean floor surface temperature of the slim ondol system was greater than 29℃, indicating that it is capable of low-temperature water heating with the supply water temperature being lower than 50℃.

3) The heating energy consumption necessary for keeping the indoor temperature constant was measured with the unit thermal performance test specimen. The energy saving effect in case of low-temperature water heating (supply water temperature 45℃) was about 6% as compared to the wet-type ondol system (supply water temperature 60℃). Accordingly, in consideration of the heating load characteristics, such as the energy saving effect in the boiler due to low-temperature water heating and the heat storing, the energy saving effect of the slim ondol system is believed to be greater than in actual buildings.

Meanwhile, in consideration of the high oil prices constantly rising past the 100$ mark and energy consumption which accounts for about 80% of greenhouse gas emissions, this technology, capable of reducing energy consumption and environmental load at the same time by improving the efficiency of energy use while maintaining the same thermal environment, is thought to be of great significance.

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A HIGH STANDARD OF SUSTAINABILITY FOR NEW ZEALAND HOMES

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Summary

Why is it that we know more about the performance of our cars than we do about our homes? Homes are typically New Zealanders' largest single investment, and the place where we spend most of our time. Yet the performance of New Zealand homes is generally poor, with high economic, health and environmental costs for occupants and for New Zealand as a whole. Research shows that it doesn't have to be this way. New homes can be built to a much higher standard of sustainability and existing homes can be similarly retrofitted.

To support the shift to warmer, healthier and more resource-efficient homes, Beacon Pathway has identified a series of benchmarks that define a High Standard of Sustainability™ for New Zealand homes. This paper discusses key design choices made in developing the High Standard of Sustainability™, and argues for a performance-driven benchmark approach to both identify the sustainability potential of a home and to educate occupants about the effect of their behaviour on whether that potential is achieved or not. It identifies some of the challenges inherent in defining a High Standard of Sustainability™ for New Zealand homes, as well as the anticipated benefits.

1. Introduction

Why is it that we know more about the performance of our cars than we do about our homes? When we buy a new car, we think about how much it will cost to run – the rate of fuel consumption, cost of servicing and replacement parts, how long the car will last, and how safe it is. Performance data is an important part of the decision-making process. So, why don't we ask the same kinds of questions when we buy a new house?

Homes are typically New Zealanders' largest single investment – the New Zealand Reserve Bank estimates that approximately 90 percent of New Zealand households' net worth is represented by housing assets (Department of Building and Housing, 2007a)[1]. Houses are also where people spend 75 – 90% of their time (Beacon Pathway et al., 2007).

Yet the performance of New Zealand homes is generally poor, with high economic, health and environmental costs for occupants and for New Zealand as a whole. Research shows that it doesn't have to be this way. New homes can be built to a much higher standard of sustainability and existing homes can be similarly retrofitted.

Beacon's objectives are: 'creating homes and neighbourhoods that work well into the future and don't cost the Earth.' Through its research and advocacy, Beacon is working towards a goal 'that 90% of New Zealand homes reach a high standard of sustainability by the year 2012.' Fundamental to this goal is establishing what, exactly, a high standard of sustainability is. How should such a house perform?

This paper discusses key design choices made in developing the High Standard of Sustainability™ (Easton, 2006), and argues for a performance-driven benchmark approach to both identify the sustainability potential of a home and to educate occupants about the effect of their behaviour on whether that potential is achieved or not. It identifies some of the challenges inherent in defining a High Standard of Sustainability™ for New Zealand homes, as well as the anticipated benefits.

[1] The housing sector underpins much of New Zealand's economy. Approximately half of the building and construction industry activity in New Zealand is residential. The building and construction sector contributed around 5% of GDP and 8% of employment in the March 2007 financial year (Department of Building and Housing, 2007a).

2. New Zealand's Housing Stock: the Need for a High Standard of Sustainability™

There are approximately 1.6 million houses in New Zealand, with an additional 25,000 dwellings built each year (Beacon et al., 2007). The majority of the population will continue to live in houses that have already been built, and were not designed to achieve a high standard of sustainability.

Achieving a high standard of sustainability across New Zealand's housing stock – both new and existing, and at all socioeconomic levels – is important for several reasons, leading to health and economic benefits to residents and the wider community, as well as environmental benefits.

2.1 Health Benefits

New Zealand enjoys a temperate climate, but the country's houses are for the most part cold, damp, and hard to heat in winter (Howden-Chapman, et al., 2004). About 65% of the current housing stock was built before 1977, when there was no requirement for insulation to be installed as part of the construction process. Furthermore, many homes built since 1977 are known to still not meet basic insulation standards.[2]

Common problems identified in New Zealand homes – across all socioeconomic groups – include (Phipps, 2007):

- **cold:** New Zealand homes are on average 6°C below World Health Organization recommended minimum temperatures in winter;
- **damp and mould:** 45% of all New Zealand homes are mouldy;
- **poor air quality:** approximately 300,000 New Zealand homes have an unflued gas heater and the air inside New Zealand homes can be more polluted than outdoor air; and
- **presence of fungi and dustmites:** triggering allergenic reactions and asthma, rates of which are increasing.

These problems are significant contributors to illnesses, such as asthma and bronchial diseases. New Zealand has the second highest rate of asthma in the world, with one in six adults and one in four children experiencing asthma symptoms (over 600,000 New Zealanders), conservatively estimated to cost New Zealand $825 million per year (Asthma and Respiratory Foundation of New Zealand, 2002).

Research shows evidence of health returns well in excess of the investment in housing improvements, and the New Zealand Energy Efficiency and Conservation Authority have identified that health is a more persuasive driver for homeowners to upgrade their home than climate change or energy efficiency.

Direct health benefits to residents also contribute to substantial wider benefits to the nation, such as reducing illness-related absences from employment and education (key drivers of productivity) and reducing hospitalization and heath-care costs (Beacon et al., 2007).

2.2 Environmental and Resource Efficiency Benefits

New Zealand homes generally require substantial inputs of energy, water and materials, and generate large amounts of waste. Households directly consume 32.4% of national energy (including transport energy) (Energy Efficiency and Conservation Authority, 2007). Construction and demolition waste – a good proportion of it from residential construction and demolition – is thought to represent up to 50% of all waste generated in New Zealand (Ministry for the Environment, 2006).

Some of the country's infrastructure is nearing the end of its functional life and, with the additional load from growth in population and per capita demand, it is reaching critical capacity constraints. For example, electricity supply has relied on hydro power stations commissioned throughout the twentieth century. As demand has grown, the proportion of electricity supplied by hydro generation has declined from 85% in 1980 to 60 – 65% today, with the deficit met with a mix of gas, coal, geothermal and wind (in declining order of contribution) (Parliamentary Commissioner for the Environment, 2005). Given environmental sensitivities it will be extremely difficult to commission any further hydro power stations.

Demand side management can go some way to offsetting the need for further investment in supply. New Zealand's Electricity Commission calculated that installing 3 million compact fluorescent light bulbs[3] in New Zealand homes would save enough electricity to power up to 30,000 homes a year, generate annual household savings of around New Zealand $45 million, and reduce CO_2 emissions equivalent to taking 40,000 cars off the road (Electricity Commission, 2006).

As a signatory to the Kyoto Protocol, New Zealand has made a commitment to stabilise its greenhouse gas emissions at 1990 levels. Unfortunately, rates of emissions are continuing to accelerate, and the country now faces a significant bill for carbon offsetting. The National Value Case (Beacon et al., 2007) suggests that around 22 PJ of household energy consumption could be saved per year through simple

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[2] Minimum insulation standards in the Building Code were raised in 2007, with expected reductions in the order of 30% of energy necessary to stay 'comfortably warm' (Department of Building and Housing, 2007b). Even fewer existing homes meet these new, higher standards.

[3] This equates to replacing five standard bulbs with five CFLs in every second home in the country.

measures. That is enough energy to power over 500,000 New Zealand homes for a year, and would offset around 3,600kt of CO_2 emissions. Allowing for take-back effects (warmer, healthier homes, spending household energy savings on travel and other commodities), CO_2 savings of 1,600kt are still produced.

2.3 Consumer Expectations, and Sustainability as a Marketing Tool

After several decades of small-scale initiatives, New Zealand is now experiencing a rapidly growing level of consumer interest in all things sustainable. Energy efficiency is still the major focus of most of the schemes underway, including the Energy Wise retrofit programmes available throughout the country since the mid-1990s, and the newly launched voluntary Home Energy Rating Scheme (HERS) run by the government Energy Efficiency and Conservation Authority.

However, the scope of initiatives is beginning to extend beyond energy, with various tools and rating schemes being released to support home owners to make informed choices in all aspects of their home's design and operation, including the Smarter Homes and Homesmarts websites.[4] Other tools are also being developed, for example rating tools by the New Zealand Green Building Council. There has been very low uptake of rating schemes in the past (the most notable New Zealand example of a rating scheme being the Green Homes Scheme run by BRANZ), so it will be interesting to see if increasing consumer interest leads to greater uptake.

The marketing of building products is certainly responding to increasing consumer expectations (or may even be driving them), with companies claiming energy efficiency, healthy homes, future-proofing and the like for their various products. Yet, as sustainability becomes something of a marketing tool, there is the potential for a great deal of confusion – just what makes for a sustainable home? How can homeowners make the best choices for their specific needs?

All of these factors point to a need for New Zealanders to be able to define what achieving a High Standard of Sustainability™ in a home means – how the home should perform, and what features are necessary to deliver that level of performance.

3. The High Standard of Sustainability™

The High Standard of Sustainability™ (HSS) developed by Beacon identifies a set of benchmarks by which homeowners can:

a. understand the performance of their homes; and

b. gain insight into the effect of their behavioural choices (that is, the gap between the home's design potential and its actual performance).

Five key performance areas have been selected to define the HSS: energy, water, indoor environment quality, waste and materials (Easton, 2006). These are underpinned by issues of affordability and future flexibility (consistent with Beacon's objectives, introduced above). In combination, these performance areas ought to demonstrate whether a home is performing sustainably or not.

Beacon's focus is on the homes of ordinary New Zealanders rather than any particular income or demographic group. For this reason, the HSS is defined within the confines of *what is reasonably achievable for the mass market today*. This tempers the level of the benchmarks, down from what might be achieved with excellent design or significant capital investment, to a level that is more reasonably aligned with the potential of 'mainstream' design, industry expertise, and consumer acceptance. It is anticipated that the HSS will be staircased to require higher levels of performance over time, as sustainable design is increasingly employed.

Affordability was a significant consideration in setting benchmarks. The cost of implementation (whether retrofitting or new development) and length of payback period were taken into account to set benchmarks which are practically achievable. Future flexibility was also a concern. Benchmarks and features were selected so as to be adaptable to changes in dwelling use, household structure, and the changing ethnic and socio-economic mix of the population.

Initial benchmarks have been established as a "first cut" starting point from which to assess Beacon's high standard of sustainability for houses, and are set out in figure 1. The benchmarks were established based on the best available national information. For example, this included the Household Energy Enduse Project and the ALF3 model for setting energy benchmarks (BRANZ, 2006), and work

[4] The Smarter Homes website (www.smarterhomes.org.nz) is an initiative of the government Department of Building and Housing and is 'aimed at home owners and renters, people looking to buy or build houses, and at building and property professionals who want an overview of smart home and building issues.' Its intent is 'to provide clear, independent, factual information about sustainable home design, building and lifestyle options.' This is supported by the Homesmarts tool (www.homesmarts.org.nz), which provides a more detailed level of advice, including a Smart Home Tour and Home Health Check, modelled on the findings from Beacon's Now Home® research programme.

commissioned to assess national levels of domestic water consumption (on a per capita basis) for the water benchmark (Lamborn, 2006).

The benchmarks provide a baseline of information for researching Beacon's hypothesis that it is possible to build new homes and retrofit existing homes to achieve a high standard of sustainability within a framework of affordability and use of existing technology. It is entirely expected that the benchmarks will be revised over time as data sets improve, and work is already underway in this regard.

As a set of benchmarks, the HSS is intended to operate as the *underlying standard* that is promoted through a range of tools, including the Homesmarts website and Beacon's design guidelines for construction and renovation of new and existing homes. It may also be used as an underpinning common reference point for the various home rating tools that exist in the New Zealand market-place (or are currently in development). It must be underlined that the HSS is not a rating tool in its own right, and there are no plans to develop it as such. The intention is for the HSS to work with rating schemes, ensuring compatibility rather than competition.

Energy

- New homes: 7,600 kwh/yr (climate zone 1), 8,500 kwh/yr (climate zone 2), 9,800 kwh/yr (climate zone 3)
- Existing homes : 9,050 kwh/yr (climate zone 1), 11,000 kwh/yr (climate zone 2), 12,000 kwh/yr (climate zone 3)

Water

- 180L/person/day

Indoor Environment Quality

- temperature: 16° C bedroom mean min temp; 18° C living room mean min temp
- ventilation: 0.4 -0.6 air changes/hour (new homes), 0.5 – 0.75 air changes/hour (existing homes)
- relative humidity: mean relative humidity 20 - 70% in bedrooms and living space
- checklist: mechanical extract ventilation of kitchen, bathroom and laundry; windows with passive venting; no unflued gas heaters; Environmental Choice certified paints and finishes; no air conditioning

Waste

- Provision for kitchen waste composting or storage space for kitchen waste collection
- Space for recyclables storage
- No in-sink waste disposal unit
- New building construction or renovation in accordance with REBRI construction guidelines

Materials

- New homes checklist: materials which promote good indoor air quality, have minimal health risks during construction or retrofitting, are durable and have low maintenance requirements, incorporate recycled content or can readily be recycled, reuse existing or demolished building materials or can readily be reused, are made from renewable or sustainably managed resources, have low embodied energy including minimal impacts due to transport, choices, construction (waste) guidelines, have low impact on landfill or are biodegradable, have third-part certification (e.g. NZ Environmental Choice, Forest Stewardship Council.
- Existing homes checklist: applies principles from new homes checklist to retrofit or renovation, where appropriate.

Figure 1 The High Standard of Sustainability™

4. A Whole-of-House Approach

Many of the sustainable housing initiatives that exist in New Zealand are focused only on one issue – particularly energy efficiency. It is a key Beacon assertion that the sustainability of a home is an interdependent web of features/performance areas (see fig 2). It is not possible to address only one resource stream and call the house sustainable.

Focusing on a single issue can lead to compromises and under-performance in other aspects of the home. Energy efficiency can be achieved through under-heating the home, but this compromises indoor environment quality. Conversely, heating the home for IEQ reasons (without also improving the dwelling's thermal performance) can lead to high energy demand. High water use also has energy implications - approximately 30% of typical New Zealand household energy consumption is spent heating water. Plus, there are infrastructure costs for collection, storage, transport, treatment, use and disposal of water.

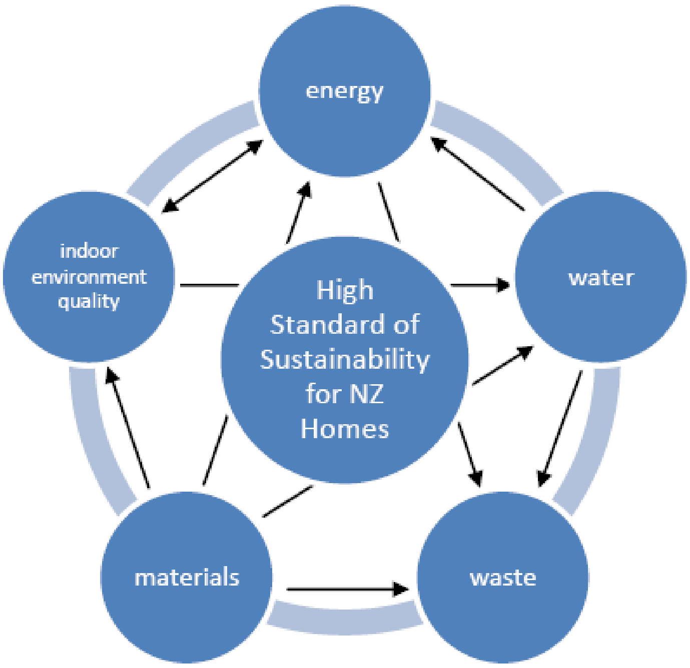

Figure 2 Sustainability as an interrelated web of features

5. A Measurable Approach: Benchmarks versus Checklists

As far as possible, the HSS benchmarks have been established as measurable units, rather than as checklists of features. Providing checklists of features is an extremely useful approach for identifying the range of options available to improve a home's performance, however checklists tend to lack a connection to performance outcomes – particularly due to the variable effect of occupant behaviour.

Preliminary data from Beacon research indicates that a sustainably designed home will perform better than a conventional one, regardless of occupant behaviour, but that the extent of the improvement is dependent in large part on the behavioural choices of the occupants.

Following a checklist should make a home warmer, healthier and more resource efficient, but once the features are installed, checklists may not support improved occupant practices. For example, leaving taps running and drapes open can undermine the intended benefits of these features.

By specifying measurable benchmarks, the HSS identifies the design potential of a home and establishes a simple feedback loop between occupant behaviour and home performance. Occupants can regularly measure their performance against the benchmarks, and better understand where they can make improvements. For some performance areas, such as reticulated energy, the measurement can be easily obtained from power bills. The same applies to reticulated water in places where it is metered. Indoor environment quality is a more complicated set of measurements, and a simple monitoring tool for New Zealand homes is in development as part of Beacon research.

For the IEQ, materials and waste performance areas, the HSS has had to rely on checklists - due to the nature of the performance being measured and the lack of available data to set measurable benchmarks. As research progresses, it may be possible to specify measurable benchmarks for these areas.

6. Application in Beacon's NOW Homes®

As part of developing and testing approaches to increase the sustainability of New Zealand homes, Beacon is building a series of NOW Homes® – resource efficient homes defined to be affordable to most New Zealanders. Beacon is also currently monitoring retrofits of nine "average" homes to increase their level of sustainability – this number will increase significantly in the immediate future.

The Waitakere NOW Home® was completed in August 2005. The home was designed and built to budgets and constraints typical of "ordinary" New Zealand housing rather than aimed at the top 5% of the market more typical of other "ecohomes". Passive solar design, resource efficiency, minimisation of hazardous materials and future flexibility were all key considerations in designing and building the home. As a result less than 2.5 tonnes of construction waste was produced, compared with a study of 'conventional' new 3-bedroom homes, which each produced 6 tonnes of construction waste (Kazor and Koppel, 2007).

The first twelve months of monitoring from the Waitakere NOW Home® demonstrated that the house can meet the HSS benchmarks. The home used 7400 kWh/year of electricity, with supplementary space heating being required for only two days. When compared to the occupants' previous dwelling, this was 45% less electricity than they used in their previous home (French et al, 2007). There has been an increase in the second year, with the occupants using 8500 kWh/year. Analysis shows that this "take back" has been in the form of additional hot water use (longer and more frequent showers) and additional appliances being introduced into the home – an important illustration of the home's design capability versus the effect of its occupants' behavioural choices.

In contrast, water usage has declined, from 100L/person/per day reticulated water (a total of 189L/person/day including rainwater) in the first year, down to 85**L**/person/day reticulated water (and a total of 172L) (Pollard et al, 2008). In addition, the quality of the indoor environment and occupant satisfaction is very high, and the health of the family living there has improved (French et al, 2007).

7. Challenges for Design and Implementation

Measuring the performance of New Zealand homes and establishing generally relevant benchmarks is not a simple task. Accounting for variability, and finding meaningful methods of communication are two of the key challenges.

7.1 Variability

Variability is one of the greatest impediments to establishing appropriate, generally applicable benchmarks. The challenge arises in terms of:

- Significant variability in the performance of the housing stock, due to climate, construction type, size, etc. resulting in a wide range of starting points and potential for improvement;
- Major issues over the availability and reliability of existing data; and
- Wide variability in the effect of operator influence.

7.1.1 Housing stock variability

There will always be differences arising from climate conditions and housing typologies. A brick and tile unit in Auckland (climate zone 1) cannot be equitably benchmarked at the same energy performance levels as a draughty villa in Invercargill (climate zone 3). This is recognised to an extent in the HSS, with differential benchmarks according to climate zone and whether the house is new or a retrofit.[5] It is anticipated that greater levels of differentiation will be developed over time and as data becomes available (for example, setting benchmarks for different housing types).

7.1.2 Data variability

A key issue for the HSS is the variability – and in some cases simple lack – of data on which the HSS benchmarks rely. For example, data relating to average domestic potable water consumption is extremely variable, with no accepted national average. In a country where water has been a relatively abundant resource, there is little knowledge about where our water actually goes. Some of this variability may be due to regional differences in water use (due, *inter alia,* to climate, soil type and water charging practices) and some due to different measurement methods (with some places measuring only gross per capita consumption, including agricultural and commercial uses, as well as losses due to leaky supply infrastructure). However, it makes it difficult for Beacon to determine an appropriate baseline benchmark. For this reason, the benchmarks have been specified as 'first cuts' that will need to be reviewed as Beacon and other research organisations develop a stronger evidence base.

[5] Similar performance differences occur for water (particularly due to garden watering), and indoor environment quality (due to humidity levels). These benchmarks are currently set at a relatively low threshold and apply nationwide. Further research underway may suggest a more fine-grained approach, setting benchmarks to better reflect local conditions.

7.1.3 Operator variability

As noted above, occupant behaviour has a marked influence on home performance. The HSS benchmarks focus on the performance potential of the physical fabric of the home, based on best available data (related to both the particular dwelling and to average data). Benchmarks need to be carefully defined to ensure that the HSS is not seen as an accurate prediction of actual consumption or a guarantee of performance, but rather as an indication of design potential. This issue is not unique to New Zealand. Comparable international standards (e.g. the UK Code for Sustainable Homes and New South Wales' BASIX tool) all come with provisos that their measures are established to be design tools rather than a guarantee of operational efficiency (BREEAM Centre at the Building Research Establishment, 2007, p. 70, Centre for International Economics, 2005, p. 2).

7.2 Communication

A further challenge for the HSS is in communicating a wide range of information simply and meaningfully. Using actual measurements is important for the educational and management purposes of the HSS, but the range of units – litres per person per day, kilowatt hours per year, rate of air changes per hour, degrees Celsius – could potentially be overwhelming. At this stage it is proposed that the HSS be communicated in two layers – a first, simpler layer of percentage savings compared to conventional dwellings of a similar style and location (as is done in BASIX and other such tools), and a more detailed layer for application once users are more familiar with the range of issues and measurements.

8. Anticipated Benefits

The High Standard of Sustainability™ is a key measurement tool for Beacon to establish, pursue, and monitor its objectives. Successfully defining and applying the HSS through its research programmes should help to deliver a better understanding of the sustainability of New Zealand's housing stock, with an improved data set, gathering and comparing performance data about New Zealand homes against a simple set of measures for sustainability. It should also provide an improved evidence base for investment and decision-making at both household and national levels. Perhaps most importantly, the development of a simple measurement tool should help to improve New Zealanders' understanding of:

- their home's performance – in the first instance, this is likely to be an awareness of the substandard nature of the majority of our homes;
- the effect of their behaviour on their home's performance; and
- the sustainability features to look for when buying or renovating a home.

Achieving the HSS in a growing proportion of New Zealand homes will generate benefits for residents, the housing industry, the public sector and the environment, including improving New Zealanders' quality of life through healthier homes, reducing the demand for valuable resources such as energy and water, and reducing carbon dioxide emissions. It will help to increase productivity and make more efficient use of New Zealand's resources, and improving the resilience of the New Zealand housing stock to global challenges such as climate change, resource availability, and population change.

9. Further research

As identified above, the benchmarks identified within the HSS are a 'first cut' – largely due to the poor understanding of housing performance in relation to sustainable development. As more data becomes available, it is expected that the HSS will be reviewed and recalibrated accordingly.

There will be an ongoing challenge to ensure the HSS strikes a balance between 'stretch' and achievability (that is, setting the benchmarks high enough to make a notable difference in the sustainable performance of dwellings but not so high that the HSS is out of reach of the mass market). The variability of New Zealand's housing stock – in terms of design and climate, means that setting appropriate benchmarks for some performance areas, particularly energy, needs to be more fine-grained.

Further research is also needed to support implementation of the HSS – for example, conducting life cycle analysis on systems used in construction to inform materials choices, and developing packages of features that can be expected to achieve the performance benchmarks.

There is potential for the HSS to expand to include other performance areas, e.g. more specific provisions around stormwater, wastewater, ecology, and social sustainability dimensions such as building homes that are adaptable to changing resident needs. How wide the scope of the HSS should be is a question of finding an appropriate balance between comprehensive cover and ease of use.

10. Conclusions

The poor standard of the majority of New Zealand homes, combined with increasing consumer awareness of the benefits of more sustainable homes, means that the HSS is a much-needed benchmarking tool – communicating possibilities, establishing expectations, and leading change. The High Standard of Sustainability™ is a way of establishing how New Zealand homes can be expected to perform – equipping residents with information to benchmark their homes, to understand what they can achieve within their home, and to signal where improvements can be made.

Providing a simple means to measure – and consequently to manage – is also fundamental to Beacon achieving its goals nationally: creating homes that work well into the future and don't cost the earth. It provides the information necessary to understand the condition of New Zealand homes, and to make a business case for change, enabling the nation's housing stock to be progressively improved over time.

Establishing appropriate benchmarks – that is, benchmarks that are measurable, achievable and yet also lead to a significant improvement in housing quality – is an ongoing challenge for Beacon. The HSS benchmarks are expected to be made more stringent over time, as data improves and as it becomes easier to incorporate sustainable features into the majority of homes.

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TROPICAL DAYLIGHT SYSTEMS FOR ZERO ENERGY OFFICE BUILDING IN MALAYSIA

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Summary

The tropical Zero Energy Office (ZEO) building in Malaysia is nearly 100% daylit without causing glare and over-heating to the building occupants. This key daylight design strategies were 1) orientation of the building facades North and South to take in diffuse light and block direct sun light 2) facade with split window design and lightshelf 3) development of a daylight window with a fixed blind that allows light entry and prevents glare 4) development of roof lights and 5) a daylight response electric lighting system. The split window design ensures that the daylight performance is maintained even though occupants by the facade engage the roller-blind, as it only covers the lower viewing window.

All workstations were given task lights to give the occupants individual control of their lighting environment. The lighting control strategy for the general lighting is 'automatic off' and 'manual on', so the electric lights only are switched on when needed.

Despite the lack of a culture of working in a 100% daylit environment, the Malaysian occupants of the ZEO building found the work environment pleasant and use minimal electric lighting.

1. Introduction

1.1 Overview of Cast Study Building

In October 2007 the Malaysian Energy Centre (Pusat Tenaga Malaysia) moved into their new headquarter building, the Zero Energy Office building, which is a cutting edge demonstration project for energy efficiency and renewable energy in a tropical office building. The zero energy design (3270 m² air-conditioned floor space) married super low-energy building designs/technologies with 92 kW_p building integrated photovoltaic panels. While typical Malaysian office buildings have an energy index of 175 kWh/m² floor area per year, the ambitious energy index of the ZEO building is 35 kWh/m² per year (EAEF, 2006). An international team of expert consultants collaborated with the Malaysian Energy Centre and local consultants to meet the target; fine-tuning of the building is still on-going. One of the key features for achieving the low building energy index was the extensive use of daylighting throughout the building.

Figure 1 Zero Energy Building photographed from entrance and at photovoltaic roof

1.2 Daylight Availability

Tropical Malaysia has an abundance of daylight. At latitude of 3.15° North the change in weather is very minor across the year. Daylight hours are from 7 – 19 o'clock. Diffuse sky radiation, which is best suited for daylighting purposes, accounts for about 60% of the global radiation, which means the sky often is overcast or partly overcast. The average diffuse radiation reaches a peak mid-day value of 50,000 lux, whereas it drops to 15,000 lux at 8 o'clock in the morning and 17 o'clock in late afternoon; see Figure 2. The annual sun path, also shown in Figure 2, comes close to zenith all year with a slight tilt of the sun to the North in the summer months and a slight tilt to the South in the winter months.

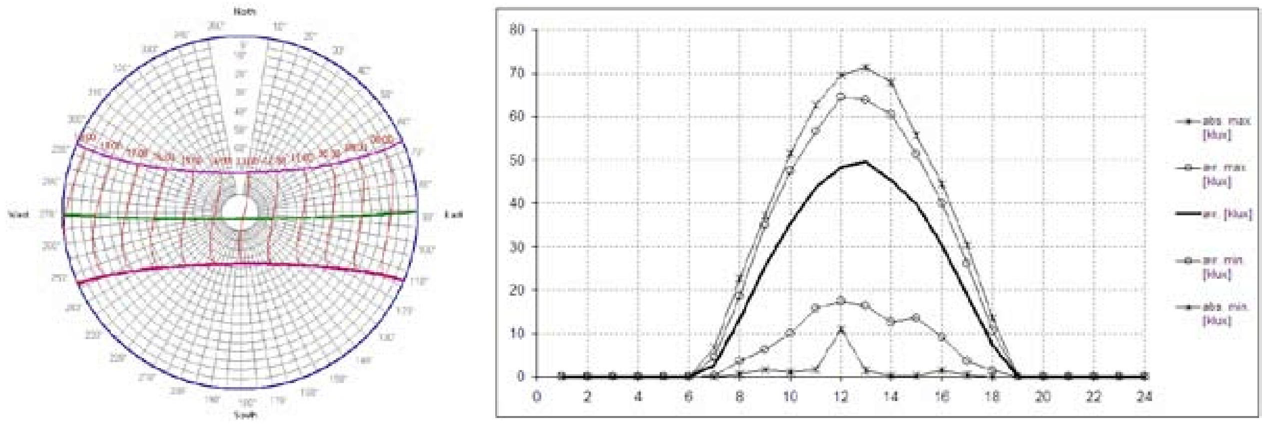

Figure 2 Annual sun path (left) and annual average diffuse sky radiation for Kuala Lumpur, Malaysia

The Malaysian building code (MS1525) recommends an office task light level of 300 - 400 lux. This is only a fraction of the outdoor lighting level, as can be seen in Figure 2. Daylit buildings are often designed to meet a certain daylight factor. A daylight factor is the amount of diffuse daylight measured horizontally indoors divided by the amount of diffuse daylight measured outdoors on a horizontal unshaded surface. For Malaysian office spaces it is recommended to have a daylight factor of 1 - 2% on the desk table top. This means that the at an outdoor diffuse illuminance level of say 20,000 lux top, the light level on desk table top with be 200 - 400 lux. It is worth noting that most people can work comfortably at indoor illuminance level of down to 150 lux or lower – particularly if they are doing computer work. Figure 3 below illustrates the frequency by which the lighting requirement of 300 lux is met by different daylight designs in Malaysia.

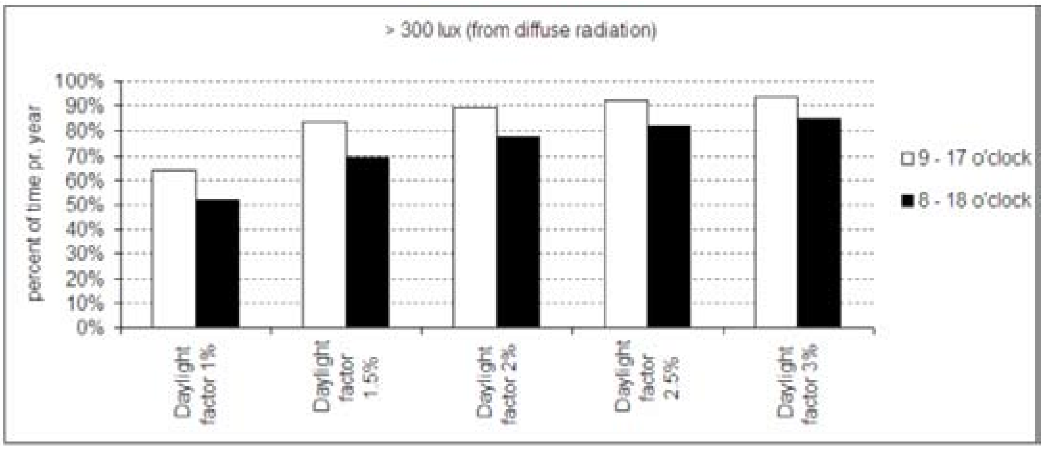

Figure 3 Annual frequency by which the 300 lux requirement is met at for rooms of a different daylight factor in Kuala Lumpur, Malaysia.

Figure 3 shows that for a room with a daylight factor of 1.5% the 300 lux requirement will be met 83% of the time between 9 – 17 o'clock and 70% of the time between 8 – 18 o'clock. Keeping in mind that people often accept working at lower light levels, a daylight factor of 1.5% seems like a reasonable design target to achieve a high annual daylight utilisation without providing excessive daylighting. The daylight factor should not be too high, as increased light levels might cause glare and/or wash-out of the computer screen. For these reasons, Nabil and Mardaljevic (2006) recommends for office daylight values to stay below 2000 lux. Moreover, an increase in light entry also means a higher solar gain, which – unlike in temperate climates – always is undesirable in the tropics.

1.3 Tropical Daylight Design: Building Orientation

Diffuse daylight is the preferred light source for daylighting because it varies less than direct sunlight, it is softer and it has a slightly higher lumen efficacy than direct sunlight. In tropical countries the North and South facade orientations are both well suited for daylighting purposes because these facades easily can be shaded completely by a limited horizontal overhang (see Malaysian sun path diagram in Figure 2).

1.4 Tropical Daylight Design: Room Depth

Daylight can only reach so far in side-lit rooms. Therefore, the room depth should not be too deep. The general rule of thumb is that rooms can be daylit corresponding to 2.5 times the window height; see Figure 4 below.

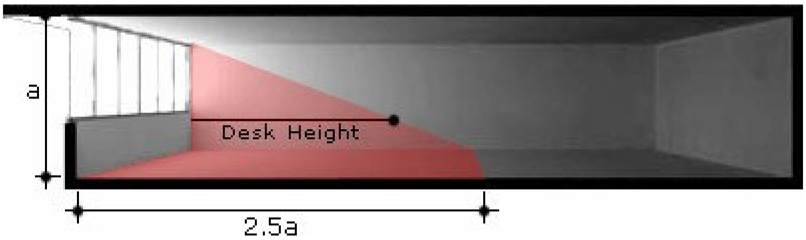

Figure 4 Rule of thumb for reach of usable daylighting for side-lit rooms (Square One, 2007).

Workstations should be placed along the facade where the daylight is found and circulation spaces, which have a lower lighting requirement, should be located towards the back of the room where daylight levels are dimmer. People should face parallel to the facade when working and care should be taken that their workstation cubicle walls do not block the daylight, for example by using transparent or translucent partitions as is done for the Zero Energy Building (see Figure 7).

1.4 Tropical Daylight Design: Glare Prevention

The combination of strong tropical sun and a light cloud cover can make the sky very glary. A direct view to the sky should therefore be limited in order not to cause visual discomfort for the building occupants. The alternative of choosing a heavily tinted glazing (light transmittance < 30%) is not a good option as it cuts away too much of the daylight. A split-window design is therefore recommended, where the upper daylight window is fitted with a dual function (fixed) blind or optical glazing that both directs light onto the ceiling and blocks a direct view to the sky. This allows the light transmittance of the upper daylighting window to be high. The lower viewing window – that typically would run from the floor or parapet wall and up to a height of approximately 2 meters from the floor – can have a lower light transmittance and a manually operated blind for glare prevention and/or to ensure privacy. It is recommended to have an external lightshelf between the upper and lower windows in order to shade the lower window at direct more light through the upper window.

1.5 Tropical Daylight Design: Glazing Properties

The following performance is recommended for the glazing listed in order of priority:

1) Spectrally selective coating (light passes through, infrared and UV light is reflected)
2) Low-e coating (heat radiation from window is reduced)
3) Double pane window (thermal gain through window is reduced)

Soft coats work most efficiently and they have to be applied to the protected pane surfaces inside a sealed double-pane window. The lumen efficacy of daylight is about 200 lm/W when spectrally selective windows are used. For comparison, the best lumen efficacy of fluorescent light is only about half.

1.5 Tropical Daylight Design: Daylight Responsive Lighting System

The electric lighting system must be zoned and daylight responsive to benefit from the daylighting design.

2. Daylighting in the Zero Energy Office Building

2.1 Facade Design

The facades of the ZEO building are facing North and South. They are perfectly shaded from direct sunlight because the building is self-shading by stepping out 1 meter for each consecutive floor as shown in Figure 5.

Figure 5 Section of typical facade (left) and section of self-shading building stepping out 1 meter each floor (right)

In Figure 5 the substantial 1.4 meter deep lightshelf give able shading for the lower viewing window. The mirror lightshelf also reflects diffuse light through the upper daylighting window and onto the ceiling as illustrated in Figure 6 below. The lower window has a manually operated blind that does not impair the daylight performance of the facade if left engaged, as 80% of the daylight in the office comes (> 2 m from facade) comes from the upper daylighting window.

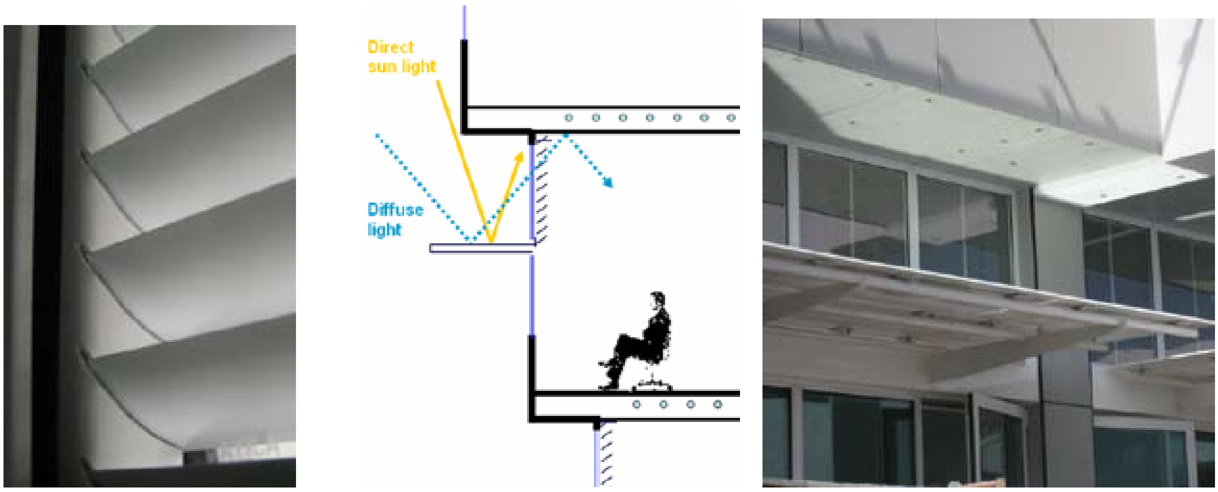

Figure 6 Close-up of fixed blind for upper daylighting window (left). Illustration of how facade lets lower angle diffuse light pass through and blocks off higher angle direct sunlight (middle). Photo showing that the facade design intent works (right).

The right-hand photo of Figure 6 shows direct sunlight is seen deflected from the mirror lightshelf and onto the bottom side of the overhang. The photo was taken on 12 June, i.e. almost at the maximum North tilt angle of the sun, so since no direct sunlight enters the upper daylighting window at this time it will also be the case the rest of the year. The fixed blind for the upper daylighting window (Figure 6, left) is mounted inside the double pane window. The blind has been designed exactly to block the view out of the window when seated at the last row of workstations 5.2 meters from the facade. This allows for a gradually increasing blind spacing from bottom blind to top blind such that the blind spacing is 24% higher at the top to maximise daylight entry. It is also worth mentioning that the lower side of the blinds, which can be viewed from the inside, is painted matt white to avoid veiling reflections and visual discomfort, whereas the upper side of the blinds are specular reflective to maximise daylight. Key data of the facade daylighting system is given in Table 1 below.

Table 1 Material properties for daylighting facade system

Item	Light transmittance	Reflectance	Specularity	Comment
Upper daylighting window, no blind	0.71			
Lower viewing window	0.5			
Lightshelf, top surface		0.85	0.8	Mirror
Fixed daylight blind, top surface		0.85	0.8	Reflective aluminum
Fixed daylight blind, bottom surface		0.85	0.05	White matt paint
Tannenbaum ceiling, no clear lacquer		0.85	0.7	10° tilt angle profile
Ceiling		0.85	0.05	White matt
Walls		0.85	0.05	White matt
Floor		0.5	0	Light brown carpet
Manual blind	0.25			For lower window

The 1st floor has the least daylight towards the back of the room because it has not roof light. A so-called Tannenbaum reflective sheet was mounted on the ceiling in a 2.5 meter deep perimeter to increase light reflection towards the back of the room. The Tannenbaum has a small 10° profile engraved into its semi-specular surface, such that glare from the ceiling is avoided because reflected light is directed downwards at a sufficiently steep unlike for a flat semi-specular sheet (Figure 7).

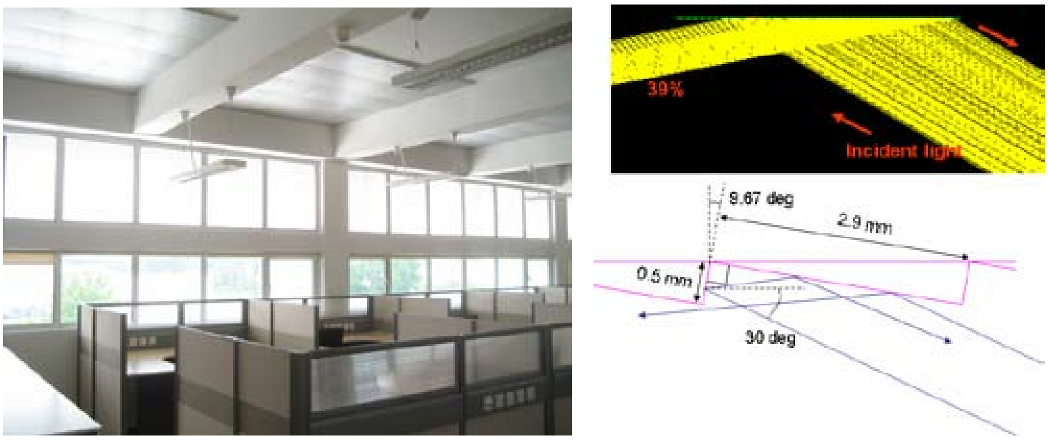

Figure 7 Reflective Tannenbaum ceiling panel for 2.5 meter perimeter of 1st floor

Daylight measurements from all three rows of workstations from the facade are show below in Figure 8. The measurements show that indoor light levels are adequate and not overpowering for a wide range of outdoor lighting conditions. The daylight levels in workstation rows 2 and 3 is very stable and are not affected much by variations in outdoor lighting conditions and/or use of the curtain (i.e. roller blind for the lower viewing window). This means that occupants in workstation row 1 can use the roller blind without obstructing the daylight concept for the rest of the office.

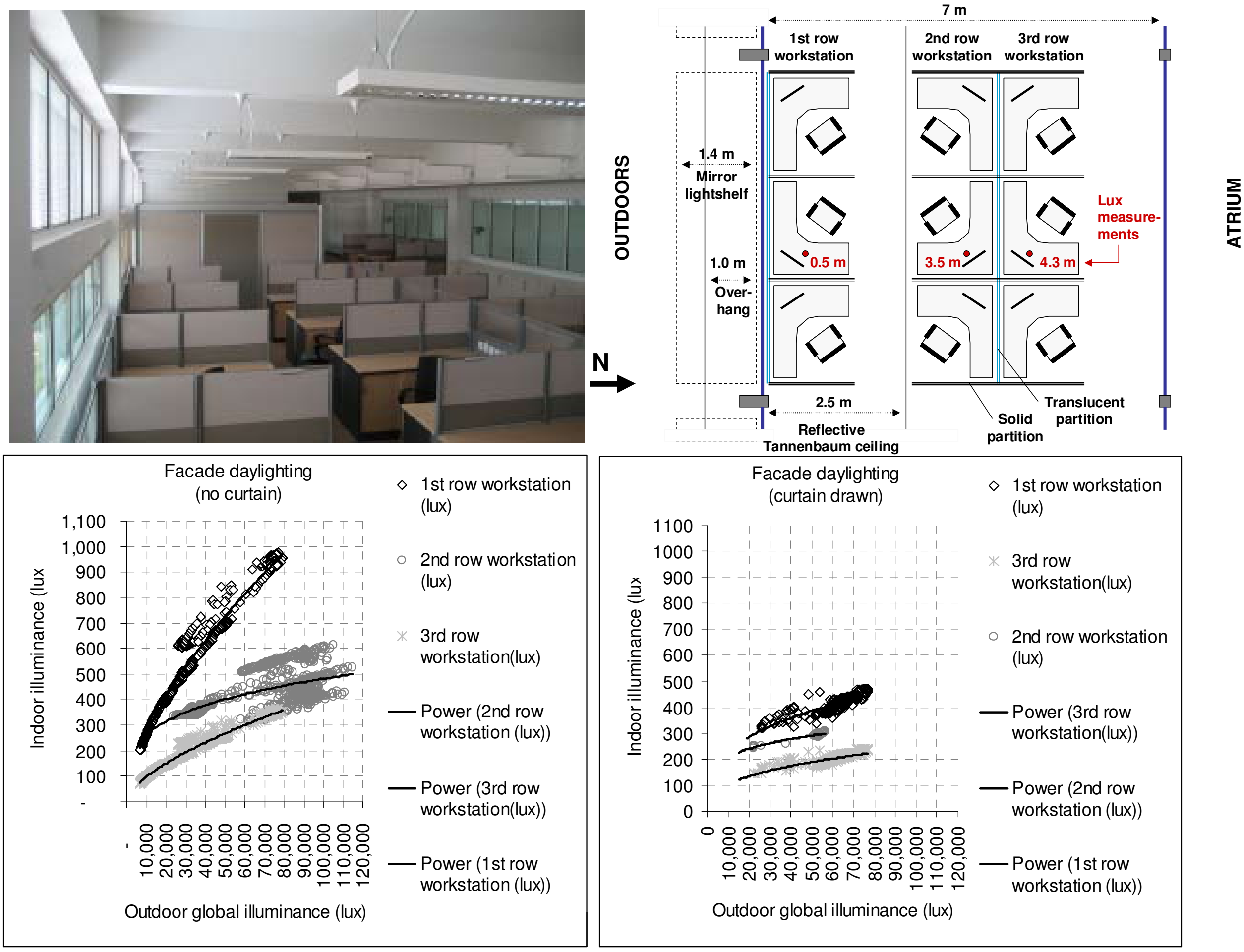

Figure 8 Daylight measurements in three rows of workstations from the facade in the 1st floor open plan office of the ZEO building.

The 300 lux code requirement for office lighting is met most of the day for workstation rows 1 and 2, whereas workstation row 3 often falls a bit short with only 200 lux, which in practice has not posed a problem. People often work at daylight levels down to 100 lux – especially for computer work – before deciding to switch on the electric light. Efficient 6.2 W table lamps are provided for each workstation giving each building occupant the possibility of supplementing the daylighting. The general lighting can only be switch on when outdoor daylight levels are low.

The measurements show that the facade daylighting system works well. Electric lights are off in the office areas except during the dim early morning and evening hours – or during the occasional thunderstorm. The installed lighting power is 4.8 W/m², but the measured lighting consumption is less than 1 W/m²; see Figure 9.

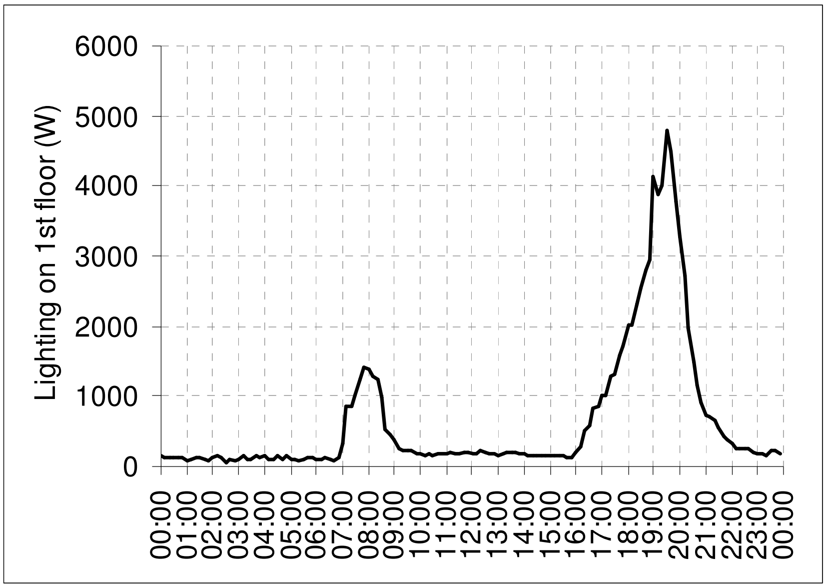

Figure 9 Average electric lighting consumption for the 1st floor (3 months data)

The electric lighting consumption in Figure 9 shows a minimal consumption during the day and some consumption in the morning and in the later afternoon / evening when there is little/no daylight.

2.2 Roof Light Design and Light Tube

The roof has several light scoops that only allow entry of diffuse daylight in from the North. Reflective cladding inside the roof light directs the daylight downwards. From inside the building the roof lights look like an ordinary light fixture. Measurements below the roof lights show that the 300 lux requirement on average is met between 8:30 and 17:30 o'clock; the maximum measured light level is 1250 lux.

Figure 10 Roof lights oriented to the north photographed outdoors and indoors

Two roof light tubes were punched through the 1st floor to provide daylight to the entrance at ground floor level. Each light tube has a cross sectional area of about 1 m² and are clad with spectrally reflective aluminum on the inside. They look similar to the roof lights (Figure 10) but have a weaker light output due to the longer shaft. Moreover, they have the disadvantage of taking up floor space in the levels above.

2.3 Daylight Atrium with Integrated Photovoltaics

Solar cells were sandwiched in between the laminated atrium glazing to yield both daylighting and power production (12 kW_p).

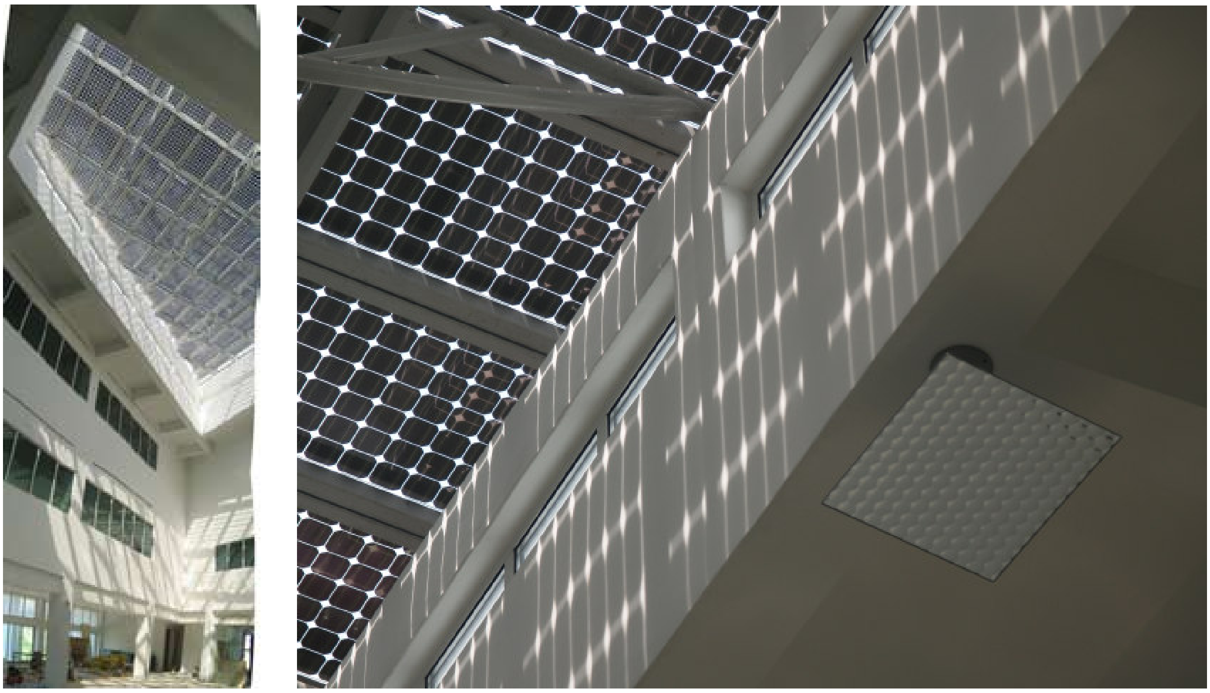

Figure 11 Atrium with integrated solar cells

About 13% of the roof was open to daylight penetration giving a pleasant light level (1% daylight factor) and giving beautiful sunshine patterns on the atrium floor and walls

3. Conclusion

The ZEO building has successfully employed innovative facade and roof daylighting technologies to off-set nearly all electric lighting. Since the building was occupied in October 2007, the electric lighting consumption during office hours has been less than 1 W/m². In the tropics there is no culture of working in 100% daylit office environments. Nevertheless, the occupants are happy to work in the daylit environment with typical daylight levels of 200 – 1200 lux.

The daylighting design for the office spaces relies on diffuse sky radiation whereas direct sun light is blocked out. This gives a stable indoor light level despite big changes in the outdoor lighting level. Measurements from the second row of workstations show that a 5-fold variation in the outdoor light level only causes a 2-fold variation in the indoor lighting level.

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SUPPORTING AND GUIDING DESIGN TOWARDS A GREEN BUILDING

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Keywords: guideline, manuscript, sustainable, building, conference, green, frame, structure

Summary

A 100-meter high big transparent parallelepiped combining lightness and a strong capacity to characterize the surrounding territorial environment: that's how Roman architect Massimiliano Fuksas imagined and conceived the new headquarters of the Piemonte Region.

The complex will consist of two elements: the 100-meter tower that will house the Region's offices and a lower building that will develop horizontally and will serve as a congress centre to accommodate up to 150 people and will be the headquarters of other services of the city of Turin.

The sustainability level of the building will be evaluated throughout the different steps of the project by means of a methodology based on the ITACA protocol, which is in turn based on the GBC methodology.

The methodology was defined and applied by ITC-CNR and iiSBE-Italia with the main purpose of defining performance guidelines to steer design, right from its early steps, towards constructive and technological solutions able to enhance the environmental quality of the building once they are integrated into it.

The evaluation system was used in synergy with common design tools in order to increase designers awareness of the fallout on energy-environmental performances of the architectural and technological choices of what will become one of the symbols of the city of Turin.

The paper describes in particular the practical issues related to the integration of the tool, largely depending on the interaction of two distinct processes such as design and verification of sustainability and the results obtained in terms of analyzed performance indicators.

1. Introduction

The assessment of the new Piemonte Region headquarters was carried out in compliance with a well structured approach, extensively used for residential buildings, but still quite experimental with regard to tall buildings.

Anyway, in the context of the accreditation process of the Italian chapter to the WGBC (World Green Building Council) a deep change of the so far used methodological approach is under way, towards a real building energy-environmental sustainability certification system, with rigorous rules, organized in the form of certification procedures, where the activities and the responsibilities of the several involved actors are specified.

Such a system is growing around the well proven assessment tool "Protocollo ITACA", Italian version of the known SBTool, through the following actions:

- identifying the organizations, which shall assess/certify the building by the application of the already defined evaluation procedure;
- defining the qualification and independence criteria of the assessors who shall work in compliance with the procedures defined for the building certification;
- defining the accreditation criteria for the organizations, which shall work within the framework of the defined certification system.

On the contrary, as stated above, the assessment tool is ripe enough form the conceptual and methodological point of view, though it requires the planning of R&D activities aimed at the optimization of the weighting, benchmarking and criteria analysis procedures, identifying suitable calculation tools for the determination of the performance indicators on the basis of the normative and legislative framework in force and of the technical-scientific literature.

Even in this very dynamic context that is going through a reorganization phase, the case study carried out allowed to verify the usefulness of the assumed methodological approach, in particular for designers, forced to face a wide set of performance targets, partially dependent from each other, in directly or inversely proportional way. This provided incentives to the interaction among the different professionals involved in the design team and the identification of an interdisciplinary connection technical figure able to communicate with the assessment team using a 360 degrees vision.

Also, the performance-based approach used to measure the building quality showed how the construction market could be naturally boosted towards the realization of buildings with a high environmental sustainability level, if only the final user or the investor were aware of the reachable performance targets and of the consequences in terms of performance (with regard to both resources consumption and indoor environmental quality) for the building they are using or purchasing.

The "Italian system" is complex and structured, all the more so over the last years due to the so-called "devolution", that transferred several governmental powers from the Central State to the Regions, not always ready to plan and manage the new technical issues. In this picture, though starting from a common tool as the "Protocollo ITACA", applications diversified both in terms of rules and contents were experimented. The assessment of the new Piemonte Region headquarters, due to its meaningful institutional role and representativeness, would also be a reference case study in order to exemplify that it is possible to structure a transparent and repeatable assessment process regarding a difficult subject like environmental sustainability, above all when the building typology shows very complex peculiarities too.

2. "Protocollo ITACA" for tall buildings

A specific assessment tool was defined for the building analysis, allowing to evaluate the peculiar aspects of tall buildings, that very often have unique constructive and technological solutions, which are hard to include into a too rigid evaluation scheme.

Such a tool was part of a certification process involving all the stakeholders: the buyer (Piemonte Region), several institutional organizations, the designers, the local utilities with regard to energy matters, obviously the Italian GBC (Green Building Challenge) chapter, and somehow also Turin's citizens (who will have the skyline of the city they live in, changed) with some public assemblies for the presentation of the project.

The buyer fixed the building's synthetic performance target, the assessors set the assessment tool, defining weights, benchmarks, criteria analysis methodologies, legislative and normative references. Together with the instructions for the use of "Protocollo ITACA" specific sheets were defined for the collection of data and design documentation, in order to facilitate the information exchange among the involved actors, allowing the designers to identify the essential information in order to characterize the solutions chosen for the assessment.

Actually the design team self-assessed the building project by calculating the performance indicators with regard to the several criteria of the assessment tool, providing at the same time the data and documentation necessary to control such a self -assessment.

Considering the still experimental condition of the certification system the objectives were essentially two:

- to define a methodological approach that could be a support/guide for the design process, towards a performance target fixed by the buyer;
- to devise the methodological calculation approach of the performance indicators with regards to the several criteria used to verify the design solutions quality.

From the point of view of the assessment tool the main issues faced concerned the weighting system and the definition of reference performance ratings (benchmarking), which are general issues for all the assessment tools, even more important in this case where an ambitious performance target was fixed.

3. Case study

3.1. The building

The assessed building is a big transparent parallelepiped, that rises up to a height of 100 m and brings together lightness and a strong capacity to mark the urban land: that's how Roman architect Massimiliano Fuksas imagined and conceived the new Piemonte Region headquarters.

The building will be built in the so-called "Spina 1", in the former Materfarro area (a surface of about 40,000 m^2) also marked by the railway link and it will contribute to redefine the image of the regional capital of Piemonte which, over the last years, has made strong efforts to carry out important architectural projects.

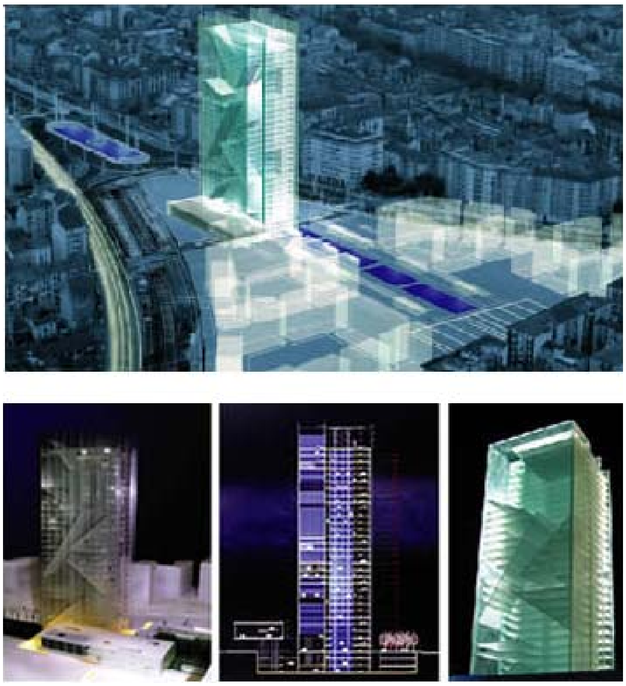


Figure 1. The new Piemonte Region headquarters

The arrangement of the indoor “big void”, the emphasis of the structural blades that partition the atrium space at full height and the personalization of some special internal functions are marks of a language directly referable to the latest architectonic avant-garde. Then the 100 m tower will be an evident sign in the Turin landscape, though without wanting meaning to attract attention on itself at all costs. It is of course a symbolic building, but its integration in the surrounding urban tissue is clear and recognizable. The belonging to the citizens community is underlined by the entrance hall, that is forced access to the different parts of the system: the Piemonte Region offices, the boardrooms, the congresses center and, significantly, the garden in front of the tower, as a point of confluence of Turin’s “Spina Centrale”, the 12 km boulevard stretching from South to North. Finally the architectural solutions seem to find a natural and unstrained harmony with the technological systems of which they are the legitimate precondition both for the ordinary arrangement of spaces and for the progressively and always different discovery of the big “chimney” rising from the entrance hall.

Besides, its realization was conceived within the framework of a strengthening plan regarding the area where it will be built, both from the functional and from the architectural point of view.

The overall cost of the works, also including the construction of a big car park, was estimated to be 100 millions euros.

The new glass building will host 1,300 employers, distributed in seven Councillor’s offices and twenty Directorate-General offices.

3.2. The assessment tool

The assessment tool used consisted of around twenty five assessment criteria, subdivided into the following issues:

1. resources consumptions;
2. environmental loads;
3. Indoor Environmental Quality (IEQ);
4. service quality.

A serious effort was made in order to reduce the tool complexity and to tailor it considering the preliminary design phase of a very complex building. Some assessment sheets are reported below as examples.

1. Resource consumption
- 1.1. Annual non-renewable primary energy expected for heating
- 1.2. Cooling
  - 1.2.1. Solar radiation control
  - 1.2.2. Thermal gain time shifting and attenuation factor
  - 1.2.3. Annual non-renewable primary energy foreseen for cooling
- 1.3. Renewable energy: foreseen production of energy by PV systems
- 1.4. Potable water consumption
- 1.5. Eco-compatible materials
  - 1.5.1. Use of recovered or recycled materials
  - 1.5.2. Use of materials by renewable source
  - 1.5.3. Embodied energy

2. Environmental loads
- 2.1. Equivalent CO_2 emissions
- 2.2. Centralized area for the solid wastes separate collection
- 2.3. Permeability of external areas
- 2.4. Liquid wastes
- 2.5. Heat island
  - 2.5.1. Heat island effect – landscaping and paved areas
  - 2.5.2. Heat island effect – covering

3. Indoor Environmental Quality
- 3.1. Thermal comfort
- 3.2. Visual comfort
  - 3.2.1. Daylighting
  - 3.2.2. Illumination
- 3.3. Acoustic comfort
- 3.4. Indoor Air Quality
- 3.5. Electromagnetic pollution

4. Service Quality
- 4.1. Controllability of the technological systems
- 4.2. Ability to modify facility technical systems
- 4.3. Adaptability to future changes in type of energy supply
- 4.4. Maintenance of building envelope performance
- 4.5. Creation and maintenance of a building log

Figure 2. The assessment criteria

Criteria 1.2.2. is an example of how a classic criteria of the "Protocollo ITACA" was transformed in order to suit the skyscraper, which is a building typology with light envelope, keeping unchanged the requirement to be satisfied, modifying the performance indicator, no more related to the envelope (thermal gain decrement factor and time shift as calculated in compliance with EN ISO 13786), but to the effect on building performances (indoor temperature without air-conditioning plant). The reference standard is the recent EN 15251, that defines dynamic comfort limits as a function of weather conditions.

Criterion 1.3 was tailored on the recent developments of the Italian power production market, that has lately started a liberalization process and allows the final user to choose the supplier or to self-produce on his own on-site. With respect to the structure and configuration of the SBTool, the on-site and off-site production was evaluated at the same time, in general rewarding the electricity production using renewable sources.

Also criterion 4.4 was modified as a function of the analyzed building typology, introducing in the qualitative scenarios some tests specifically defined for light envelope elements.

SUB-CRITERION: 1.2.2 – Thermal gain time shift and decrement factor	
Issue: 1 – Resources consumption	
Criteria: 1.2 - Cooling	
Requirement: to maintain good thermal comfort conditions in the built environment during summer, avoiding air overheating.	**Performance indicator**: indoor temperature without cooling system.
	Unit: °C

Method e and calculation tools

In order to assess the criteria the following procedure has to be used:

- Calculation of the external average dynamic temperature from 20th to 26th of July by the following equation:
  Trm= (Ted-1+0.8*Ted-2+0.6*Ted-3+0.5*Ted-4+0.4*Ted-5+0.3*Ted-6+0.2*Ted-7)/3.8
  Where:
  Trm = External average dynamic temperature (°C)
  Ted-n = Average temperature of the n-th previous day (°C)
- Calculation of the average operative temperature in the occupational period without a mechanical cooling system
- Calculation of the weighted average operative temperature:
  $To = (To_1 Surf_1 + To_2 Surf_2 + \ldots\ldots + To_n Surf_n)/(Surf_1 + Surf_2 + \ldots + Surf_n)$
  Where:
  To_n = Indoor average operative temperature n (°C)
  $Surf_n$ = Net room surface n (m^2)
- Identification of the comfort zone using the graph below.

Performance scale	Score
Beyond class III	-1
Class III	0
Class II	1
	2
Class I	3
	4
Class I+	5

Technical Literature, Legislative References and Normative References

EN 15251 "Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics".

Sub-criterion weight	40	%

Documentation

Provide a Technical Report for the assessment of sub-criterion 1.2.2, containing the following information:

- Reference weather data and description of the calculation carried out aimed at the determination of the whole building performance indicator.

Notes

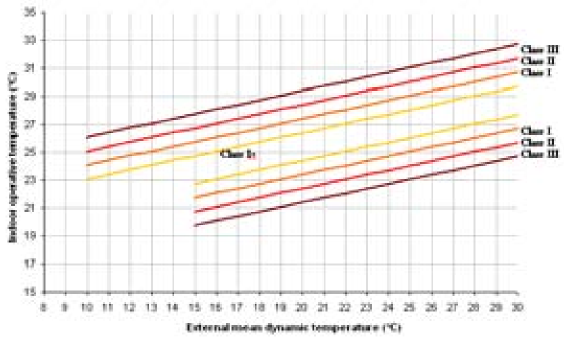
- The graph below is referred to buildings without mechanical cooling system.
- The operative temperatures reported in the graph apply to office rooms or similar, where sedentary activity is essentially carried out (activity from 1,00 to 1,30 met) and where the user may control window openings.
- According to statistic data the yearly warmest week for the city of Turin is from 20th to 26th of July. If simulation tools with different weather data are used, the simulation itself has to be carried out in the week with the warmest average temperature.
- The equations representing the straight lines in the graph are:

Class I+ Upper limit: $To_{max} = 0.33T_{rm}+18.8+1$
Lower limit: $To_{min} = 0.33T_{rm}+18.8-1$

Class I Upper limit: $To_{max} = 0.33Trm+18.8+2$
Lower limit: $To_{min} = 0.33Trm+18.8-2$

Class II Upper limit: $To_{max} = 0.33Trm+18.8+3$
Lower limit: $To_{min} = 0.33T_{rm}+18.8-3$

Class III Upper limit: $To_{max} = 0.33Trm+18.8+4$
Lower limit: $To_{min} = 0.33Trm+18.8-4$



CRITERION: 1.3 – Renewable Energy: foreseen production of electricity by Renewable Energy Sources

Issue: 1 – Resource consumption

Requirement: Promoting the use of electricity by renewable sources	**Performance indicator**: CF_{res} – Renewable Cover factor: estimated percentage of electric energy need covered by renewable sources
	Unit: % (kWh/kWh)

Method e and calculation tools
In order to assess the criteria the following procedure has to be used:
- calculation of the amount of electricity produced by renewable sources with regard to the power supply contract, the design and constructive choices for possible on-site renewable sources production systems, the weather data of the specific location;
- calculation of the ratio between the overall electric energy by renewable sources and the total estimated electric consumption;
- comparison of the calculated CF_{res} with the benchmark scale and assignation of the score.

Performance scale	**Score**
-	-1
16	0
19	1
22	2
25	3
28	4
31	5

Technical Literature, Legislative References and Normative References
Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market.

Criterion weight	25	%

Requested data
Provide a Technical Report for the assessment of criterion 1.3, containing the following information:
- characteristic of the power supply contract;
- components technical specifications and characteristics of the RES on-site production system, if present;
- Net building surface (m^2).

Documentation
Annexed to the Technical Report containing the requested input data necessary in order to evaluate the criteria 1.3, provide the following documentation:
- description of the analysis carried out for the possibly rough dimensioning of the power production system from renewable sources, if present;
- sketch of a cost-benefit analysis with the calculation of the payback time.

Notes
The reference electric load is 20 kWh/m^2year (source: EN ISO 13790).
In the case of off-site production by photovoltaic system, report the technical characteristics of the supply plant.

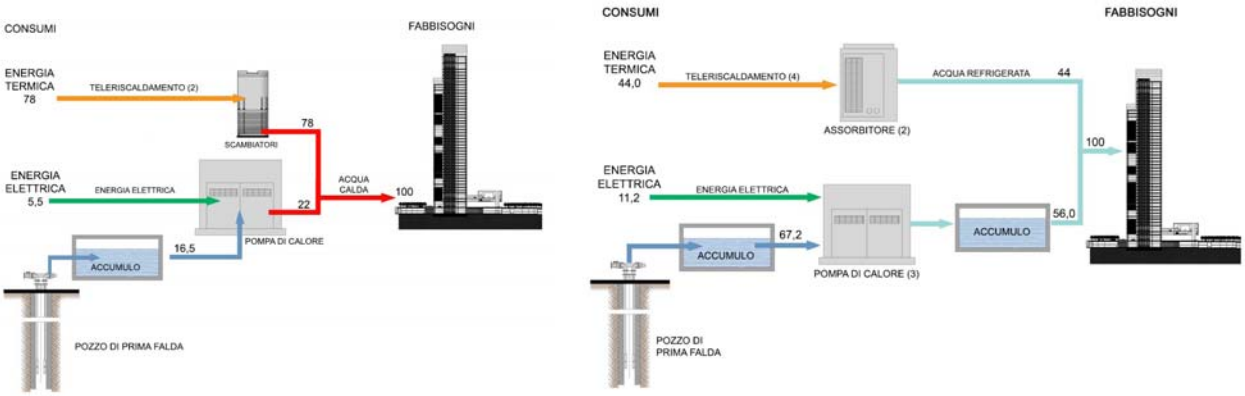


Figura 1. Energy supply system layout; winter (left) and summer (right) case

CRITERION: 4.4 – Maintenance of building envelope performance	
Issue: 4- Service quality	
Requirement: To ensure that detailed design minimizes the risk of moisture accumulating in the building envelope, where it is most likely to shorten the lifespan of building elements.	**Performance indicator:** surface relative humidity **Unit:** qualitative indicator

Method e and calculation tools

In order to assess the criteria the following procedure has to be used:

- calculation of the performance indicator in compliance with the standards UNI EN ISO 13788 and UNI EN ISO 10211-1 for low thermal inertia elements and other opaque envelope components next to thermal bridges;
- description of possible tests and analyses to be carried out during the construction phase;
- choice of the scenario that best describes the building characteristics and score assignment.

Performance scale	Score
The surface relative humidity of the low thermal inertia elements (transparent envelope components or opaque envelope components with surface mass lower than 230 kg/m^2) is greater than 0,8, while the surface relative humidity of the opaque envelope components with mass greater than 230 kg/m^2 or next to thermal bridges is equal to 1.	-1
The surface relative humidity of the low thermal inertia elements (transparent envelope components or opaque envelope components with surface mass lower than 230 kg/m^2) is lower than 0,8, while the surface relative humidity of the opaque envelope components with mass greater than 230 kg/m^2 or next to thermal bridges is lower than 1.	0
	1
	2
The surface relative humidity of the low thermal inertia elements (transparent envelope components or opaque envelope components with surface mass lower than 230 kg/m^2) is lower than 0,6, while the surface relative humidity of the opaque envelope components with mass greater than 230 kg/m^2 or next to thermal bridges is lower than 0,8.	3
	4
The surface relative humidity of the low thermal inertia elements (transparent envelope components or opaque envelope component with surface mass lower than 230 kg/m^2) is lower than 0,6, while the surface relative humidity of the opaque envelope components with mass greater than 230 kg/m^2 or next to thermal bridges is lower than 0,8. Pressurization tests and thermograph analysis for the evaluation of thermal bridges are scheduled for the operative phase in compliance with standard UNI EN 13829 and UNI 9252.	5

Criterion weight	25	%

Requested data

Provide a Technical Report for the assessment of criterion 4.4, containing the following information:

- average external minimum temperature (calculated on a daily basis) from December to February;
- external RH at the reference external temperature;
- indoor air temperature in compliance with the legislation and regulations in force for the specific building typology (report also the reference legislation or regulations);
- indoor RH.

Documentation

Annexed to Technical Report containing the requested input data necessary in order to evaluate criterion 4.4, provide the following documentation:

- technical report containing graphs and calculations with regard to the surface and internal condensation control for all the envelope components including the construction elements described in the technical sheet 1.1 (external envelope, roof, floor);
- description of the possible experimental plan and of the methodological approach.

Notes

- The satisfaction of the minimum requirements reported in standard UNI EN ISO 13788 has to be verified for all the construction elements described in the technical sheet 1,1 and for the structural nodes that could be thermal bridges.
- Low thermal inertia elements are the transparent envelope elements (note that the requirements have to be met both by glass and frame) and the opaque envelope elements with surface mass lower than 230 kg/m^2.
- For the definition of thermal bridges see standard UNI EN ISO 10211-1 at paragraph 3.1.1.
- For the definition of surface relative humidity and its calculation methodology see standard UNI EN ISO 13788 at paragraph 5.

The examples stated above would demonstrate the need to have an assessment system tailored on the specific building typology and placed in a specific context, considering the local rules and practice frameworks. Although the overall assessment tool structure and the methodological approach remain unchanged, weights, benchmarks, and criteria calculation references (theoretical picture and tool) should be accurately chosen in order to optimize the communication of the several involved stakeholders, increasing the awareness of the target and specific building performance that determine the final synthetic score for the building environmental sustainability level.

4. Discussion

Many criteria were assessed more on the basis of the designers' intentions than on the detailed description of the constructive and technological solutions, because design itself is still at an early phase.

It is then necessary to continue until the realization of the building, updating the criteria depending on the phase and verifying that a high level of sustainability is maintained first through a simulation software and then through an appropriate environmental monitoring.

Main lessons learned

- It is important to coordinate the design team and to identify a specific professional figure or group of experts able to prepare the data necessary for the assessment on the basis of the design documentation.
- Tall building is a peculiar building typology and there is still a big amount of work to do on the matter of environmental sustainability assessment: the tool has to be more and more tailored on this building typology and the design team must start thinking that they will have to interface with such a tool needing synthetic data, that could efficiently describe the designed solutions; the procedures used to produce and record the design documentation have to be thought in a new way, in order to be used to demonstrate effectively the building expected performances. The documentation currently prepared to "display" the building and to demonstrate the compliance with the legislation in force should be aimed also at this new communication intended both for the user and/or investor and for the assessor of the environmental sustainability level.
- Using clear performance indicators solves a lot of communication problems among the involved stakeholders.
- It is very important to underline the different building analysis phases: design, diagnosis, assessment/certification. In fact, the building performances analysis implies several activities each one with specific objectives, relevant methodological approaches and support calculation tools:
  - New building design;
  - Energy/environmental diagnosis;
  - Retrofit.

  The different building analysis phases must not be thought in straight lines, even if led by different persons who should, on the contrary, be given enough time to schedule meetings and discussions. As an example, the energy diagnosis results obtained by auditing and dynamic simulation are necessary data for the planning of energy retrofit actions; finally the assessor will use synthetic parameters derived from design documentation and from the use of products' technical sheets aimed at assessing the building energy potential. A subsequent collection and elaboration of actual consumption data will allow to verify the proper realization and management of the building, which might lead to suggesting suitable actions in order to fully exploit the building's potentials.

5. Conclusions

The case study carried out underlines the need for a connection among the institutions managing the certification system at national level, because by now design companies, investors and real estates, and builders are companies that operate at global scale and they should be able to face as uniform and consistent as possible assessment approaches to optimize performance indicators recognized and really representative of the environmental quality of the chosen constructive and technological solutions.

What's stated above is neither meant as a criticism to the assessment methods market, nor as a promotion of a tool rather than another; the main point is concentrating on the only really important target, that is the promotion and realization of buildings with a high environmental sustainability level, optimizing and enhancing the virtuous choices of designers and builders so as to turn some specific performance targets into common practice.

If on the one hand the commercial promotion of certification systems and tools has stimulated all the stakeholders to deal with building environmental sustainability, on the other hand it risks to choke down the objective to reduce the environmental impact of this sector, satisfying at the same time the final user performance requirements in a rat race to the certification market.

The path covered far for the new Piemonte headquarters assessment produced rewarding results for all the involved stakeholders who expressed the wish to continue walking this path mainly because the interaction among the parties was based on the use of a methodological objective, referenced, transparent and repeatable approach, giving guarantees both to the user and to designers with regard to the final building performance and the correct assessment of the solutions pointed out, respectively.

A PROCESS-ORIENTED SUSTAINABILITY APPRAISAL FRAMEWORK TO INFORM PLANNING FOR A SUSTAINABLE URBAN RENEWAL AT EAST LAKE, CANBERRA

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Keywords: Integrated Assessment Framework, Sustainability Appraisal, Sustainable Urban Renewal, Participatory Action Research, Transdisciplinary Urban Research, Social Learning, Decision Support Tool, Discourse Analysis

Summary

Many existing sustainability assessment tools for urban planning lack a scientifically sound framework and urban systems context for sustainability evaluation and appraisal. In fact existing decision-support-tools are often rather technical, limited in their scope, and insufficient to meet the complex process, integration and communication requirements of real-world planning and the challenge of implementing sustainability.
This paper argues for a more comprehensive, process-oriented sustainability appraisal framework of collaborative research that offers several capacities of supporting urban planning and its decision-making for sustainability. Such an innovative approach has been developed for the East Lake Urban Renewal in inner Canberra, Australia, and is based on a transdisciplinary research partnership involving science, policy and the community. Designed as a participatory action research process that is "learning by doing", the project has been developing and testing an "Integrated Urban Planning and Assessment" approach that is flexible and adaptive to the local context and creates systems-based, integrated knowledge on sustainable urban development. A key part of this approach is a continuing stakeholder engagement and deliberation process to identify different needs and experiences, to induce social learning and to inform research and planning. Qualitative and quantitative urban research combines stakeholder knowledge with the latest scientific insights and delivers integrated, community-supported planning documents and a set of process guides, methods and tools to test different urban planning scenarios and to explore the various flow-on consequences of planning decisions with stakeholder groups.

1. Introduction and Background

Many cities around the world are increasingly focusing their attention on urban renewal as a process for revitalizing poorly managed or neglected inner urban locations, often typified by industrial decline. While the drivers for this style of development are often the social and economic factors associated with convenience and lifestyle preferences, urban renewal is also increasingly being seen as a means for producing higher density and more compact cities reducing resource consumption and thus helping address climate change. While there remains considerable debate about the various environmental costs and benefits of 'greenfields' versus 'brownfields' urban development, this only acts to highlight the growing need for policy-relevant approaches to provide integrated and evidence-based information on planning processes.

1.1 Sustainable Development and Decision Making under Uncertainty

As with many other policy fields, urban planners are charged with developing policy responses to problems that are often characterized by a high degree of complexity and interconnectivity where *"typically facts are uncertain, values in dispute, stakes high and decisions urgent"* (Funtowicz et al. 2002). Take for example, the pressing challenge of how best to deliver sustainable urban development in the context of a changing global climate and a national housing affordability crisis. In the face of such dilemmas, many urban planners are now turning to scientists for practical methods of sustainability appraisal to better inform their decision making on issues characterized by a multiplicity of perspectives, complex systems interactions and a high degree of uncertainty.

This paper examines the emerging role for applied science in urban planning processes, as explored through the development and application of an Integrated Urban Planning and Assessment Framework (IUPAF) to support decision making for the sustainable urban renewal of East Lake in Canberra, Australia.

1.2 Planning the Sustainable Urban Renewal of East Lake

East Lake was identified in the Canberra Spatial Plan (ACT Government 2004) as a significant area of the city that is suitable for future infill urban development. It is located within inner Canberra, close to central employment nodes and major transport routes. Nearly half of the 471 hectare East Lake site is dedicated to the Jerrabomberra Wetlands Nature Reserve, with the remaining areas comprising predominantly mixed industrial and commercial uses including the Canberra railyards and Fyshwick Fresh Food Markets. There is also a small area of residential development known as 'The Causeway', which is primarily public housing.

In September 2007, coinciding with the public release of the East Lake Draft Planning Report, Planning Minister Andrew Barr announced a partnership between CSIRO and the ACT Government to showcase sustainable urban renewal in the East Lake area. Implemented through CSIRO's Sustainable Communities Initiative (SCI) which brings together participants from across the public, private and civil society sectors, the partnership is focused at the nexus between sustainability research and policy implementation, with the aim of working closely with the community to develop innovative solutions to key urban sustainability challenges.

The foundation for the partnership is based on the premise that neither a standard consulting nor classical scientific research approach is sufficient to tackle the many challenges and opportunities associated with implementing sustainable urban development. Munda (2006) arrived at a similar conclusion stating that *"… scientists cannot provide any useful input without interacting with the rest of society and the rest of society cannot perform any sound decision-making without interacting with the scientists".* As such, new modes of partnerships between science, policy and the community are required, that deliver context-driven research for stakeholders, residents and policy-makers, building capacity and producing broadly accepted outcomes.

2. Towards an Integrated Urban Planning and Assessment Framework

For the East Lake project an Integrated Urban Planning and Assessment Framework was developed that is based on Participatory Action Research (Whyte 1991). This approach was adopted because it is a way of capturing 'real world' understanding of the issues and policy implications of a change process such as urban renewal. Our framework aims to inform East Lake planning decisions through a process that acts to deliver a common understanding and integrated knowledge-bases. These outcomes are pursued by combining, interpreting, integrating and communicating systems-based knowledge derived from stakeholder engagement, science-policy collaboration as well as qualitative and quantitative urban analysis (see Figure 1).

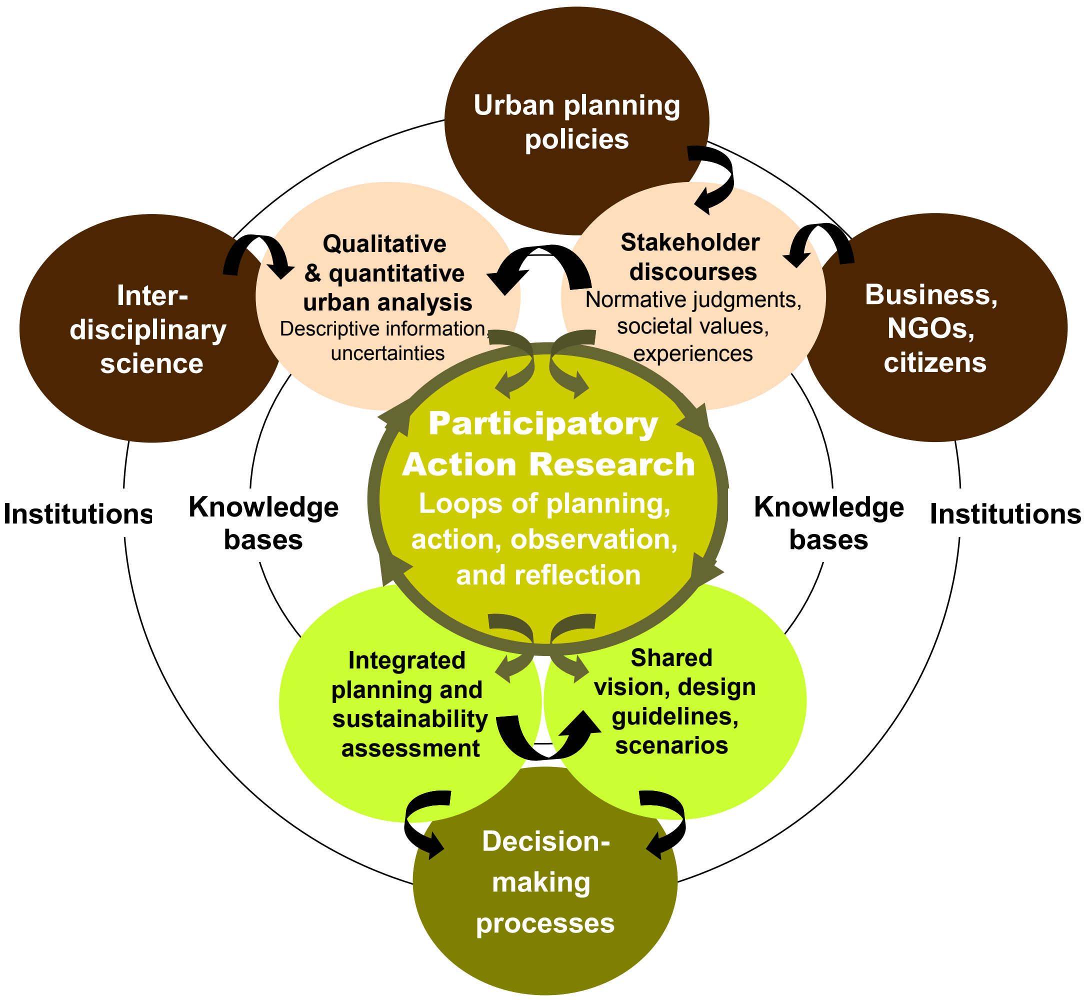

Figure 1 Integrated Urban Planning and Assessment Framework to inform planning for East Lake (based on Rotmans and van Asselt (2002) with own amendments)

The Integrated Urban Planning and Assessment Framework developed for East Lake is process-oriented with active dialogue among science and local stakeholders that enables social learning throughout the research process. The aim is to develop a set of techniques and tools to analyze, explore and evaluate various alternatives for sustainable urban planning in terms of plausibility, desirability and feasibility (Rotmans and van Asselt 2002). Context-driven outcomes are intended to inform policy and support decision making.

The project was implemented in an iterative and 'spiral' procedure with several loops of planning, action, observation and reflection. Participatory elements ensured that those traditionally the subject of 'research' are involved in some or all stages of the research as active participants (Pain 2004). Knowledge sourced from different institutional perspectives (science, public and private sectors) was also fed into the research process and outcomes were shared with participants and policy partners. It therefore created open dialogues in which stakeholders, experts or citizens could communicate their knowledge, experiences and views, thus establishing a degree of ownership over the process. As such, it is important to recognize that sustainability research does not only rely on the contribution of scientific knowledge from different disciplines but must also integrate the highly valuable and legitimate local knowledge of policy-makers, practitioners and lay persons.

This form of research goes beyond multidisciplinary and interdisciplinary approaches and is often referred to as transdisciplinary research (Bergmann et al. 2005, Müller et al. 2005). Transdisciplinary research recognizes that scientists' theories of local issues are no longer more valid than the everyday experiences of local experts, businesses and citizens (Elden and Levin 1991). This refers to a new scientific paradigm called 'Post-Normal Science' (Funtowicz and Ravetz 1991) that considers in particular science and policy challenges associated with implementing sustainable development (Ravetz 2006). Post-Normal Science emphasizes the collaboration of scientists with 'extended peer communities' to enable issue-driven research outcomes, to generate publicly shared knowledge, and to raise broad commitment for resolving complex policy issues.

As a holistic framework, the objective is not to optimize one aspect of sustainability (e.g. energy efficiency) by blanking out all the others (e.g. economic feasibility or social equity), but rather to focus the attention on the multiple dimensions of urban sustainability and to increase awareness and understanding of the flow-on consequences of decision making, technical indeterminacies and system uncertainties (Ravetz 2000).

3. Participatory Action Research and Discourse Analysis

A defining feature of this project and fundamental tenet of the Integrated Urban Planning and Assessment Framework was to achieve meaningful participation and involvement of East Lake stakeholders from the early stages of the project onwards. What this means is that participants are able to actively contribute to the research and development of new ideas and options. This participatory action research approach contrasts with other rather passive forms of stakeholder consultation which often only give participants the opportunity to comment on ideas experts have developed with limited scope for influence (Tippett et al. 2007).

With the above in mind a Participation Strategy was developed for the East Lake project outlining the major goals of the stakeholder participation:

(1) Making the planning process for East Lake more transparent and inclusive by ensuring all relevant stakeholders are informed on the ACT Government's initial thinking for the future of East Lake (embodied in their Draft Planning Report) and then explicitly asking stakeholder's for their views, feedback and inputs,

(2) Raising awareness and building capacity for sustainable urban renewal by conducting facilitated workshops and group discussions with various stakeholders and experts thus stimulating social learning processes and an appreciation of multiple and diverse viewpoints concerning pathways to sustainability, and

(3) Creating a growing sense among participants of belonging to a "community of interest" that is working together in a broad and inclusive partnership for a sustainable East Lake by exploring a common vision and emerging design principles that can form the foundations for all follow-up planning activity within East Lake.

The East Lake stakeholder participation process was comprised of three stages; identification, mobilization and integration. Relevant stakeholders for East Lake were identified by conducting an institutional analysis (Munda 2006). These stakeholders were then grouped into four clusters: Individuals and representatives from the *'local community'*, general *'interest groups'* relevant to the East Lake area, *'professional bodies'* representing business and industry, and *'government agencies'* relevant for planning a sustainable East Lake. A focus group was facilitated for each stakeholder group to mobilize different players and engage them in an East Lake discussion. The focus group method is an approach that is often used in sustainability assessment. It consists of a focused interview encouraging group discussion (Kasemir et al. 2003).

A series of guiding questions was used to structure the East Lake focus group discussions, firstly, focusing on the qualities and values of East Lake now, then on the various visions and concerns held for the future, and finally, on the process of getting from where East Lake is now to where stakeholders would like it to be in the future. Follow-up interviews with similar structured questions were applied to elicit the views of underrepresented stakeholders. A fifth focus group discussion was held with a particular citizens group of mainly public housing residents at The Causeway precinct to gain additional insights and perspectives.

The East Lake stakeholder participation and its analysis were based on a discourse approach (Dryzek 2005) which aims to identify various debates between stakeholders as well as possible interconnections between different debates. Such discourses provide us with stories from multiple perspectives which help to unravel characteristics of a complex systems problem. They represent shared narratives of how issues concerning the East Lake urban renewal are understood, illuminate the various interconnections, and can inform urban planning on discourses to which decision making should respond in order to foster sustainability transitions.

A key step in the process of integrating these disparate views from science, business and community, was the facilitation of a design principles workshop where representatives from different stakeholder groups and professional backgrounds were brought together to explore the development of a common vision and design principles for East Lake. This workshop provided the first opportunity to begin to integrate the many and diverse stakeholder views and to facilitate a social learning process for urban sustainability at East Lake.

4. Social Learning Approach Applied at East Lake

Social learning is a specific, collective form of learning from past experiences, different patterns and various ideas (Holden 2008). A key focus of social learning is to understand policy changes and therefore it is significant in urban planning, in particular to achieve and accelerate sustainability processes. In this project we adopt a transdisciplinary social learning approach which conceives planning, science and deliberation as learning processes (Müller et al. 2005) which follow several related learning cycles (see Figure 2).

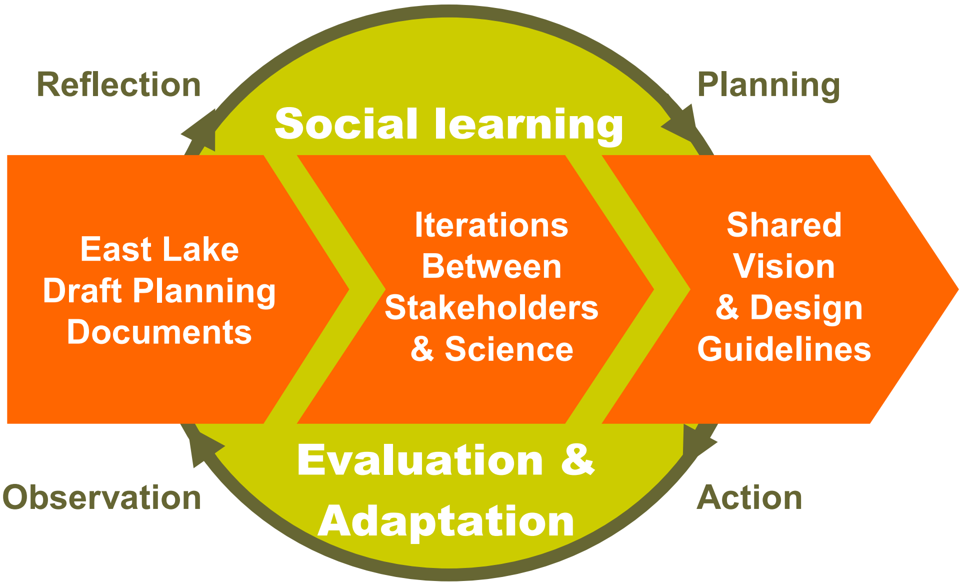

Figure 2 The related learning cycles of a transdisciplinary social learning approach applied at East Lake

Social learning, evaluation and adaptation were cross-cutting themes throughout the East Lake project. The project team applied several innovative methods to analyze when and how learning for sustainability occurs:

(1) A social scientist was employed as a 'learning facilitator'. In this role the learning facilitator observed all stakeholder engagement processes and team processes in order to analyze how groups deal with different discourses, associated conflicts and how compromise and a common understanding emerges in the process.

(2) 'Interim learning evaluations' were conducted by interviewing project team members (researchers and planners) and other involved stakeholders in the process on their insights, understandings and opinions. The results of this learning evaluation were fed back to the research and planning team in order to reflect actions and pick up identified learnings for the next planning and research phase (adaptation). This refers to an iterative and 'spiral' research procedure with several loops of planning, action, observation and reflection.

(3) Members of the project team (researchers and planners) also conducted 'shared learning and evaluation trips' to sustainability case studies within Australia that were relevant to the urban renewal of East Lake. The focus was not so much on visiting sites, but rather meeting and learning from associated project managers and researchers on their common experiences. After each of these trips, the project team would meet again to reflect on shared learnings and to discuss innovations in planning, design, governance and implementation that could be applied at East Lake.

5. Results So Far and Emerging Insights

The ACT Government's 'East Lake Urban Renewal Draft Planning Report' was used as a key input for stakeholder participation. The following results are based on focus group discussions and personal interviews with professional bodies, interest groups, Government agencies, and the local community.

Most frequently mentioned issues and shared narratives deal with preserving the ecological value of the Jerrabomberra wetlands, followed by a need to provide for affordable accommodation in such a premium location and to maximize benefits from the market attractiveness of the land by applying long-term investment strategies and new business models to foster sustainability innovations. Other frequently mentioned narratives refer to improved access and connectivity within and across the East Lake area and the need for rapid transport networks, mobility concepts and logistics management. Maintaining and integrating all heritage sites and existing social infrastructure, such as Fyshwick Markets, Kingston Railway Station, industrial heritage sites or The Causeway, is suggested to ensure preserving the historical sense of the place. It is argued that for East Lake to become a showcase in urban sustainability that planning approaches must go well beyond current practice in Canberra in order to position East Lake as a catalyst and exemplar for sustainability. High land prices are seen as a major driver of development costs and there is some concern that this may hinder a developer's ability to deliver sustainability. In general, the ACT Government is seen as a major developer who has the responsibility to arrange binding development guidelines and expected outcomes, to provide seed funds by partly reinvesting profits from land sales and to coordinate an ongoing evaluation and monitoring process. It is argued that desirable design for diverse user groups might be more likely if socio-demographic changes and needs of different target groups and future residents are addressed more explicitly, via strategies for social integration, employment and community.

The ACT Government's 'East Lake Urban Renewal Draft Planning Report' reflects most stakeholder perceptions, but could outline more explicitly the implementation process related to governance and management processes that guarantee the transparency and integrated character of the process required to foster greater stakeholder commitment.

One of the collective learnings for sustainability is that social interaction and stakeholder engagement is needed to access and make use of different forms of knowledge relevant to sustainability, to broaden more narrow individual perceptions on planning challenges, and to enable the social environment for arriving at integrated planning solutions. Another important aspect of social learning for sustainability refers to the local context of planning challenges and the need to identify integrated sustainability strategies and measures adapted to local characteristics and development needs. Sustainable urban planning of any neighbourhood needs to be plausible, desirable and feasible for a range of stakeholders in the local area. To identify most plausible, desirable and feasible planning scenarios for sustainable development, applied science needs to deliver beyond environmental technologies or sustainability assessment tools – it needs to embed these "hard aspects" into policy-driven, socially sound research processes including social interaction and deliberation between relevant stakeholders to arrive at both meaningful and acceptable local sustainability outcomes. Moreover in a policy-driven approach, the collaboration process not only needs to effectively garner understandings from the stakeholders to be an effective process but also needs to be timely to influence planning outcomes. In the case of East Lake the emerging insights from the process need to meet the timelines for releasing land in order to be considered and inform the packaging of the actual product put to sale (i.e., scope, scale, features, targets, development requirements).

6. Summary and Next Steps

An Integrated Urban Planning and Assessment Framework has been developed to inform the planning processes for sustainable urban renewal of East Lake. Several techniques and research methods, both qualitative and quantitative, were combined to facilitate and analyse a participatory action research process.

Aspirations and concerns of local stakeholders have been reflected in a stakeholder participation report that identifies important planning issues and challenges for East Lake. This input has been fed into the process of developing an integrated vision and design guidelines that provide the foundation for the sustainability directions of the East Lake planning process. An integrated sustainability assessment software tool has been developed as part of the project to assist stakeholders explore sustainability implications of decision-making.

The project is now nearing the first year of completion with future activities to involve refinement of the Integrated Urban Planning and Assessment Framework and associated tools and outputs, with a view to incorporating more focused design expertise and investigations as the project gets closer to implementation.

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AIA CHICAGO COMMITTEE ON THE ENVIRONMENT'S CARBON REDUCTION STRATEGIES FOR THE CHICAGO REGION

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Summary

The American Institute of Architects Chicago Chapter Committee on the Environment (AIA Chicago COTE) launched the "Carbon Reduction Strategies for the Chicago Region Pilot" in November of 2007. The CRS Pilot is a matrix outlining sixty strategic action items in four categories: Immediate, Short-Term, Middle-Term, and Long-Term. Action items indicate policies, design strategies, and existing technologies to be implemented in design, construction and operation of existing buildings, renovation and new construction.

The CRS Pilot matrix is envisioned as an open-source tool for defining pragmatic steps aimed at improving energy efficiency in buildings and reducing the carbon footprint of existing or newly built structures. While created mainly for use by architects, the CRS Pilot has flexibility that lends itself to any building industry professional interested in reducing their carbon footprint: architects, engineers, contractors, developers, and building operators.

The AIA Chicago COTE's CRS Pilot references the "Architecture 2030" initiative and carbon reduction goals set forth by the US Conference of Mayors "Challenge 2030". The CRS Pilot is formatted to address climate issues specific to the Chicago metropolitan region. Once implemented, proposed actions would help decrease global warming and its impact on the Chicago region by reducing carbon footprints of buildings through energy conservation and "smarter," high-performance design.

1. Global Warming and Climate Change

1.1 Impact of Global Warming on Large Urban Centers

Existing scientific evidence and global consensus continues to strengthen the idea that global warming and climate change represent a real threat to the environmental, social and economic health of global communities, especially those located in highly populated urban areas and those along the coastal areas.

Our ability to effectively address and mitigate the effects of global warming and climate change will have significant impact on human activities and overall living and economic conditions, particularly in the large urban centers. Many urban centers, in the U.S. and abroad, are already developing climate change-specific local policies, action plans or have comprehensive programs put in place, aiming to reduce global warming pollution and to mitigate the effects of impending climate change. However, more action is needed at the local, state, and federal levels to meet the future challenges of global warming and the climate change.

1.2 The Kyoto Protocol

On February 16, 2005, the Kyoto Protocol - the international agreement to address climate disruption caused by global warming, became law for the 141 countries that have ratified it to date. The Kyoto Protocol now covers more than 170 countries globally and more than 60% of countries in terms of global greenhouse gas emissions. The treaty expires in 2012, and international talks began in May 2007 on a future treaty to succeed the current one. The advocates of the Kyoto Protocol state that reducing global carbon emissions is critical, as the current increase in carbon dioxide levels is directly related to the heating of the earth's atmosphere and therefore global warming.

2. The Kyoto Protocol Implementation in the Cities of the United States of America

As of December 2007, the U.S. and Kazakhstan are the only signatory nations not to have ratified the act. The United States, although a signatory to the Kyoto Protocol, has neither ratified nor withdrawn from the

Protocol. The signature alone is symbolic, as the Kyoto Protocol is non-binding on the United States unless ratified. At the end of 2007, the United States remains the largest single emitter of carbon dioxide resulting from the burning of fossil fuels.

2.1 U.S. Conference of Mayors and the American Institute of Architects Act on Climate Change

On February 16, 2005 in the United States, Seattle Mayor Greg Nickels launched the U.S. Conference of Mayors (USMC) initiative to advance the goals of the Kyoto Protocol through individual leadership and coordinated action by at least 141 American cities. This initiative was strongly supported by the American Institute of Architects (AIA), which provided significant research and guidelines for planning and design of energy-efficient and environmentally friendly cities. By the U.S. Conference of Mayors annual meeting in June 2005, 141 mayors had signed the USCM Climate Protection Agreement – symbolically, the same number of nations that ratified the Kyoto Protocol.

In early 2006, the AIA issued “The AIA Green Cities Toolkit” and the “AIA 50to50” document, intended to serve as a set of policy and design guidelines to the U.S. Conference of Mayors’ Summit on Energy and the Environment, held in Chicago in 2006. The AIA simultaneously launched the “Architecture 2030” initiative aimed at exploring the strategies for reducing carbon emissions in U.S. cities.

The U.S. Conference of Mayors’ Resolution 50, sponsored by the mayors of Chicago, Seattle, Miami, and Albuquerque, specifically cited the AIA sustainable practice initiatives and called on the U.S. Conference of Mayors to endorse a goal of carbon neutrality for all city-funded buildings by 2035. The mayor’s group organized the Chicago Summit on Energy and the Environment in May 2006, in response to the nation’s ongoing energy crisis. The AIA cosponsored this groundbreaking event, and two architects presented at the meeting: Ed Mazria, AIA, who gave a keynote address on the relationship between buildings and climate change; and Vuk Vujovic, Assoc. AIA, who presented on energy efficiency and carbon reduction strategies related to new and existing buildings.

Mayors’ Resolution 50 was subsequently approved during the U.S. Conference of Mayors annual meeting in June 2006, which resulted in adoption of the U.S. Conference of Mayors’ Climate Protection Agreement in 2006. By the April 2008, the number of U.S. mayors who signed the agreement has reached 830, representing variety of municipalities throughout the 50 states, the District of Columbia and Puerto Rico, on behalf of a total population of over 79,535,702 citizens.

2.2 U.S. Conference of Mayors Climate Protection Agreement

Under the initial USCM Climate Protection Agreement, participating U.S. cities commit to take following three actions:

- Strive to meet or exceed the Kyoto Protocol targets in their own communities, by implementing actions ranging from anti-sprawl zoning, land-use policies to urban forest restoration projects and public information campaigns focused on sustainable development;

- Urge their state governments, and the federal government, to enact policies and programs to meet or exceed the greenhouse gas emission reduction target suggested for the United States in the Kyoto Protocol: 7% reduction from 1990 levels by 2012;

- Encourage the U.S. Congress to pass the bipartisan greenhouse gas reduction legislation, which would establish a national emission trading system.

2.3 Chicago Climate Change Related Initiatives

2.3.1 Climate Change Impact on Chicago Metropolitan Area

Cold winters and humid summers in Chicago would seem to describe the general weather patterns experienced over any given year during the last century. There are some exceptions, such as unseasonable extreme temperature conditions during winter and long periods of hot weather experienced during summer months. These intermittent climatic anomalies are considered to be precursors of the more extreme climate changes that are possible in the future and which are being taken seriously by the Chicago municipal government.

Climate researchers predict that Chicago’s climate over the next few decades will grow increasingly hotter. Recently, the Chicago metropolitan area was reclassified from Climate Zone 5 into a hotter Climate Zone 6, indicating the potential and type of impact impending climate change could have on Chicago Metropolitan area. The City government is concerned about the impact this climatic changes would have on the general population of Chicago, and about what those changes would mean for its citizens, especially the young and elderly, the City infrastructure, energy and food supply, and local economy.

With such serious issues facing Chicago, the municipal government is looking into the ways to mitigate some of the effects of the climate change, and is looking into active measures that could be taken early, such as greening their vehicle fleets, improving the energy efficiency of municipal buildings, introducing drought-resistant native vegetation and promoting public transit use and alternative transportation throughout the City.

2.3.2 Chicago Climate Protection Strategy

The City of Chicago began development of the Chicago Climate Agenda in 2006 and the associated Chicago Climate Strategy and Implementation Plan in 2007. In partnership with the Global Philanthropy Partnership and with the support of The Joyce Foundation, the Lloyd A. Fry Foundation, the Grand Victoria Foundation and the Clinton Foundation, the City has been able to engage three different research teams to answer the following questions:

- What will be the specific impact on the Chicago's infrastructure, buildings, emergency services, energy, food and water supplies, and local ecosystems?

- What are Chicago's current baseline carbon emissions and where are the best opportunities to reduce those emissions?

- What are the environmental, economic and social impacts of any climate change related action?

The Chicago Climate Strategy is intended to enable the Chicago municipal government, various design, real estate and construction industry professionals and Chicago residents to take proactive steps to combat climate change by understanding its key sources and most critical impacts. The climate change related policies and measures instituted today will make a critical difference in the City of Chicago for generations to come. The City government intends to engage thousands of local residents through the public information and education process to understand what's most important to Chicagoans and how the Climate Change Strategy can be of most use to them.

3. The Role of the Design Professionals

U.S. design professionals have the unique opportunity to address and help mitigate the effects of global warming and climate change on buildings and cities. Through the implementation of readily available building technologies, high-performance building systems and materials, and through the education of general public and the municipal governments, architects and engineers can highlight the opportunities for change in existing codes, regulations and policies, and propose actions and measures that could start the change today.

3.1 American Institute of Architects, Chicago Chapter Sustainable Initiatives

The American Institute of Architects, Chicago (AIAChicago) is a professional organization of licensed architects, architectural interns, and allied professionals expressing their commitment to excellence in design and livability in our nation's buildings and communities.

The AIA Chicago supports the AIA's global position statement on climate change, calling for the immediate energy reduction of all new and renovated buildings to 50 percent of the national average for a particular building type. The increased reductions of 10 percent every five years so that by the year 2030 all buildings designed will be carbon neutral, meaning the future structures would use no fossil fuel energy for production, construction or demolition of buildings.

3.1.1 AIA's "50to50" Guidelines

The AIA's "50to50" resource is intended to assist architects and the construction industry professionals in moving toward a minimum 50 percent reduction of fossil fuel consumption in buildings by 2010 and carbon neutrality in buildings by 2030. The AIA recognizes that built structures are responsible for approximately 48 percent of energy consumption in the U.S. The ongoing operation and maintenance of built structures account for approximately 76 percent of U.S. electrical use. Given the above facts, it is not difficult to establish that built structures represent one of the primary sources of the greenhouse gases contributing to global warming and climate change. This realization has established carbon reduction as the top priority of the AIA's sustainable design initiatives and for design professionals nationwide.

3.1.2 AIA Calls for 50 Percent Carbon Reduction in Buildings

The 50 carbon reduction strategies proposed by the AIA have been selected to provide readily available and effective tools and techniques that will have an effective and immediate impact on an architects' ability to achieve significant carbon reduction. The strategies span a spectrum from broad-based site and building planning objectives to specific, building-based concepts. Each strategy includes an overview of the subject, typical applications, emerging trends, links to information sources, and important relationships to other carbon reduction strategies.

3.2 AIA Chicago's Committee on the Environment

AIAChicago's Committee on the Environment (AIA Chicago COTE), promotes the design and construction of sustainable and high-performance buildings in the city of Chicago and the region. AIA Chicago COTE is committed to educating local architects on sustainability principals by bringing local and national experts to Chicago to discuss strategies, policies and methods of implementing sustainable architectural design, metrics to obtain such design, as well as reinforcing the multidisciplinary collaboration approach true sustainability demands.

Through its work with the City of Chicago and the Department of Environment, AIA Chicago COTE represented a broad group of local design professionals and provided information critical for the success and implementation of the Chicago Climate Change Strategy. The AIA Chicago COTE's "Carbon Reduction Strategies for the Chicago Region" (CRS) Pilot is a direct result of the cooperation between the AIA Chicago COTE and the City of Chicago's Department of Environment.

4. AIA Chicago COTE's "Carbon Reduction Strategies for the Chicago Region" (CRS) Pilot

4.1 Initial Development

The AIA's CRS Pilot was envisioned as a matrix-based resource tool incorporating practical action items grouped in four time and project phase specific categories based on typical project delivery phases.

The AIA Chicago' s Carbon Reduction Strategies Pilot is envisioned primarily as a tool for defining pragmatic, actionable steps that can be taken to reduce the energy use and/or carbon footprint of any existing or newly built structure. While created mainly for use by architects, the CRS Pilot tool has a built-in flexibility to lend itself to any building industry professional interested in carbon footprint reduction: architects, engineers, contractors, developers, and building operators.

The CRS Pilot relates to the "Architecture 2030" initiative's carbon reduction goals and the AIA Sustainability Discussion Group's "50to50" recommendations but is formatted quite differently in order to address issues specific to the City of Chicago and the wider urban region. If implemented on a global scale, proposed actions would help decrease global warming impact on Chicago region by reducing the carbon footprints of buildings through energy conservation and "smarter," high performance design.

4.2 Cooperation with the City of Chicago's Agencies

Through AIA Chicago COTE's cooperation with the local municipal agencies such as Chicago's Department of Environment (Chicago DOE), proposed policies could be implemented throughout the City on both public and private buildings, also on the existing structures or the new construction. The widespread use is intended to reduce energy consumption and measure proposed design and policy effectiveness on a broad scale. The Pilot tool matrix incorporates some of the broad policy ideas and expands them into strategies that can be used on all building types.

AIA Chicago COTE's relationship with Chicago Center for Neighborhood Technology (CNT) was established with the assistance of the City of Chicago, and was instrumental in getting early energy and cost information incorporated into the matrix. With this information, AIA Chicago COTE was able to establish preliminary cost scale, approximate energy savings, and estimate potential carbon reduction levels for each action item.

4.3 Carbon Reduction Strategies Pilot Structure

The AIA Chicago COTE's Carbon Reduction Strategies Pilot matrix is comprised of four strategic categories with sixty specific actionable items. The proposed strategies correspond to building design and construction timelines defined by the political, economic, and ecological relationships already in place.

AIAChicago COTE has received extensive input from the committee's membership, and the Carbon Reduction Strategies Pilot Sub-Committee. The sub-committee incorporated local experts and building industry professionals, including lighting professionals, building system engineers, and the City officials.

If implemented, the actions proposed in the AIA Chicago COTE's Carbon Reduction Strategies Pilot would help decrease global warming by reducing carbon footprints of buildings through energy conservation and "smarter," high-performances design.

5. Carbon Reduction Strategies for the Chicago Region Pilot: Strategies

The matrix divides strategies into four implementation categories: Immediate, Short-Term, Middle-Term, and Long-Term. Actionable items indicate possible policies, design strategies, building systems, materials and existing technologies to be implemented in building design, construction, operations and maintenance, on existing buildings, renovations and new construction.

The Pilot tool matrix incorporates some of the broad policy ideas discussed with Chicago Department of Environment and expands them into actionable strategies and measures that can be used on existing and new buildings of all types.

Since the target audience is quite diverse, comprised of building industry professionals, city officials, building owners, and general public, non-technical language was used as much as possible throughout the matrix to allow the reader to use or combine the action items for implementation or further discussion. The intention was to include specific links for each item to ongoing initiatives already in place or explanation of the specific approach.

5.1 Immediate Strategies

These approaches are achievable virtually without cost. It is recommended that the user starts with these strategies first.

5.1.1 Turn off lights when they are not required

5.1.2 Program computers and office equipment to "power-save (sleep) mode"

5.1.3 Reduce overuse of space heaters

5.1.4 Reduce programmed HVAC temperature setbacks

5.1.5 Adjust common area Lighting

5.1.6 Check the economizer cycle

5.1.7 Regulate air-conditioning temperatures

5.1.8 Change the furnace filters at the preset schedule

5.1.9 Secure all the cabinet panels

5.1.10 Regularly clean air condenser coils

5.1.11 Check the register airflows

5.2 Short-Term Strategies

The short-term approaches are achievable with low first costs and require little or no design integration. They can be implemented today or incrementally over short period of time.

5.2.1 Replace and/or relamp light bulbs or lamps with the most efficient available products

5.2.2 Install programmable thermostats

5.2.3 Add insulation to plumbing supply piping

5.2.4 Lobby Local and National Legislature for Green Tax Incentives

5.2.5 Include ceiling fan/Light combination fixtures

5.2.6 Purchase U.S. Environmental Protection Agency's (EPA) "Energy Star" rated appliances and products.

5.2.7 Provide bicycle parking in all private and public buildings

5.2.8 Provide dimming and photocell controls on light fixtures

5.2.9 Seal leaks in HVAC ductwork

5.2.10 Install most efficient light fixtures available on the market

5.2.11 Purchase carbon emission offset credits

5.2.12 Change building and/or zoning codes to performance based model

5.2.13 Implement building commissioning

5.2.14 Provide recycling and composting space

5.2.15 Utilize car and bicycle sharing programs

5.2.16 Design efficient site and amenity lighting

5.2.17 Use "smart" lighting design in parking lots – do not provide more that what is required.

5.2.18 Implement preventive maintenance programs

5.2.19 Increase all building and/or energy codes to follow best practices in the country/region

5.2.20 Use deconstruction / material salvage when demolishing buildings

5.2.21 Give incentives to green design during building code reviews

5.2.22 Implement advanced thermal envelope design (exterior wall)

5.3 Mid-Term Strategies

The approaches listed below are achievable with moderate cost and most require modest design integration. These strategies can be incorporated as upgrades and/or during renovations.

5.3.1 Achieve fully integrated architectural and building engineering services design process

5.3.2 Install radiant heating and cooling systems

5.3.3 Upgrade roof insulation to R-49

5.3.4 Give tax incentives for smaller, higher density, more proportionately sized homes

5.3.5 Utilize heat recovery ventilation in HVAC systems

5.3.6 Update exit signage with energy-efficient LED bulbs/fixtures

5.3.7 Design using daylighting and daylight harvesting principles

5.3.8 Include demand-controlled ventilation (DVC) systems or CO_2 monitoring in HVAC systems

5.3.9 Install evaporator fan controllers and modulating ventilators in commercial kitchens

5.3.10 Install point of use water heaters

5.3.11 Install geothermal heat wells and HVAC systems

5.3.12 Sequester carbon emissions on site

5.3.13 Replace windows with triple glazed units, up to R-10

5.3.14 Tie property taxes to benchmark CO2 emissions for individual building types

5.3.15 Install low flow (minimum 1.25 gallons per minute) or dual flush toilets

5.3.16 Utilize natural ventilation and "stack effect" to supplement HVAC system

5.3.17 Mandate use of energy modeling to design building systems

5.3.18 Utilize U.S. Environmental Protection Agency's (EPA) "Energy Star" high albedo ("cool") roof systems

5.3.19 Use off-peak cooling for larger commercial or industrial buildings

5.3.20 Install brise soleil or sunshades on building exterior to eliminate heat gain and glare

5.4 Long-Term Strategies

The approaches listed below are achievable with moderate cost and do require higher design integration. These strategies are most applicable for new construction and are readily available today.

5.4.1 Increase building energy "independence" by providing on-site power generation

5.4.2 Create neighborhood based (sized) infrastructure

5.4.3 Integrate building's energy production systems

5.4.4 Design fully automated building systems

5.4.5 Incorporate "intelligent building design" into all disciplines throughout design and construction

5.4.6 Implement "smart growth" based urban design and planning

5.4.7 Mandate policies that promotes longer lasting buildings

6. AIA Chicago's Carbon Reduction Strategies for the Chicago Region Future Development

The development of the AIA Chicago CotE's CRS Pilot tool is envisioned as an on-going process. During this process, the AIA Chicago COTE intends to expand the 2007 Pilot matrix by continually developing and refining the information and post the final version as an open-source, interactive online tool by January, 2009.

AIAChicago CotE is interested in receiving and integrating into an online tool any constructive feedback from both AIA members and the wider building industry community, especially those operating in the Chicago metropolitan region. The final online version will be posted on the AIA Chicago website as an online interactive tool available to all.

The matrix was Inspired by the AIA's Green Cities Toolkit, Architecture 2030 initiative, the "U.S. Conference of Mayors Climate Protection Agreement" and is aimed at significantly curbing carbon emissions in U.S. cities across the nation.

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8 FUNDAMENTAL STEPS TOWARD ENERGY EFFICIENCY IN AIR-CONDITIONED BUILDINGS FOR TROPICAL CLIMATE

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Summary

Energy efficiency in air-conditioned buildings for tropical climate has been a subject of much discussion, especially among the building construction practitioners such as the architects and building services engineers. There exist many myths about the efficacies of various features in the building as energy flows in building remains largely unfamiliar to most. This is because even a simple building has a very complicated energy transfer process converting electrical energy into things that are useful to the building occupants, such as lighting and computational need and then into heat, where electricity is used again to provide comfort by removing heat from the space, and all this while, the climate outside is influencing the space by radiating solar gain, conducting heat and infiltrating air into the building.

This paper addresses the need for an easy method of understanding energy efficiency in buildings by providing a simple and yet comprehensive picture of energy flows in buildings by providing the 8 fundamental steps for energy efficiency for air-conditioned buildings in tropical climate. This 8 fundamental steps covers all the energy components to achieve an energy efficient building, from architectural, mechanical, electrical and energy management point of view for an air-conditioned building. Steps 1 to 7 are building design steps that are listed based on its amount of energy consumptions with the highest energy consumer listed first and the lowest energy consumer listed last, simply because, it would be the most important to reduce the energy consumption of the item with the highest energy consumption first before focusing effort on less important items that would contributes a smaller amount to the total energy consumption of the building. Step 8 is for energy management, that is to ensure that step 1 to 7 are being practised correctly in the actual building after the completion of construction.

The 8 Fundamental Steps Towards Energy Efficiency in Air-Conditioned Buildings for Tropical Climate are:

1. Chillers System Efficiency
2. Lighting Efficiency
3. Small Power Efficiency
4. Fan Power Efficiency
5. Control of Infiltration (Moisture Control)
6. Control of Solar Radiation
7. Control of Conduction Gain (Building Insulation)
8. Energy Management.

1. Introduction

The 8 steps towards energy efficiency for air-conditioned building in tropical climate is a resultant of the re-evaluation of the Overall Thermal Transmittance Value (OTTV) in Malaysia in 2005-2006.

The Overall Thermal Transmittance Value (OTTV) was first developed for Malaysia in 1987. The OTTV was developed using computer simulation to provide an easy method for architects and engineers to manually calculate the average heat gain that is being transmitted into a typical office building via the building fabric due to orientation, windows to wall ratio, wall properties and glazing properties. Since 1987 (a time when personal computer is not wide spread yet), there have been no re-evaluation of the OTTV until this study in 2005 undertaken by the Danida project for Energy Efficiency in Malaysian Buildings.

The re-evaluation of the OTTV was conducted using computer simulation to get a fundamental understanding of the behaviour of a typical building thermal and energy characteristic based on Malaysia's climatic data. The results of this study provided remarkable insight into the thermal and energy performance of air-conditioned buildings in tropical climate that not only provided valuable input for the updates of the Malaysian MS1525 (Malaysian Standard for Energy Efficiency in Non-Residential Buildings), but it has also provided a key summary of the steps required for an air-conditioned building to be energy efficient a tropical climate.

The re-evaluation of OTTV was conducted with a simulation of more than 40 case scenarios by varying different properties of the building. The results showed that the variation of the building envelope properties have a small effect compared to the variation of different internal load of a typical building on the total energy consumption of the building. Therefore, the development of the 8 steps towards energy efficiency for air-conditioned building was largely based on the results of 3 case scenarios that varies the internal energy load of the building while keeping the building envelope constant. This would simplified the complexities of energy flow in building to a manageable analysis while providing enough useful information. The 3 selected case scenarios are:

1. Worst Case Building Scenario
2. Base Case Building Scenario
3. Ministry of Energy, Water and Communication (MEWC)'s Low Energy Office Scenario.

2. The OTTV Model

Three (3) case studies were set up and simulated to get an understanding of how energy is used in a typical office building today. These case studies were:

1. Worst Case Scenario (2005)
2. Base Case Scenario (2005)
3. MEWC's Low Energy Office (2005) - calibrated to an air-conditioned space of 5,200 m2 instead of 19,000 m2

The worst case scenario describe a building with high energy consumption due to high internal load. An internal lighting load of 21 W/m² and a small power consumption of 24.5 W/m² is allocated for this building. In addition, this building is also assumed to have a bad energy management with an approximately 40% of lights and small power still running during non-occupied hours. It was also assumed that the building is very leaky with an infiltration rate of 2 air-changes per hour (ach).

The base case scenario attempts to describe a building with the most likely scenario of current buildings in Malaysia. It has a lighting load of 18W/m² and a small power load of 19 W/m². A moderate scenario of energy management is assumed for this building where approximately 30% of the lighting and small power load is still running during non-occupied hours. It was assumed that this building is also leaky with an infiltration rate of 1 ach as Malaysia do not have a culture of providing air-tightness in buildings.

The Low Energy Office (LEO) scenario is based on the actual measurements obtained from the Ministry of Energy, Water and Communication's Low Energy Office building after approximately 9 months of operation. A lighting load of 5.5 W/m² and a small power load of 6 W/m² was measured in this building and is used for LEO case scenario. During non-occupied hours, approximately 20% of the lighting power is still being consumed, while the small power consumption during these hours represented approximately 54% of the peak daytime load. No measurement of air-tightness was made for the LEO building, however, based on the fact that fresh air is not required for the building from the system (CO_2 sensor controlled) and the measured CO_2 in the building range from 400-500 ppm, it is rational to assume that the infiltration rate is 1 ach for this study to represent a fairly leaky building.

The shape and properties of the Malaysian Base Case building in 1987 was retained in this initial study, while the internal loads were varied as shown in the table below. The base case office building shape and dimension of the simulation model in 1987 has the following properties:

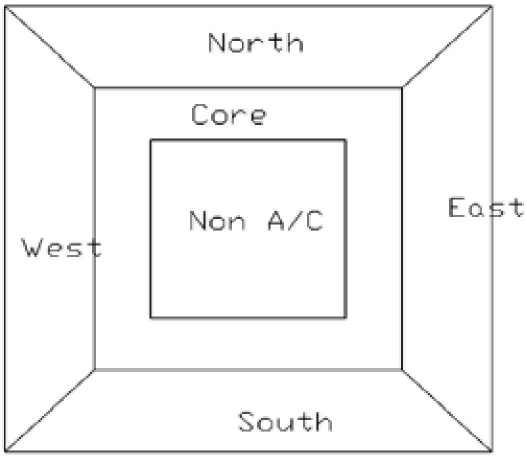

Figure 1 Plan View of the Malaysian Base Case building with 10 floors and 5200 m² of total conditioned floor space.

Table 1. Base Case Building. 10 Story office building, perfect square

Descriptions	Key Numbers Used
Air-Conditioned Space	5200 m²
Core Space	1000 m²
Windows to wall Ratio	0.4
Shading Coefficient of the Glazing	0.69
Brickwall U-value	2.6 W/m²/K
Roof (Highly Insulated)	0.001 W/m²K
Lighting Load	21 W/m²
OTTV	66 W/m²
COP of Chiller	4.1
People Density	9m²/person
Small Power Load	5.35 W/m²
Infiltration	1 ach
Fresh Air	3.3 lit/sec/person
Variable-air-Volume Air Conditioning System	50% minimum flowrate

The roof was simulated with a high insulated value to remove the effect of roof from the simulation, as the OTTV equation only describe the façade of the building excluding roof.

Table 2. Description of input data for 3 different case scenarios.

Descriptions	**Proposed Worst Case (2005)**	**Proposed Base Case (2005)**	**MEWC LEO (2005)**
Lighting Load (W/m2)	21	18	5.5
Lighting Operation Hours	100% 8am to 5pm 40% 5pm to 8am	100% 8am to 5pm 30% 5pm to 8am	100% 8am to 5pm 20% 5pm to 8am
People Density (M2/person)	10 as stated in UBBL	10 as stated in UBBL	60
People Working Hours	1% 7:30am-25% 8am 25% 8am-100% 8:30am 100% 8:30am-5pm 100% 5pm-5% 10pm 1% from 10pm-7:30am	1% 7:30am-25%8am 25% 8am-100% 8:30am 100% 8:30am-5pm 100% 5pm-5% 10pm 1% from 10pm-7:30am	1% 7:30am-25% 8am 25% 8am-100% 8:30am 100% 8:30am-5pm 100% 5pm-5% 10pm 1% from 10pm-7:30am
Small Power Load (W/m2)	22.14 W/m2	17.67 W/m2	4.5 W/m2
Small Power Operation Hours	100% daytime 45% nightime	100% daytime 29% nighttime	100% daytime 54% nighttime
Computer Load per person (W/person)	180 (18 W/m2) 100% Daytime, 35% night	150 (15 W/m2) 100% Daytime, 15% night	120 100% Daytime, 15% night

Server Room, Load/AC Area (W/m2)	2.5 100% 24 hours	1.5 100% 24 hours	1.5 100% 24 hours
Shared Office Load (W/m2)	0.5 100% 24 hours	0.25 100% 24 hours	0.25 100% 24 hours
Core Load (W/m2) of Core Area	5 100% Daytime, 50% night	4 100% Daytime, 50% night	4 100% Daytime, 50% night
Fresh Air	AC hours: 2 ach 20 l/s/person (10500 l/s) approx. 650ppm CO2 level Off AC: 1 ach	AC hours: 1 ach 10 l/s/person (5250 l/s) approx. 920 ppm of CO2 Off AC: 1 ach	AC hours: 1 ach 60 l/s/person (5250 l/s) Off AC: 0.5 ach
Fan Static Pressure	1250 Pa	750 Pa	250 Pa
Chiller COP	4.1	4.1	4.1
Air Delivery	VAV	VAV	VAV

Notes on the LEO case:

1. Lighting load of 5.5 W/m2 was based on actual monitored usage. Installed lighting capacity is 12 W/m2.
2. Occupant density in MEWC is approximately 60 m²/person.
3. Small power load of 4.5 W/m2 was also based on actual monitored usage.
4. Computer load of 120 W/person was computed from the small power load and occupant density of MEWC.
5. Server Room, Shared Office Load and Core Load of MEWC were all calibrated based on actual monitored values in the current MEWC office.
6. Fresh Air intake is also calibrated to the CO2 sensor reading in the building. 1 ach rate is required to keep office CO2 reading below 460 ppm. Monitored CO2 reading in the MEWC is between 400 – 500 ppm in most areas.

3. The 8 Steps Toward Energy Efficiency in Buildings

The simulation results of the 3 case scenarios were tabulated in a bar chart (displayed in Figure 2) to provide an overview of the various breakdown of energy consumption in a building.

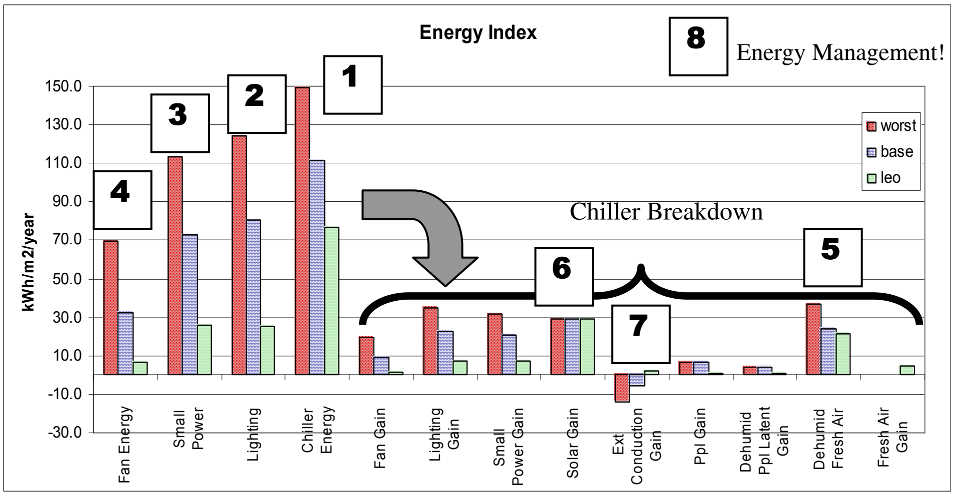

Figure 2 Energy Index breakdown of 3 different types of building scenario.

The energy index breakdown in Figure 2 shows that there are basically 4 major energy consumption in an air-conditioned building in tropical climate. These are:

1. Fan Energy
2. Small Power Energy
3. Lighting Energy
4. Chiller Energy

Usually the chiller energy and fan energy are combined and called as air-conditioning energy; however, for the purpose of understanding the energy flow in building, it is useful to it split up in order to provide a breakdown of chiller energy into each heat element that the chiller is required to remove from the building.

The chiller energy breakdown showed the following heat element that is removed by it from an air-conditioned space:

1. Fan Sensible Heat Gain
   - The fans have a motor that drives it. The motor would then generate waste heat. This heat is introduced directly into the air-conditioned space.
2. Small Power Sensible Heat Gain
   - All equipments that are plugged into the powerpoints constitute of small power energy use. As a law of energy conservation, all electrical energy used by these equipment will end up as heat in the air-conditioned space.
3. Lighting Sensible Heat Gain.
   - Similar to the small power sensible heat gain, all electrical energy used by lighting will end up as heat in the air-conditioned space.
4. Solar Radiation Sensible Heat Gain
   - The heat gain due to solar radiation through the building windows are known as solar radiation sensible heat gain.
5. Conduction Sensible Gain due to External Facade
   - The heat gain due to conduction through the building façade excluding the roof space.
6. People Sensible Heat Gain
   - The sensible heat gain from people is the heat emitted by people in the air-conditioned spaces.
7. Dehumidification of People Latent Heat Gain
   - The latent heat gain from people is the moisture emitted by people in the air conditioned spaces.
8. Dehumidification of Fresh Air Ventilation
   - The infiltration of fresh air (outside air) into air-conditioned spaces bring along moisture content of the outside air.
9. Fresh Air Ventilation Sensible Heat Gain
   - The infiltration of fresh air (outside air) into air-conditioned spaces bring along heat/cooling content of the outside air.

The chiller energy is used to remove all the heat generated in the list described above in order to maintain the comfort temperature and humidity in the air-conditioned space.

The chiller energy is the highest contributor to the total building energy use for all the cases. The electricity used for lighting is consistently the second highest, followed by small power and lastly the fan energy that is used to deliver cold air into the spaces.

Figure 2 is a very insightful chart. It shows that in the worst case scenario the heat generated by lighting and small power is higher than the heat from solar radiation or conduction heat gain in the building.

More interestingly is the fact that the worst case scenario, the net conduction gained over a year is negative, meaning that heat is being conducted out of the building more than being conducted in. This is due to the reason that in a worst case scenario, a significant amount of small power equipment and lighting system are still running during non-occupied hours (e.g. night time to early morning), at hours where the outside temperature is low. The air temperature in the office space during night hours would then be higher (due to the internal equipments and lighting that are still in operation) than the outside air temperature. Therefore, heat is being conducted out of the fabric of the building, helping to cool the building during night time. This chart also shows that conduction gain is high for the base case in 1987 due to the reason that the building in 1987 does not have night load inside the building because it does not have equipments that are running during night such as computers, fax machine, server room, control room and etc.

The dehumidification of fresh air in the worst case scenario is also shown to contribute more energy to the chiller than the solar radiation heat again. This is largely caused by the high moisture content of a hot and humid climate such as Malaysia. In addition the removal of moisture from the air is phase-change process that requires large amount of energy to convert moisture in vapour form into water in liquid form.

It is also interesting to note that the air-conditioning that is used for the primary purpose of providing comfort to the building occupants (people). However, the sensible and latent heat gain from people represented only a fraction of the chiller energy use.

It is also shown in Figure 2, that the heat generated internally by lighting and equipment (small power) represented a significant amount of heat removed by the chiller, clearly indicating that the reduction on energy consumption of internal loads such as lighting and equipments will also lead to significant saving on chiller energy consumption.

Finally the chart shown in Figure 2 allows the following general interpretation to be made to provide a sort of checklist of priorities for energy efficiency features in building starting from the items that consumed that highest amount of energy to the item that consume the least:

1. **Energy efficient chiller system.** A low efficiency chiller system will increases the total energy use within a building significantly as it increases the energy used to remove heat from the air-conditioned space. The term 'chiller system' consist of the chiller, chill water pumping system, chill water piping system and condenser system such as the fans for the cooling tower and the pumping system of the condenser system. Energy efficiency of the whole 'chiller system' is required in order to gain efficiency in this area.
2. **Reduce artificial lighting load.** Natural daylighting is the best because it provide the highest amount of light with the least amount of heat. Other methods include the use energy efficient lighting system, proper zoning of lighting circuit and etc. Night lighting should be carefully considered and should never be over provided.
3. **Reduce small power load.** This would means that energy efficient computers, servers, and control system should be used. Nighttimes energy consumption of small power should be closely monitored.
4. **Minimise fan power**. The fan is used for the air-conditioning system. The energy use by the fan is mainly contributed by two factors, fan efficiency and ductwork total pressure. Selection of fan with high efficiencies will reduce the energy use by fan significantly, while larger duct sizes will have lower pressure loses and therefore lower overall static pressure and thereby reducing energy use of the fan.
5. **Control of fresh air intake and infiltration.** Air-tightness of building is now shown to be more important than preventing solar radiation heat gain as the infiltration of humid air into air-conditioned spaces contributes significantly to the energy used by the chiller. In addition, it is highly recommended to install CO_2 sensor in the air-delivery system to control the amount of fresh air introduced in air-conditioned building in this climate. The CO_2 sensor will ensure that the quality of air is maintained adequately without over providing fresh air via the air-delivery system to minimise the energy used to dehumifidy outside air.
6. **Control of solar heat gain.** Building orientation, exterior shading devices and glazing properties should be carefully considered by the architects to minimize heat gain from the sun.
7. **Insulation of building fabric.** Building fabric should only be well insulated when night load in the building is well controlled. Otherwise, the insulated fabric will trap the heat generated during night hours. It is also possible to use vegetation (greeneries) outside the building to help to keep the micro-climatic surrounding the building to be cooler.

A low energy building design need to address all these 7 steps, as these are the fundamental steps towards energy efficiency for air-conditioned buildings in tropical climate. It should also be noted that in each proposed step there are many possibilities to achieve the same intended objective as every building is built unique. It is up to the designer of the building to be creative to provide the most appropriate solution for their client while addressing these 7 fundamental steps for energy efficiency in air-conditioned building in the tropical climate.

Step 8 is energy management of the building after construction. This is to ensure that steps 1 to 7 are being practised in the building during the actual operation of the building to achieved the intended effect of a low energy air-conditioned building in tropical climate.

4. Summary

The re-evaluation of the OTTV offers an opportunity for an insightful analysis of typical energy consumption in buildings. As energy flow in building is often a matter of great complexity, this analysis simplified and put in perspective of the relationship and quantity of the possible energy saving potential of each element of a typical building into 8 fundamental steps. More importantly this analysis aided in providing a form of general checklist of priorities in the design of energy efficient buildings for the building designers such as the architect and engineer.

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ENVIRONMENTAL ASSESSMENT OF BUILDING MATERIALS – BVB, A SWEDISH TOOL FOR SUSTAINABLE CHOICES.

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Keywords: Building materials, sustainability, environmental assessment

Summary

BVB is a Swedish database tool for environmental assessment of building materials. This system developed as a voluntary measure of the construction industry to incorporate environmental concern in housing construction. One of the main environmental impacts of housing comes from the materials that are used for construction and interior design of buildings. In order to support builders in making sustainable choices, a system has been developed by the major building companies and owners, for environmental assessment of building materials and chemical products in Sweden. The following paper presents the tool and the work behind it. On a globalized market there is a need to coordinate processes such as the assessment of building materials. The authors hope that this presentation of the BVB tool will enable exchange of ideas for fruitful cooperation and development of environmental concern in the building industry.

1. Introduction

One of the main environmental effects of housing and construction is related to the materials and products used in the construction and maintenance of buildings. If today´s main environmental question is climate, then the second is surely the existence of chemicals and hazardous substances in the environment. In the construction industry, thousands and thousands of products are used, resulting in long term consequences for humans and environment. Asbestos, freon, cadmium and PCB are examples of building material composites that have been used but are now not approved in the construction business for environmental reasons.

In order to coordinate and streamline efforts, the major housing companies together with the major construction companies in Sweden, most of them based in Stockholm, joined forces to establish a mutual system for environmental assessment of building materials. HSB, one of the founders of the BVB, is a housing cooperative which was set up in 1923 with the aim to provide quality housing for its members. In Sweden one home in ten has been built by HSB. A few of the parties involved, including HSB, had already made attempts to establish systems of their own. Hence a large part of the initial work with the BVB was to coordinate and synchronize. The needs of the market for quantitative, environmentally related information are increasing, especially in the construction sector. Therefore, systems for environmental declarations based on ISO and LCA methodologies are developing in Sweden and Europe.

In February 2008, a press release was issued stating that the BVB was launched and operative. The tool is comprised of a database containing to date 5 000 of the most frequently used products in the Swedish building industry. The basis for information in the database is a building product declaration supplied by the producer of the product according to a format developed by the Ecocycle Council in Sweden.

In a globalized world, building materials are transported all over the world, and building companies carry out jobs abroad. The standardization of building product environmental assessment would be an efficient aid to the development of environmentally sound construction methods.

2. Criteria

The building materials are assessed according to criteria developed in a wide group of experts. Seven categories of criteria are set:

- Declaration of content
- Raw materials, origins
- Stages in the life cycle:
    - Construction
    - Use
    - Deconstruction
- Waste and byproducts

- Interior environment

All of these components are valued according to a three part scale: Recommended, Accepted and To be avoided. Apart from the three categories, there are zero-tolerance criteria for certain substances. These include specific metals, toxic, carcinogenic, mutagenic and persistent substances, and producers of construction materials shall certify that the materials do not contain the specified substances.

3. Process

Construction materials producers and suppliers produce BVB through a form that is filled in and submitted to the BVB owners for introduction to the database. Today, about 5 000 building materials are part of the system, and have BVB declarations. This is only a minor part of all constructions materials available on the Swedish market. However, the use of the BVB is growing, with the increasing awareness of health and environment in relation to construction and maintenance of buildings, as well as the demand from construction companies.

The criteria are published on a website for transparency. After assessment takes place each product is assigned a color; green for “recommended”, yellow for “accepted” and red for “To be avoided”. Producers can comment on the result of the assessment. All assessments of building materials are stored in a database with a date assigned to the product since building materials change over time. This will insure that a retroactive assessment can take place for buildings that are already constructed.

The database is set up with a searchable website application. The system is user-friendly and can be adapted for specific building projects. The tool is available to all who sign up for a user license at a set fee, as well as a demo version. There is a format introduced in order to facilitate searching the internet for BVB available on the web.

The system is financed through licenses that are sold for access to the assessment. A licensee can apply to have the building materials assessed, and the producer of a building material can also apply to have the product assessed.

4. Results

Two important applications for BVB can be discerned:

- Environmental assessment of new construction materials. BVB can be a part of assessment of construction materials in the planning phase, and the purpose of the assessment is here to support the choice of a suitable construction material in the planned application.
- Documentation of already built-in construction materials. BVB can be used as a tool to document the buildings environmental effect for future needs, for example at deconstruction, or for decision support regarding exchange of products.

The system will grow as producers of building materials supply building materials declarations to the database, and as construction companies start to demand environmental information when buying products.

5. Discussion and conclusions

The system has not been running long enough to generate data that can be subject to evaluation. However, some initial observations can be made:

- The amount of building materials assessed and presented in the BVBs does not yet meet the expectations of the founders of the BVB. One reason could be that the BVB are perceived as difficult to fill in, and that it entails some work to find all the data that is demanded.
- Suppliers of construction materials are sometimes perceived as uninterested due to lack of interest among customers. The coordination between demand by the industry on one hand, and the willingness of producers to supply information has not gone hand in hand during the start-up phase of the BVB.
- Another aspect that has hindered the growth of the system is lack of competence to value the information presented in the BVB. The tool is intended to simplify for construction companies, hence a simple scale and coloring scheme has been introduced where green stands for “recommended”, yellow for “accepted” and red for “to be avoided”.

The information presented in the BVB was initially of a qualitative character; however, as time went on, more and more quantitative figures were presented. This is one aspect of the maturation of the system, since the information on chemical products is difficult to value. As time goes, more detailed information will be available, on a more and more quantitative scale.

BVB is not yet a suitable tool to value energy consumption and emissions. In Sweden a process is under way to implement energy declarations, which is seen as a credible tool to assess energy demand. BVB has so far not seen a need to incorporate the energy use.

The technical capacity of the construction materials is not included in the assessment, nor is occupational hazards or legal aspects. However, there is synchronization between the information in BVB and the security data sheets supplied according to chemical regulations.

For more information please contact the author or the BVB office at info@byggvarubedomningen.se.

Website: www.byggvarubedomningen.se (In Swedish)

THERMAL PROPERTIES AND ENERGY-SAVING EFFECTS OF GREEN ROOF SYSTEM

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Summary

In this study the thermal properties and heat transfer properties of rooftops, based on the light-weight green roof method in consideration of the characteristics of Korean buildings and ordinary rooftops, according to the materials and the cross-sectional configuration were analyzed through on-site experimentation on experimental houses and real buildings over a period of 4 years.

The analysis found that 1) the soil in the green roof case obviously deferred heat transfer and heat insulation during air-conditioning. As compared to concrete rooftops, those with tree planted on the rooftop decreased the daily average room temperature by about 2K. 2) The green roof system saved heating energy by about 6%~10% as compared to concrete rooftops during heating, and reduced energy consumption by about 12%~15% during air-conditioning. 3) The thermal and energy effectiveness were also analyzed according to the types of soil, the configuration and location of heat insulating materials, and the characteristics of the drain system. This study is an output of the long-term research conducted to develop the best green roof system suited to the buildings and weather conditions in Korea, and objective research results will be obtained by continuously expanding demonstration projects and application to more diverse buildings.

1. Introduction

In December 1997, a protocol was adopted indicating the beginning of the environment round in accordance with the‘United Nations Framework Convention on Climate Change.’This became an opportunity to again raise global consciousness on the importance of environment and energy in the viewpoint of Earth environment preservation. Accordingly, the developed nations are raising the pace in developing technologies for energy savings and environment friendly alternatives across all industries including the buildings sector.

In city concentrated countries like Korea green roof systems are being noticed as a realistic alternative that can simultaneously resolve the urban ecological problems as well as energy issues. That is, the green roof system holds the meaning of restoring the ecology damaged by construction & urbanization on the building exterior. In the viewpoint of energy also, it is known to relieve the urban heat island phenomenon, which has recently been recognized as a significant problem, and have great reduction effects on the rising energy requirements for building cooling purposes.

Apart from this, the green roof system is being recognized as an alternative that possesses air & water purification effects and can rationally and fundamentally resolve flooding and underground water problems.

This study seeks to construct a database through objective and quantitative performance evaluation in relation to the various properties and effects held by the green roof system, and based on this propose the optimal green roof system appropriate to the Korean buildings, climate conditions, and other general matters.

2. Thermal Performance Test

In this study onsite tests were conducted in the test housing and actual buildings over 4 years in order to evaluate thermal properties, heat transfer properties in accordance with material & sectional composition of the green roof system developed with low management & light-weight rooftop greening methods and the current pressed concrete roof systems.

2.1 Test Outline

Thermal performance evaluation in relation to the roof systems was conducted in 8 blocks of test housing located in Ilsan, Gyeonggi-do and actual buildings (Asan Medical Center, dormitory buildings).

With the results from the test housing, 1 pressed concrete roof system and the green roof system applied test housing number 7 were analyzed as the main subjects.

2.2 Test Method & Details

In the case of the green roof system, thermal performance evaluation was conducted on the soil layer composition, soil layer thickness, application of storage & drainage systems, internal & external insulation methods in accordance with the position of the insulation material as these are the major factors that affect thermal performance.

The test was conducted measuring the indoor temperatures of the test housing and temperatures in 128 points by attaching T-type temperature sensors to the structures comprising each roof system. For the energy performance, the heating & cooling energy consumptions needed to maintain identical indoor temperatures were measured for the periods (1 month) in winter & summer with the highest load.

Table 1 shows the measurement details and methods, and Table 2 shows the major test details.

2.3 Test Housing

The test housing was constructed to possess solar radiation effects from nearby buildings and satisfy climatic factors such as wind direction and wind velocity conditions, and the spaces between the blocks were designed to ensure identical solar radiation conditions.

The dormitory building where the onsite test was performed is a 2 floor building with 6 units, and centering on the central corridor, a green roof system was constructed on 3 units (east direction) and comparative tests were conducted in identical indoor temperatures as the existing roof (west direction).

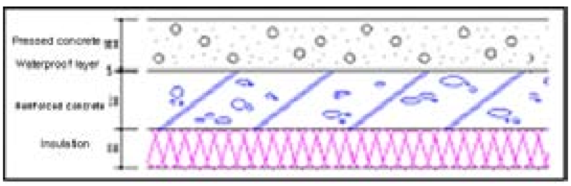
Preliminary tests revealed that there was no significant difference in building load due to solar radiation etc. in each of the units during the test period, and in order to maintain more similar solar radiation conditions for the external wall, black anti-sunlight barriers were installed for the entire wall with a 1m interval.

Table 1. Measurement Method & Details

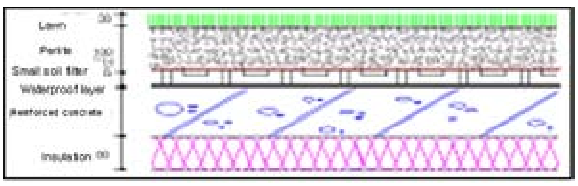
Item	Measuring Device	Details	Particulars
Temp.	·Automatic temperature recording device (Digistrip Ⅳ) ·T-type thermo-couple (Φ0.25mm)	·Boundary layer temp. for the composition of each system ·Outside temp. ·Indoor temp	Measured year round
Energy Consumption	·Power Guide(0.5 grade UPM320)	·Heating energy ·Cooling energy	Measure for winter & summer
Weather data	·Meterological measurement device (Grant Meterological measurement device)	·Temp, humidity, wind direction & velocity, solar radiation, rainfall	Measured year round

Table 2. Main Test Details

Item	Test Details	Particulars
Soil Type	a) Perlite artificial light-weight soil b) Volcanic rock mixed soil c) Natural soil (general soil)	2 types of light-weight soil that can be mass produced
Soil Depth	a) 100 ㎜ b) 200 ㎜ c) 300 ㎜	Test housing Test housing Dormitory (site)
Insulation Layer Position	a) Internal insulation b) No insulation c) External insulation	Heating system structure interior
Drainage System	a) 2 types of storage & drainage plates b) water permeability board (20%)+drainagesoil30mm c) Drainage mat	Test housing

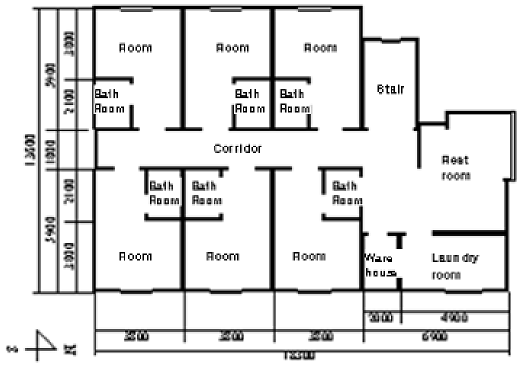


a) Pressed Concrete Roof System (Test Housing 1)



b) Green Roof System Example (Test Housing 7)

c) View of the Test Housing 8 Blocks



d) Ground Plan of the Dormitory where the Onsite Test was Conducted

Figure 1. Roof Section of the Test Housing & Ground Plan of the Onsite Building

3. Winter & Summer Thermal Performance Test Results

3.1 Surface Temperature of the Roof System Facing the Open Air

Figure 2 shows the upper part temperature of the pressed concrete (test housing 1) facing the open air during the cooling period, and the surface temperature of the soil layer in the green roof system (test housing 7). During the test period the outside air temperature was about 20℃ ~ 40℃, and in the period August 10 ~ 17, the maximum temperatures increased everyday ranging 37℃ ~ 40℃.

During the 8 days of the highest outside temperature the surface temperature of the pressed concrete in the daytime was 47℃ ~ 50℃, approximately 10K ~ 12K higher than the air temperature, and about 28℃ was maintained during the night time. The surface temperature of the soil layer in the green roof system during the daytime was about 35℃, approximately 3K ~ 5K lower than the air temperature, and during the night time temperatures about 3K ~ 5K higher than the air temperature were maintained.

When we examine temperatures according to time, on August 12th and 13th the pressed concrete rose to 50℃ by about 14:00 in accordance with the rise in air temperature, and in the early morning at 3am when temperatures dropped to about 24℃ a high temperature of 30℃ was sustained. On the other hand, the upper surface of the green roof system rose to 37℃ which was similar to the air temperature at 14:00, but decreased below 30℃ with the drop in air temperature from about 20:00.

The surface temperature of the roof system facing the open air influenced the inside temperature of the structure with a time lag, and consequently as shown in Figure 4, the surface temperature of the lower slab section in the pressed concrete roof system increased to a maximum of 40℃ between 18:00 ~ 22:00, whereas the green roof system maintained a temperature about 10k lower measuring approximately 30℃.

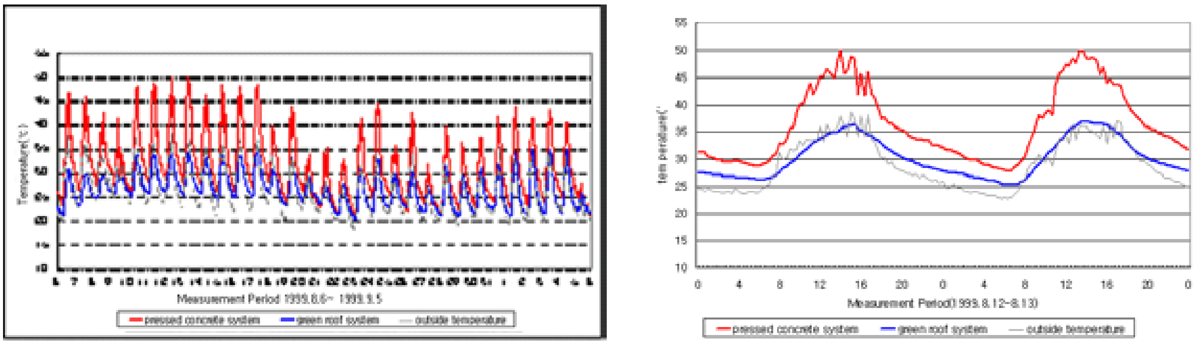
Eventually, due to this temperature reduction effect it is expected that the movement of heat passing through the green roof system structure will decrease considerably. The inside temperature of the green roof system applied test housing during the same period showed a maximum of 36℃ in natural conditions without operation of any internal cooling systems, and this was about 2K ~ 3K lower than the daily maximum of 39℃ under the pressed concrete system.

As a result, the green roof system can effectively reduce cooling load from solar radiation at the soil layer surface, and this reduction in cooling load is expected to have been jointly influenced by the solar radiation blockage effect including the reflection in the green layer situated on top of the soil layer, the latent heat effects from the evapotranspiration in the vegetation section, and the physical insulation function held by the soil layer.

Figure 3 shows the test results during the heating period where the outside temperature range was -12℃ ~ 10℃, and from January 7 the outside temperature dropped drastically where the design air temperature (-11℃, based on central heating) of the heating system in the building was reached in the period of January 8 ~ 13.

According to the figure, the surface temperature of the pressed concrete showed an overall similar fluctuation pattern to the outside temperature (-12℃ ~ 10℃) without time-lag, and although the soil layer surface of the green roof system (soil depth 0cm) was similar to that of the pressed concrete, when the outside temperature dropped drastically in the period January 8 ~ 10, it maintained a temperature of -7.5℃ which was about 5K higher than the minimum of -12.5℃ on the pressed concrete surface.

The 0.5cm depth point from the soil layer surface maintained a temperature of about 0℃ even though the outside temperature dropped to approximately -7℃ in the period January 1 ~ 7, and on January 8 ~ 10 it held a temperature about 7K higher than the pressed concrete surface after which it gradually decreased. However, from the 11th it showd a similar fluctuation range to the outside temperature and the upper soil layer surface temperature (soil depth 0cm) indicating that the soil layer froze down to the measurement depth.



a) Measurement Period: Aug 6, 1999 ~Sep 5 *b) Measurement Period: Aug 12, 1999 ~Aug 13*

Figure 2. Fluctuation in Temperature of the Surface Facing the Open Air (cooling period)

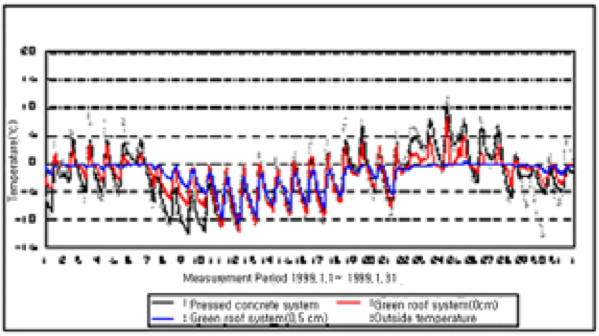


Figure 3 . Fluctuation in Temperature of the Surface Facing the Open Air (heating period)

3.2 Surface Temperature of the Lower Slab Section (upper section of the insulation material)

Figure 4 shows the fluctuation in the lower slab section surface temperature of the pressed concrete system and the green roof system (test housing 7) during the cooling period.

The lower slab section is the part that directly influences the ceiling surface and inside temperature as it borders the insulation layer in buildings with large scale insulation systems, and according to the figure, in the period August 8th to the 10th when the outside temperature rose to the maximum, the pressed concrete system showed a 5～6 hour time-lag in relation to the outside temperature during the daytime (about 14:00) when the temperature was the highest indicating a temperature distribution of about 35℃. However, at about 20:00 when the outside temperature dropped below 30℃, the lower slab section surface temperature remained at close to 40℃ due to the time-lag. Moreover, in the night time also when the outside temperature dropped to 22～23℃, the lower slab surface maintained a high temperature at about 33℃.

The lower slab section surface of the green roof system had a daily fluctuation rate of about 3K (28℃～31℃), and during the entire cooling period except for the days of rainfall (Aug 20th～23rd, 27th～28th), it maintained maximum temperatures of 8K below that of the pressed concrete system and minimum temperatures of about 2K～3K below that of the pressed concrete system.

Therefore, the pressed concrete roof system with large scale insulation systems continually maintains temperatures higher than the green roof systems in the lower slab section which is the upper section of the insulation material, and especially due to the time-lag, it causes the highest cooling load during the night time at about 20:00.

In real building if the insulation works are poor done or the connection points such as the joints are large, this high slab surface temperature directly affects the building's cooling load, so the difference in cooling energy consumption between the 2 systems is expected to be higher.

Figure 5 shows the test results during the heating period with the inside temperature kept constant at 18℃, and the pressed concrete system had a fluctuation range about 1/2～1/3 below the outside temperature fluctuation range while maintaining a similar fluctuation pattern.

The green roof system was found to maintain temperatures of about 4℃～8℃ during the test period when the minimum temperature range was -12℃～-5℃, and especially when the outside temperature continually stayed below 0℃, it maintained a temperature of about 5℃.

Because the insulation works were solid in the test housing, the maintenance of the constant internal temperature in the structure was not due to the heat transfer from the indoors, but rather due to the thermal properties of the soil layer comprising the green roof system. That is, it is positioned above the insulation material with sufficient insulation capacity, and the fact that the lower slab surface (lower section of the soil layer) maintained a temperature of 5℃ during the 12 days with outside temperature range -12℃～-5℃ was not solely attributable to the heat accumulation and insulation properties of the soil layer but also due to the existence of a temporary heat source that can somewhat counteract the outside temperature fluctuations.

Heat sources that can exist within the soil layer during the heating period first include microorganisms that produce heat through biochemical reactions. Generally, it is known that temperature increases from biochemical reaction are about 2K, and the vegetation rooted in the soil can also influence the overall thermal performance of the soil layer. However, it is difficult to see that these factors can maintain consistent temperatures when the outside temperature fluctuates as low as -12℃. Thus, it is judged that the sudden outside temperature fluctuations are first blocked by the soil layer surface, the heat insulation effects of the frozen layer created, and the effects of the thermal capacity in the soil layer. Moreover, apart from the insulation & heat accumulation effects of the soil layer, temporary thermal factors like the latent heat effects of moisture based on the frozen layer seem to have a greater influence on the maintenance of constant temperature.

Ultimately, as shown in Figure 5 the green roof system was found to be more advantageous in terms of heat than the pressed concrete system during the entire heating period of the test from January 1st to January 31st.

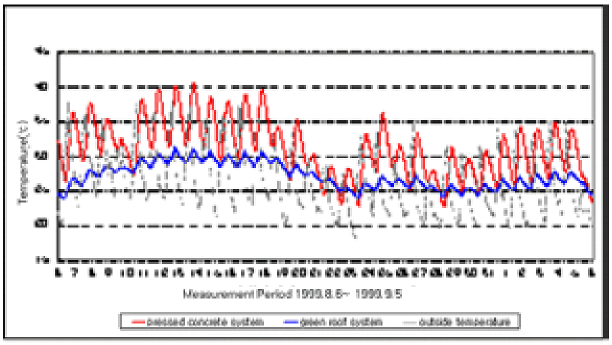


Figure 4. Lower Slab Section Surface Temperature Fluctuations (cooling period)

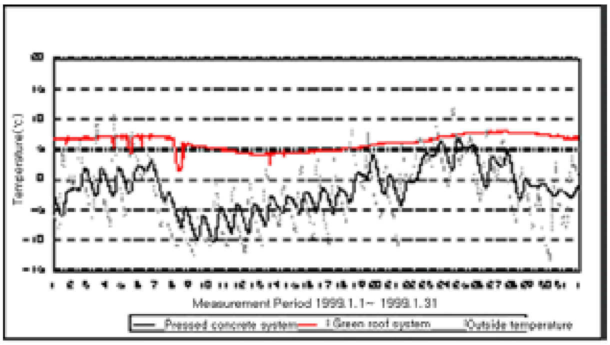


Figure 5. Lower Slab Section Surface Temperature Fluctuations (heating period)

3.3 Thermal Properties in Accordance with Soil Layer Thickness

Figure 6 shows the temperature fluctuations of the lower most soil layer section in the green roof system (onsite test located in Asan) in accordance with changes in soil depth.

As seen in the figure, the temperatures in the lower soil layer section (upper slab section) showed clear differences according to the thickness of the soil layer. When the soil layer was set at 10 ㎝, the daily maximum fluctuation range was 2.5K˜3K, and the maximum temperature 28℃, but the soil layers with thickness of 20 ㎝ and 30 ㎝ had relatively lower fluctuation ranges. The 30 ㎝ soil layer showed a temperature distribution under 25℃ with outside temperatures rising to 38℃ during the cooling period, and with daily fluctuation of less than 1K, it was found to maintain a very stable temperature.

3.4 Thermal Properties in Accordance with Soil Layer Composition

Figure 7 a) shows the temperature fluctuation within the soil in accordance with the soil layer composition during the heating period. As seen in the figure, the temperature within the soil consisting mainly of volcanic rock shows the largest fluctuation range in accordance with the outside temperature fluctuation, and especially around January 7th when the outside temperature dropped drastically, a similar fluctuation pattern was seen.

The perlite and natural soils maintained their internal temperatures at about 0℃ until January 7th gradually decreasing from the 8th, and from about the 11th a similar periodic fluctuation pattern to the outside temperature was seen. After the 18th when the outside temperature was again maintained above 0℃ the perlite and natural soils maintained their internal temperatures consistently at about 0℃ whereas the volcanic rock soil layer rose above 0℃.

Therefore, under identical conditions clear differences were seen in the soil layer internal temperatures depending on the soil composition, and these differences are expected to be influenced by whether a frozen layer has formed and the depth of the frozen layer. Furthermore, it was revealed that 1) physical thermal performance of the soil particles (insulation & heat accumulation performance of the particles), and 2) the amount of heat accumulation in the soil layer (soil moisture content - the shape, rate , and numbers of apertures in accordance with the particle size and structure) were revealed to be the major variables affecting the frozen layer.

In the case of the perlite soil used in this study, the soil itself has excellent insulation properties, and compared to the light-weight soil like volcanic rock, it has larger retention capacity, so the amount of heat accumulation increases relatively higher indicating more superior thermal properties during the heating period.

Actually, in the case of the volcanic rock soil layer during the analysis period, the entire soil layer was frozen until January 21st, whereas the perlite and natural soils contained relatively higher levels of moisture and the lower soil layer section did not freeze until January 7th. In the case of the perlite and natural soils, there is heating energy reduction effects for a period of time with the sudden drop in outside temperature, but the opposite effect could occur when the outside temperature rises due to the inherent heat accumulation properties.

Figure 7 b) shows the temperature fluctuation within the soil in accordance with the soil layer composition during the cooling period. As seen in the figure, the temperatures within the perlite soil layer showed the lowest fluctuation indicating the maintenance of stable soil temperature, and just like during the heating period the volcanic rock soil showed the highest temperature fluctuation with relatively higher temperatures.

In terms of the soil layer composition, the type & growth of plants, management performance of the greening system, building load etc. must also be taken into account together with the many factors discussed in this study, and in this study the perlite artificial light-weight soil was proposed for the low-management light-weight green roof system.

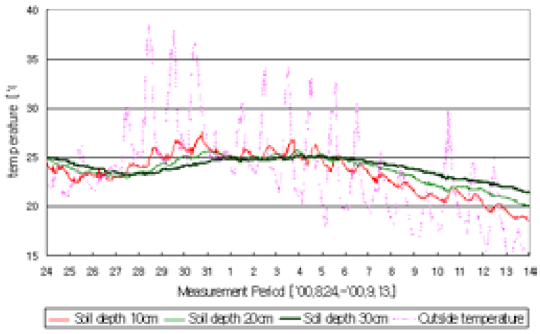
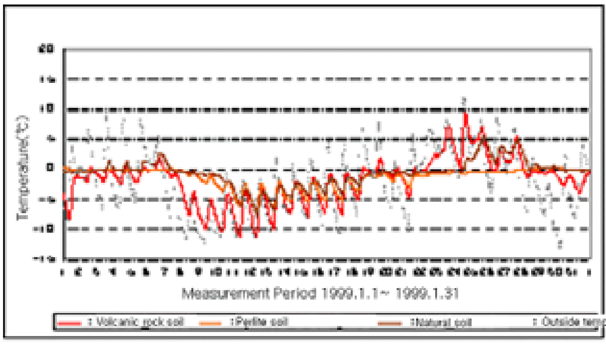
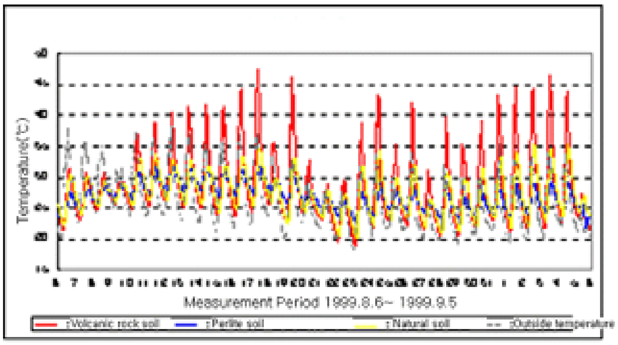


Figure 6. Lower Soil Layer (upper slab section) Surface Temperature Fluctuations According to Soil Layer Thickness (cooling period)



a) Heating Period Test Results



b) Cooling Period Test Results

Figure 7. Soil Temperature Fluctuations According to Soil Layer Composition

3.5 Thermal Properties in Accordance with the Drainage System

Figure 8 shows the lower drainage system section surface temperatures for the 4 test houses with different drainage system applications. Firstly, if we examine the case where drainage soil & water permeability plate were applied and the case where the storage & drainage plate developed for this study was applied, from January 10th when the daily minimum outside temperature remained under -10℃, the water permeability plate fell below 0℃ and froze, and under the same conditions the surface temperature of the storage & drainage plate fell to about 0℃ but did not freeze.

Moreover, the storage & drainage plate developed for this study showed similar thermal properties to the existing storage & drainage plate (D company of Germany), and the drainage mat which includes the air layer had moderate thermal performance lower than the storage & drainage plate but higher than the water permeability plate, and like the water permeability plate the lower section surface froze when the outside temperature fell over a long period of time.

Therefore, the 4 drainage systems each have different thermal properties, and in terms of thermal property, the storage & drainage plate containing expandable polystyrene was found to have the highest heat resistance, and the drainage mat also was found to have superior thermal performance compared to the existing drainage and the water permeability plate systems.

3.6 Thermal properties of Internal & External Insulation Systems

Figure 9 a) & b) shows the temperature inclination after measuring the temperatures over a 24 hour period (16.1.1999) in 20 minute intervals for the major layer boundaries of the green roof system with internal & external insulation under constant room temperature conditions.

With the external insulation system in a) the difference between the daily average room temperature and the temperature of the lower insulation section (upper slab section) was found to be about 3K, and the surface temperature difference between the upper and lower slab sections was less than 1K, so the slab holds thermal properties as a heat accumulation layer without heat resistance. The heat that passed through the slab makes contact with the green roof layer bordering the insulation layer, and here, the temperature difference between the upper & lower section of the insulation material ranged 10K ~ 12K showing a high temperature inclination. Moreover, the lower section of the storage & drainage plate on the upper section of the insulation material recorded temperatures 2℃ ~ 4℃ and did not freeze when the outside temperature dropped to -12℃, and the upper section of the storage & drainage plate fluctuated in the range -8℃ ~ -1.2℃ together with the soil layer.

In the internal insulation system of b) there was a temperature difference of about 10K bordering the insulation layer, and the upper section of the slab in contact with the green roof system layer recorded 1.4℃ ~ 1.9℃ showing a temperature distribution about 0.6K ~ 2K lower than the external insulation system. Therefore, the internal insulation system showed a lower frozen layer depth in the green roof system than the external insulation system under identical outside temperature conditions.

Generally, the probability of dew condensation inside a structure increases at the point of large temperature difference and when the inside temperature is low, so in identical humidity conditions the internal insulation system has higher probability of dew condensation occurrence on the slab and insulation material compared to the external insulation system. In existing buildings it is common not to incorporate a damp proofing layer on the interior ceiling, and if the connecting parts of the insulation material are not firm, internal dew condensation can occur on the boundary between the insulation and slab.

In the case of the external insulation system also, the moisture infiltrating into the structure through the slab can give rise to internal dew condensation on the boundary between the insulation and slab, that is why when the external insulation is incorporated into the green roof system in countries such as Germany and Japan, a damp proofing layer is always applied to the lower section of the insulation material.

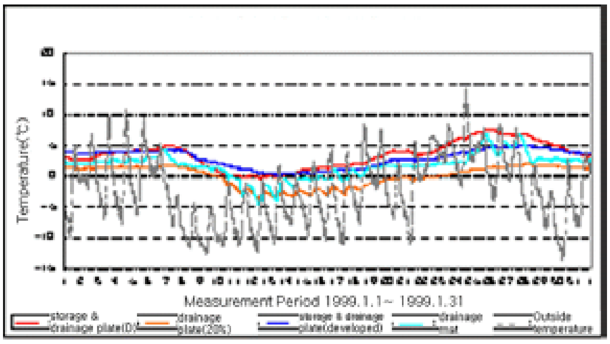
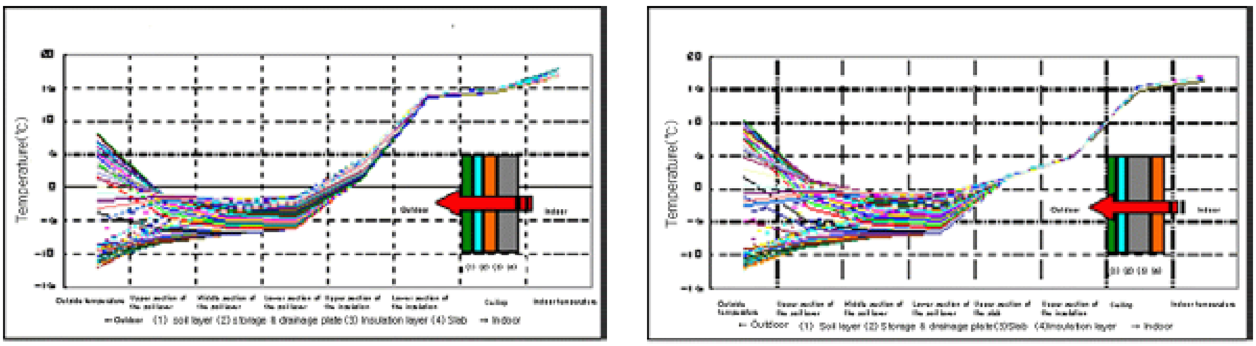


Figure 8. Fluctuation in the Upper Slab Section in Accordance with the Drainage System



a) External Insulation System b) Internal Insulation System

Figure 9. Sectional Temperature Inclination in Accordance with Insulation Material Position

4. Energy Performance Evaluation

4.1 Heating Energy Performance Evaluation

Table 3 shows the heating energy consumption in maintaining the constant room temperature for the test housing during the heating period from January 13th to the 23rd (phase 1 test). The total energy consumption in the case of the pressed concrete system was 17.5[kWh] while the green roof systems recorded 16.4[kWh] and 15.2[kWh] respectively. Consequently, it can be seen that the green roof systems have energy saving effects of about 6.4% ~ 13.3% compared to the existing pressed concrete system.

Figure 10 shows the measurements of heating energy consumption in the low management light-weight green roof system introduced in the phase 2 test. Test housing number 2 was comprised of perlite artificial light-weight soil (soil depth 100mm) and water permeability plate (20%) & drainage soil as the drainage system, and with the same structure, test housing number 7 incorporated the storage & drainage plate developed for this test.

The total average daily energy consumption in the case of the pressed concrete system was 1.27[kWh/day] while the green roof systems recorded 1.19[k Wh/day] and 1.14[kWh/day]. The total energy consumption during the analysis period in the case of the pressed concrete system was 36.7[kWh] while the green roof systems recorded 34.6[kWh] and 33.1[kWh].

Therefore, it can be seen that the green roof systems introduced in this test have heating energy saving effects of about 6% ~ 10% compared to the existing pressed concrete system.

Table 3. Heating Energy Consumption (Test Housing)

Item		Pressed Concrete Roof System (Number 1 House)	Green Roof System	
			Number 2 house	Number 7 house
heating Energy Consumption [kWh]	Phase 1 test (13.1.1998 ~ 23.1)	17.5 (100%)	16.4 (93.6%)	15.2 (86.7%)
	Phase 2 test (24.12.1998 ~ 1.22.1999)	36.7 (100%)	34.6 (94.3%)	33.1 (90.2%)

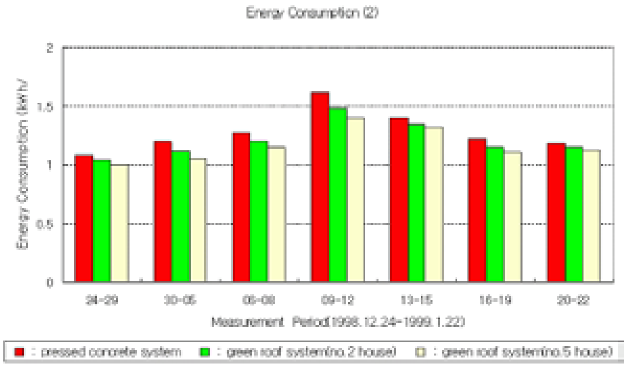


Figure 10. Heating Energy Consumption (Test Housing)

4.2 Cooling Energy Performance Evaluation

Figure 11 shows the daily cooling energy consumption in maintaining the constant room temperature for the actual building during the cooling period.

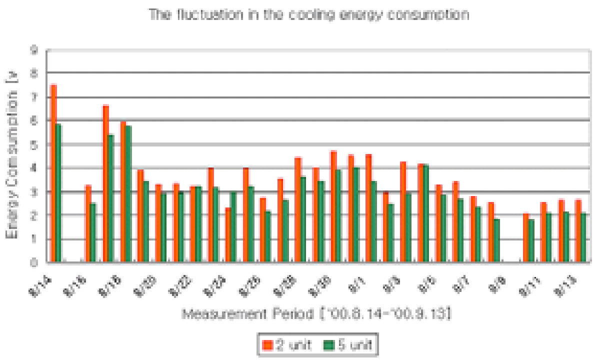
The onsite test was done on the 2 floor dormitory building located in Asan, Chungnam Province, and of the 6 units on the same floor, the green roof system was applied for 3 units and the existing pressed concrete roof system was maintained for the other 3 units.

Room air conditioners with cooling capacity of 1,800kcal/h were installed in each unit, and the room temperatures were maintained at 23.5℃ with no temporary adjustments. As a result, the room temperatures of each unit satisfied the constant test conditions of 23.5℃±0.3℃.

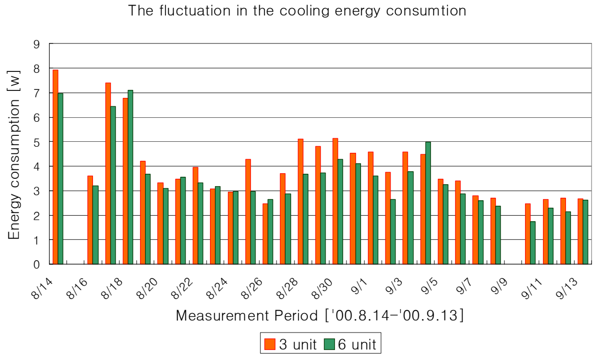
a) shows the fluctuation in the daily cooling energy consumption for the number 2 unit (pressed concrete system) and the number 5 unit (green roof system) whose side walls do not face the open air. Throughout the entire cooling period, the unit that applied the green roof system showed more than 15% less energy consumption than the pressed concrete unit. Especially when the outside temperature rose above 35℃, the difference in energy consumption between the green roof system and the pressed concrete system reached up to 17%.

b) shows the fluctuation in the cooling energy consumption for the number 2 unit (pressed concrete system) and the number 5 unit (green roof system) whose side walls face the open air. The unit that applied the green roof system showed about 10% less energy consumption than the pressed concrete unit.

During the analysis period, the total energy consumption in the pressed concrete units 2 & 3 was 108.82 [kWh] & 116.92 [kWh] respectively, and under identical load conditions, the green roof system applied units 5 & 6 showed energy consumption of 91.63 [kWh] and 102.62[kWh] respectively. Therefore, it was found that the green roof system gives rise to about 12% ~ 15% cooling energy reduction compared to the existing pressed concrete system.



a) Units that do not Face the Open Air



b) Units that Face the Open Air

Figure 11. Cooling Energy Consumption (onsite test)

Table 4. Cooling Energy Consumption (Dormitory Building)

Item	Pressed Concrete Roof System		Green Roof System	
	Unit 2	Unit 3	Unit 5	Unit 6
Cooling Energy Consumption [kWh]	108.82 (100%)	116.92 (100%)	91.63 (84.2%)	102.62 (87.8%)
Unit Position	Internal unit	Side wall unit	Internal unit	Side wall unit
Particulars	-	-	Soil depth 200mm	Soil depth 300mm

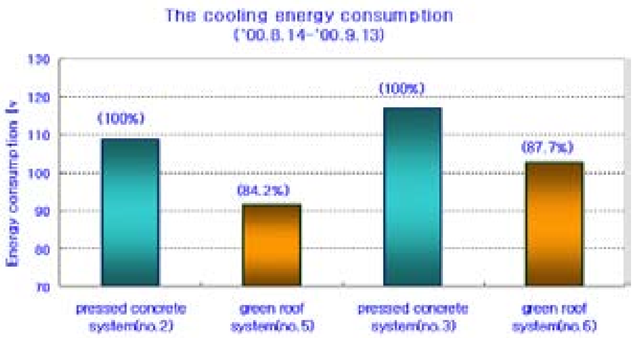


Figure 11. Total Cooling Energy Consumption (onsite test)

5. Conclusion

1) In the cooling period the soil layer of the green roof system clearly showed heat transfer time-lag as well as insulation performance, and without any separate cooling or heating source it showed a daily average room temperature reduction effect of about 2K. During the heating period also, unlike the existing recognition, the soil layer showed to possess sufficient thermal effect due to the heat insulation effect and heat accumulation properties.

2) In order to evaluate energy performance held by the green roof system, thermal performance tests were conducted on test housing and an actual building. The results suggest that the green roof system (perlite soil layer) gives rise to about 6% ~ 10% heating energy savings effect compared to the existing pressed concrete roof system, and during the cooling period it was able to secure energy saving effects of about 12% ~ 15%.

3) The test results of the major composition in the green roof system revealed that the physical properties of the soil particles and the moisture content had significant effects on the thermal properties of the soil layer during the cooling period. Especially during the heating period, it was shown to directly affect the degree of frozen layer occurrence within the soil and the subsequent thermal insulation effects. With the soil layer with the major constituents applied in the test (Perlite paraso soil, volcanic rock soil, natural soil), it was found that the perlite artificial light-weight soil had relatively superior thermal properties and performance.

4) With the drainage systems, it was found that the expandable polystyrene storage & drainage plate had the most superior thermal performance along with its storage & drainage functions. With the insulation system, it was found that the external insulation system was more effective in terms of internal dew condensation occurrence. Moreover, when the external insulation system and the storage & drainage plate was applied simultaneously, it was found that a more superior insulation performance could be secured.

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AN EFFECT OF GREEN ROOF SYSTEM TO REDUCE RAINWATER FLOOD

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Keywords: green roof system, rainwater , flood

Summary

The purpose of this study is to quantify the rainwater storing and leakage reduction effect of green roof system as a realistic solution to urban ecological problems, and lay the theoretical foundation for analyzing the effect of green roof system on the improvement of urban climate. To this end, rainwater leakage experiments were conducted on experimental houses with trees planted on the roofs and with paved roofs whose rainwater leakage can be measured. As for the materials and configuration of the green roof system, a model, determined in consideration of vegetation and energy-effectiveness, was applied.

The result of the performance evaluation of the rainwater leakage reduction effect of the green roof system, made of perlite artificial light-weight soil is summarized as follows: 1) The green roof model used in the experiment was found to be excellent in rainwater leakage reduction, around 70%, thanks to the water-retaining and evapotranspiration ability of the soil and vegetation. 2) The amount of rainwater leakage differed depending on the precipitation per hour, and the amount of water contained in the soil, but the green roof model was able to retain 20 ~ 30 kg/m2 of the initial rainfall without any leakage. 3) In case of a severe rain storm with more than 80mm/hr precipitation, the system was found to reduce rainwater leakage, and defer rainwater for at least 3 hours.

1. Introduction

The ecosystem maintains stability and balance with the continuous circulation of energy and substances. Likewise, water circulation is also in a closed form consisting of rainfall, soil saturation & storage, evapotranspiration, and precipitation. 65% of the rain falling to the ground is temporarily stored in soil, rivers, lakes, and plants after which it evaporates, and 35% flow into the sea in the form of surface water and underground water.[1)] The 65% of rainfall which evaporates from the ground has a governing effect on the local climate as well as Earth's climate control.

According to W. Geiger and H. Dreisei, the rainwater leakage rate in paved areas including the roofs of standard buildings is 90 ~ 100% and is much faster & higher than areas with natural soil and vegetation which have a leakage rate of 0 ~ 20%.[2)] This clearly explains the effect of pavement on rainwater leakage, and indicates the necessity of rainwater leakage reduction measures for paved areas for the maintenance of water circulation system balance. In other words, the loss in storage & permeation in soil & vegetation, as well as evapotranspiration due to excessive surface pavement are the fundamental causes of serious ecological problems such as the urban heat island phenomena, urban flooding etc.

With this background, green roof systems gained attention from the mid 1990s as the most economical and realistic measure against urban ecological problems due to the loss in the ecological function of soil and water circulation functions. There were especially great expectations in relation to the contribution green roof systems can have to rainwater storage, leakage reduction effects, urban climate improvement, and prevention of urban flooding.

Therefore, detailed studies are required for the quantification of green roof system rainwater storage and rainwater leakage reduction effects in order to scientifically examine the effects of pavement & green roof systems on urban climate as the realistic measure to resolve urban ecological problems.

Ground surfaces in urban areas are mostly paved by impermeable materials such as concrete & asphalt. Seoul, Korea has been transforming into an impermeable region with 48% of the total area covered by extremely urbanized areas consisting of 70% or more paved in impermeable materials. When we examine the soil coverage type in this urbanized area, 70% or more is comprised of buildings with flat roofs. Even if we examine the whole area of Seoul, there is approximately 254 ㎢ of flat roof areas taking up 42% of Seoul.[3)] These large scale pavement areas are the major cause of current urban ecological problems while having the potential space for green roof systems indicating that this must obviously be done and the high possibility of its success.

Consequently, the development of green roof systems is needed and must obviously be conducted, and we must commence with the existing flat roofs for which the technical difficulties and cost burden are relatively low.

However, in order to apply the green roof system to existing buildings, the problem of structural safety must first be dealt with. To solve this problem we can consider building repairs and reinforcement, but this only causes a rise in green system costs, so this can become an obstacle preventing the application of green roof systems. As a result, developing an light-weight roof planting system within the scope of the allowable load for the building was judged to be the most realistic method.

In this viewpoint, this study set the research scope with the light-weight roof planting system[4)] which was judged to have the highest utility to realistic requirements and potential application. The major details are as follows.

- Quantification of the rainwater leakage effects with the light-weght roof planting system
- Comparative analysis of the summer season aggregate rainfall and rainwater leakage rate
- Analysis on the effects of the drainage system on the rainwater leakage reduction effect

2. Rainwater Leakage Test

2.1 Test Facilities

The test on rainwater leakage effects was conducted by separately installing a $4m^{(L)} \times 4m^{(W)} \times 0.25m^{(H)}$ sized test roof as the test area on a roof not affected by nearby buildings. Also, in order to analyze the effects of drainage system differences on rainwater leakage reduction, the test roof on the upper part of the test area was constructed as two separate lengthwise test roofs sized $4m^{(L)} \times 2m^{(W)} \times 0.25m^{(H)}$. The short side slope of the test roof was set at 2/100 and while constructing a 10 ㎝ wide drainage canal, a ø35 ㎜ drain was incorporated into each of the 4 corners in order to optimize the similarities with the standard light-weight roof planting system construction conditions.

In order to prevent loss of reliability due to leakage, a PVC sheet waterproof material for green roof systems was used, and after the waterproofing work, the effectiveness was verified through a water test.

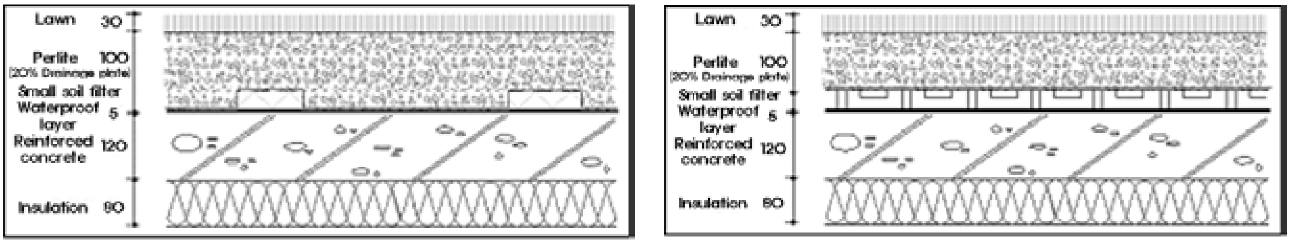
Photo 1. View of the green roof system test model

2.2 Composition of the Light-Weight Roof Planting System

The Light-Weight Roof Planting System model applied in the test is as shown in Photo 1. The system model consists of the drainage layer, soil layer, and the vegetation layer, and especially to examine the rainwater leakage differences between the drainage systems, 2 other different drainage system models were applied. Figure 1-1 is the system model combining the drainage soil and the drainage layer having an excusive drainage function, and Figure 1-2 is the model that has applied the storage & drainage layer which also has the storage function. The first model takes up 20% of the total area and after covering it with the soil particle filter the section (the remaining 80%) without the drainage layer was filled with drainage soil to an identical height (35 ㎜). On the other hand, the second model consisted wholly of the storage & drainage layer.

The soil layer comprised of the most standard perlite, an artificial soil made with plastic, and taking into account the allowable loads in existing buildings and the minimum soil depths for grass vegetation, the depth of soil was set at 10cm. The allowable stress on the roof of existing buildings is generally 200 ㎏/㎠, and considering that the moisture proportion for the artificial light-weight soil produced in Korea is 0.8 ~ 0.9, the depth of soil for the applicable light-weight roof planting system could only be limited to 10cm.[1)]

In order to minimize effects to the test, the vegetation layer was comprised of carpet type roll grass.



a) Drainage Soil System (Drainage Layer 20%) b) Drainage System

Figure 1. Roof Planting System Model 1, 2

2.3 Test Method

The rainwater leakage from rainfall was measured for the 2 green roof system models and the concrete roof surface, and a comparative analysis was conducted.

With the rainfall amount and the leakage amounts from the green roof system models the rainwater storage performance was evaluated, and by also measuring the time delay from the start of rainfall to the point of actual leakage, the rainwater leakage delay effects were analyzed.

From June to July the rainfall amount and the leakage amounts that passed through the green roof system test area were simultaneously measured, and the analysis of rainwater leakage reduction effect by the green roof system was conducted based on 24 hours of rainfall measurement results. The 24 hour periods were classified into rainfall amounts of 30mm or less, 60mm or less, and 80mm or less which calls for heavy rain advisory

he precision level of the rain gauge used in this test was ±0.5%, and it was a tipping type gauge (ø20cm, 0.5mm/pulse) approved by the meteorological administration, and the system was arranged so that automatic measurements were taken in 20 minute intervals with the rainfall converting into pulse signals.

3. Results & Observations of the Rainwater Test

Figure 2 shows the fluctuations in rainfall and rainwater leakage amounts that passed through the green roof system model within the period June 23 ~ 24. According to the figure, the rain started from 10am on the 23rd and ceased at 00:20 on the 24th. and the total rainfall amount was 33.5 kg/m^2(33.5mm) which was the aggregate of the 8.5 kg/m^2(8.5mm) for the previous day and the 25 kg/m^2(25mm) of rain over 14 hours during the analysis period.

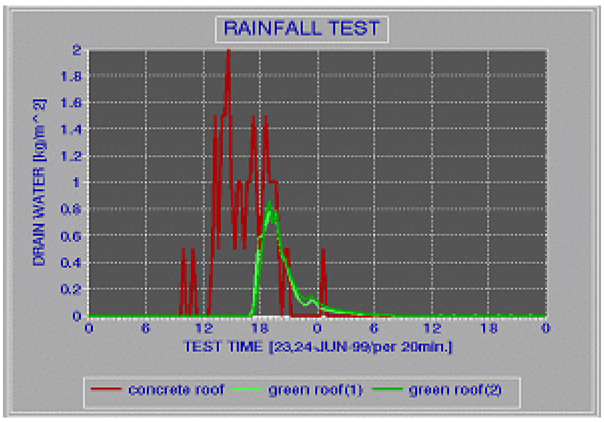


Figure 2. Rainwater Leakage Reduction Effect Case Study (Ⅰ) (Analysis Period: June 23 ~June 24)

As seen in the figure, the rainwater leakage that passed through the green roof system models 1 & 2 showed approximately a 7 hour delay from when the rain started with the leakage occurring from 15:00. Especially, the entire rainfall amount was held in the green roof system until the initial rainfall amount reached approximately 24.5 kg/m^2(24.5mm), so the rainwater leakage did not occur at all.

The total rainfall amount until the time when the rainfall amount and leakage amount was fully exhausted during the analysis period (based on 0.1 kg/m^2 or 0.1mm) was 33. 5kg/m^2(33.5mm) while the rainwater leakage amounts for test models 1 & 2 were 7.9 kg/m^2 & 8.1 kg/m^2 respectively. Therefore, the difference between the rainfall amount and the leakage amount, that is the rainwater leakage reduction effects (aggregate of the retention amount and evaporation amount) due to the green roof system in the 2 test models were shown to be 25.6 kg/m^2 and 25.4 kg/m^2 indicating that the rainwater leakage reduction rate is approximately 76%.

The water content in the green roof system models was not measured in this test, but if we take into account that there was virtually no rain within 10 days of the analysis period with rainfall measurements recording only 10mm, the maximum rainwater leakage reduction effect of the 10cm light-weight roof planting system is expected to be 25 kg/m^2 or more per unit area.

Figure 3 shows the fluctuations in rainfall and rainwater leakage amounts that passed through the green roof system model within the period July 28th to 29th. As seen in the figure, rain started falling from 4am on the 28th and by 16:00 of the same day the per hour rainfall amount reached 5 kg/m^2(5mm) and the total rainfall amount over the 2 days was 30 kg/m^2(30mm).

The rainwater leakage amounts for the green roof system test models 1 & 2 were 7.8 kg/m^2 & 8.9 kg/m^2 respectively, so the rainwater leakage reduction amounts in relation to the total rainfall were 22.2 kg/m^2 and 21.1kg/m^2 and reduction rates 74% and 70.3% respectively. The time delay effect from the beginning of the rainfall to the time of rainwater leakage occurrence after passing through the green roof system was approximately 11 hours. Here, the rainfall amount until the occurrence of rainwater leakage, that is the total rainfall amount that can be retained in the green roof system is approximately 19 kg/m^2(19mm).

The reason why the total water retention amount without leakage in the green roof system test models is different to that of 76% (25.4 kg/m^2) in figure 2 is firstly due to the intensity of rainfall, that is the scope of time in rainfall occurrence and the water content in the soil layer were under different conditions. Actually in the case of Figure 3, rainfall of 88.5mm occurred 5 days prior to the analysis period (July 22 ~ July 23), so the water content in the soil layer would have been relatively higher than in Figure 2.

However, the overall rainwater leakage fluctuation curves in figure 2 and 3 show similar patterns, and it was noticed that the green roof system models released the water slowly over time after the rain had ceased. Moreover, even after the rainwater leakage had occurred, the overall leakage fluctuation pattern moved in accordance with the changes in rainfall amount, but the leakage amount was relatively lower. At 16:00 when the per hour rainfall amount was highest, the rainwater leakage was shown to be less than half of the rainfall amount.

Figure 4 shows the fluctuations in rainfall and rainwater leakage amounts that passed through the green roof system models 1 & 2 within the period July 9th to 10th, and this analysis period was amidst the 15 days where rainfall did not exceed 0.1mm in the test area.

As seen in the figure, approximately 2.5mm of rainfall occurred from 6am to 12 noon, and during this period there was hardly any rainwater leakage. Also, the actual continuous rainfall occurred on the 9th from 20:00 recording a total of about 57 kg/m^2(57mm) until 12.

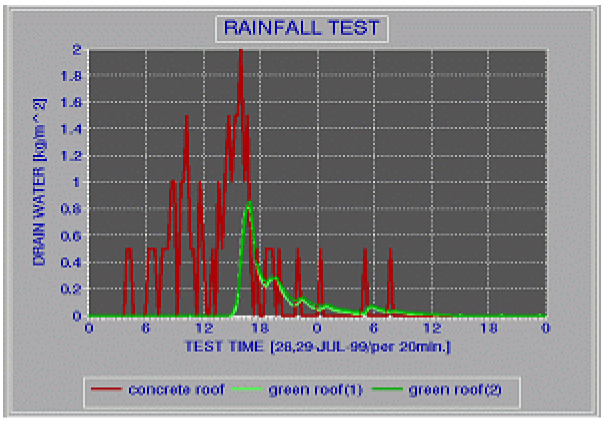


Figure 3. Rainwater Leakage Reduction Effect Case Study (Ⅱ) (Analysis Period: July 28 ~July 29)

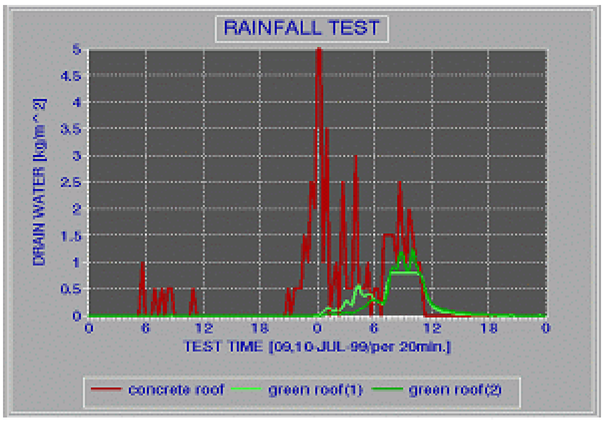


Figure 4. Rainwater Leakage Reduction Effect Case Study (Ⅲ) (Analysis Period: July 9 ~July 10)

In the figure, there was an approximately 6 hour leakage delay effect with rainwater leakage occurring from 2am on the 10th. Rainwater leakage in the green roof system models 1 & 2 did not occur until the initial rainfall reached 22.5 kg/m^2(22.5m m) and 32 kg/m^2(32mm) respectively.

Therefore, the total rainfall amount until the time when the rainfall amount and leakage amount was fully exhausted during the analysis period (based on 0.1 kg/m^2 or 0.1mm) was 57 kg/m^2(57mm) while the rainwater leakage amounts for test models 1 & 2 were 15.8 kg/m^2 & 15.2 kg/m^2 respectively. Therefore, the difference between the rainfall amount and the leakage amount, that is the rainwater leakage reduction effects (aggregate of the retention amount and evaporation amount) due to the green roof system in the 2 test models were shown to be 41.2 kg/m^2 and 41.8 kg/m^2 indicating that the rainwater leakage reduction rate is approximately 73%.

Because the analysis period was amidst the 15 days where there was hardly any rainfall, the maximum rainwater reduction effect of the light-weight roof planting system with soil depth of 10mm was over 41 kg/m^2 per unit area which is higher than the 19 ~ 25 kg/m^2 in figures 2 & 3.

Ultimately, the retention capacity of the soil layer depends on the rainfall amount, the rainfall intensity, and the amount of water content in the soil layer, but it can be confirmed that the rainwater leakage reduction rate in relation to the total rainfall amount is more than 70%.

Figure 5 shows the fluctuations in rainfall and rainwater leakage amounts within the period July 22nd to 23rd when a total rainfall of 88.5 mm was recorded within a 12 hour period. The rainfall during the analysis period exceeded the heavy rain advisory point, and especially around 9am on the 22nd the rainfall amount per hour was over 25mm.

As seen in the figure, rainwater leakage from the green roof system test models occurred approximately 3 hours after the commencement of rainfall, and until this time the water content without leakage in the soil layer was approximately 26.5 kg/m^2(26.5mm).

Therefore, the total rainfall amount until the time when the rainfall amount and leakage amount was fully exhausted during the analysis period was 88.5 kg/m^2(88.5mm) while the rainwater leakage amounts for test models 1 & 2 were 28.1 kg/m^2 & 29.1 kg/m^2 respectively. Thus, the difference between the rainfall amount and the leakage amount, that is the rainwater leakage reduction effects (aggregate of the retention amount and evaporation amount) due to the green roof system in the 2 test models were shown to be 60.4 kg/m^2 and 59.4 kg/m^2.

Moreover, the rainwater leakage amount in each green roof system model was about 4 kg/m^2 (4mm) when the per hour rainfall was at its maximum recording 25kg/m^2(25mm), so it could be seen that the green roof system is highly effective in terms of rainwater leakage reduction during times of short-term heavy rain.

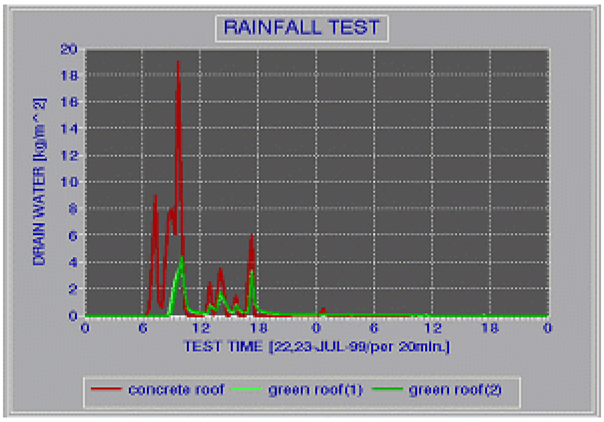


Figure 5. Rainwater Leakage Reduction Effect Case Study (IV) (Analysis Period: July 22 ~July 23)

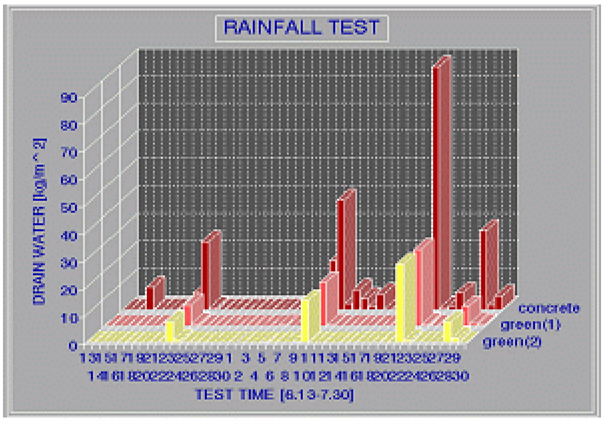


Figure 6. Comparison of the Overall Rainfall Amounts and Rainwater Leakage Amounts (Analysis Period: July 13 ~July 30

From the above results, it was found that light-weight green roof systems with soil depth of 10cm have about 70% rainwater leakage reduction rate through the retention capacity of the soil layer and the evaporation amount.

Furthermore, there were differences in the time delay effects relating to the rainwater leakage from the green roof system depending on the water content existing within the soil layer, but overall, it was found that an initial rainfall amount of 20 ~ 32 kg/m^2 (20mm/m2) could be held. Especially as seen in case IV (88.5mm rainfall in 24 hours) along with the rainwater leakage reduction effects during times of short-term heavy rain, it was found that the green roof system delays the leakage time by at least 3 hours.

The total rainfall amount for the entire analysis period (June 13 ~ July 30, 48 days) was 249 kg/m^2(249mm), and the rainwater leakage amounts for the 2 green roof system test models were 59.6 kg/m^2 and 61.3kg/m^2 respectively. Therefore, the amount of rainwater leakage reduction in relation to the total rainfall amount was 189.4 kg/m^2 and 187.7 kg/m^2 indicating a rainwater leakage reduction rate of approximately 75%.

Table 1 shows the total rainfall amount, rainwater leakage, and reduction rates for each case, and Figure 6 shows the daily rainfall amounts and the rainwater leakage amounts for 48 days from June 13 to July 30.

Table 1. Total Rainfall Amount, Rainwater Leakage, and Reduction Rates for Each Case

Category	Total Rainfall (kg/m^2)	Rainwater Leakage from the Test Models (kg/m^2)	Leakage Reduction Amount(kg/m^2)	Reduction Rate (%)	Particulars (Precipitation Conditions)
Case Ⅰ (6.23 ~ 6.24)	33.5	7.9 ~ 8.1	17.1 ~ 16.9	75.8 ~ 76	Total precipitation of 10mm or less over 10 days
Case Ⅱ (7.28 ~ 7.29)	30	7.8 ~ 8.9	21.1 ~ 22.2	70.3 ~ 74	5 days after the 88.5mm precipitation
Case Ⅲ (7.9 ~ 7.10)	57	15.2 ~ 15.8	41.2 ~ 41.8	72.3 ~ 73.3	No precipitation for 15 days
Case Ⅳ (7.22 ~ 7.23)	88.5	28.1 ~ 29.1	59.4 ~ 60.4	67.1 ~ 68.2	Approx 10mm precipitation over 9 days
Total (6.13 ~ 7.30)	249	59.6 ~ 61.3	187.7 ~ 189.4	75 ~ 76	Total over 48 days

Note) The precipitation is generally expressed as the height of rain (mm) per m2 unit, but the rainwater leakage amount is kg per m2 unit, so in order to enable comparison the rainwater proportion was assumed to be 1 and the precipitation unit was expressed as kg/m^2.

4. Conclusion

The summary of the performance evaluation in relation to the rainwater leakage reduction effect on light-weight roof planting system using perlite artificial soil is as follows.

1) It was found that the green roof system test models possessed approximately 70% rainwater reduction effects due to the retention capacity and evapotranspiration capabilities of the soil and vegetation layers. Moreover, the green roof systems show differences in rainwater leakage amounts depending on the rainfall amount and water content in the soil layer, but overall, they were able to absorb 20 ~ 30 kg/m^2 (20 mm/m^2) of the initial rainfall amount without leakage.

2) As seen in the case with the short-term concentrated heavy rain (88.5mm of precipitation in 12 hours), the green roof system was seen to have a minimum leakage delay effect of 3 hours along with the rainwater leakage reduction effects.

In order to make the data proposed in this study more realistic there needs to be large scale long-term onsite tests rather than the small scale model tests, and to raise theoretical comprehensiveness, supplementary studies on test conditions that can achieve consistency with the site conditions must be conducted.

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INTEGRATIVE SUSTAINABLE DESIGN STRATEGIES FOR ENERGY AND WATER EFFICIENCY: THE CASE OF THE EWHA CAMPUS COMPLEX IN KOREA

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Keywords: sustainable design, energy/water efficiency, eco-friendly systems, energy-saving technology

Summary

The Ewha womans university Campus Complex (ECC) is designed to be a completely eco-friendly underground campus building that will symbolize the vision of sustainable design for the 21st century. In order to achieve this objective, the building is planned to reduce energy costs and the environmental load as well as to promote energy/water efficiency by applying optimal eco-systems such as a thermal labyrinth, geo-thermal energy, concrete core activation and others in order to use less primary energy. Furthermore, the envelope is effectively designed to save energy required for cooling and heating by providing an earth berm, a massive construction and a green roof system for the top of the building. In addition, windows that can be opened located on the valley side (opposite side to the earth-sheltered envelope) will improve natural ventilation during mid-season. Various water sources such as ground water, rainwater, and de-watering, etc. will also be applied to the building complex. As explained above, the ECC is a low-tech building designed with a focus towards saving energy and water and maximizing the recycling of the spent energy and water.

Figure 1 Ewha womans university Campus Complex (ECC) in Seoul, Korea (January 2008)

1. General Building Description

Table 1 Building information

Project	Ewha Campus Complex		
Architects	DPA Dominique Perrault Architecture (France) and Baum Architects (Korea)		
Engineers	HLPP Consult (Germany) and HIMEC (Korea)		
Location	Seodaemun-gu, Seoul, Korea		
Services	- Academic program: learning and sport-term project space, libraries, cafeteria - Administration - Commercial area: cinema, theatre, shops as well as external sporting spaces and car parks (20,000 ㎡)		
Site area	19,000 ㎡	Built-up area	70,000 ㎡
Structure	RC + SS	Estimated completion	2008

Above and below the land previously occupied by the Ewha square and the athletic field, the new campus valley provides both Ewhaians and prospective female leaders with the much-needed space for continuing education and student services. The concept design proposed by Dominique Perrault (France) was accepted at an international design competition held by the Ewha womans university in 2004, in order to develop the massive educational-cultural complex. The campus complex to be constructed is designed to offer a new sense of direction for higher education in the 21st century. It will establish organic relationships between the new building and the surrounding areas of the campus as well as between the above ground and underground spaces. The entire campus complex comprises six floors of underground structure. The 20m wide x 300m long campus valley connects the front gate and the main building and is composed of two floors of parking lots and four floors of educational-cultural welfare establishments.

2. Central Plant and HVAC Systems

The central plant systems of the ECC are designed as ecosystems that maximize energy and water saving. The various eco-friendly systems are also organically unified.

Cooling systems comprise heat pump type chillers, absorption chillers and a thermal storage system. In the night charging mode, the cooling system is operated by storing heat in the thermal storage tank using the less expensive night thermal storage power service during the night and using the discharging mode in the daytime. It is intended that the cooling systems will be operated in the order of the stratified thermal storage tank, the absorption chiller and the heat pump type chiller, according to the rate of the cooling load.

Heating systems serve the heating spaces and the heat pump units, which are reversed in the operating mode into the heating and the hot water boilers, produce domestic hot water. Numerous heat exchangers are installed separately in accordance with the amount of hot water required for each area, while the primary loop pumps are constant speed pumps and are controlled by the return water temperature in order to reduce the pump power. The secondary loop pumps are adapted to a variable speed either by the inverter control or by the quantity-related control, according to the heating load.

Table 2 Designed as a highly efficient heating and cooling system to deliver services

Equipments		Capacity	Quantity	Operation	Services
Cooling	Geo-thermal energy	100 kW	-	24 hours	CCA (concrete core activation)
	Ground water	40 kW	-	24 hours	CCA & condensate water
	Absorption chiller	1,266 kW	1 EA	24 hours	Day time: AHU, CHR & CCA Nighttime: CCA & nighttime zone
	Heat-pump type chillers	745 kW	2 EA (Stand-by)	24 hours	Daytime: AHU, CHR & CCA Nighttime: thermal storage tank
	Water thermal storage system	6,680 kWh	750 ton	24 hours	AHU, CHR & CCA
Heating	Geo-thermal energy	150 kW	-	24 hours	Heat-pump type chillers (chilled water)
	Hot water boilers	1,163 kW	2 EA	-	AHU, CHR, CCA & domestic hot water
	Heat-pump units (hot water)	958 kW	2 EA (Stand-by)	-	AHU, CHR & CCA

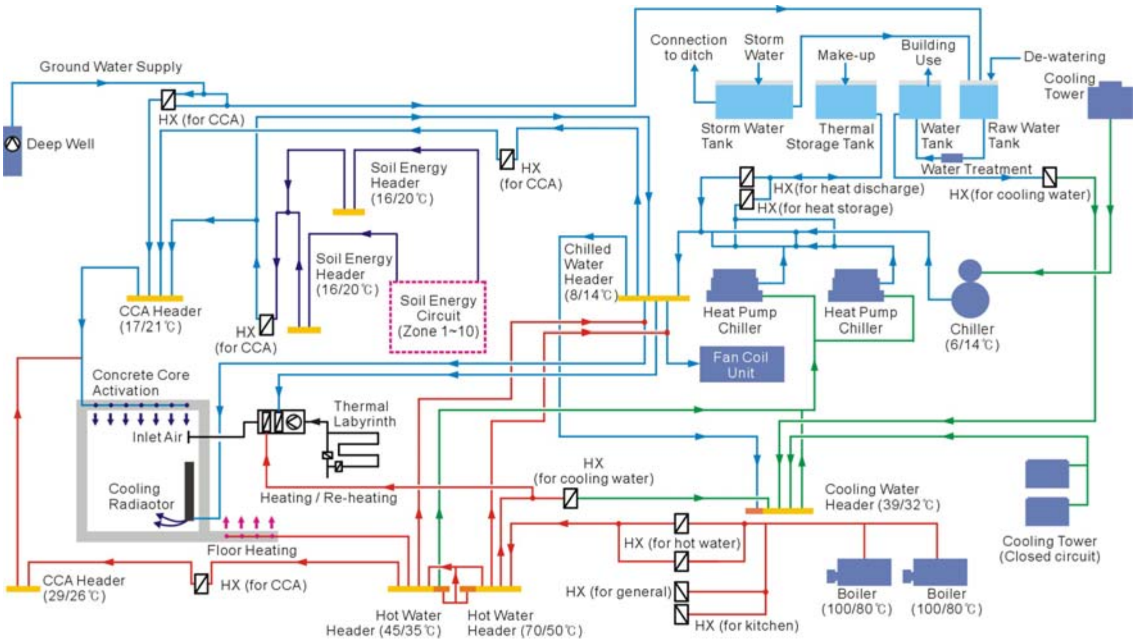

Figure 2 Central plant system diagram and equipment used for energy and water recovery

Re-cooling systems are prioritized to supply the condensate water that is exchanged with the domestic cold water and to use the waste heat from the AHU re-heating system in the summer season. In addition, if there is an insufficient capacity, the system is built to be able to control the quantity-related control of the closed circuit cooling tower.

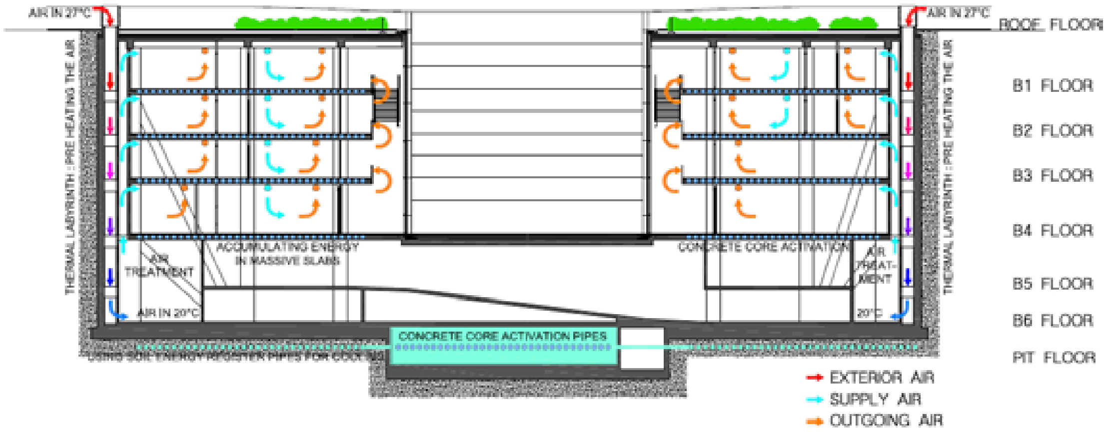

Figure 3 Section of ECC and how the design provides paths for air (cooling mode)

3. Eco-friendly and Energy Conservation Technologies

3.1 Thermal Labyrinth

The thermal labyrinth is a pre-cooling and pre-heating system supplying fresh outdoor air by taking advantage of building underground where there is a regular temperature all year round. There is no burden of extra construction cost for labyrinth structures because of the saving made in the use of a double layered space, which is necessary to install for the base structural system of earth coupled buildings. An analysis revealed that there is an approximate 10℃ pre-heating effect in winter and a 7℃ pre-cooling effect in summer, demonstrating that this system can save the energy that is otherwise required in HVAC systems for the pre-cooling and pre-heating of fresh outdoor air and can downsize the capacity of the boilers and chillers of central plants. Due to the air resistance of the labyrinth concrete structure, these benefits are greater than those gained by increasing fan power consumption.

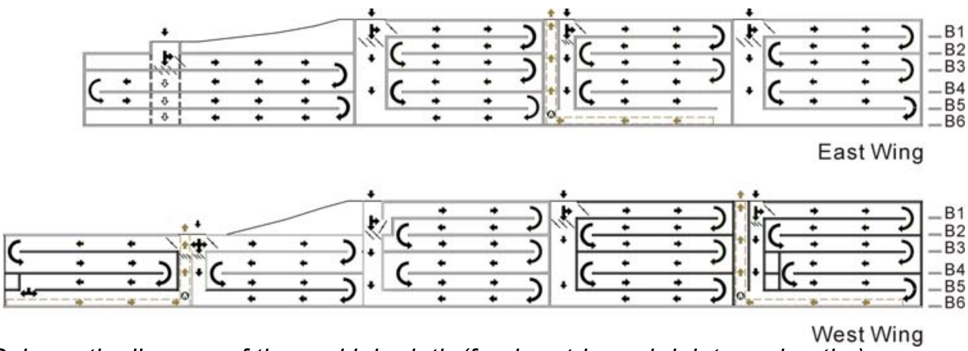

Figure 4 Schematic diagram of thermal labyrinth (fresh outdoor air inlets and paths)

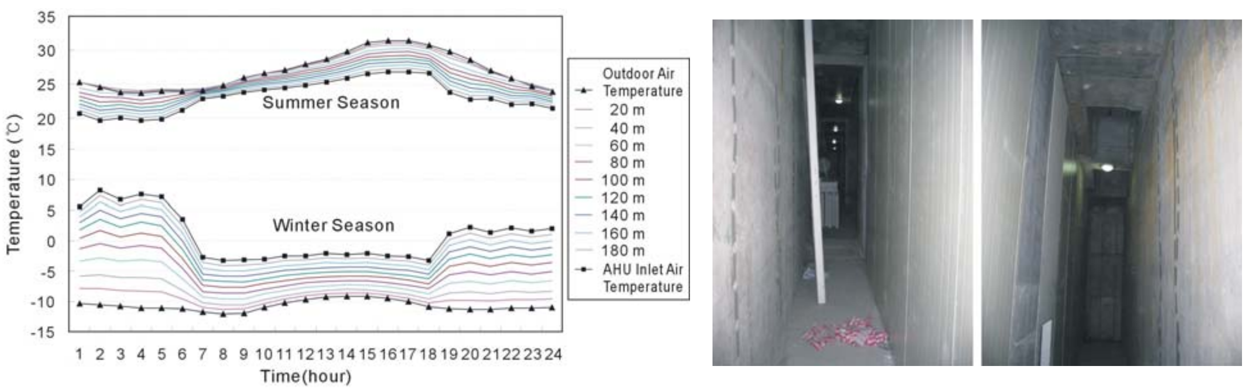

Figure 5 Effects of thermal labyrinth in summer / winter and actual figures of thermal labyrinth

For HVAC systems, during mid-season, when the outside temperature ranges from 12 to 18℃, the outdoor air is directly introduced through the vertical shaft. Conversely, a thermal labyrinth is composed of nine sections and eight outdoor air inlets. Because the ECC comprises a west wing, an east wing and a valley in the middle, the thermal labyrinth is divided into five sections in the west wing and four sections in the east wing. It is designed so that the fresh outdoor air is supplied to the two-storied mechanical room in the 6th underground floor and the heat is exchanged with the earth via the approximately 240m long soil duct connecting to the air handling units. The factors that affect the efficiency of the thermal labyrinth are thermal conductivity, density, heat capacity of the soil and the superficial area on the soil surface, resistance, the duct path of the thermal labyrinth, and the speed of air, etc. The results of an energy simulation taking these factors into account, demonstrate that it is possible to reduce the approximate 411kW peak heating load and the approximate 324kW cooling peak load. The equipment capacity of both the boilers and chillers can therefore be downsized.

3.2 Geo-thermal Energy

The main concept of the geo-thermal energy system is the use of cooling and heating source energy obtained from heat exchanged with the soil via the buried small-caliber pipes in the concrete floor slab of the 6th underground floor. During the summer season, the chilled water that has been heat exchanged with the soil is used for part of the cooling systems of the CCA and should be operated within 24 hours for thermal mass storage. The geo-thermal energy system comprises 10 different zones. In the cooling mode, the chilled or hot water is supplied through the CCA pipes for thermal mass storage and will be supplied to the hot water supply header in the heating mode. In Korea, it is known that the underground temperature regularly ranges from approximately 14 to 15℃ above a soil depth of 6~7m. The building was therefore designed so that the cooling system uses heat exchanged by the buried pipes between the concrete floor slab and the sand and gravel above the building foundation under the 6th underground floor. The temperature of the water is estimated to be about 16℃ after passing through the buried pipes and is supplied at about 17℃ via geothermal heat exchange before it is supplied to the CCA. The diameter of the pipe for the geo-thermal energy buried under the floor slab is 25mm and the pitch is 500mm.

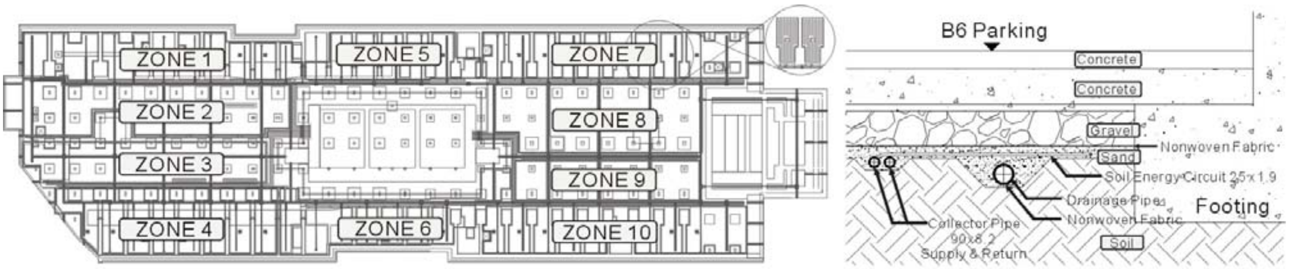

Figure 6 Plan of the geo-thermal energy system zonings and detailed schematic diagram of buried pipes

Figure 7 Construction pictures of geo-thermal buried pipes and supply header (B6F)

3.3 CCA (Concrete Core Activation)

The CCA system is the radiation cooling/heating system that controls the inside temperature by using the surface temperature of the radiation of the thermally activated building system. The system was proposed in order to save energy and to shift the peak load times due to the effect of thermal storage. Since the CCA system controls the space cooling/heating by using the radiation of thermal mass, residents are able to feel more comfortable at a higher indoor set temperature than when the conventional all air HVAC system is used. In addition, because of the low airflow rate compared to that of all-air systems, the duct works could be downsized along with the air delivery system energy. A total of four CCA zones are accommodated in accordance with the different load profiles between the inner zone and the outer zone. The inner zone is the valley area that faces the outside, while the outer zone faces the soil and the chilled/hot water loop pump zoning is separately installed. The CCA pipes buried in the concrete slab are of polyethylene material with a 20mm pipe diameter, a 150mm pitch, and are buried at a depth of 125mm from the ceiling (350mm of the thickness of the slab). It is intended that the entering/leaving chilled water temperature will be 17/21℃ for cooling and that of the entering/leaving hot water temperature for heating will be 29/26℃. Each zone area of the CCA is approximately 50~60 ㎡. From the results of simulation, considering the day time discharge efficiency (30W/㎡) and the night time charge efficiency (10W/㎡) at the early stage of design, a 60mm burial depth for the CCA in the concrete slab was proposed. A CCA system that utilizes various eco-friendly and natural energy methods uses geo-thermal energy primarily for the chilled water supply. When geo-thermal energy has insufficient capacity to serve the system, the chilled water will be supplied from the ground water or chillers. The reverse valves will control the exchange between chilled water and hot water seasonal supply in each season. In addition, a regular temperature of the CCA chilled water is maintained by primary variable speed pumps and 3-way valves in order to prevent dew condensation forming on the ceiling surface. In each room, the CCA that has buried pipes in the concrete slab controls sensible cooling and heating loads, while OHUs (outdoor air handling units) control the latent loads that are related to ventilation and dehumidification. VAV units control the airflow rate of ventilation according to the number of people in each area.

Figure 8 Detailed schematic diagram of CCA and construction pictures of CCA pipes

Figure 9 Indoor spaces of CCA system and cooling radiator

Using this method, any direct drafts from the cold air and shock from the difference in temperatures between the indoors and outdoors can be prevented. In addition, the heat generated from the human body is not rapidly eliminated, as it is with forced convection HVAC systems. Furthermore, this system can reduce the risk of dew condensation, via the latent heat load removal and ventilation. The finishing method for the ductwork is designed to reveal the ceiling in accordance with the interior concept, while the supply and return air ducts are arranged in a row. The VAV units are installed in the mechanical room in order to harmonize with the interior concept and to improve the convenience of maintenance.

3.4 Total Water Recycling System

Ground water maintained at a regular temperature is used for the heat source of the CCA operating 24 hours; after the ground water has been used for the CCA, it is collected in the water tank and is finally used for the domestic water through various steps, after being used for the heat sink of the condensate water of the cooling towers. As using ground water, the rainwater and de-watering are collected in the raw water tank, since after water clarification the heat sink for condensate water can save energy within the system. Using ground water also helps to improve the COP (coefficient of performance) of the chiller because the chiller can generate a lower temperature than that of the normal entering/leaving water temperature of cooling water. During the design stage, it is intended that the well sinking capacity will be 8.5 tons per hour and it is anticipated that the de-watering will be about 150 tons per day. The re-cooling capacity generated by the total water resource-recycling system is expected to be about 500kW.

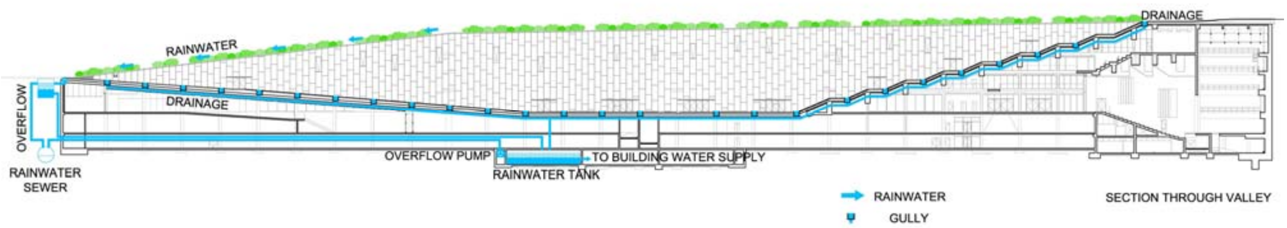

Figure 10 Use of rainwater for flushing toilets, irrigation, vegetation watering

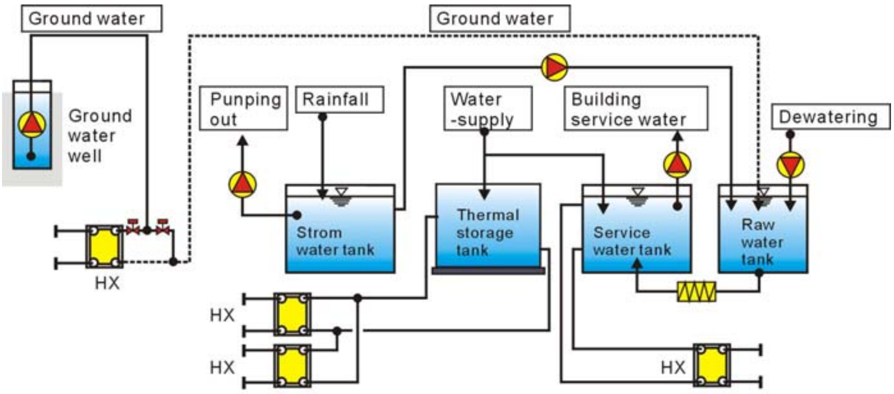

Figure 11 Schematic diagram of total water recycling system

3.5 Earth Berm: Earth-sheltered Building

As mentioned above, the optimum feature of the ECC is its massive construction for thermal storage and the application of soil energy as the source of energy. Because most of the exterior walls of the ECC are underground, the solar radiation and envelope load are effectively reduced. From an analysis of the building peak load, it is estimated that the load will be reduced by more than 20% of that of a similar sized building constructed above ground and that it is possible to reasonably downsize the capacity of the central plant equipment.

3.6 Waste Heat (from Exhaust Air) Reuse of Underground Car Parks

The air in the 6th underground floor car park is composed of the exhaust from the AHU and the fresh outdoor air for ventilation. In order to recycle the exhaust (waste) heat from the AHU into the re-cooling heat sink of the heat pump type chillers, the cooling towers for the chillers are installed on the 6th underground floor. To prevent an increase in the indoor temperature of the 6th underground floor, it is charged by heat-exchange of the soil with the underground car parks. The results of the simulation considering this condition show that during rush hour, when the maximum heat is generated from car engines, the indoor temperature of the underground car parks is maintained at under 27℃, which is the same as the entering wet bulb temperature of the closed circuit cooling tower. Therefore, the entering/leaving water temperature for the cooling tower is set at 32/39℃ and the re-cooling capacity is about 1,000kW.

Figure 12 Louvers for the waste heat reuse of the HVAC and the closed circuit cooling tower in the underground car parks

3.7 Re-heat System and Heat Recovery System for AHUs

Humidity control is very important in order to prevent dew condensation on the surface of the concrete slab, which is one of the problems of the CCA system. Dehumidified and over-cooled air is passed through the cooling coil in order to control humidity during the summer season. Hot and wet outdoor air is supplied to the indoors after again passing through the re-heating coil to meet the indoor set temperature. The re-heating energy is the recycled waste heat from the heat pump type chillers and the capacity of the re-heating coil is designed to be about 200kW.

3.8 Natural Ventilation and Green Roof System

At the main entrance of the ECC, the glass walls that face the valley are designed to facilitate natural ventilation. In addition, the green roof system on the top of the building is designed to provide places for relaxation and to reduce the cooling and heating envelope load of the indoors through the roof.

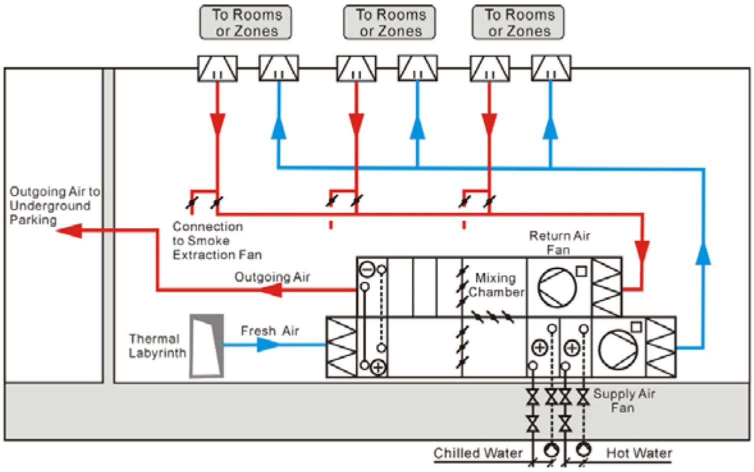

Figure 13 Schematic diagram of the re-heat and heat recovery system for air handling units

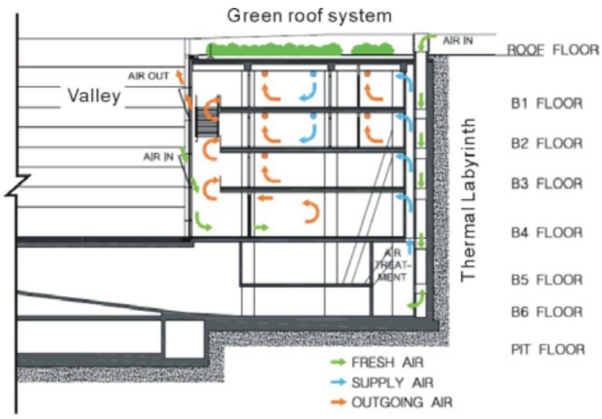

Figure 14 Outdoor air inlet windows for natural ventilation and green roof system of ECC

3.9 Water Thermal Storage System

The water thermal storage system stores (and charges) the chilled water, which is heat exchanged with the low temperature chilled water generated by the heat pump type chillers, in the stratified thermal storage tank installed under the 6th underground floor. This helps to reduce the operating cost by using the less expensive night thermal storage power service and by rapidly reacting to the load profiles. The temperature of the stratified thermal storage tank is charged at under 6℃ by the heat pump type chillers. A heat exchanger with a capacity of 840 kW for discharge is adapted.

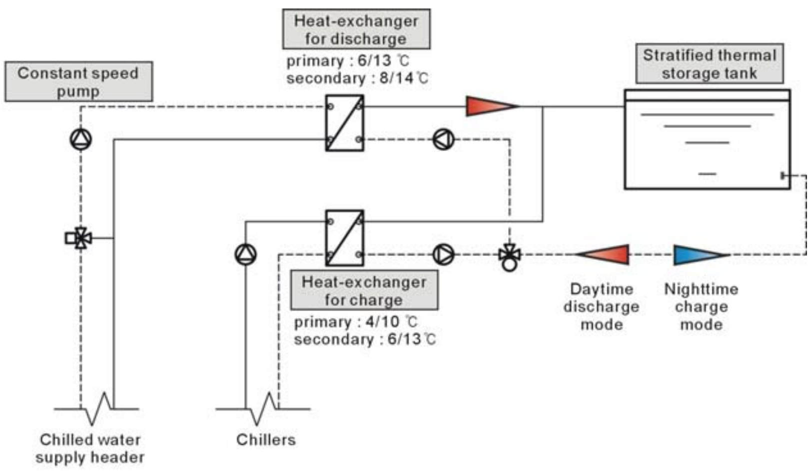

Figure 15 Schematic diagram of the water thermal storage system

4. Conclusion

In this study, the Ewha womans university campus complex (ECC), which organically connects eco-friendly and energy saving systems, is briefly introduced. The sustainability initiatives used in the design of the ECC encompass a range of well-integrated energy and water saving approaches, as well as a number of innovative techniques, such as a thermal labyrinth, CCA, and a geo-thermal energy system. Because the systems adapted in this building are somewhat unfamiliar, it is important to determine a method that will maximize the capacity to meet the climatic requirements and to be able to continuously monitor and analyze the operating data. Therefore, tests and verification of the systems are continuously required, as outlined below.

Firstly, the estimated capacity of the systems where eco-friendly and natural energy system design strategies have been integrated should be compared to the real capacity after the system has been in operation in order to detect and resolve any problems.

It is necessary to detect any problems related to the building control method by estimating the input/output energy of each organically connected system and to resolve such problems in order to create optimal operating systems.

In order to establish the concept of the design and construction of eco-friendly and sustainable buildings, it is necessary to investigate methods to improve such systems and to reduce the initial costs by improving the method of construction in order to protect the eco-system.

It is possible for eco-systems to be recovered to stable energy and water flows as macro environmental problems are solved through the removal of micro environmental problems within buildings. Consequently, when an integrative sustainable design is carried out, not only energy saving factors but also environmental factors need to be practically examined.

Acknowledgement

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Figure 1 (a 3d rendering image) from Dominique Perrault Architecture (2004)

Figure 3 from sustainability: moderate climate ventilation shame / Dominique Perrault Architecture (2007)

Figure 6 (right) from HLPP Consult (2005)

Figure 8 (a 3d rendering image) from concrete core activation-technology of the future / Velta Contec (2005)

Figure 10 from sustainability: rainwater reuse / Dominique Perrault Architecture (2007)

Figure 14 (right) from Dominique Perrault Architecture (2007)

LESSONS IN SUSTAINABLE CONSTRUCTION

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Summary

The term “sustainable construction” could be defined as a building contractor’s involvement in a sustainable development or simply the instigation of sustainable practices on a project. Understanding the associated risks, rewards and lessons learnt all come from that experience.

Understanding the levels of responsibility, cost and time can be defined as quantitative concerns. Understanding material selection, procurement processes and delivery techniques are qualitative concerns in the sense that they are of greater quality and should provide a superior result.

This paper attempts to summarize some lessons learnt over a number of sustainable or “green” projects.

1. Introduction

This paper is written from the view point of a main building contractor. It applies most pertinently to major construction projects with a sustainability agenda. However, some messages in the following would be pertinent throughout the building design and construction industry. My experience, for the most part, is that in office and hospital buildings with a sustainability agenda, some of which have pursued a *Green Star* rating.

Today’s building contractors are now involved in projects in different capacities than that of the traditional builder. It could be at the development instigation phase or, as part of a development consortium. The involvement can continue as facilities managers actually operating the facility, sometimes for up to 30 years. Building contractors are becoming involved in the whole of a building’s life.

In order to participate in the different phases of a building’s evolution, the building contractor must provide greater skills, knowledge and information than that traditionally offered.

The following provides an overview as to some of the challenges faced in sustainable construction.

2. Risk

Risk can be viewed as a challenge; it can also be viewed as an opportunity. It is all about understanding the issues presented.

A building contractor has to determine what level of responsibility they will be accepting.

There are many different contracting methods including Lump Sum, Alliance, Managing Contractor, Design and Construct (D&C) and now Public Private Partnerships (PPP). Each infers a different level of responsibility.

Many building contracts are now requesting the contractor be responsible for the sustainability outcome. This maybe measured through the *Green Star* tools, the ABGR or NABERS tools.

The Green Building Council of Australia’s (GBCA) suite of *Green Star* tools are formulated based on the building contractor being engaged on a lump sum basis with no design responsibility. Utilizing these tools under a design and construct contract can pose interpretation challenges.

The office building market is serviced by the Australian Building Greenhouse Rating scheme (ABGR) and National Australian Built Environment Rating System (NABERS) output based tools, whereas *Green Star* is an input based tool. In order to achieve an ABGR score the building must operate for a minimum of 12 months, most likely 18 months. This poses some complications to contracts with a standard 12 months defects liability period.

Risks can be seen throughout the delivery process of a commercial building, most of this paper is dedicated to the risks associated with sustainable construction.

Risks can differentiate you from your competitors, who are less informed or willing to accept the challenges.

3. Cost

Sustainable or “green” buildings typically contain 3 levels of features over that of a basic building.

(1) The ‘bolt on’ accessories typically associated with technology, such as co-generation, rain water storage or blackwater treatment.

(2) The 'increased specification' items, such as AAAA in lieu of AAA tapware, higher performance glass, substitute materials for piping, low Volatile Organic Compounds (VOC) and formaldehyde products.

(3) The 'inherent building form' items such as sun shading, thermal mass and orientation.

The 'bolt on' accessories are quite simply quantified and costed.

The 'increased specification' item can be analysed to determine any premium. However, depending on the cost drivers, this may not be undertaken for all projects.

A 'lump sum', project for example, with a clear specification for materials would not warrant a contractor performing a cost comparison. A D&C project, where the contract maybe on a guaranteed maximum price would warrant the comparison in order to determine the best value for money inclusions.

The 'inherent building form' items are more difficult to quantify.

Assumptions are made as to building mass and shading based on previous building projects versus the sustainable project in order to determine a premium. This is risky as the 'previous' project may not have suited the site. The orientation is normally accepted as good design.

As contractors continue to have more early involvement, they find themselves providing earlier and earlier cost advice. This is often termed cost planning. To do this on a "green" building requires some experience, as new technologies and methods can be difficult to quantify with out a full design.

Another aspect to "green" buildings and some others, is the concept of Whole of Life (WOL) based selections. This is where a low capital cost item may not be adopted due to higher ongoing costs. This type of analysis is commonly calculated, but once again not traditionally by a building contractor.

Some aspects within the *Green Star* tool are difficult to quantify due to the immature market. This applies to the role of the Independent Commissioning Agent whose role could vary from a $5,000 engagement to a $100,000 engagement dependant on the brief.

Our experience in commercial office buildings supports recent findings by Quantity Surveyors, Davis Langdon Pty Ltd and the GBCA, who find that a 4 star *Green Star* project attracts no cost premium. A 5 star attracts a premium between 3-5% and a 6 star project somewhere in the order of 10-15%.These findings assume that the projects obtain an as built rating and an ABGR score. It depends very much on the delivery method and scale of the project. A large design and construct project may attract less premium than a small 'lump sum' project in percent terms.

4. Materials

Sourcing materials to comply with an Ecologically Sustainable Development (ESD) brief or specification has challenges.

Initially, these challenges involve understanding the technical drivers, then locating suppliers and then verifying technical compliance. This is where the term "green wash" is real and causes building contractors confusion.

The selection of materials typically forms 3 types

- Materials with low emissions
- Materials with recycled content
- Materials with stewardship measures

Some of the lessons learnt throughout a selection of "green" building projects are that;

- Zero Ozone Depleting Potential (ODP) insulants, 20% fly ash in concrete, low VOC paints, sealants and adhesives and low formaldehyde, E1, MDF panel board are commonplace.
- Forestry Stewardship Council (FSC) certified timber and recycled structural steel is very difficult to source.
- Peak energy reduction plant like cogeneration, the use of an Independent Commissioning Agent and effluent treatment systems are expensive inclusions.

There needs to be more feedback to Suppliers, Architects, Engineers and organizations like the GBCA, from the construction industry, if the market is to respond effectively on sustainable materials. For example a tool such as *Green Star*, should in my opinion, reward best practice and some innovation. Whereas how things stand today some credit is provided for business as usual and then the rest of the criteria requires market transformation.

The best way of saving the amount of material wasted in the construction process is not to have it in the first place. By performing a waste minimization review with your design team; issues like minimizing off cuts can be reviewed by using standard sized items.

As a practical measure, a sustainable materials database with real selections can assist. Subcontractors maybe responsive to an actual complying selection.

What is mostly unknown in the construction sector, is the amount of embodied energy or water contained within our selected materials. Consideration must eventually be given to whether a product includes the transport energy from China or whether it is sourced locally.

Perhaps we should take a lead from the hospitality industry who are embracing a "locavore" principle, meaning to source produce locally, in their case from within a 10 mile radius. Can the construction industry construction source the materials required for a building is a similar manner?

5. Procurement

These days, the building contractor for a commercial property development can be contracted in many different fashions. For larger scale developments in is less likely they will be purely "The builder" working on a traditional lump sum contract with no design risk. They are more likely to be on a D&C, guaranteed maximum price (GMP), managing contractor, alliance model or now within a PPP.

These different models allow greater flexibility in procurement of subcontractors. For an outline of these different risk profiles refer section 2 of this paper.

Early subcontractor involvement can achieve tangible cost, time and quality improvements. For a "green" project the subcontractor may bring experience in the issues faced by the design and construction teams. They will also certainly bring another perspective to the discussions.

My experience in green building has shown me that all parties must cooperate in a collaborative environment. All parties will, of course, have varying viewpoints and agendas, but with the right leadership this can develop into organized teamwork which is most healthy when reviewing potential features and solutions. The suite of *Green Star* Tools certainly helps with this alignment, as long as they are not treated too much as compliance measures.

With the main contractor employed under a collaborative framework, there should then be consideration to selected specialist subcontractors joining your team. Not in a fixed price, lump sum, deemed to have included for everything model, but in an aligned collaborative model. Lump sum models can tend to lead to confrontation over allowances, diverting your focus from the real agenda.

A relationship model starts out collaboratively and can allow the subcontractors to understand the projects objectives, the main contractor's drivers and input into the desired timeframes.

This is certainly worth considering for the services trades, such as mechanical, electrical, fire protection and hydraulic services. Other useful considerations are the façade contractor, the flooring contractor and the waste removal contractor.

The services trades' impact can be over 30% of the total cost and they have more impact on the projected energy use than any other sector.

The façade contractor can assist in analyzing window selections for shading and will provide build-ability advice. The flooring contractor could range from a raised floor contractor, in a displacement ventilation project, where leakage and programming are critical issues. They could also be a floor finishes supplier who through innovative purchasing methods or products who could bring better sustainable solutions to the project. These range from increased recycled content, no PVC, whole of life modeling of selections and return the supplier end of life products.

The waste removal contractor can monitor and measure your construction waste and hopefully direct portions to varying reuse schemes in order to ensure that high waste by weight percentages are achieved. On site separation is an important consideration, it can increase your percentage recycled, but also instill a culture on site to separate. Separation could be a concrete bin, steel bin or plasterboard bin all of which would be removed by different parties and reused in entirely different applications.

The perceived resistance from subcontractors to these sustainable measures is actually based on a lack of understanding and guidance. My experience is that most parties embrace the opportunity to do improve their practices if they know the parameters of their obligations and responsibilities.

Of more relevance is the trade availability. Finding basic structural trades who want to embark on something non standard can be challenging in a heated market.

Some procurement takes more research and involvement, for example to obtain FSC certified timber. This is a chain of custody scheme of which may not have all products you require, or may require you to negotiate with a timber mill as well as a merchant.

Contracting with subcontractors can include sustainability considerations. One such method is contracting the subcontractor to the site Environmental Management Plan. Ensuring the subcontractor implements and reports on their appropriate parts on the plan, will certainly achieve a better than business as usual outcome. The subcontractors will also provide ideas and advice based on their experience elsewhere which will help the main contractor continually improve their methods.

Contracting such that packaging is returned to the supplier is also a clear message. The main contractor does not want the packaging and certainly does not want to dispose of the waste. Sending the packaging back to the supplier and hopefully the manufacturer may also promote less packaging or more innovative techniques.

6. Programming

"Green" projects can be more innovative than some other projects and as such could be more complex. This complexity needs to be considered when approaching the scheduling of the project. Questions like the lead time on unfamiliar products, the increased quality assurance and the increased commissioning and tuning all require review on standard delivery timeframes. The building may include more built form or activities with longer durations.

Depending on the method of building contractor engagement is the time taken to analyze sustainability design options. Continual modeling of options with your team is required to ensure the best for project outcome. It is acknowledged that this time is well invested up front, however must be considered on the scheduling of a "green" building.

Specific issues for consideration are; Raised floors used for displacement ventilation require a rethink on standard processes. As services are installed below the floor and access equipment cannot cross these pipes, trays and ducts, the ceiling must be installed first. Then the under floor services can be carried out, then the floor. The floor cannot typically support the weight of access equipment so any work from this new level must be performed from scaffolding.

The use of fly ash in concrete is now becoming commonplace. However the more fly ash the longer the curing times. It the case of precast panels this may leave them "on the bed" for more time which equates to higher cost.

Another specific example is the installation of black water treatment or sewer mining systems. These systems treat effluent into non potable water. For the systems to be commissioning they need the effluent to process, which will not exist until the building is occupied. A typical building contract includes "practical completion" prior to building occupancy. In a project with effluent treatment it could be 6 months before the system is operating correctly.

One issue mentioned previously is the risk of achieving the desired ABGR score. Commissioning is crucial to ensure the building operates as designed. Especially when using an Independent Commissioning Agent who reports to your Client. Depending on the project's contractual arrangement the building contractor could be responsible for ensuring or even just obtaining the ABGR score. The score cannot be achieved for a minimum of 12 months (most likely 18 months to 2 years) from building occupancy. This is necessary as the building needs to operate, as designed, through all 4 seasons. Typical building contracts include for a 12 month defects liability period which would have expired by the time obtaining a rating was applicable.

7. Auditing

Specifying the environmentally friendly products and services is one thing. Ensuring that the subcontractors are using the products is another.

Continual checking and reviewing is required to ensure the as built solution will be equal to that specified. This auditing can be done using many methods. My experience has contained some of the following;

The "green" clauses can be hidden within specifications and subcontractors may not appreciate their relevance. So highlighting their commitments in a separate document helps clear the agenda. Depending on the delivery technique the tenderer will most likely appoint a Project Manager, unfamiliar with the documentation, and an ESD precommencement meeting assists to ensure the Manager understands the subcontractor's commitments.

The collation of *as built* data, i.e. Concrete mix designs or recycling percentages should happen progressively. Obtaining the information after the subcontractor has completed their works and is on another project is difficult. Also auditing the content of this information progressively, helps you ensure correct procedures are undertaken, that your format of reporting is appropriate, and that targets will be met come the end of the project.

It is important to develop an effective management system, in order to standardize reporting. Obtaining and collating information needs a structure.

Actually contracting the subcontractor to your Environmental Management Plan somewhat empowers them to play a role in the overall solution. Auditing that compliance is then a teamwork issue.

Instigating your own environmental initiatives on site also shows leadership. Sensors in lunchrooms, bottle and can recycling, bike parks for site workers, site education and branding creates a sense of ownership and helps other "green "issues seem standard.

8. Commissioning

Building commissioning is not often done well. The activity includes testing, balancing, witnessing, record keeping and "putting to work" the systems as designed. The activity often comes under time pressure as it is the last activity often undertaken on the program.

The inherent risks of not commissioning a building correctly are exacerbated in “green” buildings as their energy use is closely monitored.

If the building is attempting to achieve an energy rating, such as the office system ABGR, ensuring the systems operate concurrently, in unison and as a whole of building would in reality, is crucial. Then ensuring they are operating as efficiently as possible to ensure the best result.

It is for these reasons the GBCA’s rating tools include for the use on an Independent Commissioning Agent to oversee the commissioning management process. This engagement should begin with reviewing the design, to ensure the team understands the time required and to oversee that the activities are undertaken in accordance with best practice. The scope of the agent’s role is still a little vague in the market place and the fees paid for such activities are not commensurate with the level of risk mitigation being employed.

The level of planning, monitoring and record keeping is often greater on a “green” project as unfortunately best practice techniques are not always implemented on other projects. It is also because “green” projects often incorporate a higher level of new technology and are inherently more complex.

Some specific issues associated with commissioning include;

- The air sealing of plenums and the building. Under floor plenum systems inherently leak, however this need close attention around the perimeter and between the zones or air highways. The façade system should also be closely inspected for leakage points.
- Daylight control systems. The systems typically involve automatic dimming and interface with an automatic blind system. The blinds close to reduce glare based on the sun angle however then the lighting levels increase to compensate.
- Metering and energy monitoring. The building’s energy data will typically be collected by the building management system (BMS). This capture of the metered energy use will correspond to the carbon dioxide output for the building. The metering can be extensive, needs to be calibrated and may need to be added to some “standard” equipment not usually remotely read i.e. authority meters.

Finally performance testing during the right climatic conditions is the only real test. Functional trials involving the running of all equipment as it should and then simulating occurrences is the best preparation for real occupancy.

9. Handover

A successful project is often measured by the handover from the building contractor to the user. This handover is no longer simply, handing over the keys. It includes training or more correctly orientation of all the features, submission of all the building records including operation and maintenance manuals, warranty schedules and *as built* drawings.

Training infers a transfer of skills with the trainee demonstrating some proficiency. Training in the building sector is more accurately described as orientation for which specialist trade subcontractors will explain the features to designated Client personnel. “Green” buildings bring another dimension to these orientation sessions. To start with the building may have employed a separate Facilities Manager (FM) who will not be aware of any of the features and will require orientation. Also, the building is likely to incorporate new technology which will be unfamiliar to those under instruction. The building contractor is more often facilitating formal sessions to ensure the activity is performed correctly and effectively. Facilitating training such that trainees take on an empowered level of ownership will ensure some transfer of responsibility.

The *Green Star* tool also includes for the provision of a building users guide, designed for the building occupant, not the building manager. This is in order for the staff and occupants to become familiar with the sustainability elements of the building’s design and for them to be more environmentally aware by i.e. commuting by public transport or where to deposit their recycling.

A method of reducing the environmental impact of all the *as built* paperwork is the use of electronic manuals. These can be scanned versions of manuals or proprietary online manuals. The manuals can save vast amounts of paper, but are also more secure; as it is less likely the manual will be removed and not returned.

As owners and tenants are becoming more aware of the cultural change new premises can deliver, the main contractor can be requested to facilitate or at least input into the successful transition of staff from one location to another.

10. Post Completion

These are activities performed after occupancy. They can include full facilities management, preventative maintenance of systems, essential services testing and reporting, building tuning and rectification of any outstanding defects.

It is also, on reflection, a time for analyzing what you have gained from the experience. Such an analysis might consider the capitalizing of marketing potential, the compiling of cost data and energy data, a more educated workforce and hopefully the establishment of a better profile in the marketplace.

The impact of an external FM contractor, employed by the building owner, on the running cost and energy rating of the facility must be considered. Various assumptions are made when modeling the building's performance. These assumptions maybe operational times, set points and demand. Modifications by the FM contractor could affect the building's eventual energy rating.

The *Green Star* tools also include for the provision of building tuning for 12 months. This is to ensure that set points are aligned to the design specification and that systems are operating to suit climatic conditions. This is a quarterly activity over and above maintenance. It is good practice for the building contractor to forward results of this tuning via the Consulting Engineer and the Independent Commissioning Agent for input and advice. This extends the involvement of the building contractor, albeit as required, throughout the defects liability and maintenance period.

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TOWARDS A SUSTAINABLE ASSESSMENT OF THE BUILT ENVIRONMENT

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Introduction

After a long period which can be qualified as an acculturation time all the Construction Sector agrees to wish an instrumentation of the sustainable development concept. The practitioners want to be able to make technical choices as well as to take architectural or urbanistic options in accordance with a more balanced development of the urban fabric.

We do not wish there to devaluate the tools implemented during this learning process for environmental grading. But it is time to rethink the construction process and to encompass a real sustainable approach of measurement.

To progress in this direction we must take a two steps reflexion.

1. How to structure the sustainable development dimensions?

Within the several attempts to improve a sustainable urban development we can find the same requirement: we must harmonize the different decision scales.

1.1 The urban context

Everybody recognize that a single sustainable building is not able to fulfil the sustainable requirement for a city block. It is not enough to build a friendly environmental construction to be sure that the building answers the social need of the neighbourhood.

The building must also improve the urban services and the attractivity of the area to achieve the end-user satisfaction.

These global requirements are not issued from the construction supply chain. They are basically the result of urban planners who respond to the political power. And this decision process is established at the city level.

The construction professionals cannot influence this political choice. They only can answer this will in a better way. We must conclude that the main period to improve a sustainable construction in the brief.

1.2 The construction process

We are not saying that the professionals should not contribute to a sustainable development. They only can improve the initial choice. They can help the decision making process without to disturb it. The builders are able to optimize the technical solutions for a specific use of the project.

So the more significant attitude for an improvement of the construction process is to contribute to a more lisible fitness for use.

Saying that we confirm that the professionals are not concerned by the destination of the construction but they must show to their clients the consequences of the initial decision.

At the building scale the sustainable assessment needs a functional review.

2. Towards a coherent measurement frame

To implement the previous principles we need to combine two aspects of a building: the fulfillement of use requirements and the consecutive sustainable impacts during the life cycle.

2.1 The functional approach

For a sustainable development of the urban fabric each building must be designed to support the end users activities.

To assess the result it is possible to determine how the construction fulfils seven use functions answering seven questions:

Does the building:

1. Provide space?
2. Provide an indoor climate?
3. Provide safety and security (integrity)?
4. Allow use of goods and tools?
5. Control the nearby relationship (privacy)?
6. Take advantage from the site without damaging it?
7. Provide sense (semiology)?

These use functions have been defined by a working group in 1980 using a functional analyse methodology[1].

2.2 The deployment impacts

They characterize the building in use during its life cycle.

Another working group has defined the criteria which can elicit and cover the three dimensions of a sustainable development: the economic issues, the social issues and the environmental issues.

This think tank proposed in 1990 the following nomenclature[2].

Characterizing the initial construction phase

- Permit technical and economical optimization:
  - Ability to fulfil the functions (1)
  - Impact on the financial capacity (2)
  - Logistics for the setting up (3)
- Provide it with acceptable setting up conditions:
  - Working conditions on site (4)
  - Impact on the personal valuation and on employment (5)
  - Pollutions due to the construction site (6)
- Reach minimized resources withdrawals:
  - Impact on the raw materials withdrawals (7)
  - Impact on the energy resources withdrawals (8)

Mastering the operation phase

- Guaranty the preservation of the use functions:
  - Service life duration (9)
  - Optimized up-keeping and maintenance (10)
  - Limited consumptions and rejections (11)
- Control the management of the interfaces:
  - Access cost to collective services (12)
  - People safety and health (13)
  - Immaterial features (new technologies networks) (14)
- Take part and contribute to the urban life:
  - Interconnections, transportation means (15)
  - Integration of short distance services (16)
  - Integration of avoided costs (17)
  - Impact on the patrimonial value of the place (18)
  - Impact on the natural environment (19)

Managing the upgrading, the retrofitting and the dismantling phases

- Permit refurbishing and retrofitting:
  - Ability to adaptation (20)
  - Ability to shift to another use (21)
  - Feasibility of upgrading the performances (22)
- Authorize dismantling:
  - Ease for demolition (23)
  - Ease for dismantling, sorting, re-use (24)

Therefore we obtain the sustainable assessment frame as the matrix defined by the two views of analysis: (a) the functional aspect and (b) the sustainable dimension

	Sustainable criteria (24)
Functional requirements (7)	Assessment matrix (7 x 24)

The main interest of this proposal is to provide the frame analysis of the building efficiency.

This concept has been introduced by the WBCSD. It is defined as the ratio ($\sum$ values/$\sum$ impacts)[3]. The assessment matrix answers this definition and allows new development to produce a significant indicator for a sustainable building. The values are brought by the performances level of each use function. The impacts for each value are defined as the level of responding to the sustainable criteria.

In another hand this proposal is in discussion within the ISO/TC 59/SC 17 sustainable building construction.

Conclusion

We believe that the improvement of the construction sector should be the result of three assertions:

- A building contributes to a sustainable development, when designed and operated for just matching the appropriate fitness for use, through the fulfilment of use functions, with minimum adverse environmental impacts, while encouraging improvements in economic, social and cultural aspects at local, regional and global levels.
- As a first statement, it means that a sustainable building is a building whose technical performance must be seen as an answer to a social demand: a building makes sense when and only when it is undertaken in order to meet objectives expressed by or for the users. It should be planned to provide the expected services, and this long term view can only be due to the owner, either local authority, or housing builder for social renting, or private investor. The designers and constructors come in a second step, and their role is to suggest technical solutions to meet the programme, but always considering the impacts of the technical choices on the three aspects of sustainability: environmental, economic and social/cultural.
- Consequently, as a second statement (and provided that the first one is achieved), a building is the one for which the relevant questions addressing all the stages of its life cycle have been raised at the initial stage by the owner, and answered through the technical and process choices described in the brief.

We hope promoting these principles to act as responsible professionals involved in a reengineering approach of construction.

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[3] World Business Council for Sustainable Development

IMPROVING SUSTAINABILITY OF BUILDING BLOCKS BY EXTENDED USE OF DECENTRALIZED COMBINED HEAT AND POWER SYSTEMS

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Keywords: area-wide energy utilization, decentralized combined heat and power (DCHP) , load levelling, business and living continuity plan (BLCP), benefit-cost ratio (B/C), non-energy benefit (NEB)

Summary

To achieve the Kyoto Protocol target, the concept of area-wide energy utilization system is proposed in terms of sustainability of the built environment. The key items of which are; 1) electric and thermal load levelling by block-scale load aggregation, 2) installation of decentralized combined heat and power (DCHP) system, 3) installation of private electric wire and thermal interchange pipelines in the block
Total energy performance is expected to be remarkably improved along with contributing business and living continuity in emergencies such as disasters within the block. This paper proposes policy measures to promote building block scale DCHP systems based on feasibility studies conducted to some existing blocks in a highly-density city such as Tokyo.

1. Study background and objectives

In Japan, the formation of sustainable cities requires measures on various scales, including buildings, blocks, and districts and cities. To achieve the targets in the Kyoto Protocol is a particularly urgent task for mitigation of global warming. In the building field, approaches on the level of individual buildings are not enough and initiatives for area-wide energy utilization are required to make cities save more energy and emit less carbon dioxide (CO_2). Meanwhile, all cities share the agendum of improvement to heighten their safety, comfort, and resiliency to disasters, and increase their vitality.
Based on this background, this research considered steps that would enhance urban sustainability in the aspect of energy systems.

2. Major national policies and focused tasks

The promotion of "CO_2-saving urban design" was positioned as one of the key policy directions in the Kyoto Protocol Target Achievement Plan[1)], which was prepared in 2005. National policies[2), 3)] announced in 2007 set forth area-wide energy utilization and balanced linkage between decentralized combined heat and power (DCHP) systems and large central grid power networks. The New National Energy Strategy[4)] formulated in 2006 and the National Plan for the National Land Sustainability Plan[5)], on the other hand, emphasized the importance of efforts to heighten the sustainability of the life and business basis in cities. More specifically, they called for response to diversifying risks associated with accidents and natural disasters, and approaches to self-help, mutual aid, and public assistance measures to assure safety and security.
In light of these policies, this research focused on the energy supply, both in normal times and in emergencies, centered around extensive application of DCHP systems, and took up the following two tasks as subjects of priority action.

1) Promotion of initiatives in cities to mitigate global warming
   Promotion of area-wide energy utilization and load levelling on the block scale which is effective for saving energy and reducing CO_2 emissions
2) Contribution to the continuity of business and life functions in cities in emergencies such as disasters
   Promotion of the spread of power source equipment for use in both ordinary times and disasters, and multiplexing of power sources in order to prevent and mitigate disasters

The target energy system rests on the installation of certain city blocks with DCHP systems that would convert primary energy (in forms such as natural gas and natural energy) to heat and power (i.e., thermal energy) for utilization on an on-site, on-demand basis. Their operation in coordination with the large central energy supply networks would contribute to the formation of cities with a higher overall sustainability.

3. Feasibility study of DCHP systems

3.1 Concept for introduction of DCHP systems

This research included a feasibility study (FS) conducted for blocks where area-wide utilization of DCHP systems for the aforementioned reasons could be expect to induce significant effects. The purpose of the FS was to check those effects and ascertain tasks for actual installation. It was premised on system construction with technology currently available on the commercial level, and considered types of technology that could go into diffusion with proper policies for support to this end.
The main concept is described below.

1) Heat and power interchange within building blocks
The ability for interchange of electrical heat and power among buildings on the block level could be expected to assist load levelling, which is difficult to achieve through action in units of individual buildings, and improve load efficiency. It could also be anticipated to enable avoidance of low-efficiency partial-load operation of facilities and equipment and allow efficient operation even in the face of fluctuation in respects such as weather, times of building operation, and amount of natural energy supply.
2) Medium- and large-scale gas engines with a high generation efficiency
Central city blocks have a significant scale of energy demand, and this demand is usually characterized by a high proportion of electrical energy relative to thermal energy. In such cases, the installation of DCHP systems powered by engines fuelled with natural gas with a medium or high generation efficiency (some models have an efficiency of over 40 percent (HHV basis)) would enable high-efficiency operation at a favourable load.
The above mentioned concept is shown in Figure 1.

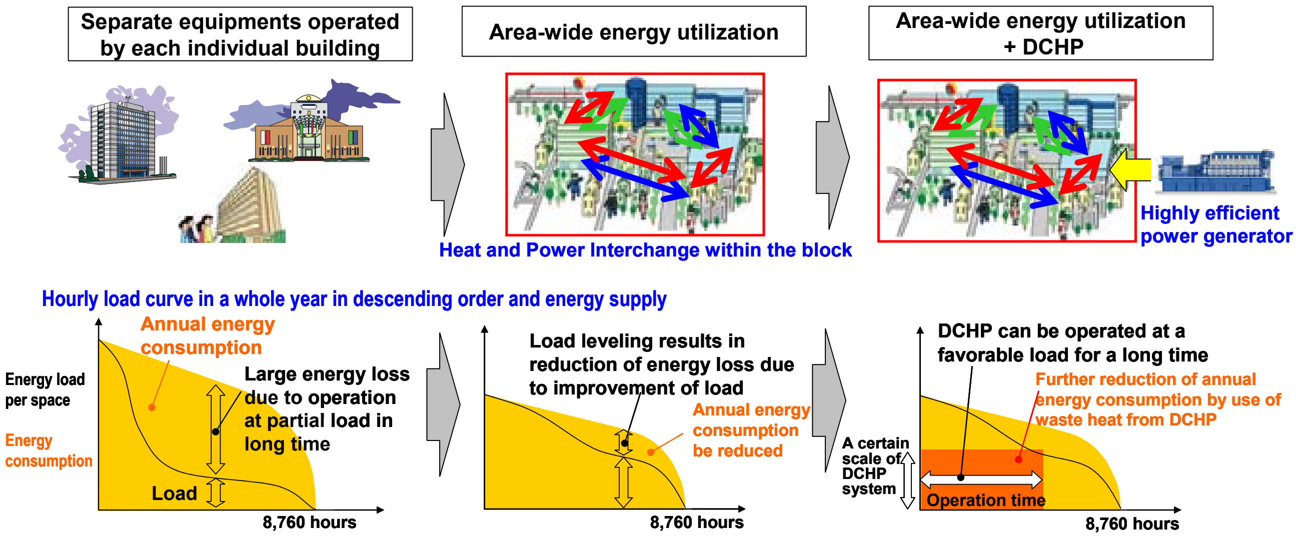

Fig.1 Image of area-wide energy utilization and with decentralized combined heat and power systems

3) Connection with the large central energy supply networks
The DCHP systems would be used to generate power in both normal times and emergencies. This would make it possible to have power sources fuelled with city gas (supplied by high-reliability medium-pressure networks) to back up the power supply, and thereby help to prevent and mitigate disasters on the block level. Figure 2 presents an image of this proposal.

3.2 Building blocks models in the FS

The FS took up a few actual city blocks which have a certain density of business/commercial buildings and apartment buildings. From the perspective of energy system planning, the blocks were classified with reference to differences in the following three aspects: 1) development status (new/existing), 2) presence/absence of district heating and cooling (DHC) facilities, and 3) character (business only/business-residential hybrid).

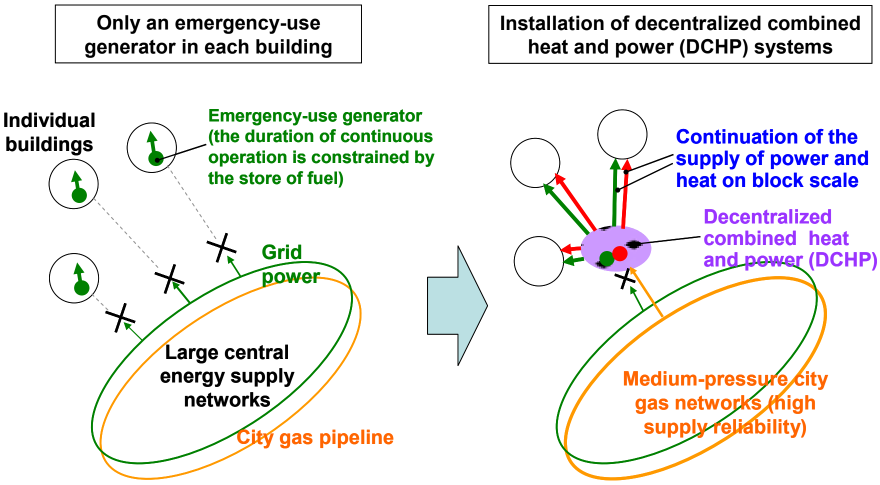

Fig.2 Image of power supply backup in emergencies

Of the blocks examined in the FS, this paper describes the findings for the three noted below. Table 1 shows the main data for each block, and Figure 3, models for area-wide energy utilization including our concept by extended use of DCHP systems in each block.

Table 1 Major data for the blocks in the FS (example)

Category	New	Existing	
	Block A	Block C	Block E
	New area-wide development	Interconnection of existing DHC systems	Connection of existing building
Block area	5.2ha	15.1ha	0.9ha
Total floor area	328,000 m^2 (4 buildings)	856,000 m^2 (15 buildings)	49,000 m^2 (4 buildings)
Block characteristics	Newly developed multiuse block with public facilities designated as evacuation shelters	Proximity of 2 zones served by DHC and 1 point heat supply (to hotels, office buildings, etc.)	Established urbanized district with a mixture of housing and business/commercial facilities
Heat load density	18,200 GJ/year･ha	36,000 GJ/year･ha	10,400 GJ/year･ha
Maximum power demand (at an emergency level of 2)	Normal times: 9,700 kW Emergencies: 2,743 kW	Normal times: 42,695kW Emergencies: 13,691kW	Normal times: 1,627kW Emergencies: 237kW
Energy system concept	Top runner model providing for a mix of uses with consideration for load leveling in the entire block, also taking into account use of natural and as yet unused energy	A model based on connection of the adjacent existing DHC systems with heat interchange pipes and a micro grid, for expanded area-wide utilization	A model for area-wide utilization based on heat interchange and a micro grid among adjacent buildings, upon rebuilding of residential facilities
Postulated case	A1 (Comparison standard) Grid power + single-building heat sources A2 Grid power + area-wide heat interchange A3 Decentralized energy systems + grid power + area-wide power and heat interchange (Decentralized energy system generation capacity: 1,840 - 9,700 kW in cases A3-1 - A3-3)	C2 (Comparison standard) Current systems C3 Decentralized energy system + grid power + area-wide interchange of heat (use within the DHC areas) C4 Decentralized energy system + grid power + area-wide interchange of power and heat (entire block) (Decentralized energy system generation capacity: 22,300 - 43,300 kW in cases C4-1 - C4-3)	E1 (Comparison standard) Current systems Grid power + single-building heat sources E3 Decentralized energy system + grid power + area-wide interchange of power and heat (Decentralized energy system generation capacity: 250 - 700 kW in cases E3-1 – E3-3)

Block A: New area-wide development

As an example of city blocks that are subjects of redevelopment plans, we selected a block anticipated to undergo integrated improvement that contains facilities also designated as evacuation shelters (a primary school and a sports center).

Block C: Interconnection of existing district heating and cooling (DHC) systems

This block contains some DHC facilities installed adjacent to each other, has one of the highest demand densities in central city, and lacks DCHP systems. It offers good prospects for remarkable improvement of energy performance around the building blocks as a whole.

Block E: Connection of existing buildings
This block is a mixture of business facilities and housing. It is smaller than blocks A and C, but is a typical case found in central city.

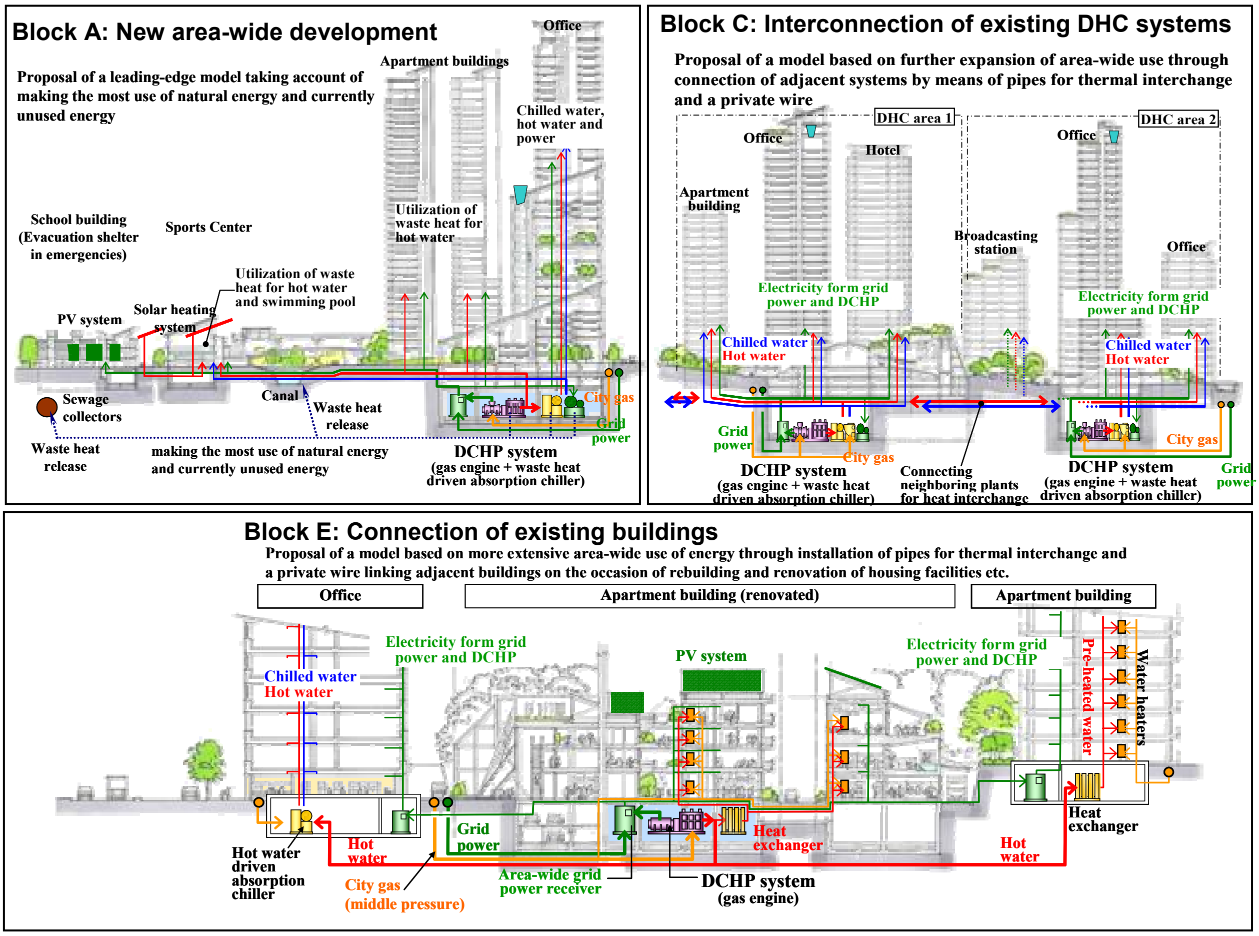

Fig.3 Characteristics of the model of building blocks and DCHP systems proposed in the FS

4. Feasibility study overviews

4.1 Assessment procedure

For the energy demand in each block, we assembled the prime units of demand and load fluctuation pattern in each category of use within each block based on the findings of preceding studies. This provided basis for the preparation of fluctuation patterns for the load demand in each time period on typical days (weekday/holiday) in each month for the block as a whole. This was followed in turn by appropriate selection of the division of capacity/number of units of DCHP systems and various heat source equipment in correspondence with these patterns, calculation of items related to the gas engine operation in each period (such as the amount of power generated, amount of waste heat utilization, amount of heat supplied by the various heat sources, and auxiliary equipment), and calculation of annual totals.
For each block, we postulated a baseline case of mutually separate heat sources in each building, and some cases of DCHP system capacity. These cases were studied to ascertain effects for energy conservation, CO_2 emission reduction, contribution to business and living continuity plan (BLCP; to be described below) for preparedness in emergencies, and benefit for cost.

4.2 Results of the energy conservation and CO_2 emission reduction

Figure 4 shows the effects for reduction of primary energy consumption and CO_2 emissions in each case studied. Basically, the calculations yielded energy-conserving effects of 10 - 20 percent and CO_2 emission reduction effects of 15 - 25 percent.
Key findings are that the effects for reducing energy consumption and CO_2 emissions rise with the capacity of the DCHP system and that the effects are also higher in blocks that are newly developed or otherwise offer a higher degree of design freedom (e.g., Block A) or have a larger subject area (Block C).

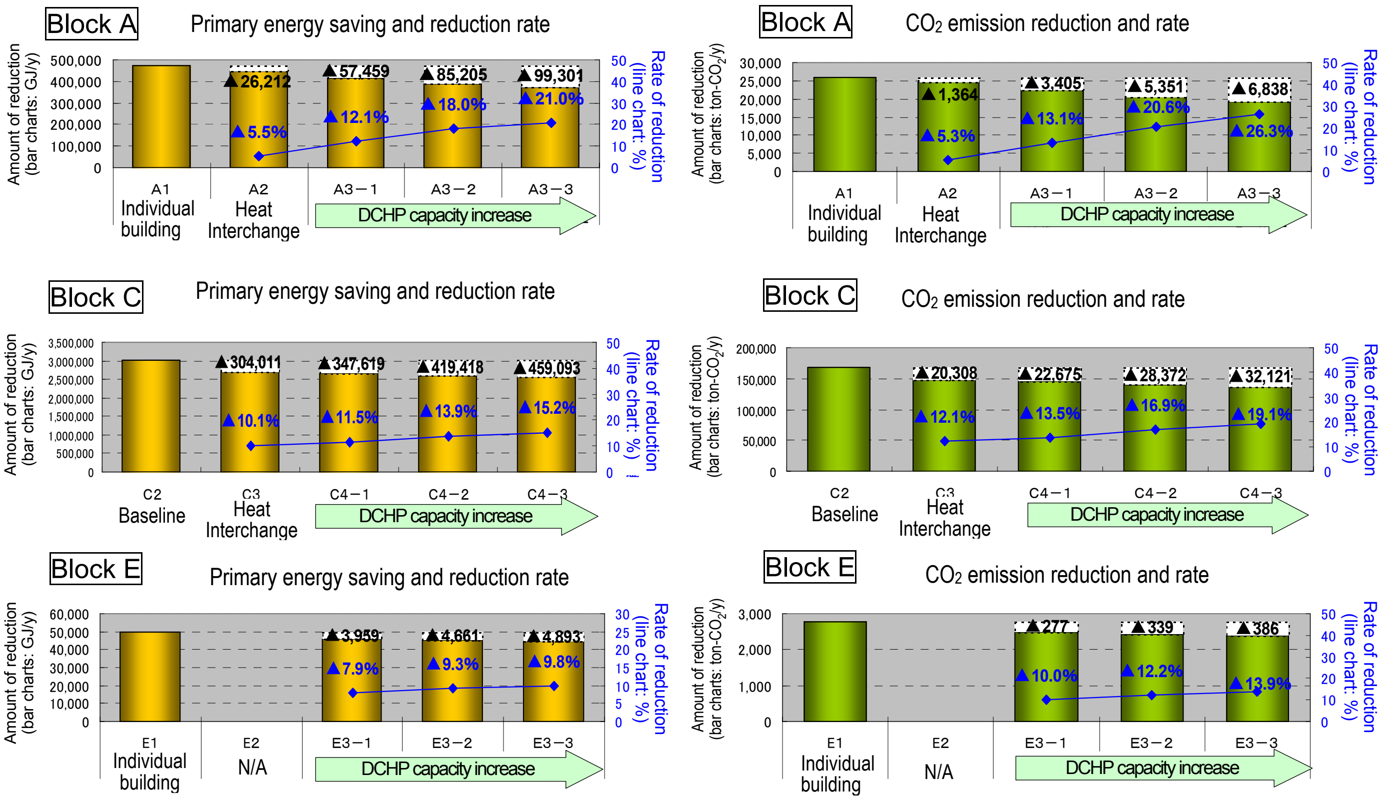

Fig.4 FS results - Rates of reduction of primary energy consumption and CO_2 emissions in each case

4.3 Assessment of energy related to BLCP contribution

Adding the element of consumer life to the well-known concept of business continuity plan (BCP), this research assessed the degree of contribution to business and living continuity plan (BLCP) in the energy aspect. BLCP was defined as the determination of systemic and environmental arrangements on the block level enabling the maintenance and prompt restoration of the minimum requisite business and life activity functions, in preparation for disasters and other emergencies.

Differences of disaster magnitude are reflected in differences in respect of the degree of lifeline damage and restoration and the functions sought on the demand side. We distinguished the following emergency levels based on the duration of energy (power) supply suspension, by referring to data from sources such as the tables of disaster statistics released by the Cabinet Office[6].

Level 1: Temporary suspension due to damage from wind/water, snow, human accidents, etc. (duration of suspension: in the range of a few hours to about 1 day)

Level 2: Long-term power outage due to earthquakes, etc. (duration of suspension: in the range of 1 day to several days)

First, we estimated the power demand required for each building in emergencies of each level. This was done by calculating the power capacity rate by application for each activity. For the power demand in emergencies, we tentatively set levels of power supply to buildings as a whole by dividing demand and totaling the amount for each component.

Next, a totalization was made for the requisite continuous energy demand in emergencies in the entire block. This was followed by a trial calculation of the extent of coverage of this demand by DCHP systems fuelled with medium-pressure city gas and capable of use in normal times as well as emergencies. This extent was taken as indicative of the emergency energy supply rate (degree of power self-sufficiency in the entire block), and was calculated as follows.

$$\textbf{[Power self-sufficiency]} = \frac{\textbf{[Continuous supply capacity in emergencies (in the entire block)]}}{\textbf{[Continuous power demand in emergencies (in the entire block)]}}$$

Figure 5 diagrams the situation in the event of a Level 2 emergency in Case A3.

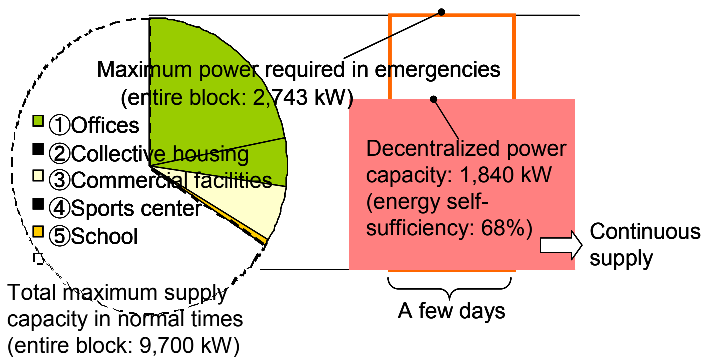

Fig.5 Example of power self-sufficiency in the entire block in emergencies

Calculation of the emergency energy supply rates in the representative cases in blocks A - E yielded rates of about 180 percent for Case A3-2, 200 percent for Case C4-3, and 105 percent for Case E3-1. In each of these cases, the system composition is an excellent one in terms of environmental performance and benefit-cost ratio (to be described below). This research confirmed that the proposed energy system concept with a power self-sufficiency rate of over 100 percent would make a vital contribution to BLCP as well.

4.4 Assessment of B/C taking account of diverse benefits

The FS found that the installation of DCHP systems on the block level could be expected to yield reduction effects for energy consumption and CO_2 emissions beyond those on the level of individual buildings. To promote such approaches, it is essential that the concerned parties in the block have sufficient economic motivation. This research consequently made an assessment of the benefit for cost (B/C) with a focus on non-energy benefits (NEBs).
According to documentation[8)], NEB is a collective term for various indirect benefits that are distinguished from the direct energy benefit (EB) of reduced utility costs and tend to be neglected in assessment of initiatives, such as the indirect economic benefits and environmental preservation benefits induced by the initiatives.
While it would be difficult at present to make a quantified assessment of all NEBs in an assessment of the effects of area-wide utilization of DCHP systems, the items of assessment in the limited scope that can be immediately examined are as follows.

1) Reduction of power, heat, and water costs (EB)
   The ability to avoid operation of various facilities and equipment at partial load and operate them on a long-term basis at favourable load would presumably increase the efficiency of energy utilization and lower these utility costs.
2) Reduction of facility management costs (EB)
   Conservation of labour due to the consolidation of facility management capabilities could be expected to lower the operation and maintenance costs for energy facilities and equipment in buildings.
3) Contribution to mitigation of global warming through CO_2 emission reduction (NEB)
   The reduction of CO_2 emissions accompanying energy conservation would contribute to efforts to mitigate global warming, which is an urgent international agendum. It would also engender an economic benefit due to emission reduction in the event of a future allocation of emission quotas in units of companies.
4) Contribution to BLCP in emergencies (NEB)
   The installation of DCHP systems would lead to the formation of highly reliable systems supported by back-up power sources and other elements. As such, it would contribute to enhance BLCP in emergencies such as storm and earthquake disasters, and consequently alleviate the economic loss.

The following equation was applied in assessment of B/C. Here, C refers to the sum of the initial and running costs.

Benefit-cost ratio (B/C) = (EB + NEB) / C

When the ratio exceeds 1, its size may very well determine the degree of priority for adoption. The following are the assumptions applied in the B/C calculation.
- Service life of facilities and equipment: 15 years
- Service life of heat interchange pipes: 45 years
- Discount rate: application of a rate of 4 percent, which is generally applied in society as a whole
- Applied period of B/C calculation: calculated in 5 years, 10 years, 15 years and 45 years respectively

- Market price per ton of CO_2 emission reduction: 2,000 yen/t-CO_2
- Probability of occurrence of emergencies in Tokyo (levels 1 and 2)
  Level 1 (Temporary suspension due to damage from wind/water, snow, human accidents, etc.)
  Division of the total number of lighting and power customers by the average number of households that experienced outages due to damage from wind/water or snow over the three-year period beginning in 2004 based on data from sources including the disaster information tables of the Cabinet Office [6] yielded an occurrence probability of 0.057.
  Level 2: (Long-term power outage due to earthquakes, etc.)
  Corresponding calculation based on data from sources including Source [9] yielded a probability of once every 115 years (= 0.0087).
- Outage cost: based on the source[7] documented data The saving from avoidance of this cost was added to the NEB quantification.
- Other initial and running costs were set on appropriate levels based on various design cases.

Figure 6 shows the example results of the B/C calculation for Block A, A3 cases as an example of trial calculation. It is thought that area-wide utilization of DCHP systems would increase the benefit and afford a B/C significantly higher than 1. While the aforementioned effect for reducing energy consumption and CO_2 emissions rises along with the capacity of the DCHP system, there is a trade-off with B/C, which may peak at a certain level of capacity.

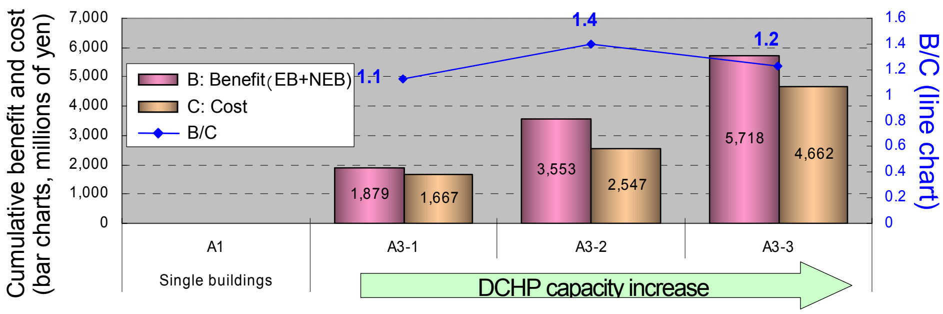

Fig.6 Example of FS assessment of benefit-cost ratio (A3 cases)

5. Policy proposals to promote initiatives for area-wide energy utilization

5.1 Business structure and role of stakeholders

Area-wide energy utilization as described in this paper cannot be achieved without proper plan and operation of projects on a foundation of cooperation by the stakeholders in the block. We therefore examined incentives for the stakeholders based on actual recent projects which are regarded as successful cases, and on the knowledge of persons with experience in promoting such projects.

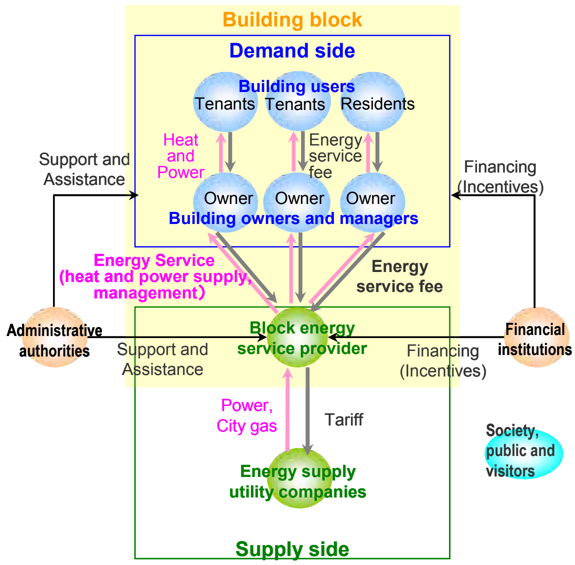

Fig.7 Conceptual diagram of stakeholders and roles in area-wide energy utilization

Table 2 Example of EB and NEB

Benefit / Stake-holders	Energy Benefit	Non Energy Benefit (Example)		
		Effect on global environment	Risk reduction against disease	Others
Demand side	• Reduction of heating and lighting expenses	• CO2 emissions reduction	• contribution to BLCP* in emergencies	• additional rentable space • improvement of landscape
Supply side	• reduction of supply cost • improvement of service standards		• adding options of energy supply in emergencies	• load leveling • flexible utilization of natural energy
Government and society		• contribution to deal with global warming	• realization of town well prepared for emergencies	• motivation of people by showing advanced model

(*BLCP: Business and Living Continuity Plan)

Figure 7 presents a conceptual diagram of the roles of stakeholders in the context of such cooperation. Besides the energy utility companies (i.e. electric power and city gas companies), we assume a block energy service providers (ESPs) supplying power and thermal energy within the building block.
Table 2 shows sample results of a tentative identification and classification of EB and NEB to encourage each stakeholder. In addition to disaster prevention and mitigation, the NEB presumably includes an increase in the efficiency and sophistication of energy system management, and reduction of project risks due to commitments by the national government and other authorities. Other NEBs should be considered further in the future study.

5.2 Proposal of policies for support

Based on the results, it formulated the following proposals to be considered for designing policy in five aspects to assist the resolution of these problems and rooting of the business model in the market.

1) Mechanism for consensus-building: offer of incentives to stakeholders (building owners, tenants, residents, etc.), assessment of the applicability of DCHP systems, and establishment of verification technology
2) Deregulation and regulatory modification: incentives such as deregulations on cubage rates for initiatives that greatly conserve energy and reduce CO_2 emissions on the block level
3) Provisions for support (project certification/administrative support): support to promote active use of the existing urban infrastructures (underground pedestrian passageways, subways, etc.) for installation of pipes for heat interchange, etc.
4) Provisions for financial assistance: assistance with enterprise investments, support for reduction of risks, and assistance beginning with the stage of studies of area-wide energy utilization.
5) Guidelines: formulation of guidelines for urban improvement to encourage application of DCHP systems

6. Conclusion

This paper proposes policy measures to promote area-wide energy utilization by extended use of DCHP systems on the block level with a view to mitigating global warming. Through FS for some cases, it is confirmed that such utilization would have effects for conserving energy and reducing CO_2 emissions which could not be induced by mutually separate systems on the level of individual buildings.
It was also shown that the proposed DCHP systems would contribute to business and life continuity plan (BLCP) for emergencies by investigating the degree of energy self-sufficiency. In addition, to design the policy measures, it suggested the importance of taking account of such non-energy benefits (NEBs), and indicated the possibilities for a further increase in benefit-cost ratio (B/C).

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TITLE: MEETING THE ENERGY CHALLENGE OF CITIES: FINDING SOLUTIONS THROUGH DISTRICT ENERGY AND GREEN BUILDING

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Summary

In response to increases in the cost of fuel and concerns over greenhouse gas emissions, there is renewed interest across Canada for the potential to integrate district energy and high performance (green) buildings to achieve a transition to a more healthy, balanced and sustainable way of building communities. To illustrate how district energy can contribute to emission reduction targets, as well as achieve community economic growth and land-use objectives, nine best practices in Canada were assessed for their capacity to achieve sustainable urbanization objectives. The review included an assessment of how district energy systems could be effectively integrated with high performance building. For communities to capture the mutual advantages and goals of district energy and high performance building, three key steps were identified including assessing sustainability at the community level, use of integrated energy planning and working to ensure local building rating systems account for the efficiencies provided by district energy.

1. Introduction

As world demand for fossil fuel increases and as energy supplies become harder to access, the price of energy is expected to rise. It is also anticipated that jurisdictions without a secure and steady supply of indigenous energy sources will be vulnerable to unpredictable energy markets. The implication for local governments and businesses is that inexpensive energy for use in heating, cooling, industrial processes, transportation and electricity generation will be at a premium. To help cities maintain a high quality of life for residents and an attractive investment environment for business, changes will be required to how we heat, cool and power buildings and communities. In Canada, there is renewed interest in the application of district energy by all levels of government and the development community to address rising energy costs, meet increasing energy supply demands, encourage the use of local alternative and renewable fuels, and lower greenhouse gas and other air emissions.

To assist communities with addressing their energy supply and infrastructure challenges, the Canadian Urban Institute, Canadian District Energy Association, and the Toronto Atmospheric Fund formed the Urban Energy Solutions (UES) infrastructure research partnership. The UES initiative set out to identify the challenges to the advancement of district energy across Canada, and demonstrate how district energy could contribute to local community infrastructure and energy conservation in urban regions.

This paper examines how applications of district energy studied during the UES initiative are contributing to community sustainable development by highlighting several best practices in Canada. The paper also outlines how district energy can be incorporated with high performance (green) building development to achieve improved energy efficiency. It concludes with a set of steps that can be used to assess the contribution of district energy and high performance building for achieving sustainable development objectives.

1.1. Managing Energy in Cities and the Role of District Energy

Cities represent less than one percent of the earth's total surface; however, urban activities around the world generate close to 80 percent of all carbon dioxide (CO_2) emissions, and use nearly 75 percent of all energy produced (United Nations Environment Program and United Nations Habitat, 2005). More than three-quarters of Canadians currently live in cities, and it is estimated that by 2020 that number will increase to 85 percent or more (Canadian Urban Institute, 2008). The current 80:20 ratio is the exact opposite of the urban-rural split a century ago. Although a significant portion of energy consumed and greenhouse gases (GHGs) emitted in cities is due to transportation, the built environment accounts for almost 30 percent of all energy consumed in Canada (Government of Canada, 2006) and nearly 30 percent of all GHGs emitted (Canada Green Building Council, 2006).

In response to the continuing growth of cities, many communities are attempting to incorporate sustainable urbanization practices such as creating land uses that support higher density populations, encouraging localized energy generation and distribution, enhancing local ecosystem integrity, minimizing air and water pollution, encouraging the use of public transportation, improving energy efficiency in the built environment and industry practices, as well as use better community energy management strategies, such as district energy (Williams, 2004).

District energy systems work to manage the energy needs of a community at the building level. By linking buildings and industrial activities together, district energy systems can aggregate the varying energy requirements into a steady heat load that can be effectively managed (Church, 2007). A typical district energy system includes one or more individual plants that use one or more types of fuels and can incorporate a combination of different heat sources and technologies (Gilmour, 2008a).

In Canada, modeling for the UES initiative identified that if every building were connected to a natural gas-fired district energy system that used combined heat and power technology, nearly 57 million tonnes of $C0_2$ emissions (almost 10 percent of Canada's $C0_2$ emissions) could be reduced, and nearly 897 million GJ of energy (11 percent of Canada's total energy consumption) saved every year (Gilmour, 2008a). These reductions arise not only from increased efficiency of combined heat and power systems compared with centralized generation, but include energy savings from avoided losses associated with transmission of electricity over long distances.

2. Achieving Sustainable Development – District Energy Best Practices

To identify the key attributes of a district energy system that contribute to community sustainable development objectives, a scan was conducted of nine district energy systems operating in Canada. The scan involved the review of each system to assess the contribution to community sustainable development with a specific focus on: intensification, re-urbanization, community economic development and sustainable energy planning. These categories were selected based on a review of relevant literature on sustainable urbanization and to test common claims made about the community social, environmental and economic benefits of district energy (Moffatt 2001; Newman 1999; Pivo, 1996; Seasons, 2004).

For seven of the district energy sites, an independent modeling analysis was conducted during the UES initiative to identify the potential reduction of GHGs and energy relative to local conventional operating practices. During the analysis, it was noted that there were regional variations in energy intensity and mixes of conventional fuels used in Canada that can have a direct impact on the GHGs and energy efficiency comparisons. These factors were incorporated into the modeling. Table 1 provides a breakdown of the systems in terms of location, system size, energy technology used, primary fuel source and the type of sustainable contribution made to each community.

2.1. Identified Contribution of District Energy

During the review process, it was observed that district energy systems had the capacity to lower GHGs, reduce energy consumption for a community and displace the use of fossil fuels. It was also noted that district energy systems could enhance local economies, contribute to the creation of compact urban communities and help revitalize urban centres through infrastructure investment and by creating an attractive development opportunity. Several of the district energy systems studied are explored in more detail in this section for their contribution to community sustainable development.

Table 1 Profiled Canadian District Energy Systems

Location	Facility	System Size	Energy Technology Used	Primary Fuel Source	Greenhouse Gas Avoided tonnes/year	Energy Use Reduced GJ/year	Contribution of DE
Halifax, Nova Scotia	Purdy's Wharf	1,250 tons cooling	Titanium plate heat exchangers; Electrically driven centrifugal chillers	Sea Water Cooling	2,000	9,720	Community Economic Development
Charlottetown, P.E.I.	PEI District Energy System	51MW	High efficiency boilers; Back pressure boilers	41% municipal solid waste; 42% sawmill residue; 17% oil	4,883	1,749	Sustainable Energy Planning
Becancour, Quebec	Becanouver, TransCanada Energy	550MW	Combustion Turbines	Natural Gas	--	--	Community Economic Development
Markham, Ontario	Markham District Energy Inc.	12 MWt 3.5 MW electricity 4600 tonnes	High efficiency boilers; Centrifugal Chillers; Spark-ignited engine; Reciprocating Engine	Natural Gas	4,893	88,902	Intensification
Toronto, Ontario	Enwave Energy Corporation	75,000 tons cooling	Cold-energy transfer loop	Deep Lake Water	13,348	355,573	Sustainable Energy Planning
Hamilton, Ontario	Hamilton Community Energy	12.5MWt and 3.6 MW electricity	High efficiency boilers and Reciprocating Engine	Natural Gas	4,403	45,431	Intensification
Okotoks, Alberta	Drake Solar Landing Community	1.5 MW	Thermal solar panels, gas furnaces, borehole storage	Solar Radiation and Natural Gas	152	3,0444	Sustainable Energy Planning
North Vancouver, British Columbia	Lonsdale Energy Corporation	6 MW	Condensing high efficiency boilers	Natural Gas	3,713	44,797	Re-Urbanization
Revelstoke, British Columbia	Revelstoke Community Energy Project	1.5 MW	Biomass burner and backup propane	85% wood waste; 15% propane	--	--	Community Economic Development

2.1.1. Intensification

The movement towards intensification within developed areas and on green field sites (virgin areas of land) is a trend of growing importance. Between 2002 and 2007, Canada had over 1.3 million new housing starts across the country (Gilmour, 2008b). The majority of this new development commenced on tracts of land outside cities. This pattern of growth is placing additional stresses on communities by consuming more land than does compact development, using more energy, increasing transportation needs and increasing infrastructure costs for various services including public transit. To address these growth challenges, communities are striving to encourage intensification through mixed-use development. Mixed-use development – the concentration of land uses and built form such as residential, commercial, industrial, office, and institutional – is an established approach for creating urban environments where people can live, work, and meet everyday lifestyle needs.

The Markham District Energy Inc system illustrates how district energy can contribute to creating more compact urban environments that support mixed-use development. Since the late 1990s, Markham, Ontario has added over 110,000 people to its community. Although the Town has developed quickly, it adopted a planning vision based on the principles of New Urbanism of compact and land-efficient urban form, higher density development, a wide range and mix of land uses, a pedestrian friendly and connected grid pattern of streets and high quality urban design. Although Markham was recognized for its innovative planning approach, the Town identified that while planning objectives where being met the impact of new development in terms of GHGs and energy reduction was not being adequately dealt with.

For the Town's largest development project, Markham Town Centre, emphasis was placed on creating a complete, self-contained community with minimal impact on the environment. In addition to setting high standards for promoting mixed-land use and encouraging design that reduced dependency on the automobile, the Town also set a goal to lower energy consumption by 20-30 percent. Early into the development process, the Town identified district energy as an important component for achieving expected energy reduction and land use development objectives in the Town Centre. For Markham, district energy provided the capacity to promote compact, mixed-use development by concentrating development through piped infrastructure, while ensuring that all of the heating and cooling requirements for new development could be met. The Town also worked with the local development community to ensure new buildings connecting to the district energy system incorporated advanced high performance building standards to further lower the level of energy consumed in the community and improve the overall efficiency of new buildings.

2.1.2. Re-urbanization

Private sector investors have avoided investment in brownfield sites (former industrial or otherwise potentially contaminated lands) where real or perceived issues of environmental concern exist. The challenge for communities is to improve sites to a state where investors find them attractive to develop. Traditional strategies have included investment in infrastructure, such as the development of stacked parking facilities, various financial incentives such as tax breaks and loans, and creating innovative partnerships that mitigate risk for the private sector.

An example of the capacity for district energy systems to be part of a regeneration and economic development program for industrial lands is the Lonsdale Energy Corporation district energy system. In the City of North Vancouver, British Columbia, Lower Lonsdale was characterized by vacant or under-used lands that created a discontinuous space in the centre of a busy urban area. In the early 1990s, the City launched a planning process to redevelop the municipally owned waterfront and urban area. The initiative called for the establishment of higher-density, mixed use development that could contribute to the development of a vibrant downtown and lead to job creation. Local officials for the City, who participated in an energy study tour to Europe, recognized district energy as a promising opportunity to help achieve municipal objectives for the reduction in GHGs, as well as provide an important incentive to developers and potential employers to purchase and invest in the waterfront lands.

For the City of North Vancouver, district energy offered an additional level of investment incentive for developers and investors by reducing the need for capital investments in building heating and cooling systems, lowering building costs associated with operation and maintenance, and improved returns by removing space needed for mechanical systems and allowing the area to be used for more efficient revenue generation.

2.1.3. Community economic development

Across Canada, communities have experienced the impacts of national and global economic change. In some cases, communities have adjusted to the potential for little or no growth in terms of population and investment, while others have experienced a reduction in employment opportunities from the introduction of productivity technologies. Canadian communities that have adjusted well to economic change, largely as a result of finding the right balance of infrastructure investment, human resources, creative talent, and location advantage (i.e. proximity to markets), are continuing to receive higher levels of population settlement and economic growth. However, the impact of economic change has been widely uneven among Canadian communities, with some having to adopt and contend with a variety of challenges that can negatively impact economic viability and the quality of life of a community.

The opportunity for district energy to be incorporated as part of a strategy for community economic advancement and retention is illustrated by the Revelstoke Community Energy Corporation. In the late 1990s, the Town of Revelstoke in British Columbia was faced with several significant and interconnected economic challenges including the potential closing of the Town's sawmill, a major employer and supporter of many local industries, and the continuing decline of the population. As a result of a change in regulations concerning the burning of wood residues, sawmill operators across the province of British Columbia where faced with the potential of having to use alternative heating methods to dry wood for processing or relocate operations closer to advanced wood residue processing operations. With over 25 percent of the local economy supported by the forest industry in Revelstoke, the threat of a move, closure or reduction in operational size of the mill had the potential to severely impact the Town's economic vibrancy and health.

For the Town of Revelstoke, maintaining the presence and economic integrity of the sawmill became a priority and resulted in the formation of a public/private partnership between the Town and the owners of the sawmill to develop and operate a renewable fuelled (wood biomass) district energy system. The district energy system served to meet the economic needs of the sawmill operator by providing a needed and affordable heat source to operate wood drying kilns and supply the Town with a largely free source of heat for local businesses, institutions and municipal operations, including schools and a community centre. For the Town, district energy offered the economic benefit of reduced operating costs for local businesses and contributed to securing the long-term operation of the sawmill. The district energy system also provided the Town with the added benefit of reducing reliance on the truck delivery of propane as the main source of heat fuel.

2.1.4. Sustainable energy planning

Across Canada, communities have traditionally given minimal consideration to the role of energy in terms of supply and use. However, as the price of fuel rises, the demand for energy grows and the potential for power outages due to severe weather become more frequent, there is renewed interest in assessing the opportunities to minimize energy waste, reduce reliance on centralized grid generation, increase local energy supply security and apply advanced land use development practices that reduce energy consumption. Today, long-term planning for municipal growth and economic vitality is requiring an approach that looks beyond traditional areas of concern. For municipalities, planning for population growth no longer just includes potential increases in revenue from property taxes or the requirement to adjust development charges to cover investments in new infrastructure. It also requires an understanding of how a community can plan to reduce GHGs and energy use, ensure the secure supply of energy, and substitute fossil fuels with alternative and renewable sources of fuel.

The Drake Solar Landing Community in Okotoks, Alberta provides an innovative example of how sustainable energy planning can be incorporated into the design, development and operation of communities. In the late 1990s, Okotoks was the first community in North America to establish growth targets in a master plan based on the local carrying capacity of the watershed to treat and dispose of effluent. As part of the plan, a sustainability vision was developed that outlined the objectives for development in the Town, including energy use in the community. Additional sustainable design objectives where also set including reducing reliance on the centralized electricity grid system and encouraging the use of localized solar energy production.

To help advance the plan, a partnership was established between the Town, a local land developer and the federal government of Canada to develop a solar power district energy network for a new residential subdivision in the Town. By developing all of the homes connected to the district energy network based on Canada's highest standard for energy efficient homes (R-2000), nearly 90 percent of all space heating needs for the homes are now met by solar energy. The district energy system has also contributed to allowing each home to reduce its GHGs by nearly 6 tonnes and energy consumption by 110 GJ per year. For the Town of Okotoks, the use of the district energy network contributed to enhancing the overall sustainability of the community by reducing energy costs, lowering the reliance on fossil fuels and mitigating the overall environmental impacts associated with new construction.

3. Compatibility of District Energy and High Performance Building

In less than a decade, high performance "green" building has become synonymous across Canada with achieving sustainable development principles and having a measured impact on greenhouse gas reduction. As a result of the increase in general awareness and importance of incorporating high performance design and development standards into buildings, there is a need to better understand the compatibility of district energy systems with high performance designed buildings. This section reviews the suggestions and experiences of operators across Canada, provided during the UES initiative, with high performance buildings and district energy systems.

3.1. Applying Integrated Design

Traditionally, energy planning for communities has resulted in keeping the optimization of district energy systems and improved environmental performance for buildings separate. Today, there is an increasing understanding that to ensure the successful integration of district energy systems to achieve the highest efficiency levels possible requires that design engineering teams for a high performance building be encouraged to also consider the performance metrics of a district energy system from day one of a project and evaluate the performance of proposed buildings and energy supply systems as a single integrated system with the goal of minimizing energy use and emissions production from that integrated system. Keeping informed on the latest advancement in the application of district energy can be a challenge. Design teams not familiar with district energy might apply "conventional rules of thumb" when evaluating efficiencies of various systems that do not account for currents costs or performance considerations.

In order to achieve the benefits of a high performance building and to ensure that known attributes are applied, district energy design teams need to work closely with owners' or developers' design engineers during the construction of a high performance building to avoid multiple iterations of design concepts. An integrated design process sometimes involves redesigning various distribution systems and reviewing the building envelope design to achieve consistent thermal loads/balances. This close interaction of the design teams can lead to improved system efficiencies, as well as a better environmental building design while reducing the overall design effort and cost.

3.2. Moving Beyond the Building Envelope

Most of the building rating systems applied in Canada are designed to achieve improved building envelope performance, reduce overall energy consumption in a building and ensure that in-building heating, cooling and circulation systems have a high level of operational efficiency. Generally, the building rating community in Canada has been concerned that rewarding the energy supply savings from a district energy system could compromise progress on the level and extent of energy-efficiency measures incorporated into a building. Great strides have been made in building energy efficiency design and implementation. The concern that a systems approach to building energy emissions might blunt progress in building design improvements is legitimate.

The achievement of equivalent reductions in emissions through the use of district energy generally has not been recognized as equivalent to improvements in the building envelope in most building rating systems, which often focus on building envelope energy cost savings rather than system emission reductions. However, there is growing consensus within the U.S. and Canada that energy efficiency evaluations should put less emphasis on cost savings and more emphasis on reducing the environmental impact of a specific building, especially in terms of GHGs and other air pollutants.

In order to achieve the most economic method for minimizing energy use in a building, the efficiency of energy supply as well as the efficiency of the building envelope needs to be considered equally and consistently. Carrying out such an assessment on an objective basis can result in the cost effective method for achieving green building performance and the lowest life cycle costs. This process should be carried out in a manner that continues to encourage improved building envelope design so that the total potential reduction in energy use, GHGs and other air emissions can be captured.

4. Transferring Lessons From Canada: Steps For Advancing District Energy and High Performance Building

Although there are many successful district energy systems across Canada in operation, municipalities and businesses continue to experience challenges to using district energy to achieve sustainable development and energy efficiency. Overcoming challenges to the wider application of district energy can require innovative approaches to determine community interest in sustainability, the use of advanced planning practices and encouraging broad community support from the green building community. Suggestions for how district energy and high performance buildings can be better integrated to achieve sustainable community development objectives are discussed below.

4.1. Assess Sustainability at the Community Level

Among the key determinants for assessing the potential for district energy and high performance development to be successful in any community is the importance placed on reducing GHGs and energy consumption. Municipalities across Canada are responding to the impact of climate change by developing comprehensive action plans that provide clear targets for GHG and energy reductions through the environment, while other communities are enacting new guidelines and legislation that encourage decentralized energy production. Municipalities that have identified energy as part of their long-range planning or a central objective of managed community growth are likely to be more receptive to the potential application of district energy and high performance building development. Influential leadership from the public and private sector can also improve the potential for a community to consider district energy and high performance building for meeting sustainable development goals. Key considerations:

- When an Official Plan or equivalent municipal statement references energy or GHGs reduction, this can contribute to broader community awareness and can encourage policy decision makers to explore how district energy and high performance building can be used to meet sustainable development objectives.
- Official Plans should also address energy supply security and overall sustainability issues for the community. These issues are integral to community long-term well being, but are often given less

prominence than the achievement of shorter term goals such as economic growth and job creation. Awareness of the need to truly include these concepts in Canadian municipal planning is increasing.

4.2. Use Integrated Energy Planning

To help achieve a high level of energy performance in buildings, building design teams now use an integrated design approach (IDP). IDP provides the ability to ensure that all aspects of a project are assessed at the concept stage and decisions are made throughout the design and implementation process that support sustainable design. A similar process is also being applied to communities in the form of integrated energy planning. This process can allow a community to identify how district energy can serve as an energy broker to collect, generate and distribute energy in an efficient and economical manner. Integrated energy planning can enable communities to meet energy demands by examining opportunities to lower energy use across an entire community, improve the energy efficiency and operating performance of buildings, capture excess energy from industrial process, and determine how district energy can contribute to sustainable development.

When applying an integrated approach to the planning and development of district energy, consideration should be given to developing a catalogue of thermal resources – types of alternative, renewable, fossil and waste heat fuels used in a community – for heating, cooling and electricity needs. The use of an inventory can allow a community to better assess the potential applications and location for a district energy system. For instance, municipal services can provide sources of heating such as heat from sanitary wastewater and cooling from naturally extracted cold drinking water sources that can be used in a district energy system. Key considerations:

- Understand the role, types and distribution of energy within a community and assess how to accommodate growth in the built environment that would not dramatically increase energy consumption;
- Encourage compact urban form and mixed land uses (such as commercial, institutional, office and residential) that support district energy;
- Use regulation, such as zoning controls to create energy zones that encourage building developers and owners to use high performance building standards, meet energy efficiency targets and consider the use of a district energy system to meet heating and cooling requirements;
- Consider the opportunity to require that terms of reference for land use planning studies and infrastructure development (i.e. new waste treatment facility or new sewer systems) assess the inclusion of district energy applications with high performance building; and,
- Encourage municipal officials to document and provide access to energy data that can be used to forecast heating and cooling demands. This information can be used to make a more accurate assessment of energy requirements for new development and assist developers of high performance buildings and district energy facilities to better assess the integration of thermal systems.

4.3. Build Partnerships and Work with the “Green” Building Community

Many of the challenges experienced while initiating a district energy system or a high performance building result from a lack of public and industry awareness concerning the ability of district energy and high performance building to meet the energy and sustainable development objectives of communities. Developing partnerships with local building organizations, various levels of government, utilities and non-government agencies to assist with funding and implementation is important for creating a local community that is accepting and capable of implementing district energy and high performance building. Partnerships between various organizations, whether public or private, can contribute to overcoming knowledge gaps and assist directly with the implementation of strategies to develop and deliver education programs and implementation tools. Key considerations:

- Explore the opportunity to use public private partnerships. Private sector partners can bring needed expertise and, in many cases, provide “turnkey” services to the design, build and operation of a project. In these arrangements, the community may become a financial stakeholder in the project or simply the purchaser of services provided. This can allow for the challenges for integrating district energy and high performance building to be assessed early on in the design stages and financial risk lowered by the municipality through activities such as providing access to public right of ways, securing commitment for connections and encouraging density of built form.

- Work with local building rating assessment systems to integrate a process for evaluating green features, such as district energy systems that use alternative and renewable fuels, which can contribute to reducing the environmental impact at the community level and at the building site level. The development of a transparent process that reflects the full life-cycle cost benefits and energy enhancement capabilities of district energy can contribute to improving the overall design and energy efficiency a new building and lead to the reduced dependence on non-renewable fuel sources.

5. Conclusion

Across Canada, district energy systems are providing the heating, cooling and electricity requirements needed to meet the growing energy demands of cities and businesses. At the same time, high performance building development is helping communities to reduce overall energy consumption. When integrated with sound community planning and modern urban design strategies, district energy and high performance buildings can assist communities to use less energy, keep energy dollars local, address energy security and resiliency concerns, contribute to brownfield remediation and, overall, allow communities to achieve their sustainability development objectives.

The use of integrated energy planning to connect district energy and high performance buildings may also be one of the greatest and most economically attractive opportunities available for reducing energy use and emissions on a local, regional and national basis. To fully recognize this opportunity, there remains a need for the building and district energy industries to work together to ensure that policy makers provide the appropriate incentives and regulations to maximize the uptake of improved energy efficiency building design, as well as improved building energy supply efficiency.

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The Carbon Balance of Symbiotic Plants - An Example on the Vertical Planting System in Archilife Symbiosphere 1 Center

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ABSTRACT: A vertical planting system is equipment that wraps up the peripheral of Archilife Symbiosphere 1 Center. Plants may play an important role in buffering the disaster induced by drastic climate change. The records of sampling survey of container indicate that average fresh weight of plants on each container is 801g, and the average dry weight of plants on each container is 82g. The TOC-5000A in the experiment is adopted to sense the carbon storage content in plants on VPS. The average of carbon content is 41% which depends on the different kinds of plants. The carbon content of the medium on VPS ranging is higher than uncultivated medium. Through the calculation with photosynthesis formula, the AS1C is compared with the buildings without any plants absorbed more 1024 kg of CO_2.

KEYWORDS: Sustainable building, Vertical Planting System (VPS), Archilife Symbiosphere 1 Center (AS1C), Plants, Carbon Dioxide (CO_2), Climate Change.

1. INTRODUCTION

A vertical planting system (VPS) adhering to the experimental has been designed to evaluate the feasibility of food production and additional ecological benefits to the inhabitants of the sustainable building (figure 1) [2], [6]. VPS forms a small nature symbiotic ecosystem [2], [6]. Base on the changes of CO_2 and temperature of the earth in foregoing 400,000 years [5], the period climate change was around 100,000 years. We are going to experience the change of next period, which follows by violent change of climate. The diversity of dry regions displayed the greatest increase in diversity due to increased CO_2 [4]. Plants may play an important role in buffering the disaster induced by drastic climate change [1], [3]. And, the major source of energy on the earth is the radiation of the sun. As the life of humankind is heterotrophy, they are necessary to choose symbiotic species. Consequently, humanity can choose solar-energy-transformable plants as symbiosis species.

Figure 1. A VPS was introducing ecology into Sustainable buildings.

2. MATERIALS AND METHODS

Plants material

Taiwan is rich in its indigenous flora. Some 564 species have been found within an area of a radius of 500 meters around the AS1C. Among these species, 124 are edible. We were collected and propagated either reproductively or vegetatively on the VPS in the AS1C [2], [6]. After three year, a great part of the plantings showed good symbiotic effects. We were collected Samples (figure 2) from the VPS in the AS1C. We were collected 38 kinds of plants (Sep, 2006~Jan, 2007) [6].

Figure 2. There were much symbiotic plants on the VPS in AS1C.

Preparation of samples

The VPS comprises 17 planting towers, each again comprises 80 containers. Each container is 94cm in length, 23cm in width and 24cm in height for plants growing. There were 1,360 containers in the AS1C [2], [6]. As the planting by sampling 1 from 100 says, which harvested chose 15 containers continually. The first step in the procedure for preparation of plants was cutting each part separately. After drying 70°C over 72 hours, samples milled 10~30 seconds at room temperature, and then stored at 70°C for further analysis [6]

Figure 3. The simple procedure for preparation of plants as show in the pictures.

TOC5000A analysis carbon storage content

The TOC5000A (total organic carbon analyzer) in the experiment is adopted to sense the carbon content of the plants on the vertical planting tower. The first procedure for analysis carbon content was warming-up 30~45mins (Figure 4**)**.

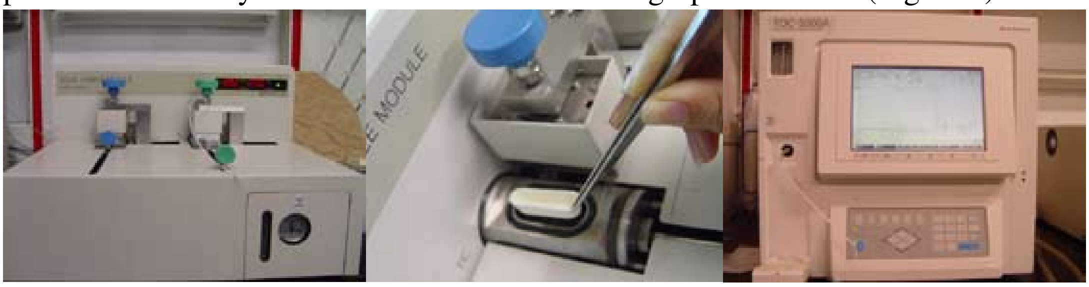

Figure 4. The simple procedure for TOC5000A as show in the pictures.

3. RESULTS

The records of sampling survey of container indicate that fresh weight and the dry weight of plants on each container (Figure 5).

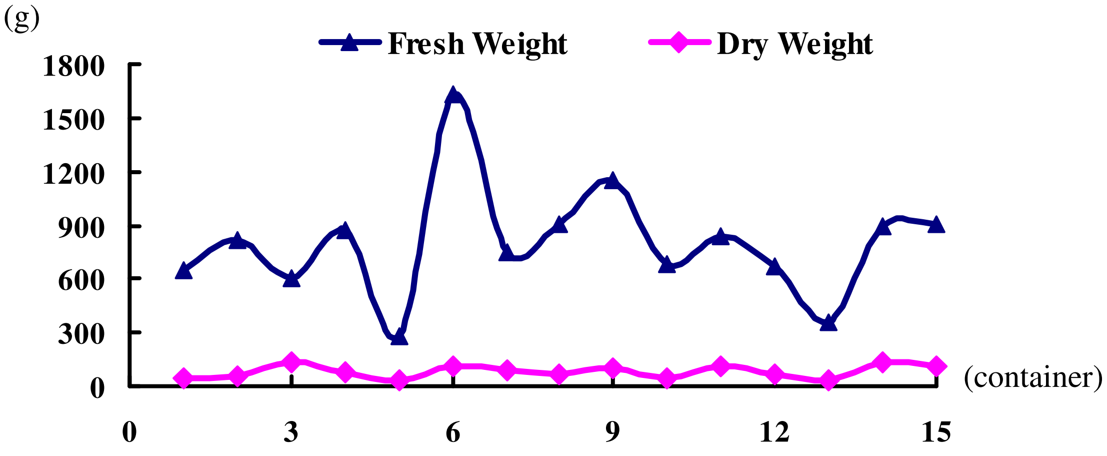

Figure 5. Each container has the fresh weight and the dry weight of plants.

We were cutting plants from root, steam, leaf, fruit, seed and etc. The carbon storage content in the different parts of plant was show as Figure 6.

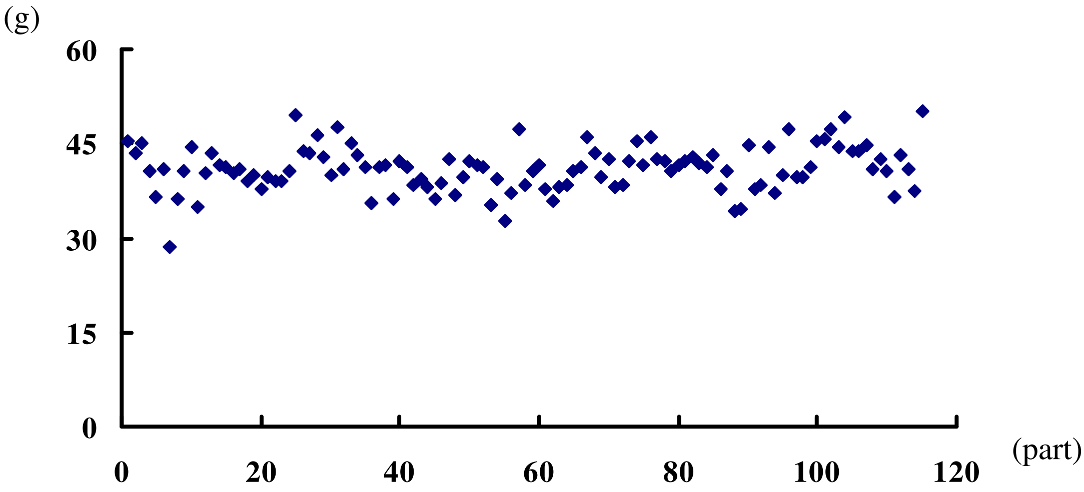

Figure 6. The carbon content measured in the different parts of plants.

We measured the carbon storage content of the medium with different position in AS1C (Table1). The carbon content of uncultivated medium was 35.89%.

Table 1. The carbon content measured in the different positions of mediums.

	Position	Plant Types	Medium Average TC%	Medium Average pH
VPS	East	3	39.20	6.6
	South	4	36.61	6.2
	West	4	35.66	6.2

4. CONCLUSIONS

VPS is equipment that wraps up the peripheral of AS1C. This forms a small nature symbiotic ecosystem. The records of sampling survey of container indicate that average fresh weight of plants on each container is 800.76g, and the average dry weight of plants on each container is 82.24g. The TOC5000A in the experiment is adopted to sense the carbon content of the plants on the VPS in the AS1C. The range of carbon content from 28.69% to 50.09% depends on the different kinds of plants, and the average carbon content is 41.03%. The carbon content in the fruits & seeds is especially high. In the root of the *Composite* is higher than leaf and steam. The carbon content (like that in the taros) turning into amylum is fixed. The literature review shows that the C4 plants has the stronger ability to fix CO_2. The fixed carbon has been taken into crops is decomposed back into the circle. In this always changing balanced carbon circle, a little more weight on the end of fixed carbon is useful to slacken the climate change. The carbon content of the medium on the planting tower ranging from 33.64% to 40.90% depends on the different positions, and the average carbon content is 37.19%. The carbon content of the medium on the planting tower is higher than that of the never planted medium at 35.89%. Therefore, the fixed CO_2 should have come from the air. Through the calculation with photosynthesis formula, the AS1C is compared with the buildings without any plants absorbed more 1024.27 kg of CO_2. The result of the next study should be compared with that of this study for the correlation. Another kind of measurement is recommended next time so that

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PROFIT OF EXERGY IN THE BUILT ENVIRONMENT

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Keywords: thermodynamics, profit, exergy, stakeholders, building process, life-cycle costs

Summary

In the Netherlands three technical universities are participating in a new research project "Exergy in the built environment", that aims to contribute to sustainable building by investigating the potential financial benefits of exergy saving techniques. Exergy is a concept used in thermodynamics to express the maximum amount of mechanical work that can be obtained from an energy flow or a change of a system in relation to its environment. In contrast to energy, exergy can be destroyed and by that means exergy can express the finiteness of resources better than energy can.

In the building process investors currently use life cycle costing to calculate the returns on their investments in buildings. The life cycle costing method however does not take into account an important organizational issue. Namely, that the stakeholders who benefit from exergy saving techniques not necessarily include the investing stakeholders. The aim of the research on the profit of exergy in the built environment is to develop an improved model to predict the potential added value of exergy saving techniques by linking this thermodynamic concept to building processes and to investment appraisal. In this proposition paper the objectives, methodology and theoretical framework will be explained.

1. Introduction

Since stated by the World Commission on Environment and Development in 1987, sustainable development receives world wide attention. In the building industry the term sustainable building is used to address all techniques and approaches in terms of source efficiency, quality improvements and pollution reduction, *which not compromise the ability for future generations to meet their own needs* (Brundtland et al., 1987).

Within sustainable development and sustainable building the reduction of energy use and lowering the pollution have much attention. In the Dutch building industry innovative techniques, like solar chimneys, heat pumps and mechanical ventilation systems with heat regeneration, are introduced to supply heat efficiently during winter and to keep the heat inside as long as possible by using new types of insulation and heat exchangers. It is even possible to build houses that offer comfortable temperatures without the necessity of any external energy infrastructure to supply them of resources or heat at all; autarkic houses.

However, the Dutch building industry seems to see the national Building Code, with its explicitly stated energy performance, as a guideline for the maximum level of necessary performance. The Building Code should although be considered as a minimal required energy performance. The building industry is rather reluctant to apply these necessary energy saving techniques. Contractors often do not know which broad range of energy saving techniques is available and the direct costs of some of these existing techniques are simply too high, so it seems.

One method to get something implemented in the building industry is to enforce it by law (e.g. building codes, regulations). Another method to get something implemented in the market is by showing its commercial value. A logical motivation will lie in making this task easier to reach by pointing out the financial advantages of the techniques and approaches. Research is therefore needed to explain the financial benefits of exergy saving techniques (including the formerly known energy saving techniques).

Exergy is a concept based on the first and second law of thermodynamics. Exergy is the maximum amount of mechanical work that can be obtained from an energy flow or a change of a system in relation to its environment. In contrast to energy that is only based on the conservation principle of the first law of thermodynamics, exergy can be destroyed. Therefore, exergy can express the finiteness of resources better than energy can. In other words exergy expresses the quality of the quantity energy. The relation between energy and exergy can, according to Ala-Juusela et al (VTT, 2003), be embedded in a quality factor (see Eq. 1 in combination with Table 1).

$$Exergy = Energy \times Quality\ \ Factor \tag{1}$$

Table 1 Quality factors for multiple energy sources based on an ambient temperature of 20°C (VTT, 2003)

Source	Quality factor
Mechanical energy	1,00
Electrical energy	1,00
Solar radiation	0,95
Nuclear fuel	1,00
Fossil fuels	0,90
Thermal at 100°C	0,21
Thermal at 40°C	0,06
Thermal at 20°C	0,00

Although there is much thermal energy needed in the built environment to generate a comfortable indoor climate, the exergetic value of heat in an indoor environment of twenty degrees Celsius is very low. When it is twenty degrees Celsius outside, the value even equals zero, because there is no temperature difference between the analyzed system and its environment.

To generate the proper indoor climate of approximately twenty degrees Celsius, a fossil fuel named natural gas is commonly being used in The Netherlands. This fuel can be burned at high temperatures; therefore the generated thermal exergy will almost equal its formal internal energy. However, the generated high thermal exergy does not match the needed low thermal exergy for the indoor climate. The principle of using high quality sources in degrading steps, so called cascade principle, can be introduced to make efficient use of fossil fuels. Another possibility is, of course, to use alternative (renewable) sources for heating residential and commercial real estate.

2. Research objective

The planned research is aimed to contribute to the adoption of exergy saving techniques in the built environment by giving insights in their financial consequences. These techniques will help to lower the amount of harmful emissions and can provide the correct quality (in terms of the ability to generate mechanical work) and quantity of energy, expressed by exergy, in a more effective way. The relation between thermodynamics, economics, and sustainable development has been described most challenging by Valero et. al. (1993):

Developing techniques for designing efficient and cost-effective energy systems is one of the foremost challenges energy engineers face. In a world with finite natural resources and increasing energy demand by developing countries, it becomes increasingly important to understand mechanisms which degrade energy and resources and to develop systematic approaches for improving the design of energy systems and reducing the impact on the environment. The second law of thermodynamics combined with economics represents a very powerful tool for the systematic study and optimization of energy systems.

In a time of governmental deregulation, improvements in adopting exergy saving techniques need to be facilitated by specifying the financial benefits for the stakeholders in the building process. The main research question can be stated as a single line question in the following way:

What are the financial benefits of exergetic optimization of real estate?

Although there is a common awareness of the ecological and social benefits or other externalities of exergy saving techniques, the financial costs and benefits will be the major point of concern in the decision making process on investments in real estate. In the process of addressing this concern the financial benefits of exergetic optimization will be mainly approached from the investor's and user's point of view.

The appraisal of exergy saving investments does take the benefits during utilization into account (for example in the method of life cycle costing), but stakeholders in the building processes often do not communicate about, or take the time to weigh, the costs and benefits of life cycle investments. Furthermore the methods for calculating the yearly cash flows do not incorporate all benefits of exergy saving techniques yet. The main contribution of this research can be found in offering a model to overcome these two aspects.

3. Societal relevance

Given that many modern (starting somewhere during the industrial revolution) emissions harm the environment and given that the supply of fossil fuels is finite, the adoption of exergy saving techniques is of great importance. It can help to use the supply of fossil fuels more effective or to use sustainable sources that do not harm the environment.

The fact that the building industry and the built environment as a whole are, according to the EPBD (EC, 2002), responsible for at least forty percent of the total energy consumption, and the given fact of an increasing number of restrictions on the energy consumption of buildings, make it interesting and wise to stimulate techniques that can reduce the exergy consumption in a cost effective way.

The Return on Investments (RoI) in exergy saving techniques will mostly benefit the user of the building. This user is in most cases not the same person or corporation as the constructor who paid for the investments during the construction phase. During the habitation of a dwelling or the use of an office some actions will be undertaken by the user to lower the energy consumption. Until 2003 there were different subsidies to trigger these users e.g. to insulate their buildings, most users however do not know which level of adoption of energetic techniques is attractive from a financial and/or energetic point of view.

Current developments that can stimulate customer awareness on the energy consumption of buildings, involve the Dutch Energy Performance Coefficient (EPC) and the European Energy Performance Building Directive (EPBD):

- The EPC expresses the energy efficiency of buildings and is included in the Dutch Building Code (2003) regarding building licenses for new buildings. Its introduction was in 1995 for dwellings and it gradually lowers the building related energy use of all new buildings by lowering the numerical value of the coefficient from 1.5 in 1995 to 0.8 in 2006. The energy performance of offices and other utilities has been regulated and lowered since 1998.
- The EPBD passed the European parliament and council at 16 December 2002 and should have been converted in laws by the member states since 4 January 2006. Twenty one European countries were however not able to finish the preparations in time. The Dutch government has introduced the derived laws on the certified energy performance of existing buildings and inspections of heating and cooling systems at the first of January 2008.

The certification of the energy performance of existing buildings can result in recognition of their energy use. An appreciation of a good energy performance can positively affect the market value and therefore the financial benefits of an exergy saving measure will be higher.

4. Scientific relevance

By focusing on the financial benefits of exergy saving measures in real estate objects the research takes place in an area, in which three scientific fields overlap; building processes, economics and thermodynamics (see Figure 1). The relevant theories for these three fields shall now be addressed.

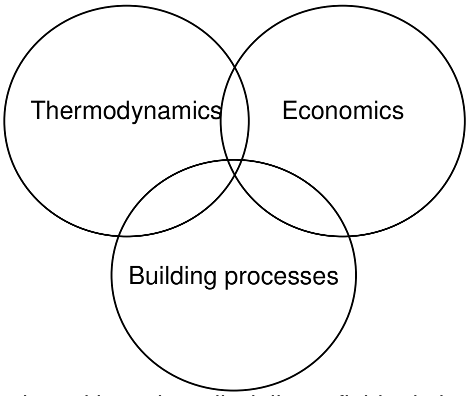

Figure 1 The research will be conducted in an interdisciplinary field relating thermodynamics and economics in interaction with the building process.

4.1 Building processes

In the Netherlands the implementation of energy saving measures in real estate is at this moment mainly enforced by law (Building Code, 2003). Although investments by commissioning commercial organizations or private persons are mainly weighed by their financial returns and technical aspects (Vermeulen et al., 2006), it seems that the goal realization or development in sustainable building by the temporary organization of the building process also can be stimulated by respectively transactional or transformational leadership (Bossink, 1998). It is not only important to do research on the financial benefits and technical aspects, but also on the organization of the stakeholders in the building process.

Research of Van Soest (2005) e.g. shows, that an increase of environmental taxes and quotas does not necessarily induce early adoption of energy saving technologies in firms. This seems to conflict with the findings of Vermeulen et al. (2006), where the economic assessment is one of the main variables. According to their findings the use of subsidies effected especially the economic assessment of young innovations. The research of Van Soest had a focus on one single firm that is both the investor and user of the object. However, in case that user and investor are different parties the cost benefit considerations might be different for both parties. As a consequence their decision to adopt specific energy saving technologies and techniques will most likely also differ.

In the first part of the research a stakeholder analysis needs to clarify where in the process the objectives for reducing the exergy consumption are developed and where their financial consequences are addressed. It is important to know at which moments in the design, construction and utilization phase, intervention to adopt the exergy saving technologies is possible. The influence of the stakeholders and uncertainty in the early phases of the building process in relation to the project's value generation has been studied before by Kolltveit et al. (2004), but this research did not specifically focus on energy or exergy saving techniques. Therefore this research can make an innovative contribution by specifying the opportunities and restraints in adopting energy saving techniques in building processes.

4.2 Thermodynamics

The basic methods of energy and exergy analysis from the field of thermodynamics are generally used to optimize the designs of power plants, but in recent years some building related installations have been analyzed, for example heat pumps (Ozgener et al., 2005; Ucar et al., 2006). Methods to address the costs and benefits of exergetic optimization processes are referred to as thermoeconomics (Szargut, 1988) or exergoeconomics (Tsatsaronis, 1985).

The possibilities to reduce energy consumption and to save exergy in the built environment are numerous. An average dwelling in the Netherlands uses for example 1,736 m^3 natural gas and 3,346 kWh electricity each year (SenterNovem, 2006). The efficiencies of many exergy saving techniques have been addressed e.g by Gustafsson (2000), Xiaowu et al. (2005) and Nagano et al. (2006). A preliminary literature study on exergy saving techniques however shows that so far, little research has been done on passive solar systems. This research will contribute to this research on exergy saving techniques by conducting an experimental study of a passive solar system.

4.3 Economics

A basic method to specify the financial costs and benefits of real estate investments is Life Cycle Costing (LCC). It recognizes that the total cost of ownership of a product is not solely reflected in its purchase price. The purchase of certain products should in other words be considered as an investment for which both benefits and additional costs are incurred over the life of the product (McEachron et al., 1978). Although there are some difficulties still to overcome (see e.g. Gluch et al., 2004), this method can be used for the analysis of design options regarding conventional energy efficiency. Lutz et al. (2006) used it for example for weighing the costs of residential furnaces and boilers and Gustafsson (2000) optimized insulation thickness.

LCC has been improved from an environmental point of view by integrating the product's or investment's results from Life Cycle Analysis (LCA) and the customer's willingness-to-pay for the related environmental improvements (Bovea et al., 2004, Banfi et al., 2006). However, despite these improved LCC methods, there are still possibilities for further improvements. The application does not take into account the possibilities of increasing the value of real estate by means of improving its efficient energy performance. Although this aspect is related to the willingness-to-pay principle, it is the first time that financial data from the existing building stock can be related to energy performance certificates based on the European Building Directive on Energy Performance.

Furthermore, in the case of residential real estate the availability of fuel resources are not accounted for in LCC yet, although the prices of car fuels for example are strongly related to their availability. Alanne (et al., 2006) performed a first study on the reliability of decentralized energy systems and Awerbuch (2000) already addressed the urgency to improve the traditional valuation models by introducing the Capital Asset Pricing Model (CAPM) for investments in photovoltaics. CAPM explains the relationship between risk and the investor-required return rate for an asset. Awerbuch's statement "by ignoring financial risk, lenders and investors understate the value of PV projects relative to fossil alternatives" and his suggested solution to use the portfolio theory of Markowitz (1952) to relate cost and risk contribution of alternative resources, offer a basis to investigate the value of the quality of energy; the so called exergy. At this point the economic aspect of the research can be linked with the already mentioned thermoeconomics or exergoeconomics.

5. Research methodology

Three research questions regarding the building process, the field of thermodynamics and field of economics are defined to achieve the objective of the research. This research methodology is based on Verschuren et al. (1999). The first research question will focus on the building process and the relevance of (conventional) energy saving techniques for stakeholders within this process.

Question 1: Which opportunities and restraints during the development of real estate can be distinguished in adopting energy saving techniques?

To combine the advantages from the collective thermodynamic and economic approach on exergy saving techniques the building process and its stakeholders need to be described. Four different project types in describing the processes can be distinguished:

1. Residential real estate developed by private ownership;
2. Residential real estate developed by housing corporations;
3. Commercial real estate developed by investors;
4. (Commercial) real estate developed by the government.

Research on building processes for residential real estate in relation to sustainable measurements has been done by De Man (1983) and Bossink (1998) for example. Research of Vermeulen et. al. (2006) has a focus on commercial real estate. To reflect on the international context of this first research question it is possible to use the research of Lo et al. (2006) on the opinions of building professionals in Hong Kong and Shenyang on sustainable measures.

The interaction between the stakeholders can be based on different management structures; traditional management structure, construction management structure and project management structure (Best et al., 1999). Is it the customer or client who makes the decisions or is the adoption driven by the design of the architect? Relations between the stakeholders will be overviewed to identify certain bottle necks or changes for the implementation of sustainable techniques in building processes.

This first question refers also to the possibilities for the stakeholders to introduce certain techniques to save exergy in the building process. The building process is described by the Jellema series (Woude et al., 1997) for the Dutch situation for example. Internationally reference can be made to Pietroforte (1996), Arditi et al. (1998), Winch (2002) and Turin (2003). The possibilities to interfere in the design and building process are often bound to the first phases of the project (Kolltveit et al., 2004).The quality of the product resulting from the building process is strongly driven by the Dutch Building Code. This law specifies a minimum quality level for all buildings and is therefore an important aspect in the adoption of energy saving techniques in the built environment (Building Code, 2003; NNI, 2004). Buildings must have a certain energy performance, which makes investments in energy saving techniques necessary. Which techniques are being used for which reasons? What are the best practices in relation to these regulations?

By conducting a literature study and interviewing stakeholders the necessary insights will be collected for answering this first research question. The content of the interviews will be based on mentioned theoretical references. An interview is one of the most important sources for case study research (Yin, 2003).

Question 2: What is energetic and exergetic optimization of real estate objects?

It has already been mentioned that more than forty percent of the energy consumption in Europe can be assigned to the building industry. The second research question will focus on the possibilities of lowering this energy consumption and of applying exergy saving techniques to match the provided quality of energy with the quality needed. The appropriate science for this goal can be referred to as thermal-fluid sciences, which can be studied under the subcategories of thermodynamics, heat transfer, and fluid mechanics (Çengel et al., 2005).

The first law of thermodynamics on conservation of energy is commonly known, but the second law is less familiar. Society needs to become more familiar with the possibilities of exergetic analyses in the built environment. A literature study on this concept will be conducted. Important sources are the thesis of Cornelissen (1997) on "Thermodynamics and sustainable development" and the "Fundamentals of thermal fluid sciences" written by Çengel et al. (2005).

The exergy consumption of the built environment can only be reduced effectively, when the current conventional energy consumption of buildings is known. To get a grip on the potentials of exergy saving in the existing building stock a preliminary study has been made of three commercial real estate objects. For the explorative research among residential real estate there are eight houses available constructed in the years 1913, 1925, 1939, 1948, 1964, 1972, 1982, 1992. By using the standardized data on energy consumption (Novem, 2003, SenterNovem, 2006), the normalised method to compute the building related Energy Performance Coefficient (NNI, 2004) and the actual energy consumption data, it is possible to analyse the potential energetic benefits in real estate objects. It is important to reflect on the effectiveness on past policies and regulations which influenced the physical state of buildings.

There are many studies available on specific energy and exergy saving technologies. The Network of International Society for Low Exergy Systems in Buildings listed many possibilities to lower the exergy consumption of buildings (VTT, 2003), however several of these techniques have not been tested or analyzed yet. This research can contribute to existing studies by performing an energy and exergy analysis on an exergy saving technique that has not yet been analyzed. A literature study will be made of the existing energetic and exergetic analyzed parts of buildings (e.g. Gustafsson, 2000; Xiaowu et al., 2005; Ucar et al., 2006; Nagano et al., 2006). In this research one promising and innovative technique will be thermodynamically analyzed and tested to address the benefits of the concept of exergy in practice (this technique will also be used for testing the model on financial benefits of exergy saving techniques). A first scan of the available theory showed that passive solar (ventilation) systems are not well represented yet. An experimental case study on a passive solar system seems promising.

Question 3: What model can be developed to express the financial benefits of exergy saving techniques?

The third research question will refer to the economic element of the research. As a basis standard investment appraisal methods will be used. In this research the focus will be on, like expressed in Figure 2, (1) the stakeholders involved at the moment of the decision to invest and (2) the variables that form the cash flow. Two new variables will be introduced in the second in depth study: (A) the actual market value of the real estate object and (B) the price of the reduced form of exergy as a result of the depletion of fossil fuels.

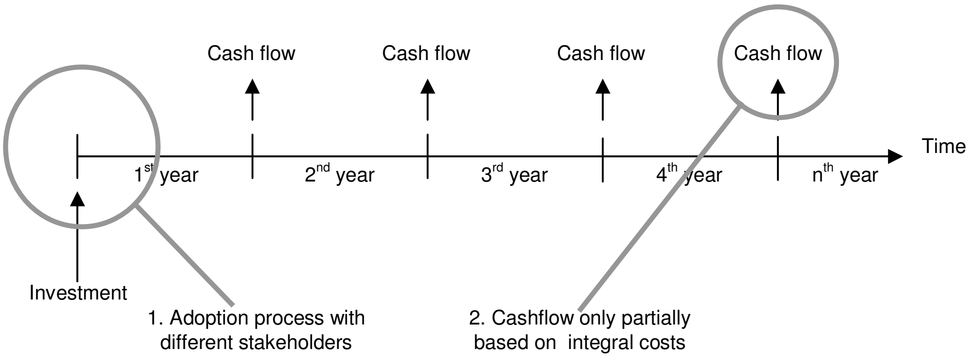

Figure 2 Model showing two problems regarding investments in exergy saving techniques.

When the principles of conventional capital budgeting methods are used on building related investments, they are commonly referred to as life cycle costing. Life cycle costs can be used for the appraisal of exergy saving investments by taking into account the direct costs, the yearly costs of maintenance and the yearly costs of (fossil) fuels. A conceptual discussion given by Gluch et al. (2004) offers important shortcomings to overcome, before adoption of life cycle costing in the building industry can be further stimulated. Not withstanding these shortcomings, the LCC method is commonly used for comparing designs in civil engineering projects (e.g. Noortwijk et al., 2004; Zen, 2005; Singh et al., 2005; Ugwu et al., 2005) and it is also used for environmental orientated investments (e.g. Reich, 2005; Nakamura et al., 2006). Theory on the basics of life cycle costing (originally developed at the American Department of Defense) is offered by McEachron et al. (1978) and Stern (1978).

Two financial benefits of exergy saving techniques are not yet addressed in the theory on the traditional life cycle costs. The first is the willingness-to-pay for real estate that consumes less exergy than conventional real estate. Research on the value development of real estate regarding their energy performance in the past will be conducted by comparing the actual market values of the case objects with the investment costs of specific energy saving techniques. Papers in the field of willingness-to-pay are for example Banfi et al. (2006) and Bovea et al. (2003). The second category of financial benefits is related to the depletion of fossil fuels. With a fixed demand for fossil fuels; the scarcity will increase and therefore the price. By analyzing the energy prices it is possible to specify an interest rate for the yearly positive cash flows generated through exergy saving.

The third research question also involves the applicability of the model for the stakeholders in the building process. The costs and benefits of the exergy saving investment are not in the hands of one and the same stakeholder. In principle there are two possible solutions to deal with this aspect; (1) the model needs to incorporate this separation or (2) the building process needs to incorporate the exergy saving investment appraisal. Depending on the results of the first research question a solution or manual can be offered as a spin off of this research.

6. Conclusions

Based on the existing debates in society on the depletion of fossil fuels, energy consumption, and carbon dioxide emissions, the time is there to introduce the concept of exergy within a broader community. The national Dutch research project "Exergy in the built environment" will introduce this concept in the building industry by providing tools and catching applications, that give insights in the advantages regarding comfort (people), the environment (planet) and economy (profit).

The presented research will focus on the financial benefits. At this moment the prices of multiple energy forms are based on a combination of production costs, governmental surcharges, and market principles. The quality of the energy form, expressed by exergy, is not incorporated in the price setting.

Furthermore, building processes are in general not accommodated to stimulate investments in techniques that reduce the energy and exergy consumption. Stakeholders that invest in a lower energy consumption and stakeholders that financially benefit from these investments, should be brought together within the buildings process or the indirect financial relation should be brought to the surface.

By offering more insights in the cash flows that are generated by installed energy saving techniques in existing buildings and by smoothening building processes, we expect to be able to stimulate the adoption of more and newer exergy saving techniques. Summarizing, this research will comprise:

- Investigating the possibilities to save exergy in the built environment by conducting an experimental study on passive solar systems;
- Investigating decisive considerations to adopt exergy saving techniques to adopt exergy saving techniques from a multiple stakeholder perspective;
- Developing an improved model to estimate the added value of implementing exergy saving techniques, considering their life-cycle costs and benefits.

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Name: Adriano Bellone

Paper Title: Regional Strategies for the Development of Sustainable Building

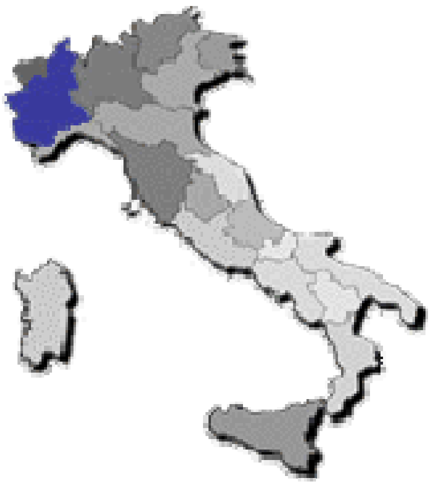
SB08 Abstract/Paper Reference: ABSN7 –LE527 – ZM2X6- QCFT4

Relevant Topic Code(s): 4.2

Summary
The Italian Regions have developed a sustainability assessment tool called "Itaca Protocol".
Piedmont Region is experimenting the assessment tool and developing policies and projects for urban reneval and building sustainability.

Keywords: Sustainable Building Certification System**,** Itaca Protocol, Green Buiding Challenge, iiSBE Italy, Piedmont Region**,** Social Housing Program, Skyscrapers, Sustainable District, Municipalities, Sustainable School Building, Sustainable Health Building.

1 Introduction



Piedmont is an Italian region, part of north-western Italy, bordering France and Switzerland. It is economically prominent amongst the twenty Italian regions.
Piedmont and its capital city, Turin, are focusing on urban renewal as the main way to develop sustainable building practices.
With the industrial areas' displacement, the regional government and the local administrations have found a way to redeem the mistakes in architecture and urban planning made from the 60s through the 70s.
Parts of the former factories are destined to new functions (i.e. museums); other industrial buildings are replaced by new areas, which will reweave the urban fabric and remove its rifts.

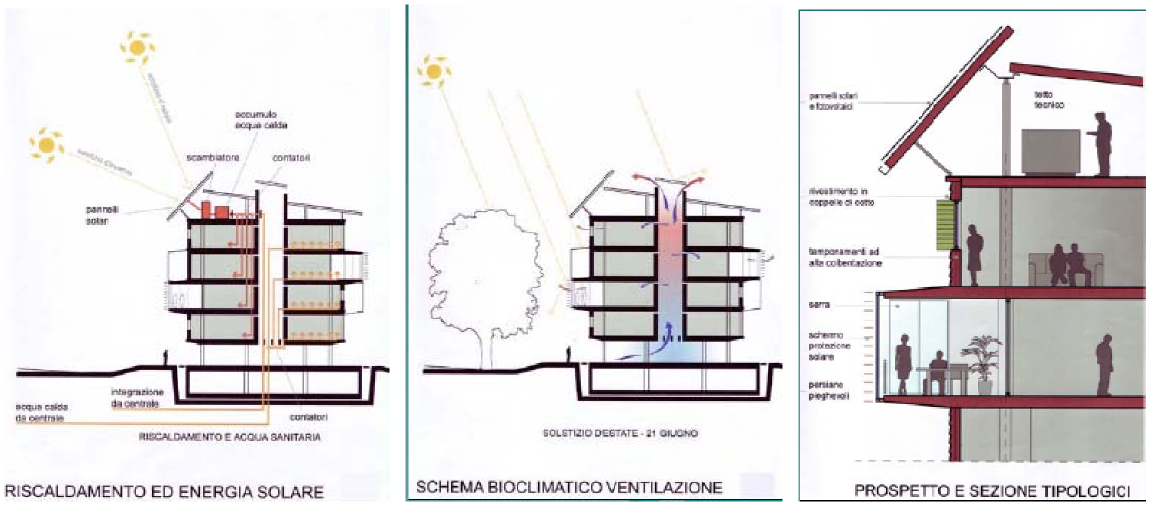
In such context, Piedmont promotes sustainable building through its policies and incentives. The Region works towards sustainable building through strategies such as urban renewal and industrial reorganization; the projects include new buildings which will be models for future realizations.
For these projects Piedmont allotted 4 billion euros, to be used over the next 6 years.

2 Urban renewal and the territory

Urban renewal involved 17 important Piedmont municipalities.
The urban planning choices have been made towards redeveloping industrial areas transformation; these projects notably include a strong support to sustainable building, through increased investments in sustainable building.
The regional funding contest requires the application of the ITACA Protocol (based on GBC) to assess buildings. This requirement encourages qualified design, emphasizing the use of new materials, and a focus on water reuse and renewable energy.
These programs, called "district contracts", require investments for ca 700 million euros; 54% of these investments (375 millions euros) are made by private funds.
The second version of the district contracts' program required the application of the abridged version of ITACA Protocol. This version evaluates twelve criteria, and is the most commonly used adaptation of the system approved by the regions.
On a stronger take on the subject of sustainable building, Piedmont launched the "Regional housing program: 10.000 apartments within 2012". This program requires the application of ITACA Protocol.
The regional housing program covers:

- 6063 apartments to rent, destined to social housing;
- 1973 apartments partly in permanent location, partly redeemable in 15 years;
- 300 flats for people over 65 years old;
- A warranty fund up to 60.000 euros for apartment, granted to the buyers of apartments realized by builders which took part in the program.

The assessments are carried out by iiSBE Italy. The certifications issued grant a reimbursement for additional building costs, covering 4%-8% of the total cost; the overall allocation sums up to 56 million euros.
The first results of the housing program are now available; the program has generated investments for over 1 billion euros, involving about eighty Piedmontese municipalities, working with builders, housing cooperatives, and ATCs (Agenzie Territoriali per la Casa - Territorial Housing Agencies, formerly Social Housing Independent Institutes) (Fig. 1, 3).
Another group of projects, launched in some of the main towns of Piedmont, will allow the realization of new districts; these areas will mainly house the families of army staff and police officers. Each of these projects will include housing for ca 1000 people, and the realization of new commercial areas and services. Currently 6 of these projects are planned. Before the building phase starts, the projects must be assessed by iiSBE Italy through ITACA Protocol; every project must achieve a score of at least 2 points on the Protocol scale. The total investment for these projects is ca 500 million euros (Fig. 2).
The effort towards sustainability goes beyond housing projects; the Region launched a new plan for 2007-2009, concerning schools. The school building involved in the plan will be refurbished, focusing on high structural and service standards. The assessment will be carried through an experimental version of ITACA Protocol, which will evaluate the fulfilment of eco-efficiency standards. The main areas of assessment include energy performance and indoor air quality. Piedmont allotted 25 million euros on this plan for schools' renewal.
In the town of Novara (near Milan, with ca 90.000 inhabitants) the Region has placed its "Health City", a new hospital, research and university complex. This project received a fund of ca 360 million euros; every building in the project must fulfil the requirements of ITACA Protocol, which will be adjusted by iiSBE Italy to suit these peculiar building typologies.
An interesting application of the ITACA Protocol will be carried out in Valdieri, a small thermal centre near Genoa. The thermal complex will be designed to achieve a score of 2 on the Protocol scale.



(fig.re 1)

(fig.re 2)

3 The skyscrapers

As of today, the Piedmont Region has 15 departments, each with its head offices, all in Turin.
In order to concentrate all the activities in one headquarter, the Regional Executive Committee has planned the realization of two towers designed by Massimiliano Fuksas; one of the towers will be 220 metres tall, and will be linked to the second through a lower building, destined to lodge an indoor garden (Fig. 4a).
The area will also include residential buildings, shopping centres and underground parking lots; the project will renew the former Fiat Avio area, close to Lingotto (previously hosting the Fiat group headquarters, known for its roof track for test drives). The area's ground level will be destined to public park, for pedestrians only.
The Regional Executive Committee resolved to apply ITACA Protocol to the whole area, requiring a minimum score of 2.5. Due to the complexity of the area, the protocol will be adjusted by iiSBE Italy and I.T.C.-C.N.R.[1] to ensure the fulfilment of the sustainability requirements by all buildings.
The regional investment for the towers alone adds up to 200 million euros.
On the other side, the Intesa-San Paolo banking group has chosen the Porta Susa district for its headquarters. Porta Susa is planned to become Turin's main train station, and will be displaced underground. The new Intesa-San Paolo headquarters will be hosted in a skyscraper, 219 m tall, designed by Renzo Piano (Fig. 4b). The project's highlights are the use of geothermal power, coupled with an highly insulated envelope, and the use of the stack effect during summer. Every floor of the building will host an indoor garden facing south.

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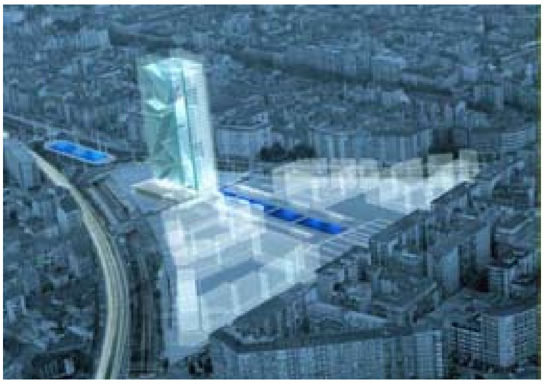
[1] *Istituto Tecnico Delle Costruzioni – Centro Nazionale Ricerche (Building Technical Institute – National Resarch Centre)*

This building as well will be assessed through ITACA Protocol, to evaluate the performance of the systems and techniques used.
On a side note, the Group Intesa – San Paolo has recently created a new financial product, called Aedifica-Bioedilizia, to encourage sustainable building. Both the builder and the buyer will receive funding, upon verification of the bulding's eco-efficiency level.
A third skyscraper will be built close to the Intesa – San Paolo one, by the insurance society Sai – Fondiaria. The tower, 140 m tall, will collect most of the society's offices in a place conveniently close to the Porta Susa station, in the renewed area called "Spina 2". This building too will follow energetic and environmental criteria.



(fig.ra 4)

(fig.ra 5)

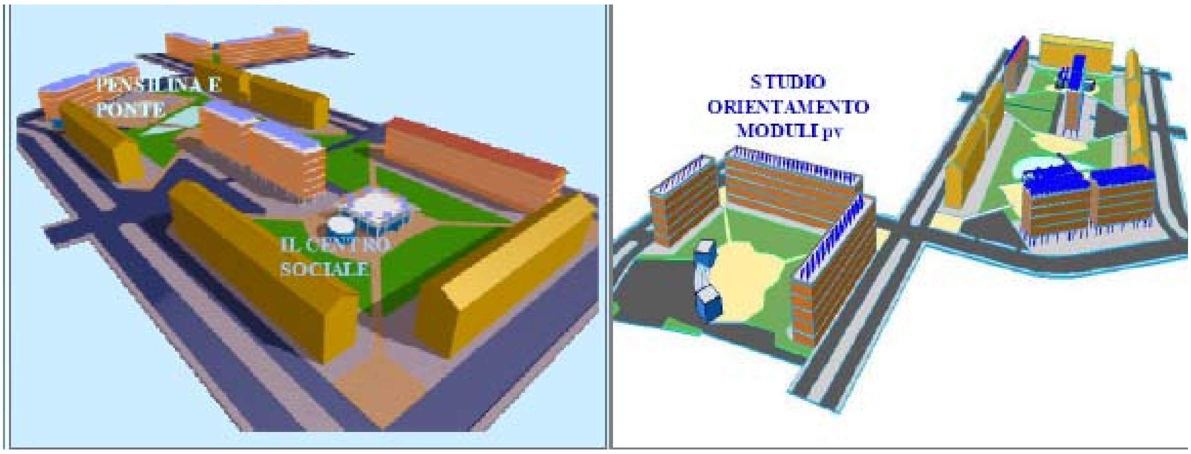
4 The sustainable district and the wood manufacturing process

The paradigm shift towards sustainable building happens in part through the aforementioned programs (including social housing, incentives, notable buildings such as skyscrapers); but these projects need a strong technological backup, which must be developed on the territory.
Piedmont will use 800 million euros from the F.E.S.R. (European Found for Regional Development) to encourage the design of sustainable materials and technologies, and to help the former industrial processes to take part in the production of such new materials. The aim is to develop and produce sustainable technology in Piedmont.
In the Monregalese area, in southern Piedmont, a similar project is under way. The effort is to create a productive network in the whole area, which will cover various steps of the wood manufacturing; the Monregalese area will host the production and the first stages of wood processing. The following steps up to the final product could be made in the province of Alessandria (southeastern Piedmont, ca 70.000 inhabitants) which is renowned for its wood processing industry.

5 The agreement protocols

The Region, whishing for a correct application of ITACA Protocol and its sustainability principles, promotes work agreements with the municipalities; one of this agreement protocols has been concluded with the Alessandria province and municipality. The Region's target is to allow the drafting of local energy and environment management plans and building regulations.
The protocol includes tutoring by iiSBE Italy to assist the municipalities in drafting new projects for sustainable building.

Piedmont has also arranged an agreement with iiSBE Italy (control body of ITACA Protocol) to provide training and technical counselling to builders enrolled in the "Regional housing program: 10.000 apartments within 2012".



(fig.re 3)

(fig.ra 3)

6 Sustainable building examples in Piedmont

- Vercelli: renewing Sambonet industrial area (Fig. 1);
- Torino: new district for security corpses' families (Fig. 2);
- Alessandria: new photovoltaic village (Fig. 3);
- Torino: Regional headquarters' skyscraper (Fig. 4a);
- Torino: Intesa- San Paolo banking group skyscraper (Fig. 4b).

7 Conclusion

Every Country has its own problems, but undeniable common need are: developing strategies to manufacture new ecological materials, building reference projects to boost future sustainable realizations, and strongly supporting sustainable building wherever possible, through public financial support.
Piedmont and Itaca, through iiSBE Italia's activities, strive to set a pattern for sustainability policies.

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SUSTAINABLE DESIGN; ECOLOGY, ARCHITECTURE AND PLANNING

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Keywords: ecologic models; watershed planning; sustainable design and planning, bioregionalism; biourbanism; carrying capacity; climate change.

Summary

The significant impacts on urban settlements due to climate change require a similar scale of design intervention. The problems associated with housing and feeding an additional billion people or transporting them out of harms way, are not solvable on the architectural scale alone. Designing at the urban and regional scale is central to this need.

Design as the regional scale begins with applying the knowledge of the region's ecology as it is the form and structure created by large and sustainable energies. This approach recreates synergistic connections between the design and the sun, soil, air, water, and gravity. Design at this scale enhances the regions' social, ecologic and economic health and is the forcing function of sustainability at the neighborhood scale. The removal of these connections has decreased the quality of life as it has exponentially increased taxes and stress on the global social, ecologic and economic systems.

Integrating the knowledge derived from systems ecology into the design program illustrates a systems approach to resource protection, quality of life and sustainable community design. These designs use the "free work" of nature and provide better places at lower costs and impacts.

Community designs that incorporate renewable resources and are respectful of the natural cycles create compelling neighborhoods while protecting the resource base. Solar driven urban and regional design creates a community that is efficient, economical and compatible with the regions resources.

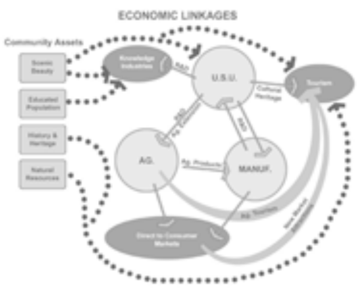

Figure 1. An ecological systems model of community, economy and environment

1. Issues of Sustainability

Land has a purpose and function over and above its real-estate value and that purpose and function needs to be understood, valued, preserved, protected and integrated into our planning and design efforts. Planning on a regional scale is one of the most effective methods of assuring available natural resources for future generations.

Figure 2. Regional “systems” planning includes economic development, social equality, and environmental protection while assuring a future desired.

1.1 Water as the Common Denominator

In the book *The Last Oasis*, the author Sandra Postel states, "Although water is a renewable resource, it is also a finite one. The water cycle makes available only so much each year in a given location. That means supplies per person, a broad indicator of water security, drop as population grows. Thus per capita water supplies worldwide are a third lower now than in 1970."

For example, in the United States even Florida is running out of water. Despite more than two decades of growth management, the health of the State's fragile ecosystem continues to decline. This decline is the subject of intense scrutiny ranging from the 1998 Governor's Commission for a Sustainable South Florida to the many Army Corps of Engineer restoration projects, which seek to mitigate the negative impact of landuse development. Although the causes of this decline are many and complex, clearly growth management has failed to successfully integrate landuse and water management planning.

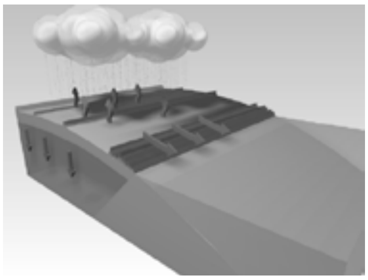

Figure 3. The hydrologic cycle is a free water distribution system

Land use affects water supply as well as water quality. South Florida's water shortage problems are not so much an allocation problem as a problem of where to store the abundant wet season rainfall so that it can be used during the dry season. Land use decisions ultimately affect the amount of water that will be stored on the land and in aquifers. As more and more land becomes developed, recognizing the influence of land use on water becomes more important.

Water is a renewable but limited resource. In most communities, water is used at a far greater rate than it is being supplied by natural rainfall or is available by annual storage capacity. Fresh, clean water is increasingly scarce and costly. Globally we are not using water resources are a rate that is sustainable for the future.

Water is often the most invisible yet critical limit to growth and development. Areas of the country are now restricted in their development due to insufficient water supply—a situation that can only get worse. Development outside of existing urban patterns increases demand and decreases land area available for recharge. Present-day development trends are inviting water shortages on a scale that is unsustainable, with near and long-term impact the economy, the environment, and the quality of life.

Buildings, cities, and communities are as dependent upon water as upon electricity. All buildings and materials, construction processes and labor forces rely on water. Once built, a building cannot function without water—it is no longer useful. Drinking water sustains human health. Water is used to clean the building, to cool equipment and space, to irrigate landscape and to remove wastes from the building. After a building's useful life, water is used to deconstruct the building. Dust control and biodegrading of many of its materials is reliant on the availability of water. Without water there is no construction, no building, and no community.

For all of human history, we have used clean water for all water uses, not only drinking, but for every other convenience, including transport of sewage. The wasteful use of water is very similar to our use of fossil fuel—we perceive the supply as unlimited. The "work" that water does for society is enormous. Its energy value is greater than that of gasoline. Water shortages are more critical than fossil fuel shortages.

1.) Water supply is among the least understood and yet critical factors of sustainable development. The global hydrological cycle supplies and distributes water, but with great variation, subject to location and seasonal weather patterns. In some arid regions of the globe, the sole and increasingly costly sources of water are importation from afar, deep well digging deeper into once plentiful but now dwindling aquifers, and desalinization. In contrast, all water in the United States for all practical purposes comes from rainfall.

2.) Annual rainfall of a region determines its water income or budget that is available on any reliable basis to support natural landscape and human requirements. Annual rainfall varies, especially in arid drought-prone regions, so that sound planning for water needs has to extend over many years, if not decades.

3.) Peak weather events establish the severity and risk from local natural weather hazards. In some regions, hurricane, storms and flooding are the foremost natural disaster threats. In other regions, lack of water, drought and resulting forest fire hazards pose the greatest risk, while in the same regions flashfloods need to be anticipated and mitigated. With the global climate trending toward more severe weather events, regional landscape and infrastructure need to be enlarged to anticipate greater peaks and variations. These preparations need to be made part of every regional and municipal watershed plan and infrastructure.

4.) Water storage, either in natural water bodies and available aquifer, or structured storage systems, is essential to a sustainable approach to providing for present and future water needs. Currently, water storage systems globally are for the most part inadequate to meet future demands of their regions and communities.

This presents a design opportunity for watershed planning: critical relationships between how we build, where we build, and how we preserve the water supply have not been studied or implemented as an integrated system. Techniques for water storage are available and affordable for projects at every scale. Implemented together within a region, they can quickly restore and improve the quantity and quality of a community's water independence.

Figure 4. Architecture can create its own water supply by receiving, collecting and storing precipitation. The very form of the building can also capture renewable energy such as solar and thermal ground energy.

1.2 Living within the Carrying Capacity of the Region and Site

The local rainfall represents the most readily available and predictable *"income"* for water supply in a region. Regions where annual rainfall can meet annual demand require effective ways to store and disperse that income. Arid regions where the annual rainfall is insufficient have to invest heavily in transport from afar, with greater cost of infrastructure and management, which increase as fresh water supplies become scarcer. In both instances, conservation and reuse are far more effective.

The local aquifer and man-made storage represents the *"bank account"* for a regional water resource. The quality and availability of the aquifer represents its "water wealth." The water infrastructure at regional, community and building scale represents the means of investing that resource—determining the cost and "budget" of water on which to live. When primary needs are met, the balance represents its "disposable income."

The design and technology of water use—how we design and construct the landscapes and structures of the built environment— represent our *"spending habits,"* determining rate at which we expend our water budget. Currently, too many of our practices are profligate, and without any saving plan. In every region, community and building project, there is room for improvement, conserving while also improving life and water quality.

Recovery and reuse of water after primary use represents the *"savings and investment plan."* Without one, the water account is soon depleted. With planning and designing for water conservation and quality improvement, we create a *"water endowment."* In the terms given by the goal of sustainability, that endowment should last forever. Water supply is best thought of as a savings account where using the interest – water over the required need for the system – is good practice. Using the principle is not advisable as it reduces the overall system supply and stresses or degrades the future supply.

We know that we are able to create a *"water budget plan"* appropriate for each region, community and building, to conserve and improve water resources and to provide a higher quality of life for the greatest number.

1.3 Watershed Principles

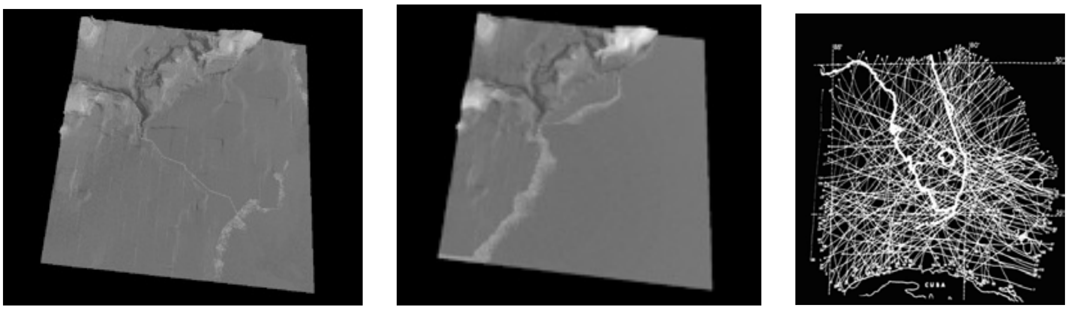

Figure 5, 6, 7. Changes in sea level greatly impact ground water storages and consequently supply. The regional natural disasters can greatly influence urban and regional form and inform sustainable patterns.

Consumption and demand for water are increasing globally. Population growth and continued expansive regional development has, most notably in the arid regions where water resources are already strained, relied upon water imports from other regions or from vanishing storages. Due in part to planning, fresh water, a free gravity-distributed resource, is now a costly commodity. Water is needlessly costly in cases where there is no water budgeting and no savings plan or water endowment for the future. Urban design with watershed planning as its ecological systems planning tool provides opportunities that are of high value for all systems:

(1) Reducing water consumption, to live with the regional and local water budget.
(2) Increasing water storage systems that mimic natural system hydrographs,
(3) Creating water green-infrastructure that cleans and reuses water, uses gravity to distribute it and be responsive to climate change and sea level changes.
(4) Improving water quality and storage at each step.

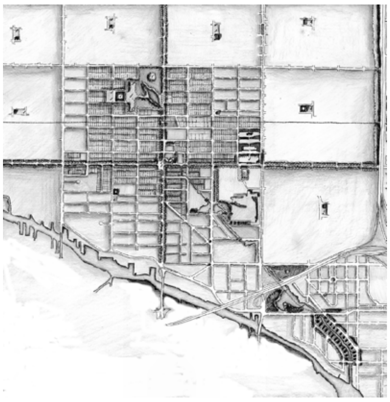

Figure 8. An illustration of an urban pattern retrofitted to provide a sustainable water supply, walkable neighborhoods and economic vitality.

These four steps that protect the water resources are appropriate at all scales: regional and urban planning, landscape and community design, building and plumbing technologies. By establishing large planning efforts that are detailed with the knowledge of the hydrology of the region, a future with water can be assured all while creating livable-desirable communities – without this planning it is assured the result will not be desired.

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ALTERNATIVE CONCRETE COMPOSITES IN AN INTEGRATED COLLABORATIVE BUILDING SYSTEM FOR A QUALITATIVE STRUCTURE IN THE RECONSTRUCTION OF HOUSES

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Keywords: concrete composite, durable material, sustainable construction, seismic desert, weight reduction.

Earthquakes annually cause big economic and human impacts on world's society such as losses of energy (causing depletion of natural resources in a large scale), efforts, and lives. Declining the vulnerability of inhabitants in a building is a major ambition for designers and the construction industry as well as for politicians and decision makers. With building destruction in seismic areas, the collapse of construction materials and their weight is the main reason for fatalities and severe injuries. Houses as the major inhabited buildings are the main subject of the collapse or damages in earthquakes. Therefore, appropriately materialization of houses is highly important in seismic areas.

This study concentrates on the reconstruction of houses in a seismic desert city. To ensure the sustainability, by an integrated design and a qualitative building system, materialization is the main subject in this work. A concrete composite will be the basic material of the structure. As concrete is relatively heavy, the focus lies on decreasing the weight by options such as replacement of the heavy ingredients in the composite. The aim is to investigate the influence of such materials on the durability of the concrete composite for this particular application in a sustainable approach.

1. Introduction/ Reconstruction and materialization

Housing was and always will be the most concerning factor (related to buildings) for humans (Oliver, 1969); therefore it is a major ambition for the building industry (Habraken, 1998). Earthquakes are happening frequently. For instance, since1900 (until 2007), around 919 strong earthquakes (i.e. magnitudes 5 and more) were registered. This includes 224 earthquakes with magnitude of 5, about 370 with magnitude 6, magnitude 7 about 283, magnitude 8 about 38, and magnitude 9 or more 4 earthquakes (USGS, 2006). As houses form the major part of the built area, to decline vulnerability of the inhabitants of buildings, designing and materialization of houses in seismic areas are very important. Therefore, for increasing the efficiency in the construction industry, the durability of materials for houses (Hendriks, 2002) should be seriously taken into the account as an essential contributor for economic and human safety.

The other important concern of this study is the desert climatic condition, because the reconstruction of the houses will occur in a desert circumstance. Deserts include 1/3 of the surface of the planet Earth, while only 15% of the world's populations live in deserts (Gradus, 1985). This unequal dispersion of population with the land area is due to the harsh climatic and land condition (Pyper, 2000). Durably materializing the houses in the desert cities in addition to the economic and social efficiency (Newman et al., 2003), will end with material minimization (Groot, 2005). This results in less depletion of natural resources being distracted for raw materials (Yu, et al. 2006). Consequently, the pollution which may be results of the production process of construction materials will decrease and thus the virtual pollution prevention costs such as eco-costs will decline (Vogtlander et al. 2004).

For reconstruction in such a situation, the study was confronted with two contradictory phases. For a seismic design decreasing the weight is important. However for the desert situation the thermal mass helps to save more energy which will be used for the cooling in the summer and the heating during the winter. Besides the temperature difference between the night and the day time in these circumstances is high. Therefore, the weight of the materials can be decreased as much as it does not affect the required mechanical and other properties. However, to compensate the extra burden from the climate when the thermal mass is decreased, insulation capacity of the material will be a crucial factor. This weight decreasing in a concrete composite is possible by using substitution materials for the ingredients of a conventional concrete. For such purpose some alternatives are available. For example decreasing the amount of the cement in the composite by replacing it with a light weight material or finding an appropriate replacement for the conventional aggregates and for the conventional reinforcement method will help to reduce the weight; because concrete is a very flexible material to be combined with a large range of materials (Li, 2005). These methods have also positive effects on the sustainability of the materialization in the construction/reconstruction, not only by directly declining the environmental impacts but also by improving some of its mechanical properties. With this background, this study investigates the influences of some substitutive and additives on the durability of a concrete composite in a sustainable framework.

3. Approach and methodology

The broader research, of which this study is a part, is divided into the three levels of: Macro (urbanism), Meso (building, component, and element), and Micro (materials dividable in sub-levels). Thus the work presented in this piece is placed in the micro level of the general research on sustainable houses for seismic desert areas. However, the material investigation, itself, has been worked in different scales. To ensure sustainability of a reconstruction in a desert area decreasing the weight by using the sintered clay and fly ash was the general assumption. Furthermore, the influence of some fibers (as the substitutes for the steel reinforcement) on the durability of a concrete composite has been investigated. Although in order to achieve more sustainability of the final composite, replacing the aggregates with recycled materials was another concern during the investigations, it is not the issue of this paper. As the first concepts of the design for the reconstruction were dome concepts for houses; the concrete composite was casted in the dome form. These have been shown in the table 1.

For laboratory tests and observations, in addition to the building elements and panels, two models of the complete houses were materialized with the concrete composite in a time difference of about 1.5 years, using the earth-casting technique for the molding (i. e. figure 1.).

Figure 1. a, b, and c

Models were made in a scale of 1:25 with the circle plan as the footprint of radius of about 5m. They were materialized with a concrete composite based on a conventional mix of the Portland cement, normal fine and coarse aggregates. A shell structure was the main concept for the modeling with the thickness of more than 8 mm for both of the models. Table1. shows the models and the related characteristics). The sizes of the clay particles were various, but mainly according to the thickness of the shell structure; because, it needed to be covered by the cement in the matrix like a thin sheet all around the particle. Therefore the sizes are scaled and so they are relatively smaller than the range that can be used in an application into the 1/1 scale structure.

Table 1. the two models of the dome concepts materialized with the concrete composite including the expanded clay particles

Specifications	Model number 1	Model number 2
Figure		
Age of the composite	25 months	7 months
Size range of the clay particles (Ø mm)	2 – 5 2-5 mm	2 – 7 2-7mm

The concepts were modeled and cured in an indoor environment with the mix of a water/cement ratio of about 1/3. The time difference between the models was about 1.5 years, and the tests and observations were done more than a half year after the second model was built. For preparing the test samples thin-sections have been done in the Micro lab of the TNO Delft in two consequent processes. The specimens were made by first cutting the samples to an appropriate size (ca. 0.5 mm), thereafter stabilization using resin impregnation under vacuum, and then cutting these into thin sections (25-30 μm) using a diamond roller (DBT) and grinder (Grinder/86). UV-light was used to cure and harden the resin whereby these could then be ground and polished. Observation and analysis of the composite on a micro-scale was undertaken using both polarized light and UV-fluorescence light microscopy. These are shown in the figure 2. a, b, and c. Moreover, the snapshots of the microscopic observations were made with different magnifications and are used here to show for comparison.

Figure 2. a, b, and c . parts of the sample preparation by impregnation and polarization.

4. Results

The produced composites (liquid phase and the solid phase) of sintered clay, which was mixed with an approximation, were lighter in weight in both cases. The weight difference is shown in the table 2

Model number one		Model number two	
Basic concrete	With expanded clay	Basic concrete	With expanded clay
100%	92.5%	100%	91.01%

Table 2. the comparative weight reduction in the different aged models

The other part of the main results from the tests and observations can be summarized as:

- Carbonation was observed, distributed irregularly. However, in the samples from the second model carbonation defected zones were relatively ignorable

- Model two (the younger model) showed a better zonnation around the lightweight aggregates in the matrix (i.e. figure 3. a, b, and c).

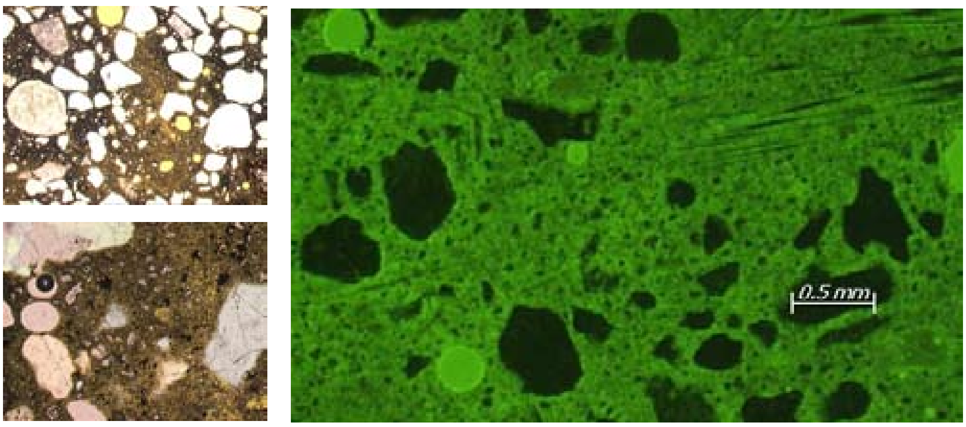

Figure 3. a, b, and c

- Porous zones are more distributed in the samples from the model one, in which carbonation was the consequence.

- Although the matrix in the second model was more homogenous (from the mix), the interfacial structure in the matrix between the expanded clay, fibers and the bulk was still heterogeneous and problematic (i.e. porosity)

- In the area around the expanded clay particles, some iron look areas were observed (i.e. figure. 4)

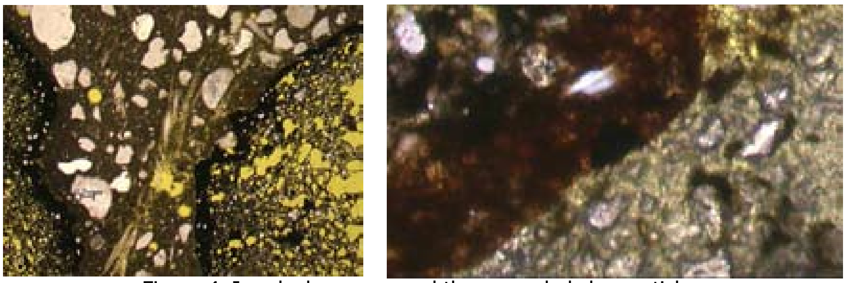

Figure 4. Iron look area around the expanded clay particles

- The compaction problem was not seen in the parts where fly ash was added in the mix neither the porosity problem. The results were homogenous bulks.

- Exceptional crack about 15 mm long was observed (i.e. Figure. 5), in addition to the partially distributed interfacial and internal curing problems in the model one.

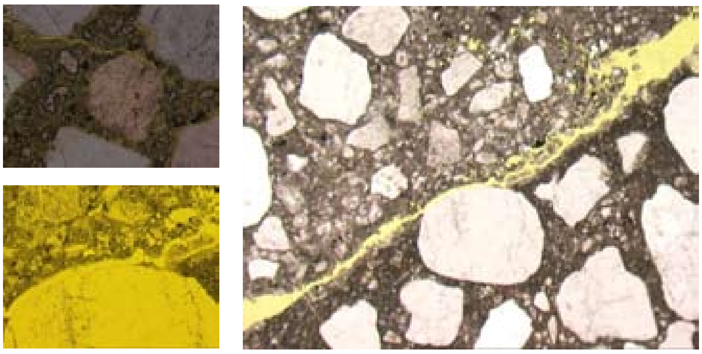

Figure 5. the exceptional crack observation in the microphotographs

6. DISCUSSION

Although seismicity is a big threat to the buildings, it is not the only important concern. The environment is a very important issue for the construction industry. According to the book of WCED (1987) and the Brundtland-report (UN, 1987) the construction industry is an important contributor in world's economy. It contributes on average 10% of GNP and about 50% of the capital investment in most countries world-wide (Durmisevic, 2006). CICA (2002) reported that the building industry includes the largest industrial employer with 111 million employees. In a global perspective the construction industry poses 40% of the air pollution, and 50% of the waste (Durmisevic, 2006).

Despite the impact that this industry may directly cause on the environment, it can highly influence some other aspects, ending in serious problems such as desertification. As a global problem, desertification threats a vast range of desert areas. This is a problem with which a land loses its biological potential 'ultimately leading to the desert condition' (Pachaury et at., 1997). For example the Sahara desert is expanding southwards, degrading grasslands at a rate of 30 mils every year. However, deforestation as an important phenomenon, which can also lead to the desertification, is happening in a larger variety of lands (than only desert areas). It can also ultimate the soil instability and consequently flooding (Kibert, 2005). Besides, with diminishing the forests (i.e. about 20 million hectares of rain forest are cut down every year), the amount of carbon emission, which can be stored in the trees' masses, releases in the air (CCAP, 2007). Thus, places that are located in the vicinity of deserts are considered as more endanger. Therefore, construction/ reconstruction in a desert land is highly sensitive and needs extra attentions. As the dominate buildings, design and materialization of houses in an efficient system will not only help the land from desertification, but also incorporates with the other aspects of sustainability (Shahnoori et al., 2008). With this, durability of the material plays a major role, because using durable materials can end with very efficient results such as decreasing in the depletion of the natural resources, air pollution, and the eco-costs.

As an available construction material in a large range of places in the world, concrete with the required mechanical properties is a durable material (Hendriks, 2002). However, a conventional concrete composite makes a rather heavy structure. On the other hand materials' weight is important because the structure (materialized with heavy materials) should carry more dead load. Besides, transportation and performance related costs increase as the weight increases (Beukers et al. 2005). Moreover, in seismic design for houses the weight can lead to additional problems such as more vulnerability of inhabitants in the next earthquake, when the structure meets the load bearing limits (Booth et al., 2004). However, as another important quality of concrete, this material is very flexible to be combined with some other materials to upgrade particular mechanical and other properties (Li, 2005).

Cement is the basic material in a concrete mix, which is responsible for most of the environmental impact (Hendriks et al. 2000) that is the main part of the impact of concrete. Because, in the conventional production process to produce one ton cement approximately1.25 ton carbon emission releases in the air (CCEC, 1993). Therefore, an important method that is being worked out is to find substitution materials for cement with the same or similar mechanical properties. This substitution material can also be lighter in weight than the cement, such as fly ash (Anderson, et al. 2007). Similarly to the study of Anderson et al. (2007) fly-ash used in this study models not only did not have negative influence on the durability of the concrete composites, but also the matrix in the areas around the fly ash particles showed a homogenous bulk, and no failure was observed. Apart from the specific properties of the fly ash, this can be assumed as a result of the lower water/cement ratio required for the workability of the concrete composite (i.e. using the fly- ash). Also the early shrinkage cracking and generally the cracking were relatively low (especially in the second model), and in the case of the exceptional cracking, large dimension cracks were not observed. One reason to introduce the micro or macro cracking and thus impairing the concrete quality is autogenous shrinkage (Lura et al. 2002). Therefore, using the fly ash in the concrete in the current tests similar to the study of Ridging et al. (2008) with reducing the heat of hydration of the cementitious materials may decline the risk of cracking.

Working on these substitution materials mostly concentrates on obtaining optimal mechanical properties such as strength while decreasing the cement in the composite. With which the fly ash is a good alternative as it results also in less weight for the final composite (van Breugel, 1999). Many of these materials (substitutes) are basically subjects to pollute the environment as they are counted as waste (i.e. mostly by products), such as blast furnace slag or silica fume. In about thirty years ago manufacturers who produced silica fume as by products had to pay for removing this by products from their site. However, regarding to the potential qualities, as the demand for this material has enormously increased, they are not counted even as cheap materials. Because for instance adding the silica fume to the mix increases the strength and reduces the porosity (Lura et al., 2002). However, it also increases the relative humidity (RH) drop in the mix (Jensen et al., 1996). Besides, as it was stated in the study of Jensen (1993) adding 6% silica fume to the pastes of different w/c ratio led to two times higher shrinkage (about 1000 μstrain vs. 500 μstrain, for w/c ratio 0.35). Therefore, to avoid carbonation problem in a normal situation it can be a good alternative substitution.

Another example that results in a more environmentally friendly approach for concrete producers, although it is not the focus of this paper, is replacing the aggregates (or reducing their ratio) with recycled items (Lauritzen, 1998). With this not only natural resources will be preserved (for more/future demands) but also processing and reusing the stony construction and demolition waste decreases the impact on the environment. For example it has been estimated that by the year 2002 in Europe, about 200-300 million tones of building and demolition waste was land filled or used in road foundations (Symonds, 1999). Using the recycled aggregate in a more efficient way is vastly increasing in some countries such as Japan and European countries by applying special policies. For example in the Netherlands in 1990 about 60% of this kind of waste was recycled, but after establishing the tax policy for the landfill, this amount increased to above 95% (Pietersen et al., 2002). However, this percentage was only used in the road construction, but since 1995 Dutch standard VBT (NEN 5950, 1995) recycled concrete (or mix) aggregates can be applied for 20% of the natural aggregates (Pietersen et al., 2002). Although, it has not been used in High Performance Concrete (HPC) properly, yet, for the concrete industry it is still a very efficient way to decline the negative impact on the environment (UEPG, 2006).

The weight of a concrete composite can also be lowered by appropriately replacing the aggregates as heavy segments in the mix (ESCSI, 2004). An alternative which is considered as a sustainable, available material is clay. Clay is available in a vast variety of places across the globe. If it is not being used in a huge scale, the use will result a sustainable construction (Videla et al, 2001). With great characteristics, clay can be worked out into different products for various applications such as Nano-clay, sintered and expanded clay. Moreover, because the materialization of the houses as a purpose of this study is being used for a seismic desert area, clay is an affordable material for using in the concrete composite. Besides it has a good thermal insulation capacity. However using various clay products (e.g. sintered clay) may have different effects on the concrete.

As several involved factors make the prediction of the durability of a concrete structure difficult (Jones et al. 2002), more investigations are necessary to increase reliability of this prediction. For example carbonation is not considered as a fatal problem for concrete (Yu et al., 2006). However, in a reinforced concrete structure it will defect the durability by generalizing corrosion, which induces failure of pre-stressing or generally the steel (Proverbio et al., 2002), mainly by depasivation. Passivating stainless is to remove the iron from the surface and create a nickel and chrome- rich surface that is not the subject to rust (Brwer, 2001). In the current tests, the porous areas around the clay particles which were appeared to be more dispersed in the older model (the first model of the concrete composite presented in this work) may be due to the characteristics of the sintered clay. The extremely fine particulate clay minerals (i.e. normal) and the activity of their surface generally increase the required water for the workability of the concrete. This is a reason that clay is supposed as a harmful material in the fine aggregates inside the concrete (Yool, et al, 1998). In the presented samples, although carbonated zones were almost dispersed in the older model, they were mostly concentrated around the lightweight aggregates, which can be assumed as a result of more permeability of the matrix due to the porosity.

As it was indicated before the carbonation- induced corrosion is harmful mostly for the steel reinforced concrete, where the moisture saturation level of the capillaries is suitable for supporting both CO2 ingress and steel oxidation (Jones et al. 2002). Therefore 2/3 of steel reinforced structures (which are exposed to the rain) are subjected for such corrosion (Parrot, 1996). With this background Hobbs et al. (1998) counted the service life of most reinforced concrete buildings structures to be governed by cover carbonation and subsequent reinforcement corrosion. On the other hand, the Concrete Society (1996) claimed that carbonation- induced corrosion is rarely catastrophic. However, this is a major issue in the tropical deserts (Shahnoori, 2000), but not for the dry desert areas. Jones et al. (2002) concluded that the potential carbonation resistant of concrete is dependant on permeation and alkalinity of the cover concrete. It can again be concluded that it is not harmful for the non-reinforcement segments (directly). Therefore, as this study is concentrated on using mainly fibers to increase the ductility of the concrete for an application in the seismic desert areas, this problem is not a fatal issue for such purpose. Although fiber-matrix interface problem was also observed, it was mainly due to the typology and geometry of the fibers that have been used, which is beyond the scope of the presented work.

7. Summary, conclusion, and recommendations

The sintered clay in the version that was used in these mixes resulted in relatively light weight concrete. The insulation capacity of the sintered clay is also considerable. However the durability of the concrete was susceptive to be influenced. Therefore, by using the sintered clay in the concrete for load bearing structural elements in seismic areas, apart from the strength, the durability of the concrete composite will not be guaranteed. For such purpose in a sustainable reconstruction further treatments may help to deprive the negative influences of the sintered clay on the strength and durability of the concrete composite. This needs further researches.

The positive effects of fly-ash (and silica fume) on the strength and durability of the concrete was also observed. Using fly-ash in the concrete mix for the structural load bearing purpose can result in a sustainable reconstruction. Besides preference of polymer and glass fibers than the natural fibers (i.e. no chemical treatment were used), inside the concrete mix, which was the subject of the former study, were observed. For these fibers longer fibers showed better potentials for durability to be used in such a composite.

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INNOVATIVE TEACHING OF BUILDING TECHNOLOGY TO ARCHITECTURE STUDENTS IN THE UNIVERSITY OF MALAYA

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Keywords: Building Technology, Energy conservation, Sustainability issues, Building Services.

Summary

The built environment is an integral part of the infrastructure necessary for human survival. Current concerns over the environmental sustainability of our biosphere for future generations are being scrutinised on the fringes of the higher education. The focus of this paper is on the teaching approaches of academicians of a public university in Malaysia, specifically on the integration of building technology and sustainability issues into the subjects offered. Architecture teaching involves not only the teaching of art and aesthetics but also the science of building. With the increased use of high-rise construction, intelligent building features as well as the use of building services to make the buildings habitable, it becomes imperative that the students of architecture understand and appreciate the complexities of the engineering systems to make the buildings sustainable and energy efficient, so that their carbon footprint is minimal. The process of architectural design starts with the sketch design as well as a statement of design intent including sustainability and targets by the architectural student. At this point several major decisions are being made with respect to the orientation, fenestration, service cores, environmental control systems etc. These preliminary design decisions would affect the overall energy efficiency of the building as such. It is thus necessary for the architectural student to comprehend and assimilate advanced building technologies. This paper presents a novel approach adopted in the Department of Architecture at the University of Malaya for the teaching of Building Analysis to year 3 students as well as Advanced Building Technology to Year 4 students in a five year Architectural programme.

1. Introduction

Buildings are increasingly becoming more complex and more sophisticated due to advances in building technology, construction and engineering (Gyula Sebestyen 2003). Thus the Architect needs to depend upon a team of specialists who can handle the different aspects of the design and construction of the buildings. Unlike in the earlier days the architect and hence the architecture student should be aware of the latest technological developments and their adaptation for the successful design as well as running of the buildings

2. Architecture through the ages and the building envelope

The "Pre-Industrial" architecture was characterized by abundant resources and limited technology. During that period the architects necessarily had to use the building envelope as the modulator and filter for the harsh outdoor climatic conditions. The building envelope was the PRINCIPAL means of controlling the visual and indoor thermal environment in the buildings. The luminous environment in the buildings was by day lighting in most instances.[1] The "Industrial revolution" markedly changed the above parameters. The advent of new materials coupled with advances in mathematics, structural engineering, building services engineering etc., has immensely contributed to the growth of the modern day skyscrapers and intelligent

[1] We require from buildings, as from men, two kinds of goodness: first the doing of their practical duty well: then they be graceful in doing it. (John Ruskin: The stones of Venice,1851).

buildings. The exterior wall now simply becomes a member supported by structural framework at each floor. The exterior wall thus becomes a skin to exclude wind and rain water penetrations into the buildings. The concurrent developments in air-conditioning, lighting, lifts and escalators allowed the buildings to become deeper and deeper in plan as well as to be designed to greater heights (Fuller Moore, 1993, Gyula Sebestyen 2003)

The "Modern movement"[2] used the freedom thus gained by the technical and engineering developments to explore new building forms. Economy of structure, space, labour and construction became the characteristics of the new International style. The concurrent developments in the horizontal and vertical transportations in buildings allowed the buildings to be designed to greater heights. Hence the new buildings are designed to be heavily dependent on electrical energy for their sustenance. This can be construed as "energy dependent" architectural style (Fuller Moore, 1993, Gyula Sebestyen 2003)

3. Architecture studio teaching

In the Architecture Studio, Design projects are the main vehicle by which all the subjects taught in the lectures, seminars as well as from fieldwork are integrated to enhance the learning and creative design skills. (Esa 2002).Figure1 is a simplified illustration of the architecture educational process. The project becomes the central objective for students. (Tony Brown 2001)

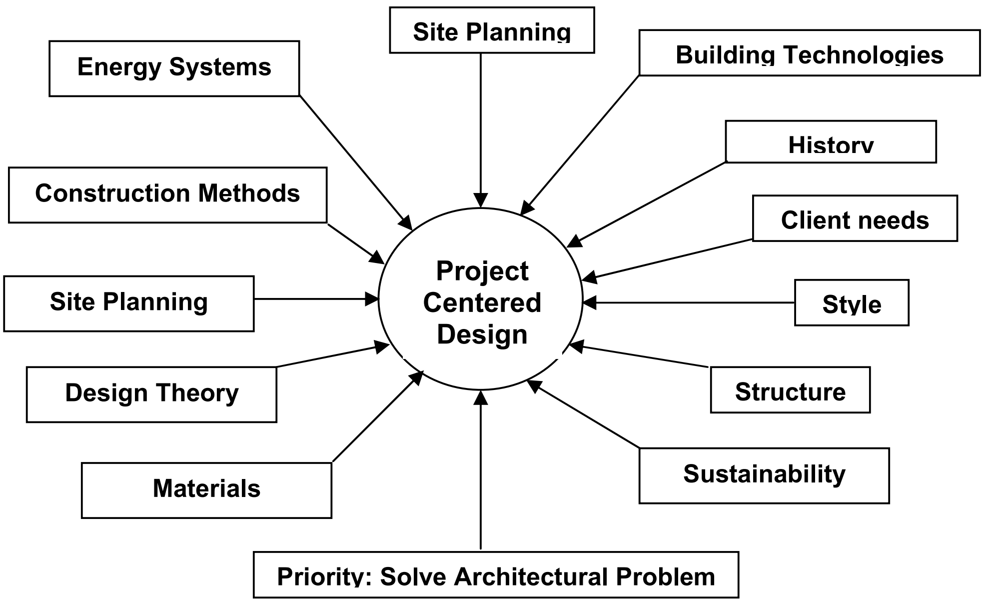

Figure 1 Architecture Studio Teaching Process (Tony Brown 2001)

Project based learning as a subset of Problem-Based-Learning techniques are often used in teaching as a method of achieving deep learning and simultaneous mature participation within the education process. Project-based techniques may range from the search for an optimal solution to precisely framed problems through to scenarios more akin to complex real life situations where the principal difficulty is one of identifying and framing the appropriate parameters (Peter Skinner 2002).

4. Teaching of sustainability issues to students of Architecture in the University of Malaya

The ambience in and around buildings is the result of the built environment. The responsibility for this falls squarely on the architect (Flynn et al, 1992). The extent and contents of the requirements has grown more complex in recent times as shown in Figure 2 ((Gyula Sebestyen 2003)

[2] This is expressed, perhaps, as the new spirit of the 20th century in the claim by Gropius that the designer was released at last from the "tyranny of the wall", which had become merely a boundary between the outside and inside of the buildings.

The architectural curriculum in the University is based on Design as a vehicle for integration of all the taught subjects. During the first three years of their course the students are given inputs on environmental physics, building structures, building materials, and construction as well as building services. As part of this exercise, students are set to solve practical problems, which would involve environmental sustainability issues. The students are encouraged to be proactive in their research and presentations. The students are taken on field trips as well as practising architects are invited to the studios to show how they tackle sustainability issues. The Faculty is fortunate to have eminent architects assisting the students to understand and design environmentally sustainable buildings.

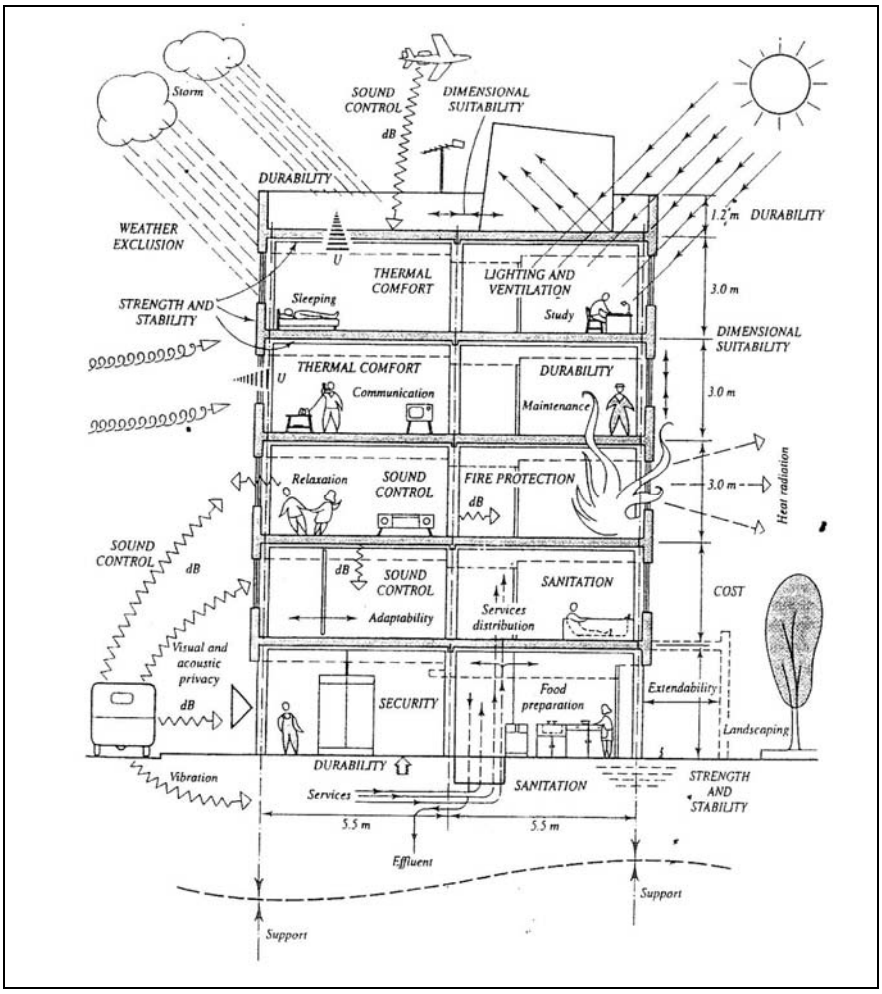

Figure 2 Performance requirements for buildings (Gyula Sebestyen 2003)

The University's research facility on renewable energy is to be used as a test bed to test new ideas in the future. The facility is being used at present to monitor the performance of some of the building integrated photovoltaics. The students are encouraged to have meaningful discourses in the studio setting for achieving an environmentally sustainable building.

In year 3 studio one of the assignments encourages the student to include the passive and active architecture aspects in their design showing the cause and effect of the sustainable features chosen to the occupant by doing virtual studies of their proposal. They are also exposed to site visits to the internationally known Low Energy Buildings.

5. Innovative teaching of Building Technology at the University of Malaya

The modern day skyscraper is dependent on energy resources and engineering services systems for its daily operations. These services are commonly grouped under the generic heading of "Building Services". Figure 3 shows some of the major components of the Building services for an Intelligent Building.

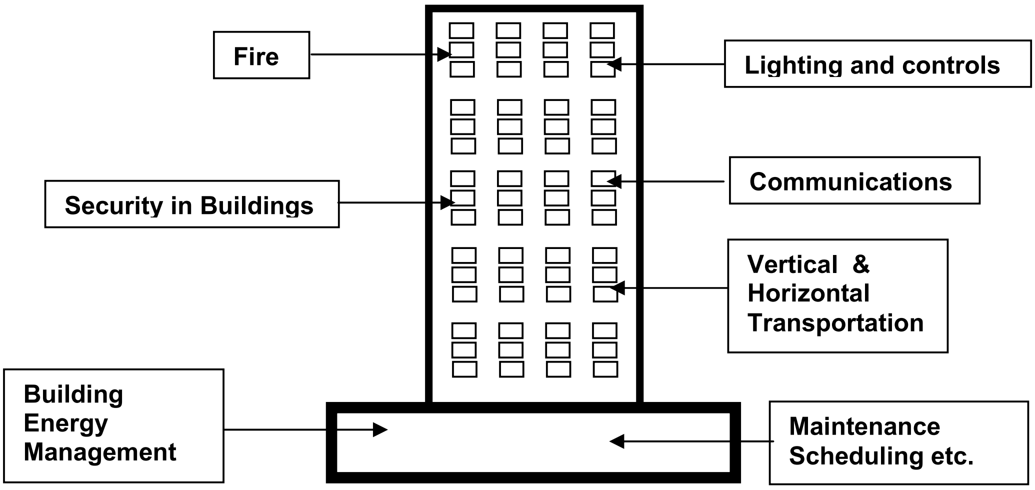

Figure 3 Components of an intelligent building

The scope, complexity, value, use and installation of the specialised building services machinery are increasing rapidly with the advent of the intelligent buildings. An architect is expected to have a basic understanding of the building services so that proper space allocations for plant rooms, ducting, cooling towers and other equipment are made during the initial design phase. Any miscalculations at the sketch design stage are detrimental to the servicing and maintenance of the buildings, leading to Indoor Air Quality (IAQ) problems in the buildings.

5.1 Building Analysis & Report

The arrangement discussed above seems to be satisfactory at first. The studio based assignment does achieve the object of integration. However, it was felt that the students were not benefiting fully from the programme, as it was largely left to the lecturers to integrate the assignments and lectures with the studio. The students were bogged down by the lectures rather than learning on their own.

One of the strategies adopted by the authors is to introduce a special subject 'Building Analysis & Report' in year 3. The subject is introduced in semester 6, the last semester of the first tier programme. It consists of two parts combined together in our effort to maximize the possibility of fulfilling the overall goal of integrating the various subjects.

To achieve the goal, this subject has been formulated with two objectives:

i) To train students in making critical assessment of an existing building from various aspects, covering site suitability, structures, environmental physics, method and detail of construction, use of materials, building services, landscape, etc.
ii) To give guidance in the preparation of a technical report that will accompany their Comprehensive Design Project, covering all the above aspects.

In consonance with the objectives, the subject combines the following two components,

5.1.1 Component 1

This component is a group work, for which students are divided into several groups, each comprising 4-6 persons. The formation of the grouping takes into consideration ethnic, gender and individual performance of the student to ensure that all the groups are more or less of similar composition and strength. Every group is required to select an occupied building of not more than 4 storey-high of acceptable complexity, which must have been in use for at least one year, since brand new buildings are considered unsuitable for this exercise. After their choice has been approved, students have to make a critical analysis of the building, covering all the above mentioned aspects. As a general guide to write the report, they should respond to the following questions and instructions, which by no means are exhaustive.

i. Explain briefly the function of the chosen building.
ii. Is it appropriately located on site in terms of orientation and context?
iii. Look at pedestrian movement, car parks and landscaping and give comments.
iv. How does the building respond to the tropical climate?
v. Is the structural system suitable for its function?
vi. What do you think of the construction of the building?
vii. How about the choice of materials?
viii. Study the engineering services used in the building
ix. Fire prevention and fire fighting systems etc., their strengths and weaknesses?
x. Suggestions to improve the sustainability aspects of the building?
xi. Are there any serious defects on the building? Is it because of the inappropriate choice of materials or faulty detailing?

The 'Building Analysis' exercise requires a holistic and comprehensive approach, which will inevitably touch on design issues. However, it is not meant to be a design analysis per se. The students' progress is monitored through weekly seminars and they are required to submit their report at the end of the seventh week. The product of this exercise will be in the form of a detailed report containing the building records, such as drawings, photographs, sketches, and an analysis that critically describes the coordination and integration of various aspects of building with the plans and elevations. Students are also required to give suggestions for the improvement of construction details that they consider to have caused problems or undesirable effects to the building performance and users. The analysis should contain not less than 5000 words, complimented with pictures and sketches with proper annotations. The power point version of the report will be used by each group in presenting their work in a series of seminar conducted during the second half of the semester.

5.1.2 Component 2

This is an individual work in the form of 'Technical Report' that every student shall prepare during the second half of the final semester and hand in at the end of the 15th week. Having gained experience from the preparation of 'Building Analysis' previously, he/she is expected to be able to write the report that will complement his/her Comprehensive Design Project (BAEA 3276) which is meant to be the culmination of his/her project solving ability at the end of the first tier programme (Part 1 level of the Malaysian Board of Architects as well as Part 1 RIBA)

The report shall contain,

i. Site analysis and site studies
ii. Project brief/Client brief
iii. Compilation of initial sketches, concept/intention, massing and photos of initial models
iv. Summary of relevant clauses in Uniform Building Bye Laws related to the building needs
v. Building purpose group, travel distance, fire fighting appliances, etc.,
vi. Local Authority's guideline concerning planning, plot ratio, plinth areas, parking
vii. Calculation of plot ratio, plinth areas and parking requirement of your project
viii. Land use diagram, site planning and landscape
ix. Building services: water, electricity,& electronic, sanitary, telephone, lift & escalator, solid waste disposal system, etc.(Drawings must be in ACAD).
x. Structure and Elevation studies
xi. Interior design
xii. Photos of final model in context

5.2 Advanced Building Technology

The aims of teaching technology to the architecture students in the upper years can be itemised as follows,

- To explore and understand technological possibilities and limitations,
- To learn various aspects of building design and construction
- To integrate technology into design and
- To understand the roles of consultants amongst others.

There has been a conscious effort to integrate technology subjects into architecture design in recent years (Lim 1999, Rao et al 2003). Specialist technology tutors have been traditionally invited into the studio to understand and aid the design process. The mathematical content of the technology subjects are kept to a minimum and integration and exploration of technology subjects are encouraged. At the Department of Architecture, Advanced Building Technology has been traditionally taught over two semesters at the Year 4 level. During both the semesters, the students are given eight lectures on specialist topics by in-house lecturers as well as by visiting experts and from the trade. The students are also taken on site visits and are required to complete two assignments during the semester, to show their understanding of the design and operation of tall buildings under the Malaysian climate. One of the assignments is set in the context of studio design.

Starting from academic year 2004-2005 onwards, it was decided to bring all the lectures for the building technology to semester one. Thus, the students will get concentrated inputs on building services, structures and construction technology. Various specialist lecturers were invited to talk about their specialities and its application to the high-rise building with special reference to Malaysia. A simple 2-week assignment was set to understand the concept of service cores and their utilization. A second assignment was set in the context of Putra Jaya, the new administrative capital of Malaysia, to give a feel for technological developments.

In the Second semester, the students were introduced the innovative teaching of technology subjects. Figure 4 shows the buildings that have been utilised for the study since 2004, they are: the Securities commission building, the Telecom Tower, the Putrajaya Convention center and the Low energy office building in PutraJaya.

The Securities Commission Building Kuala Lumpur, Malaysia	The Telecoms Building Kuala Lumpur, Malaysia	Putra Jaya Convention Center, Putra Jaya, Malaysia	Low Energy Office Building Putra Jaya, Malaysia

Figure 4 Buildings chosen for study for advanced building technology since 2004.

These are very unique buildings both for their architecture as well as for their innovative technological features. Three of the buildings have won international awards for energy conservation and for innovative design features. The technology aspects of the buildings were itemised and introduced to the students in the inaugural session. The students do a study of the overall building and its design as well as to individually do a deeper study of their chosen topic. The students had to organise their study methods and site visits. They have to liaise with the various consultants and specialist contractors. All this has to occur within a period of eight weeks. The students regularly meet-up in a discussion session with the coordinators once every two weeks to discuss the materials collected, analyse their utility and share the knowledge across the class. The coordinators acted as facilitators and gave directions for further work as well as explained any new concepts and ideas the students encountered. The students have milestones and targets to meet during the semester. The whole process is perceived to be a student-led educational adventure and learning experience.

6. Conclusions

A new and innovative concept of teaching advanced building technology is described. The students are required to do an in-depth study of a building with reasonably complex structures, services as well as construction features. They have learned fast and seemed to find the teaching process more exciting and useful. The teaching process has met its intended objective of creating enthusiasm and excitement for learning of technology amongst the students. The students appreciate the building technology aspects of design as it is based on a real building ably assisted by the consultants and experts involved in its design as well as in the operation of the building.

7 Acknowledgements

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SUSTAINABLE AIR-CONDITIONING FOR OFFICE BUILDINGS IN THE TROPICS

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Keywords: Sustainable buildings, Partial air-conditioning, total energy systems.

Summary

Tropical climates are thermally uncomfortable and are mostly unhealthy to the occupants of the modern skyscrapers, both residential and commercial buildings. The outdoor air dry bulb temperatures are on the hot side coupled with high relative humidity's. The population living in the tropics, especially in countries like Malaysia, is affluent and can afford to air-condition their residences and offices. Installation of air-conditioners is almost synonymous with prestige. This way of living leads to increased electricity usage and energy consumption in the buildings. However, switching-off the air-conditioning is not an option for the modern day buildings, as it would affect the health of the people as well as their productivity. This paper proposes innovative indoor units that will contribute to energy conservation by utilising principles of partial air-conditioning. The outdoor units could be utilised for clothes drying or for providing hot water to the occupants of the building of residential buildings, thus reducing the energy requirements in the buildings. Thus the utilisation of partial air-conditioning will lead to enormous savings in energy consumption in the buildings.

1.0 Introduction

In the humid tropical climate of Malaysia, the differences between indoor and outdoor air temperatures are not high. Sun is the single most important natural element to be considered in the building design. It affects almost every design decision and has a direct impact on the energy budget of the building. Thermal Comfort analysis may be used to assess a given environment and is important in determining an energy management strategy in buildings. The human body temperature regulation determines the physiological thermal comfort of the occupant of a room, as the human body exchanges heat with the environment. Heat is exchanged by radiation, convection and evaporation. The heat is primarily produced by metabolism. During normal rest and exercise, this results in an average temperature of the vital organs of near 37 deg C. The body's temperature control system tries to maintain this temperature in the varying thermal environment.

2.0 Climate of Malaysia

The main features of a hot-humid climate like that of Singapore and Malaysia are the relatively uniform temperatures, small variations in the diurnal temperature variations (approximately 7 deg C). However the associated high relative humidity is high. Also, there is abundant rainfall due to the maritime exposure and proximity to the equator. Throughout the year the temperatures are fairly uniform. The mean monthly temperature does not vary by more than 1.1 deg C from the mean annual value of 26.6 C. The average diurnal variation of temperature is about 7.0 deg C. Excessively high or low temperatures are rarely experienced. For the period 1934 to 2007 the highest temperature recorded is 35.8 C and lowest is 19.6 C. The mean annual R.H. over the period 1934 to 2007 is 84%. However, there are large diurnal variations from 60% to 95%. The mean daily maximum and minimum values are 96% and 64% respectively. There are no distinct seasons and rainfall occurs during every month of the year. December is usually the wettest month of the year with an average monthly rainfall of 280 mm and July if the lowest with an average monthly rainfall of 160 mm.

Thus, the salient features of a hot-humid equatorial climate are,

- high rainfall and high humidity, associated with a low diurnal range
- a relatively high and even temperature throughout the year

- light winds and long periods of still air
- high radiation intensities.
- rain usually in afternoon often accompanied by violent thunder-storms (Sumatra's)

2.1 Solar radiation intensities (Lim et al, 1979, Rao 1994)

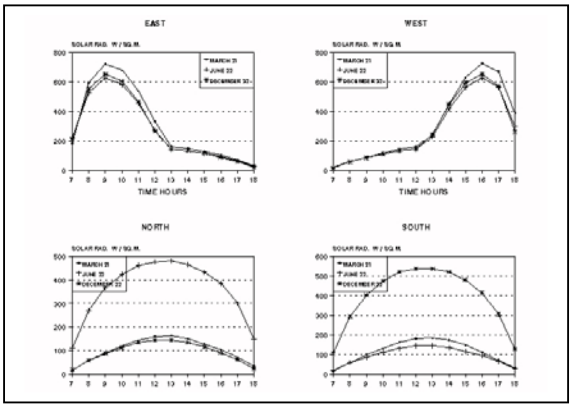


Figure 1 Typical Solar Radiation Intensities in Singapore measured data (Rao 1994)

Figure 1 shows the measured solar radiation intensities for Singapore. Table 1 (Mohamed Ali. 2004 and Malaysian Meteorological Office) is a summary of 30-year average of dry bulb temperatures, relative humidity's and mean wind velocities for various months in Kuala Lumpur, Malaysia. It experiences high relative humidity, varying from 67% to 96 % with an average value of around 80%. The outdoor air temperature varies from 24 deg C to a maximum of 33 deg C. There is no dominant wind direction.

TABLE 1 Monthly Means of Outdoor Air Temperatures, Relative Humidities and Wind Speeds Kuala Lumpur, Malaysia. (Mohamed Ali. 2004 and Malaysian Meteorological Office)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp.deg C	26.9	27.2	27.5	27.6	27.7	27.8	27.3	27.3	27.1	27.0	26.6	26.6	27.23
Mean Max. Temp deg C	32.5	33.3	33.5	33.5	33.3	33.1	32.6	32.7	32.5	32.5	32.1	31.9	32.79
Mean Min. Temp deg C	23.1	23.4	23.8	24.2	24.3	24.1	23.7	23.7	23.6	23.7	23.6	23.3	23.71
R.H %	78.4	78.2	79.3	81.5	80.6	78.9	78.9	78.9	80.6	81.6	83.6	81.9	80.20
Mean Wind Speed (m/s)	1.02	1.10	1.06	1.00	1.00	1.07	1.17	1.15	1.03	1.16	0.97	0.90	1.05

2.2 Thermal comfort in the Hot-humid climate (Ellis 1953, Humphreys 1975, Lim et al 1979,Mohamed Ali 2004, Rao et al 1979,Rao 1993, Webb 1959)

Creating a thermally comfortable environment is one of the parameters to be considered when designing buildings. Thermal comfort has been defined as the condition of mind that expresses satisfaction with the thermal environment. The reference to mind emphasises that comfort is a psychological phenomena too. There is a wide variation in thermal requirements and in thermal sensitivity between individuals in a given group. The aim should be to create conditions for optimal thermal comfort to satisfy the highest possible percent of the group. Probably at best only 80% of the occupants would be comfortable at any one time under the best possible conditions. The individual differences in preferred temperatures would arise in part from the differences in the clothing, activity and acclimatisation to the local climate. Hence results of comfort studies made elsewhere may not necessarily be applicable to the Malaysian conditions.The factors, which affect indoor thermal comfort, are the air dry bulb temperature, humidity, air movement and solar radiation. In order to combine the effect of these factors several thermal comfort indices have been proposed. These indices attempt to combine the effect of two or more variables into a single variable on humans. Several such indices have been developed for the tropical climates.

2.2.1 Thermal comfort studies in Malaysia (Abdul Malik et al 1993, Zain Ahmed 2000, Mohamed Ali 2004)

For comparison purposes, the results of the criteria from several sources are summarized in Table 2. For example, the temperature range obtained from Zain is between 24.5-28.0 deg C, which is lower than Abdulmalik, but higher than the range suggested by the Ministry of Energy, Telecoms and Posts [13]. This table comprises eight thermal comfort studies, four of which have been carried out on Malaysians either in climate chambers or as field studies. The outcomes of the studies differ slightly due to different test procedures. However, most of the studies seem to agree on a Malaysian comfort zone of around air temperature of 25 deg C.

Table 2 Thermal Comfort Studies in Malaysia (Mohamed Ali. 2004)

Study	Comfort Zone (°C)	Type of Study	Humidity range (%)	Air Velocity (m/s)
Zain Ahmed	24.5-28.0	Field Study	72-74	0.3
Abdulmalik	25.5-29.5	Climate Chamber	45-90	-
Davis	24-28	Field Study	-	-
Ministry of Energy, Telecom and Posts, Malaysia	22.0-26.0	Field Study	-	-
Abdul Rahman	27.4	Climate Chamber	54 -76	0.1

3.0 Air-conditioning

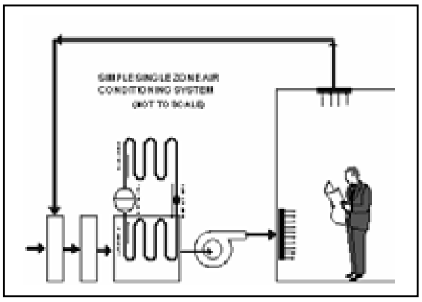


Figure 2 Simple Single zone air-conditioning system

Air-conditioning is defined as a process that heats, cools, cleans and circulates air and controls its moisture content. Ideally, it does all these simultaneously and on a year round basis. Thus air conditioning makes it possible to change the condition of the air in an enclosed area. Figure 2 shows a simple air-conditioning system.

3.1 Chilled water air-conditioning systems for typical tall building structures

Figure 3 shows a schematic layout of a chilled water system. In this system heat from air passing through the air-handling unit is collected by chilled water and is transferred to the refrigerant passing through the evaporator coil. The heat from the refrigerant is transferred to the cooling water in the condenser. The cooling water carries the heat away to the cooling tower where it is dissipated in the atmosphere. Thus the chilled water system is an indirect system where the refrigerant chills water, which is then circulated through pipe work to the air-handling units which can be located anywhere in the building.

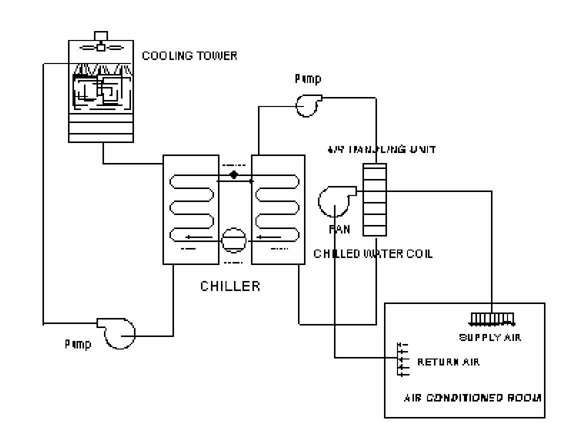


Figure 3 Chilled water air-conditioning system

3.2 Air-conditioning for residences in the hot-humid tropical climate

Figure 4 A typical split-system air-conditioning system for both high-rise and low rise residential units

Almost all of the split system air-conditioning units utilise the mechanical vapour compression refrigeration cycle shown in Figure 2. The split unit system contains two major elements: one is the indoor unit that blows the cool air, called fan-coil unit, second is the outdoor unit as shown in Figure 2, called a condenser unit. These two are linked with copper piping that carries the refrigerant gas. The out door unit work as chillers, where the refrigerant is compressed and pumped back to the indoor unit. The outdoor unit contains an electric motor to blow away the heat as a result of the mechanical vapour compression of refrigerant. It is worthwhile to study the various potential of this reusable energy, as it is has significant impact on the architectural design and environment such as in Malaysia

4.0 Concept of Partial air-conditioning

This section investigates the possibilities of raising the set temperatures in the air-conditioned space with appropriate increase in air-velocities by supplementary fans, without sacrificing occupant thermal comfort.

4.1 Cooling effect of air movement (Aynsley 2006)

The manual of Naval preventive medicine covers the cooling effect of air movement on people. Figure 5 is redrawn from the original, amplifying the region of air velocities of 0 to 2 m/s. There are several other sources indicating the cooling effects of air movement.

Figure 6 shows the effects on the Predicted mean votes (PMV) due to air movement at various dry bulb temperatures for air velocities of 0.1 m/s and 0.3 m/s. It can be observed that the DBT can be raised to 25 deg c in an air-conditioned office, provided the air velocity is held at 0.3 m/s. This will reduce the energy for cooling the supply air. This is the concept of partial air-conditioning.

Large ceiling fans can mix the air in atria to a uniform temperature. Aynsley (2006) demonstrates a system of de-stratification fans in an air conditioned atrium as shown in Figure 7.

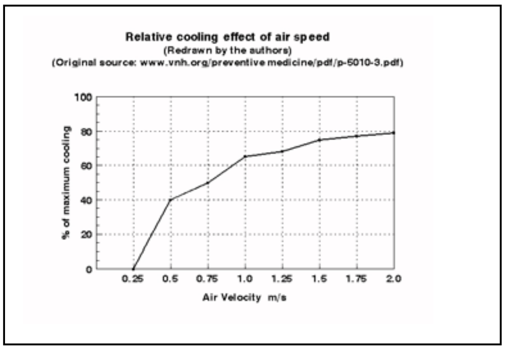


Figure 5 Relative cooling effect of air speed (redrawn from www.vnh.org/preventivemedicine, p3-7)

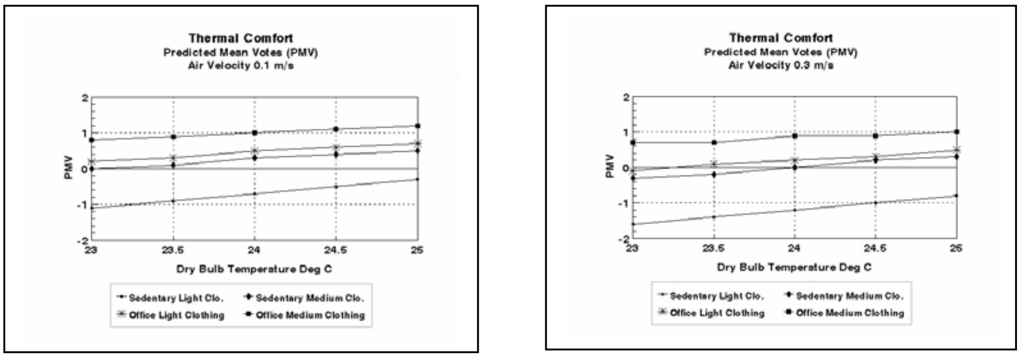


Figure 6 Predicted Mean Values for air velocities of 0.1 m/s and 0.3 m/s (based on Fanger 1972)

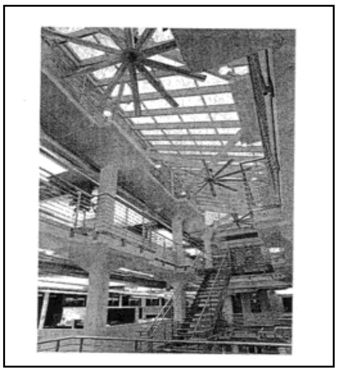
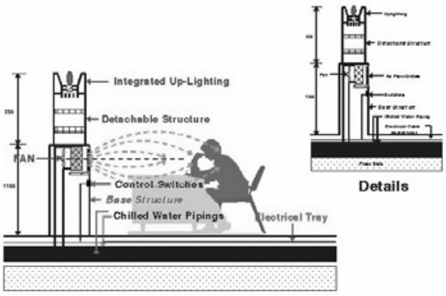
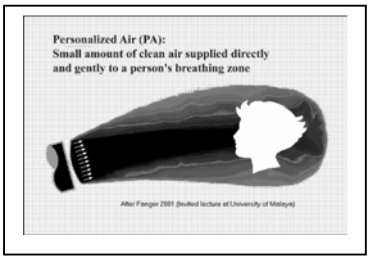


Figure 7 De-stratification fans in an air conditioned atrium (Aynsley, 2006)

4.2 Modified personal air-conditioning fan-coil units (Personal air-conditioning Systems) for effective partial air-conditioning

The concept of partial air-conditioning is proposed by the authors to provide adjustable personal environments to individual work stations in open plan offices. This involves the provision of individual air-conditioning outlets and delivery systems. Personal air-conditioning allows every office worker to gain control over their immediate thermal environment (Fanger 2001, Pan et al 2005). The air is delivered at a slightly higher velocity of 0.3 m/s and at a dry bulb temperature of 25 deg c at 60%R.H. The office worker could be provided with controls to control the air temperature as well as the air speed. As shown in Figure 6, this will still be within the thermal comfort zone as it is closer to PMV values of +1.00, which is comfortably warm. This would lead to conservation of energy by reducing overcooling of the space. This concept has been reinforced by the latest statement by Rob Traynham about the new Nissan headquarters in USA “Air conditioning and heat are controlled through outlets at each work station: You heat the people and not the space” (Yahoo News: Nissan goes green in new US headquarters, 8 March 2008). This firmly reinforces the authors' proposal of partial air-conditioning with the delivery of the conditioned air directly at the workstation and not through the conventional ceiling outlets. Figure 8 demonstrates the modified fan-coil units for air delivery at the work stations.



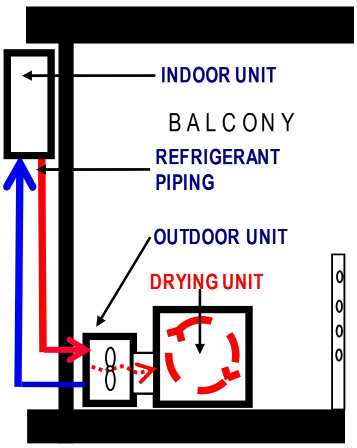


Concept of personalised air delivery (after Fanger 2001)

Figure 8 Personal air-conditioning for office work stations (authors proposal)

5.0 Using the waste heat from the condenser for drying clothes in residential units.

Currently the out door units are installed at the discretion of installer. The maximum length of the refrigerant copper pipes governs the limit of furthest distance. Usually there are no problems in selecting the location for the outdoor unit for the detached houses. It is easy to gather outdoor units together to collect the hot air from it. In comparison to the apartment unit, the designer usually would allocate a drying yard near the kitchen for laundry or general cleaning facilities. Out door unit could be placed in the drying yard and if the waste heat is channelled properly to help speed up drying the laundry. Tests have shown that temperature of the waste heat is about 40 ° C with the corresponding humidity of about 38 %. (Zunaibi et al 2002 and Rao et al 2005). Placing the outdoor units in the yard will help in reducing the number out door unit arbitrarily installed on the building facades. The average size of out door unit for 3 TR air-conditioning split unit systems is 1030x850x 400mm. Individual units of drying facilities can be placed in the drying yards. Re-channelling by capturing the hot air could reduce to muffle the noise created by the units. One unit of 1 hp outdoor unit could produce a noise level of about 60dB



CONCEPT:

- It consists of a standard commercially available electrical tumble-dryer unit.
- The heater module is disassembled from the tumble-dryer.
- This modified tumble-dryer is coupled with the condenser unit of the split system, by using suitably designed ducting.
- The whole assembly is designed to be arranged in the balcony to provide an aesthetically pleasing environment.

Figure 9 Use of condenser units for drying clothes in an apartment unit.(Zunaibi et al 2002, Rao et al 2005)

6.0 Conclusions

This paper proposes an innovative concept for the indoor units that will contribute to energy conservation by utilising principles of partial air-conditioning coupled with the personal air-conditioning systems. It has been proven that the air dry bulb temperatures can be raised upto 25 deg c with an accompanying air velocity of 0.3 m/s This does not compromise thermal comfort of the occupants of the office spaces. Because of the increase in the set-point temperature there will be a corresponding reduction in the air-conditioning cooling loads, leading to energy conservation. Also, the outdoor units could be utilised for clothes drying to the occupants of the residential buildings.

This will lead to enormous savings in energy consumption in the buildings and can be summarised as follows,

i. The utilisation of the principles of partial air-conditioning will lead to savings in energy for air-conditioning.

ii. There is no need for the Air-handling units (AHU) as they are no longer required. This saves valuable FLOORSPACE in a building.

iii. There is no need for the false ceiling, as there are no air-conditioning ducts. This will lead to a better interior architecture as the ceiling spaces can be exposed. The space saved can be utilised to provide additional rentable space in the building, for a given plot ratio.

iv. The personalised air-conditioning system is the most energy efficient system. The system will guarantee the best possible indoor air quality to the occupant of the space. (Most healthy environment).

v. Gives freedom to the architects and interior designers of office buildings to organise the workstations more efficiently. This in turn, will lead to better aesthetics.

vi. The waste heat from the Split-system air-conditioning units in residential units are used to dry clothes. This will eliminate electricity consumed for drying clothes in a tumble dryer. Also, it will lead to a more aesthetically pleasing building exterior. This will lead to a better quality of life for the residents

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SOCIAL INDICATORS FOR SOCIAL HOUSING PROJECTS IN BRAZIL

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Keywords: social indicators, social housing projects

Summary

A worldwide need to solve problems related to social housing has been observed alongside the evolution of the concept of sustainable construction. In the majority of Latin American countries, social housing is produced by informal self-construction. This fact highlights the importance of encouraging the community's participation and strengthening as well as the formalization of constructive processes, materials, and local components in order to provide greater environmental comfort at a low housing cost. This paper aims to develop and reveal social indicators for social housing projects in Brazil according to the local reality by means of categories of essential and characterization criteria. The results shown will provide data for the development of an evaluating tool for social housing projects.

1. Introduction

Agenda 21 charter for sustainability in developing countries such as Brazil shows the necessity of reducing social and economic inequality as well as the crucial necessity of balance between environmental costs and benefits.

As far as Brazil's sustainable development is concerned, it is necessary to correct one of its most noticeable social problems: the lack of low-income population housing. Furthermore, there is a need to integrate the various dimensions of sustainability - social, economic, environmental, spatial, and cultural - in order to produce social-interest housing. Only then the solution would be effective and efficient, providing performance optimization throughout the housing's useful life.

According to Choquil (2007), in order to solve the problem of sustainable housing and to make it economically viable, socially acceptable, and characterized by a workable and environmental compatibility with housing policies, the following are required: (1) Community participation in all stages in search of cost reduction, satisfaction of all those involved, and quality guarantee; (2) Good quality material and accessible costs related to environmental preservation; (3) Minimum performance standards such as health, hygiene, fire performance, flexibility, and security demands; (4) Elongated funding; and (5) Proper land availability for construction by means of social soil recovery. Such standards may be obtained by indicators.

ISO/TS 21929-1 (ISO 2006) defines *Indicators* as elements which are able to extract simplified information from complex phenomena, such as social, economic, and natural impacts, in a relatively easy way to use and understand. The main functions are quantification, simplification, and communication. According to OECD (1993), an indicator is directly related to a value.

An indicator needs to be relevant and its value needs to be found by appropriate ways, thus capturing tendencies to inform decision agents such as managers, employees, and designers; guide the development and monitoring of policies and strategies; and facilitate the report of measures adopted when establishing the sustainable construction.

This study has as its main objective the establishment and presentation of social indicators for Social Interest Housing (HIS) in Brazil.

The performance indicators set by this study have the purpose of evaluating social interest housing projects and allowing comparisons between individual projects.

2. Social Indicators

According to Silva (2007), sustainability indicators first appeared internationally as a response to Agenda 21. Several levels of indicators were established: national indicators OECD, UN, World Bank, CSD[1]); civil construction sustainability sectorial indicators (CIRIA[2], CRISP[3]); organizational sustainability indicators – construction and design companies (Global Reporting Initiative Guidelines) and project/building indicators (LEED, BREEAM, GBC). Indicators defined in more restricted evaluation spheres have to be aligned to indicators and goals of sustainable development on both national and worldwide levels.

Social themes for sustainable construction in the United Kingdom are: (1) Respect to staff: (1.a) effective training provision and staff evaluation; (1.b) equality of terms and conditions; (1.c) equal provision of staff opportunities; (1.d) health, security, and appropriate work conditions; (1.e) support for staff morale and satisfaction; and (1.f) participation in decision-making; (2) Relationship with local communities: (2.a) minimization of local disturbance; (2.b) construction of effective ways of communication; (2.c) contribution to the local economy; and (2.d) delivery of buildings and structures that improve the local environment; (3) Establishment of partnerships: (3.a) construction of a long-term relationship with clients; (3.b) construction of a long-term relationship with suppliers; (3.c) corporative citizenship; (3.d) conclusion of buildings and structures that increase satisfaction, welfare, and value for clients and users; and (3.e) contribution to global sustainable development (CIRIA, 2001)

At building level, ISO/TS 21929-1:2006 (ISO,2006) defines a framework for sustainability indicators for buildings based on the premise that sustainable construction achieves the required technical performance of the construction with minimum environmental impact. At the same time, sustainable construction encourages economic, social, and cultural improvement at a local, regional, and global level.

Social indicators are used to describe how buildings interact in relation to themes regarding sustainability with the local community[4]. As for social aspects, ISO/TS 21929-1:2006 (ISO,2006) suggests that indicators should consider the following themes: (1) quality of buildings as a place to live and work; (2) building-related effects on health and user safety; (3) barrier-free use of buildings; (4) access to services needed by users of a building; (5) user satisfaction; (6) social cohesion and participation of users and other interested persons in the building process; (7) architectural quality of buildings; and (8) protection of cultural heritage, which may also be expanded.

Mahammad and Amato (2006) have defined sustainability indicators for public housing in Hong Kong and established a criterion that determines a great area of concern subdivided in specific key questions, such as: (1) Social preconditions for ecological sustainability (values, habits, rules, lifestyle, environmental consciousness, regulations); (2) Equitable housing distribution and consumption (housing equity, housing standards, affordability, government role, housing subsidy policies); (3) Harmonious social relations (landlord and tenant relationship, existing or not relationships, housing subsidy policies); (4) Quality of housing and living environment (internal housing conditions, immediate environment); (5) Cultural preconditions conducive to environmentally sustainable housing (values, habits, rules, lifestyle, environmental consciousness, regulations); (6) Acceptable quality of housing conditions (internal housing conditions, immediate environment); (7) Preservation of housing heritage (internal housing design, external housing design, housing structure, reflection of the way of life of people from past to present, cultural identity, collective memory, and location of a contemporary society in its traditional context).

Benett and Sattler (2004) performed a research amongst low-income families in Brazil in order to identify popular housing sustainability indicators. The following themes were pointed out for

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[1]Internationally, CSD Theme Indicator Framework organizes indicators into four dimensions (social, environmental, [……])

[2]CIRIA - Construction Industry Research and Information Association. Sustainability indicators for construction industry in the United Kingdom (CIRIA, 2001).

[3]CRISP - Construction and City-Related Sustainability Indicators. Sustainability Indicators for construction industry in the European Union. (CRISP,2001)

[4] [4]Community-level issues which may be relevant are urban sprawl, mixed land use, access to basic services including public transport, availability of green and open space, attractiveness of city centers, development of brownfields, housing availability, social segregation, cultural quality and protection of cultural heritage, safety, noise, and air quality. (ISO,2006)

social indicators: public transportation, security, public phoning, nurseries, and medicine access.

This study reveals the necessity to include social and cultural indicators in project decision in order to avoid a series of problems concerning management, conservation, and maintenance of housing projects, as well as a need to reach an improved quality of life for the people involved.

3. Method

In order to obtain the proposed indicators, an extensive research has been done through this project, taking in account national and international authors, looking for reported concepts on this subject, and after some questions related to social aspects have been formulated:

1- What existing necessities concerned to social aspects are to be contemplated?

2- How can social aspects be measured?

3- Are social aspects applicable in social-interest habitation?

4- Are social aspects applicable in project phase?

5- Can these aspects be arranged in a checklist form?

All aspects which have obtained positive answers were joined in categories and subcategories, like one can see in table 1.

Table 1 Division in categories and subcategories of the selected aspects

Category	Subcategory
Social	1.Infra-structure 2.Comfort and health 3.Quality of product/habitation 4.Relashionship with local community 5.Participation
Cultural	6.Cultural heritage
Political/ Institutional	7.Public policies 8.Environmental education
Generating income and social responsibility	9.Construction companies 10.Designer companies 11.Sellers to enterprises of projects 12.Users
Security	13.Security

Inside each category, questions (subjects) were developed to check how the project contemplates the selected aspects, as exemplified in table 2. The next step in order to set the indicators was to define a essential criteria of determination and characterization [5], like below:

Table 2 Example of questions (subjects) defined to each subcategory

Category	Subcategory	Subjects
Social	4.Relashionship with local community	4.1 Are there coexistence grounds to stimulate the community strengthening and coexistence? 4.2 During the project execution, have social relationship promotions been done? 4.3 During the project execution, have the cohesion among social necessities been reached? 4.4 Has the neighborhood analysis to implant the entrepreneurship been done? 4.5 Does the entrepreneurship bring benefits to the neighborhood? 4.6 Is the entrepreneurship to be implanted harmonious with the neighborhood?

[5] Essential criteria: were obtained from positive or negative (yes/no) answers; characterization criteria: are obtained from quantification answers.

The indicators were obtained from this criterion: the essential indicators are that ones measured according to quantity of positive answers (yes) among total number of questions. The characterization indicators were obtained from quantifications, of questions, in math fractions, like, for instance: number of bus stops and distance between them. The objective of obtaining characterization indicators is to develop *benchmarks*.

In brazilian specific case, the number of questions (subjects) defined to each subcategory are shown in tables 3 to 7. This quantity can vary according to local necessity, goals established to reach continuous improvement and excellence and sustainability standard aimed.

4. Results

4.1 Essential Indicators of Social Category

The essential indicators of social category are defined and shown in table 3, which vary from zero to one.

Table 3 - Essential indicators of social category

Indicators	Equations [1]	Number of questions (subjects) for each subcategory
4.1.1. Infra-structure indicator (IF)	$IF = QS/QT$ (1)	11
4.1.2. Health and comfort indicator CS)	$CS = QS/QT$ (2)	9
4.1.3. Quality of product/housing indicator (QP)	$QP = QS/QT$ (3)	10
4.1.4. Relationship with the local community Indicator (CL)	$CL = QS/QT$ (4)	6
4.1.5. Participation indicator (P)	$P = QS/QT$ (5)	8

[1] being:

QS= Number of answers 'YES' obtained from subject questions.
QT= total number of questions.

The indicator of social category is defined in equation (6):

$$Social\ indicator = \frac{IF + CS + QP + CL + P}{5} * 100 \qquad (6)$$

4.2 Essential Indicators of Cultural Category

The essential category of cultural indicators are defined and shown in table 4, which vary from zero to one.

Teble 4 – Essential indicators of cultural category

Indicators	Equations [1]	Number of questions (subjects) for each subcategory
4.2.1.Cultural heritage indicator (HC)	$HC = QS/QT$ (7)	8

[1] being:

QS= Number of answers 'YES' obtained from subject questions.
QT= total number of questions.

The indicator of cultural category is defined in equation (8):

$$Cultural\ indicator = HC * 100 \qquad (8)$$

4.3 Essential Indicators of Political/Institutional Category

The essential indicators of political/institutional category are defined and presented in table 5, which vary from zero to one.

Table 5 - Essential indicators of political/institutional

Indicators	Equations [1]	Number of questions (subjects) for each subcategory.
4.3.1.Public policies indicator (PP)	$PP = QS/QT$ (9)	18
4.3.2.Environmental education indicator (EA)	$EA = QS/QT$ (10)	3

[1] being:

QS= Number of answers 'YES' obtained from subject questions.
QT= total number of questions.

The essential indicator of political/institutional is defined in equation (11):

$$Pol/inst \quad indicator = \frac{PP + EA}{2} * 100 \qquad (11)$$

4.4 Essential Indicators of Income Generation and Social Responsibility Category

Essential indicators of income generation and social responsibility are defined and presented in table 6, which vary from zero to one.

Table 6 – Essential indicators of income generation and social responsibility category

Indicators	Equations [1]	Number of questions (subjects) for each subcategory.
4.4.1.Building companies indicators (EC)	$EC = QS/QT$ (12)	31
4.4.2.Design companies indicator (EP)	$EP = QS/QT$ (13)	35
4.4.3.Supplier indicator for project companies (F)	$F = QS/QT$ (14)	9
4.4.4.User indicator (U)	$U = QS/QT$ (15)	3

[1] being:

QS= Number of answers 'YES' obtained from subject questions.
QT= total number of questions.
The essential indicator of income generation and social responsibility category is defined in equation (16):

$$Inger/resp \quad indicator = \frac{EC + P + F + U}{4} * 100 \qquad (16)$$

4.5 Essential Indicators of Security Category

The essential indicators of security category are defined and shown in Table 7, which vary from zero to one.

Table 7 Security category essential indicators

Indicators	Equations [1]	Number of questions (subjects) for each subcategory.
4.5.1.Security Indicator (S)	$S = QS/QT$ (17)	4

[1] being:

QS= Number of answers 'YES' obtained from subject questions.

QT= total number of questions.
The essential indicator of security category is defined in equation (18):

$$Security\ indicator = S * 100 \quad (18)$$

The general indicator for social and cultural aspects (*Social and Cultural Indicator - SCI)*, generated from equations (6), (8) (11), (16) and (18), is defined in equation (19):

$$SCI = \frac{social + cultural + pol/inst + inger/resp + security}{5} \quad (19)$$

4.6 Characterization Indicators of Social Category

Characterization indicators (*IC*) of social category were defined only for social category. Hence, there are no obstacles to define new indicators, according to the necessity of regions to be eventually studied.

$$IC_a = \frac{\text{Proposed Actions to Mitigate Impacts}}{\text{Coverage Area}} \quad (20)$$

$$IC_b = \frac{\text{Number of Stops}}{\text{Coverage Area}} \quad (21)$$

being:

IC: Characterization Indicators

5 Final Consideration

The objective of the proposed indicators was to develop a comparison criterion among social-interest housing projects in order to select the one which presents the best rates from the social aspect. However, it is evident that environmental aspects also need to be considered towards a more complete evaluation about the sustainability of projects.

It is also noticeable that the number of proposed questions was defined in accordance with local reality, therefore updates and innovations are likely to occur.

Indicators defined by this study aim to provide the necessary feedback to their users in order to establish a performance benchmark, thus contributing to social awareness and establishing a comparison basis between a project's decision-making and strategic planning.

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SUSTAINABILITY IN PRODUCTION OF WALLS OF SOCIAL HOUSING IN BRAZIL: A STUDY OF CASE IN GOIÂNIA-GO

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Keywords: ceramic block, concrete block, soil-cement brick, sustainability criteria

Summary

A built environment is one of the survival strategies of human beings and of local socio-economic development. Recently, there has been intense debate over environmental impacts related to its production and use. Studies regarding indicators and sustainability criteria which aid in the specification of materials and construction components are highly necessary, as well as comparative studies between existing solutions. Such studies aim towards an emphasis on cultural aspects, greater economic efficiency, and reduced environmental impact. In the Brazilian field of social housing, one may often observe users' preference for ceramic block in certain locations instead of concrete block or soil-cement brick. Therefore, this paper aims to present a comparative study of sustainability in the production of masonry for social housing projects via the use of ceramic block, concrete block, and soil-cement brick in Brazil, in the city of Goiânia - Goiás. The parameters under analysis in this comparative study were: incorporated energy in components, use of recycled materials, and potentiality for recycling

1. Introduction

The selection of construction materials and components has a strong influence on environmental comfort conditions as well as on the performance and useful life of buildings. Therefore, priority should be given to those materials which generate lower environmental, social, and economic impacts. The selection or specification phase is relevant in any sustainability study because the manufacturing processes of construction materials and components contribute decisively to the generation of greenhouse effect gases.

This study aims to contribute to impact quantification when using natural resources by considering energetic consumption, use of recycled material, and recyclability of masonry components. The functional unit considered is 1 m² of masonry for 50 years of performance for every subsystem. The selected components for this study are ceramic block, concrete block, and soil-cement brick. This information is useful to the formation of a database that will act as a sustainability evaluation tool in the conscious choice of materials and components.

This project's choice of masonry components is justified: (1) by the high quantity of material used in this subsystem, as may be seen in Pictures 1 and 2, which show the results of a research that investigated the mass quantity of the material used in several Social Interest Housing projects in Goiânia, Brazil; (2) by the fact that the subsystem in question frequently presents sharp losses[1]; (3) by the fact that these components reveal the majority of innovations and rationalizations of the field, (4) by the fact that the production of these materials generates many environmental, social, and economic impacts; (5) by the fact that they are responsible for a considerable part of the edification performance; (6) by their close relation with the occurrence of pathological problems; and (7) by their constitution, in many cases, of the building structure itself.

Sposto et al. (2006) studied energy consumption and loss of ceramic and concrete blocks that supply Brasilia's market. As regards energy consumption, the authors concluded that the production requires 3,92 MJ and 2,90MJ, respectively.They observed that the ceramic block case suffers the greatest loss due to its higher variation in the produced dimension.

Emmanuel (2004) quantified the environmental impact of five materials and components that constitute masonry walls in an attempt to identify, as regards the production and the reality of his country's (Sri Lanka)

[1] – The loss in this subsystem occurs due to the low quality of blocks and craft processes frequently used in the region under study.

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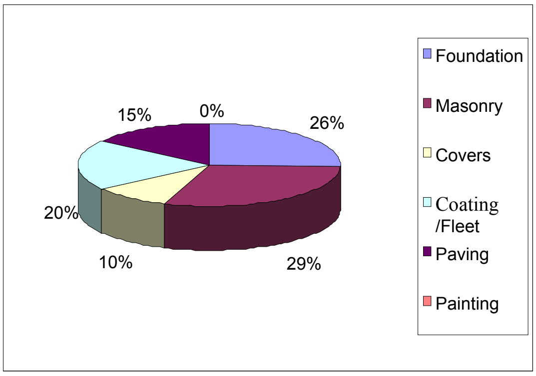
characteristics, which were the most sustainable and of the lowest impact, including less energy consumption during production, highest recyclability potential, and lowest life cycle cost.



Picture 1 – Mass amount percentage (kg/m^2) for each subsystem related to an average of three projects in Goiania – GO – Brazil.

Picture 2 – Social Interest Housing - Goiania – Go – Brazil.

2. Method

The methodology used herein consists in a survey about energy consumption, usage of recycled components and recyclability potentiality, as shown in tables 1,2, and 3.

Table 1- Energetic Index Survey.

Component	Energetic Index MJ/kg	Reference
Ceramic block(9x19x19)	4.88	Sposto, 2007
Concrete block (9x19x39)	5.37	Barros; Sposto, 2005
Soil-cement brick	0.14	Silva, 2005

Table 2 – Recycled Material Usage Index

Component	Incorporates recyclabe input	Waste	Composition	Researched Industries	Reference
Ceramic (block, tiles and brick)	Depends on industry	- fuel material - Chamote (ground waste)	Several industries use sawdust, wood splinter, wood retails and rice bark as combustible. These are others productive processes waste, obtained with sawmills, timbers and furniture industry. Burn phase waste is also reincorporated to the mass by some industries, being ground and nominated Chamote.	Do not incorporate	MANFREDINI; SATTLER, 2005 GOUVEIA (2008)
Concrete block	Depends on industry	Cement with RDC additional.	CP II –E -6-34% of blast-furnace clinker CP III - 70% of blast-furnace clinker CP IV -50% of fly ash	Incorporate	FARIAS et al., 2005[1]
Soil-Cement Brick	Depends of the industry	Cement without additives.		Incorporate	-

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Table 3 – Recyclability potential arise

Component	Recycling process	Impacts/ Limitations	Recyclability Potential	Reference
Cerâmic (blocks)	Knap/ Grinding to generate aggregate	Waste variability	Recyclabel	ZORDAN, 2001; CONAMA n° 307, 2002; WOOLLEY *et al*. 1997; HENDRIKS, 2000
Concrete and mortar	Knap/ Grinding to generate aggregate	Waste variability	Recyclabel	ZORDAN, 2001; CONAMA n° 307, 2002; WOOLLEY *et al*. 1997; HENDRIKS, 2000
Soil-cement brick	Knap/ Grinding to generate aggregate to be paving base and sub-base.	Waste variability	Recyclabel	CONAMA n° 307, 2002;

The block quantity necessary for 1m² of masonry have been considered as functional unit execution, for calculations. The second part of analysis uses a “value index”. For example, VI_e for embodied energy is derived from equation 1:

$$VI_e = (LV/E)*100 \quad (1)$$

where:

VI_e= embedded energy index value.

LV= embedded energy lowest value

E= embedded energy

The calculus of index value for usage in recycled material is:

$$VI_r = (LV/R)*100 \quad (2)$$

where:

VI_e= recycled materials index value.

LV= recycled materials biggest value.

R= recycled materials

The index value for recycling potentiality is calculated as:

$$VI_p = (LV/R)*100 \quad (3)$$

where:

VI_e= recycling materials index value

LV= recycling potential biggest value

R= recycling potential.

After index value calculations for each parameter, it has been calculated the Environmental Suitability Index (ES) in equation 4:

$$ES = VI_e + VI_r + VI_p \quad (4)$$

3. Results

3.1 Embodied Energy

In table 4 are presented the results of incorporate energy (to execute the functional unity – 1m² of masonry)

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Table 4 – Energetic consumption of the material to 1² execution

Component	Functional unit (pç/m²)	Mass (kg)	Material quantity (kg)	Energetic index (MJ/kg)	Total (MJ)
Ceramic block (9x19x19)	25	2.6	65	4.88	316.88
Concrete block (9x19x39)	13	11.77	153.01	5.37	821.66
Soil-cement block	80	2.3	184	0.115	21.16

In table 5 are presented the VI of studied components.

Table 5 – Incorporated energy Index Value for studied components.

Component	VI_e
Ceramic block (9x19x19)	6.7
Concrete block (9x19x39)	2.6
Soil-cement brick	100.0

3.2 Use of recycled materials

In table 6 are presented the results of components which use recycled material.

Table 6 – Mass quantity of recycled material used for component manufacturing

Component	Functional unit (pç/m²)	Mass (kg)	Recycled content	Which content	Quantity of recycled material for one block (kg)	Total Kg
Ceramic block (9x19x19)	25	2.6	no	-	-	0
Concrete block (9x19x39)	13	11.77	yes	cement[1]	1.97	25.61
Soil-cement brick	80	2.3	no	-[2]	-	0

1 In the factory studied, to produce one concrete block, 5,64kg of cement are consumed; the cement is CP II, which has 35% of blast-furnace clinker.

2 In the factory studied, it has been used the soil-cement brick, produced with cement CP1.

In table 7, also is presented the Index Value of studied components.

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Tabela 7 –Index Value for recycled material of studied components.

Component	VI_r
Concrete block (9x19x39)	0.0
Ceramic block (9x19x19)	100.0
Soil-cement brick	0.0

3.3 Recycling Potentiality

In table 8, results of mass quantity of material and components related to recycling potentiality are presented:

Table 8 – Results of mass quantity of material and components related to recycling potentiality

Component	Functional unit (pç/m²)	Mass (kg)	Recycling Potential	Total kg
Ceramic block (9x19x19)	25	2.6	yes	65
Concrete block (9x19x39)	13	11.77	yes	153.01
Soil-cement brick	80	2.3	yes	184

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In table 9 are presented the index value VI_p for recycling potential of studied material.

Tabela 9 – Index value for recycling potential of studied material

Component	VI_p
Ceramic block (9x19x19)	100.0
Concrete block (9x19x39)	42.5
Soil-cement brick	35.3

In table 10 is presented the calculation of environmental sustainability index (ES) for studied components, considering the parameters submitted to analysis in comparative study, which are: incorporated energy in components, use of recycled materials and potentiality for recycling.

Tabela 10 – Environmental sustainability index

Material	VI_e	VI_r	VI_p	ES	Environmental Sustainability Rank
Ceramic block (9x19x19)	6.7	0	35.3	42.0	3
Concrete block (9x19x39)	2.6	100	83.2	185.7	2
Soil-cement brick	100.0	0	100.0	200.0	1

As noticed, the best index for the analyzed parameters has been the soil-cement brick, followed by concrete block.

4. Final Consideration.

This study attempted to gauge the environmental sustainability of the most commonly used wall components in Goiânia, Goiás, Brazil: ceramic block, concrete block, and soil-cement block. Environmental suitability is estimated on the basis of an E which depends on embodied energy, use of recycled materials, and potentiality for recycling.

One of the crucial findings of the present study is that the concept of “environmental suitability” is a relative phenomenon. We cannot truly say in the present context that material “A” is better than material “B”. Thus, a definitive statement such as “Material ‘A’ is the most suitable wall material” cannot be made.

One of the most evident limitations is the number of parameters under consideration. There is a necessity to include others, for instance energy on transportation, CO_2 emissions generated during production and transportation, socio-cultural and economic aspects, among others.

In addition to the features considered in this study, there are certain limitations involving the collected data, which are characterized by the current research stage regarding sustainability. This data will be more complete once the life cycle analysis (LCA) of construction materials and components is effectively performed.

The final goal of an exercise such as the present study is to develop a decision-support tool enabling building design professionals to make rational decisions about the environmental consequences of their choice. This research is only a tentative beginning in this direction in Brazil.

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ENERGY CONSUMPTION ANALYSIS OF AN ELEVATED TRADITIONAL CHINESE KANG

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Keywords: Chinese kang, elevated kang, thermal storage, energy saving, DeST

Summary

Heating of rural houses now constitutes 25% of total building energy consumption in China. Hence, the transition and new technologies for rural home heating is considered as the top priority for managing future building energy consumption in China. Chinese kang, the most traditional and widely used heating and sleeping bed system, has been regarded as a potentially sustainable and energy-saving solution.

In this paper, we integrated a macroscopic heat transfer and airflow model of an elevated kang system into the existing Chinese building environmental system simulation and analysis software-DeST. The new integrated software can serve as a design and energy analysis tool for rural houses with the elevated kang heating. The basic methodologies and mathematical model for the elevated kang are presented and some preliminary results obtained from simulations of a typical house in northern China are also discussed.

1. Introduction

With the rapid economical development and urbanization in China, the living environment of people in rural areas has received increasing attention. Rural house heating (including biomass energy) constitutes now 25% of total building energy consumption in China. Hence, transition and new technologies for rural home heating is considered as the top priority for managing future building energy consumption in China.

The Chinese kang has been used for home heating for more than 2500 years (Men 2004). There are currently nearly 200 million people using this kind of heating system in northern China. Figure 1 illustrates a typical arrangement of an elevated kang heating system. It utilizes the residual heat of fume from the cooking stove, and uses the kang body to release heat to indoor environment. Kang plates, often made of materials with high thermal storage capacity, can store heat and maintain a heating period of several hours or more and also create local warm climate under the blanket for sleeping. Chinese kang has been regarded as a kind of potentially sustainable heating system, although its design has been mainly based on the experience of craftsmen. Investigations have shown the potential of energy-saving while providing a comfortable indoor thermal environment by the elevated kang, the latest design of kang (Chen et al. 2007). The performance of some of the buildings using these systems has been reported by, among others, Yang (1963), Deguchi and Sanda (2002). These reports, however, often lack the information about the likely effect of key parameters on the heating energy requirements of a building with such a system. For example, there appear to be no studies that identify clearly the contribution of the kang alone to the overall energy savings of the building. Thus, a thermal analysis tool for buildings with kang systems is needed for designing the kang in a house.

In this paper, the macroscopic thermal and airflow model of the elevated kang is developed at the first, and the approach of integrating the kang model with a building energy simulation software (DeST) is given. The thermal performance of the elevated kang and its effect on indoor environment in a typical house in northern China are investigated by applying the tool developed.

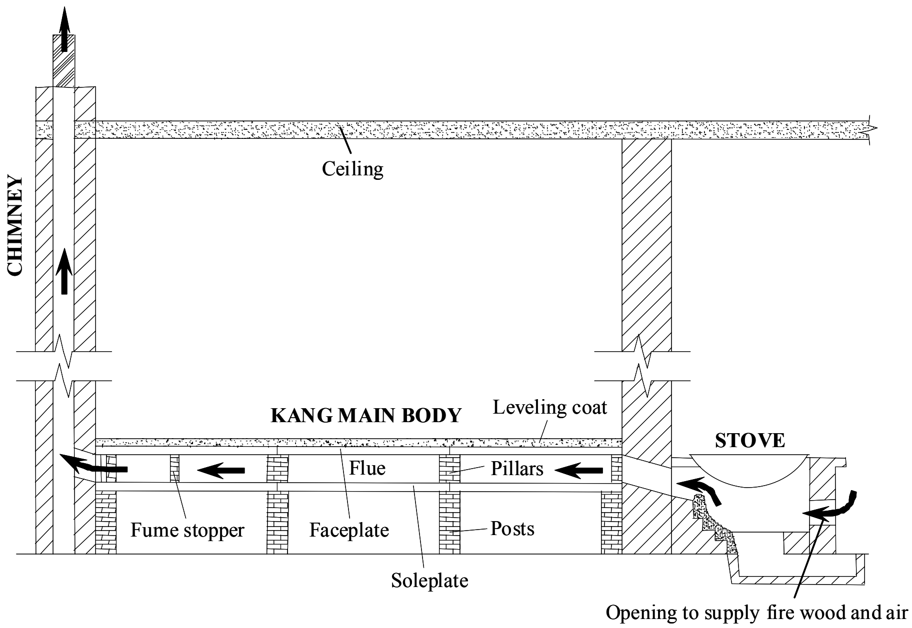


Figure 1 Schematic representation of a typical elevated kang system

2. Approach

A mathematical model for a house integrated with an elevated Chinese kang (HIEK) heating system has been developed for building energy simulation, which was validated using the test data (Zhuang, 2007). Because the heat transfer and airflow between smoke and kang plates is a coupling process, it is more adaptive to analyze the elevated kang using the macroscopic method. The entire elevated kang heating system is divided into three zones, Zone 1 (stove), Zone 2 (kang main body) and Zone 3 (chimney), as shown in Figure 2.

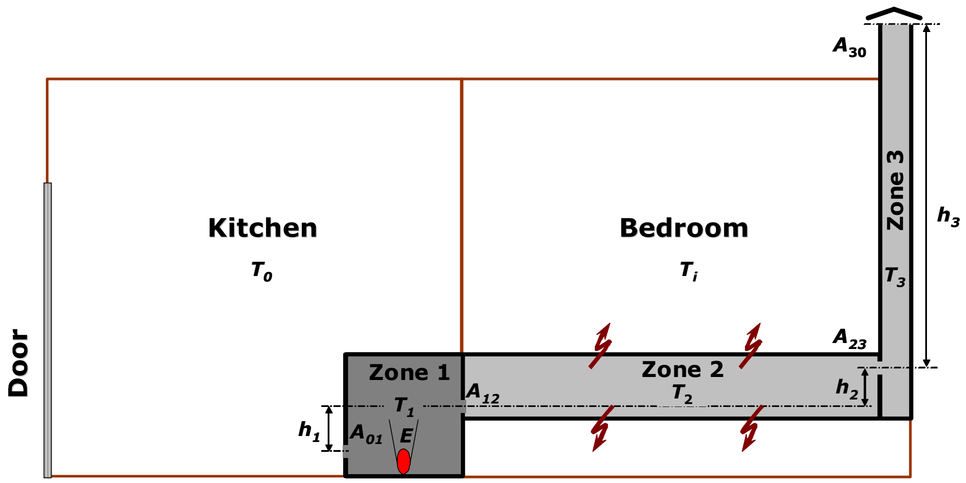


Figure 2 The general notation for the macroscopic model of elevated kang heating system

Considering the relatively small sizes of space in kang heating system, the uniform air temperature in each zone is assumed, which is often adopted in building thermal analysis. This approach enables relative, if not absolute, predictions of the effects on heating energy requirements to be made. The proposed program is mainly developed for researchers or experts. For building designers its use is, however, severely limited due to some shortcomings such as inconvenient input and output methods. If this model is integrated into available building simulation software, it can be used to investigate alternative operational strategies and to determine kang system performance for a range of climates. Due to the fully development of building energy simulation techniques over the past decades, several programs are widely used with mature techniques and friendly visual interface, like Designer's Simulation Toolkit-DeST (Tsinghua University DeST Group, 2006).

DeST is a simulation tool for building thermal performance & HVAC developed by Tsinghua University during 1990s, and now widely used in Chinese building industry. The approach taken in this project was hence to integrate the proposed kang model into the DeST software.

The core issues on integration are the input and output linkage between the kang model and the DeST software. The output parameters from DeST such as indoor air temperature, solar radiation and building envelope surface temperatures are used as inputs for the kang module. The heat release from a kang should be transferred to DeST likewise at each time step. Another item noticed is to deal with the inconsistent time step. In this project the outputs from DeST with the time step of 1hour are linearly interpolated into 60 parts and input the kang model with the time step of 1 minute. The integrated DeST-k can predict the indoor air temperature, heating load, heat release from kang plates, surface temperatures of kang plates, mass flow rate of kang system and so on.

3. Case setup and simulation details

The design for buildings with the elevated kang heating system is to achieve or check the two main aims: firstly people often lie on the kang plates to sleep, and the kang needs to be felt thermally comfortable. Thus the surface temperature of kang plates should be maintained within the range of 25-30°C (Guo, 1998). The heat input pattern can be controlled to regulate the surface temperature, such as changing the heat source power, firing time and firing duration. Besides, the kang configurations like plate thickness and materials also affect the surface temperature. The second design aim is to efficiently utilize the heat input of kang to improve indoor thermal environment. That needs to improve the heat release and heat storage capability of kang and the thermal physical level of building itself such as enhancing insulation, decreasing building air infiltration, or installing auxiliary heating systems. The integrated DeST-k can serve as a useful tool for energy analysis of buildings with elevated kang heating systems to obtain the design aims described above.

A base case house with elevated kang heating was selected for case study, see Figure 3. Note that this building was representative of commonly found homes in rural area in northern China from surveys (Zheng, 2007). The total building area was 66m^2, and the heating area was 33m^2.There were two bedrooms with one living room between them. The living room was mainly used as kitchen and dining place. The elevated kangs were placed in each bedroom for heating. The parameters of one bedroom are listed in Table 1. The TMY data provided hourly climate data. Shenyang, the capital city of Liaoning province in Northeast China, was chosen as the base location. The elevated kang was 3.0 m long and 2.0m wide with often used concrete kang plates. The base plate thickness was 60mm. For heat transfer from the slab surface to the room, a combined linearized radiation and convection heat transfer coefficients were used. The convection coefficients were obtained from recent experimental results, and the heat power of smoke into the kang body was fixed at 35KW during firing time (Zhuang, 2008). There were three firing times during a day, at 6:00 am., 12:00 am. and 18:00 pm., lasting for 90 minutes respectively. It should be noted that heat release from the stove is not included in the following simulations.

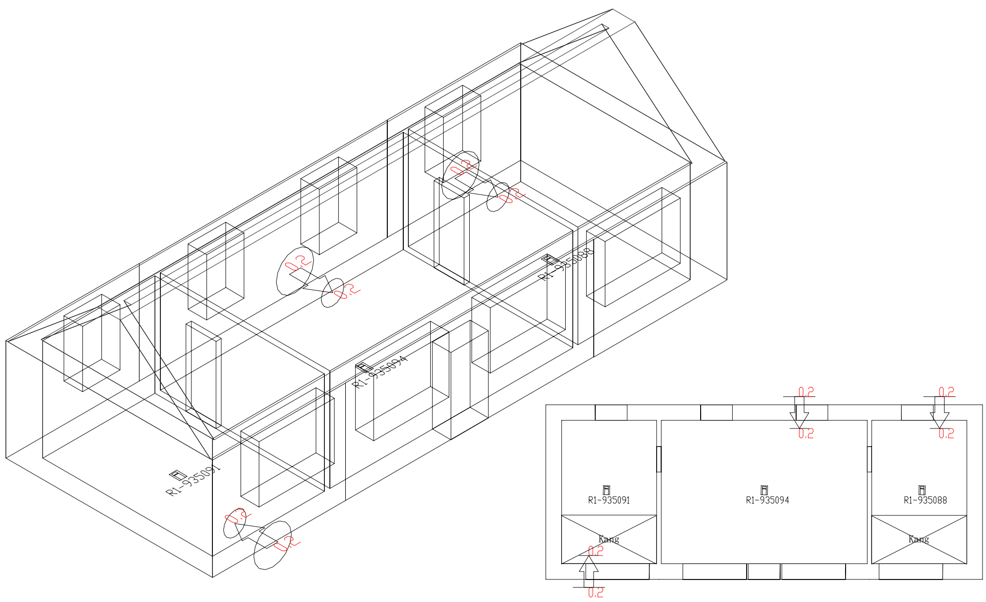


Figure 3 Layout of a typical rural house in northern China

Table 1 Materials, dimensions and assumptions used in the base room

Item	Description
Room size (L×W×H)	5.0 m×3.3m×2.7m
External wall construction	370mm clay brick with 20mm plaster layer
Internal wall construction	120mm clay brick with 10mm plaster layer either side
Roof construction	10mm tile, 160mm clay with 80mm straw
Ceiling construction	10mm plasterboard
Floor construction	50mm concrete with 100mm soil
South window construction	Single, 6 mm thick, plain, size: 2.0m×1.8m
North window construction	Single, 6 mm thick, plain, size: 1.5m×1.0m
External door construction	Timber framing, size: 2.0 m×1.0m
Internal door construction	Timber framing, size: 2.0 m×0.8m
People	2×64W/person, from 18:00 pm. to 6:00 am.
Lights	60W, from 18:00 pm. to 22:00 pm.
Air change rate	2 ACHs (ACH is a short of “air change per hour”)

Performance sensitivities to a variety of parameters were determined by changing the inputs to the base case model. Various simulations were performed to investigate the effects of kang configuration, building insulation, room air change rate and climate on indoor thermal environment and heating load. Three different plate thicknesses (40, 60 and 80 mm) were arranged. These dimensions are typical of the sizes used in an elevated kang. To evaluate the insulation effect, only the external walls were insulated by adding 100mm polystyrene panel outside. Four different room air change levels were assumed, namely 0.5, 1, 2 and 4 air changes per hour (ACH), to represent the range of ventilation rates most likely to be used in a residential building. The effect of climate on performance was investigated by running the models described above using climatic data for three different capital cities in northern China listed in Table 2. All the simulations were performed only in the heating season. Considering the low living level in most rural families in China, the design indoor air temperature for heating was fixed at 14 ^{o}C, which is often adopted in passive heating building design.

Table 2 The climate in three locations during the heating season (National Meteorological Information Center and Department of Building Science of Tsinghua University 2005)

Location	Shenyang	Beijing	Xi’an
Heating degree days (base 14^{o}C)	3063	1978	1572
Average temperature in the coldest month	-11.46 ^{o}C	-3.83 ^{o}C	-0.35 ^{o}C
Average temperature in the coldest day	-17.50 ^{o}C	-10.00 ^{o}C	-3.45 ^{o}C

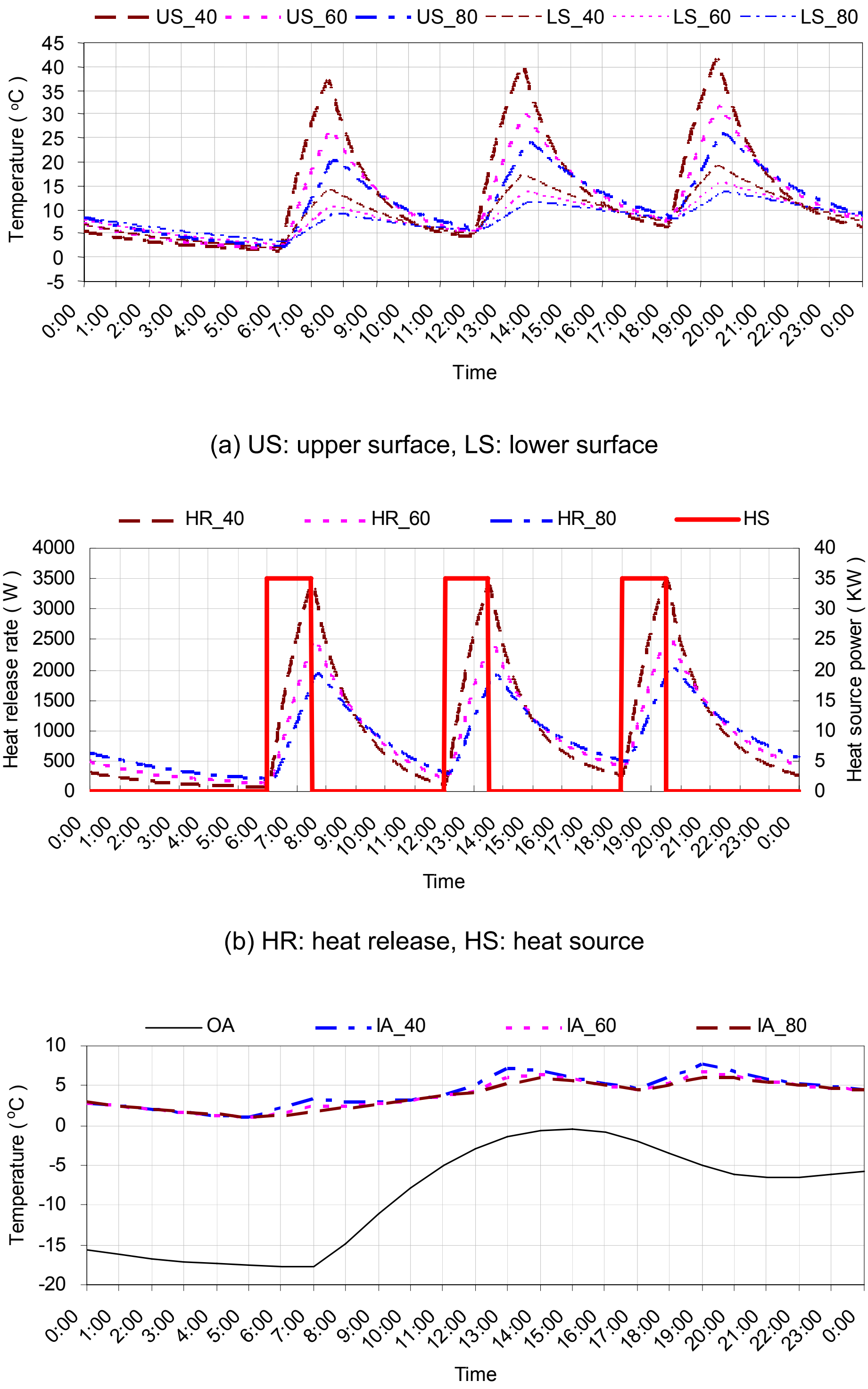
4. Results and discussion

4.1 Thermal performance of the elevated kang

The thermal performance of the elevated kang can be investigated from its thermal responses. The change of surface temperatures of kang plates with three different plate thicknesses during one day is shown in Figure 4(a). It can be obviously seen that the upper surface temperatures of top plate fluctuate a lot due to the firings. The amplitudes of them decrease from about 30 ^{o}C to 15 ^{o}C as the plate thickness increases from 40mm to 80mm. The thicker plate has more thermal capacity which helps to moderate the change of temperature. While considering body thermal comfort requirement, the recommended thickness is 40mm leading to upper surface temperature within the range of 25~30 ^{o}C in most of time. The amplitudes of lower surface temperatures of bottom plate are relatively small, within 10 ^{o}C in all cases. This is mainly caused by the low heat convective coefficient at the inner surface of bottom plate (Zhuang, 2008).

The heat release from kang plates directly describes the heating capability. From Figure 4(b), it is found that a decrease in plate thickness results in an increase of transient heat release during the firing periods. For example, the maximum transient heat release rates with 40, 60 and 80mm thick plates are 3500 W, 2596 W and 2070W respectively. By calculation, the heat efficiencies, the ratio of total heat release to heat source power, are 15.4%, 14.1% and 13.3% for the kang with plate thicknesses of 40, 60 and 80mm respectively.

Figure 4(c) illustrates that the indoor air temperature can be maintained above 2 ^{o}C under the kang heating despite of the lowest outdoor air temperature of -18 ^{o}C. The thickness of kang plates has little effect on indoor air temperature, which only changes somewhat during the firing periods. The main reason is that the change of total heat release from kang is relatively small comparing to building heat demand.



(a) US: upper surface, LS: lower surface

(b) HR: heat release, HS: heat source

(c) OA: outdoor air, IA: indoor air

Figure 4 Dynamic thermal response of the elevated kang during one day

4.2 Effect of the elevated kang on indoor air temperature

Figure 5 shows the indoor air temperature frequency distributions for different proposed cases. For case NIWK, the indoor air temperature is the basic result telling the current thermal level of rural building without insulation, and even 8.2% of indoor air is lower than -2.0 °C. There is an urgent need to improve indoor thermal environment. The effect of building insulation on indoor thermal environment can be evaluated with case NIWK and case WIWK. By adding wall insulation described above (for case WIWK), the indoor air temperature can be further improved by about 2.0 °C. Besides, the indoor air temperature distribution of case WINK is better than case NIWK. It can be said that insulation plays an important role in improving indoor air temperature, even better than using the kang heating system. For case WIWK, 13.5% of indoor air is still lower than 2.0 °C, which may be caused by the uniform heat input of kang at the fixed times. The heat supply is not completely based on the requirement.

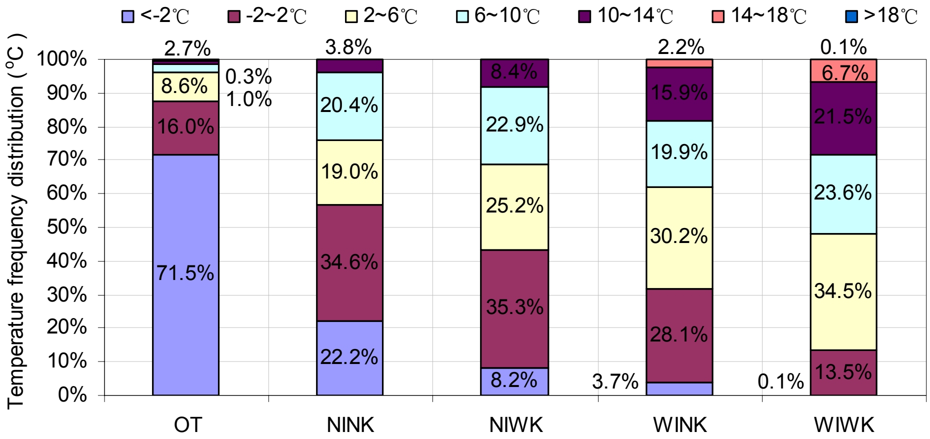


Figure 5 Indoor air temperature frequency distribution with and without kang heating and wall insulation (OT: outdoor air temperature, NINK: no insulation and no kang, NIWK: no insulation and with kang, WINK: with insulation and no kang, WIWK: with insulation and with kang)

4.3 Effect of ACH on indoor air temperature of room with elevated kang heating

Figure 6 gives simulation results of the room with four ACHs under the elevated kang heating. The air infiltration of room greatly affects the indoor environment in cold regions. For airtight room with ACH of 0.5, the indoor air can be kept above 6 °C in 99.5% of heating reason.

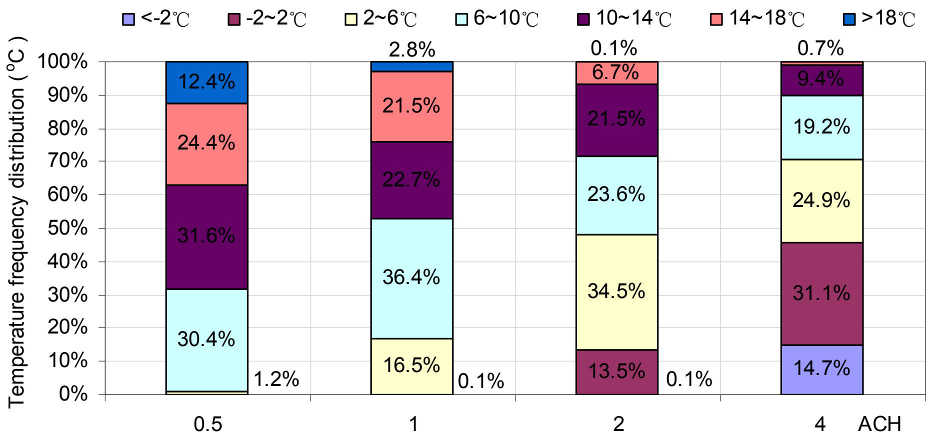


Figure 6 Indoor air temperature frequency distribution under different ACHs

4.4 Effect of the elevated kang on building energy consumption

Table 3 lists the cases of various simulations described above for the heating load prediction. Predictions of heating energy and peak demand as a result of using the kang heating system and wall insulation are summarized. A brief discussion of the use and meaning of the simulation results is presented below.

Table 3 List of simulation results for a room with an elevated kang system

Case	Location	ACH	Heating energy (KWh/m^2)	Peak heating load (W/m^2)
NINK	Shenyang	2	201.64	149.09
NIWK (base)	Shenyang	2	133.09	143.15
WINK-1	Shenyang	2	149.95	121.39
WINK-2	Beijing	2	66.01	83.37
WINK-3	Xi'an	2	67.37	66.40
WIWK-1	Shenyang	2	86.13	115.03
WIWK-2	Beijing	2	33.07	70.12
WIWK-3	Xi'an	2	19.2	53.41

Figure 7 compares the heating load index under kang heating and building insulation. The heating load index per square meter is decreased from 54.8 W/m^2 to 40.7W/m^2 by the elevated kang when the external walls have no insulation, saving 25.7% of heating load. By adding wall insulation, the energy saving by the elevated kang is improved by 5.8%, providing 31.5% of heating load. It illustrates that the elevated kang can contribute more energy savings as the building is better insulated. While the total heat release from kang is slightly affected by the building insulation, the heat efficiencies of the kang body are 14.22% for external wall with insulation and 14.24% for external wall without any insulation.

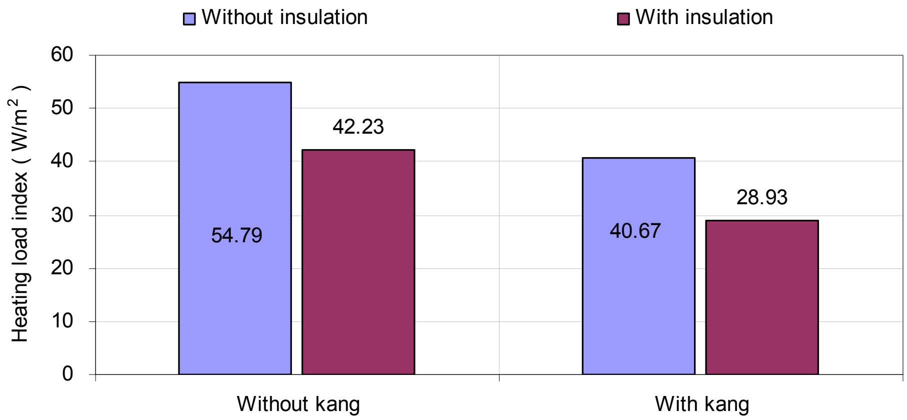


Figure 7 Comparison of heating load index under kang heating and building insulation

4.5 Effect of climate on building energy consumption of room with elevated kang heating

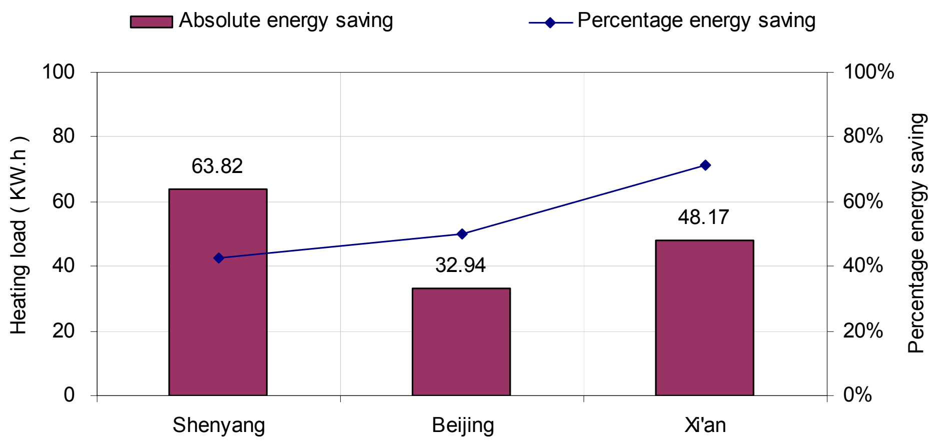


Figure 8 Predicted heating energy savings by the elevated kang in three climates

The heating capability of the elevated kang in various climates is investigated. Three representative regions in Northeast China, North China and Northwest China respectively are selected. Overall it is important to understand that it is not possible to identify a “best” system for any particular location. In this paper the judgment depends on how much the heating energy consumption is reduced. The absolute energy saving is defined as the difference between heating load for room using a traditional air-conditioning system and the auxiliary heat energy required as using the elevated kang to reach the designed indoor air temperature. The percentage saving is a convenient indicator of system performance, which evaluates the heating potential of the kang system. From Figure 8, the elevated kang is the most effective in reducing heating energy consumption in areas with the climate like Xi’an, 71.5% of heating load can be provided by the kang alone. It is also interesting to observe that 49.9% of annual heating load is saved for the Beijing climate. However, the annual heating load saving in this location is 51.6% of the result in Shenyang area.

5. Conclusions

Chinese kangs have been widely used in northern China as a potentially sustainable heating system. The elevated kang model has been integrated into a building energy simulation software (DeST) to predict the indoor air temperature and energy consumption for houses with the elevated kang heating. The performance of this system in a typical rural house has been predicted under different proposed cases to investigate the effects of kang configuration, building insulation, room air change rate and climate on indoor thermal environment and heating load.

The simulations show that the indoor air temperature can be improved under the kang heating, and building insulation plays an important role in further improving indoor air temperature. The heat supply of kang should be based on the requirement to maintain continuous indoor thermal level. The heating performance of the system is not very sensitive to the thickness of kang plates. The air infiltration of the room greatly affects the indoor thermal environment in cold regions. The elevated kang can contribute more energy savings if the building is better insulated. The elevated kang system offers either energy and/or peak load savings in almost all locations investigated. It is the most effective in reducing heating energy consumption in areas with the climate of Xi’an, 71.5% of heating load can be provided by the kang alone. These results support the general consensus that the elevated kang system is suitable for climates with not too cold regions. For the extreme cold regions, the design indoor air temperature cannot be achieved only by the kang heating system. Further research is needed to fully explore other controls parameters and strategies for kang system.

Acknowledgement

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BUILDINGS, USERS, CLIMATE AND ENERGY EFFICIENCY

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Keywords: architecture, climate, user, energy, technologies, holistic, education, planning

Summary

The project integrates the fields of building climate, energy technology and building informatics in order to develop a holistic planning concept for administrative buildings in different climate zones. The aim is to create sustainable buildings that can afford a maximum of comfort with a minimum of energy and costs during the building life cycle. Architecture and building services technology can therefore not be planned as a uniform series, but need an interdisciplinary team to work out the relationships between the daylight situation, the facade concept, room conditions, technical systems and energy generation and to show the consequences of planning decisions.

Planning tools should be easy to handle and useful both in education and in the design process. Architects and engineers have to understand the interplay between user requirements, environmental potential and the building concept in order to activate synergetic effects and optimize the potential of the holistic building. This makes it possible to reduce the planning time and at the same time create sustainable buildings that take both the needs of the user on a given site and the overall ecology and economy into consideration.

1. Relevance of the Concept Phase

All over the world, the building industry is faced with ever tighter planning schedules and the need to minimise planning costs. This is compounded by time-consuming planning and increased costs for innovative concepts, which aim to increase comfort while simultaneously reducing energy consumption and technology investments (Hindrichs et al., 2007). If this challenge is to be mastered, additional planning methods and tools that provide fast, cost-effective guidance when making decisions during the conceptual phase, are called for.

Energy and room climatic objectives play a major role in architectural competitions. Principals and investors must often specify the requirements concerning the energy and the room climate. There is insufficient knowledge about the energy and technical consequences closely related to the particular requirement, e.g. the room operating temperature in summer related to the technical effort in the building (Hausladen et al., 2008).

In view of the level of detail involved, conventional simulation programs are of only limited use during this early planning phase. The many as yet unspecified parameters and the high initial number of variants cause (fig. 1) an enormous amount of work of limited relevance. Instead, there is a need for decision guides that restrict the number of variations worth pursuing. During the concept phase, it is not so much the acquisition of absolute values that is of interest, but the choice of planning variants, and this must take priority.

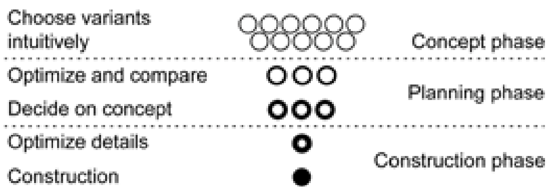

Figure 1 Requirements in the different planning stages

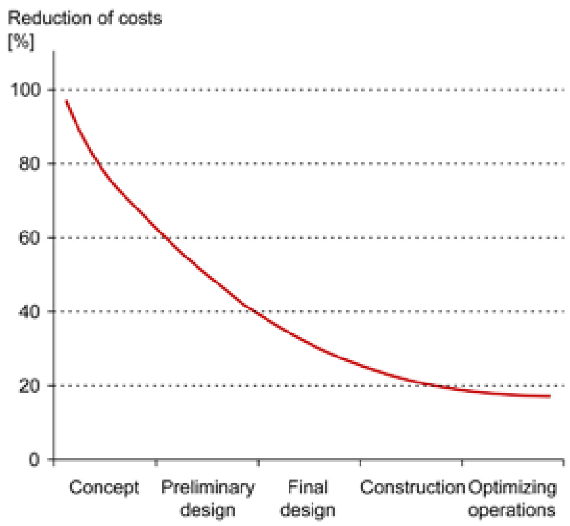

Figure 2 Potential reduction of costs in the planning process

2. Research Approach

The research approach treats buildings in different climate zones (tropical humid, subtropical, hot arid and Mediterranean) holistically, incorporating the building concept, façade planning, building technology, the generation of energy in keeping with the outdoor climate, user requirements, indoor climate and energy efficiency in a comprehensive context that highlights their interrelationship.

The participating institutes are (fig.3) Dept. of Computation in Engineering Steering, Prof. Rank, Dept. of Energy Management and Application Engineering, Prof. Wagner and the initiator, Dept. of Building Climatology and Building Physics, Prof. Hausladen. The initial point of the research project is the concept presented here, with the building representing a holistic system.

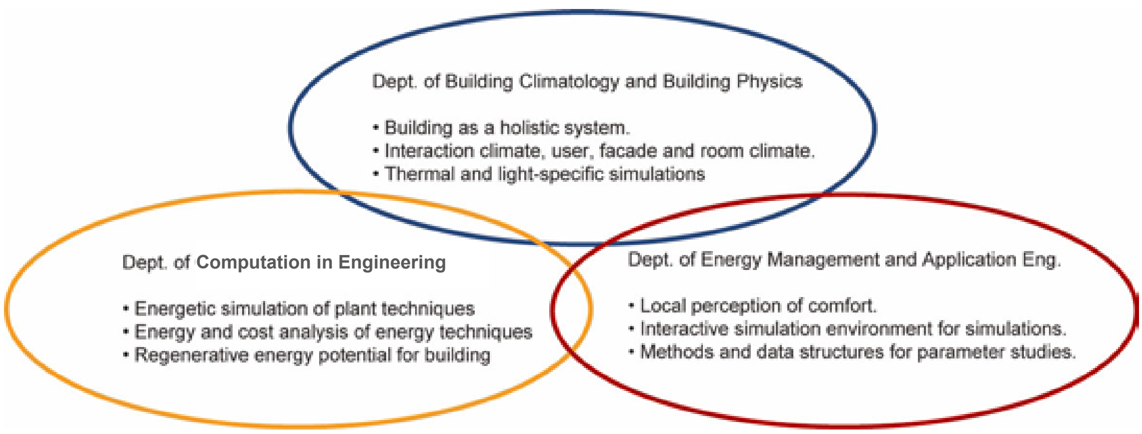

Figure 3 The interdisciplinary team and their core themes

2.1 Objectives

The research objective is to support architects and engineers during the conceptual phase of planning administrative buildings in different climate zones. During the draft concept phase, tools that that allow the energy and indoor climate requirements to be gauged in the absence of detailed planning data are essential, as professional planners are not normally involved at this stage.

In-depth knowledge of the climatic challenges and potential and the required standards of comfort is often lacking in building projects for other climate zones. An exact analysis of the climatic conditions and the site is, however, essential when planning buildings with optimised energy and indoor climate systems in order to align the structure of the building and the façade accordingly and to exploit the potential for the energy and room climate concept (fig. 4). A critical examination of the relevant utilisation and comfort criteria and an accurate analysis of the outdoor climate and site conditions support the development of appropriate room climate concepts.

In this way, it is possible to realise energy saving potential, achieve regenerative energy generation systems and reduce the building's technical installation costs. A good indoor climate is the basis for the well-being and performance of the users.

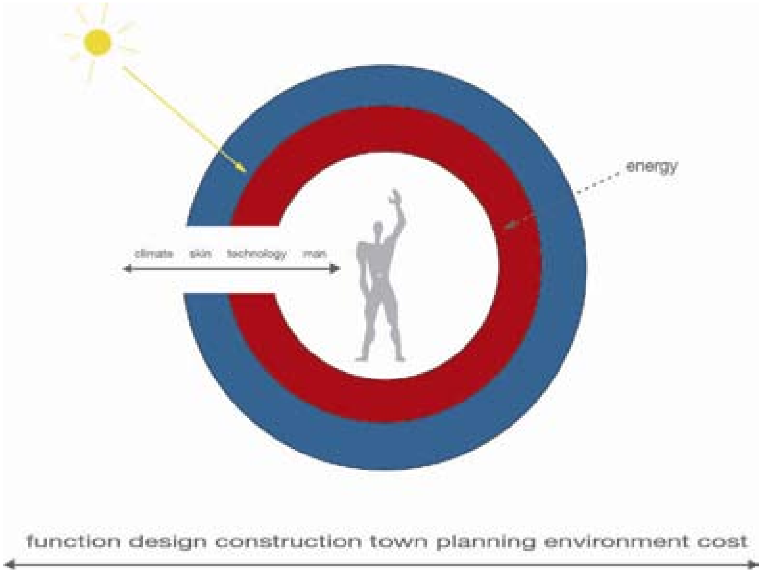

Figure 4 The building seen as a holistic system. The better the building reacts to outside climate conditions, the less technology and energy is required to achieve a comfortable thermal climate for the occupants

2.2 Support Of A Holistic Planning Basis

A holistic planning basis for building in various climate zones supports architects and engineers in education and planning practice.

Table 1 Support

Categories	Advantages
Building with the climate	Recognition of the potentials of the respective site Utilisation of regenerative energy generation systems
Specification of requirements	Depiction of synergetic effects and interaction in the building system Revelation of optimisation potential during the concept phase
Challenges in the planning process	Submission for international competitions Cutting planning time Systematic analysis of suitable energy technologies and combinations
Life cycle	Reduction in energy consumption and costs Holistic optimisation of the energetic and economic life-cycle balance by incorporating production, utilisation and disposal/recycling

3. Realization

The results of the research are to be implemented in straightforward planning tools and a planning manual designed to define and quantify the interaction between the outdoor climate and indoor/room climate as well as the engineering concept. The aim is for them to set out the basic principles of optimum climatic concepts in different climate zones during the conceptual phase by enabling a rough estimate of the indoor climate and energy consumption to be drawn up. By revising existing detailed surveys, these can be integrated into an overall context in such a way that interaction becomes visible.

3.1 Planning Tools

Planning tools that can be utilised after a reasonable period of familiarisation are to be devised for individual features. These include planning graphics, execution diagrams and tools for doing an initial (basic) draft of the building from the point of view of energy and room climate aspects. It is also planned to create a software tool that scans the relevant planning parameters at the concept phase and hazards an approximation of the building's future behaviour. The main aim is not so much to quantify an exact planning result but to make a quick comparison between diverse planning options.

Planning aspects that cannot be depicted directly in the software or are not immediately quantifiable are expounded in a supplementary planning guide, and their relevance is shown qualitatively. This planning manual for architects and planners depicts the inter-relationship between planning factors and the consequences of planning decisions in different climate zones, and is intended to allow a fast practical implementation. The themes are to be presented in a simple, easily comprehensible manner in order to lend assistance in planning decisions at the concept phase.

3.2 Interaction Matrix As An Example For A Planning Tool

The starting-point for developing a building concept is the needs and standards of the users. The planner responds to these requirements by designing the façade and choosing the air-conditioning concept. These two aspects together influence the desired indoor climate during the summer. Moreover, the façade determines the daylight situation. The air-conditioning concept affects the possible cooling systems.

The result is an inter-relationship between light, indoor climate and cooling system (fig.5), which works both ways. This in turn sparks reciprocal action between the cooling strategy and the availability of daylight.

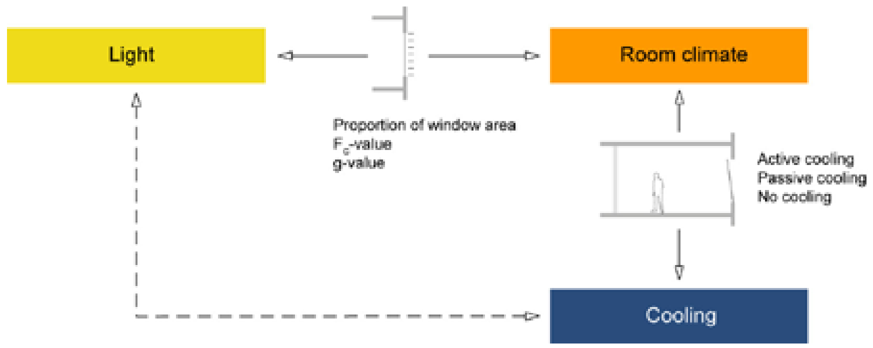

Figure 5 Inter-relationship between light, indoor climate and cooling system

For standard cases, a parameter study coupling the aspects of light, façade, indoor climate and building technology has been drawn up for the reference climate in Germany (fig. 6). This enables several fundamental simulations for the concept phase to be replaced. For a better detailed analysis of the connections, the results pertaining to light, indoor climate and energy have been summarised in an all-embracing matrix.

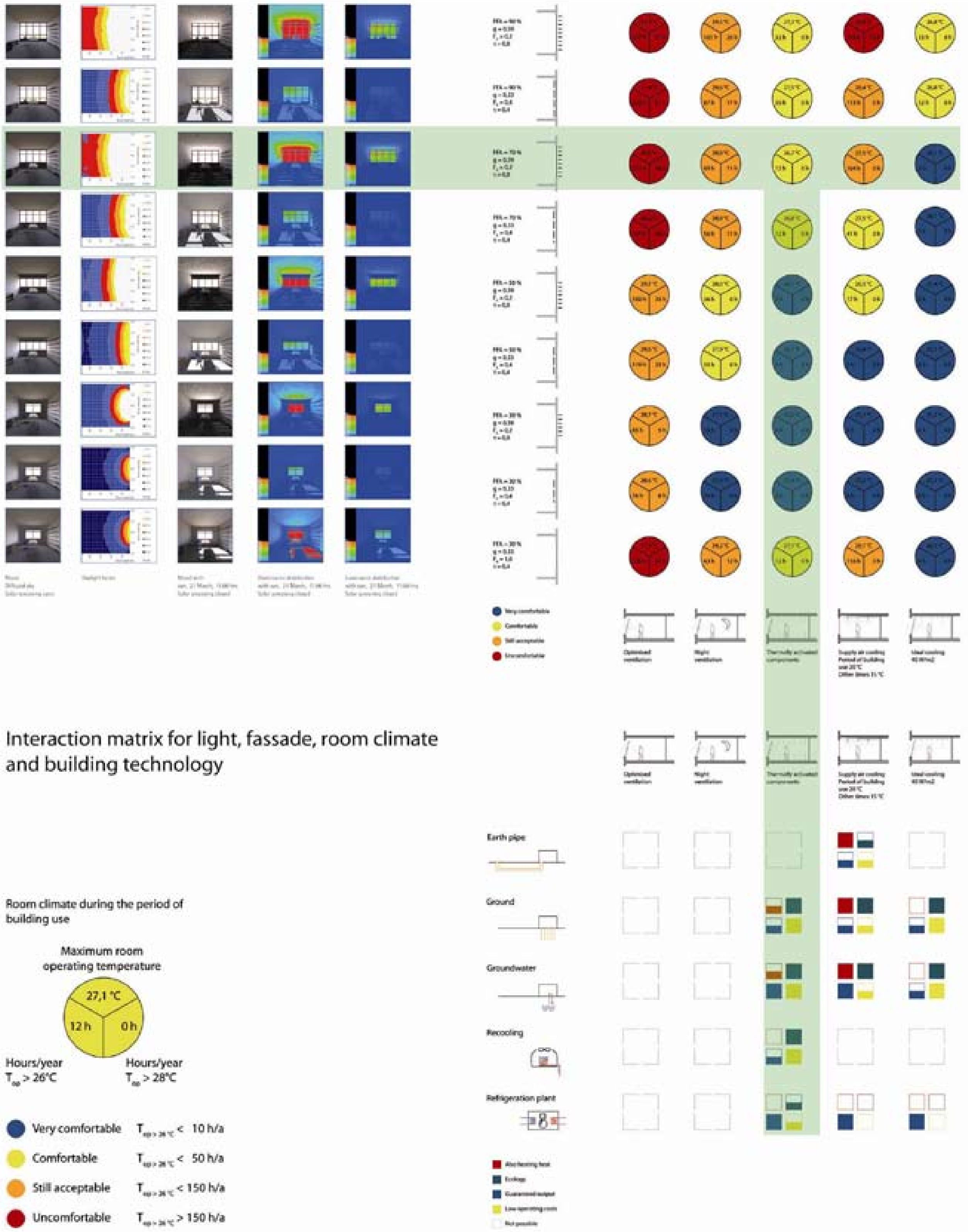

Figure 6 Interaction- matrix daylight situation, façade, indoor climate, air conditioning and energy generation and legend for the room climate

For better understanding, the interaction-matrix presented in figure 6 will be described by the following example (highlighted in green). If, very good daylight provision is desired, it can be achieved with a proportion of window area of 70% with conventional glazing. In combination with external solar screening, a good room climate (yellow circle) is achieved with thermally activated components, a very good climate (blue circle) with active cooling.

With thermally activated components, regenerative energy sources such as ground cooling, groundwater and night recooling are used. Regenerative cooling has low operating costs (filled yellow square) and is very ecological (filled green square). The output from groundwater cooling is always guaranteed to be available (filled blue square). With night recooling there is a dependency on night outdoor air temperature, ground cooling may become exhausted (half-filled blue square). Ground and groundwater can also be used for generating heat in winter by means of a heat pump (half-filled red square).

To ensure a very good room climate with active cooling, a mechanical cooling system would be required. The output is guaranteed (filled blue square). Operating costs with this option are generally high (empty yellow square). The interrelationships also work in the opposite direction.

3.4 Preview

Planners of building projects in other climate zones frequently lack a detailed knowledge of the climatic conditions and comfort criteria. But it is precisely at the early planning phase that a fast assessment of the interaction between the façade and building technology is essential. Detailed calculations are less practical because of the unverified boundary conditions and the large number of variations (Hyde, 2008).

Parameter studies for standard cases enable several fundamental simulations for the concept phase to be replaced. The Interaction matrix daylight situation, façade, indoor climate, air conditioning and energy generation makes it possible to record the effects of planning decisions using a holistic approach.

This planning tool serve as a starting-point for considerations in different climate zones and is currently being developed in the research project. In education and professional training (e.g. the international and interdisciplinary master course “ClimateDesign” started in October 2007) architects and engineers should be prepared for the new challenges and changes in the building industry with these tools and developed concepts.

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A STUDY ON THE USE OF THE COMMUNITY FACILITIES OF SUPER HIGH-RISE MIXED-USE APARTMENTS

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Keywords: the Super High-Rise, the community facilities, the satisfaction, preference

Summary

This study aims to be a reference on the basis of residents' use of community facilities. And it is to suggest design guide lines for each community facility of the Super High-Rise Apartments.

The process of this study are as follows; 1. Varieties and sizes of the community facilities on the drawings of the nineteen cases, which are built in Seoul Metropolitan area, were analyzed. 2. Questionnaire was conducted to the dwellers that live in the four cases among those nineteen cases.

The results of this study are as follows; 1. Based on the analysis of the drawings, the number of residential unit is positively correlated with the size of the community facility area, whereas the family density in that building is not correlated per residential unit. 2. Sports facilities were found to be arranged in the most nineteen cases than in any other types of other facilities. The Sports facilities have the highest level for averaging the time-duration in use for a week basis among the community facilities of the Super High-Rise Apartments.

1. Introduction

After the Sewoon Commercial Apartment was built, and this was the first high-rise mixed-use building in South Korea, a new housing scheme was introduced in Seoul in the late 1980s. The high-rise mixed-use apartments were expanded which was based on easing regime in the mid 1990s and it settled down as a new style of urban residence. The high-rise mixed-use apartments were a center in the super high-rise traditions and it weighed a huge scale in the late 1990s. These days mostly people think the high-rise mixed-use apartments were as an elegant type of housing. The facilities for community and the commercial in the mixed-use apartments, they seem to have a trend, variety-featured and elegance in compared with the normal multifamily housing since risen income and changed life styles. Although the high-rise mixed-use apartments were high buildings with a high residence-density, in process of planning there were no accurate studies in terms of their size, variety and amenity that was to complement for poor outdoor spaces, and shared spaces, and other life services.

Recently in the super high-rise mixed-use apartments are studied actively based on above issues about community facilities, and many previous researches understand the characteristics of the plan that was through the literature survey, and the researches understand about residents utilizing the community facilities that was interviewed through the staff. It was surveyed on the residents for their satisfaction about the community facilities.

As the housing gets taller, the building emerges to have characteristics being high density housing, which is mostly recognized as one unit of one community. The community facilities in the Super High-Rise Mixed-Use Apartments have functions, which are semi-public space as a buffer zone (connecting unit house and outdoor space), defensible space (protection from outdoor threat) and amenity (upgrading for residents' convenience and welfare).

This study should be used as a preliminary data to draw the criteria for unit planning. The aim of the study was to find out the residents' utilizing the community facilities, the residents' satisfaction and their preference for community facilities in the super high-rise mixed-use apartments. The study is expecting for helpful designing the community facilities and for improving for residents' quality of life.

2. Methods

For choosing some cases in this study, we selected the buildings that were built after year 2000 and those that named by mixed-use apartment. They appeared on the real estate websites and on the authorized building lists. The study was geographically limited in Seoul Metropolitan and Bundang areas because in other cities, there were poor numbers of cases, different income level and density of residence.

The process of this study is as follows;

First, through the literature survey we considered concept of community facilities and space functions in the Super High-Rise Mixed-Use Apartments. The buildings were classified by types and functions of the community facilities from the analysis of the mixed-use developments.

Second, Variety and size of the community facilities were analyzed in which shown on the drawings of the nineteen cases in Seoul Metropolitan and Bundang areas.

Third, survey was conducted to the dwellers living in the four cases with variety of the community facilities and with good brand quality among all nineteen cases.

3. Results

3.1 Types

The community facilities in the Super High-Rise Mixed-Use Apartments include functions such as semi-public space which refers as a buffer zone between each unit and with outside and defensible space which is a safety function and amenity that is to improve for residents' welfare and their convenience.

From the analysis of the previous research on the community facilities, it was classified by their functions, residents' behaviors, indoor and outdoor. In this study it classified about the indoor community facilities into the followings, residential service, the residents' communication space, sports facilities, leisure-culture facilities, and education facilities.

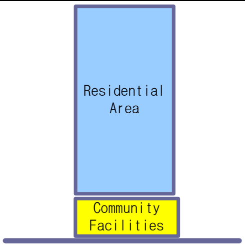
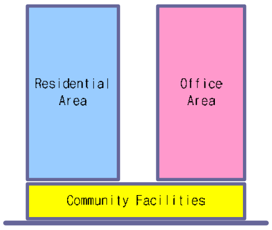
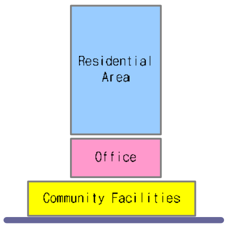
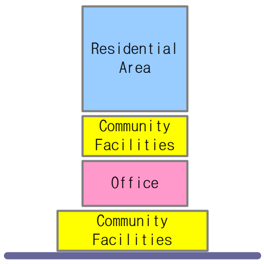
Table 1 The type of community facilities in the Super High-Rise Mixed-Use Apartments

Functional index	Residential service	Residents' communication space	Sports	Leisure/Culture	Education
Community facilities	Hall/Lobby Living Center Storage Business room Laundry Guest room Indoor garden	Banquet Hall Meeting room Residential rest room Business room Club house Silver room Multi−use	Indoor golf Gym Aerobics Pool Sauna Tennis/Billiards	Exhibition room Habby Multimedia room Karaoke DVD room	Study room Kids room Library PC room

The Super High-Rise Mixed-Use Apartments is classified by three types and the types are residence and neighborhood, horizontal residence and office, and vertical residence and office which based on the location of community facilities and other non-residence facilities.

The residence and neighborhood type was made up of residence and commerce area that next to each other at low-level story and entrances were separated between each area. If there were no restriction for floor space index, there would had been some advantages for designing the user's path and make house comfortable, even if a flat and one-hall apartment was planned. For the type of the horizontal residence and office, if the office proportion weighed high it should separate the residence and office building in order to prevent from the residents being crowded. Then it can make community facilities comfortable by locating them at low-level in the residence building. The vertical residence and office type was subdivided by podium style and mixed style. The podium style distinguished the residence and the office vertically and the community facilities were located at low-level in the building. The podium style can have high floor space index in the tower shape, there are advantages for residents' amenity between the connections from the community and the commercial facilities. The mixed style which refers to the community facilities at low and middle floors of the building and it worked to make the residents convenient. This style can control about the proportion and the use of the semi-public spaces in low and middle floors in the building.

Table 2 The type of community facilities' location in the Super High-Rise Mixed-Use Apartments

Community facility types		Diagram	Name of complex
Residence and Neighborhood type (RN)			Royal Palace 1 (RN-1) Michellan Shervill (RN-2) Castle Ivy (RN-3)
Horizontal Residence and Office type (RO)			Park View (RO-1) Obelisk (RO-2) Royal Palace 2 (RO-3)
Vertical Residence and Office type	Podium (P)		Tower Palace 2 (P-1) Tower Palace 3 (P-2) Super vill (P-3) Acrovista (P-4) Gelleria Palace (P-5) I-park 1(P-6) I-park 3(P-7) Hiperion 2 (P-8)
	Mixed (C)		Trump world 2 (C-1) Richensia (C-2) Tower Palace 1 (C-3) Hiperion 1 (C-4) Trump world 1 (C-5)

3.2 Size

The means of the public space area were 5250.16m^2 and the numbers of the community facilities were 13.42 in the housing complex. Sports facilities were quite big proportions of the most complexes. Every complex had education facilities (study room and kids' playing room) and the life service facilities like lobby. Residents' community facilities such as meeting room, karaoke, guest room, club house, and so forth which were established for at least three in every housing complex.

The numbers of the residents correlated between the area of the leisure and culture facilities and the area of sports facilities in the super high-rise mixed-use apartments. Therefore the community facilities in the super high-rise mixed-use apartments, the facilities are as important like in the normal multifamily housings. If the community facilities were satisfied to be common level the expansions in the area of the community facilities were meaningless, because the number of residents had no correlation between education facilities, residential community facilities and residential service facilities.

Table 3 The area and number of community facilities

Community Facilities		RN-1	RN-2	RN-3	RO-1	RO-2	RO-3	P-1	P-2	P-3	P-4	P-5	P-6	P-7	P-8	C-1	C-2	C-3	C-4	C-5
Education	Study Room	88	133		163			39.7	298	483	215	63				23	112	198		56
	Kids Room	82	52	35			277	129	172		91	51	64	51			79	60	13	
Comm-unity	Meeting Room	128			206		406		268				120	94	61					
	Banquet Room		169		442	79		152	645									155		142
	Multi-use			124						112		72				109		96	182	
	Silver Room	69	37		192		196				64	89	61	69		23			26	
Leisure /Cultural	Hobby	147	36	51	209	60										30	66			60
	Karaoke		71		88			53	83								53	26		
	Guest Room				68	116		50	225									27	139	
	Game Room				68			76	212									60		
	DVD Room	69						23	96									20		
	Club House	147		59	40			63	258					157			99	132		26
Residential Service	Lobby	451	897	873	897	873	873	873	897	451	533	533	873	313	451	873	533	451	533	897
	Coin Laundry		1156	28				20	60									23		
	Banking	87	225							182	285								231	20
Sports	Pool	471	403		3638	263		334	496	453	586	470	995		1119	430		1408	393	512
	Gym	38	552	314	550	166		170	500	407		264		736		162	284	119	363	142
	Aerobics	522	73	94	120					99			180				208	99		
	Indoor Golf	606	791	674	4104	219		426	618	532	932	501				175	248	2995	225	737
	Sauna	682	364	293		809		426	476		342	490	707		1688			3653		
	Squash																278	139	119	
Commercial		6166	3462	3462	3462	1305	3462	1305	3462	6166	7720	7720	1305	2522	6166	1305	7720	6166	7720	3462
Sum		9752.5	8420.5	6007.7	14246	3890.2	5213.4	4140.1	15828	8884.9	10766	10253	4305.8	3942.8	9485.3	3130.4	9680.9	8763.9	9944.6	6055
The number of Facilities		15	15	11	15	9	5	15	18	9	9	10	8	7	5	9	11	16	11	10

Table 4 The correlation between the number of family and the area of each facility

Area	Pearson Correlation	Sig. (2-tailed)
Education/Children Care	0.33	0.17
Community	0.42	0.07
Leisure/Culture	0.71	0.01
Residential service	0.18	0.47
Residential service sum	0.68	0.00
Sports	0.51	0.03
Total community facility sum	0.59	0.01

There was no correlation between the family density and the facility area per house. If the family density was measured less than 800, that could had been a strong negative correlation to each other. On the other side if the family density was over 1000, it means the facility area per house had expanded hugely.

Table 5 The correlation between the family density and the facility area per house

	Pearson Correlation	Sig. (2-tailed)
Facility area per house	-0.21	0.38

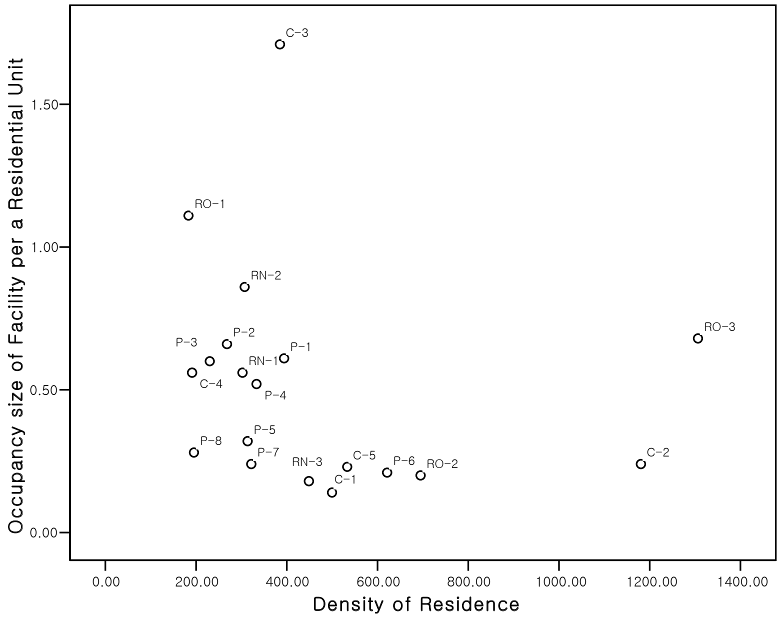


Figure 1 Distributed chart between the family density and the facility area per house

3.3 Use

The mean hours in utilizing each community facility were less than 2 hours per person in a week except for the study room, the lobby and the sports facilities; but aerobic room was used less than 2 hours. When comparing the utilization average hour for each room, study room, lobby, swimming pool, gym, golf lounge, sauna, and commercial facilities in low-level of the building and they averaged more than 2 hours. More than thirty percent of the respondents used all these facilities.

Community facility	Sum(hours/ people)	Utilization average hour	Community facility	Sum(hours/ people)	Utilization average hour
Study room	99/39	2.5	Lobby	110/42	2.6
Kids room	26/20	1.3	Banking	22/16	1.4
Meeting room	26/20	1.0	Club house	27/14	1.9
Banquit room	6/6	1.0	Pool	193/50	3.9
Multi-use room	5/5	1.0	Gym	393/87	3.9
Silver room	17/13	1.3	Aerobics	22/14	1.6
Habby	39/21	1.9	Indoor golf	197/53	3.7
Guest room	2/2	1.0	Sauna	309/69	4.5
DVD room	15/11	1.4	Commercial	110/52	2.1

4. Discussion

There was correlation between the area of community facilities and the number of houses in the super high-rise mixed-use apartments but the area of community facilities per house did not correlate with residence density. Therefore the numbers of the houses were the most important issue about designing of community facilities when the facilities' size was considered.

The highest utilization from the community facilities was the sports facilities and the lobby, but residential community facilities were not used and the facilities had low satisfaction level even though there were many sorts of them. Therefore residential community facilities in the super high-rise mixed-use apartments should be simplified and have flexibility rather than make it various. The lobby with a high level of utilization is needed to make it-self comfortable and should design the mixed space based on the functions of the residential communication.

As for the education facilities, the study room was the highest level in utilization and satisfaction, but for the kids' playing room the utilization and satisfaction was low. There are a lot of teenagers who are more than children and who are not even entered into school living in the super high-rise mixed-use apartments, because these days the apartments were developed in a huge size of unit for the

residents. When planned for the education facilities, there are needs to analyze about the members of the residents thoughtfully, and check out any programs that needed for kids.
The needs for the facilities' expansion, and variety, elegance for the community facilities in the super high-rise mixed-use apartments were shown clearly, so such needs will be important for commercializing. When the community facilities are planned, it is important to understand the residents' needs and traits. The community facilities should concern about their flexibility in planning because of low-level of utilization in the facilities after had been occupied by the residents.

Acknowledgement

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A STUDY FOR WINDOW-TYPE DOUBLE SKIN FACADE FOR SUSTAINABLE RESIDENTIAL BUILING

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Keywords: Building envelope, Double Skin Façade, Residential building, TNRSYS

Summary

Recently, the interest in the green house gas problem keeps increasing. The international community is trying to reduce green house gas emission according to the Kyoto Protocol on Global Warming. As well as global warming issue, occupants' health in building is widely concerned as also important. Double skin façade is used in many sustainable building projects and well known as an innovative solution of ecological façade system. The aim of the facade is, on the other hand, to increase internal comfort and, on the other hand, to decrease energy consumption. Within this context, the necessity of developing optimized double skin façade system for specific building types, and the detailed behavior of such façade need to be understood.

The paper deals with development of window-type double skin façade which is optimized for sustainable residential building. The façade system is based on the box-type window for protection of privacy by sound transmission through the cavity spaces and to avoid dispersion of cooking smell. First of all, parametric studies on how to decrease energy consumption by changing depth and height of the cavity spaces are proceeded with TRNSYS simulation, which is validated by the mock-up test. Furthermore, the case studies on how to decrease energy consumption by the operation methods of facade are also examined. Finally, the reduction of energy use by applying optimized window-type double skin façade to a residential building is assessed by the TRNSYS simulation that is calibrated in the real energy consumption data.

As the results, the reduction ratios of gas and electricity use by applying optimized window-type double skin façade to a residential building with 0.7 times of air change rate are 10.78% in terms of annual gas consumption and 8.66% in terms of annual electricity consumption.

1. Introduction.

1.1 Background and starting point

Following the 1973 energy crisis, interest has rapidly increased in the possibility of designing buildings that incorporate passive building technologies and efficient mechanical systems and that use significantly less energy than do conventional buildings. In December 1997, the international community has decided to adopt 'Kyoto Protocol on Global Warming' in Conference of the Parties, to cope with aggravated global warming problem. The committee chose CO_2, CH_4, N_2O, HFC, PFC and SF_6 as the six main green house gases. Also, in compliance with requirements of the Kyoto Protocol, each country has to reduce the magnitude of the green house gas emission according to 5.2 percent less than in 1990. The protocol means that enormous green house gas market is appearing as well as war of new technology begins. Europe Climate Exchange, trades 80percent of world green house gas, said that their trading volume of the green house gas in 2005 had grown 2400 times more than in 2004. Also, they foresee that the market would grow to as much as $25 billion until 2012. In order to take over the market, government and industries form developed countries struggles to preoccupy the right of green house gas emission with various policies and technical innovations. CDM (Clean Development Mechanism) is a typical example.

In December 2007, the 13th Conference of the Parties was held in Bally in Indonesia and the committee adopted 'Bally Roadmap'. The roadmap insists a developing country to comply with voluntary negotiation for reduction of green house gas emission. Korea has not only got the most rapid increase in magnitude of CO_2 emission among the OECD countries but also, imports 97 percent of nation's energy from other countries. In addition, the construction of energy is mostly based on fossil fuel and nuclear. Experts prognosticate that if Korea becomes a country obligated under the Kyoto Protocol, $11.2 billion would be spent to purchase the right of green house gas emission in 2015. The foundation of Korean economy can be threatened by this heavy expense and rapid energy cost increase with the poor energy structure, similar to underdeveloped country. Therefore, Korea also has to prepare for the reduction of green house gas to survive in the international society, even though it is not obligatory at the moment.

Since buildings consume approximately 35 - 40 percent of a nation's energy for their operation as well as the load of a building is mainly related with the building envelope, which is a climate filter for the indoor environment, it becomes clear that the necessity of developing optimized double skin façade for specific building types is increasing. Moreover, the detailed behavior of such façade is needed to be well understood. In this regard, this study purposes a development of window-type double skin faced for residential building in Korea which is able to be widely adopted without a large initial cost increase.

1.2 Prototype model of the facade

Basically, a building façade should have enough air tightness and overall U-value. The overall U-value of a façade is influenced by the layer composition of the wall and the window, but mainly by the glazing ratio. External insulation is a good solution for improving thermal performance of a façade and for avoiding problems with thermal bridge. It does not only give advantages of easy maintenance but also, the room temperature fluctuation can be minimized by the large area of thermal mass inside. Opaque wall is only related with thermal flux, but transparent or open window is a pathway of heat, light and air. So that, window as a climate filter should be able to respond dynamically to the outdoor climate changes.

Double skin façade is used in many sustainable building projects and well known as an innovative solution of ecological façade system. The aim of the facade is, on the other hand, to increase internal comfort and, on the other hand, to decrease energy consumption. The paper deals with development of window-type double skin façade which is optimized for sustainable residential building in Korea. The façade system is based on the box-type window for protection of privacy by sound transmission through the cavity spaces and to avoid dispersion of cooking smell. Using dual window can help improving thermal performance and air tightness of the façade. The cavity space between window layers, with natural or mechanical ventilation devices, acts as a thermal buffer and introduces preheated air in winter. Also, the cavity provides room for shading devices and protects them. Those shadings functions as avoiding cooling load increase in summer as well.

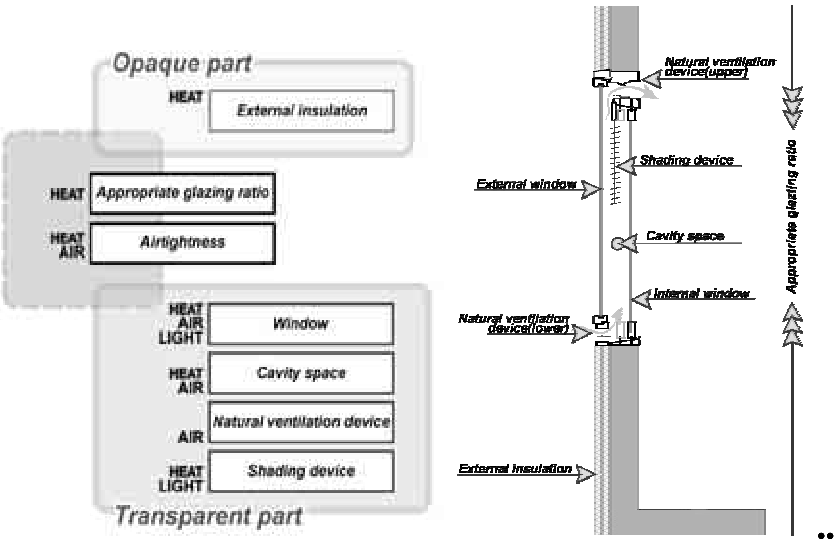


Figure 1 Concept and the prototype of window-type double skin façade.

Figure 1 shows the conceptual model of window-type double skin façade. Usually, increased depth of a double skin façade causes increase of thermal performance. The façade in this paper, however, is aiming widely adopted without a large initial cost increase. Hence, limit in the depth of the window is set to 250mm (depth of a typical wall). Also, the height of the window is restricted within the ceiling height (2500mm) because the façade is based on the box-type window

1.3 Process of the study

This paper describes a series of TRNSYS simulation for understanding thermal action in the window-type double skin façade, also finding appropriate window sizes and seasonal operation methods of the facade.

Firstly, a mock-up test with the prototype of the façade is proceeded for validation of the simulation. Actual air temperatures and surface temperatures of the cavity are observed with environmental conditions during the time of the test. After that, the TRNSYS simulation model of the mock-up test is coded and calibrated under the same environmental conditions of the test.

For better understanding of thermal action in the façade 4 sets of simulation cases are studied. Next, parametric studies with 36 cases on how to decrease energy consumption by changing depth and height of the cavity spaces are proceeded. Also, 18 kinds of operation methods were compared for finding the most efficient seasonal operation methods. Finally, the reduction of energy use by applying optimized window-type double skin façade with only natural ventilation devices to a residential building is assessed by the TRNSYS simulation that is calibrated in the real energy consumption data.

2. Calibrate the simulation model

Figure 2 shows the interior dimensions of the test cell, the dimension of natural ventilation device and installed window which was used in the mock-up test. The window of the prototype in installed at the 580mm high from the bottom of the facade. The window frame is made of aluminum, and the glass is 24mm double pane with 2.87W/m^{2}K of U-value and 0.74 of g-value.

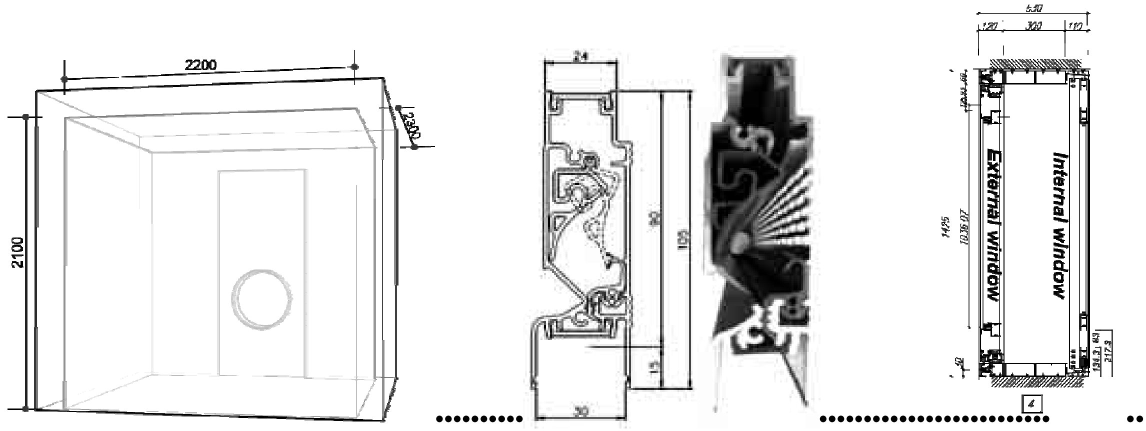


Figure 2 The test cell, the natural ventilation device and the window of the façade that was used in the test.

Figure 3 Thermocouples on the facade and the blower door with highly sensitive wind speed sensor.

9 points of the cavity air temperature, 15 points of the surface temperature of the each side of windows and 3 points of the outside and inside air temperature were observed with T-type thermocouples. Also, to make nearly constant air flow, blower door was used with minimum fan speed. Highly sensitive wind speed sensor was installed in a 300mm long pipe at the outlet of the blower door fan to measure the airflow. The test was at the nighttime from 05:00 to 06:00 in October 2007 when there is no influence of sunlight and is the coldest on the day. Under floor heating was used to maintain the indoor temperature. The set point was 30°C, because the outside temperature was not cold enough.

The cavity and the windows of TRNSYS simulation model is divided in parts at each 500mm high for more accurate analysis of the thermal action. Massless type layer is used on the connections of thermal zones, and the solar absorptance of the layer was set to 0. To calculate solar energy distribution to each zone accurately, an additional self-designed Geosurf module is used for the later use, because Type 56 does not calculate the geometry of a thermal zone. Especially in a dual window, with default Geosurf value 0, the insolated energy through a pane of glass is considered as diffused light, so the temperature of the cavity is exaggerated in the calculation.

As the simulation results, all the error between the median values of the measured and the simulation result is within 10%: the cavity temperature and each surface temperature at each 500mm high. Also, the error range is from -8.57% to +9.96%. *Figure 4* compares the measured data at the test to simulation result of cavity air temperatures at each height. With the results, the simulation model is reliable in the thermal action analysis of this type of the window.

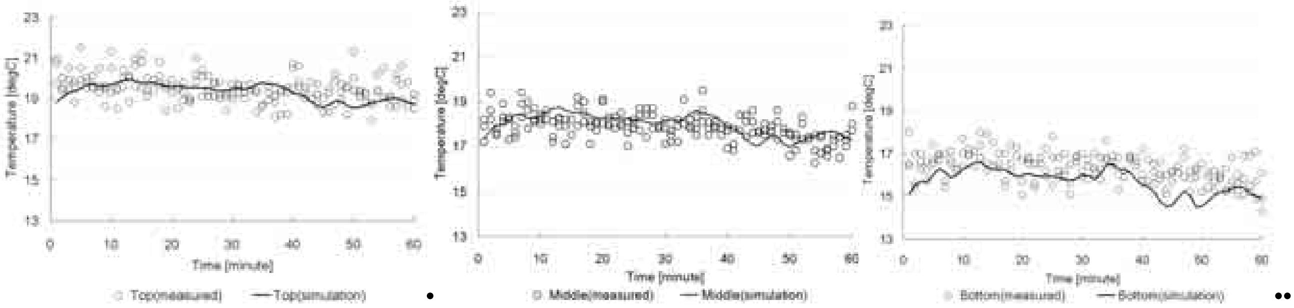


Figure 4 *comparisons the measured data to simulation results of cavity air temperatures at each height*••

3. Parametric studies

3.1 Heat flux at the window

For the better understood of heat flow at the window of the façade in winter, 8 cases according to existence and nonexistence of solar radiation, airflow directions and whether the air flows through the cavity or not are studied. *Figure 5* shows the analytical cases and the temperatures and heat transfer rates at the each height of the windows and the frames. Furthermore, it shows heating load, room air temperature, operative temperature and heat loss by ventilation of each case. The validated prototype simulation model is used. Ventilation rates are fixed to 15.38kg/hr for making similar conditions with real building: The regulation of ventilation rates in residential buildings in Korea is 0.7 ACH, and Window area to Volume ratio of the biggest room of a typical residential building is 0.125m^2/m^3. Accordingly, the ventilation rates follow the regulation, with the window which has dimensions of 2.29m^2 (window area at the test), is 15.38kg/hr. The boundary conditions of outdoor climate used in the simulation is shown at Table 1. The climate conditions are from the weather data of Sosan area in Korea in 2006. The set point is 20°C, and the simulation is conducted under the steady state.

Table 1 Climate conditions

Date/time	DBT	RH	Sky temp.	Solar incident angle	Total solar radiation	Direct solar radiation
12.22/12:00	6.3°C	74%	-7.61°C	32.04°	1746.96kJ/m^2	714.12kJ/m^2
12.22/00:00	-1.25°C	90%	-14.68	-	-	-

In contrast between Case A and B, the cold outdoor air is preheated by solar radiation and taken heat from the room while it passes through the cavity. We can see that the total heat loss to outside, in Case B, though the surface of the external glazing is smaller than Case A, despite the cavity air temperatures and inside glazing temperatures are lower. It is because that the temperature difference, in Case B, between the cavity and the outdoor is smaller than Case A. The similar thermal characteristic is shown in the contrast of Case C to B, even without solar radiation. In Case D, the heat flux to the cavity at the internal glazing is bigger than Case C, yet the heat flux to outside at the external glazing is smaller. The sensible heat is taken from the room through the internal glazing by the introduced cold air into the cavity; in the mean time the air in the cavity lose less heat to outside as the smaller temperature inclination between the outdoor and the cavity. Therefore, the heating load and the ventilation loss of Case D are smaller than Case C. From the result of the case E and F with outflow of air and solar radiation, the temperature of both the room and the cavity of Case E are higher than Case F. Since, the air in the cavity works as a thermal barrier, as the warm indoor air flows into the cavity constantly. We can find from Case G and H that the effect of the action is much bigger at the nighttime. The studies in this chapter consider natural ventilation only, buy the benefits from the inflow and outflow of the air through the cavity can be applied to a mechanical ventilation system. However, more specified studies are required for applying them to a mechanical ventilation system. For instance, if we use heat exchanger, it can make the cavity air temperature too cold at daytime which causes bigger heat loss and discomfort by cold draft.

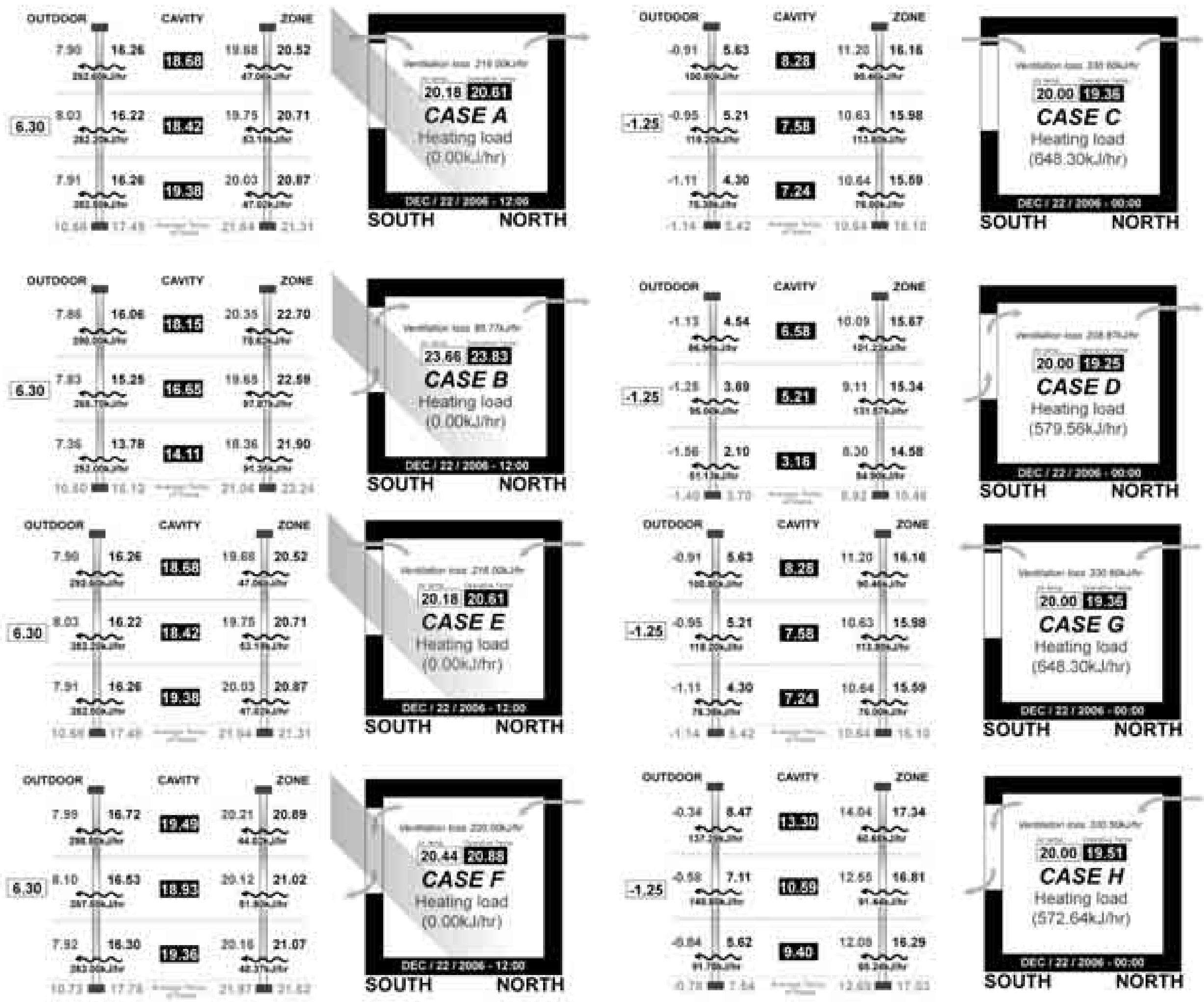


Figure 5 Heat flux intensity at the each part of the window according to cases.••

3.2 Depth and height of the cavity

Figure 6 shows 36 cases according to existence and nonexistence of solar radiation, airflow directions and heights and depths within the limit for finding the appropriate height and depth of the cavity. The simulation is conducted under the same climate conditions, the ventilation condition as well as set point condition as chapter 3.1 and under the steady state.

Figure 6 Analytical cases for depth and height of the cavity.••

As you can see from the result of Case A, there is no heating load when the height is 1500mm and the indoor temperature is 23.73°C. Although, it shows the biggest heat loss by ventilation and fairly big heat loss through the external window surface, yet it is because the indoor temperature is higher than the others. Also, the average heat losses through the external window surface are 298.33kJ/hr at the height 2000mm and 376.33kJ/hr at the height 2500mm. The values mean that heat loss through the external window surface is also increased even though the absorbed solar radiation is increased by increment of the height of the window. From the result, we can find that the longer height, the worse thermal performance under the circumstance. Besides, the result shows that increase of depth causes less heating load, but it makes little change in thermal performance. On the other hand, the additional simulations with the height 1000mm show relatively meaningful changes in heat loss through the external window surface. We could expect that the faster airflow prevents heat transfer by convection from the results.

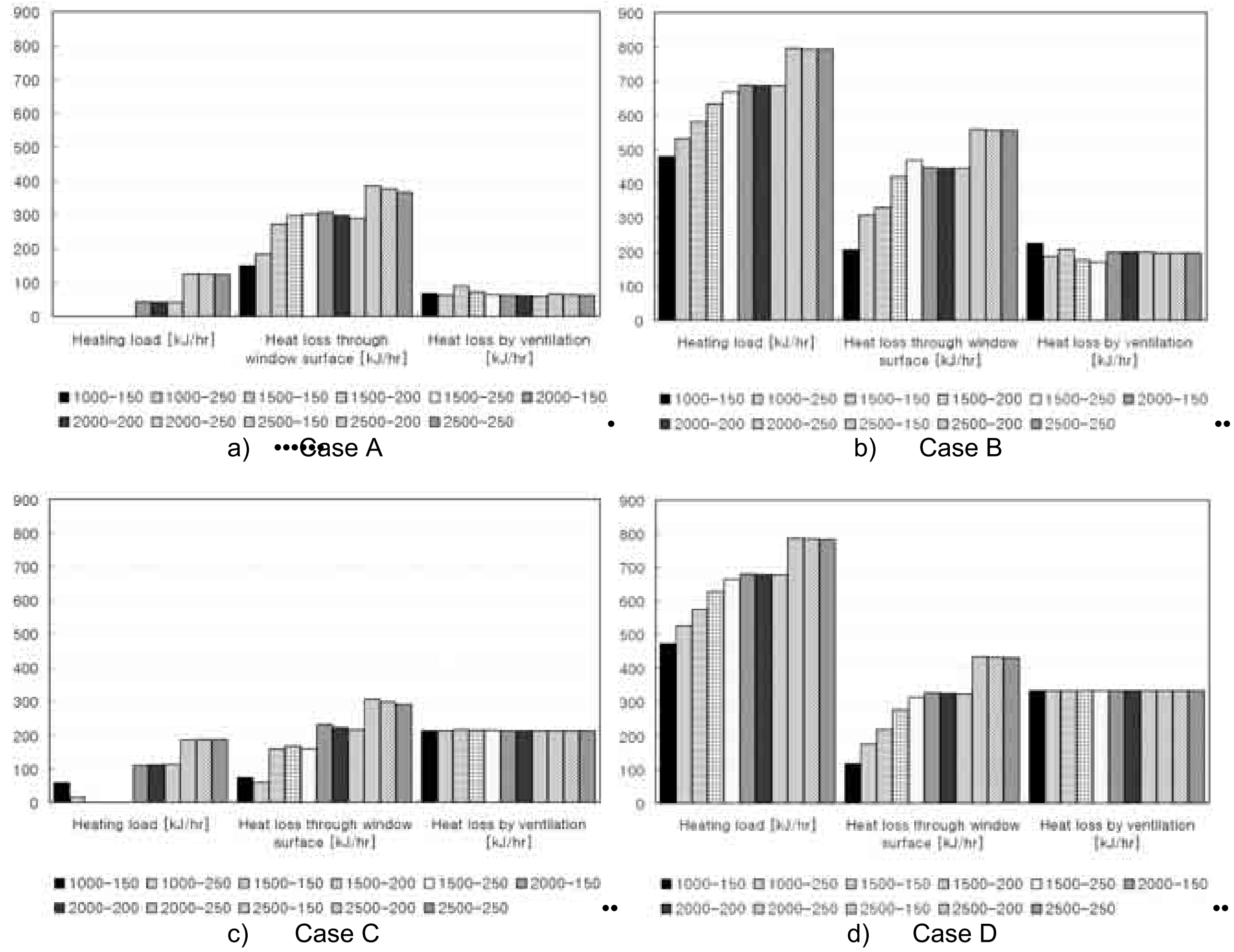


Figure 7 Simulation results of each case: heating load and heat loss through the surface and ventilation.

From the Case B, we could find the similar results in changing height with the Case A but not in depth. The heating load and the heat loss through the external window surface are proportionate to the glazing ratio. However, with the window height 1500mm, the heating load and the heat loss through the surface are in inverse proportion to the depth, also the influence is quite big especially when the height is short and there is no sunlight. This phenomenon is also able to be described by increment of convection current. Case C shows that no heating load is when the height is 1500m. Particularly, overall heat loss through the external window surfaces is smaller than Case A. It is supposed that the temperature of the cavity is kept higher enough to reduce heat loss by exhausted room air, which is nearly 20°C, through the cavity. The action of constant heat supply reduces heat loss through the window surfaces. Moreover, less heat loss does not mean less heating load. We can find it from the result of height 1000mm at Case C. For enough heat gain appropriate glazing ratio is required. Case D shows expected patterns from the previous cases. The surface heat loss is in proportion to the glazing ratio and is in inverse proportion to the depth.

As the results, increment of the depth within the limit decreases heat loss little when the cavity volume is big, but it shows contrary results when the volume of cavity is small. On the other side, the window area within the limit is proportionate to total heat loss. At the additional simulations of the window with height 1000mm, they do not show better results than the windows with higher heights under the conditions of Case A and C. However it shows better thermal performance under the condition of Case B and D. So that, height 1500mm, depth 150mm at the southern façade and height 1000mm, depth 150mm at the northern façade, consider the visual contacts, would bring a fine thermal performance.

3.3 Operation methods

Effective operations are essential to obtain the best possible performance from passive features. However, because of the nature of residential buildings, sophisticated controls are not well harmonized with them. The controls should be rather simple and easy. This study chooses 9 simple operation methods for natural ventilation according to use of ventilation flaps and opening or closing the windows. The analytical cases for various operation methods are shown in *Figure 8*. The simulation is conducted for comparing heating loads of each case in December and cooling loads in August with minimum ventilation rates.

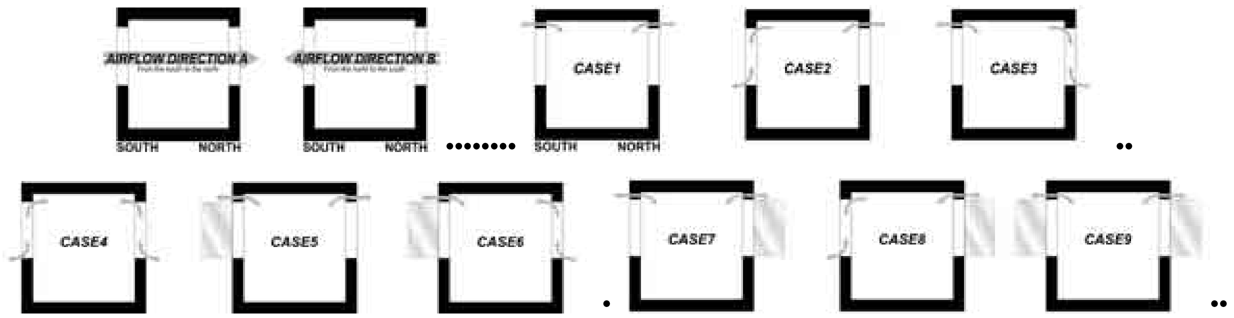
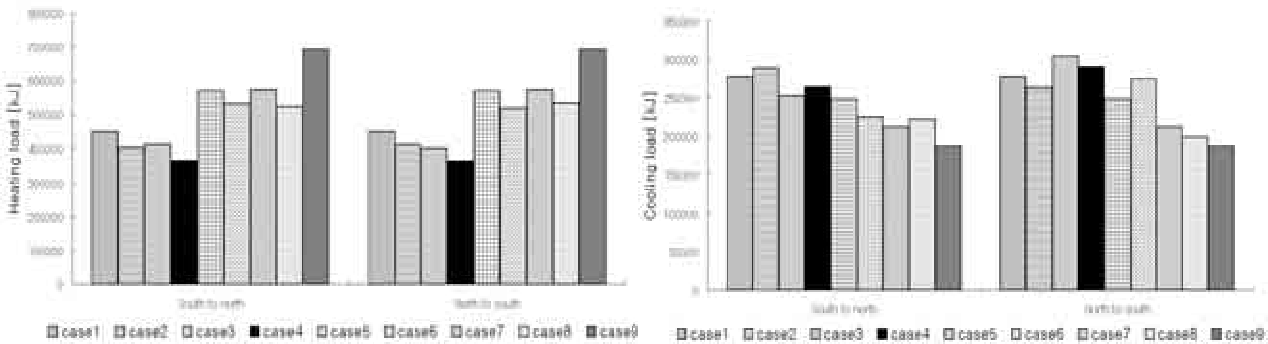


Figure 8 Analytical cases for operation methods.

The results of the simulations are shown in *Figure9*. Heating load is found all through the month in the every case. Generally, Case 1 to 4, with closed window, show less heating loads than Case 5 to 9. Case 4 shows the smallest heating load independent of the direction of airflow. As we have seen in Chapter 3.1, airflows through the cavity in both directions dose not only show less heating load at the southern façade but also at the northern façade. The patterns of the average operation temperatures are analogous to the heating loads. Case 4 shows 0.3°C higher operation temperature than Case A. The cooling loads in August show that opening the external windows for prevention of overheating of the cavity decreases the cooling load.



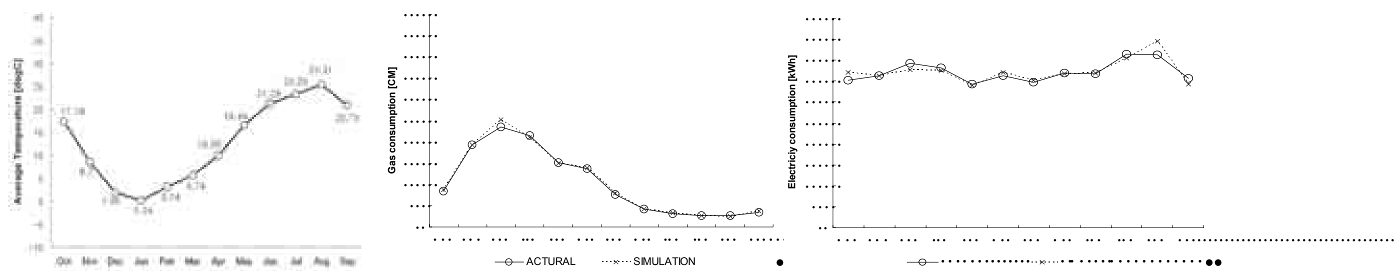
a) Heating load (December) b) Cooling load (August)

Figure 9 Simulation results of each case: heating load during December and cooling load during August.

4. Reduction of energy use by applying the façade

The reduction of energy use by applying the window-type double skin façade to a residential building is assessed by the TRNSYS simulation that is calibrated in the real energy consumption data. Before the assessment of energy use reduction by applying the façade, the existent unit of a residential building which has got balconies is modeled and calibrated at first. *Figure 10* shows monthly average temperatures of Sosan from October in 2006 to September in 2007 and the comparisons between simulations and actual data for gas and electricity consumption with the least 0.7 ACH of natural ventilation. The error ranges between the actual data and simulations of the gas consumptions and the electricity consumptions are within 10%. The range of the gas consumption is from -4.34% to 7.76%, and of the electricity consumption is from -4.07% to 7.66%.

The modified simulation models, to the balcony extended and the window-type double skin façade applied, are simulated to assess the reduction of energy use by applying the façade. The applied building façades are followed the conclusion of chapter 3.2, and the seasonal operations are followed the chapter 3.3.

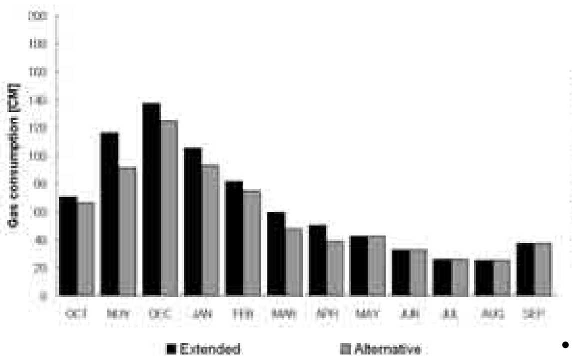


a) Average DBT(monthly) b) Gas consumption c) Electricity consumption

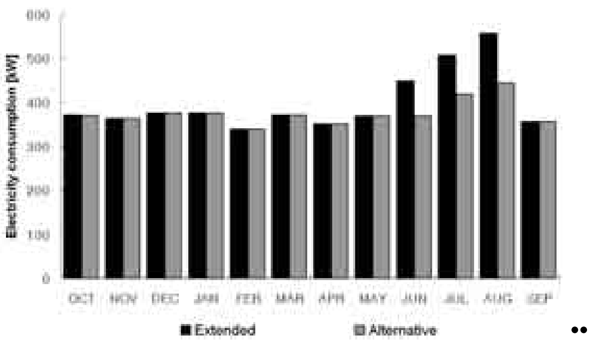
Figure 10 Annual temperature of Sosan and the comparisons between simulations and actual data.

The U-value of the aluminum window frame used at the balcony extended model and the façade applied model is three times bigger than the PVC frame of the existent model. The overall glazing ratio is reduced 11.19% and the window frame area ratio is increased 15% at the façade applied model than the balcony extended model. Also, the shading devices are used form June to August in the simulation of the façade applied model.

As the results (*Figure 11),* the reduction ratio of gas and electricity use by applying optimized window-type double skin façade to the balcony extended unit of the residential building with the least 0.7 times of air change rate are 10.78% in terms of annual gas consumption and 8.66% in terms of annual electricity consumption. ••



a) Gas consumption reduction



b) Electricity consumption reduction

Figure 12 Analytical unit plans: existent unit and balcony extended unit.

5. Conclusion

This paper deals with development of window-type double skin façade which is optimized for sustainable residential building. The façade is based on the box-type window and has got natural ventilation devices and shadings. Parametric studies for finding appropriate height, depth and seasonal operation methods are conducted. As the results, the reduction ratios by applying the façade to a residential building are 10.78% in gas consumption and 8.66% in electricity consumption.

This study focuses on heating load in winter season for the most. Further studies are required for more detailed thermal actions of the façade in cooling season. Also, it should be studied about prevention of heat transfers with smaller air volume of cavity by analysis of computational fluid dynamics or tests. Moreover, studies about integration of the façade with mechanical ventilation systems should be executed in detail.

Acknowledgment

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A STUDY ON ENVIRONMENTLALLY SUSTAINABLE FLOOR COMPONENTS THROUGH ANALYSIS OF ENERGY CONSUMPTION AND CARBON DIOXIDE EMISSION

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Keywords: energy consumption, carbon dioxide, wet floor, dry double floor, dry radiant double floor, dry radiant floor

Summary

The global warming has been raised as the most serious problem all over the world at the present and many countries have been working out to reduce carbon dioxide emission which is the main factor to occur the global warming. The carbon dioxide is generated in all industries and particularly, construction industry occupies 42% of all industry wastes. Therefore, it is sorted as the environment obstruction industry. So, the development of environmentally sustainable construction materials is required to reduce carbon dioxide on the stage of producing construction materials. In this study, the energy consumption and carbon dioxide emission in the object floor components are analyzed and compared to each other with SUSB-LCA ver 1.0. As the result, dry double floor has the best performance and dry radiant double floor has the worst performance in terms of environmentally sustainable performance.

1. Introduction

1.1 Research Background and Purpose

Global warming is one of the most terrible environmental disasters which the world faces at the present. Several countries including OECD recognize global warming as the most difficult problem that human beings should solve. Carbon dioxide occupies the most portions of greenhouse gases.

The construction industry which occupies 48% of material consumption and 40% of energy consumption in all industries is the mass consumption industry. It also occupies 42% of all carbon dioxide emission and generates 20% of all industrial waste and 60% of illegal waste. In terms of resource and environment, as the construction industry fatally affects environment of the earth, environmentally sustainable countermeasure against the problem has to be established as soon as possible. Therefore, the reduction of energy consumption and technology for development of environmentally sustainable materials are required at the stage of producing construction materials. As an effort to realize this, developing and utilizing a variety of construction materials and components based on compatibility of construction materials. However, as for a interior component of buildings, a quantitative study on the amount of energy consumption and the carbon dioxide emissions to know the environmental load in buildings have not been sufficiently performed yet.

Consequently, in this study, a floor component of buildings to be able to reduce energy consumption and carbon dioxide emissions was screened out by comparing carbon dioxide and energy consumption between existing floor component and several types of a dry floor component quantitatively. The results of the research would be utilized as a fundamental data to select the best environmentally sustainable components at the planning stage of architecture.

1.2 Research Method and Procedure

In this paper, the study is performed to reduce the energy consumption and carbon dioxide emissions of floor components through the procedure on figure 1.
Firstly, the method of the study is set up after choosing a building and floor components which become the subjects of the study through previous research. Secondly, the mount of materials is calculated through an on-the-spot survey and data research for the material requirement estimation in each floor component.

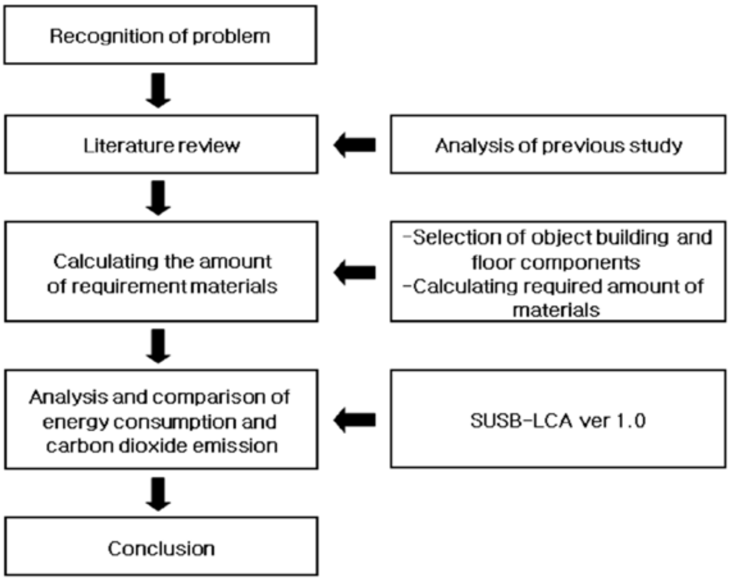

Figure 1 Research Process

2. Literature Review

In this study, to quantitatively and objectively evaluate the energy consumption, we used CO2 emission in floor components, SUSB-LCA ver. 1.0 and searched for energy consumption and carbon dioxide emissions of building interior component materials. In this study, SUSB-LCA ver. 1.0 which is the program to evaluate environmentally sustainable performance in buildings is used to quantitatively and objectively calculate energy consumption and carbon dioxide emissions of component materials.

2.1 Summary of SUSB-LCA ver 1.0

SUSB-LCA ver. 1.0(Sustainable Building Life Cycle Assessment ver. 1.0) is the useful program that can be used to calculate LCE(Life Cycle Energy), LCCO2(Life Cycle CO2), LCC(Life Cycle Cost) and assess environmental performance quantitatively. Moreover, SUSB-LCA ver 1.0 makes it possible to compare relatively environmentally sustainable technology-applied building with existing buildings built in terms of LCE, LCCO2, LCC, and assess comparatively reduction impact on LCE, LCCO2, LCC by application of environmentally sustainable architectural technology.

Major function of this program is calculating LCE, LCCO2, LCC over L.C.C of building, and it is possible for it to compare with the output of each object when environmentally sustainable technology is applied to objects. Furthermore, the by putting the data such as the amount of materials, energy consumption in operation stage and the amount of waste in removal stage into the program, the LCE, LCCO2, LCC can be output.

2.2 Assessment Method

The environmental load of building life cycle is evaluated with SUSB-LCA ver 1.0 in 3 stages divided which are construction stage, use and maintenance stage and removal stage.

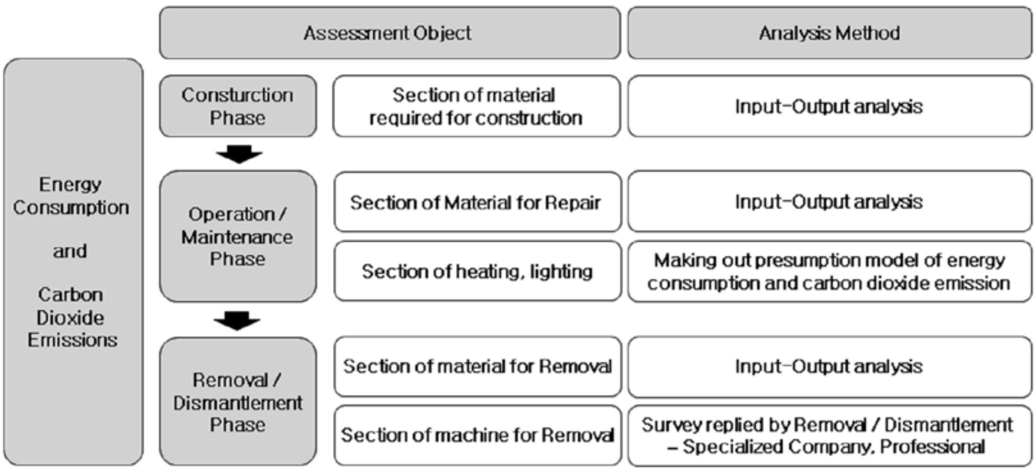

Figure 2 Environmental load assessment of building by SUSB-LCA ver. 1.0

The construction stage is divided into three stages such as material production stage, material transportation stage and onsite construction stage and the use and maintenance stage is divided into building use stage and maintenance stage. Besides, Removal/Discard stage is divided into Building Removal and Discard of building waste from removal work. The figure 2 below indicates the way to make assessment of environment load by SUSB-LCA ver 1.0.

3. Selection of Object Building and Floor Components

3.1 Object Building Selection

The object building is a normal apartment constructed in B district in Korea in 2004. Brief information of RC-structured Building is like table 1 below.

Table 1 Brief Information of Object Building

Category	Data		Category	Data
zoning district	Central commercial zone, urban planning district		Rate of building volume to lot	355.99%
Lot area	99,744 ㎡		Building coverage ratio	59.21%
Total floor area	Aboveground	355,075 ㎡	Structure type and scale	RC structure, 35 stories above and 3 stories below the ground
	Underground	82,654 ㎡	Building-covered area	59,061 ㎡
	Sum	437,729 ㎡	Gardening area	29,109 ㎡

3.2 Selection of Floor Components

As for choosing the types of floor component as an object, totally, 4types of floor are chosen, one of them is wet floor, which has been used from the past and is one of general types in housing, and the others are 3 types of a dry floor lately invented and used for construction. The table 2 below is for composing material according to each floor type.

Table 2 Composing material of floor components

Floor type	Composing Materials
Wet floor	fire insulating material(20mm) + bubbled concrete(60mm) + copper pipe +mortar(40mm)
Dry double floor	protection against dust + base panel(25mm) + floor finishing material(12mm)
Dry radiant double floor	sound insulator(20mm) + protection against dust(350mm) + plywood(12mm) + panel(30mm) + heatproof panel(2mm) + XL pipe +aluminum panel(2mm)
Dry radiant floor	fire insulator(20mm) + panel(30mm) + heatproof panel(2mm) + panel(12mm)

4. Energy consumption and Carbon Dioxide Emission of Floor Components

4.1 Output Standard of Required Materials in the Floor Components

The calculation of energy consumption and carbon dioxide emissions is progressed with focus on unit (width:1m, length:1m). And in order to calculate the amount of materials, the materials used for each component are searched through visiting site and data review. In addition, the amount of required materials is calculated at firsthand with integration method. The calculation of required materials is done by two professionals who have more than five years experience. Also, cross check is also performed not to make any omissions.

4.2 Comparison and Calculation of Energy Consumption and Carbon Dioxide Emission

4.2.1 Energy Consumption

By analyzing energy consumption classified by floor component type, the result as figure 3 is drawn.

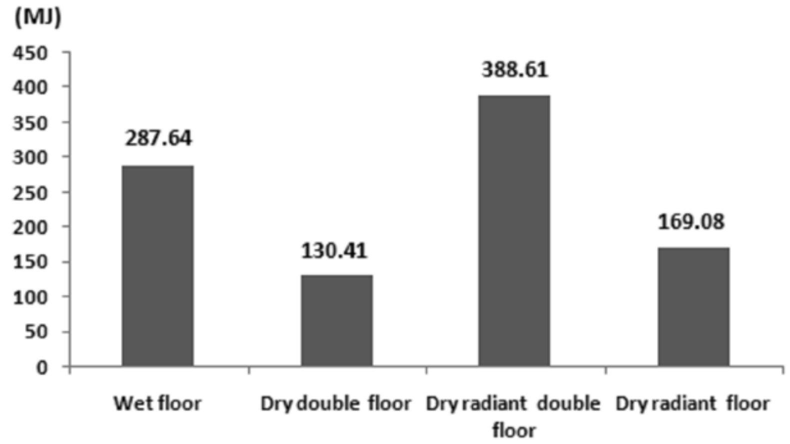

Figure 3 Energy consumption of the floor components.

First of all, dry double radiant floor occupy 388.61MJ as the most energy consumption of them. Next, wet floor has 287.64MJ and dry radiant floor has 169.08MJ. Lastly dry double floor has 130.410MJ as the least energy consumption.

As a result of showing percentage comparing three types of dry floor components to existing wet floor, dry radiant double floor is 135.1%. dry radiant floor is 58.8% and dry double floor 45.3%. According to this order, the dry double floor has a superior performance in terms of energy consumption as the least energy consumption.

4.2.2 Carbon Dioxide Emission

As a result of analyzing carbon dioxide emission of the components, the result is like figure 4 below.

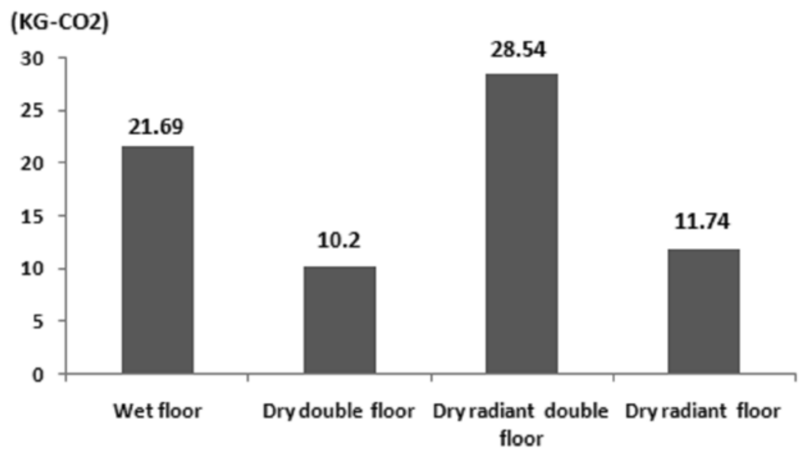

Figure 4 Carbon dioxide emission of the floor components

The result of the analysis classified by a floor type is like figure 4. It shows that Dry radiant double floor has 28.54KG-CO2 as the most carbon dioxide emission. As for carbon dioxide of the others, the existing wet floor has 21.69KG-CO2. Dry radiant floor has 11.74KG-CO2 and dry double floor has 10.2KG-CO2 as the least carbon dioxide emission. As the result of showing in percentage, dry radiant double floor has 131.6%. Dry radiant floor is 54.1% and dry double floor is 47.0%. It is proved that carbon dioxide emission of dry double floor is the lowest among them.

5. The Decrease Rate of Energy Consumption and Carbon Dioxide Emission in the Case that Alternative Components are used for Object Building.

The decrease rate of energy consumption and carbon dioxide emissions over Life Cycle are analyzed under applying each component to object building according to the standard of object building which has existing wet floor. The result is like the table 3 below.

Table 3 The decrease rate of energy consumption and carbon dioxide emissions in the case that alternative components are used for object building.

Floor type	The reduction rate comparing to the existing object	
	Energy consumption (%)	Carbon dioxide (%)
Dry double floor	0.51	0.41
Dry radiant double floor	-0.32	-0.28
Dry radiant floor	0.38	0.32

As a result of this study, energy consumption and carbon dioxide emission rate of dry double floor are 0.51%, 0.41% and it shows that it has the most reduction rates of energy consumption and carbon dioxide emission. Next, as the numerical values of dry radiant floor are 0.38%, 0.31%, it also has considerable decrease in energy consumption and carbon dioxide emission.

But in case of dry radiant double floor, the energy consumption has the increase of 0.32%. This means that energy consumption and carbon dioxide production of it increase more than the wet floor.

6. Conclusion

But in case of dry radiant double floor, the energy consumption has the increase of 0.32%. This means that energy consumption and carbon dioxide production of it increase more than existing wet floor. Continuous and comprehensive efforts to realize this are being promoted in building industry. Many components, which is based on development of various building materials and utilization of it, compatibility of building, are being developed. In this study, energy consumption and carbon dioxide emission of wet floor component which is the most general type of the several components is compared with dry double floor, dry radiant double floor, dry radiant floor component in terms of energy consumption and carbon dioxide emission. The result is like these followings.

Firstly, in respect of energy consumption, it is found out that wet floor component is 287.64MJ. Dry double floor component is 130.41MJ and dry radiant double floor component is 388.61MJ. Lastly, dry radiant floor is 169.08MJ. Therefore, the energy consumption of dry radiant double floor was relatively the most, and energy consumption of dry double floor is the least. Secondly, in respect of carbon dioxide emissions, wet floor is 21.69KG-CO2, dry double floor component is 10.2KG-CO2, dry radiant double floor component is 28.54KG-CO2, dry radiant floor is 11.74KG-CO2. Furthermore, when applying three types of dry floors to the object building which adopts the wet floor, in case of the reduction of energy consumption, dry double floor has the reduction rate of 0.51%. Besides, dry radiant double floor has the increase of 0.32% and dry radiant floor has the decrease of 0.38. In case of the reduction of carbon dioxide emission, dry double has the reduction rate of 0.41%. dry radiant double floor has the increase of 0.28% and dry radiant floor has the decrease of 0.32%.

The result of this study can be used as a basic data for selection of best alternative component by analyzing and estimating environmental impact in advance at the planning stage. In addition, this would be able to be used as a basic unit to assess environmental load of rebuilding for remodeling. And the order of priority to select alternative technology environmentally demanding materials could be judged. Dry double floor supposed proposed in this study is the component being developed continuously in respect of energy consumption and carbon dioxide emission. Particularly, if variableness, noise, disaster prevention and heating are pieced out by double floor system, it will be expected to increase the efficiency of building work and environmental amenity.

Acknowledgement

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A STUDY ON THE INFLUENCE OF THE STORY ON RESIDENTS' HEALTH IN THE HIGH-RISE APARTMENT.

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Keywords: the High-Rise, Health, Story, Apartment

Summary

This study aims to gather preliminary data for future high-rise apartment planning involving city-based residents in order to objectively understand their health condition. In this study, a survey was conducted that involved those who visited the general hospital for general checkup, and the survey limited its region to residents in the southern area of the capital city. The survey was structured with 13 sections and involved 107 symptoms.

In the study's results, the floor level on which residents live was determined to have no influence on residents of high-rise buildings' health conditions in the High-Rise building. On the other hand, the financial status seemed to have a general effect on the health of residents, and regular exercises seemed partially influential as well.

1. Introduction

The rapid increase in the number of constructed high-rise apartments (Super High-Rise Apartment, Mixed-use Apartment) is part of the drive to make efficient use of limited urban land. As people who live in the city consider the building's effectiveness and economic aspects, and because of the continuing improvements with high-rise apartments, our cities today have a thriving high-rise apartment communities.

Recently, there has been increasing interest in public health, which has spilled over in issues concerning high-rise apartment communities and other various highly concentrated residential environments. In a domestic study on high-rise apartments and related health issues, it was found that "those that live on the 16th floor or higher visit a healthcare professional twice more often than those who live on the fifth floor or lower (Choe et al, 1998).", "Those living on high floors get stressed out from fear and the sense of being isolated from the ground, from noise and accidents and crimes, and these seem to affect children more than adults" (Shim et al, 1996). Such findings indicate that living in a high-rise apartment has something to do with the residents' health. In one domestic documentary (Park et al, 1993) and quoting from findings in other countries, it was determined that living in a high-rise apartment had a correlation with residents' medical pathology.

However, considering cultural differences, systematic differences of buildings, and lifestyle, it is difficult to accept the findings and assertions of such studies made in other countries (Kang et al, 2003). There were, however, domestic partial studies, but these focused more on mental than physical stress, aggravated by the fact that insufficient samples were used.

Author	Main contents
Kim, Namgil (1996)	· A sense of isolation from the ground in high-rise residences has a psychological and physiological influence on dweller
Sim, Soonhee (1996)	· The noise and the use of elevator, and the perception of accidents in high-rise residences seem to contribute to the high stress level of dweller
	· The minimal social exposure in high-rise residences has a negative impact on the development of independence of the human child.
Park, Chulsoo (1993)	· Dweller in high-rise residence is exposed to allergy, respiratory diseases, impaired lung functioning, low physical strength, and the risk of gynecological disease.
	· High-rise building syndrome (ringing ear, headache, enervation, irregular menstruation, blurry vision, pain in the inner ear)

Kang, Inho(2003)	· Insufficient ventilation and dry air in high-rise residences influence the health of the dweller's respiratory system.

This study aims to build preliminary data for future high-rise apartment planning involving city-based residents to understand their health condition objectively. We also determined how economic status and regular, exercise.

2. Methods

The current study's context, we first analyzed the residents of high-rise and mixed-use apartments to determine the differences in health conditions depending on the city's residential type. Second, as there can be differences in the cities' environments depending on specific areas, we chose cities in southern Kyunggi-do in South Korea as target cities.

As for the targets of the study, we relied on the health questionnaire data obtained from the health center of a university hospital. The said data contained information on 21,199 residents, 34,000 people that had health-related general check-ups in the years 2005 and 2006, and those who live in selected high-rise apartments in southern Kyunggi-do.

As for the general medical examination by interview, we used self-reported health evaluations. This type of examination is performed by each participant responding to health-related questions. In studies in other countries, this self-reporting of one's health condition proved adequate in predicting health conditions, diseases, and death rate (Peter Franks et al, 2003). The tools of the current study were constructed with general symptoms in the respondents and consisted of 104 symptoms for 13 parts that were developed by the health questionnaire in the general medical examination.

In the analysis, respondents' health-related data as dependent variables were examined for architectural correlations such as with the dwelling's floor level. Furthermore, we studied possible influences to health, apart from the floor level factor, by analyzing the interrelations between expenditure and health.

3. Analysis

The group we studied mostly lived in the fifth floor or lower, 426 people who live higher than the 21st floor. It was shown that 98% of residents live below the 20th floor in South Korea, and it showed that living up to the 20th floor is common living floor. The studied target group of 77.4%, shown as the property owners, it is understood that they are capable of self-managing their property. In the part of the survey that asked the respondents their financial ability, 67.7% answered 'moderate', and 14.9% answered 'stable', which indicates that financial difficulty was rare, and the given financial situations were not relatively different from one another. On the other hand, monthly expenditures ranged widely, from less than 1 million won and to more than 6 million won.

Characteristics of Residents		Frequency	Percent
Living floor	Lower than 5th	6,647	31.4
	6th -10th floors	6,107	28.8
	11th -15th floors	5,289	24.9
	16th-20th floors	2,530	11.9
	21st floor or higher	426	2.0
	Nil	200	0.9
	Total	21,199	100.0
Type of dwellings	Renting	3,531	16.7
	Owned	16,405	77.4
	Monthly renting	230	1.1
	Nil	1,033	4.9

	Total	21,199	100.0
Financial stability	Stable	3,169	14.9
	Moderately stable	14,343	67.7
	Unstable	852	4.0
	Nil	2,835	13.4
	Total	21,199	100.0
Monthly expenditures	Less than 1 million won	1,718	8.1
	1-2 million won	4,038	19.0
	2-3 million won	3,708	17.5
	3-4 million won	1,342	6.3
	4-5 million won	957	4.5
	More than 6 million won	414	2.0
	Nil	9,022	42.6
	Total	21,199	100.0

The self-reported recording method by symptoms was existence or non-existence for those thirteen parts and the total of one hundred and seven of symptoms. Those thirteen parts were inclusive of the general medical examination (8), and dermatology (5), optical (5), auditory (6), breathing (9), vascular (5), digestive (15), kidney/urinary (10), gynecology (10), internal (7), hematology (5), skeletal (7), mental and nerve (12). For each medical part, it studied the frequency of symptom as for varied amount, and in all parts average per one person of symptom frequency did not exceed over two.

Series	*Symptoms*	*Mean*	*Std. deviation*
General Symptom	pale/fever/cold fit/cold sweat/sleeping disorder/lost appetite/fatigue/feeling stiff	1.623	0.985
Dermatology	skin rash/urticaria/tumefaction/boil/itching/	1.132	0.381
Optical	visual disturbance/dim-sighted/diplopia/sore eyes/dry eyes/ /eye mucus/inflamed	1.600	0.978
Auditory	hearing disturbance/sore ear/otorrhea/ringing ear/vertigo/dizziness	1.270	0.596
Breathing	sneezing, running nose, block nose/sore throat/substance in throat/husky voice/cough/phlegm/blood phlegm/hemoptysis/dyspnea	1.632	0.992
Vascular	dyspnea/palpitation/chest pain/chest discomfort/irregular pulse	1.385	0.699
Digestive	indigestion/belch/upper abdominal discomfort/epigastric pain/stomach pain after meal/nausea/gastralgia/vomiting/jaundice/lower abdominal pain/constipation/diarrhea/pain in bowel after emptying/blood in motions/melena	1.838	1.253
Kidney/ Urinary	frequent urine/irregular urine/dysuria/hematuria/pain in urination/urgency/oliguria/body swollen/lost sexual desire/incontinence	1.595	0.958
Gynecology	menstruation irregular/menorrhagia/dysfunctional uterine bleeding/longer duration of menstruation/excessive period /profuse menstruation/vaginal itching sense/vaginal rash/decreased secretion/pain from sexual activity	1.662	0.968
Internal	thirsty, increased urine/enlarged thyroid gland/hyperhidrosis/flushiong/increased appetite/anorexia	1.427	0.706
Hematology	vertigo/frequent nose bleed/gum-bleeding/easy bruise/hypertrophy of lymph gland	1.260	0.516
Skeletal	back pain/joint pain/restricted range of motion/neck stiffness/shoulder pain/numbness and pain	1.767	1.018
Mental/Nerves	headache/nervous /lacking concentration/sensitive nerves/memory impairment/struggling speaking/quadriplegia/syncope/depress/anxiety/insomnia	1.972	1.325

Each symptom and living floor by body parts, as results of scatted analysis on monthly expenditures and financial abilities, the living floor showed ineffective influence by different living floors. In contrast, the figure telling for financial stability and monthly expenditure showed a strong effectiveness, and the average of exercising per week had showed effective on the general medical examination, optical, kidney, urinary, gynecology, and internal. In those thirteen symptoms since the symptoms by the living floor did not differ, so the residents' health conditions and the living floor level do not correlate each other. As for the dwellers' financial stability, the average difference of ten symptoms out of that thirteen symptoms were analyzed to be meaningful and monthly expenditures were analyzed the average meaningful in the eleven symptoms. Especially, in the general medical examination the explanatory (F=20.330) appeared to be the highest. Although it did not reach as much as like by financial ability, regular exercising was decided partial influential on the inhabitants' health conditions.

Symptom Series	Dwelling Floor		Financial Stability		Monthly Expenditures		Weekly Exercises	
	F	Sig.	F	Sig.	F	Sig.	F	Sig.
General Symptoms	1.930	0.102	13.097	0.000**	20.330	0.000**	1.942	0.016**
Dermatology	0.996	0.408	1.718	0.179	3.141	0.008**	0.316	0.987
Optical	0.925	0.448	5.641	0.004**	4.459	0.000**	4.022	0.000 **
Auditory	0.599	0.663	3.139	0.043*	6.389	0.000**	0.450	0.943
Breathing	0.349	0.845	4.337	0.013	7.625	0.000**	1.005	0.441
Vascular	0.576	0.680	5.755	0.003**	4.534	0.000**	1.777	0.060
Digestive	0.308	0.873	7.567	0.001**	9.151	0.000**	0.454	0.957
Kidney	2.137	0.074	7.715	0.000**	4.961	0.000**	2.474	0.002 **
Gynecology	1.527	0.191	4.043	0.018**	1.855	0.099	2.398	0.006 **
Internal	0.602	0.661	5.313	0.005**	8.391	0.000**	2.331	0.008**
Hematology	0.263	0.902	0.106	0.899	1.692	0.133	1.524	0.101
Skeletal	1.223	0.299	11.819	0.000**	12.209	0.000**	0.756	0.718
Mental/Nerves	0.850	0.493	15.081	0.000**	3.071	0.009**	0.852	0.597

4. Conclusions

The bottom line is, the living floor in the High-Rise Apartment is determined not influential for the residents' health related conditions and symptoms. In contrast, the financial level had generally shown meaningful influence for their health, and regular exercising was analyzed being partial influential. Despite financial level being a difficult factor to be enhanced by some physical environmental, that physical environmental factor that is in order to develop the residents' health conditions, then well-planning for easing access to regular exercises will be the best effective way.

This study has limitations that it did not reflect for the real health conditions which were supposed to have analyzed by the residents' self-reported survey for existence and non-existence of the symptom frequency. Therefore, in the future, the study will have to be implemented better in which based from the previous medical examination data. Moreover, because the ratio for those apartments higher than 25th floor level in the southern Kyunggi-do was very less number, and so the small gap between the living floors, this study was enable to result for its reliability.

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A study of Outdoor Thermal Environment in Apartment Complex by Actual Measurement and CFD Simulation

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Keywords: Urban Heat Island, Block space, Green space, Water space

Summary

This study aims to produce an optimized arrangement of apartment complexes that considers various factors such as the exterior finishing materials and the arrangement of apartment complexes that influences the outdoor thermal environment of cities, and also to draw a more realistic conclusion through actual measurements and simulation inspections. The results of actually measuring the air temperature around 2 pm when the temperature is the highest, by dividing the measurement points to concrete block space, water and tree space, and water space, showed the temperature to be in the order of block space (33.1℃) > green space (31.7℃) > water space (30.9℃). The simulation analysis results showed similar results to the measured results in which green space and water space had temperatures 4~5℃ lower than that of block space, and exhibited a similar pattern.

1. Introduction

As urbanization and industrialization rapidly progressed since the mid-20th century, our lives have become affluent. However, as the industrial activities focused on the urban area and economic activities and population increased, high density buildings were demanded around the urban center and various artificial heat and air pollutions generated from this changed the climate of the city. The urban heat island effect can also be seen as a result of such phenomenon and the global interest to examine and relieve this situation is increasing. The urban heat island effect refers to the phenomenon in which the temperature of the urban center increases compared to the outer areas since the amount of heat absorption and emission of the earth's surface has greatly increased and the emission of moist has also been intercepted due to the area expansion of concrete structures and asphalt roads within the city compared to the green area. The heat island effect appears more distinctly in a city that is tightly filled with cars, people and buildings. To prevent any more ecological destruction and preserve the land of Korea, finding a method to control the changes of the outdoor thermal environment of cities is urgently called for.

This study aims to produce an optimized arrangement of apartment complexes that considers various factors such as the exterior finishing materials and the arrangement of apartment complexes that influences the outdoor thermal environment of cities, and also to draw a more realistic conclusion through actual measurements and simulation inspections.

2. Outline for measurement

2.1 Outline of subject of measurement

The environment-friendly apartment housing complex of D Construction Company located in Sillim-dong, Seoul, was chosen as the subject for the measurements. The subject complex arranged the apartment houses to form a wind flow and secured green space and water space between the houses within the apartment complex. The proportion of green space is about 37% with a land area of 47,840 ㎡ and landscape area of 17,700 ㎡, and the green space is formed of broadleaved trees and grass.

The total number of residents within the complex is 853 households and the structure is reinforced concrete.

2.2 Selection of measurement points and arrangement of equipments

2.2.1 Selection of measurement points

The actual measuring points within the subject complex of measurement were measured by largely dividing the space into three groups that considered the physical environment factors of space: space finished with bricks; space densely filled with water, trees, and grass; water space that has an artificial pond. Block space were made of concrete bricks as the floor covering material, and receives sunlight directly and continuously during the afternoon. Green space is covered with broad-leaved trees and grass. Water space is of a sunken formation and the water is circulated. Figure 1 shows the main measurement points within the complex.

Fig 1 Measuring Points and Measuring space division

2.2.2 Arrangement of equipment

Multi-function measuring instruments were installed 1.5m above the earth's surface at three spots, and the temperature, relative humidity, glove temperature, and airflow velocity within the complex were measured. Thermo-hygrographs were installed at nine places in each space and measured for 24 hours, and the standard point for measurement was set at the height of 1.5m, same as the other equipment.

2.3 Period and method of measurement

2.3.1 Period of measurement

Measurements were gathered for three days from July 30 to August 1, 2007. The weather data of the Korea Meteorological Administration and the weather data through actual measurements are shown in Table 2.

Table 2. Weather data of the measuring period

Classification	Temperature			RH [%]		Velocity of air [m/s]			Solar radiation [MJ/m^2]
	Avg.	Max.	Min.	Max.	Min.	Max.	Avg.	Direction	
Actual measurement	28.7	31.2	26.4	77	54	5.8	1.4	West	15.23 (Meteorological Administration)

2.3.2 Method of measurement

The method of measurement consisted of dividing the housing complex into green, water, and block space, installing measuring equipment 1.5m high above the earth's surface, and measuring the temperature, humidity, velocity of air, and solar radiation and reflection rate that reached the complex. A weather station was constructed on the apartment roof in the center of the complex and measured the representative climate conditions. The measurement points were photographed every three hours to find out the reduced temperature effect by measuring the difference of the surface temperatures according to the exterior finishing material of the apartment complex space. Data measurement was fixed to measure every minute for all measuring instruments, and after the actual measurements, data was arranged to produce average values for every15 minutes.

2.4 Measurement results

2.4.1 Analysis of outdoor thermal environment

When the temperature data of block, green, and water space in Figure 2, excluding the globe temperature, was compared, the temperature distribution of the block space was the highest and the temperature distribution of green space and water space were low during the day. On July 31, the average temperature distribution for the day was block (28℃) > water and tree, water space (27℃). The block space was greater by an average of 1℃ with a maximum of 2.2℃ higher temperature. The temperature increase in block space progressed rapidly due to heat storage and radiation of concrete bricks, and for the green and water space, the temperature was judged to be low due to the evaporative cooling effect from the photosynthesis of trees and evaporative cooling effect of vapor. The reason why the temperature of the water space was the lowest is analyzed to be because the amount of evaporation of the pond was greater. When the airflow velocity of block, green, and water space were compared, the average airflow of the block space was the fastest with 0.87 m/s, and that of the green space was the slowest with 0.27 m/s. In the complex plane, since the block space actually does not have any apartment buildings around in the east and west direction, the flow of the airflow might seem to be smoother than that of the other spaces, but the green space and water space showed not much of a difference. When the relative humidity of block, green, and water space were compared, the relative humidity of the block points was the lowest during the day, and the humidity of the water space and green space appeared to be almost the same. Since the distribution of relative humidity is determined by temperature when it is similar to the absolute amount of humidity, it seems that the humidity was low because the temperature of the block space was relatively high.

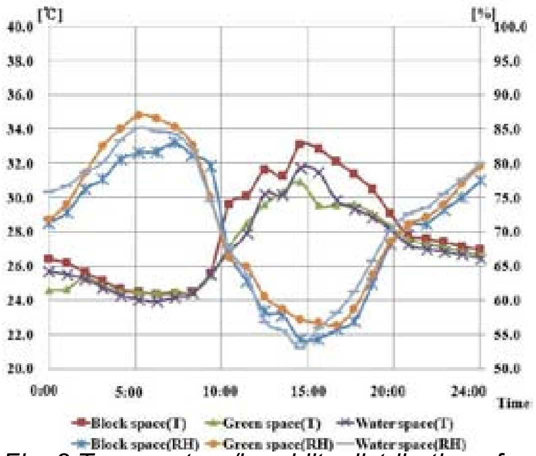

Fig. 2 Temperature/humidity distribution of each space

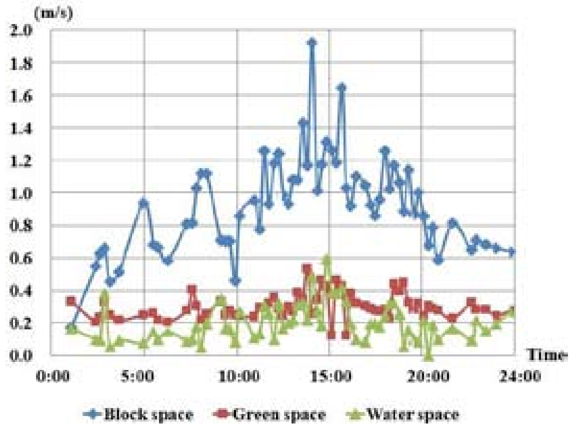

Fig. 3 Velocity distribution of each space

2.4.2 Analysis of surface temperature according to exterior finishing material

Figure 4 shows photographs of temperature distributions according to the surface finishing material during the day (3 pm, 6 pm) taken by infrared cameras. The surface temperatures according to the finishing material on a summer day appeared in the order of block > green > water. The reason why the temperature difference of the block space was large is judged to be because hot air was less stagnant despite the high surface temperature since the airflow velocity of the measuring locations were greater than that of other areas. The surface temperature according to the finishing material at night appeared in the same order as the day: block > green > water. Block space still had a higher surface temperature compared to green and water spaces, but the range of the temperature change decreased. Since the solar radiation effect was minimal, it seems the difference between the temperature of the block surface and the temperature of other points decreased. However, the reason why it still had the highest surface temperature is that the heat stored during the day was not completely emitted externally. Through the high surface temperature of block space compared to those of the grass and water space, it can be confirmed that the properties of the materials influence the heat island effect within the apartment complex during the summer.

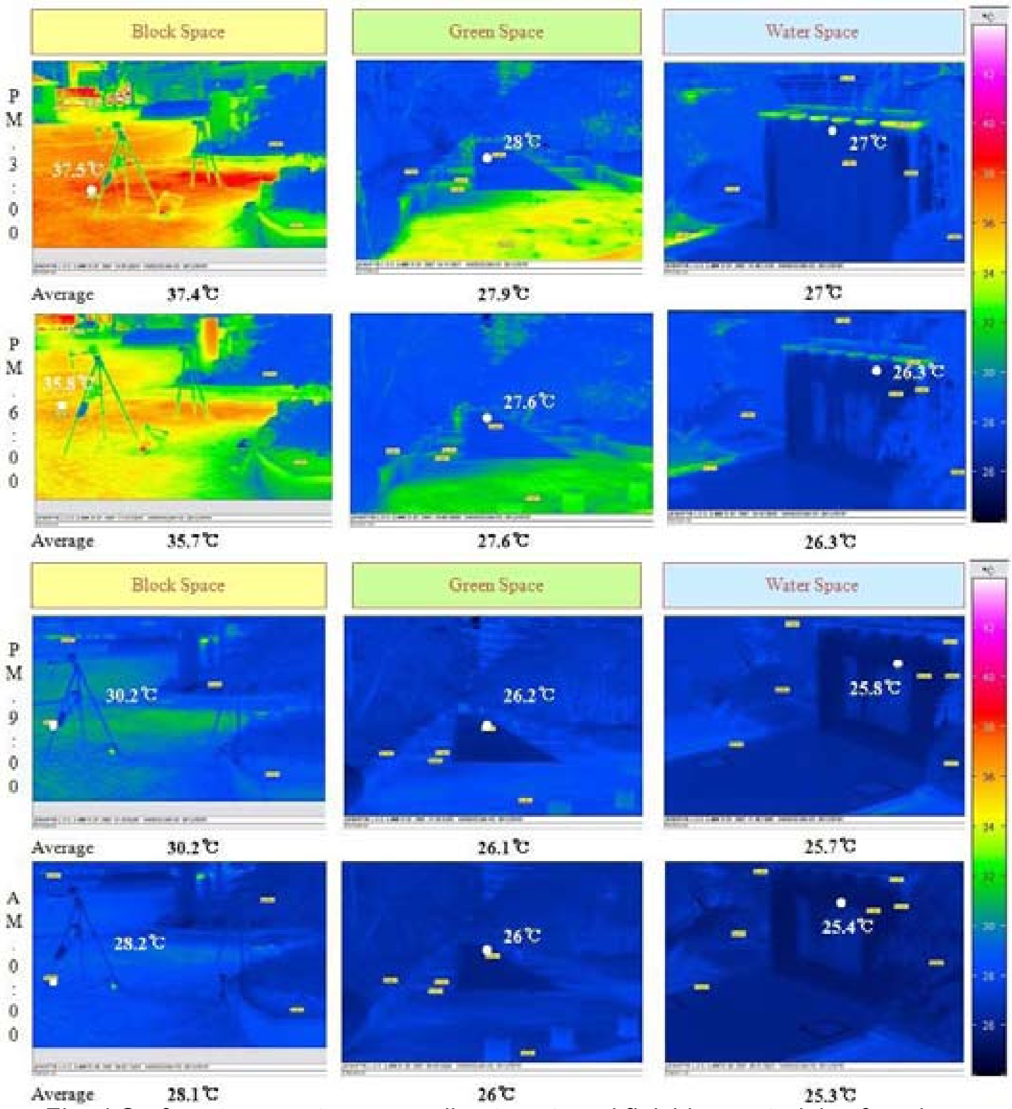

Fig. 4 Surface temperature according to external finishing materials of each space

3. Analysis of outdoor thermal environment using CFD simulation

3.1 Analysis model

This study attempts to quantitatively analyze the outdoor thermal environment of the subject complex for measurement, and compare and analyze the measured results and the simulation results in order to verify the outdoor thermal environment modeling method and simulation analysis method. The modeling subject is the subject complex for measurement and the modeling was carried out according to the characteristics of the space, such as buildings within the apartment complex, block space, water space, water and tree space, grass space, and roads. Figure 5 shows the modeling results of the subject apartment complex.

The arrangement of the building space was modeled identically to the location of the buildings within the complex and the modeling was carried out with buildings of equal height of 50m. The outdoor environment analysis area of the complex subject to analysis was modeled with a doubled the horizontal and vertical length of the subject complex and five times the height. The outdoor environment analysis area is shown in Figure 6.

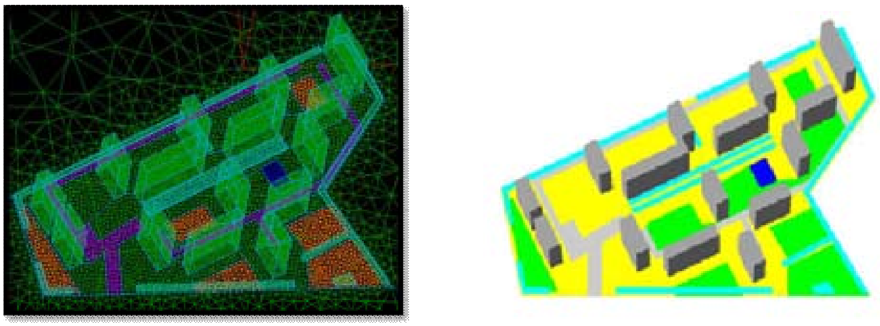

Fig. 5. Modeling of subject apartment complex

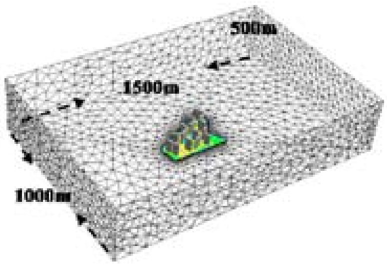

Fig. 6 Outdoor environment analysis area

3.2 Analysis conditions

The CFD method was used for the outdoor thermal environment analysis within the complex. Total space was divided into about 850,000 sub-spaces, the Korea Meteorological Administration data was used for diffuse radiation according to time, and direct solar radiation was calculated based on DIRN/HOR. For the amount of wind, the equation below was applied to carry out the CFD analysis.

$$v(z) = V_{\infty}(z/H)^n$$

z : vertical altitude from earth's surface (m)
H : height of air boundary layer (m)
V_{∞} : average wind velocity at air boundary layer altitude (z=H) (m/s)
v(z) : average wind velocity at arbitrary altitude z (m/s)
* Exponent n: roughness length of surface

In this study, surface roughness length was set at 0.3 considering that the analysis complex was located at the urban center and the fact that numerous tall buildings were located nearby. Table 3 displays the CFD simulation analysis boundary conditions.

Table 3 CFD analysis boundary conditions

Solar radiation	Total solar radiation of the horizontal surface (July 31)
	$594 W/m^2$
Amount of wind	$V(h)=V_0\times(h/10)^a$, a = 0.3(urban) V_0 : Wind velocity at height of 1.5m (=0.5m/s)
Wind direction	West wind (Weather station)
Temperature	temperature of influx of air 29℃

3.3 Analysis results

3.3.1 Airflow distribution

The measured data and the analysis results of the CFD simulation were compared. As the measured data is data measured 1.5m above the earth's surface, the CFD simulation results also attempted to compare the airflow velocity at 1.5m under the same conditions. Figure 7 shows the airflow velocity of the measured space. The simulation analysis results show the airflow velocity in the order of block space (1.19m/s) > water space (0.33m/s) > green space (0.32m/s). It is interpreted that a smooth flow of the airflow was achieved from the formation of a wind flow since there were not many trees in the block space. Overall, the simulation results of the airflow distribution according to block space, water and tree space, and water space appeared to be distributed in the same pattern as the measured results.

3.3.2 Temperature distribution

Block space was found to be about 5℃ higher with the simulation analysis results showing block space (37℃) > water space (32.8℃) > green space (32℃). It is judged that this greatly influences the thermal comfort the human body feels. A temperature reduction effect due to evaporation cooling and solar radiation blocking appeared when the outdoor was finished with water and trees, and for the water space, the temperature dropped due to a cooling effect caused by evaporation. The air temperature according to the spatial configuration was analyzed with an error percentage of less than 10% when compared to the measured values, and the simulation verification results also showed a similar pattern to the measured results.

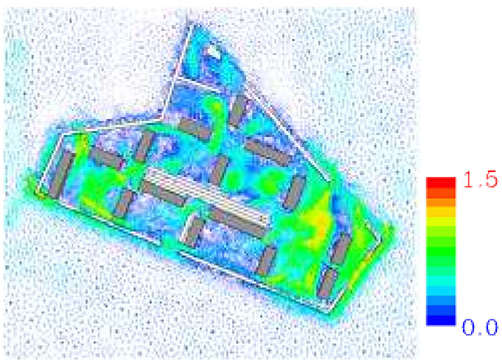

Fig. 7 Airflow distribution of analysis complex at 1.5m high (m/s)

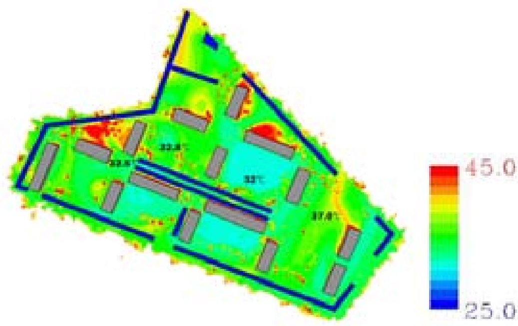

Fig. 8 Temperature distribution of analysis complex at 1.5m high (℃)

Table 4 Comparison of airflow distribution of analysis complex at 1.5m high

	Actual measurement	Simulation
Block space	1.00m/s	1.19m/s
Green space	0.30m/s	0.32m/s
Water space	0.30m/s	0.33m/s
Average	0.50m/s	0.58m/s

Table 5 Comparison of temperature distribution of analysis complex at 1.5m high

	Actual measurement	Simulation
Block space	34.0℃	37.0℃
Green space	31.7℃	32.0℃
Water space	30.9℃	32.8℃
Average	32.6℃	33.7℃

4. Methods to improve outdoor thermal environment of apartment complexes

4.1 Analysis model

Using the existing apartment complex that was measured as the subject, a method to improve and alleviate the outdoor thermal environment is proposed. CASE 1 modeled the actual apartment complex subject as it is, while CASE 2 carried out the modeling so that the block space of the subject complex was furnished with grass. The analysis conditions were made identical to the analysis conditions of the measurement of subject apartment complex and the verification stage of the simulation thermal environment.

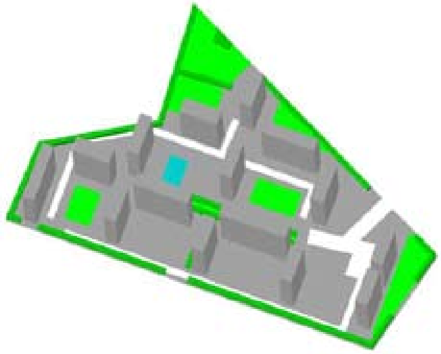

Fig. 9 Modeling of subject apartment complex (case1)

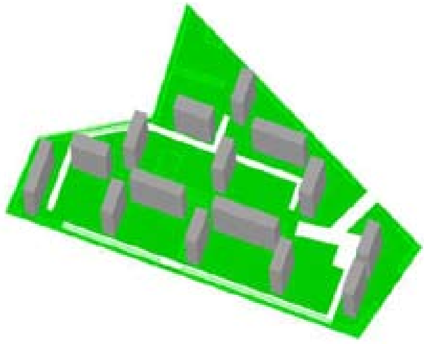

Fig. 10 Modeling of subject apartment complex (case2)

4.2 Analysis results

The air temperature of CASE 2 shows a notably low temperature distribution overall compared to that of the existing apartment complex (CASE 1). When observing the temperature distribution of CASE 2, most areas of the space show a temperature distribution between 28~31℃. The existing apartment complex (CASE 1) generally shows a temperature distribution that is 2~5℃ higher than that of CASE 2. The vertical surface temperature distribution of CASE 2 decreased remarkably compared to CASE 1. The whole complex showed a comparatively low temperature distribution due to a temperature reduction effect caused by a relatively high reflection ratio of grass and evaporation cooling effect. Such analysis results indicate that increasing the area covered by grass when planning apartment complexes allows the outdoor thermal environment of the complex to be controlled and to approach the comfort zone by mitigating the heat island effect.

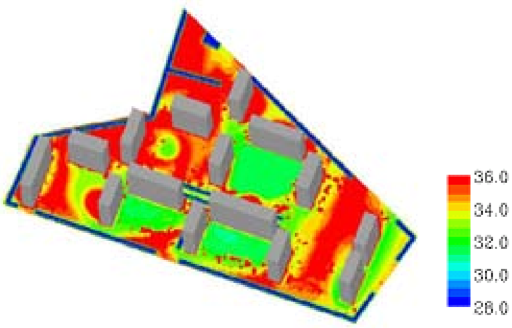

Fig. 11 Temperature distribution of analysis complex at 1.5m high(case1)

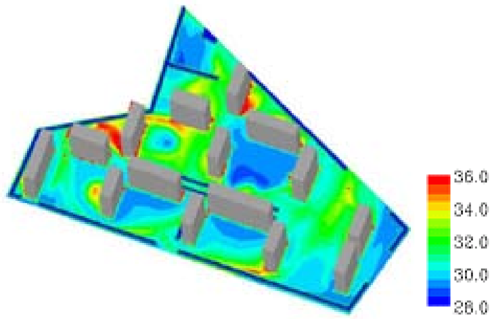

Fig. 12 Temperature distribution of analysis complex at 1.5m high(case2)

5. Conclusion

This study aimed to find a method to enhance the thermal environment within apartment complexes and mitigate the urban heat island effect using various variables by carrying out measurements of an actual apartment house complex and verifying them with simulations. The results of actually measuring the thermal environment confirmed that the microclimate of each space also differs according to the outdoor finishing materials. The results of actually measuring the air temperature around 2 pm when the temperature is the highest, by dividing the measurement points to concrete block space, water and tree space, and water space, showed the temperature to be in the order of block space (33.1℃) > green space (31.7℃) > water space (30.9℃). Furthermore, the results of measuring the surface temperature of each material by using an infrared camera appeared to be in the order of block space (37.4℃) > green space (27.9℃) > water space (27℃). It is analyzed that green space and water space have low surface temperatures compared to that of block space due to the evaporation cooling effect of moisture. The simulation analysis results showed similar results to the measured results in which green space and water space had temperatures 4~5℃ lower than that of block space, and exhibited a similar pattern. A temperature reduction effect by 2~5℃ is presented when arranging the block space of the existing apartment complex with grass space as a method to relieve the heat island effect. It is judged that planning methods that consider these factors that influence the thermal environment when designing environment-friendly outdoor spaces will alleviate the urban heat island effect and contribute to comfortable living.

ACKNOWLEDGEMENT

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INNOVATIVE PRECASTING FOR PUBLIC HOUSING CONSTRUCTION IN THE REDEVELOPMENT OF KWAI CHUNG FLATTED FACTORY, HONG KONG

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Summary

Sustainable developments have always been a continuing goal and strive for Hong Kong Housing Authority (the HA) in its provision of affordable housing to the general public in terms of tens of thousands of domestic units a year. With management commitment, project team dedication and industry collaboration, the HA has successfully developed an Enhanced Precast and Prefabrication System (the System) with many innovations in precasting. The System comprises 11 types and about 10,000 pieces of precast elements per building that altogether bring the precast concrete volume to a record 60%. There are two precast innovations: firstly, precast structural shear walls that signify advancement from minor to major structural precasting, and secondly, large-scale volumetric precast components, i.e. from conventional planar to volumetric components. A pilot project was launched to try out the System. With its completion in March 2008, the project has demonstrated sustainability benefits of the innovative precasting: better quality of works, enhanced site safety and better environmental protection, and other potential benefits. Through exhibition to the general public and site visits and sharing forum to stakeholders of the industry, the significance of innovative precasting for sustainable housing developments was promoted. The System has not only contributed to sustainable construction but also advanced the frontiers of precast and prefabrication technology in the industry.

1. Introduction

Sustainable developments have always been a continuing goal and strive for Hong Kong Housing Authority (the HA) in its provision of affordable housing to the general public in terms of tens of thousands of domestic units a year. As precasting offers better quality, safer, less-pollution and quicker construction, and in turn makes a significant contribution to sustainable developments, the HA has been a pioneer in precasting in the local construction industry. Since its introduction of precast facades in the 80s, several types of precast elements have been conventionally adopted in public residential buildings – precast facades, semi-precast floor slabs, precast staircases, precast (non-structural) partitions and precast lintels. These precast elements total to about 20% of the total concrete volume of a building. The resultant benefits in built quality, site safety and environmental protection are obvious.

However, the HA was not complacent with this level of sustainability achievements and dedicated to further explore innovations in precasting with a view to bringing greater sustainability benefits to the public and proactively meeting increasing social needs of sustainable developments.

2. Management Commitment, Project Team Dedication and Industry Collaboration

Innovations mean changes – possibly changes from conventional materials, technology or practice that have worked well. It is understandable that any change has a risk of uncertainty and therefore the employer, the designer and the contractor are reluctant to change. Successful innovative development requires firstly, management commitment that will provide full support – financial, time and manpower. Secondly, it requires dedication of a project team that will follow through the innovations in their inception, formulation, trial and full implementation. Thirdly, it requires collaboration of the industry that will help actualise the precast innovations and provide realistic competitive bidding. The HA has possessed both committed management and dedicated project team. To start its pursuit of more sustainability benefits through precasting, the HA arranged a top-official delegation to Japan to obtain first hand information about the latest development in construction of high-rise precast buildings. Then it decided to try out new types of precast elements in large scale. The project team drew on overseas experience and in-house knowledge, collaborated with local academic institutes and consultants, conducted various discussions and meetings with the industry stakeholders including precasters and contractors, and executed a series of research, site trials and mock-ups.

All these efforts brought forth an Enhanced Precast and Prefabrication System (the System) with many innovations in precasting. The HA chose the Kwai Chung Flatted Factory Redevelopment Project as a pilot to try out the System. Evolution of the System satisfactorily progressed stage by stage – from planning of the project, design development, construction of a full scale mock-up on site to the construction of the precast buildings. The pilot project was completed in March 2008, which finally marked the successful implementation of the precasting innovations that once were ideas only.

3. Enhanced Precast and Prefabrication System

The System is adopted in two 41-storey residential buildings, each of 799 domestic units. Both buildings are basically of wall-slab structural form. For each building, the precast concrete volume is substantially increased from 20% to a record 60%, involving the following 11 types and about 10,000 pieces of precast elements (Figure 1):-

<u>Conventional Precast Elements</u>
Façade, Semi-precast Slab, Staircase, Non-structural Partition and Lintel

<u>New Initiatives</u>
Innovative Precast Structural Shear Wall

- 'Welded' Wall (fully precast)
- Semi-precast Wall (some with bay windows)

Innovative Volumetric Precast Components

- Bathroom
- Bathroom-cum-kitchen
- Lift Core
- Stair Core

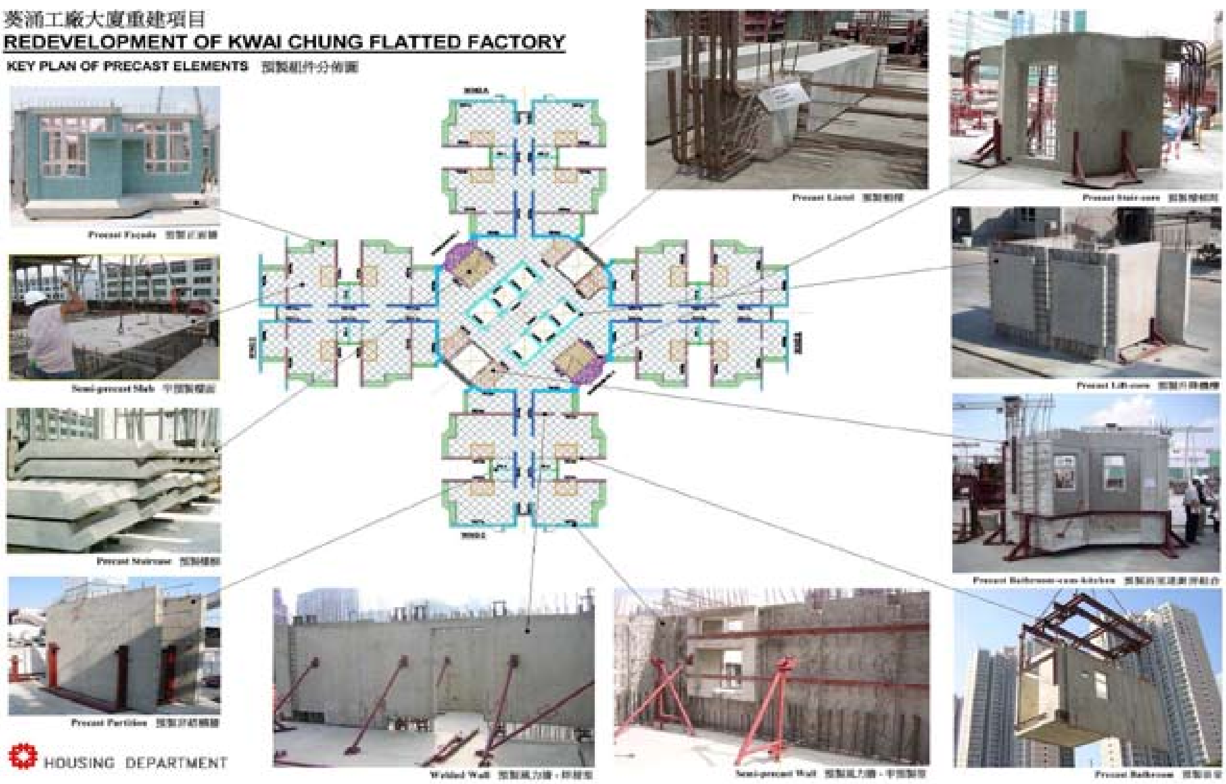


Figure 1 Layout of Precast Elements

3.1 Minor to Major Structural Precasting

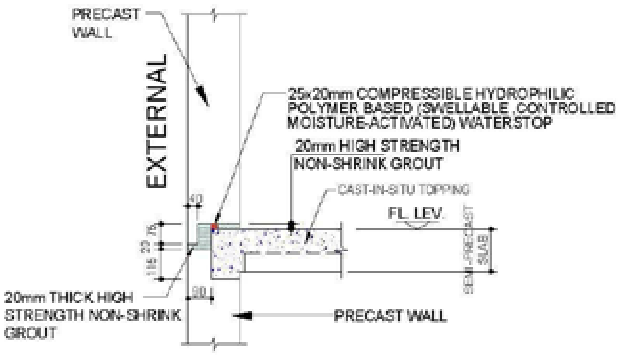
The System achieves a breakthrough development of Precast Structural Shear Walls, which signifies a great advancement from minor to major structural precasting. The conventional precast elements are all minor structural elements as they carry loads of one single storey and therefore concern local structural safety only. The design and construction are relatively simple.

In contrast, the precast structural shear walls are to carry all the gravity loads and wind loads (as Hong Kong is located in typhoon area, the buildings have to withstand winds of maximum hourly-mean velocity of 52 m/s or 187 km/h) from floors above and therefore impinge on global structural safety. The design and construction are relatively much more complicated. Besides structural aspects, waterproofing performance, buildability and cost are important design considerations for these precast walls as they are exposed, partly or wholly, to external and they are to incorporate architectural finishes and building services as far as practicable. There are two types of precast structural shear walls, namely Welded Wall and Semi-precast Wall.

3.1.1 Precast Structural Shear Walls – 'Welded' Walls

'Welded' Wall is a fully precast wall mostly used for external walls and specially designed with multiple waterproofing features at the joint – a 75x40mm downstand, a 25x20mm compressible hydrophilic waterstop and a complete filling with non-shrink grout (Figure 2). As compared to conventional insitu construction, this precast wall type can do away wall form and falsework and external working platform, not to mention that it will enhance the quality of the finished work and speed up the construction on site.

Given the unique conditions in Hong Kong that there are only a couple of suppliers of proprietary couplers for structural connections, joining upper and lower precast walls of this type is by welding of steel couplers embedded in the wall ends, i.e. structural steel sections at the two ends of the counterparts are welded together for load transmission. This connection requires neither special materials such as proprietary couplers nor special skills as qualified welders are commonly available in the market to carry out high-quality jointing work. Quality-wise it is comparable to proprietary couplers; cost-wise, it is more favourable. Besides, it has several more advantages: on-site quality control tests can be performed, and its price and supply position can be better controlled in contrast to proprietary couplers. Applying innovatively conventional welding to the structural connections is a key success to this type of major structural precasting.



JOINT DETAIL
(WITH ONE SIDE FACING EXTERNAL)

Figure 2 ' Welded' Wall

3.1.2 Precast Structural Shear Walls – Semi-precast Walls

Considering the normal lifting capacity of those tower cranes commonly available in the market and avoiding the need to upgrade the crane at an extra cost of few million Hong Kong dollars per crane, the weight of the precast components must be properly controlled. Semi-precast Wall is specifically designed for the gable end walls, furthest away from the tower crane that is usually located near the center of the block to keep the total weight within the lifting capacity of the tower crane (Figure 3). For similar lifting consideration, some of the walls of a precast bathroom-cum-kitchen are designed as semi-precast. The wall is made of an external precast wall panel and an internal in-situ concrete portion. It should be noted that the external precast panel is used as formwork for concreting the internal in-situ portion of the wall. The external precast panel is securely bolted onto the falsework at the internal side making use of the prefabricated threaded sockets cast in the stiffeners of the precast panel; thus the external wall form, falsework and working platforms are saved.

It must be stressed that the external precast panel forms an integral part of the structure to carry loads. As it is not a loss form, it will maximize the utlisation of the materials in place.

Figure 3 Semi-precast Wall

3.2 Planar to Volumetric Precast Construction

The conventional precast elements are generally planar, which are relatively easier to design, fabricate, transport and install than volumetric precast components that are sizeable in all three dimensions. The breakthrough achieved in the precast structural shear walls has enabled the development of large scale volumetric precast components integrated intelligently with shear walls (Figure 4), which satisfactorily overcome the design, fabrication and installation difficulties for such precast components of large size and weight (max 9.5 tonnes) and in large number (1,200 per block).

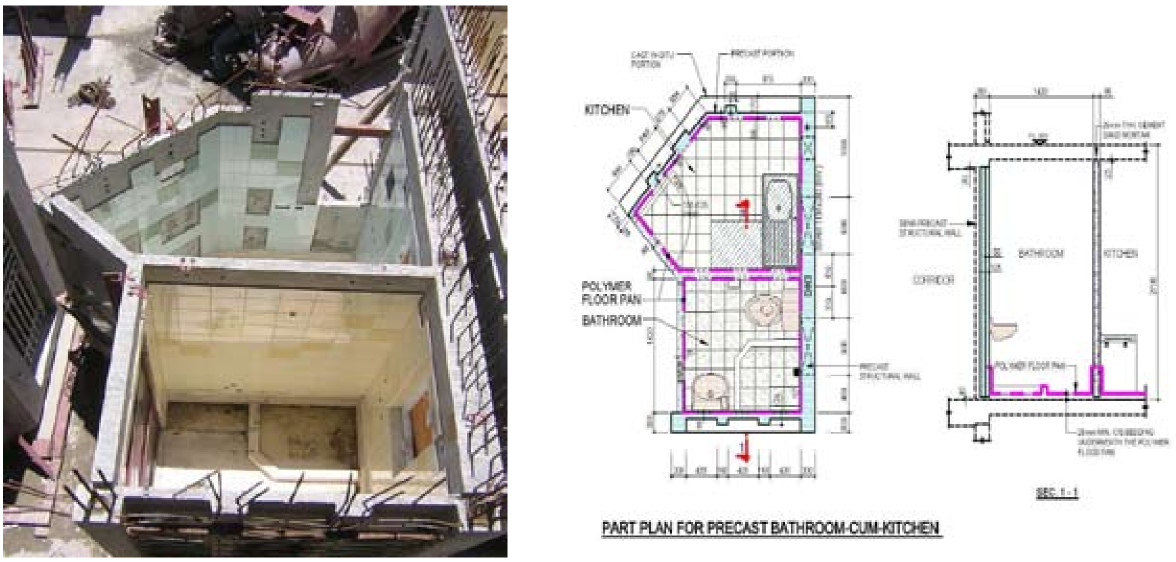


Figure 4 Framing Plan of Precast Bathroom-cum-kitchen

3.2.1 Precast Bathrooms & Precast Bathroom-cum-kitchens

The innovative precast bathroom (Figure 5) and bathroom-cum-kitchen have three special features. Firstly, they integrate intelligently with the adjoining shear walls, i.e. there will not be any double walls. Secondly, most of the architectural works are done in the precast factory, i.e. better quality control and less wet trades at working floor. Thirdly, a unique fibre reinforced polymer floor pan is used for the first time in Hong Kong to replace

- the traditional waterproof membrane,
- the floor finishes (the floor pan can be finished with different engraving, patterns and colours) and
- the base, which is normally required in proprietary products as a support for fabrication of the sanitary fittings,

Hence, there will not be double floor slabs. More usable space can be provided with less construction costs because no double walls or double floor slabs are used. The floor pan is a seamless machine-moulded pan encased into walls, which will prevent water leakage and associated concrete spalling problems. This will mean much less maintenance and in turn minimize nuisance or disturbance to residents. Besides, as most finishing works are prefabricated in factory, better quality is ensured.

Figure 5 Precast Bathroom

3.2.2 Precast Stari-cores & Precast Lift Shafts

For precast stair-cores and precast lift shafts, apart from saving of external working platforms, precast construction can achieve better quality by minimizing defects such as stepped joints commonly found in conventional cast-in-situ construction method.

4. Collaboration with Contractor in Implementation

4.1 The Mock-up

In view of the limited experience of local building contractors in the System, the HA tried out the System by constructing a two-storey one-wing mock-up structure at the Site before starting the main building contract. By process simulation, the HA could check out all the details involved in the fabrication, installation and testing. During the course of the mock-up construction, the HA worked closely with the contractor in identifying problems and developing feasible and practical solutions. The final, improved design was then let out for construction.

4.2 Building Construction

In view of their significance in overall structural stability, the precast structural shear walls were required to be fabricated on site for the purposes of close monitoring and better quality control (Figure 6).

The set up of the on-site fabrication yard took into consideration the logistics for production, the storage and erection of the precast elements with an aim to minimize double-handling in 'internal' transportation of the precast elements, which was costly. This was one of the major reasons for the awarded tender to win over other tenders.

During the course of the construction, the project team worked closely with the Contractor in overseeing the construction works, overcoming the construction difficulties and refining sequence of works and method statements.

Figure 6 Construction of the Residential Blocks

5. Achieved Sustainability Benefits

As the pilot project was completed (Figure 7), the whole construction process including the fabrication, transportation and installation of the precast elements has been thoroughly monitored and reviewed. The System has a number of major sustainability benefits and other potential benefits.

5.1 Better Quality of Works

Better quality was ensured. As precast components were mass-produced in casting yards, quality control was enhanced and construction errors were reduced. Under the System, not only were aesthetic finishes applied to the precast components, but also aluminum windows and building services devices were installed in advance. These greatly reduced potential damage to the materials arising from on-site installation while improving durability and cutting down future maintenance costs. In sum, the quality of concrete, architectural and building services works improved noticeably.

Further, by replacing the conventional waterproofing membrane with the seamless fibre reinforced polymer floor pan in bathrooms and kitchens, watertightness performance is better assured. Thus the repair and maintenance costs will be reduced.

5.2 Enhanced Site Safety

The System helped boost site safety as it re-sequenced the site works and reduced a great deal of site works at height (at working floors) such as reinforcement fixing, formwork erection and concrete pouring.

Due to the use of the System, the Contractor managed to bring down the accident rate to record low figure of 9.65 (per thousand workers), which was substantially lower than the average accident rate of 64.3 for all local construction projects in 2006. The Contractor obtained consistently high scores in their quarter safety audits carried out by external safety auditors. The Contractor had also won quite a number of safety awards in the years 2005, 2006 and 2007 for this contract[a].

5.3 Better Environmental Protection

The mechanized production of precast components in casting yards was much more environmentally friendly than conventional cast-insitu construction. With reduction in wet trades, it reduced both material wastage and construction waste. The Contractor reckoned that the average daily waste production for the project was 80% less than that for the Contractor's other projects.

At the same time, as less concrete pouring work was carried out on-site, noise, air pollution and other associated nuisance to nearby residents had been minimized and the workers were provided with a cleaner and more healthy environment to work in.

For this pilot project, the Contractor had won a number of awards on environmental protection in the years 2005, 2006 and 2007[b].

Figure 7 Completed Blocks adopting the System

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[a] The Gold Award for Building Sites (Public Sector) of the Hong Kong Safety Award Scheme for the Construction Industry (2005); the Best Building Site Safety Record Award of the Hong Kong Quality Public Housing Construction (2006) organized by the Housing Department, HKSAR Government; the Gold Award of the Hong Kong Considerate Contractors Site Award (2006) organized by the Works Bureau, HKSAR Government; and the Hong Kong Considerate Contractors Site Award (2007) organized by the Works Bureau, HKSAR Government.

[b] The Gold Award of Hong Kong Eco-Business Award in the Category of Green Contractor (2005); the Gold Award of Outstanding Environmental Management & Performance Grand Award (2006) organized by the Works Bureau, HKSAR Government; and the Outstanding Environmental Management & Performance Grand Award (2007) organized by the Works Bureau, HKSAR Government.

6. Potential Benefits

6.1 Time Saving

For this pilot project, construction time of approximately five more months was required. This included three months allowed for on-site fabrication of precast structural walls and two months for resolving technical difficulties such as the fabrication details for the new precast components, the methods for assembly of the precast components, the dove-tailing details between insitu and precast construction. With the experience gained from this pilot project, the additional construction time may be trimmed down for future projects.

Volumetric precast components (integrated with precast structural walls) were used for the first time in public housing construction. Despite their sizeable dimensions and heavy weights, these components were installed quite expeditiously[c]. After the building industry has became familiarized with the System, it is anticipated that a shorter construction period can be achieved.

Time saving is also expected in the latter stages of the construction since as much as 36% of the originally on-site finishing works have been prefabricated onto the precast elements at the casting yard.

6.2 Cost Saving

The cost of the Building Contract was approximately 8% more than that adopting conventional construction method. When comparing costs on block basis, each building with the System was found to cost approximately 13% more than a conventional building. The comparatively higher cost was attributed to firstly, the additional cost for the new precast initiatives which demand substantial capital investment in design and manufacturing of the new steel moulds and extra cost for learning and mastering their production and installation, and secondly the set up cost for on-site fabrication of the precast structural shear walls (a specific requirement of this pilot project).

The extra cost is not surprising, considering this is a pilot project. We anticipate that the cost will go down if the new precast initiatives are widely used in future, as in the case for precast facades[d], and the scale for on-site fabrication is reduced. At the same time, lower maintenance cost due to better built quality is expected to make up for the higher capital cost, e.g. the fibre reinforced polymer floor pan will effectively prevent water leakage and the associated concrete spalling problems.

7. Promotion of Sustainable Construction Through Innovative Precasting

Through an exhibition of the System in the Innovation Expo 2005, Hong Kong, which was very well received by approximately 15,000 visitors, the HA successfully demonstrated to the public that the System was one of the HA's initiatives for sustainable public housing developments.

With so many new initiatives, the pilot project has indeed not only advanced the frontiers of precasting and prefabrication technology in public housing developments but also, through more than 30 site visits and experience sharing forums that involved more than 1,100 delegates from various stakeholders - academic institutes, public utility companies, consultants, contractors and government departments – from Hong Kong, China, Australia, Singapore, Korea and Japan, promoted awareness of the stakeholders on how the construction industry could contribute more to sustainable developments through innovative precasting.

8. Conclusion

Innovation in a public organization is not an easy task – stepping out from established conventional construction practice to trying out innovative precasting, putting down the innovation ideas and concepts on the drawing boards and finally turning them into reality. The success of this pilot project is indeed a result of the HA's relentless strive for sustainable public housing developments and collaboration with the industry, particularly the Contractor during the implementation stage.

The valuable precasting knowledge and experience in public housing developments will continue to be a prime mover for sustainable construction in the industry and will certainly contribute to the quality and sustainability of public housing developments and help to meet the ever-increasing expectation of the public.

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[c] Installation (excluding post-installation jointing works) time for precast bathroom (9 tonnes), precast bathroom-cum-kitchen (8.5 tonnes), precast lift core (6.5 tonnes) and precast stair core (9 tonnes) are 8, 15, 10, 15 minutes respectively.

[d] Facade unit cost decreased from $11,520 in a pilot project in 1990 to $5,156 in 2002 (about 53% decrease). Since then the facade cost has increased because of firstly less competition with the shut down of a number of precast plants and secondly more market demand with the increasing need of precast units from the private sector. The latest facade cost in year 2006 was $6,799, which was still about 41% less than that of the pilot project.

SOCIAL DIMENSION OF SUSTAINABLE BUILDING

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Keywords: social aspect, sustainable building, productivity, quantification

Summary

A brief history on the development of the concept of the sustainable building is presented and the relevant social aspects are identified and discussed. Social interaction, cultural enrichment, health of users, facilities for the disabled, security, productivity, public participation in decision making for the buildings are the elements identified. Public participation encourages individuals to be a part of decision making for issues that concern them about building. It ensures that the development is acceptable to society and promotes equity. The inclusion of social aspects in building sustainability assessment brings up the issue of its quantification. The social aspect is an intangible feature which presents difficulties in its quantification. Full cost assessment (FCA) is a decision making tool and may be used to estimate the cost of social aspects. The main barrier in its adoption is insufficient and poor quality data.

1 Introduction

The concept of sustainable building is far from being well defined, it is under constant evolution and new themes have been added to it since its emergence. There is no general consensus between different authors about the concept of sustainable building. Several terms are being used to describe the relationship of buildings with the environment such as energy-smart building, green building, intelligent building, sustainable building *etc*. Green building, as the term depicts, refers mainly to the environmental aspect. It involves minimisation of pollutants, reduction in energy use and environmental damages. The United Nations Commission on Sustainable Development in 1993, included economic aspects, as well:

> "to use the limited resources more efficiently and promote the solutions in economy and environment problems, further more to improve the living environment, is called the Green Building." (GBC 1998).

A statement or definition of sustainable building was described in the 2000 conference of Sustainable Building as:

> "A sustainable agenda operated on scales of materials, buildings, and urban regions, and must also include consideration of functional, social, economic and ecological factors. Strategies for reaching a sustainable built environment must reflect varied regional conditions and priorities, and different models for implementation: think global, act local." (SB 2000).

Thus, sustainable building presents a broader agenda encompassing several aspects. Therefore, to achieve a sustainable development in a community, the emphasis should be on sustainable building, which includes the community in decision making. A more comprehensive definition of sustainable building would be the one incorporating environmental, economic and social aspects and public participation.

2 Evolution of Sustainable Building

Before delving into the social dimension of sustainable building, a brief history of the evolution of the sustainable building concept is discussed. An early definition of sustainable construction was presented by Charles Kibert during the First International Conference on Sustainable Construction held in Tampa, Florida, US in 1994. "Sustainable construction is the creation and responsible management of a healthy built environment based on resource efficient and ecological principles" (Kibert 1994). It is evident that the foremost stress was given to resource efficiency and ecological principle as was justified by the Rio

Declaration on Environment and Development in 1992. With the passage of time, the concept of sustainable construction/building has evolved and a broader picture has emerged.

Figure 1 shows the evolution of sustainable construction concept over the passage of time. The traditional ideology was to consider time, cost and quality during the construction. Later on, issues such as resource depletion, emissions, and conservation of biodiversity took a forward step and a bigger picture encompassing these issues emerged as is supported by Agenda 21 on sustainable construction (CIB 1999). Finally, a broader concept evolved to covering economic, social and cultural issues as well. However, the social aspect has not yet gained sufficient recognition among the policy makers. The meaning of social sustainability must be recognised in order to identify the main social benefits and features of buildings.

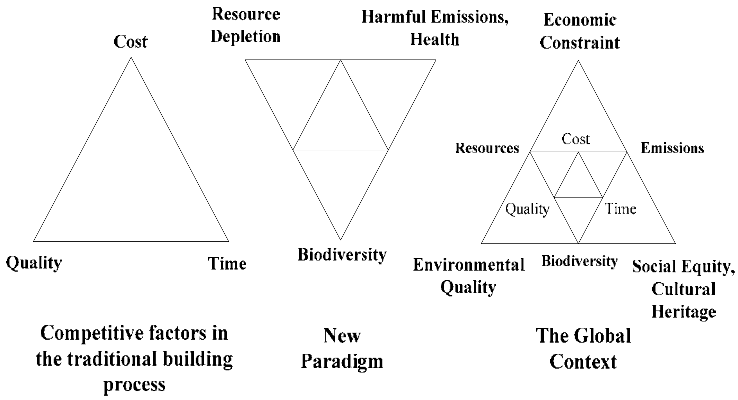

Figure* 1*: Traditional concept of sustainable construction (Source: Bourdeau 1999)

3 Social Sustainability

Black (2004) defined social sustainability as “the extent to which social values, social identities, social relationships and social institutions can continue into the future”. In terms of buildings it can be interpreted as social interaction, cultural enrichment, health of users, facilities for the disabled, security, productivity, public participation *etc*. Public participation in planning is a central issue and this concept has not yet gained its roots in the construction industry. Strong interaction among several sections of the construction industry is required. This may lead to modifications of the list of stakeholders who should have a say in built environment decision-making (Kaatz *et al*. 2005, p. 447). Public participation allows the views and concerns of all affected parties to be heard, thus satisfying the *equity* principle. Furthermore, it also increases the awareness within society about its responsibility towards sustainable development (Kaatz *et al*. 2005, p. 445). It may include architects, construction workers, engineers, owners, end users, property managers, facilities managers *etc*. It encourages the individuals to be a part of decision making for issues that concern them (Mitchell *et al*. 1995, p. 107). Its importance was realised at the Rio Declaration on Environment and Development (UNCED 1992) where it was added as the tenth principle and is as follows:

> “Environmental issues are best handled with participation of all concerned citizens, at the relevant level. At the national level, each individual shall have appropriate access to information concerning the environment that is held by public authorities, including information on hazardous materials and activities in their communities, and the opportunity to participate in decision-making processes. States shall facilitate and encourage public awareness and participation by making information widely available. Effective access to judicial and administrative proceedings, including redress and remedy, shall be provided.”

Public participation promotes equity by ensuring that the development is acceptable to society and does not create a monopoly for a certain section of a community (Kaatz *et al*. 2005, p. 442). Pearce (2003) published a report on the social and economic value of the construction industry and identified certain social values that need to be considered in the construction industry. This report realigned the concept of sustainable building by incorporating social and economic aspects. He argued the need to consider economic, environment and social issues alongside each other to better assess sustainability. The report brought forth the social dimension of the construction industry in terms of wealth, culture and ecology and highlighted the lack of quality data as a barrier in sustainability evaluation. He treated the built environment as a capital stock and sketched out a schema shown in *Figure 2* which gives an understanding of the wider social sustainable dimension in the construction industry and shows the capital approach to various aspects of sustainable building.

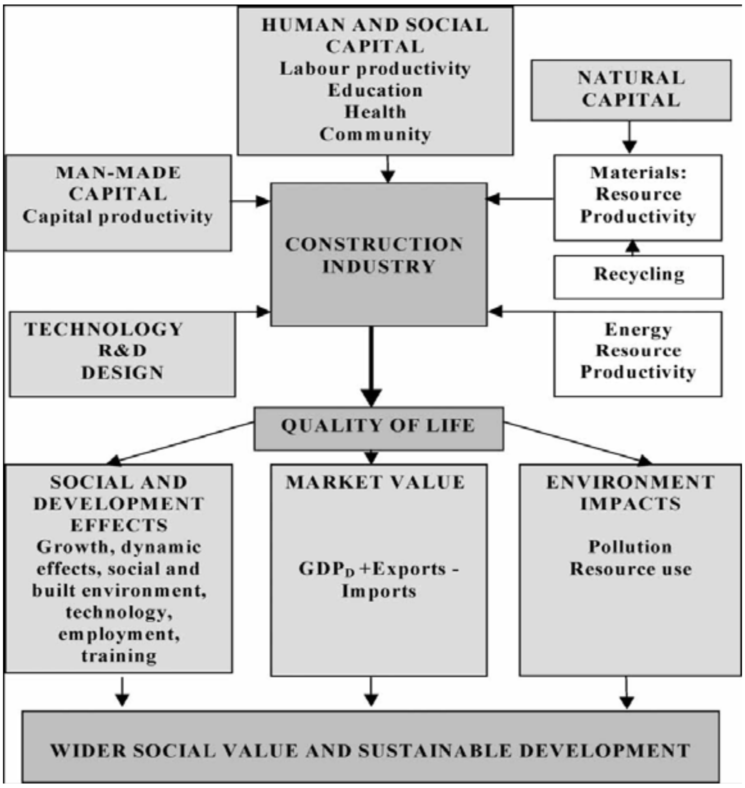

Figure 2: Pearce's Schema
(Source: Pearce 2003)

4 Importance of Social Aspects

Buildings should be seen as wealth generating stocks and in this context productivity of the occupants should be a major design consideration. Their productivity depends directly upon the indoor environmental quality (IEQ). As most of the people spend about 80% of their time indoors, IEQ needs to be monitored carefully and encompasses several areas such as ventilation, thermal comfort, lighting, noise, indoor air pollutants *etc*. Several researchers have shown a decrease in building occupant productivity with a poor IEQ. One such study revealed a high rate of employee sick leave in the face of poor ventilation conditions in office buildings (Kumar & Fisk 2002). The study was part of an occupational and environmental health evaluation at Polaroid Corporation, in which sick leave data and ventilation rates were analysed from 40 buildings. A low ventilation rate was found to be associated with a higher percentage of sick leave. An economic analysis revealed that the annual energy cost required to improve the ventilation rate would be more than compensated by the reduced cost of sick leave. There are several other studies which point towards the same direct relationship of poor IEQ with showing decrease in occupants' adverse health effects. Use of natural daylight in commercial buildings is not only energy efficient but also beneficial to the occupants' health. Landman (1999) cited a study in which the occupants of a commercial building reported 20% less sick building syndrome in occupants working closer to the windows. Other such factors affecting productivity include floor space, layout, noise *etc*. Sustainable buildings attract more tenants who extend their leases as a result of higher IEQ standards. The value of commercial buildings can be further enhanced by incorporating features such as showers, bike racks and proximity to public transport.

Lorch (2003) has discussed the benefit of social capital values in the community by providing social identity and complying with the basic needs of indigenous users. Heilbrun & Gray (2001) highlights certain social features which can be integrated into the built environment to improve its value and act as a source of revenue by attracting tourists (museums, art galleries *etc*.). A well planned housing community (open spaces, parks, bicycle tracks, accessibility to public transport *etc*.) can be a source of high capital return for the developers. More work is required to incorporate such features in neighbourhood design.

Including sustainable aspects of a building in its appraisal is likely to become a norm in the future and buildings with higher green star ratings may achieve higher prices and increased returns on equity. In 2000, New York offered an incentive package by passing a green building tax credit to encourage developers to incorporate sustainable practices. Such steps will further attract developers and investors to embrace sustainable building practices in future. Further value to the society can be added by adopting environmental practices such as using recycled materials and proper disposal of the waste to reduce the burden on landfills etc.

5 Quantification and its Barriers

The inclusion of intangible social aspects in building sustainability assessment brings up the issue of difficulties in its quantification. However, once made part of the assessment process, it can aid in bringing such issues to the forefront and making them part of managerial decisions and finding better alternative options both in terms of the economy and occupational health and safety. Full cost assessment (FCA) is a managerial decision making tool and may be used to estimate the cost of social aspects. The main barrier in its adoption is the insufficiency and poor quality of data. The estimation of full costs requires major effort and involves not only future forecasting but also occupants' environmental and health issues, productivity, loss or gain of revenue depending upon the reputation of a building or housing society (sick building syndrome may lead to poor reputation). Estimations can be made by studying past projects which have certain social sustainability e.g., museums, better security, open spaces *etc*. While designing the buildings, such productivity and wealth generation factors should be considered. There are a few building assessment tools that quantify certain social aspects - Green Star Rating Tool by Green Building Council of Australia and LEED. However, their effective use is limited by the input information and data availability.

6 Conclusion

The sustainability of building is a broad term encompassing various disciplines such as environment, society, economy. Buildings have a direct impact on society and can benefit society in terms of wealth generation, providing security, social capital and cultural preservation. Public participation in the decision making is identified as an important aspect of sustainability. Recognition and appreciation are needed by all the stakeholders to improve the occupants health and productivity and to incorporate flexibility in design for future modifications, accessibility *etc*. At this time full cost assessment (FCA) is limited by a lack of quality input data which should be developed in the future.

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COMPUTATIONAL DESIGN OF HYGRIC AND THERMAL PROPERTIES OF MATERIALS IN MULTI-LAYERED BUILDING ENVELOPE SYSTEMS: A GOOD PREVENTION OF DAMAGE

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Keywords: computational design, internal thermal insulation system, heat and moisture transport, damage prevention

Summary

Sustainable design principles of interior thermal insulation systems are formulated and the appropriate design methodology is given in the paper. In a practical application of the methodology, an interior thermal insulation system on hydrophilic mineral wool basis provided with several types of water vapor retarders and applied on several types of different load bearing structures is subjected to a detailed computational analysis of coupled heat and moisture transport. Temperature, relative humidity and overhygroscopic moisture fields are calculated for the time period of several years using the computer code TRANSMAT 6.3 and the long-term hygrothermal performance of studied building envelopes is assessed. The results of computational design reveal that such a combination of hygric properties of water vapor retarder can be found which results in flawless hygrothermal performance of the interior thermal insulation system on hydrophilic mineral wool basis, no matter the type of load bearing structure. This means that the retarder with such properties can be considered as universal solution for the studied interior thermal insulation system. The mentioned properties of water vapor retarder can be met for instance using a common lime plaster or lime-metakaolin plaster with up to 25% of metakaolin as lime replacement.

1. Introduction

The application of interior thermal insulation systems on building envelopes is not a natural solution but sometimes there is no other option available. A typical example is a historical building, where the facade has to be kept in its original appearance mostly, and the exterior insulation systems are excluded for that reason. In that case the development of such an insulation system would allow to prevent moisture damages and to upgrade the thermal properties of the envelope as the only reasonable option.

A common solution to this problem consists in placing a vapor barrier just under the internal plaster, on the surface of the insulation layer, so that both the insulation layer and the load bearing structure are protected against water vapor. However, this is a solution, which can perform well on the theoretical level only. In the practice, it is not possible to avoid mechanical damage of water vapor barrier placed in such an inappropriate way. A sole nail or hook driven into the wall for instance if hanging up a painting can destroy the function of the barrier. In addition, even in the case that the barrier would perform without mechanical damage, the absence of water vapor removal from the interior through the envelope in the winter period, when the air ventilation in the interior is usually limited, would lead to undesirable increase of relative humidity in the interior and worsening of the internal microclimate.

The mechanical damage of water vapor barrier can be avoided by placing the barrier between the thermal insulation material and the load bearing structure. However, the amount of water condensed in the insulation layer would be also in this case for certain time period of year relatively high. It is naturally possible to design such a thermal insulation material, which cannot be damaged by long-term water exposure, but the presence of water will always have a negative effect on the thermal insulation properties of the material. In the climatic conditions of North and Middle Europe the danger of liquid water generation is concentrated to winter months mostly. Therefore, the worsening of thermal insulation function would occur just in the winter period of year when it is absolutely undesirable.

An alternative to the application of traditional water vapor barriers is using a vapor retarder instead, which permits a part of water vapor to diffuse further to the load bearing structure. Then, even if the retarder is placed between the thermal insulation layer and the load bearing structure, the amount of condensed water in the thermal insulation layer is lower, and the structure is not damaged because it is exposed to such a water vapor flux only, that can be transported through it without condensation.

The requirements to the thermal insulation layer in the above arrangement are quite high. It should have a low thermal conductivity in dry state, and the thermal conductivity even should not increase too much if moderate presence of liquid water appears. In addition, the material should have a high capillary activity because it is supposed to redistribute the condensed water backward to the indoor room as fast as possible in order to maintain a sufficiently low moisture level and corresponding sufficiently good thermal insulation properties of the layer.

The application of the capillary activity of insulation materials as a dehumidification method is a big innovative step in the building insulation/renovation technology and offers the possibility to develop new solutions for old, long-lasting problems, where expensive traditional renovation methods fail.

As it has been mentioned before, the retarder layer controls the outward directed vapor flux. The vapor flux must be adjusted according to the properties of the old construction and its climatic zone. Therefore, also the hygric properties of the retarder layer have to be chosen in an appropriate way. This design can be done most effectively by a computational simulation.

An exact specification of hygric properties is not the only requirement to the water vapor retarder. The retarder layer should keep together the thermal insulation layer and the load bearing structure to avoid appearance of air gaps. This can be achieved by an application of a glue, a mastic or a resin with an exactly specified workability, which should be long enough to allow the binding of both layers on a sufficiently large area. Assuming that this area could be for instance a wall of a living room, we arrive to a typical workability in the range of 2-3 hours. On the other hand, the hardening of the retarder layer should not be too long to avoid the movements of the thermal insulation boards after installation.

In this paper, sustainable design principles of interior thermal insulation systems are formulated, and design methodology is given. In a practical application of the methodology, an interior thermal insulation system on hydrophilic mineral wool basis provided with several types of water vapor retarders and applied on several types of different load bearing structures is subjected to a detailed computational analysis of coupled heat and moisture transport. The long-term performance of studied building envelopes is analyzed using a computer code. Temperature, relative humidity and overhygroscopic moisture fields are calculated for the time period of several years and the hygrothermal performance of the systems is assessed.

2. Basic principles of computational design of interior thermal insulation systems

Building envelopes always behave as systems and therefore, the properties of the parts of the system, of the particular materials have to be compatible. It is not sufficient to develop and employ one excellent material, but it is necessary to develop working multi-layer systems consisting of different materials. This is the most important feature of any computational design of a building envelope from the point of view of building physics. Therefore, we will consider a system consisting of internal plaster, thermal insulation material, water vapor retarder layer, the material of the load-bearing structure, and the external plaster in Figure 1.

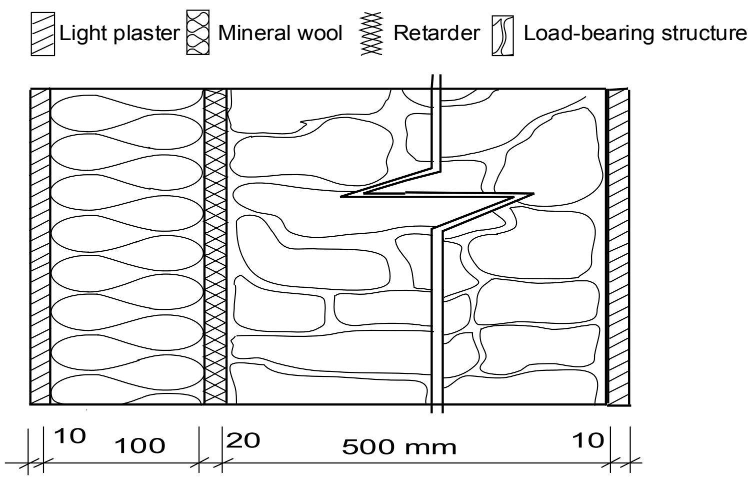

Figure 1 Composition of building envelope used to computational simulations.

An unavoidable preliminary condition for any reasonable computational design is the application of an appropriate mathematical model and the respective computer code. For the calculations we employed the computer simulation tool TRANSMAT 6.3 [Maděra J., Černý R. (2005)] which was developed in the Department of Materials Engineering and Chemistry, Faculty of Civil Engineering, Czech Technical

University in Prague. The construction of the code is based on the application of the general finite element computer simulation tool SIFEL (SImple Finite ELements). The moisture and heat balance equations were formulated in the simplified form suggested by Künzel [Künzel H.M (1995)].

It is necessary to perform the hygrothermal calculations in a sufficiently long time period. Under certain circumstances the hygrothermal properties of the system can worsen gradually, slowly, so that the damage can appear after a longer time period. Therefore, not only the actual values of main hygrothermal quantities are important but also their development in the subsequent years. The time period of 5 or 10 years appears as reasonable in deciding if the designed system will perform without substantial damage.

The proper initial and boundary conditions of the model are another crucial factor affecting the reliability of the calculations. Therefore, the calculations should be done for exactly the same situation as it will be done in the practical reconstruction on building site. First, the boundary conditions for the external side should be as accurate as possible. This can be achieved by using the meteorological data for the locality as close as possible to the real object. From the point of view of long term reliability, the application of so called “reference year” data should be preferred. Second, the initial conditions should be realistic. To this point, the calculations should be done first for the construction without the interior insulation system in order to find the long-term conditions in the wall before the reconstruction. The comparison of calculated data for two subsequent years in a longer time period can be an evaluation factor in this respect.

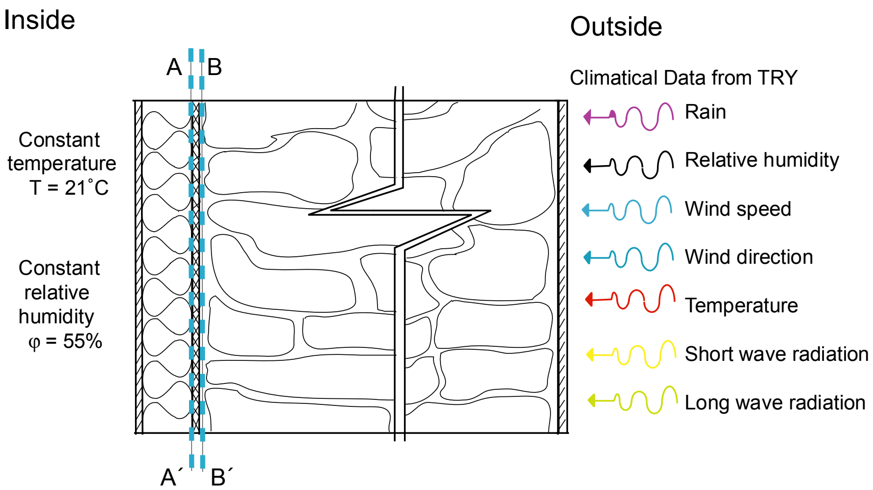

Figure 2 Boundary conditions for the studied envelopes.

Third, the calculations with the interior insulation system should be started exactly in the same time of year when the real reconstruction will begin.The long-term performance of the system should be characterized not only by calculated temperature and relative humidity. Also overhygroscopic moisture fields have to be determined, which decide about the real hygrothermal performance of the system. The critical places, where long-term water accumulation can appear, should be detected. This will make it possible to perform critical experiments in the semi-scale conditions in order to verify the model calculations and to perform the necessary inverse modeling.

The following basic criteria for the design of interior insulation systems can be formulated:

1. In the material of load-bearing structure, there should not appear any overhygroscopic moisture due to the moisture transport from the inside.
2. The thermal insulation material should have a high capillary activity, so that liquid water, which possibly condensed in the insulation layer, could be transported back to the interior in a short period of time.
3. Possible liquid water appearance in the thermal insulation layer should be limited to short time periods of year and small space intervals.
4. The water vapor retarder should have exactly specified hygric properties. First, it can allow to penetrate only such amount of water vapor that will not lead to the condensation in the load bearing structure. Second, it should be impermeable for liquid water.
5. The material of the retarder should have good glueing properties and exactly specified workability to keep together the material of the load bearing structure with the thermal insulation layer.
6. The thermal insulation layer should have besides good thermal insulation properties also good mechanical properties in order to resist mechanical damages.

7. The retarder should be placed in such a position in the system that any mechanical damage would be minimized.
8. The internal plaster should have an open porous structure in order to be able to evaporate a part of moisture, which was transported back from the thermal insulation layer, into the internal space.

3. Practical application of the methodology of computational design

We assumed three alternatives of the load bearing structure, the alternative No. 1 was the brick wall, No. 2 the concrete wall and No. 3 the sandstone wall. The thickness of the all types of wall was 500 mm. On the internal surface of the envelope, there was lime-metakaolin plaster. As the thermal insulation material, hydrophilic insulation boards on the mineral wool basis Dachrock with the thickness of 100 mm which were developed by Rockwool, SA, were used [Jerman et. al. (2007a)]. On the external side there was the same plaster as inside, with the thickness of 10 mm.

The basic parameters of materials of the described building envelope are shown in Table 1. Here, ρ is the bulk density, θ_{hyg} the maximum hygroscopic moisture content, θ_{sat} the moisture content corresponding to water saturation, λ_{dry} the thermal conductivity corresponding to dry sample, λ_{sat} the thermal conductivity corresponding to water saturation, κ the moisture diffusivity, c the specific heat capacity and μ the water vapor diffusion resistance factor.

Table 1 Basic properties of materials of building envelopes

	ρ [kg/m^3]	θ_{hyg} [m^3/m^3]	θ_{sat} [m^3/m^3]	λ_{dry} [W/mK]	λ_{sat} [W/mK]	κ [m^2/s]	c [J/kgK]	μ [-]
Plaster	1490	0.095	0.42	0.5	1.53	8.0e-9	1004	18
Brick	1746	0.015	0.33	0.69	1.9	3.0e-7	895	16
Concrete	2423	0.047	0.122	1.6	3.2	8.9e-10	801	25
Sandstone	1890	0.009	0.32	0.48	0.65	2.5e-6	850	7.5
Dachrock	170	0.0021	0.93	0.047	0.72	4.84e-5	801	7.1

The main aim of the computational simulations performed was to analyze the hygrothermal performance of the designed insulation system with different values of the water vapor diffusion resistance factor, moisture diffusivity and hygroscopic moisture content of the water vapor retarder. The basic material parameters of the retarder are shown in Table 2, the optional parameters in Table 3.

Table 2: Basic material properties of water vapor retarder

ρ [kg/m^3]	θ_{sat} [m^3/m^3]	λ_{dry} [W/mK]	λ_{sat} [W/mK]	c [J/kgK]
1500	0.5	0.5	2.0	1000

Table 3: Optional material parameters of water vapor retarder

	κ=1·10^{-6} m^2/s	κ=1·10^{-8}m^2/s	κ=1·10^{-10} m^2/s	κ=1·10^{-12} m^2/s
μ = 5, θ_{hyg} = 0.02 m^3/m^3	V1K1	V1K2	V1K3	V1K4
μ = 10, θ_{hyg} = 0.01 m^3/m^3	V2K1	V2K2	V2K3	V2K4
μ = 50, θ_{hyg} = 0.005 m^3/m^3	V3K1	V3K2	V3K3	V3K4

The sorption isotherm was assumed in the following simple form:

$$\theta_1 = \left(1-\sqrt{1-\varphi}\right)\frac{\theta_{Hyg}}{1-\sqrt{1-\varphi_{Hyg}}}, \quad (1)$$

and the water retention characteristic in a similarly simple form

$$\theta_1 = \theta_{Hyg} + \frac{\varphi-\varphi_{Hyg}}{1-\varphi_{Hyg}}\left(\theta_{Sat}-\theta_{Hyg}\right), \quad (2)$$

where φ is the relative humidity, φ_{Hyg} the maximum hygroscopic relative humidity.

The thermal properties of the water vapor retarder were not considered in a variant form in the final stage of computational design because preliminary calculations showed their negligible effect on the hygrothermal performance of the studied building envelopes.

4. Computational results

The long-term performance of the system should be characterized not only by calculated temperature and relative humidity. Also overhygroscopic moisture fields have to be determined, which decide about the real hygrothermal performance of the system. The critical places, where long-term water accumulation can appear, should be detected. We have chosen three critical profiles in the evaluation of the hygrothermal performance of the envelope, A-A´, B-B´, where the profile A-A´ was between water vapor retarder and insulation material, B-B´ between the load-bearing structure and water vapor retarder. In these profiles we calculated the dependence of the relative humidity, overhygroscopic moisture content and temperature on time. The results are organized according to the particular alternatives.

4.1 Alternative No 1 – brick wall

Figs. 3 a,b show the relative humidity in the A-A´ profile (the interface between thermal insulation and water vapor retarder). For all variants of retarder maximum relative humidity in this profile was far from the condensation limit.

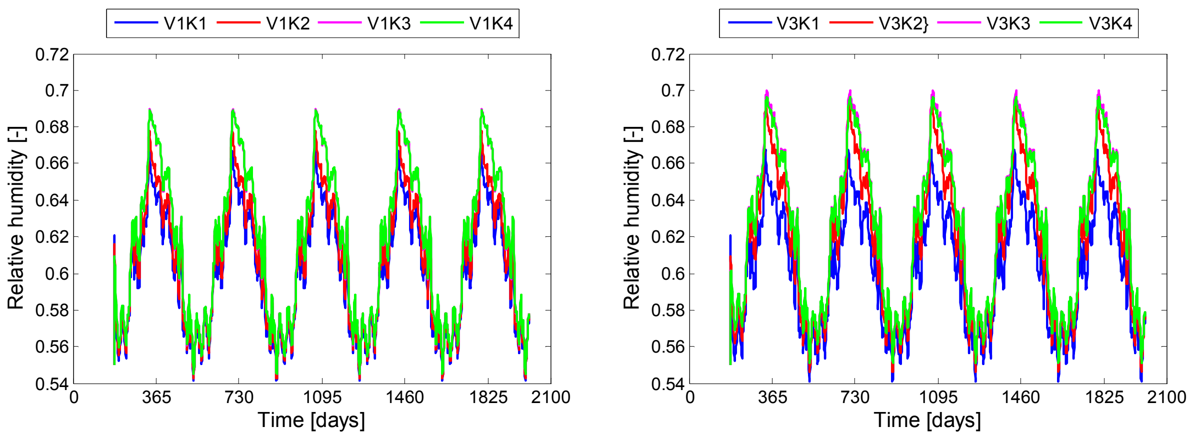

Figure 3 Relative humidity in A-A´ profile, brick wall - a) μ_{ret} =5 ,b) μ_{ret} =50.

Figs. 4 a,b show that also the relative humidity in the B-B´ profile (the interface between water vapor retarder and brick wall) was sufficiently low, and no risk of water condensation appeared there.

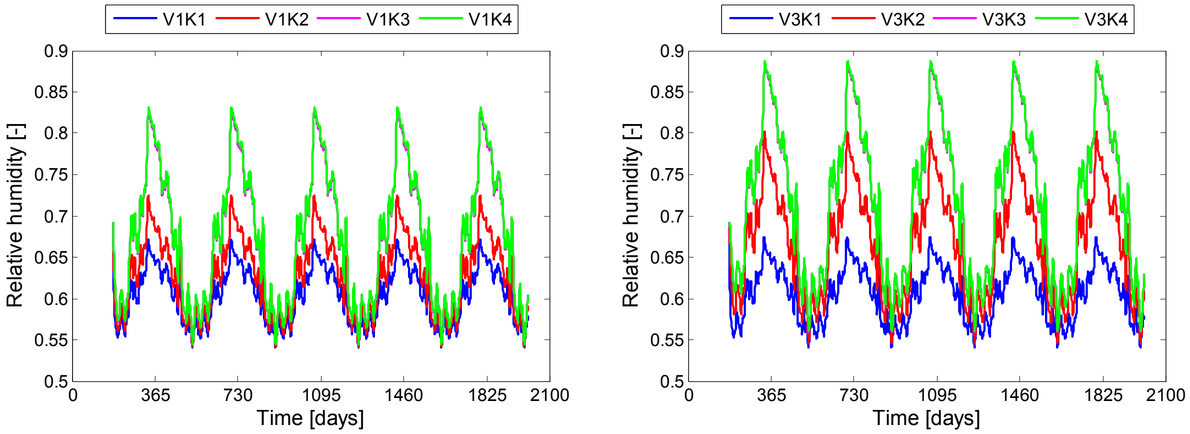

Figure 4 Relative humidity in B-B´ profile, brick wall - a) μ_{ret} =5 ,b) μ_{ret} =50.

4.2 Alternative No 2 – concrete wall

Figs. 5 a,b show the relative humidity in the A-A´ profile (the interface between thermal insulation and water vapor retarder), Figs.6 a,b in the B-B´ profile (the interface between water vapor retarder and concrete wall). For all variants of retarder the maximum values of relative humidity in both profiles were far from the condensation danger.

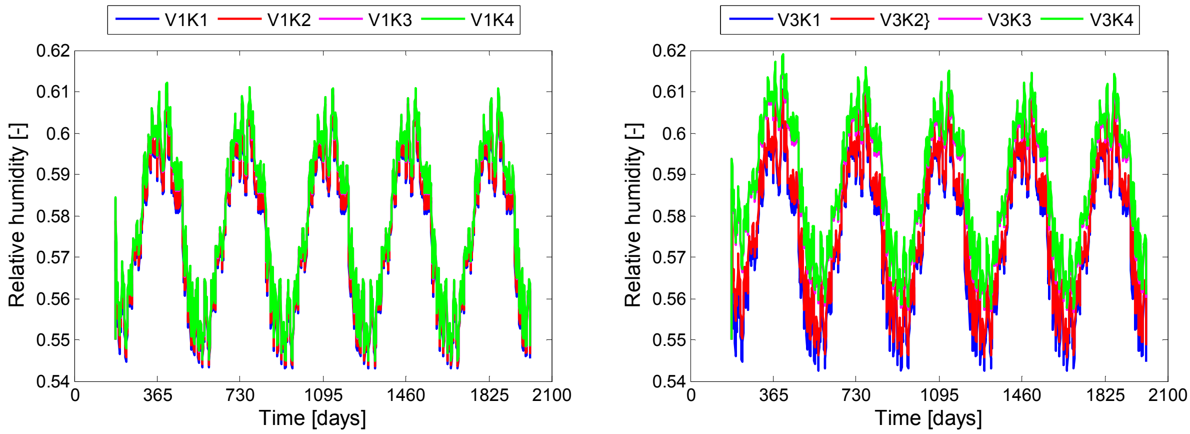

Figure 5 Relative humidity in A-A´ profile, concrete wall - a) μ_{ret} =5 ,b) μ_{ret} =50

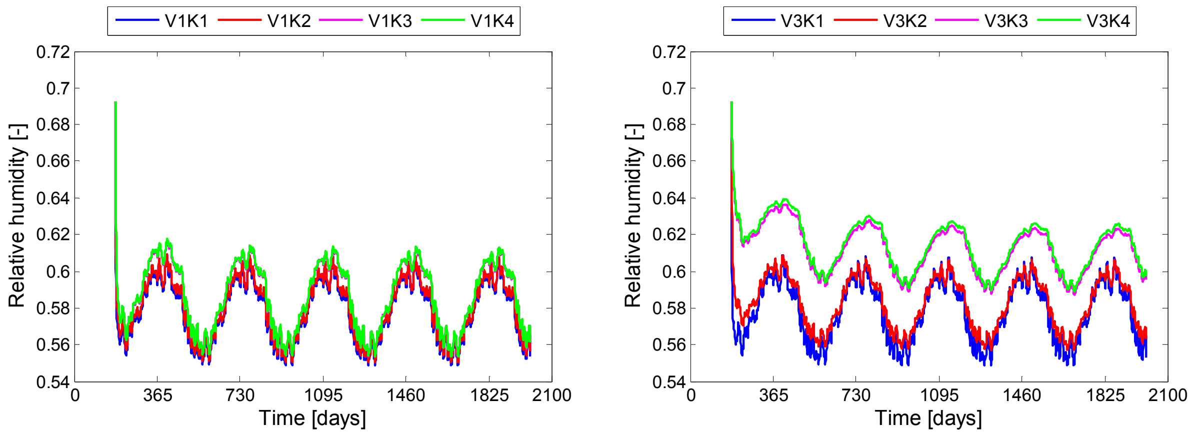

Figure 6 Relative humidity in B-B´ profile, concrete wall - a) μ_{ret} =5 ,b) μ_{ret} =50

4.3 Alternative No 3 – sandstone wall

Figs. 7 a,b present the relative humidity in the A-A´ profile (the interface between thermal insulation and water vapor retarder), which were far from the condensation limit. However, Figs.8 a,b show that in the B-B´ profile (the interface between water vapor retarder and concrete wall) for some combination of properties of water vapor retarder the risk of condensation may become real.

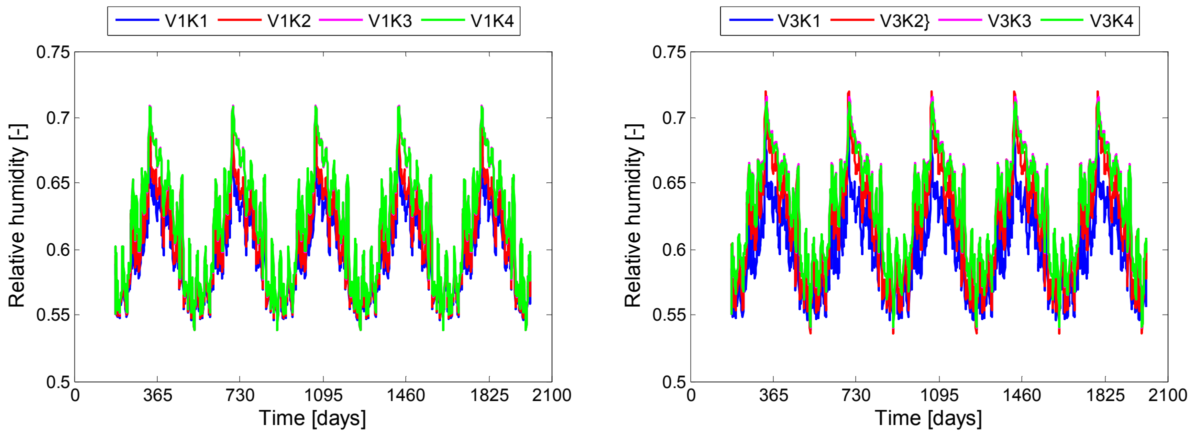

Figure 7 Relative humidity in A-A´ profile, sandstone wall - a) μ_{ret} =5 ,b) μ_{ret} =50.

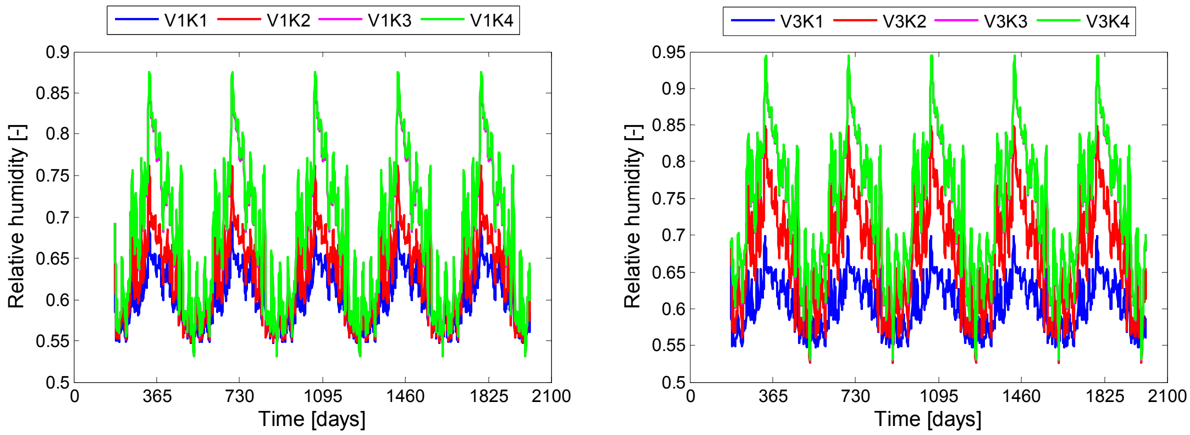

Figure 8 Relative humidity in B-B´ profile, sandstone wall - a) μ_{ret} =5 ,b) μ_{ret} =50.

5. Discussion

Computational results summarized in the previous section revealed that for the brick wall the optimum combination of hygric properties of water vapor retarder was: μ = 5, θ_{hyg} = 0.02 m^3/m^3, κ = 1.10^{-6} m^2/s. The maximum values of relative humidity in the whole envelope were during the five-year calculation time period lower than 68 %, which is safe from the point of view of possible water condensation. On the other hand, the combination with μ = 50, θ_{hyg} = 0.005 m^3/m^3, κ = 1.10^{-12} m^2/s resulted in maximum relative humidities on the interface between water vapor retarder and brick wall which can be considered as a critical place in the construction of about 90% - this does not mean water condensation yet but the RH value is already near the condensation limit.

In the concrete wall the maximum values of relative humidity were lower than in the brick wall, 64% for all studied variants of hygric properties of water vapor retarder. This was a consequence of very low water and water vapor transport rate in concrete combined with very high water and water vapor transport rate in hydrophilic mineral wool. For such combination of material properties of load bearing structure and thermal insulation layer the hygric properties of water vapor retarder apparently lost their significance.

For the sandstone wall the results were qualitatively similar as for the brick wall. The optimum combination of hygric properties of water vapor retarder was: μ = 5, θ_{hyg} = 0.02 m^3/m^3, κ = 1.10^{-6} m^2/s. The maximum value of relative humidity was 69% in this case. The other extreme in hygric properties of the retarder, μ = 50,

θ_{hyg} = 0.005 m^3/m^3, κ = 1.10^{-12} m^2/s, led to an increase of relative humidity on the interface between water vapor retarder and brick wall up to 95% which already meant that the condensation risk might be very high.

The results of computational simulations with very different properties of load bearing structures and water vapor retarders made possible to formulate some generalizations for the studied system. The combination of hygric properties of water vapor retarder in the form μ = 5, θ_{hyg} = 0.02 m^3/m^3, κ = 1.10^{-6} m^2/s resulted in flawless hygrothermal performance of the interior thermal insulation system on mineral wool basis with Dachrock mineral wool, no matter the type of load bearing structure. This is a very positive outcome of the computational design performed in this paper. The mentioned properties of water vapor retarder can be met quite easily; any common lime plaster or lime-metakaolin plaster with up to 25% of metakaolin as lime replacement have the required properties [Jerman et. al. (2007b)].

6. Conclusions

The computational results presented in this paper confirmed that computational design of hygric and thermal properties of materials in multi-layered building envelope systems can be considered as a good prevention of damage. In the computational simulations of hygrothermal performance of the studied interior thermal insulation system on hydrophilic mineral wool basis, an optimized universal variant of hygric properties of water vapor retarder was found which led to flawless hygrothermal performance of the system for all types of analyzed load bearing structures. In addition, proper materials with the hygric properties identified as optimal were found as already available on the market. This is a very prospective outcome because the designed solution can substantially reduce the risk of water-induced damage due to the improper use of materials in the interior thermal insulation systems in the building practice.

Acknowledgement

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Some diversity for low income housing in downtown areas of São Paulo City

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Abstract In contrast to Europe's inner cities, whose typological standardization instills a sense of coherence and harmony in its already built heritage, São Paulo's inner city landscape is contradictory, hybrid and contiguous. It has been continuously reconstructed, although its present configuration remains from the episodic 20's and 30's transformation, and to a certain degree, more accentuated, based on the 50's and 60's last century's changes.

São Paulo City's central area problems are related to its historical past, its geographic base, its urban development as a whole and its local economic context, which have gone through great changes in the last 40 years. The reconstruction of its buildings on the same nesting level in old urbanization areas mark the city's evolution aspects, the soil parcel which represent a specific period, as well as the consequence of the building code in effect, inside the limits of neighboring scale parameters.

Since the 1980s, inner cities in developing countries as Brazil have faced the deterioration in their living conditions. In such cases, low-income population lives in precarious housing conditions with the lack of proper ventilation and insulation for thermal comfort. However, all show characteristics of degraded dwellings, with high density population and cohabitation. The tenement houses occupied by squatters (*cortiços*) occur in old large houses of the central area, which have been transformed in collective dwellings.

Actions from an architectural project proposed vision are intended to meet the future users' needs. This housing complex, which is based on the Performance Program in Tenement Houses (PAC), deals with broad aspects rather than narrowing them down to city planning, urban opportunities and dwelling units to be offered to a population that prefers to live in the downtown area and needs dwelling solutions to suit their income needs.

Key words: urban renewal; public sector investments; low-income housing projects; sub dwelling.

1. Central areas

In contrast to Europe's inner cities, whose typological standardization and/or stylistic definition from the 19th century capital cities, São Paulo City instills a sense of coherence and harmony in its already built heritage, and its inner city landscape is contradictory, hybrid and contiguous. It has been continuously reconstructed, although its present configuration remains from the episodic 20's and 30's transformation, and, to a certain degree, more accentuated, based on the 50's and 60's last century's changes. This process resulted in a city that does not display a united architecture vision, but a sedimentary one, in terms of urban life accumulation (Benfatti *in* Schicci, 2004).

Problems in the inner central area are related to its historical past, its geographic base, the agglomeration urban development as a whole, the local economic context, the country and even the world. Today, evident problems are shown in different dimensions and with interrelated specific aspects that elapse the proper process of São Paulo City's urbanization.

The process of depreciation of downtown buildings, in a broad sense, is directly linked to the phenomenon of abandonment of the area by the elite city dwellers. This process started late in 1990's, with the city growth due to the coffee expansion. From 1870s, the urban expansion surpassed the limits of its historical peak, originally, the place where the city was founded. The elite land divisions had moved towards the West, which was topographically more favorable, and the Southwest, while the railway line and the flooding fertile valleys areas of the Tamanduateí and the Tietê Rivers depreciated the Northern and Eastern areas, where popular and/or industrial districts were established. In the subsequent decades, this dichotomy reproduced the structure of the wcity's central area. A new downtown area (known as the "New Downtown") was consolidated in the direction of the new elite districts and their surroundings. It consolidated a new Center (known as New Downtown), with the establishment of commercial, cultural, prestigious leisure activities, which are more significant than those from the old downtown area (known as the "Old Downtown"), that continued to house the business sector. There is nothing more emblematic about this transfer than the moving of the elegant department store named Mappin from Praça do Patriarca to Praça Ramos/ Rua Barão de Itapetininga (Silva *in* Schicci, 2004).

Up to 1950-1960, the downtown area, in general terms, continued to be an area of reputation and a symbol of identity for the metropolitan population, specially the upper class. During the coffee hegemonic economy period (from 1870 to 1930), the downtown was the object of interventions, "widening and realigning streets, creating representative public areas (Largo do Palácio, Praça da Sé, Praça Antonio Prado and Praça do Patriarca), stimulating the substitution of colonial houses for small commercial buildings and an eclectic architecture, prioritizing its tertiary and institutional use, adopting sanitary policies, remodeling and removing the "undesirable" bad customs and inhabitants such as tenement dwellers, laborers, sub dwellers and prostitutes. Construction works, demolitions and sanitary norms used to promote the urban segregation, differentiating the entitled urban sectors to assume prestigious functions, particularly in the central area.

In the 1980s, a new and serious shock was granted against the prestige of the Central Area: a consolidated competition between Avenida Paulista and a business center at Avenida Faria Lima was reinforced through the appearance of a fourth center around Avenida Luis Carlos Berrini. In the 1990s, it was the time of the Pinheiros River surrounding area. Thus, there were many new sites for rent, distant alternatives and relatively not entailed to the downtown area, especially for the branch offices of leading global corporations (Silva *in* Schicci, 2004).

On the other hand, the construction of the North-South subway lines (1968/1974) and the East-West lines (1975/1986), crossing themselves under Praça da Sé, and the consolidation of the bus terminals at Parque Don Pedro II and Praça da Bandeira, among others, guaranteed exceptional accessibility conditions to the historical center in terms of mass transportation. This contributed to modify the profile of the users from downtown, and this area became a point for trade and services. The low income population, which could once be found in the Old Downtown, after 1985 could also be seen in the New Downtown, when the subway access was facilitated by the extended lines at Anhangabaú and República stations on the East-West line, and by the bus corridors on Avenida Nove de Julho and Avenida Rio Branco. The higher income population, in turn, as well as the business and cultural related activities, migrated towards the southwestern area, abandoning the central area. It is also important to notice that the two first subway lines did not establish connection with the other financial centers and offices, contributing, thus, for downtown's isolation process.

One of the most emblematic elements of this elite center transfer of the City Hall and the state of São Paulo's government premises to Parque do Ibirapuera {1} and the district of Morumbi {2}, respectively. These geographic transfers, not by chance, followed the territorial saga of the middle and high income populations along the city's southwestern vector (Silva *in* Schicci, 2004).

1.1 Residential Evacuation

The demographic evacuation of city's central region constitutes an undisputed reality. In 1980, the administrative subdistrict of Sé, which corresponded nearly to 526 thousand inhabitants, continued to lose its dwellers in a way that it had about 355 thousand inhabitants in 2002. This administrative subdistrict shelters the districts of Sé and República, which once used to be densely populated, coexisting with the commercial, services and institutional activities. In the last two decades, these districts have been characterized by an important population loss, which is associated with a great percentage of empty residences and partly or totally abandoned buildings.

Many streets which had various traditional activities, now have become completely empty after the working hours, the same has happened to the districts. This residential evacuation constitutes a problem, for the urban vitality depends directly on its mixed activities. Beyond the negative implications regarding the optimization of the installed infrastructure, the residential evacuation constitutes an aggravating circumstance to the safety conditions, so that downtown is once again occupied after the commercial hours. Therefore, an important objective of the municipal urban policies is to repopulate the downtown area so as to prevent peripheral expansion and to strategically stimulate downtown's recovery, which will contribute to the sustainability of this process (Silva in Schicci, 2004).

2 Tenement houses in São Paulo: An Old and New Topic

The tenement houses (*cortiços*), appear in the City of São Paulo late in the 19th century, from the decade of 1870 due to the coffee industry expansion, when the city faced a significant population increase, whose demand for housings was unproportional if compared to the existing offers. The demand which was created in the city, consisted mainly of immigrants, and resulted in the

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1 The headquarters transfer of the municipal administration from downtown at Rua Florêncio de Abreu, in Parque do Ibirapuera, was taken in a precarious way in 1955 and on a more effective way in 1956. The return to downtown happened in 1990, during with mayor Luiza Erundina's administration.

2 The headquarter transfer of the government state administration from Palácio dos Campos Eliseos to Palácio dos Bandeirantes was determined in April, 1964 by governor Ademar de Barros (Decree nº. 44.735). In the beginning, the new headquarters were used only eventually and they became definitive from 30/3/1970, during governor Abreu Sodré's management.

establishment of the improvised, profiting market for precarious housings for rent, most of which are collective dwellings.

The inadequacy of these houses' conditions allied to the city's precarious infra structure and the existing public services, composed a bad picture of the public health conditions, that opposed to the public power interests in promoting the necessary improvements for the urban downtown consolidation, in harmony with São Paulo City's attained economic importance at that time. The city's population, however, did not stop growing and in the first decades of the19th, the increase in the industrialization process provoked a new population growth. The industries started to be installed in the surroundings of the downtown area, stimulating the sprouting of new tenement houses in the intermediate areas such as Brás, Moóca and Pari, and even in more centralized areas, that already showed signs of deterioration, as Campos Elíseos (Silva and Caldas, 2005).

In 1934, the Arthur Sabóia Building Decree definitively banned the construction of the tenement houses in downtown and determined the demolition of the existing unhealthy ones. The objective of these legal measures was "to push away" popular dwellings from the central area offices and ended up determining the irregularity of this type of housings. Nevertheless, they continued to exist clandestinely (Bonduki, 1998). Between 1940 and 1950, the industrialization consolidation boosted Sao Paulo's City population from 1,3 to 2,2 million inhabitants, extending the demand for dwellings that started to be formed in the outskirt areas, which stressed the significant urban expansion of the city, and also stimulated the collective transportation provisions for more distant regions of the urbanized area {3}.

In spite of the restrictive legislation and the stimulation of the popular dwellings in the peripheral areas, in the decade of 1970, 8% of the city's population lived in tenement houses (Simões Jr, 1991). In 1986, the city's administrative office promoted a new research on the problems related to the tenement houses, whose final report (PMSP/SEMPLA, 1986), presented a broader approach to the urban status of the problem, pointing the confirmation of the following factors:

- *Most tenement houses which were researched were located in urbanized consolidated areas, 92.3% of the neighboring area's occupation rate was higher than 75%;*
- *94.3% of the properties which were originally considered tenement houses were located in areas that had been popular residential districts. Most of them were built during the establishment or consolidation of the districts, demonstrating that this category of tenement houses, in contrast to the adapted ones, followed the urban processes in such areas, and were not originated from them;*
- *Of the adapted properties, 90% were located in districts that, already in 1930, were densely or relatively occupied, which make us believe that this type of category of tenement houses is a characteristic of the old occupation in the districts, and that 56.6% of them occurred in districts considered of average residential standard at the time when they were created, such as Liberdade, Vila Mariana and Perdizes;*

3 For specific information about the City of São Paulo, see Bogus, L. and Pasternak, S.: *Como anda São Paulo,* in Cadernos Metropolis special number. São Paulo, 2004.

- *Therefore, it could imply the existence of two bind basic slum tenement processes at different times in the evolution of the districts: While the old urbanization areas, which had gone through transformations and led initially to the creation of slums, appeared in the districts as popular houses since their origin, and had already been conceived for this purpose. The districts which congregated both of these characteristics, that is, the old and originally popular patterns, as Brás, Pari and Moóca, have the two property categoriesf, although they appeared at different times.*

In 1994, the Institute of Economic Research (FIPE) promoted a research on the real estate of the tenement houses' characteristics and their occupants, complementing the data and consolidating the final report in 1997, with an inquiry on the terms of payment, stability and the relation between local work and housing of the target population. This research disclosed the magnitude of the problem: 600,000 people, almost 6% of São Paulo City's population, lived in 24.000 tenement houses. Late in the 1990's, São Paulo City had a lower demographic growth rate than those of the last decades. Its growth rate was 1,16% during 1980-1991, and just 0.85% during 1991-2000, according to the Brazilian Geographic and Statistic Institute's (IBGE) statistics.

2.1 Dwelling alternatives for São Paulo's low income population

Tenement houses represent a significant segment of habitation in São Paulo City, and portray the city's urban poverty as one of its oldest modalities. In 1896, the public sector (Law 286) defines the tenement houses as (Piccini, 1999):

Art. 13 – a tenement house can be defined as a set of two or more common dwellings in a same lot, that communicate with public streets with one or more entrances that serve more than one family.

Sole paragraph: each one of the tenement house's units is called room or cubicle.

Art. 14 – Cubicles are also defined as rooms from houses other than tenement houses, the ones that are divided into different rooms, each of them having a stove, and the ones that are added to them in these same conditions.

It could be perceived at that time a concern with the phenomenon of the existing conceptualization. In 1991, a century later, the Moura Law defined a tenement house according to these habitability conditions:

Art. 1 – A tenement house is defined as a collective dwelling unit, showing partly or totally, the following characteristics:

a) constituted of one or more buildings constructed in a single urban lot;
b) subdivided into many rented, sub rented or free to use;
c) a large number of people in the same room;
d) common use of not built spaces, sanitary facilities etc;
e) circulation and infrastructure in precarious physical conditions.

In the years following the metropolis expansion, the popular stratus had found another alternative, which became dominant, the tripod: one's own house, self-constructed and in irregular peripheral land division. Strengthened by the collective demand for bus transportation, substituting the trams, the city would follow a standard of expansive growth in a more distant direction towards the periphery, along the radial roads.

Table 1 shows that in last decade, central, interior and intermediate geographic rings had lost increasing population rates, while the periphery continued to grow, still in a less fast rhythm.

Table 1 – Taxes of population growth by geographic ring percentage. São Paulo City: 1960, 1970, 1980, 1991 and 2000

Geographic Ring	1960-1970	1970-1980	1980-1991	1991-2000
Central	0,69	2,23	-0,94	-2,05
Interior	0,08	1,26	-1,17	-1,78
Intermediary	2,79	1,28	-0,71	-0,79
Exterior	5,52	3,13	0,83	0,13
Peripheral	12,81	7,39	3,05	2,71
Total	4,79	3,66	1,13	0,92

Source: Pasternak, S and Bógus, L, (2004)

It can be observed that in the 1990s, the occupied lands in São Paulo City are the worst quality in topographic terms, areas with a lot of descending slopes with a precarious road system which is not articulated to the main city's. In this growth panorama of the periphery and significant expansion of the slums, the tenement houses are located mainly in the central area and continue to be an important dwelling alternative. There are several reasons and perhaps the most important question nowadays is the possibility of access to work {4}.

2.2 Characteristics of São Paulo City's tenement houses

The Santa Ephigenia Workers' Dwellings and Tenement Houses Examination and Inspection Commission Report of 1893, already presented the different typologies that had been found in that district and located each of its streets. It is possible to identify a relation between the tenement housing and the urban space organization processes in São Paulo City. In the type described as backyard tenement houses, which occupied the center of the blocks, with a small corridor for access, as reported in this Report from 1893, are associated with the formation of the industrial districts late in the 19th century and early in the 20th century and were mainly occupied by the workers population. These tenement houses appeared in the districts of Brás, Cambuci, Pari, Moóca and Barra Funda.

The tenement houses that had been created by the large houses' subdivision are a consequence of the gradual displacement of the upper and upper middle classes in direction of new areas with more prestige, abandoning the old districts as Campos Elíseos, Santa Cecília, Consolação, Vila Mariana and Aclimação. Some of these houses had been rented and gradually sub rented.

4 To understand São Paulo City's urbanization pattern, see Pasternak, S*: Dwelling alternatives for low income population: concept, measure and evolution in São Paulo City* in Synopsis no. 37I. São Paulo, 2002.

In 1975, the Social Welfare Secretariat, studying the phenomenon based on the municipality's real estate registration data, estimated that 9,3% of the population lived in tenement houses. The tenement houses' concept was of a collective dwelling unit for rent purpose, that is, "*it refers to the set of the existing constructions in the same urban lot, which can assume 3 forms: large old houses, basement used for living and precarious small buildings covered by lean-to roofs. These forms occur separately or in a combination. Another characteristic of these constructions is their subdivided rooms for rent (or sublet), although they rarely have a written rent contract (…).*

The book "Tenement Houses: face and reverse", published by SEMPLA (Municipal Planning Secretariat), describes the tenement house occupants' living conditions. It is estimated that there are 2.700.000 tenement house dwellers; which is nowadays considered overestimated. Regarding work hypothesis, it was known that the tenement house growth population rate grew as much as the slum population's due to the same impoverishment conditions. (PMSP, 1985).

The Institute of Economic Research (1991), by using the operational definition of tenement houses of Law 504/89, called Moura Law, made a research trying to up-to-date the data about tenement houses and to reduce the uncertainty from the estimates. This was a sample research, choosing randomly the people it was addressed to and based on the density of the tenement houses which were indicated by the municipality's real estate registration data from the Secretariat of Finance. There was an estimate that 23,688 properties were used as tenement houses in São Paulo, having 160.841 families and a population of 595.110 inhabitants, which corresponds to approximately 6% of São Paulo City's population. The data indicated that 46% of properties had been constructed for the main purpose of becoming tenement houses. The indicators showed this exiguity of space and comfort: the average area of the houses is 11.9 square meters, with 4.1 square meters for each person and 7.04 houses in each real estate; the number of people in each house is 2.90, 2.45 people in each room; there are 6.32 people for each shower, 9.25 for each sink, and 5.91 for bathroom. According to the Institute of Economic Research, in 1994, from all the people who lived in the tenement houses, 42.8% had a job. The workers' monthly income was, as it was already expected, very low: the great majority – 51.8% - earned from 1 up to 3 minimum wages. But 14.2% of the workers earned over 5 minimum wages (Moreira et al., 2005).

The rent paid by the dwellers for their houses, one month before FIPE's research late in 1993, was up to 0,5 minimum wages; the rent was between 0,5 and 1 minimum wages for 26% of the houses. The electric and water consumption, for the majority of the families in 1993 was less than 0,25 minimum wages.

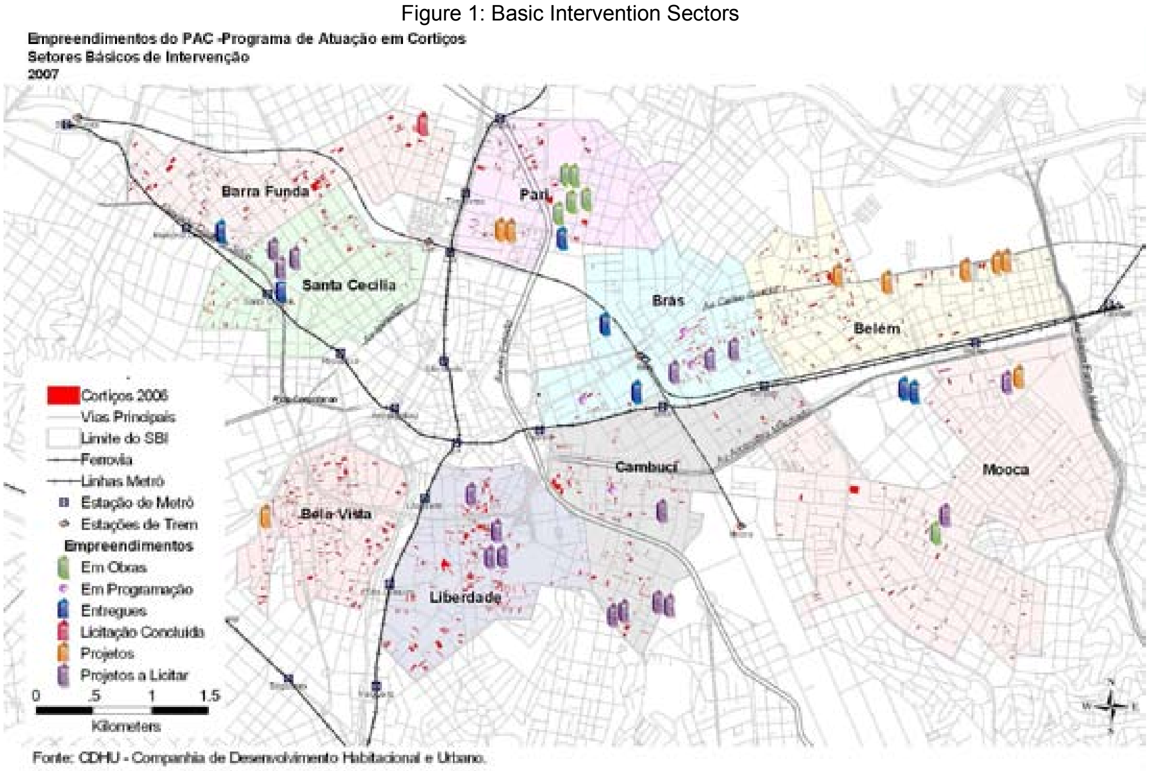
3. Action Program in Tenement Houses

PAC is the Housing and Urban Development Company of the State of São Paulo program (CDHU), a partnership with the Inter-American Development Bank (IADB). This financing program was created by the State Government's decree in 1998 in association with Inter-American Development Bank. It was effectively implemented in 2002 after a loan contract with the IADB had been signed, in the total amount of 70 million dollars in its initial phase. For the investment, USS 34 million came from IADB and USS 36 million, on the counterpart, from CDHU. For next phase of program, an additional investment of 150 million dollars is foreseen, USS 76 million from IADB and USS 74 million from CDHU, totaling a USS 220 million investment (Operational Regulation (PAC), 2002). Of the reimbursed expenditures of IADB, 21% is addressed to the management program; 50% is to the social work; 55% is to the institutional strengthening; 50% is to the credits and subsidies and 100% to the auditing activity. It is a multistage program, since it constitutes innovative introductory steps of the public social policies of the State Government. CDHU is responsible for the development and execution of Housing Programs in the State of São Paulo.

CDHU initiated its action’s strategic planning, delimiting priority areas for slum tenement population attendance, establishing defined space goals in favor of the slum tenement property concentrations, divided in Basic Intervention Sectors of (BIS). The objective of this space delimitation was essentially to program planning activities, project, group demand organization and the dwelling solutions management for the target families that would benefit from the program.

BIS comprehends these districts in São Paulo City: Barra Funda-Bom Retiro, Pari, Brás, Belém, Moóca, Cambuci, Liberdade, Bela Vista and Santa Cecília, whose total area is about 12 square kilometers. Its area of influence is estimated to be 44 square kilometers and it has a population of 516.000 inhabitants. PAC also acts in Santos, in the degraded area surrounding its port, in the district of Paquetá. In the BIS from Santos, (SEADE 2002) the totaling 340 tenement houses, with 2.992 residences and an estimated population of 7.802 inhabitants. Here, a tenement house is defined as an irregular one-family housing unit for rental purpose for the low-income class, subdivided into informal rooms for rent, which are located in areas with complete infra-structure - with precarious living conditions, having collective access, sanitary and laundry facilities. Tenement houses are private properties and have a known proprietor, through deed, although it may not be easy to contact the owner.

Figure 1: Basic Intervention Sectors



4. Objectives and features

PAC is aimed at promoting urban regeneration by recycling old buildings and by building new dwellings in downtown areas in order to improve the living conditions in degraded squattered settlements, optimizing their urban infrastructure, collective services and the public equipment already installed by the high public investments that were made in the past. In this first phase, CDHU, through PAC, privileges services to the low income families, who already lived in these downtown areas in São Paulo City and in Santos.

In the census registered property, it had confirmed the foreseen building types, as Picture 1.

Picture 1: Tenement building typology

Two-story houses 52,0%

Single level houses 47,4%

Multi level buildings 0,6%

Source: SEADE (2002)

High population density was verified, where 35 % of the tenement units have between 10 and 20 “residences”. The most preponderant physical characteristic in most of these residences is that the domestic activities such as rest, food preparation and hygiene, all take place one single space, harming the families’ quality of life. This lack of space makes some families, almost 15%, improvise internal thick partition walls, creating different environments to separate the "kitchen” from the "living room", as shown in Picture 2. However, more than 25% of the residences do not have windows in any of the rooms used as bedrooms, or they were obstructed by furniture that harms their internal ventilation. The collective use of the bathroom is for 85 % of the residences, and the shower is usually electric. To do the laundry, nine in every ten residences share the same washtub. The food preparation is made inside the residences and, since most of them have a few rooms, their occupants must use a stove (or a camping stove) in the same room which is also used as a living room or as a bedroom (SEADE, 2002).

Picture 2: Tenement houses

Photo: PAC/CDHU

4.1 Financing Resources

PAC, a dwelling financing program, provides credit for the tenement house dwellers through part of the ICMS tax (- a value added tax on goods and services – collected from specific industrialized products and services) and it is complemented with IADB's resources. In its first stage, PAC is aimed at helping 3.5 thousand families that will be living in tenement houses by 2009.The program always intervenes in existing buildings. CDHU acquires buildings to recycle or rebuild them, and lease them back to the same families, who had lived in them previously. IADB created the *self focus* concept to be introduced to PAC, where the beneficiary parts decide upon the credit options that are offered. As a result of the high population density in them, PAC must offer different credit options to families with different social-economic levels.

There are four credit options available: 1- *Individual Letter of Credit* to purchase a dwelling in the formal existing market, offering up to R$ 45 thousand, R$14 thousand of which (equivalent to US$ 5 thousand, in June 2002) are subsidized and financed to the families; 2- Financing an existing unit through CDHU's programs in other areas of the city; 3- Leasing a dwelling unit built by CDHU in downtown through the PAC program, for the first 5 years, to those earning up 3 minimum salaries, and the same US$ 5 thousand in subsidies, and after that period, the renter may become the borrower; 4- *Government Assisted Aid* provides a R$ 1.8 thousand aid for the temporary payment of rent for six months, for those families financially unable to take the previous options.

Table 2 PAC Production, in February 2008:

Table 2: PAC Production

Dwelling attendance		nº. UH
Commercialized dwelling units		**792**
Letters of Credit		**228**
TOTAL		**979**
Dwelling creation units	work in process	762
	project	465

Source: PAC/CDHU

In this production, 62% of the acquired properties through a letter of credit are located in the central area of the city. The amount spent on the dwelling access, already with the expenditures registered in the notary's office, corresponds to 30 % of the amount of the contract until February 2008.

PAC has an interface with the PMSP – São Paulo City's Administrative Office, by a Protocol of Intentions, signed between CDHU, SEHAB and COHAB, from December 19th 2003, whose objective is:

- to define performance ways that aim integrated action between State and the City Hall Administration;
- to integrate PAC (State Government) and *Live in Downtown,* a program from *the* City Administration Office's (PMSP) actions;
- to integrate and to articulate the municipal planning licensing and to verify the use to which the Program intervention will be object;
- to establish the creation of a partnership for the social dwelling which is focused on meeting the tenement dwellers' demands.

In respect to the accomplishment of the partnership, CDHU supported the technical actions from Moóca's regional administration according to Moura Law's enforcement, with the inspection of 450 tenement houses, foreseeing its recycling potential through refurbish.

4.2 The Target Public's Social and Economic Conditions

The social economic situation of this population living in all BIS researched tenement houses by the State of São Paulo Data and by the Analysis Foundation (SEADE) in 2002 (Table 3 and 4) are characterized by average young people aged up to 29, 55% of whom are male. Families are smaller than the usual standard, with 2.3 people, but with distinct composition, since only 25% of them are households with children. Half of the families with children in the researched area have only one child, followed by those with two children, with ages between 0 and 14. In terms of employment, 89% of the head of the households have formal jobs. However, the predominance for low income families is to earn 3 minimum salaries, from which rent payments represent 45% of the total income. Regarding formal instruction, the majority of head of households has no schooling and some have attended less than 4 years in elementary school.

Table 3: Some PAC research results: *cortiços* and *cortiço* inhabitants

Districts/ PAC Areas	Tenement houses	Tenement house's population	% tenement houses' population
Barra Funda/Bom Retiro	146	2.990	10,77
Bela Vista	323	8.501	22,13
Belém	177	3.473	14,84
Brás	128	2.734	18,45
Cambuci	163	3.384	17,43
Liberdade	331	9.407	23,23
Moóca	111	1.668	3,53
Santa Cecília	123	3.470	10,79
Pari	146	2.775	19,11
Total	1.648	38.403	15,75

Source: CDHU/SEADE (2002)

Table 4: Some PAC research results: dwelling index

PAC Area	People by building	Residences by building	Families by building	People by residence	People in each family
Bom Retiro/Barra Funda	20,48	8,79	9,01	2,33	2,27
Bela Vista	26,32	10,21	11,23	2,60	2,37
Belém	19,62	7,19	8,01	2,74	2,45
Brás	21,26	9,85	10,28	2,18	2,18
Cambuci	20,76	6,76	7,52	3,07	2,76
Liberdade	28,42	10,07	10,77	2,82	2,64
Moóca	15,03	5,86	6,19	2,57	2,43
Santa Cecília	28,21	11,37	12,23	2,49	2,31
Pari	19,01	7,00	8,02	2,71	2,38

Source: CDHU/SEADE (2002)

5. Selection and intervention strategies

The Sectorial Projects were responsible for the diagnosis elaboration aimed at pointing the possibility of tenement houses' intervention. Focused on the appropriate use of the soil and the standard dwelling improvement of these existing properties, it provided a description of the urban characteristics and their dwelling conditions in the studied areas, with successive approaches, comparative analyzes, with the SBI's intervention formulating plan. The attainment of solutions for the dwelling took the urban, architectural, social and economic aspects into account.

The results prioritize the purchase of property complexes involving all the SBIs, as shown in Table 5. These addresses had been identified through the prioritization of intervention parameters and criteria, considering the tenement houses' specific construction and urban aspects. The confirmation of the prioritized enterprises was based on the performance level of evaluation, after a research identified *a priori* the estimated number of houses and units in each complex, according to PAC production rules (Table 6).

Table 5: Sectorial Projects

	Sectors of Intervention characterization	Sub sector intervention potential	Interventions Prioritization	Viability Studies	
Survey from SEADE 2001	Urban Aspects	Sub Sectors Characterization	Deed analysis	Social Housing Building Potential	**Sector Consolidation Studies**
	Legal Aspects	*Added tenement houses records*	Potential of Use	Cost + Property Evaluation	
	Preservation Aspects	Preliminary Classification	Property Status	Buying Availability	
	Public equipment Infra structure	Physical / legal characteristics : list	Viability Verification	Typology	
	Vacant lots and Public real estate		Occupation/ degradation areas	Complete viability studies	
	Tenement Houses' Mapping SEADE (esc1:2000)		Real estate complex identification		
	Tenement Houses' gathering (confirm)				
	Thematic maps **P1**	Tenement Houses' Real Estate prioritized list **P2**	Prioritized property listing **P3**	Viability by levels of priority **P4**	Offer X Demand 1st phase implantation 2nd phase: supply **P5**

Table 6: prioritized enterprises

Basic sector of Intervention	Prioritized Enterprises	Eradicated Tenement houses	UH's estimates
Barra Funda	2	3	62
Belém	5	16	300
Brás	6	14	315
Moóca	5	8	250
Pari	7	21	500
Santa Cecília	4	3	180
Bela Vista	2	1	138
Cambuci	5	9	400
Liberdade	4	7	250
Santos	7	14	245
Total	**47**	**96**	**2640**

Source: P4 Sectorial Project Simulation – 2004

6. Projects

As PAC's objective is to promote the life quality improvement for the inhabitants of the central areas, by offering a dwelling solution for the tenement house's population, its premise is to develop differentiated housing solutions, tuned with the family incomes and their size.

The search for dwelling typologies to attend the tenement houses' population, with family incomes between 2 and 3 minimum wages, represent 50% of the demand for this dwelling attendance, and requires specific actions from this project in the context of the downtown area. For the development of this differentiated typological alternative, it was observed a great incidence of families with up to 3 people and a significant number of individuals living alone. Architecture projects not only inserted this concept into the Sectorial Project for all Basic Intervention Sectors, but contemplated the existing social reality and the impact of the enterprises establishment as well.

Dwelling unit areas had been adjusted to a production value that could meet the payment capacity of tenement house dwellers' demand, highlighting PAC's adopted commercialization plan, with concessionaires' services and condominium maintenance taxes added to the monthly payment amount value. For the architecture conception and the complementary development projects, the following information was provided - the urban characteristics about the use of the soil and their occupation, the neighboring area, address, physical data, area, zoning and these respective factors: soil use coefficient and occupation rate, City hall's specific policies, State registered historical heritage area: the Historical, Artistic, Archaeological and Tourist Patrimony Defense Council of the State of São Paulo (CONDEPHAAT) and the property which already is or is in the process of being declared a registered historical building by the municipal Council for the Preservation of the Historical, Cultural and Environmental Heritage of São Paulo City (CONPRESP) and the procedures of the Technical Project Manual (CDHU, 1998).

6.1 Project directives

The establishment of these dwelling solutions requires the development of projects which prioritize small enterprises and crowded dwelling units. The existing lots deed and the urban situation, the real exploitation of the property, under PAC's premises to keep the current families living in the same central region, and the analysis of the feasibility studies assure the decision of use for such properties.

The existing property existing typology, reflecting the use and occupation of the soil, the very low lot density, the used constructive technique and the precarious preservation and/or maintenance of the property general situation, as well as the economic viability simulation, generally led to the demolition of the existing properties at these addresses and consequently; the construction of a new venture. For the purpose of fulfilling the requirements of the new Master Plan and the capacity of the full use of the constructive potential of the current zoning, it was necessary to annex the selected lots in each of the complexes, attending the zoning demands. The low verticalization, the ground floor partly occupied by dwelling units for handicapped people , and the four-floor type of building, without vertical type mechanical circulation, was considered the building typology that best fits this social class, since nonexistent elevators in the buildings reduce the condominium tax in 50%.

The incorporation of CDHU's current directives related to individualized water, light and gas consumption measurement to the new public services concessionaires' norms and the remote measurement technologies, recently incorporated to the low income housing projects are present in these enterprises. The adoption of these individualized measurement readings minimizes the sociability conflict among the future users of these new enterprises, allowing better condominium management actions. The region where the enterprises are established is served with all urban infrastructures and with gas canalization.

All the projects were developed and contracted in accordance with the Federal Law n. º 8, 666 from June 21, 1993 that sets up norms for bid at auctions and contracts, since the CDHU is a public administration company.

6.2 The project program

The functional set, the dwelling unit architectural proposal, and even the complex have increased the supporting and condominium service area, the entertainment in the collective area (uncovered) and the entertainment collective and external area (open air), front desk, water, electricity and gas measurement shelters and other infrastructure installations. However, the essential uses were preserved with the creation of space, with dimensions that allowed a more appropriate disposal of furniture and objects for the development of the foreseen functional activities in the program of use of the dwelling construction.

The dwelling units' architectural proposal observed the project premises as follows:

- the concentration of wet areas, rationalizing the hydraulic installations;
- optimization of stairs and circulation in common areas;
- the best potential occupation use observed in the low income housing building legislation;
- vertical multifamily typology with 5 floors;

The complex viability was established from the lot use feasibility studies, providing a program of the project as shown below, in Table 7:

Table 7: Dwelling typology

Functional set	dwelling unit
Kitchen, laundry area, bathroom, integrated bedroom and living room;	efficiency apartment
Kitchen, laundry area, bathroom, living room, one bedroom;	1 bedroom
Kitchen, laundry area, bathroom, living room, couple's bedroom, single bedroom;	2 bedrooms

The architectural design proposal is based on the following recommendations from the Manual of Projects (CDHU, 1998): to distribute, in a balanced way, the necessary spaces for the performance of the dwelling program project's defined functions, and to search for cost compatible solutions for the specific use it is designed for, both for the construction of the building and for its maintenance.

The designs shall be in accordance with the City's construction legislation norms, the municipality's urban soil parcel and use, and other matters to be verified by the designer in the City's Administrative Office, State and Federal Departments. All the technical areas which are involved in the projects' conception complied with all the appropriate and up-dated norms and techniques from the Brazilian Association of Technical Standards (ABNT).

6.3 Projects' Characteristics

The presented solutions have maintenance and condominium low cost, and are compatible with the income of the target population, minimize the environmental impact, and do not harm the functionality, security, hygiene and the aesthetic maintenance of the buildings. The Program's differentiated actions of this project have shown different solutions, lot sites and the specification of the finishing materials, such as the use of ceramic floor in all dwelling units' rooms. Photo 3 describes some the original situations of these properties that are object of intervention in the case of extirpation of the tenement houses which are located mainly in the Basic Intervention Areas (BIS), and shows the projects designed for these lots, as well as their its electronic maquette.

Photo 3: PAC's complex

Bom Retiro B

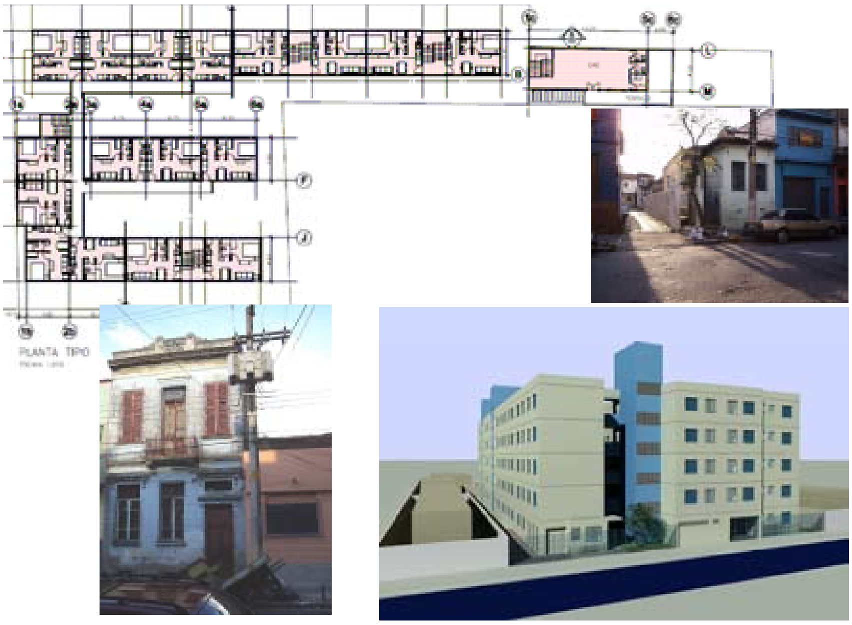
floor plan type; existing tenement houses; electronic maquette

photos and drawings: PAC/CDHU

Bom Retiro C

floor plan type; existing tenement houses; electronic maquette

photos and drawings: PAC/CDHU

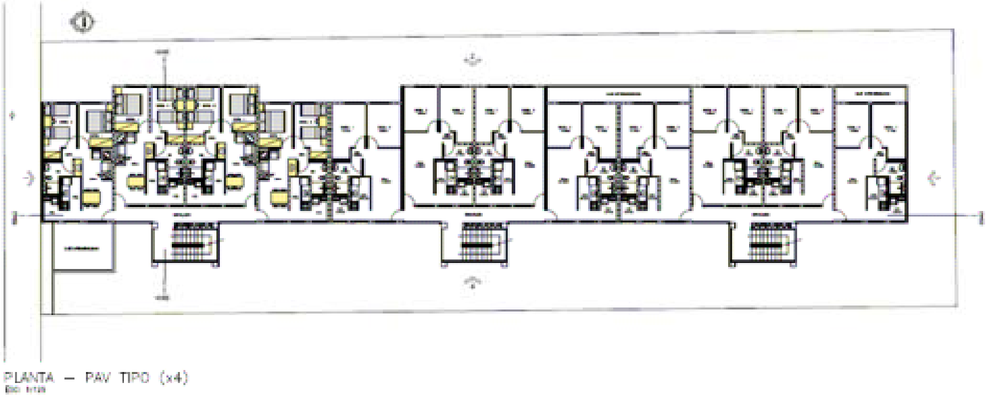


Bom Retiro D

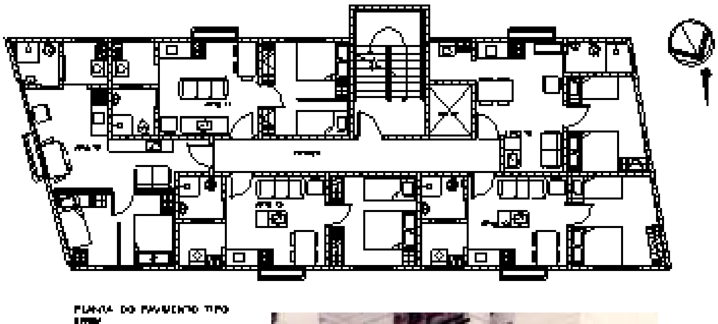
floor plan type; existing tenement houses; electronic maquette

photos and drawings: PAC/CDHU

Belém K
floor plan type; existing tenement houses; electronic maquette
photos and drawings: PAC/CDHU



Santa Cecília A
floor plan type; existing tenement houses; new building
photos and drawings: PAC/CDHU



7. Challenges and some special remarks

It is a challenge for the public sector to improve the provision of dwellings or to substitute the subnormal ones with physical delimitation in great cities' central areas, mainly in São Paulo City. The identification of the phases and evolution of this process, in order to better understand the broad context of the existence of the tenement houses, has allowed this recent diversity of dwellings of social interest which modify the characteristics of this universe to create data about the results which have been accomplished by this Program.

With the registration of some of PAC's actions in precarious tenements houses, it makes evident that the distinction between the Program's construction typologies and those designed for low income complexes of social interest located in distant consolidated central areas, since the urban lot and the differentiated zoning patterns allow it. The typologies proposed to meet the demands of the Program, which is characterized by new social groups, are crowded and completed dwelling units, which include: kitchen, laundry area, bathroom, living room conjugated with the bedroom, or an independent living room plus one or two bedrooms. In this recent universe of solutions, it is a novelty for CDHU to propose completed dwelling units with one bedroom or even a living room conjugated with the bedroom in vertical constructions and to commercialize dwelling units for people living alone, since one of the CDHU's requirements is addressed to people who have a family.

In the analysis of the procedures and development of these works, in some of the attained results, it was necessary to review CDHU's usual proceedings. The fact that the real estate selected for intervention is built in a small urban lot is a great challenge, totally different from the usual interventions. The materials' specification and specialized workmanship are other important aspects to be taken into consideration, as well as the construction to be installed in the site, which has specific characteristics and reduced dimensions, the addition to new routine tasks to be executed in civil engineering, for example, ready-to-use stucco that comes in packages easy to transport and to handle, among others.

The lots are not often located in registered historical area, which permits quick legal approval of the new enterprises in the competent departments. The necessary demolition of the existing properties in these lots was another novelty for CDHU, as well as the planning of the initial civil works and the attainment of the legal demolition conclusion document, followed by specific procedures from the City Hall, since CDHU used to intervene in great empty constructed or not constructed areas.

The project response to these central area proposals are the same as those of CDHU and other projects, in which the designer attempts to verify if it possible to adopt dwelling units with similar private area, with the rationalized optimization of the potential use of the lot. Both technological innovations and the individual water measuring for the vertical constructions were adopted, which besides meeting the demands of the new parameters of the water concessionaires, they minimize the social conflicts between the dwellers.

The commercialization of these dwelling units is made through the onerous concession contract for use during the first 5 years, and from that period onwards, this document is transformed into a contract of purchase and sell. Twenty-five years after the financing, the borrower becomes the proprietor. Such proposal aims at minimizing the dwelling unit sale process. The social work inserted into it is seen as a way to improve the dwellers' social living conditions and to make it possible for them to participate in the proposals to change their social and economic conditions and, consequently, their quality of life.

These punctual projects are a specific central area-related issue, and they have undoubtedly established a critical and creative dialogue with the existing city. City planning and project programs are based on traditional concepts and need a multidiscipline approach to meet the users' necessities.

The solution to fulfill these needs and the presented institutional responses shall have a long-term commitment.

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A STUDY OF THE GREENWAY NETWORKS IN SEOUL

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Summary

As the energy crisis becomes a matter of international concern, the Korean government hastens to institute green growth policies to conserve energy. Until now, environmental protection has been neglected for the sake of economic growth, and the quality of life in the major cities of Korea has been ranked lowest in the world. Furthermore, no energy efficiency system has been developed for the public. The Urban Design Center for the public considered greenways linking pedestrian ways as a solution to the city oriented automobiles. We divide the greenways into the hierarchy of pedestrian ways, city greenways, and neighborhood greenways. We also propose that housing be designed in harmony with the greenways. We are against the usual pattern of excessive development that does not consider the community and neighborhood. This study suggests, first, that separate redevelopment projects be designed so that they are synergistically integrated and, second, that the access to Han River be made easier with greenways. Such an approach to urban design will make Seoul become more hospitable to pedestrians and create sustainable and vibrant communities within the city. We hope that this endeavor will serve as an example to other countries in Asia as well.

1. Introduction

1.1 Background

Korea has advanced rapidly in industrial and technological developments in the past decades. The Korean economy has been ranked the 13th in the world. Advances in state-of-the-art-technology in electronic, IT, and shipbuilding have been exceptional.

However, the economic growth has negatively affected Korean society and the environment. As industry expanded rapidly since the 1960s, population density of Seoul rose to 17,108people/㎢, third highest in the world. Seoul is overcrowded and over-polluted and lacks open spaces. As a result, the quality of life in Seoul, and in other major cities, ranks low in the world index.

Urban Design Center, a non-profit organization at Seoul National University, has taken this situation seriously and started various projects, such as Greenway Planning and the Han River Waterfront Master Plan, to improve the urban environment. These projects have influenced the Seoul city government, which has begun to acknowledge that the condition of the public space is closely related to the quality of life in the city. Several meaningful projects are being spearheaded by the government: for example, the Han River Renaissance Project, the Pedestrian Improvement Plan in CBD, and the Gang-dong Greenway Project. The city of Seoul is embracing a new paradigm of urban design.

Figure 1 High-rise apartment districts have developed along the waterfront in Seoul

1.2 Purpose of Paper

Despite efforts by the government, the fundamental problem of making Seoul a livable city still remains. When large apartment complexes were first being built, they were looked at as a positive development, especially in supplying housing to large number of citizens. Soon, however, apartment buildings became convenient tools of landowners and tax collectors for yielding large economic gain, and the huge apartment complexes became the typical type of residence in Korean cities. (See Figure 1) This situation created a host of negative effects such as natural resources being in private ownership, haphazard and poorly integrated development, and large profits for private individuals in housing development. As a result, public space has almost disappeared, and no attention is being given to public interests.

The theme for the present study emerged from the question: "How can sustainable communities be design in residential redevelopment?" Beginning with an overview of current redevelopment methodologies in Korea, we discuss the elements and processes of a new planning paradigm. We would like to show a vision of Seoul through the pilot projects along the Han River and propose a way to make greenways through redevelopment of Seoul.

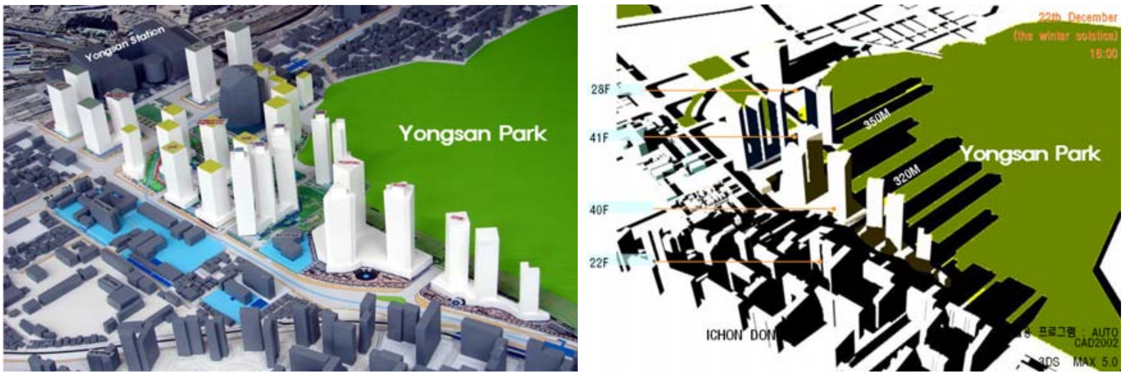


Figure 2 Despite significant investment in the area, the benefits are almost negligible in the areas adjacent to the key developments.

2. Concept of City and Neighborhood Greenways

2.1 Literature review

Greenway became widespread all around world. A fundamental factor that it has been developed is the desire to get away from the squalor, the congestion and the pollution of industrialized cities of the 19^{th} century. According to Searns (1995), Greenways help mitigate the loss of 'natural space' owing to development and provide a counter-balance to an expanding human dominated landscape. Open space planning including greenways has evolved to meet specific needs that have resulted from economic growth. (See table 1) With open space planning, neighborhood design has been studied in western countries. The concept of the neighborhood unit was formulated in the 1920s. This paradigm has been used widely as a design concept both in the United States and in other parts of the world. Korea was also influenced by this paradigm and applied it in building large apartment complexes. The method of placing schools and playgrounds in the center of districts has been a popular residential planning method until now.

Table 1 Advances in the History of Urban and Open Space Planning

Era	Urbanization by Industrialization (Mid-Late 1800s)	Development of Automobiles (Early-Mid 1900s)	Sustainability Smart Growth (Late1900s-2000s)
Problems	Poor public health and welfare in cities	Pollution and Urban sprawl	Traffic congestion and energy crisis
Urban Theory	Urban planning	Regional planning	Compact City, New urbanism
Open Space Policy	Boulevard Park	Parkway system Greenbelt	Greenway system

2.2 City Greenways and Neighborhood Greenways

The metropolitan Seoul is surrounded by a greenbelt with big mountains visited by many citizens every weekend. The greenbelt was established in 1971. The Han River is in the center of Seoul, and the waterfront is being revitalized through the 'Han river Renaissance Project.' Although amenities around the city are excellent, public open spaces of the inner city are run-down and have no access to outer city parks. Moreover, the prime locations along the Han River are the apartment districts where residential use is about 62%. Among the apartment units built in the late of 1970s are about 150,000 units all of which are designated as rebuilding districts. One recently rebuilt district is the Jam-sil apartment district. In this rebuilding project, the floor area ratio changed from 80% to 250%, and low rise (5 floors) buildings built for 30,000 units were remodeled to high-rise (30 floors) buildings for 50,000 units as shown below in Figure 3, Figure 4. Despite the waterfront is the importance public assets, the neighbor planning has not taken a broader view of the waterfront but only focused on the core of the building projects. Thus, the building districts are relatively self-contained, and the residents cannot access the waterfront easily. City greenways and Neighborhood Greenways are alternatives for improving the environment in neighborhoods. City greenways are regional-scale connections that link to natural resources and improve the accessibility of outlying areas for the public. Neighborhood Greenways are smaller-scale connections that fulfill local neighborhood needs. They connect local community amenities such as parks, schools, libraries, community centers, shops, and places of unique local significance: for example, historic sites, a group of heritage houses, or an interesting street. So the neighborhood greenways reflect local character and identity by providing opportunities for the residents to express the unique character of the area.

Figure 3 Before the redevelopment in Jam-sil

Figure 4 After the redevelopment in Jam-sil

3. The planning experience

3.1 City Greenways

The objective of city greenways in Seoul is to preserve the greenbelt and the Han River as links to natural resources. Our Greenway concept is 7 Rings and 50 trails linking the Han River and greenbelt. And provide linear parks whenever it happens to redevelop. Next picture is one of the rings in Seoul, especially central Ring. The second ring in the Gang-dong area is located in the upper zone of the Han River. The main hindrance to accessing the waterfronts is the highway constructed for the Seoul Olympics in 1988. So the Han River Renaissance Project attempts to make a mounding over the riverside highway so that the public can access the waterfront easily. (See Figure 5) And one of the bridges in the Gang-dong changed to a pedestrian bridge. The government has been trying to improve the environment and integrate all projects. Gang-dong city greenway is a ring-shaped multifunctional route that connects the waterfront park along the Han River to major parks in the greenbelt. 245million dollars was invested in this project to construct the greenway in 2 years.

Figure 5 Depressed the riverside highway and Mounding

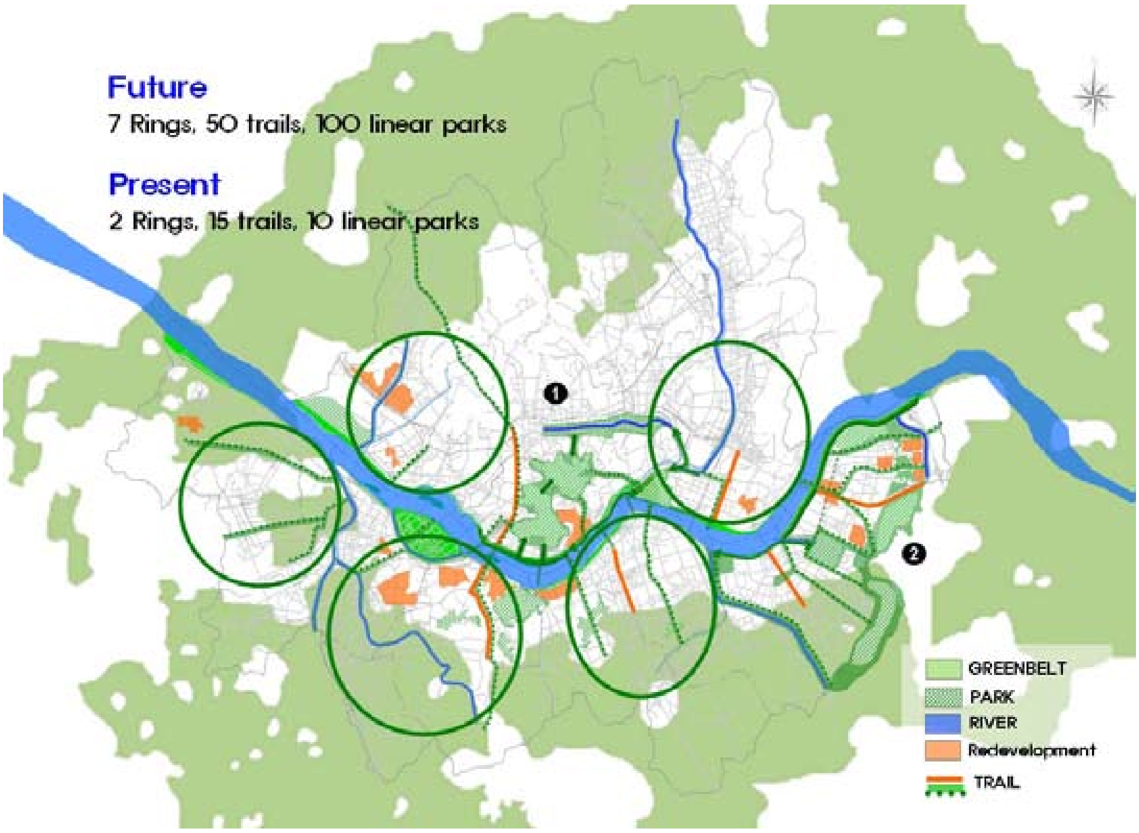
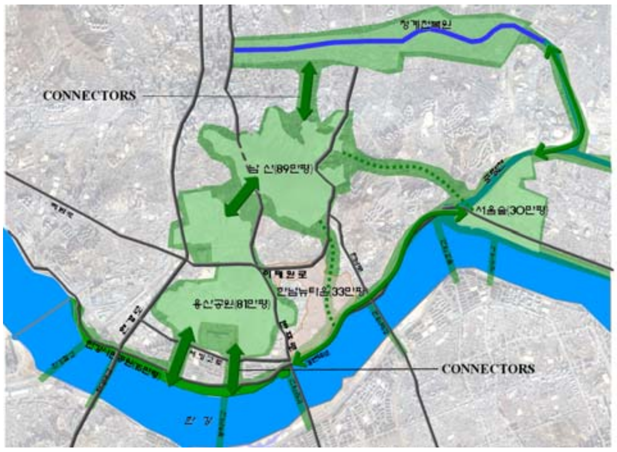


Figure 6 Seoul Greenways Concept Plan: Central and Eastern Greenways Plan completed



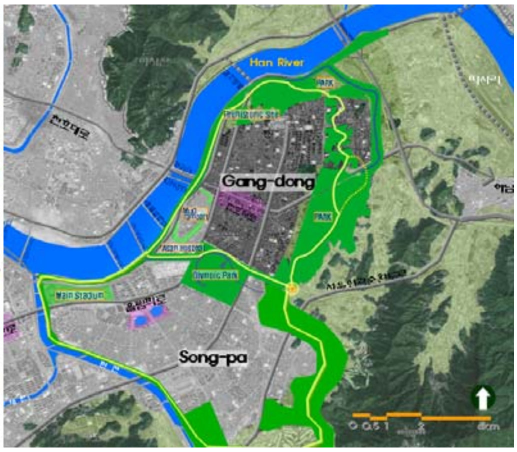
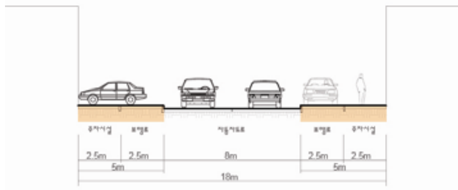


Figure 7 Central Ring① in the Yong-san Park Area *Figure 8 Eastern Ring② in Gang-dong*

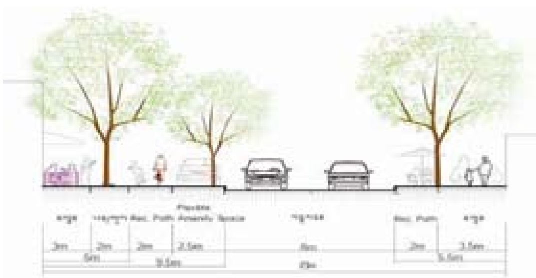
Figure 9 Gang-dong City Greenway linking of major parks and access points

3.2 Neighborhood Greenways

The object of Gang-dong neighborhood greenways is to provide the public with access to the Han River waterfront and parks in the greenbelt. Important components of a suitable greenway route are a main corridor connecting historic sites, redevelopment of over 50% of Gang-dong, the old way have been used from the Cho-sun dynasty, the roads having expansion plan and the pedestrian volume assignment. After a suitability analysis, neighborhood greenway routes were planned to enhance the waterfront access with historic corridors and boulevards and to include sidewalks, plazas, bicycle paths, and outdoor cafes.



Current Condition



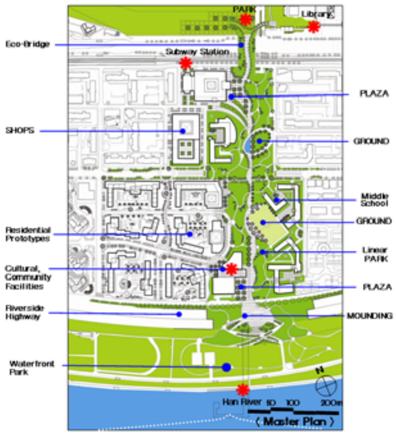
Proposed Trail

Figure 10 Neighborhood Greenways in Gang-dong *Figure 11 A Plan of the street 'B'*

The area of study consists of the two parts: the old town that was established in the 1900s and the new town with apartment districts were built in the 1980s. The residential and official districts in the old town need open space for residents and office workers to be able to enjoy outdoor activities. As such, the Neighborhood Greenway Plan of the old town has a hierarchy that consists of public trails for citizens, semi-public linear parks in residential and business districts, and private courtyards in the residential area. This area also preferred to ride a cycle in Seoul. Thus it is recommended the mixed use development for cyclists around the public trail.

Figure 12 Redevelopment districts for housing and business around street 'B'

3.3 Residential Prototypes harmonized with Neighborhood Greenway



4. Discussion

As stated earlier in this paper, the purpose of this case study is to show how make greenways through the redevelopment site in Seoul. This is a new proposal against the typical development in Korea. For example, in the prime area of Gang-dong, a new town will be built with a business district and an apartment complex. Existing proposals by the government designed by Construction Corporation call for high rise buildings at the waterfront. Each planned project is designed separately without no consideration of the regional context, and therefore many problems remain, such as unbalanced land-use, disrupted communities, and lack of urban infrastructure. The proposed projects, if completed, would not be any different from existing neighborhoods, and the city environment would not be any different from existing neighborhoods, and the city environment would move even further away from livable and comfortable arrangements with built-in green areas. In contrast, new development with greenway networks, as we propose, would enhance the comfort for pedestrians and help create friendly and harmonious communities. Although the extent of development in the new town is the same in the two scenarios, the land use is more sustainable and varied in the new scenario proposed in this study. Fortunately, the city government has eagerly accepted our proposal, and our group and the city are cooperating in the city planning, the transportation, and the open space departments. Moreover, the city has imposed a greenway requirement for reconstruction projects for apartment complexes.

5. Conclusion

This pilot study is not yet complete, and therefore it is too early to compare the new projects with other cities in Korea. We look forward to establishing greenways in the cities of Korea, re-establishing the connection between people and nature. Until now, the control of urban planning has been in the hands of construction companies and land owners, so that excessive development for the sole purpose of profit has been the usual course of events. Citizens have had no choice in the type of housing. Recently, the city has been attempting to establish policies for creating a sustainable transportation system, including mass transportation, bicycle traffic, pedestrian circulation. Many regions are awaiting renewal and greening after the rapid urbanization in the past decades. Newly proposed green development will revive the public space and enliven communities destroyed by private development. Moreover, the Korean experiment in greenway planning and implementation, now under way, can serve as model for rapidly urbanizing cities in other countries for the recognition of various human and ecological benefits of urban greenways.

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ENERGY MINIMIZING ARCHITECTURE USING ANCIENT WISDOMS AND MODERN TECHNOLOGIES

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Keywords: ancient wisdom, modern technology, outside wall ventilation, breathing outside wall, medium-to-low-grade heat source and storage

Summary

A construction method is proposed to minimize the dependence on energy by combining ancient wisdom and modern technologies. The following three elemental technologies are introduced here:

1. Exterior walls with an air passageway between them, using double exterior walls to reduce the exterior skin load by virtue of their functions as ventilation, heat insulation, and heat storage, according to ambient conditions
2. Breathing exterior walls, to respond to constant changes in external wind conditions and to ensure that fresh air is taken in by virtue of the design of exterior walls and chimney shapes or by converting a draft route
3. Medium-to-low temperature heat sources and heat storage, in connection with treatment of a sensible heat load, to increase cold water temperature and co-efficiency of performance, and to equalize the load by using latent heat storage materials having potential for heat storage at the temperature

1. Introduction

We increasingly demand a better living environment and enjoy comforts that we cannot easily give up. In most cases, building equipment makes our environment more comfortable. For example, the thermal environment can be adjusted with air-conditioning equipment, and the light environment can be adjusted with lighting equipment. However, while energy efficiency has been improved, energy depletion and environmental destruction remain serious problems.

The authors of this report intend to construct a building designed to minimize energy consumption. The building concept is based on:

- Ancient wisdom used to adjust indoor environments without depending on equipment
- Provision of building components with equipment functions
- Use of new functional materials

Based on this building concept, we developed some technologies in cooperation with the designing department, aiming to be a help at an early stage of the design. We introduce the three elemental technologies of them in this paper.

2. Elemental Technologies

2.1 Ventilation Exterior Walls

Ventilation Exterior Walls are intended to reduce the amount of heat transmitted from exterior walls. These double exterior walls have openings that open and close to an air layer, and they have a heat storage function.

Since ancient times in Japan,• "Dozo" architecture has used roofs with natural air ventilation. Also, there is a type of termite that builds nests with a ventilation function to protect their living environment. Ventilation Exterior Walls imitate these examples.

The heat load due to transmission will be reduced by opening the openings and cooling the building structure with a natural air draft in summer, and by closing the openings to form an air layer in winter.

2.1.1 Details

Figure 1 shows a cross-sectional view.

In most dry construction methods for exterior walls, pre-finished metal panels are attached to the outside of dry-laid structural walls, such as ALC panels. The space between the metal panels and the structural walls can be made to function as an air layer. Openings and mechanisms to open and close them are provided at both the top and the bottom of the air layer.

In summer, while the opening is kept open, the temperature rises mainly due to solar radiation, resulting in a stack effect in the air layer. Ventilation can therefore be achieved without using power.

In winter, an enclosed air layer is formed by closing the opening. A higher heating load reduction effect is expected from a temperature rise in the air layer due to solar radiation. The open/close switching can be achieved by using shape-memory alloy.

These effects are expected to be more prominent for heat storage materials, which are used for areas to be exposed to the air in the air layer. This can equalize the amount of heat transmitted into a room and increase the heat insulation effect.

2.1.2 Effects Confirmed by Simulation

(a) Simulation Model

A 2D heat transfer model is developed for the exterior wall area, as shown in Figure 2.

Standard meteorological data for Tokyo is used for the ambient conditions. Based on the assumption that air-conditioning is switched on between 7:00 AM and 8:00 PM in the room, the temperature is set at 26°C in summer and 22°C in winter.

The non-stationary heat balance equation is solved at each mass point to determine the temperature change over time and the amount of transmitted heat.

(b) In Summer

Figure 3 shows the calculated results of the daily integrated cooling load. In summer, it is found that providing an air layer has the effect of an approximate 30% reduction in the load due to the effect of sun-shading and ventilation.

Furthermore, when phase change material (PCM) is provided at the air layer, the load reduction effect increases to about 50%.

(c) In Winter

Figure 4 shows the daily integrated solar radiation for a clear day in winter.

of the structure On clear days, solar radiation is blocked by providing an air layer, resulting in a decrease in the temperature. Consequently, the heating load increases. Under these ambient conditions, the load increases by about 20%. The transmitted heat can be slightly reduced by using PCM.

On cloudy days as shown in Figure 5, the air layer can function as a heat resistant layer, even when it is opened to the air. Therefore, the heating load can be reduced by about 10%. As a result of the adoption of PCM, the load can be reduced by about 20%.

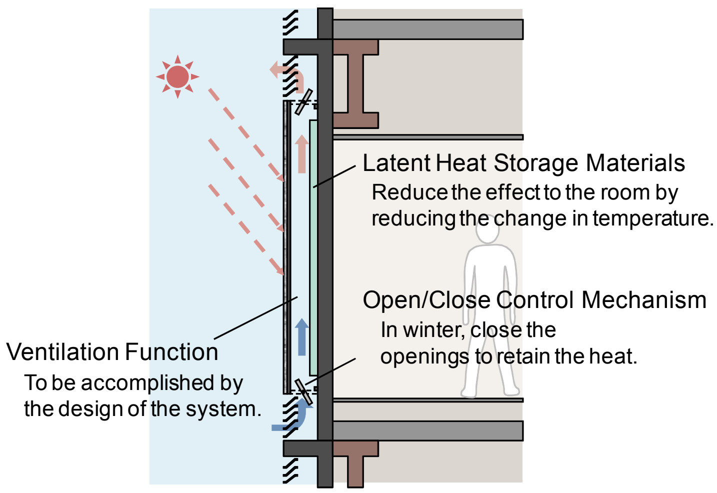

Figure 1 Cross-sectional view

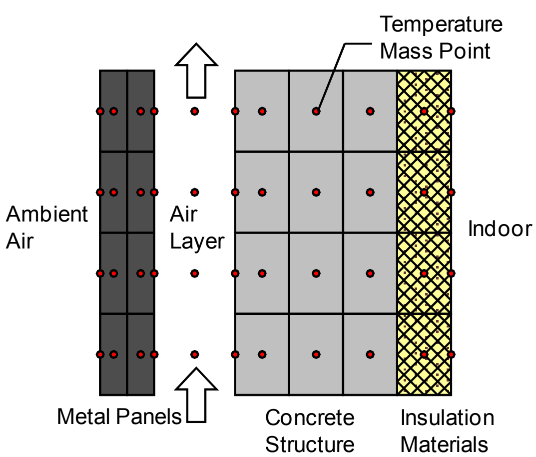

Figure 2 Simulation model

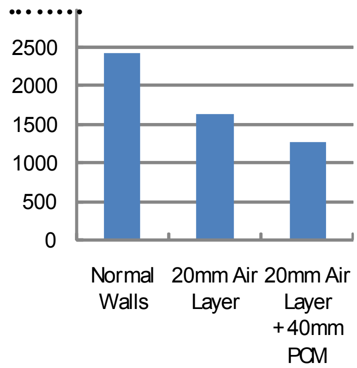

Figure 3 daily integrated cooling load in summer

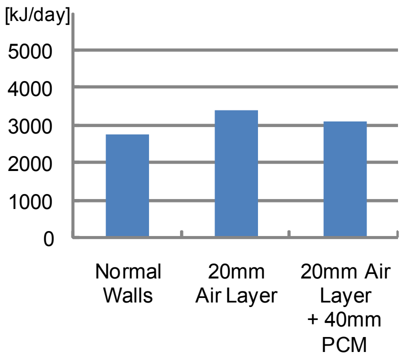

Figure 4 daily integrated heating load in clear winter day

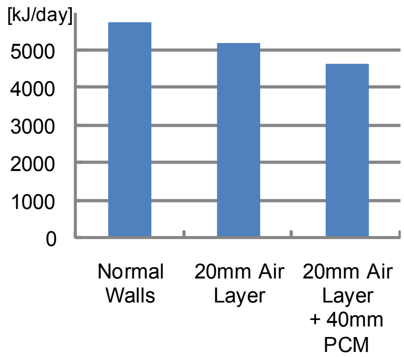

Figure 5 daily integrated heating load in cloudy winter day

2.1.3 Effects Confirmed by Actual Measurements

(a) Experimental Model

A test piece similar to the one shown in Figure 6 was measured outdoors in Osaka.

The exterior walls of the test piece comprise ALC panels with insulating material, having an air layer partially formed by being covered with metal panels. Measurements can be made under the same ambient conditions, because the part with an air layer and the part without an air layer are arranged side-by-side. The temperature measure points are located on the exterior wall as shown in Figure 7. The amount of transmitted heat is calculated from the surface temperature and heat resistance value.

(b) In Summer

Three different types of experiments were conducted for summer.

Case 1: Without an air layer
Case 2: With an air layer opened at both the top and bottom

Figure 8 shows the comparison of temperatures. In case 1, without ventilated air, the temperature rise is high (42°C) due to direct solar radiation on the surface of the ALC panels. The temperature can be reduced (33°C) in case 2 by ventilating the air space.

Figure 9 shows the amount of transmitted heat. It is confirmed that providing an air layer results in an about 40% reduction in the daily integrated load.

(c) In Winter

Three different types of experiments were conducted for winter.

Case 1: Without an air layer
Case 2: With an air layer opened at both the top and bottom
Case 3: With an air layer closed at both the top and bottom

Figure 10 shows the comparison of temperatures between Case 1 and Case 2.

In Case 1 without an air layer, the temperature rises on the outer surface of the ALC panel exposed to solar radiation in the daytime. In Case 2, the surface temperature rise is smaller due to the loss of absorbed solar radiation heat caused by air currents. However, providing an air layer has the effect of reducing heat loss due to nocturnal radiation at night, thereby increasing the surface temperature of ALC panel by about 6°C. The daily integrated amount of transmitted heat is shown in Figure 12, thus confirming the effect of reducing heat load by about 10%.

Figure 11 shows the comparison of temperatures between Case 1 and Case 3.

The temperature rise on the surface of ALC panel is more significant due to warm air enclosed by closing the opening. The effect of reducing nocturnal radiation in Case 3 is also more significant than in Case 2. The daily integrated amount of transmitted heat is reduced by about 30% from case 1 as shown in Figure 12 .

2.1.4 Conclusions

Providing a small space between a finished surface and the structure can have an effect on energy conservation. Although there were concerns about the potential increase in the heating load in winter, the results show that the effect of reducing nocturnal radiation is greater than the effect of heat from solar radiation in the daytime.

In this report, several options are available, such as using PCM or allowing the top and the bottom of the air layer to be closed. Adoption of these options can improve energy conservation, but careful consideration is required in terms of maintenance performance before adoption.

Figure 6 Experimental model

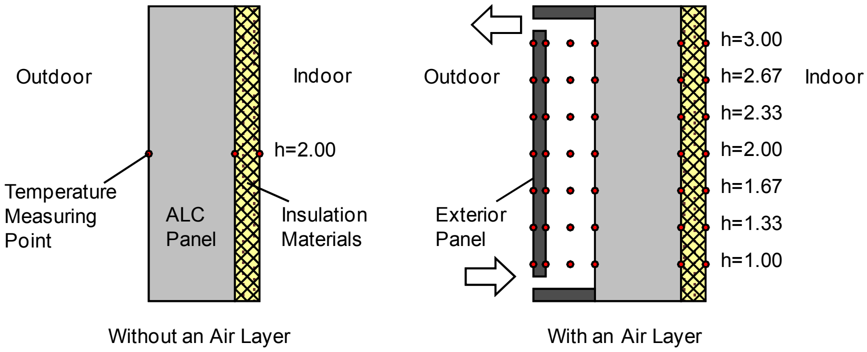

Figure 7 temperature measure points

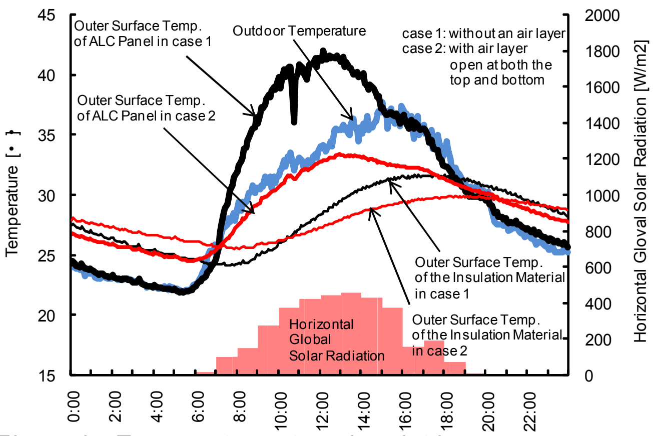

Figure 8 Temperature at each point in summer

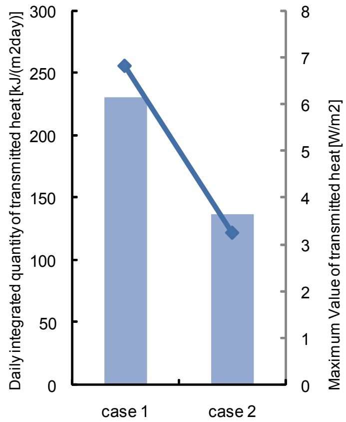

Figure 9 Transmitted heat in summer

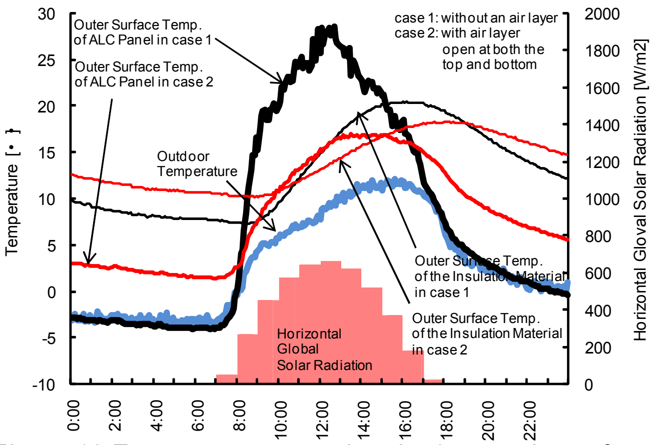

Figure 10 Temperature at each point (comparison of case 1 and 2)

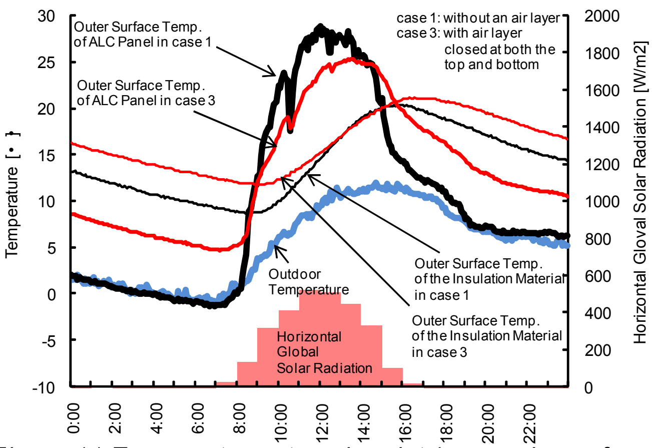

Figure 11 Temperature at each point (comparison of case 1and 3)

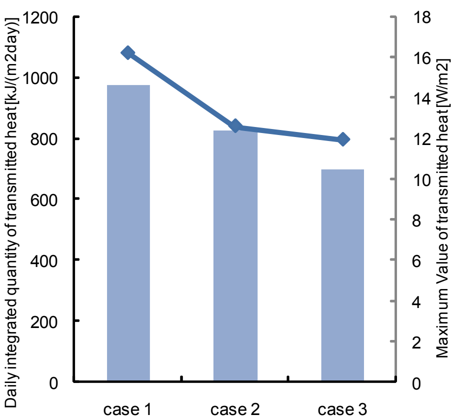

Figure 12 Transmitted heat in winter

2.2 Breathing Exterior Walls

2.2.1 Outline

Before the existence of air-conditioning, building ventilation was an important means for reducing heat. Since ancient times in Japan, it has been said that "a building should be designed mainly for summer conditions," with many openings and systematically ventilated rooms with transoms. Outdoor temperatures are actually lower than indoor temperatures at most times of year, so it is important to take natural ventilation into account in order to enhance the cooling effect. Here, we introduce a support tool at the early stages of natural ventilation design and a practical design example.

2.2.2 Design Support Tool

We introduce a design support tool enabling designers to develop a general plan for natural ventilation in the early design stage. The tool is used with Microsoft Excel, and an overview is shown in Figure 13.

The designer inputs the building conditions (shape and location (meteorological conditions)) and the position and shape of the openings. The tool provides the national meteorological data, the wind pressure coefficient on each face depending on wind direction, and the measurement data from wind tunnel experiments (corresponding to chimney shape). Input conditions of the wind environment are determined in conjunction with CFD according to the surrounding terrain and block conditions.

In response to the input conditions given by the designer, the wind that enters and exists each opening is calculated in real time, and the effect of energy conservation is summarized and output. Based on a study using this tool, the designer can arrange the natural ventilation openings or set the amount of ventilation, allowing the effect of energy conservation to be determined in advance.

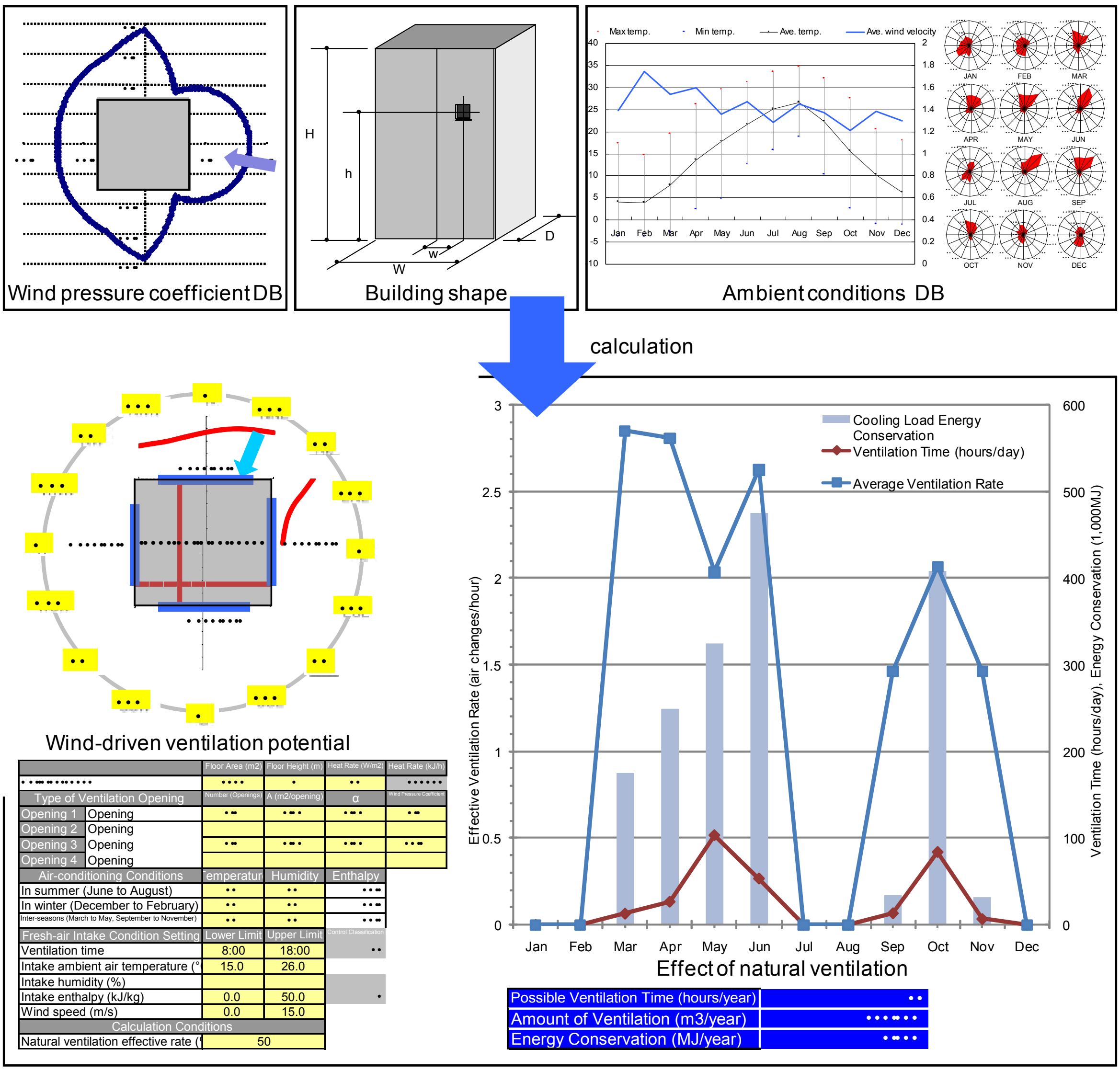

Figure 13 Overview of ventilation design support tool

2.2.3 Design Example

A design example calculated and designed in the manner above is shown here.

We introduce a university building in Shikoku. The building stretches from east to west, is composed of four floors above ground, and has laboratories lining both sides of a corridor. The building is located in a rich natural environment, and fresh air is expected to be actively introduced to promote energy conservation.

Under the local meteorological conditions, it is found that a prevailing wind blows in the longitudinal direction (east-west) of the proposed building. A natural ventilation plan is designed according to the following principal axes (see Figure 14 for outline):

- Considering the exhaust air from the top of the building, where there is constant negative pressure resulting from prevailing wind, use the staircases at both the east and west ends as exhaust routes
- Set the height to ensure sufficient induction effect and stack effect
- Provide sliding glass doors for each laboratory to directly supply fresh air as required

This building has only recently been completed, and the effect of energy conservation will be verified by future measurement study.

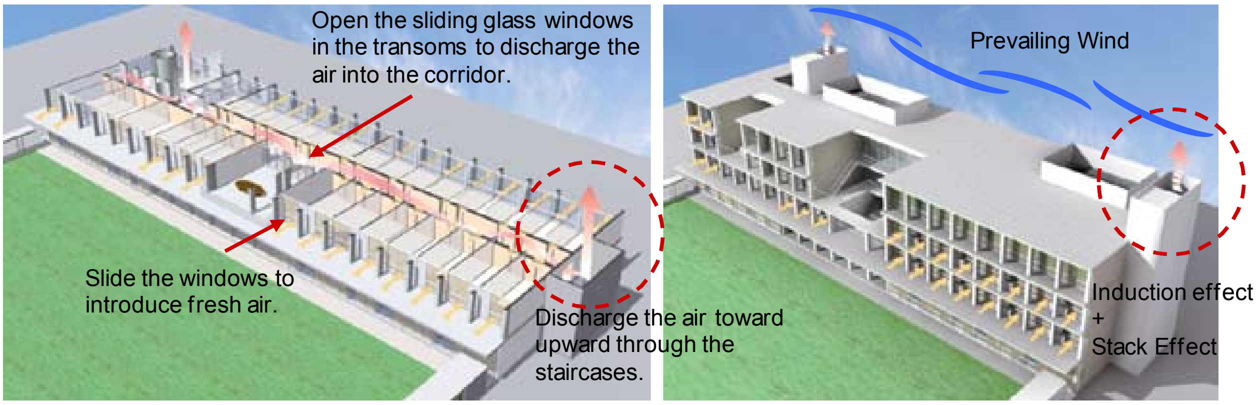

Figure 14 design example of natural ventilation

2.3 Medium-to-Low Temperature Heat Source System

2.3.1 Outline

As discussed above, it is possible to promote energy conservation by reducing or utilizing the ambient effects. However, we have to rely on mechanical air-conditioning to meet the thermal environment requirements. Here, we introduce an effort to increase heat source efficiency by using a new material.

Figure 15 shows the system concept.

The heat load can be separated into Latent Heat (LH) and Sensible Heat (SH). SH is treated by the medium-to-low temperature heat sources. It is possible to enhance the heat source efficiency, since the temperature of cold water can be increased. It is also possible to use nighttime power or natural energy and to equalize the load by storing heat in PCM for a medium-to-low temperature zone.

On the other hand, desiccant air-conditioning using water vapor adsorbent is available for LH. Heat utilization system can be designed rationally by using waste heat from heat pump for reuse of the desiccant.

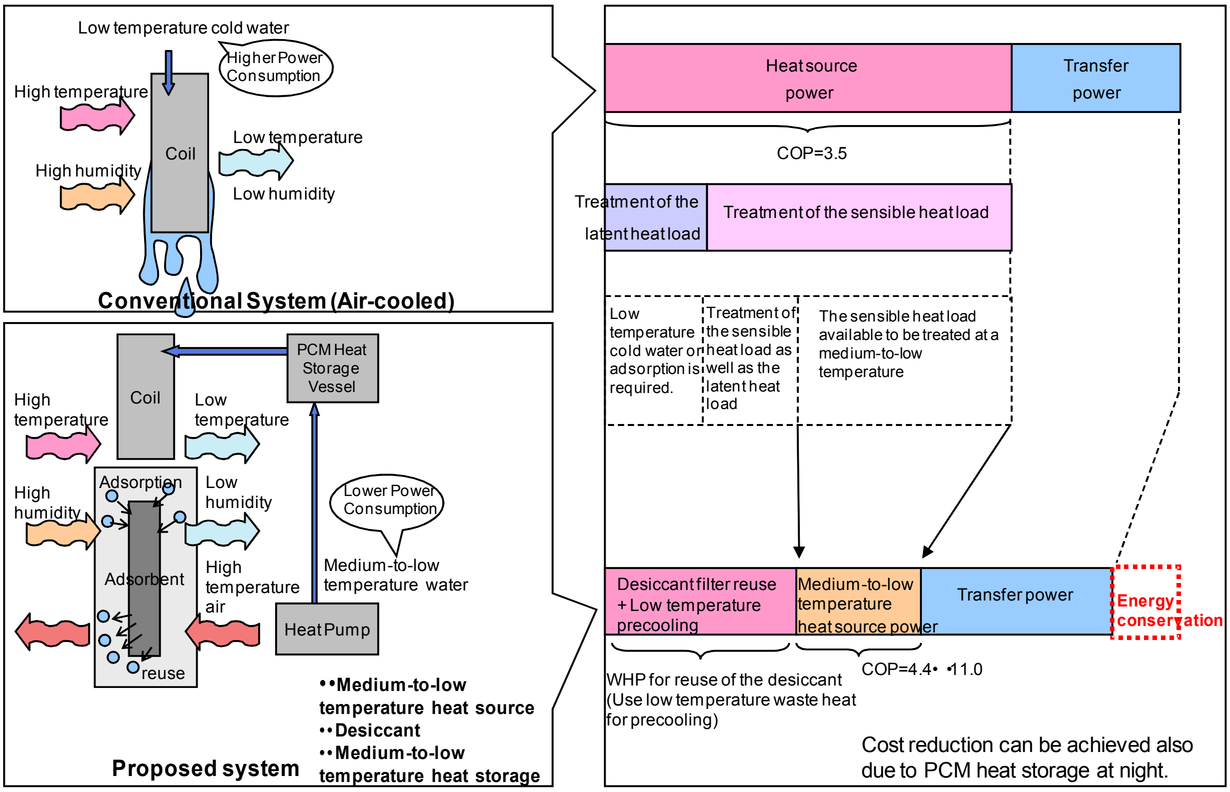

Figure 15 Concept of Medium-to-low temperature heat source system

2.3.2 Simulation

Simulations were performed for three different types of heat source systems (Figure 16).

Case 1: Ice Thermal Storage Unit
Case 2: Air-cooled Heat Pump
Case 3: Medium-to-Low Temperature Heat Source System

The subject building is a 10,000m2 office building (Table 1), and the calculation is performed under common ambient conditions based on the standard meteorological data for Tokyo. In the Medium-to-Low Temperature Heat Source System, the heat storage unit is checked and verified in advance by simulation and experiment. The desiccant dehumidification performance is checked by experiment and simulation, according to temperature and humidity conditions.

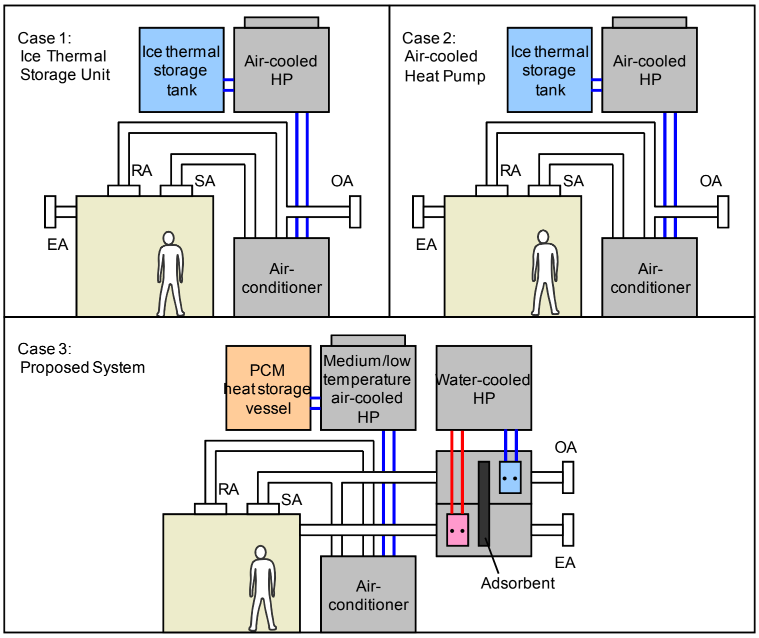

Figure 16 Three types of systems simulated

Table 1 subject building conditions

Building use			Office
Total floor area [m2]			10000
Air-conditioning area [m2]			7500
Building population density [persons/m2]			0.2
Required amount of fresh air [m3/h/person]			20
Maximum heat load	Cooling Load [W/m2]		140
	Heating load [W/m2]		80
Air-conditioning operating conditions	Operating days [days/year]		230
	Operating hours [hours/day]		10
	Set temperature [°C]	In summer	26
		Inter-seasons	24
		In winter	22
	Set humidity [%RH]		50

Figure 17 shows the calculated results of the daily variations in power consumption in July. For Case 3, it is confirmed that the load can be transferred to nighttime by heat storage and the demand is reduced compared to Case 2. The same considerations apply to Case 1. With respect to power consumption in the night heat storage time zone, the heat source COP is significantly improved compared to the Ice Thermal Storage Unit, accounting for about one third of Case 1.

Figure 18 compares annual primary energy consumption. In Case 3, although the amount of primary energy consumption is reduced due to the improved efficiency of the heat source, the power consumption of the transfer system increases as a result of pressure loss due to desiccant material and the fan power increases due to the increased number of coil rows. Consequently, the annual consumption is 3% higher than that of the Air-cooled Heat Pump. On the other hand, the power demand is 10% less than that of Air-cooled Heat Pump and approximately the same as that of the Ice Thermal Storage Unit, so the peak power cut is fully implemented.

In terms of energy conservation, further study will be conducted with the aim of reducing energy consumption more than that of the Air-cooled Heat Pump, for the purpose of increasing the efficiency of medium-to-low temperature heat source equipment and decreasing pressure loss due to desiccant material.

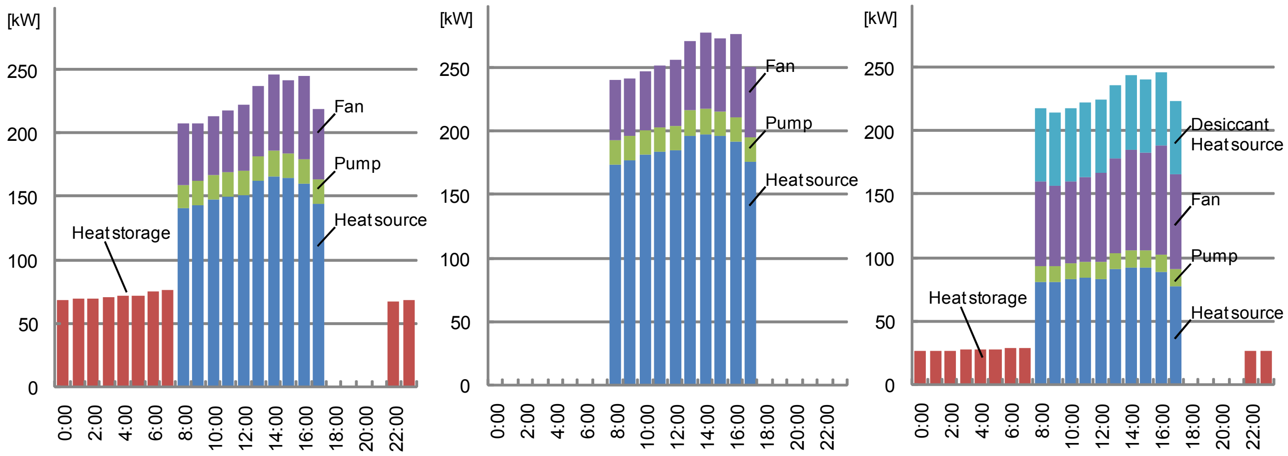

Figure 17 Daily variations in power consumption in July

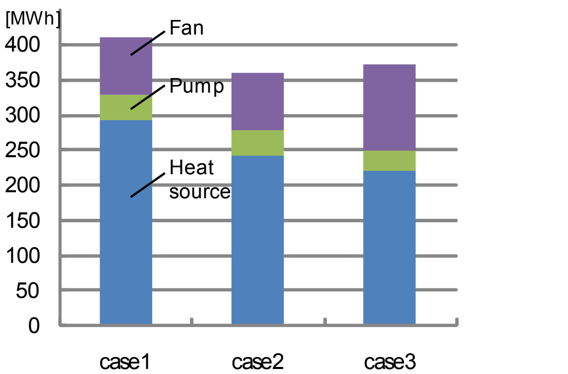

Figure 18 Annual primary energy consumption

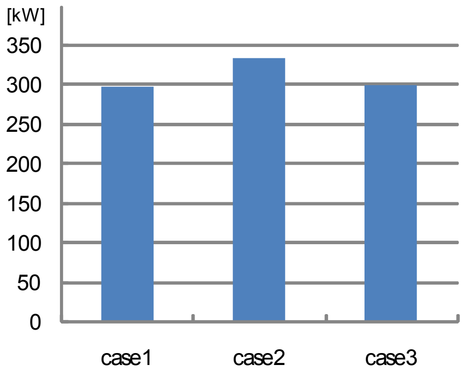

Figure 19 Energy demand

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FIVE KEY POINTS FOR COMMISSIONING MANAGEMENT IN SUSTAINABLE BUILDINGS

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Keywords: commissioning, management, leased building, retrofit, Japan

Summary

This paper introduces project management strategies for continuous commissioning process to realize sustainable building. The key points are: 1) Extracting owners and occupants' latent needs, 2) Establishing mutual understanding among stakeholders including owners, occupants, facility managers, architects/engineers, and suppliers, 3) Enhancing communication among the stakeholders, 4) Visualizing process and effect, and 5) Developing continuable activities. The active commissioning approach is necessary for sustainable building, since the sustainable building needs are usually invisible and often less prioritized. The enhanced communication helps realize sustainable building goal while maintaining customer satisfaction.

Lessons learned from two case studies are described. The first case study site is a 193,000 square-meter multi-use leased office building where over 100 tenant companies reside. The challenge was to develop a communication scheme to establish mutual understanding among numerous stakeholders. Another case study site, a 37,000 square-meter research laboratory, achieved distinguished energy reduction only by operational improvement including occupants' spontaneous action. These actions were accomplished due to enhancement of understanding and motivation. Both case studies are examined with energy consumption trends, and occupant surveys as a factor of customer satisfaction.

1. Introduction

In Japan, due to its early experience with the oil shock in 70s, the first energy conservation law was established in 1979. Since this period, the government and industries have been taking a lead of energy efficiency. While the primary focus of energy efficiency was on industrial sectors and energy suppliers, large and mid-sized non-industrial buildings also became regulated since 2003. Under the regulation, the subjected buildings are required to submit periodical energy reports and energy saving targets. Leased buildings and research laboratories started to pay close attention to energy efficiency. Now, the primary driving factor for energy efficiency investment is the responsibility for the achievement of Kyoto Protocol target, and the sense of crisis.

Based on the above background, sustainable building design has become emphasized recently in Japan. Sustainable buildings should be designed to be sustainable by owners and architects. It is also equally important for occupants to understand the design intent and practically use the sustainable features.

Building commissioning, mainly discussed in this paper, is a procedure to achieve sustainable building's goals covering various issues from occupant comfort to natural environment, as well as energy conservation. It is a universal process to guide owners' investment decision making based on their building functionalities.

It has been only few years since the importance of commissioning started to be emphasized in common buildings in Japan. The market is yet premature at the moment. Currently, Japan is leaning from the experience in U.S. and Europe. In order to disseminate commissioning in Japan, the management process has to be well considered. Expensive, excess measurements and professionals' explanation with technical jargons are not practical to achieve owners' satisfaction.

In this paper, five key points to achieve successful commissioning management are introduced based on the authors' experience with two case studies.

2. Lifecycle Commissioning

2.1 Commissioning Management throughout Building Lifecycle

In Japan, most building owners have merely referred to concrete criteria of energy efficiency and indoor environmental quality during building operation. The efficiency of business activities (including office works, merchandise, and researches) has been most prioritized in building operation. On the other hand, various stakeholders are involved in building lifecycle, including planning; design; construction; turnover and operation. The stakeholders may not often communicate each other, or even within same roles over time. After all, no one understands the holistic performance throughout the building lifecycle. Under the situation, with the increasing awareness of global climate crisis, the importance of commissioning has become obvious. The activities to be done as the lifecycle building commissioning at each building phase are,

- Planning Phase: Define the building functionalities and materialize owners' needs.
- Design Phase: Quantify the owners' needs and develop specification. Define methodologies to verify the specification with articulate criteria.
- Construction Phase: Construct the building exactly as the design. Verify the building meets the predefined specification.
- Turnover Phase: Architects/engineers and constructors report the results of the verification to the owners. Provide an operational guidance.
- Operation Phase: With understanding the design intent, improve and retrofit the building to suite the current building use and the time.

One of the most important factors in commissioning management is to define and verify the owners' requirements at any building phase, and provide both the appropriate use and the best satisfaction. To achieve this goal, every stakeholder including owners must fully understand and be satisfied.

Building commissioning generally requires measurement and verification of the building functionalities, and documentation of the results. Although this is essential to fulfill the requirements in the contract, the documentations are often too complicated and barely understandable for some stakeholders who don't have technical knowledge. To achieve the aforementioned goal of everyone's satisfaction, it is important to have every stakeholder to fully understand the building systems and functionalities. This is in deed achievable with commissioning managers' skills, even without expensive measurements and analysis software tools, or expert labor costs.

2.2 Five Key Points for Effective Commissioning Management

1) Extracting owners and occupants' latent needs: In general, owners can neither express their needs as clearly defined specification, nor gather occupants' opinions. Architects/engineers materialize owners' needs. However, the communication only between owners and architects/engineers is often insufficient to cover all the aspects. In the process of commissioning, it is recommended to gather insights from various professionals.

To extract the latent needs, it is important to find out the adequate level of quality which owners desire. Comparisons and choices should be easy to understand for owners. Secondly, terms used to express the needs and the judgment criteria should be clearly documented. Architect/engineers should avoid explaining their thoughts to owners with figurative phrases and only documenting what is decided. This process affects the relationship among owners, architect/engineers, and constructors.

2) Establishing mutual understanding among stakeholders including owners, occupants, facility managers, architects/engineers, and suppliers: Owners make investment decisions by gathering insights from various stakeholders. It is important to accommodate a place where all the stakeholders can join the decision making process. This will make the process clear and fair. By keeping the place over the building phases, one can take over and understand the sequence of the process regardless of change of participating members. This place should be maintained over transition of time and needs through the building lifecycle.

3) Enhancing communication among the stakeholders: It is difficult to thoroughly understand each other only at series of meetings. Continuous effort to develop good relationship among stakeholders leads to positive outcomes in various situations. It is important to carefully extract underlying demands from abstract expression, and considerately arrange the opportunity for every stakeholder to freely express one's opinion.

4) Visualizing process and effect: Through the decision making process, it is often difficult to present how the decisions were made for each activity in an understandable manner. In order to clearly visualize the process and effect of an activity, it is important to extract key facts from series of the data and documentations. The decision-making criteria have to be well described. In fact, requirements for building functionality are often ambiguous, except when they are regulated by laws. Clear judgment criteria based on understandable data are important in this process (for instance, simple apple-to-apple comparison, majority votes are easy to understand). It contributes to the decision makers to smoothly explain about their decisions to stakeholders including occupants and minimize complaints.

5) Developing continuable activities: It is difficult to continue the meaningful activity even with the decision-making criteria and the periodical meetings. If each of the stakeholders only cares one's own situation, they don't have to formulate their opinions into one conclusion. Therefore, commissioning managers needs to create a mutually shared objective among the stakeholders.

3. Case Study I: Large-scale Leased Commercial Building

3.1 Building Profile and Targeted Commissioning Phase

The authors conducted commissioning process at a large-scale leased commercial building during the operation phase. The building has 193,000 square-meter of floor space, consisting of high-rise office complex (110,000 square-meter) and low-rise commercial complex including movie theaters. At this building, due to the highly conscious owners, substantial time and cost were spent for commissioning from the construction phase. After the completion in Fall 2006, the commissioning team established by the owners, the architects/engineers, the constructors, the facility managers, and the commissioning managers continues the proactive efforts for sustainable energy management.

3.2 Commissioning Management on Developing Facility Management Standards

The first action taken after the completion was to develop a facility management standard. At this building, the commissioning manager led the commissioning team to develop a highly satisfying management standard by focusing on the following aspects.

1) Promote occupants' understanding of building design intent: For instance, energy efficient designs such as automated blind control or daylighting control system don't work without occupants' understanding. The commissioning team made a thorough explanation of functions and effects, by arranging sessions for key personnel of tenants and delivering information though intranet.

2) Develop standards conscious of energy conservation: Illuminance and temperature setpoint are commonly leaved for tenants' decision. At this building, the owner was proactively involved in the standard development process with assistance of the commissioning team. The team performed space environment measurement, and defined the setpoint allowance range. The team promoted cooperation of the tenants.

3) Collaborative deployment with tenants: Along with asking cooperation from the owner, the commissioning team promotes proactive actions led by tenants to be spread to others.

Through the above activities, the commissioning manager converts the owners' needs into the action plan by summarizing the key points with understandable language and multidirectional information. Series of the activities supports the holistic decision making process.

3.3 Frameworking Retrofit Plan

In conventional practice, energy efficiency improvement and retrofit planning are initially started at the timing of periodical retrofit or when deterioration of equipment or system trouble occurs. At this building, even soon after the first year of the completion, budget for a retrofit project was reserved due to the proactive attitude toward improvement. The retrofit project consists of the following categories: 1) more detailed energy measurements, 2) more detailed system controls, and 3) more energy retrieval.

Table 1 shows the expected energy saving results achieved by the operational improvement and the retrofit project planned. To frame the plan for each item, the commissioning manager analyzed and visualized the existing circumstance, and provided multidirectional insights to lead conclusions. In this project, the commissioning manager acted an important role to guide clear decisions.

Table 1 Estimated Energy Saving of the Retrofit Project at the Large-scale Leased Building

	Category	Subject	Estimated Savings*
1	Energy Measurements	Power meter installation at each tenant	Unknown
2	System Controls	Programmable operation of exhaust fans	0.17%
		Automated valve installation at tenant chilled water supply	0.66%
		Economizer optimization at office and movie theater	0.48%
		Automation of hot/chilled water control	0.59%
		VAV control optimization	0.03%
		Schedulable switch installation at elevator air conditioning	0.01%
		Optimizing Partial load operation of Hot/chilled water pumps	0.24%
3	Outside Air Utilization	Increased use of ventilation cooling	0.12%
		Natural ventilation at atrium space and electrical room	0.43%
		Total	2.73%

* Percent of total annual energy consumption of the building

4. Case Study II: Research Laboratory

4.1 Building Profile and Targeted Commissioning Phase

The second case study is a 37,000 square-meter research facility, consisting of office space and laboratory space (approx. 17,500 square-meter each). The commissioning manager was involved in the 12th year of operation to conduct commissioning process mainly at the office space. Until then, the facility management has prioritized security, occupant satisfaction, and cost. Efficiency of the system was mostly ignored. The dramatic change of the facility managers' mind was led by the new mandatory regulation to submit the energy performance and management standards.

4.2 Formulating Requirement Items for Energy Conservation Activities

At first, the commissioning manager arranged a workshop gathering the owners, occupants, architects/engineers, and facility managers. In the workshop, the requirement items for operational improvements were formulated. The workshop was carefully organized so that every stakeholder can freely express one's opinion. The opinions were summarized into 10 project requirements through fair votes (Table 2). The more than a dozen of occupants participated in the workshop were selected as leaders of the whole occupants. They were requested to place a temperature and humidity sensor at each of their desks, and gather opinions from other occupants. In common practice, retrofit plans are usually developed only by engineers and owners. It is unique to involve every stakeholder including occupants and formulate project requirements prior to the engineers' retrofit plan.

Table 2 10 Project Requirements at the Research Laboratory

No.	Location	Requirement Items
1	1st floor atrium	Improve indoor thermal environment in heating seasons.
2	Rooms/spaces without constant occupants	Improve operational rules of air conditioning and lighting.
3	Meeting room 5	Retrofit HVAC system.
4	Meeting rooms	Optimize pre-cooling/heating operation.
5	Office	Improve office zoning of air conditioning and lighting.
6	Office, meeting rooms	Instruct facility manager on energy saving HVAC operation.
7	Common to all	Optimize operation and maintenance cost of HVAC system.
8		Improve operation and maintenance of lighting fixtures.
9		Utilize ventilation cooling in nighttime and intermediate seasons.
10		Report decision-making process to occupants.

The operational improvement activity was conducted to fulfill the 10 project requirements one by one. As the result, 18% of power saving and 40% of heating/cooling energy saving could be achieved at office areas over 5 years only by the operational changes. During this process, complaints were raised regarding thermal environment and change of user rules. However, the complaints were considerately solved through mutual understanding with the occupants. This accomplishment was significantly contributed by the owners, the facility managers, and the leaders of the occupants, who mutually understood the objectives.

4.3 Contribution of Commissioning Management in Retrofit Project

While the operational improvement came to stay, retrofit of the HVAC system was planned before the 15th year of operation. The workshop with all stakeholders was arranged again, and the project requirements for the retrofit project were itemized. The commissioning manager delivered the owners' needs which represent the project requirements to the architects/engineers. The architects/engineers could minimize the design options, and the owners could smoothly turn over the project to the architects/engineers without concerns.

5. Conclusion

The most important element of commissioning management is not delivery of documents and evaluation by experts. It is the process that all the stakeholders represented by owners formulate mutual understandings toward shared, clear objectives. The process is to think, construct, and activate buildings together. The benefit brought by commissioning is to amplify the satisfaction among people.

Towards the forthcoming low-carbon society, the role of commissioning activity should be expanded from the optimization within the existing functional requirements, to optimizing the use of buildings and even optimizing lifestyle. To accomplish this goal, it is essential that all stakeholders including owners and occupants undertake the activities with thorough understandings, throughout the building lifecycle. The commissioning procedures introduced in this paper will greatly contribute to the activities.

In Japan, the benefit of commissioning will be understood through the number of examples. The authors strongly feel that the commissioning will become a new role to guide the sustainable building lifecycle in future.